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LOW-SPEED LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF A MODEL OF A BLUNT-NOSE HYPERSONIC LIFTING SPACECRAFT HAVING VARIABLE-SWEEP WINGS

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16. Abstract

An investigation has been made at low subsonic speeds of a model of a low-fineness-ratio lifting-body logistic spacecraft concept designed for a hypersonic lift-drag ratio near 1.

Variable-sweep wings were employed and mounted in a low position. Tests were made in the Langley low-turbulence pressure tunnel at a Mach number of 0.21 and a Reynolds number of 30.4×10^6, based on model reference length. Angle of attack was varied from about -4° to 18° at 0° of sideslip.

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SUMMARY

An investigation has been made at a Mach number of 0.21 and a Reynolds number of 30.4×10^6 (based on model reference length) of a model of a low-fineness-ratio lifting-body logistics spacecraft concept. The vehicle was designed for a hypersonic lift-drag ratio near 1. Variable-sweep wings, which are stowed during entry and deployed at subsonic speeds, were tested at half-chord sweep angles of 0°, 20°, 40°, 55°, and 90° (fully retracted). Longitudinal control was provided by elevons located at the body base as extensions of both the upper and lower body surfaces. Angle of attack was varied from about -4° to 18° at 0° of sideslip.

The large nose bluntness characteristic of this vehicle created a stability problem at the subsonic speeds of this study. Body center of pressure was far forward and thereby highly destabilizing for the estimated vehicle center-of-gravity location. Since the present configuration was unstable about the estimated center of gravity, the moment reference center was moved forward for most of the investigation to 45.6 percent of the model reference length, to provide approximately 1 percent stability to the configuration having a wing half-chord sweep angle of 20°. This large shift in center of gravity would, of course, have to be accompanied by large ballast weight requirements.

Locating outboard vertical tails in a low position on bodies of the present type results in large negative pressures between the body and the tails (depending on roll-out angle) which produce large adverse negative out-of-trim pitching moments.

The lower surface elevons are limited in control effectiveness, and excessive upward deflection results in loss in control as well as a destabilizing effect and resultant nonlinear pitching-moment variation with increasing angle of attack. Moderate deflections, however, when used in combination with additional longitudinal control devices in the form of upper surface elevons, are beneficial in that a positive pitching moment occurs without large trim-drag penalties and the resultant trimmed maximum lift-drag ratio is improved.

INTRODUCTION

Considerable effort is being expended by the National Aeronautics and Space Administration, the Department of Defense, and industry on studies relating to the development of manned spacecraft suitable for supporting a large orbiting research laboratory, as well as other independent missions in space. Numerous configurations of the lifting type are at present being studied for application to these overall missions.

Recent studies of lifting entry vehicles (ref. 1) have also considered the inclusion of variable-geometry features in the form of conventional wings which are stowed or shielded during entry and deployed subsonically to improve the overall aerodynamic behavior and performance for landing.

Since the required value of hypersonic lift-drag ratio has not yet been specified, the Langley Research Center has recently studied a spectrum of lifting entry vehicles having hypersonic lift-drag ratios from near 1 to about 3, with each vehicle incorporating some form of variable-geometry feature. It is the purpose of this paper to present subsonic aerodynamic characteristics for one such vehicle having a hypersonic lift-drag ratio of approximately 1. This vehicle was designed by the contractor during the study reported in reference 1. The body of this vehicle is trapezoidal in cross section and has excessively large nose bluntness. The design incorporates a center vertical tail, outboard vertical tails, upper surface and lower surface body-base elevons for control, and deployable variable-sweep wings located in a low wing position.

Tests were made in the Langley low-turbulence pressure tunnel at a Mach number of 0.21 and a Reynolds number (based on model reference length) of 30.4×10^6. Angle of attack varied from about -4° to 18° at 0° of sideslip. The variable-sweep wings were tested at half-chord sweep angles of 0°, 20°, 40°, 55°, and 90° (fully retracted). The effects of various elevon deflections and various model components were also studied.

SYMBOLS

Longitudinal aerodynamic characteristics are referred to the stability-axis system. All coefficients are normalized with respect to actual vehicle length (including the lower surface elevons) and body projected planform area (including the lower surface elevons). The longitudinal location of the center of gravity was estimated to be at 51.5 percent of the reference length. Data are presented for two moment reference centers with the location given on each data figure. Vertical location of the moment reference center was taken as 1.2 percent of the reference length below the body ordinate reference line.

a_l	lower surface semiwidth of body at station x_b, ft (m)
a_u	upper surface semiwidth of body at station x_b, ft (m)
h_l	body height below ordinate reference line at station x_b, ft (m)
h_u	body height above ordinate reference line at station x_b, ft (m)
x_b	longitudinal coordinate of body, ft (m)
x_w	longitudinal coordinate of wing chord, ft (m)
y_l	wing-panel lower surface ordinate, ft (m)
y_u	wing-panel upper surface ordinate, ft (m)
c	wing chord, ft (m)
C_D	drag coefficient, $\frac{\text{Drag}}{qS_{ref}}$
C_L	lift coefficient, $\frac{\text{Lift}}{qS_{ref}}$
C_{L_α}	lift-curve slope at $\alpha \approx 0$, per degree
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS_{ref}l_{ref}}$
$\partial C_m/\partial C_L$	longitudinal stability parameter at $C_L \approx 0$
L/D	lift-drag ratio
l_{ref}	actual body length including lower surface elevons, ft (m)
q	dynamic pressure, lb/ft^2 (N/m^2)
S_{ref}	actual body projected planform area including lower surface elevons, ft^2 (m^2)
α	angle of attack, deg

$\delta_{e,lower}$ deflection of body-base lower surface elevons, negative with trailing edge up, deg

$\delta_{e,upper}$ deflection of body-base upper surface elevons, negative with trailing edge up, deg

$\Lambda_{c/2}$ wing half-chord sweep angle, deg

Subscripts:

max maximum

min minimum

o at $\alpha = 0$

$(L/D)_{max}$ at $(L/D)_{max}$

Configuration component designations:

B body

V_o outboard vertical tails

V_c center vertical tail

C canopy

W wing panel

MODELS

Drawings of the model and various components are presented in figure 1, and a photograph of the complete model with wings extended to $\Lambda_{c/2} = 20^o$ is shown as figure 2. Table I presents body design ordinates normalized with respect to body reference length, and table II presents wing section ordinates normalized with respect to wing chord. (See fig. 1(a).) The body of this vehicle was trapezoidal in cross section with the ratio of the upper width to the lower width being 0.667. The vehicle was negatively cambered, having 33.3 percent of the body height above and 66.7 percent of the body height below the ordinate reference line. (See fig. 1(a).) Nose bluntness was large in order to reduce the hypersonic L/D to approximately 1, this value of performance being the design value.

Outboard vertical tails were located near the base of the body and were flat plate in cross section with slight inner surface boattailing at the trailing edge. (See fig. 1(b).) Leading-edge sweep angle was 60° and roll-out angle was 20° from the vertical and 40° from the body lateral surfaces. The outboard vertical tails were toed in, with the inner surface parallel to the body lateral surfaces. A center-line vertical tail having leading-edge sweep of 55° and trailing-edge sweep of 30° was also included.

The wing panels had a NACA 4412 airfoil section, a taper ratio of 0.75, and an aspect ratio of 5.33 (based on its own exposed area and span) for a wing half-chord sweep angle of 0°. The wing was tested at half-chord sweep angles of 0°, 20°, 40°, 55°, and 90° (fully retracted). Wing pivot location was at 38.8 percent of the overall model length (including elevons). The wing box gaps were sealed for all sweep angles.

Elevons were located in the body-base region as extensions of both the upper and lower surfaces of the base. The elevons were split at midspan so that the left- and right-hand sides could be differentially deflected. The ratio of lower surface elevon span to maximum body lower surface span was 0.82, with a ratio of chord length to reference length of 0.126. The ratio of upper surface elevon span to maximum body upper surface span was 0.875, with a ratio of chord length to overall length of 0.126.

APPARATUS, TESTS, AND CORRECTIONS

Tests were made in the Langley low-turbulence pressure tunnel at a Reynolds number (based on model reference length) of 30.4×10^{6} at a Mach number of 0.21. The angle of attack was varied from about -4° to 18° at 0° of sideslip.

The model was sting supported, and forces and moments were measured with an internally mounted six-component strain-gage balance. The angle of attack has been corrected for the effects of bending of the sting and balance under load. Normal blockage and jet-boundary corrections have been made in accordance with the methods prescribed in references 2 and 3, respectively. In all cases, the drag data represent gross drag in that base drag is included.

RESULTS AND DISCUSSION

Basic longitudinal aerodynamic characteristics of the vehicle are presented in figures 3 to 7. Figure 3 presents the effects of various configuration components in combination. Figures 4 and 5 present longitudinal control characteristics associated with deflections of upper and lower elevons. Figures 6 and 7 present the effects of wing deployment for the complete configuration, and figure 8 presents a summary of various pertinent longitudinal aerodynamic parameters.

The addition of the outboard vertical tails to the body resulted in a large increase in lift-curve slope and C_{L_o}, with a resultant increase in negative C_m at $C_L = 0$. (See fig. 3.) The negative C_m is believed to result from large negative pressures which act between the body lateral surfaces and the tails and thereby increase local lift at a given angle of attack, which then results in large nose-down or out-of-trim pitching moment. (See fig. 3.) The addition of the wings in a 20° half-chord sweep position further increases lift-curve slope and also increases negative C_m at $C_L = 0$. This increase in negative C_m is typical of low wing configurations. Resultant untrimmed $(L/D)_{max}$ is about 5.3 for the complete configuration with elevons at 0° setting; this maximum occurred at $C_L = 0.65$ and $\alpha = 8^{\circ}$.

The vehicle is unstable about the estimated center of gravity at 51.5 percent of the reference length because of the destabilizing effect of the body. The measured center of pressure of this highly blunted body is at approximately 39 percent of the reference length and is comparable to that obtained on a blunt-nosed, low-power-law (exponent of 0.25) body of elliptical cross section. (See ref. 4.) These results indicate that the use of excessive nose bluntness to reduce hypersonic L/D presents a balance problem at subsonic speeds. This comes from the body center of pressure being far forward and highly destabilizing. Because of this instability, the present configuration would have little application to space-shuttle design, since realistic centers of gravity for space-shuttle concepts generally are far aft.

Since the present configuration was unstable about the estimated center of gravity, the moment reference point was moved forward for the remainder of the investigation to 45.6 percent of the reference length, to provide approximately 1 percent stability to the configuration having $\Lambda_{c/2} = 20^{\circ}$. This large shift in center of gravity would, of course, have to be accompanied by large ballast weight requirements.

Deflection of the lower surface elevons up to -20° provided positive increments in C_m for the complete configuration with $\Lambda_{c/2} = 20^{\circ}$. (See fig. 4.) For $\delta_{e,\,lower} = -30^{\circ}$, however, loss in control occurred as a result of separated flow over the elevons, with accompanying losses in stability. In addition, a somewhat nonlinear variation of C_m with C_L occurs for the higher elevon settings required for trim near and above $(L/D)_{max}$ and up to the region of wing stall at $C_L \approx 0.75$. These results indicate that the lower surface elevons are limited in control effectiveness, a serious problem if excessive deflections are required for trim. Moderate deflections, however, when used in combination with additional controls, may be beneficial in that positive C_m is obtained with somewhat less trim-drag penalty.

For the complete configuration having $\Lambda_{c/2} = 20^{\circ}$, use of the upper surface elevons alone results in a more linear variation of C_m due to elevon deflection and no instabilities at the higher C_L and $\delta_{e,\,upper}$ ranges up to the point of wing stall. (See fig. 5.) By employing only $\delta_{e,\ upper}$ for this configuration, a trimmed $(L/D)_{max}$ of about 4.5 was obtained at $C_L = 0.65$ and $\alpha \approx 10.4^o$. Deflection of the upper surface elevons in combination with the lower surface elevons set at -30^o provided additional positive increments in C_m even though the instabilities noted for $\delta_{e,\ lower}$ are still prevalent. The lower surface elevon settings selected were excessive, however, as has been previously indicated, and control reversal as well as loss in stability negates the results shown, primarily since maximum trimmed L/D occurs close to the point of vehicle pitch-up.

Deployment of the wings from fully retracted $\left(\Lambda_{c/2} = 90^o\right)$ to a 20^o sweep position with lower surface elevons at -10^o and upper surface elevons at -10^o or -20^o resulted in significant increases in C_{L_α}, C_{L_o}, and $(L/D)_{max}$ (figs. 6, 7, and 8) with only small increases in $C_{D,min}$. Unsweeping the wings from 20^o to 0^o, however, provided only small additional increases in both C_{L_α} and $(L/D)_{max}$ but resulted in an unstable configuration even for the moment reference point of 45.6 percent of the reference length. (See fig. 8.)

Figure 8 presents the effects of wing sweep and various combinations of elevon settings on the pitching moment at $(L/D)_{max}$ (i.e., out-of-trim moment) along with other additional longitudinal aerodynamic parameters of interest.

For the wings-retracted configuration $\left(\Lambda_{c/2} = 90^o\right)$, the vehicle is trimmed and stable at a $(L/D)_{max}$ of about 2.48 $\left(\text{note dash curve at } \Lambda_{c/2} = 90^o\right)$. Deployment of the wings from $\Lambda_{c/2} = 90^o$ to about 40^o results in out-of-trim moment at $(L/D)_{max}$ due to the increased stability $\left(\partial C_m/\partial C_L\right)$ associated with wing sweep. Higher elevon settings than those shown are required for trim, therefore, in this region. For the settings shown, the vehicle is trimmable for $\Lambda_{c/2}$ below 40^o; however, the vehicle becomes unstable for $\Lambda_{c/2}$ below about 20^o.

A comparison of trimmed $(L/D)_{max}$ at $\Lambda_{c/2} = 20^o$ indicates that for $\delta_{e,upper} = -20^o$ in combination with $\delta_{e,\ lower} = 0^o$, the vehicle is trimmed at $(L/D)_{max}$ of about 4.5. For $\delta_{e,\ upper} = -10^o$ in combination with $\delta_{e,\ lower} = -10^o$, an increase in $(L/D)_{max}$ to about 5.2 is realized. The indication is that higher trimmed L/D can be obtained by moderate settings of lower surface elevons (well below the point of loss in control noted in fig. 4) in combination with deflectable upper surface elevons at subsonic speeds.

CONCLUDING REMARKS

An investigation has been made at a Mach number of 0.21 and Reynolds number of 30.4×10^6 (based on model reference length) of a model of a low-fineness-ratio variable-geometry lifting-body spacecraft concept. The vehicle was designed for a hypersonic lift-drag near 1. Variable-sweep wings, which are stowed during entry and deployed at subsonic speeds, were tested at half-chord sweep angles of 0°, 20°, 40°, 55°, and 90° (fully retracted). Longitudinal control was provided by elevons located at the body base on both the upper and lower surfaces. Angle of attack was varied from about -4° to 18° at 0° of sideslip.

The following observations are based on the results of this investigation:

The large nose bluntness characteristic of this vehicle created a stability problem at the subsonic speeds of this study. Body center of pressure was far forward and thereby highly destabilizing for the estimated vehicle center-of-gravity location. Since the present configuration was unstable about the estimated center of gravity, the moment reference center was moved forward for most of the investigation to 45.6 percent of the model reference length, to provide approximately 1 percent stability to the configuration having a wing half-chord sweep angle of 20°. This large shift in center of gravity would, of course, have to be accompanied by large ballast weight requirements.

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Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., November 9, 1970.

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3. Swanson, Robert S.; and Toll, Thomas A.: Jet-Boundary Corrections for Reflection-Plane Models in Rectangular Wind Tunnels. NACA Rep. 770, 1943. (Supersedes NACA WRL-458.)
4. Spencer, Bernard, Jr.: Transonic Aerodynamic Characteristics of a Series of Related Bodies With Cross-Sectional Ellipticity. NASA TN D-3203, 1966.

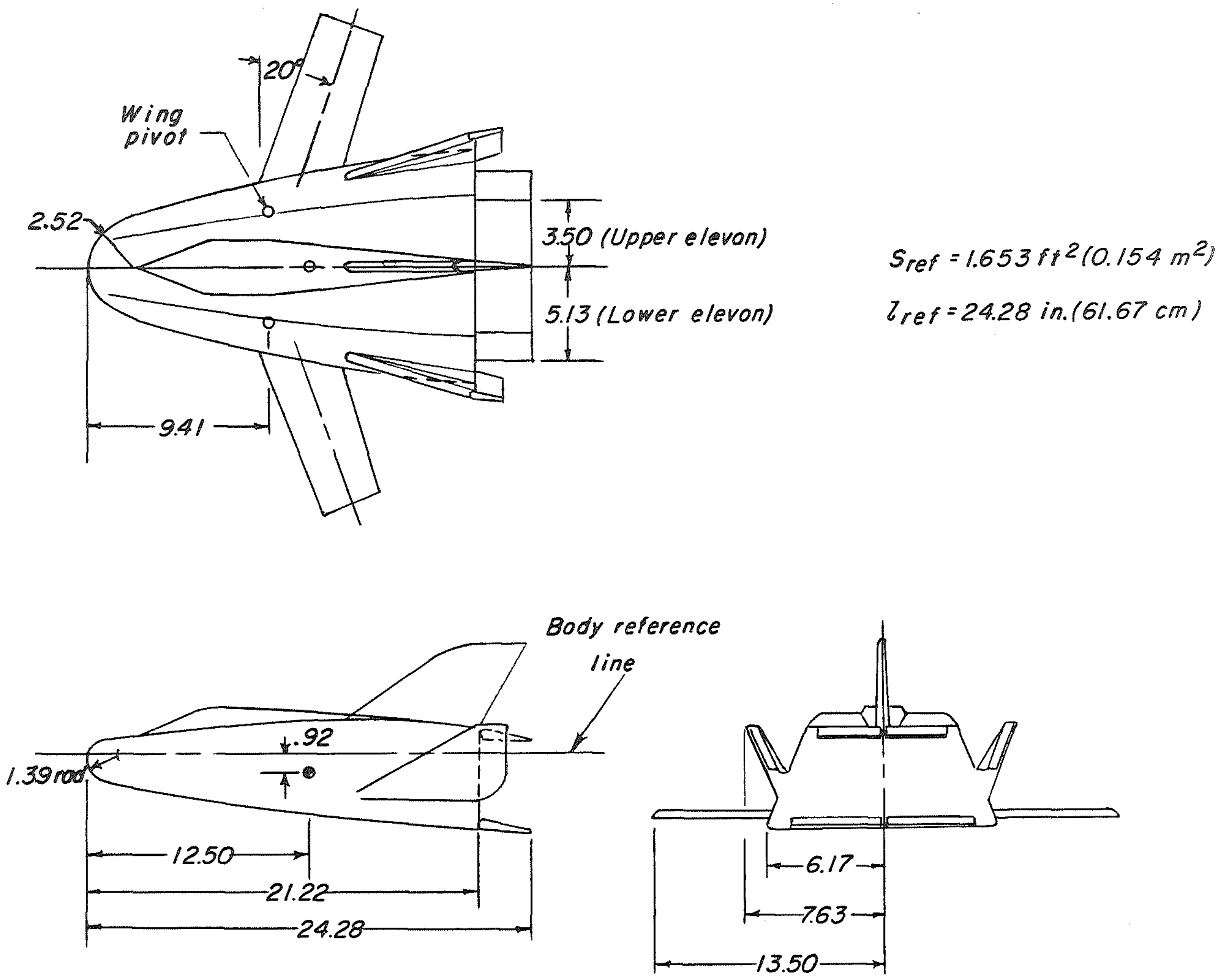
TABLE I.- BODY ORDINATES (EXCLUDING CANOPY)

x_b/l_{ref}	a_u/l_{ref}	a_l/l_{ref}	h_u/l_{ref}	h_l/l_{ref}
0	0	0	0	0
.02	.017	.010	.008	.011
.04	.029	.017	.014	.019
.07	.044	.026	.020	.029
.10	.060	.036	.028	.039
.20	.096	.058	.045	.064
.30	.128	.076	.060	.085
.40	.146	.093	.073	.103
.50	.180	.108	.085	.120
.60	.201	.120	.095	.134
.70	.220	.132	.104	.147
.80	.236	.141	.111	.158
.90	.247	.148	.116	.165
1.00	.254	.152	.119	.169

TABLE II. - WING SECTION ORDINATES

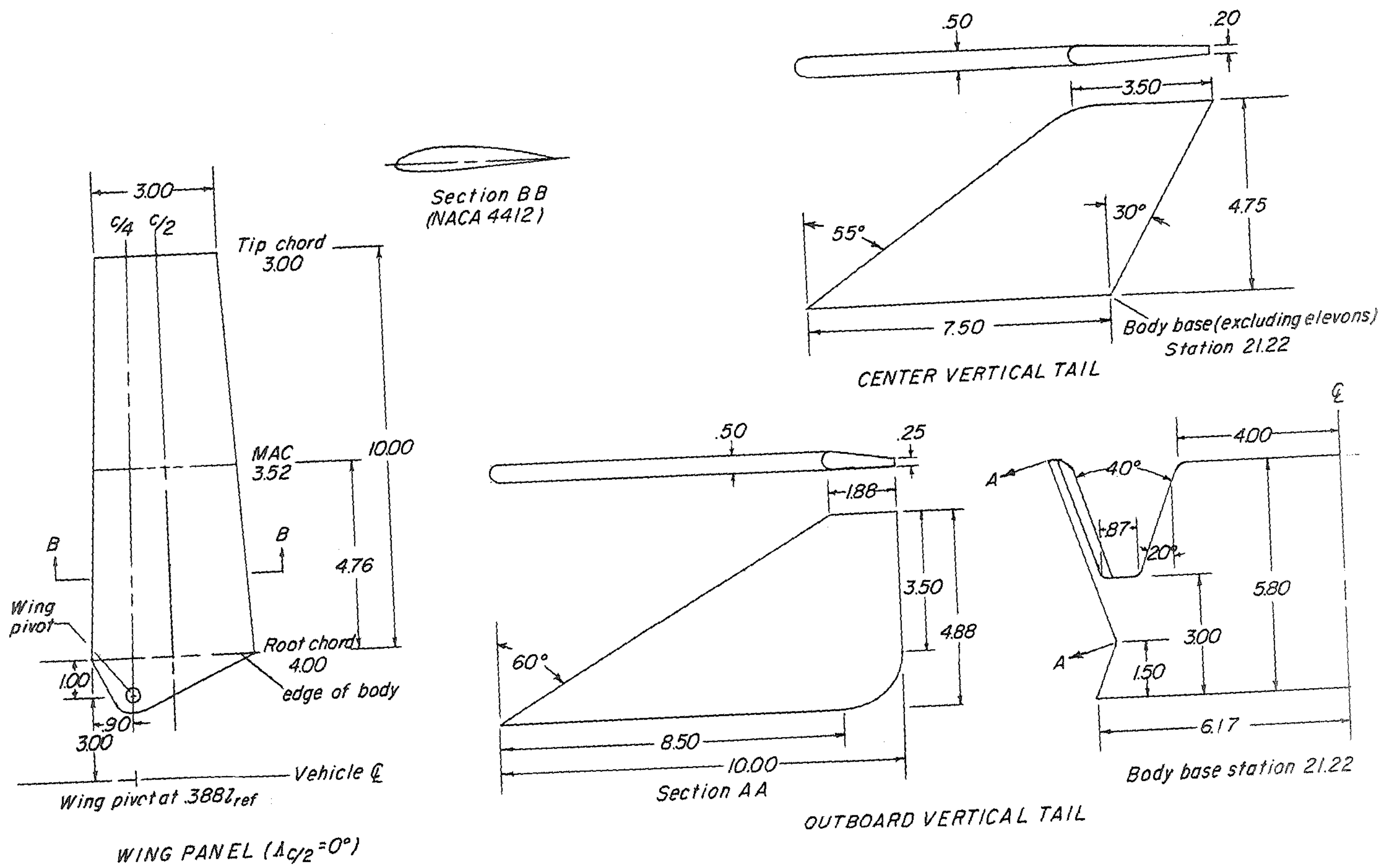
[NACA 4412]

x_w/c	y_u/c	y_l/c
0	0	0
.0125	.0244	.0143
.025	.0339	.0195
.050	.0473	.0249
.075	.0576	.0274
.100	.0659	.0286
.150	.0789	.0288
.200	.0880	.0274
.300	.0976	.0226
.400	.0980	.0180
.500	.0919	.0140
.600	.0814	.0100
.700	.0669	.0065
.800	.0489	.0039
.900	.0271	.0022
.950	.0147	.0016
1.000	.0013	.0013



(a) Complete model.

Figure 1.- Model and various components. All dimensions are in inches unless otherwise noted. Because of space limitations, conversions to SI Units are given only for the reference dimensions.



(b) Configuration components.

Figure 1.- Concluded.

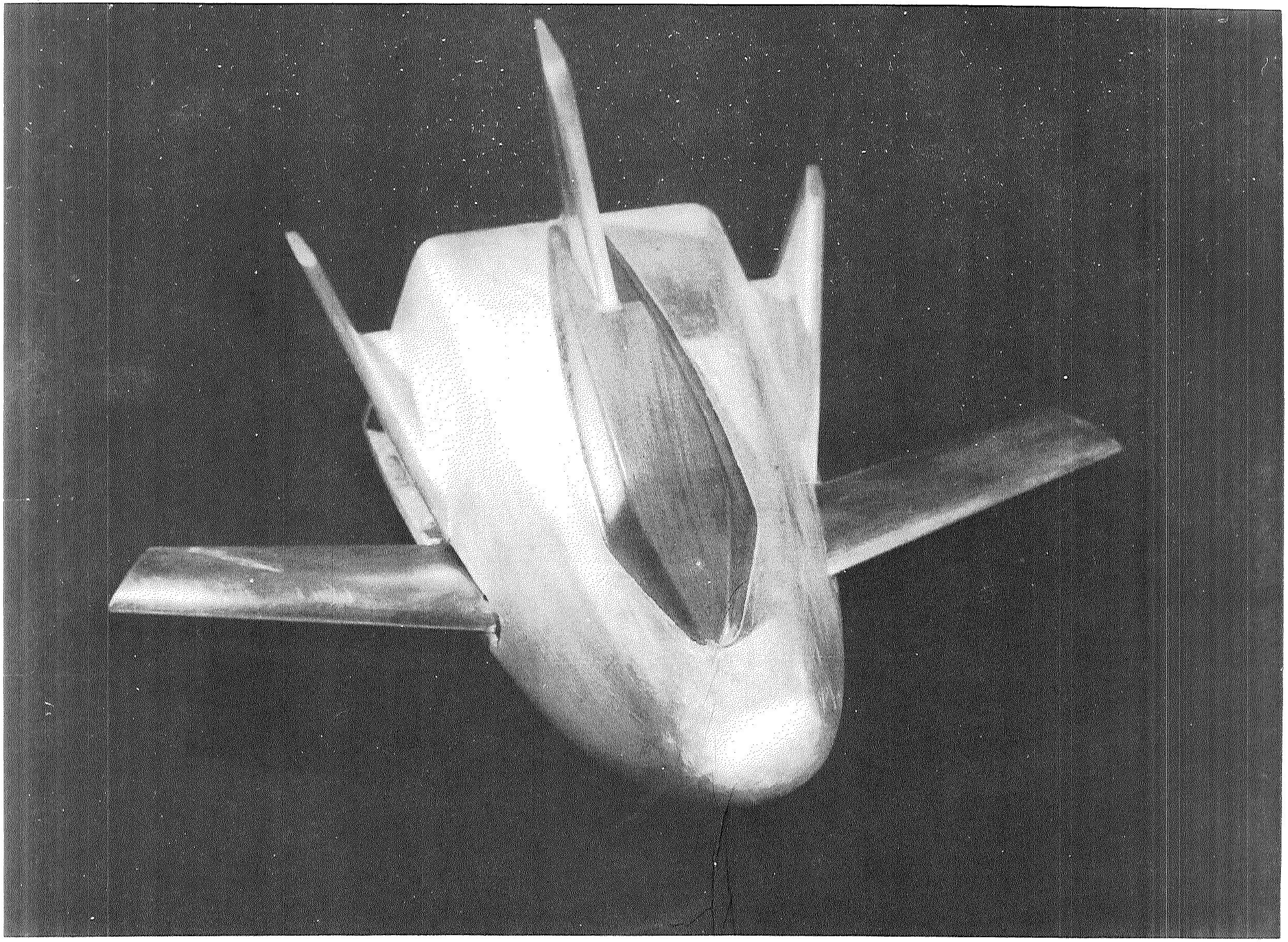


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Figure 2.- Complete model with wings extended to $\Lambda_{c/2} = 20^{\circ}$.

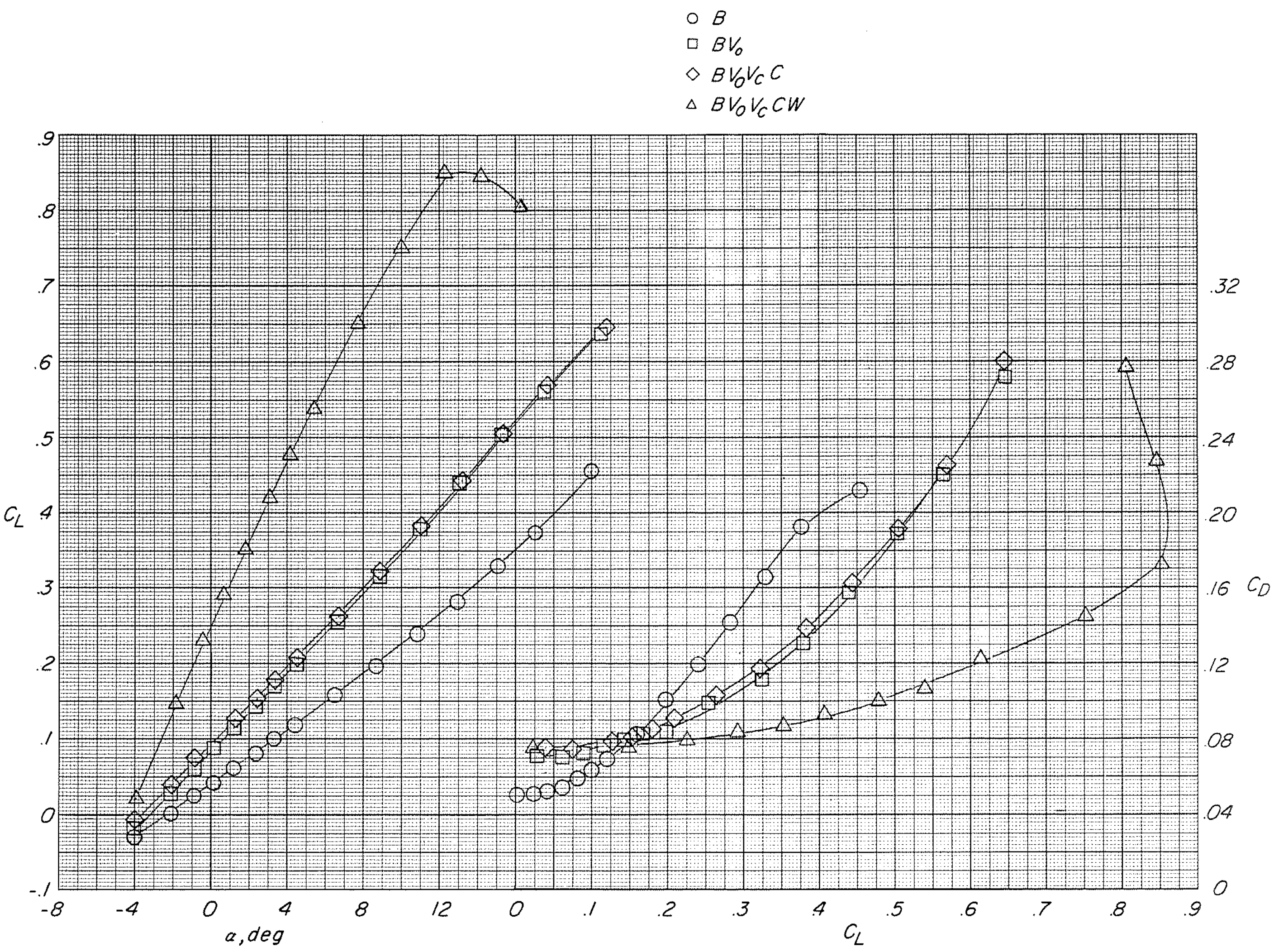


Figure 3.- Longitudinal aerodynamic characteristics showing effects of various configuration components added to basic body. Moment reference location, $0.515l_{ref}$; $\Lambda_{c/2} = 20^o$ when wing deployed.

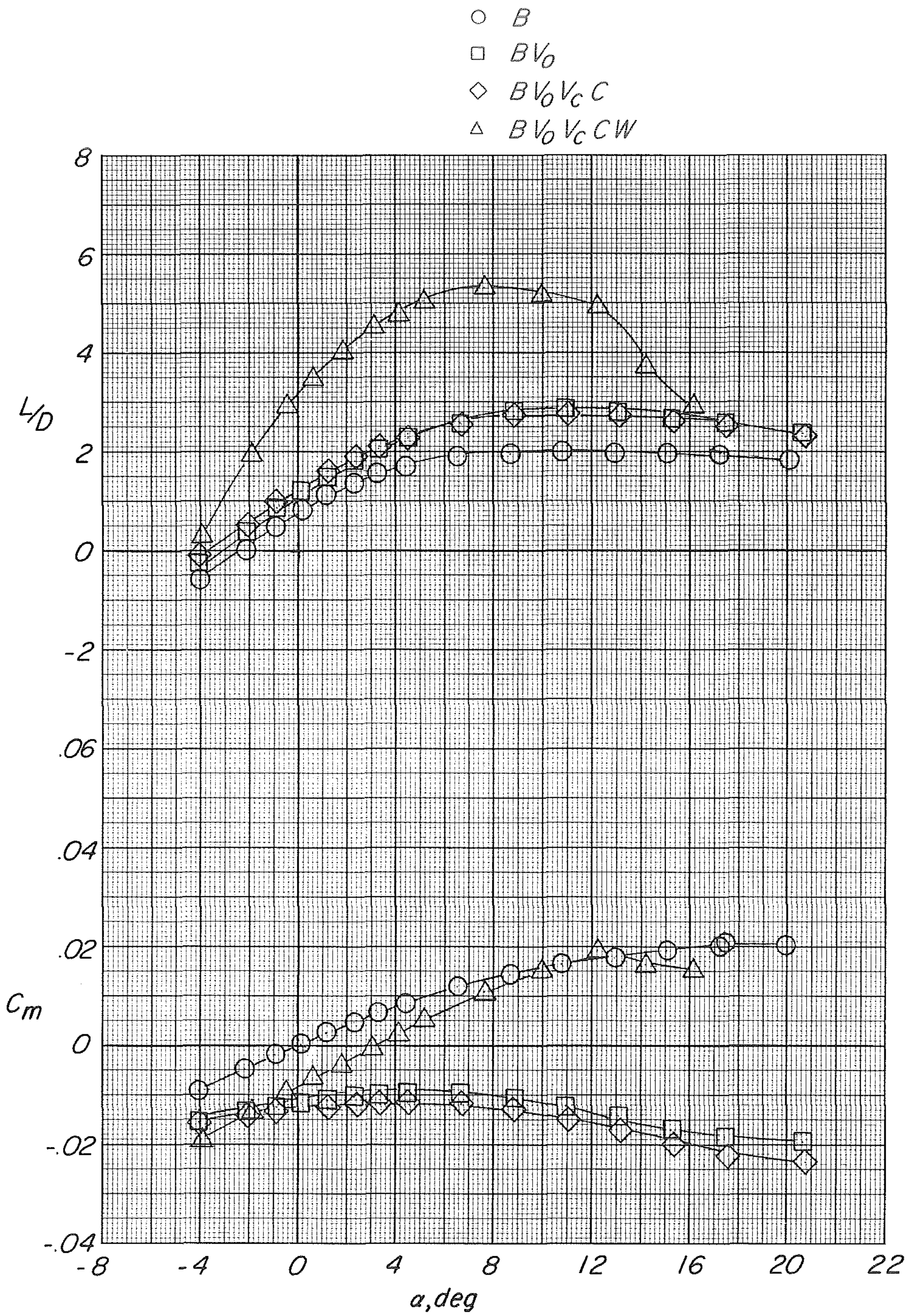
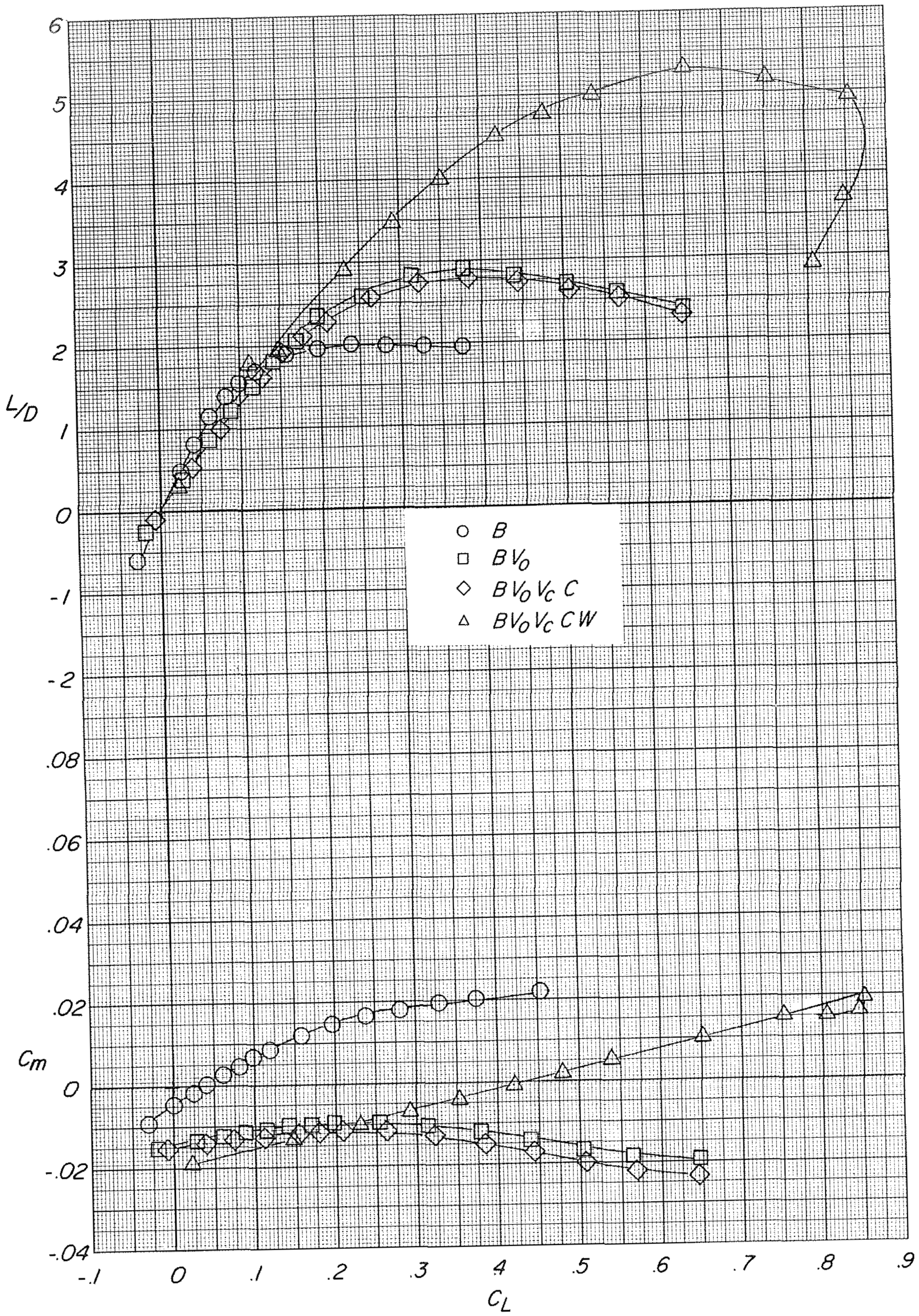


Figure 3.- Continued.



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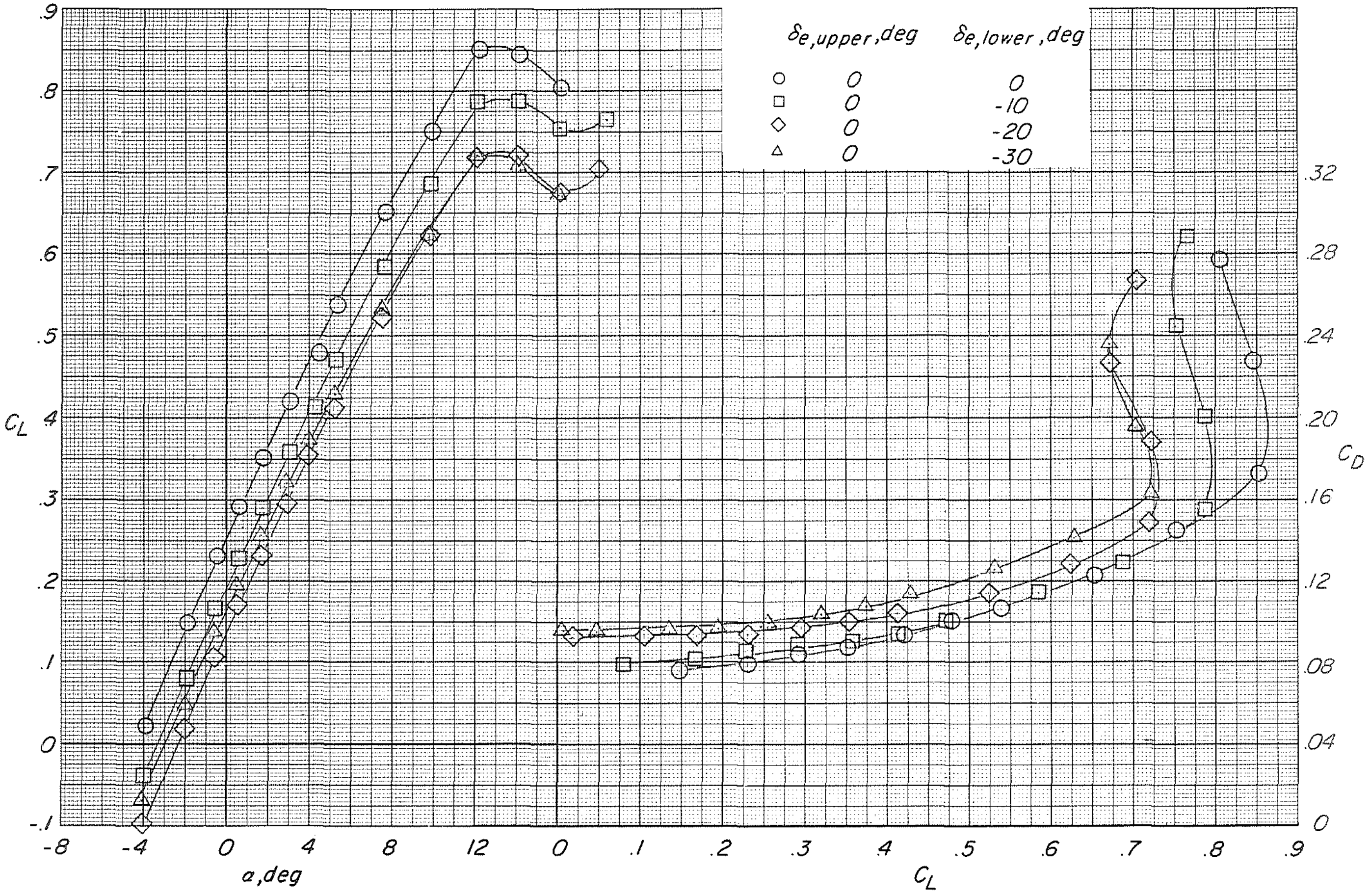


Figure 4.- Longitudinal control characteristics associated with deflections of lower surface elevons for the complete configuration. Moment reference location, $0.456l_{ref}$; $\delta_{e,upper} = 0^{o}$; $\Lambda_{c/2} = 20^{o}$.

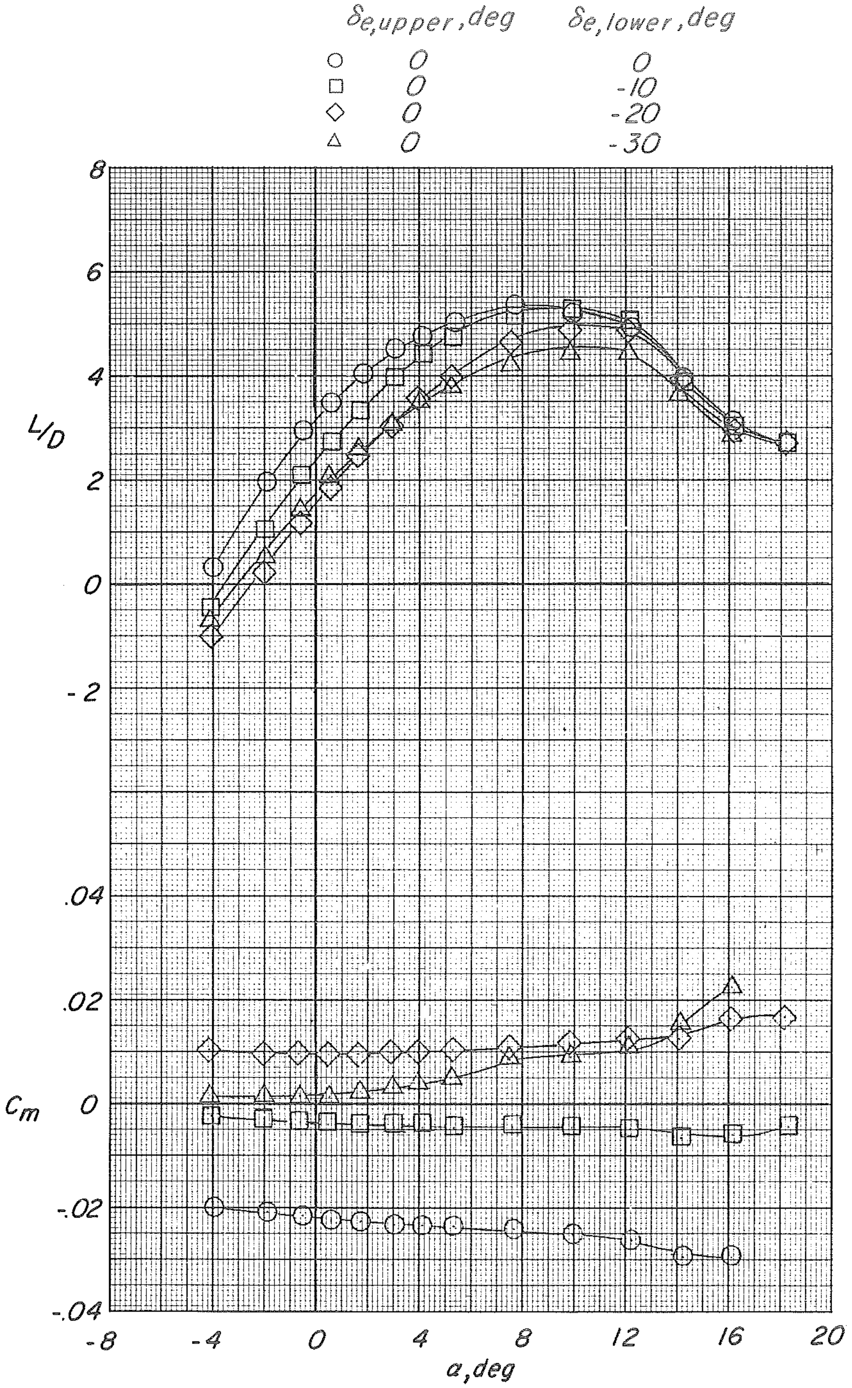


Figure 4.- Continued.

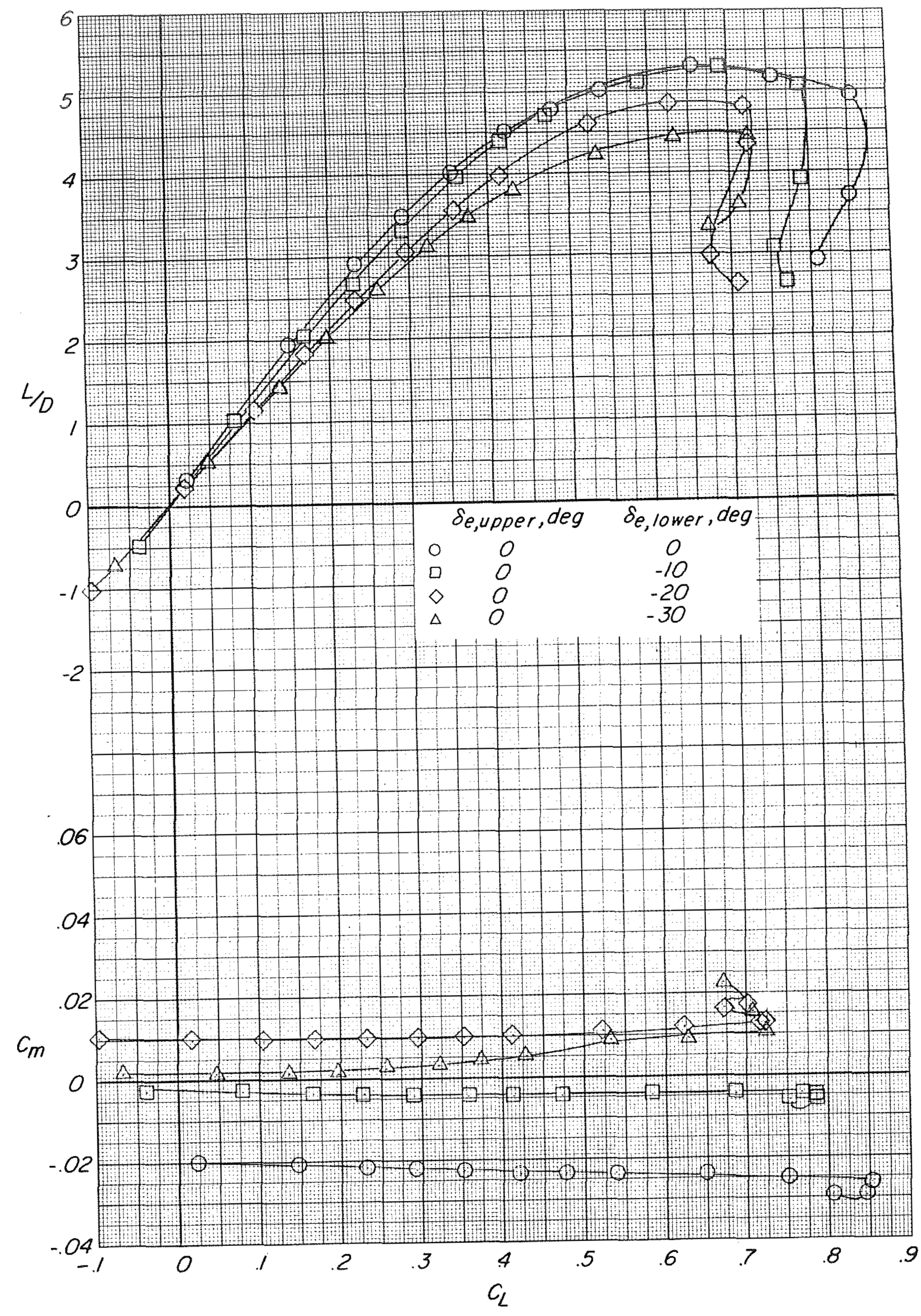


Figure 4.- Concluded.

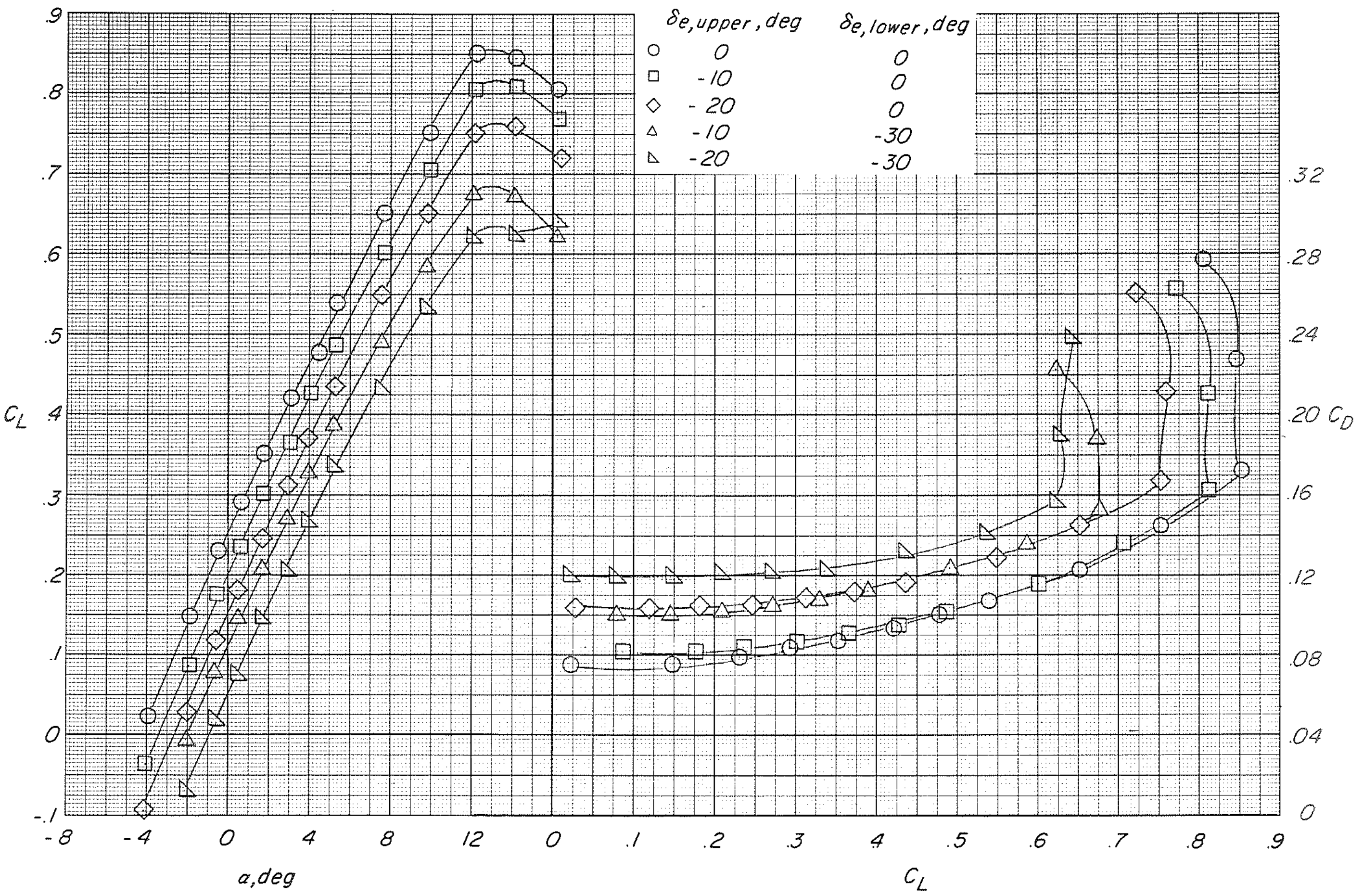


Figure 5.- Longitudinal control characteristics associated with deflections of upper surface elevons alone and in combination with lower surface elevons for the complete configuration. Moment reference location, $0.456l_{ref}$; $\Lambda_{c/2} = 20^{o}$.

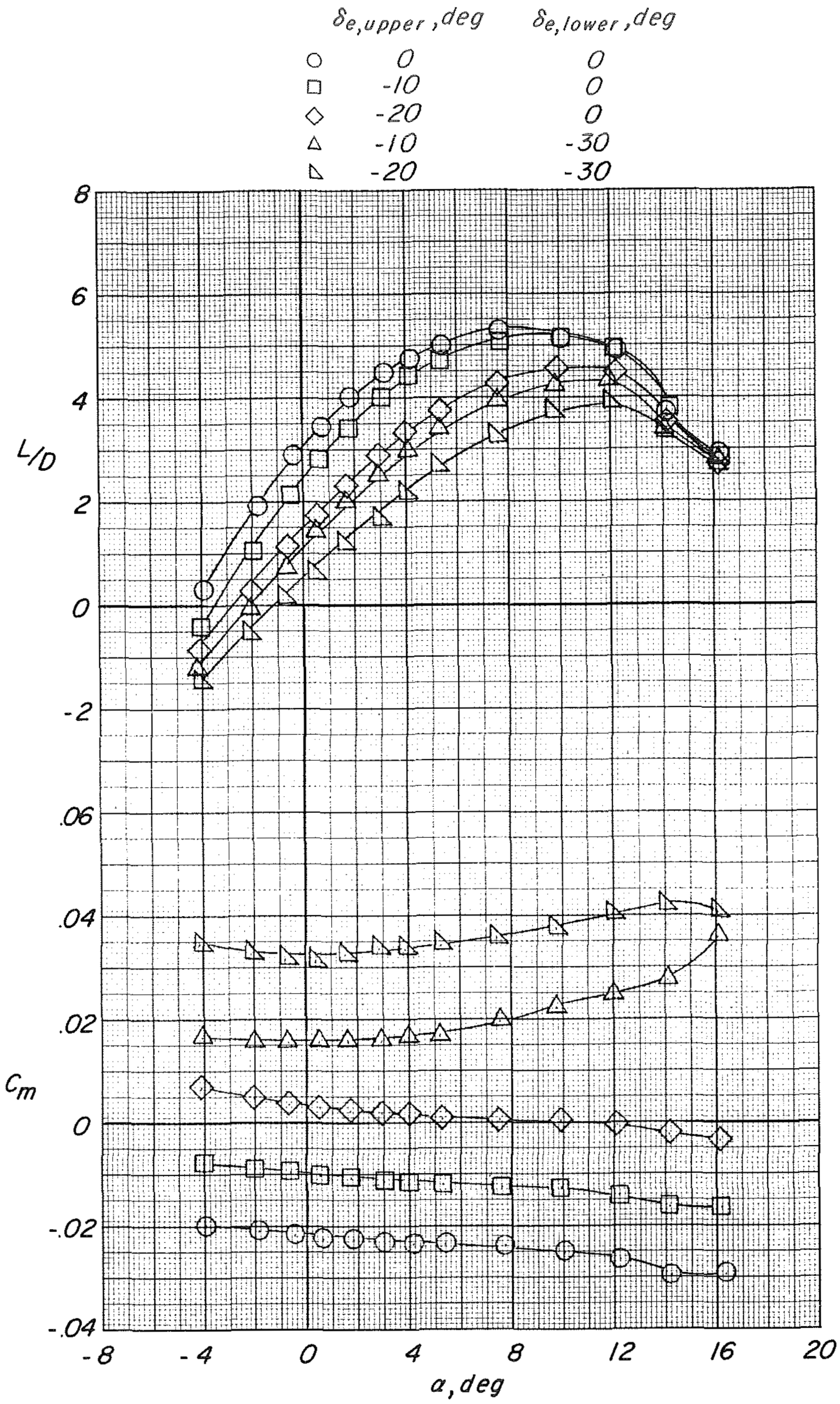


Figure 5.- Continued.

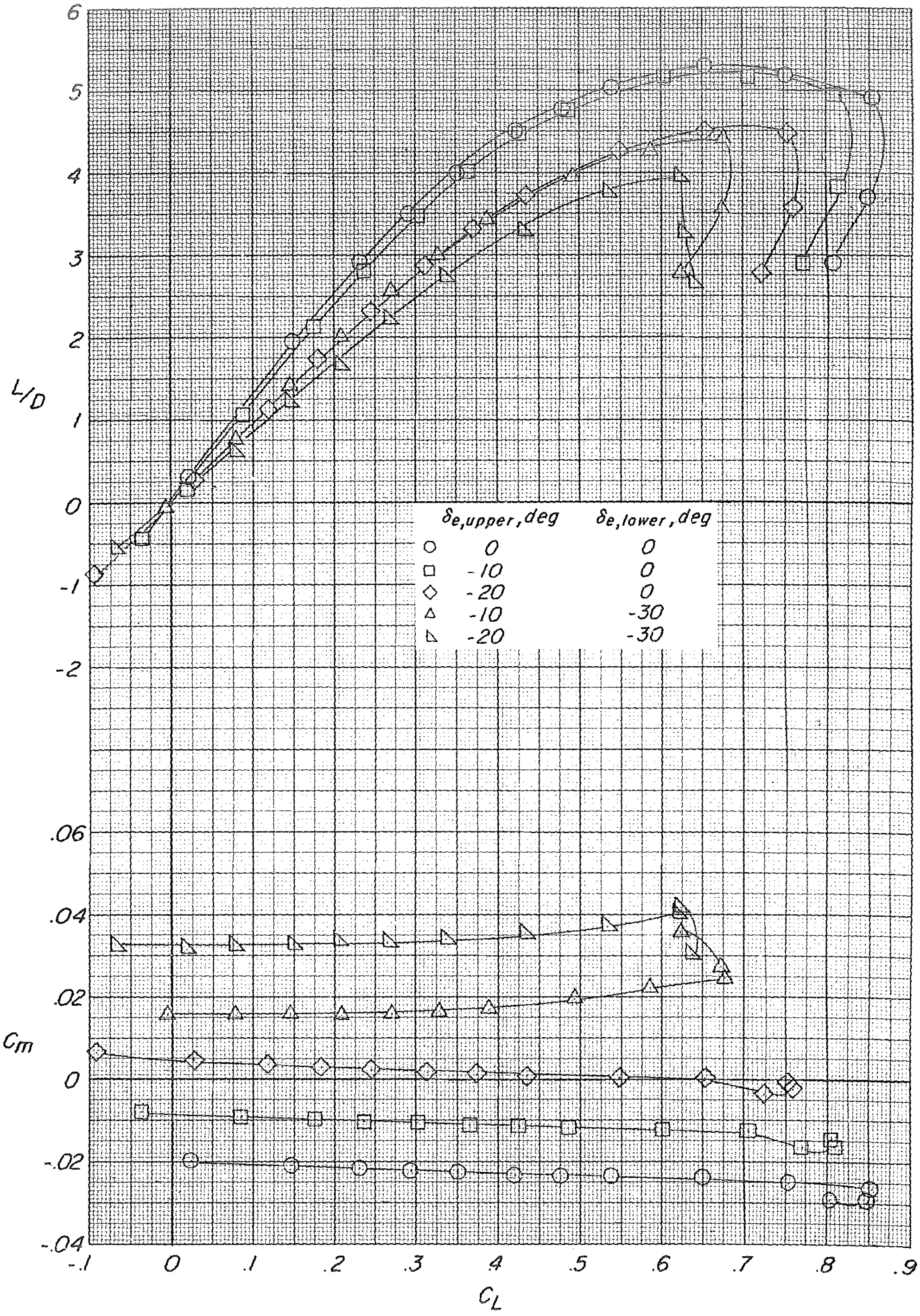


Figure 5.- Concluded.

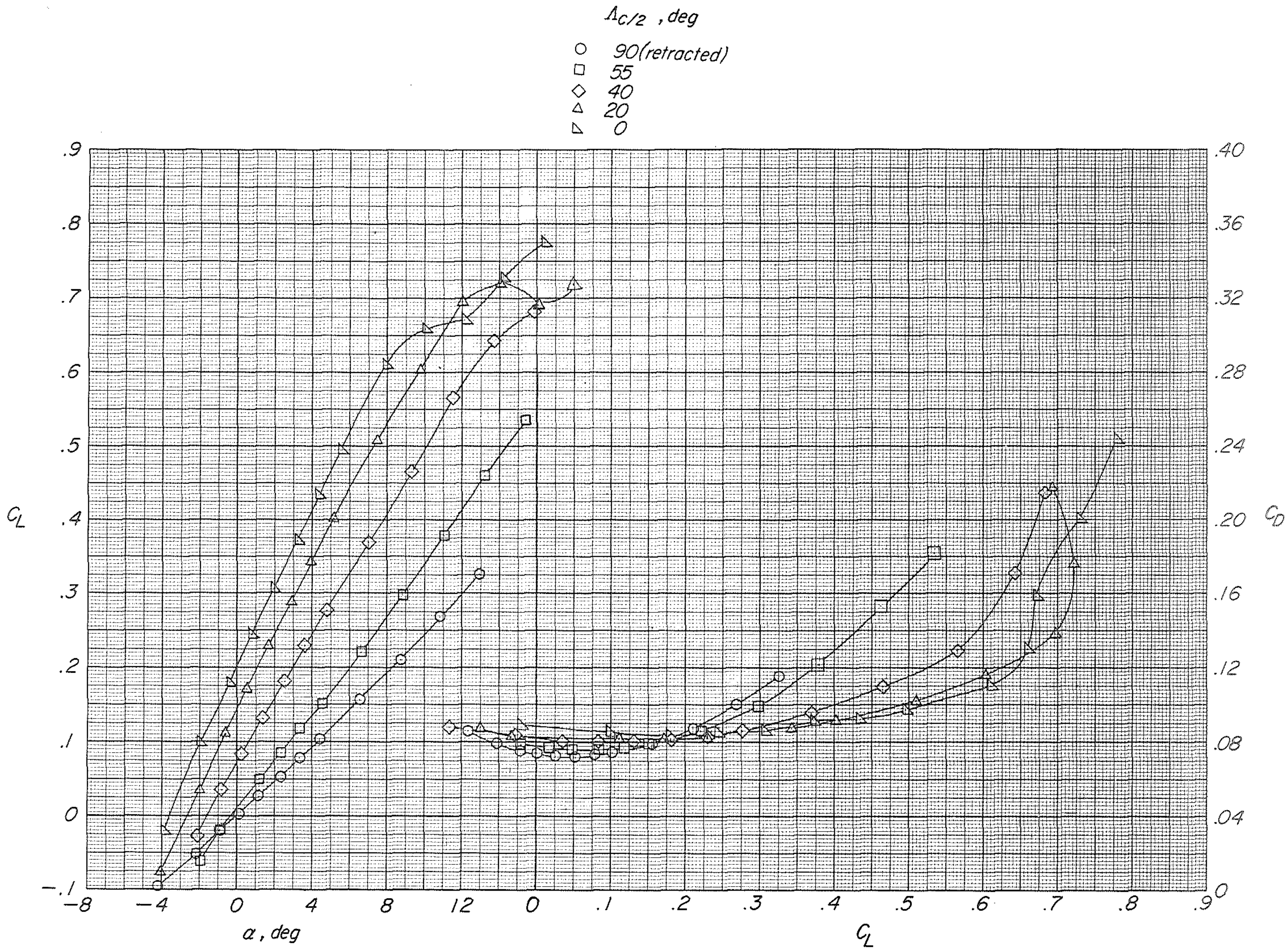


Figure 6.- Effects of wing deployment on longitudinal aerodynamic characteristics of complete configuration. Moment reference location, $0.456l_{ref}$; $\delta_{e,upper} = -10^{o}$; $\delta_{e,lower} = -10^{o}$.

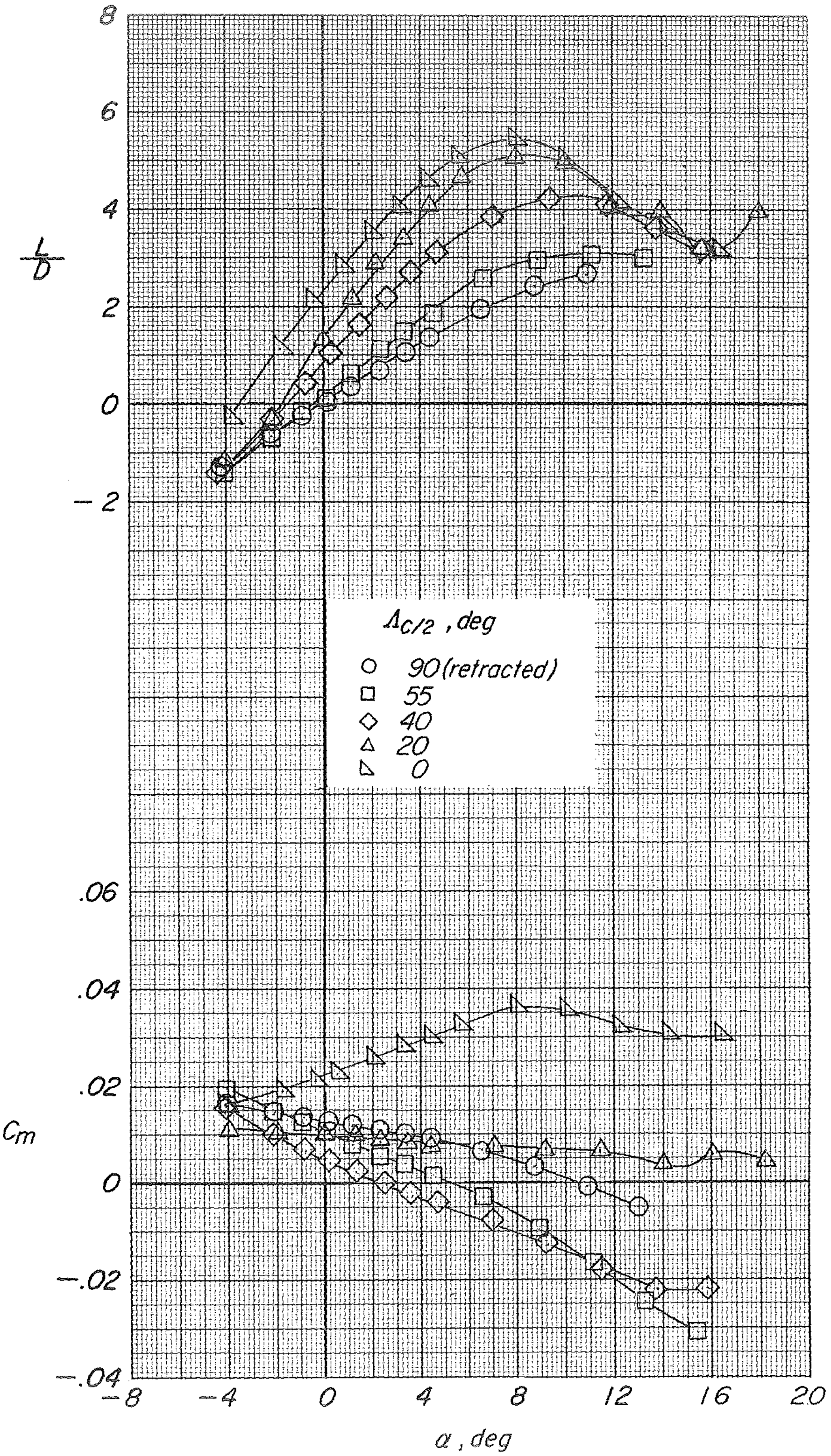
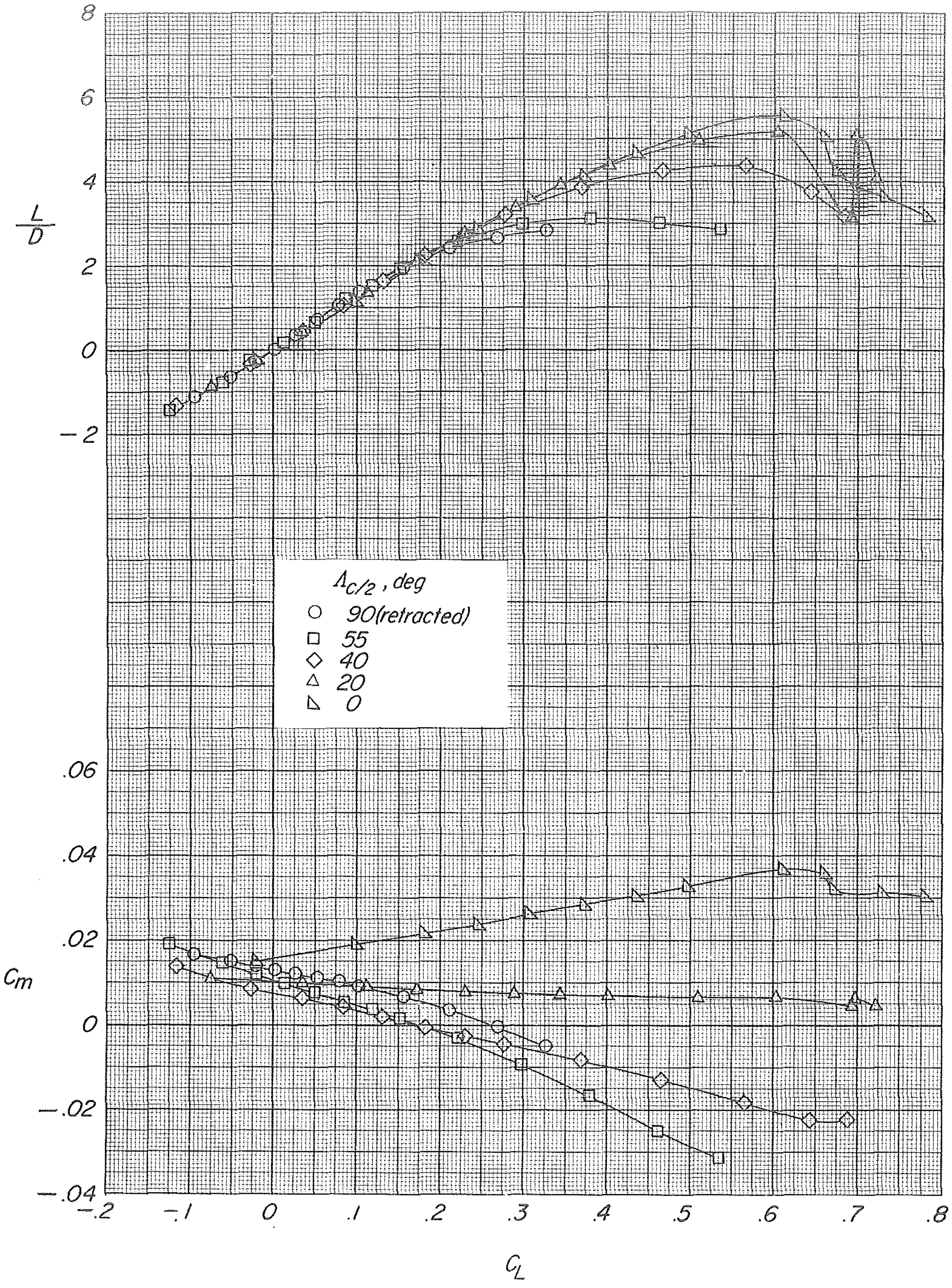


Figure 6.- Continued.



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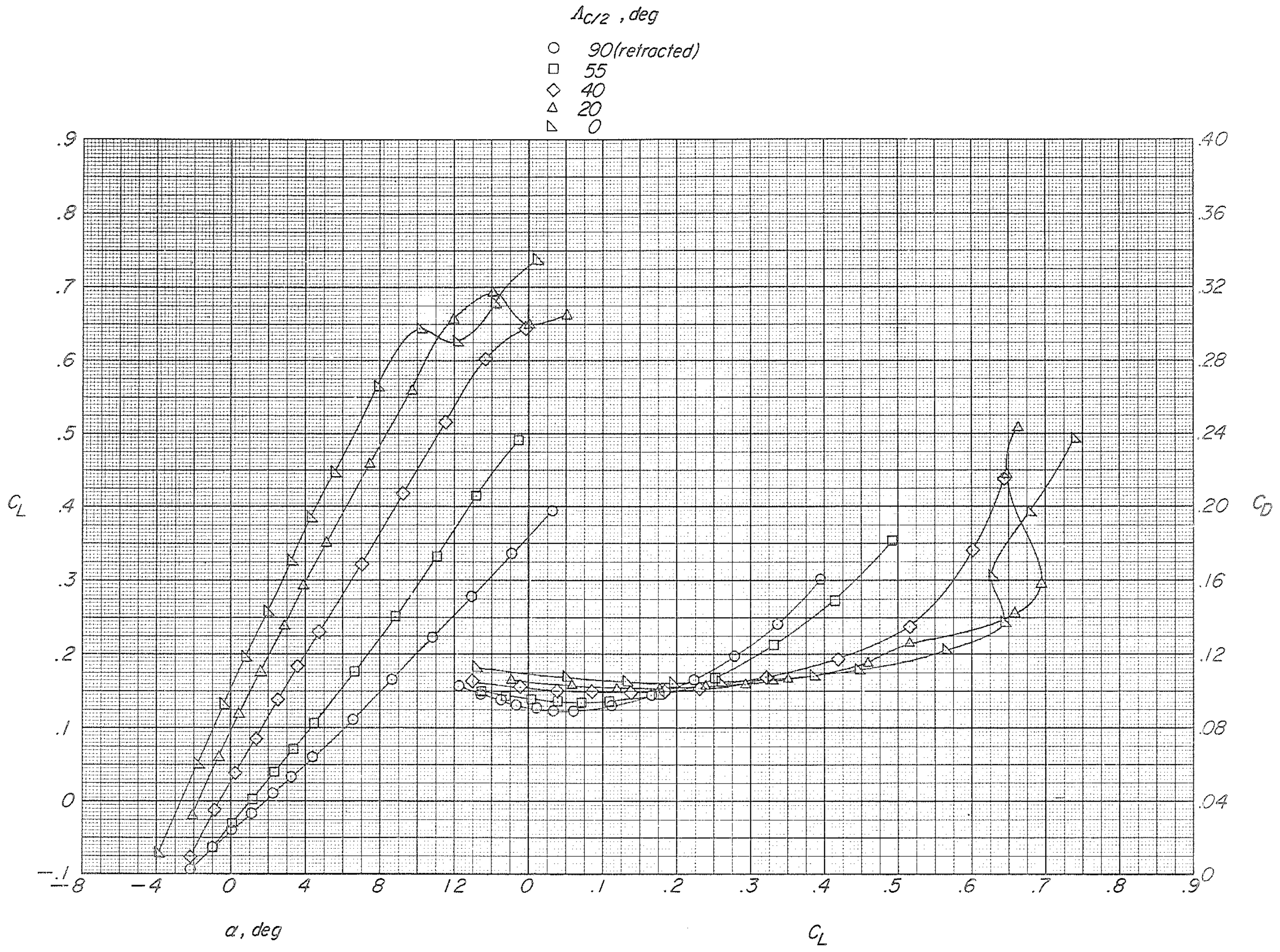

Figure 7.- Effects of wing deployment on longitudinal aerodynamic characteristics of complete configuration. Moment reference location, $0.456 l_{ref}$; $\delta_{e,upper} = -20^{\circ}$; $\delta_{e,lower} = -10^{\circ}$.

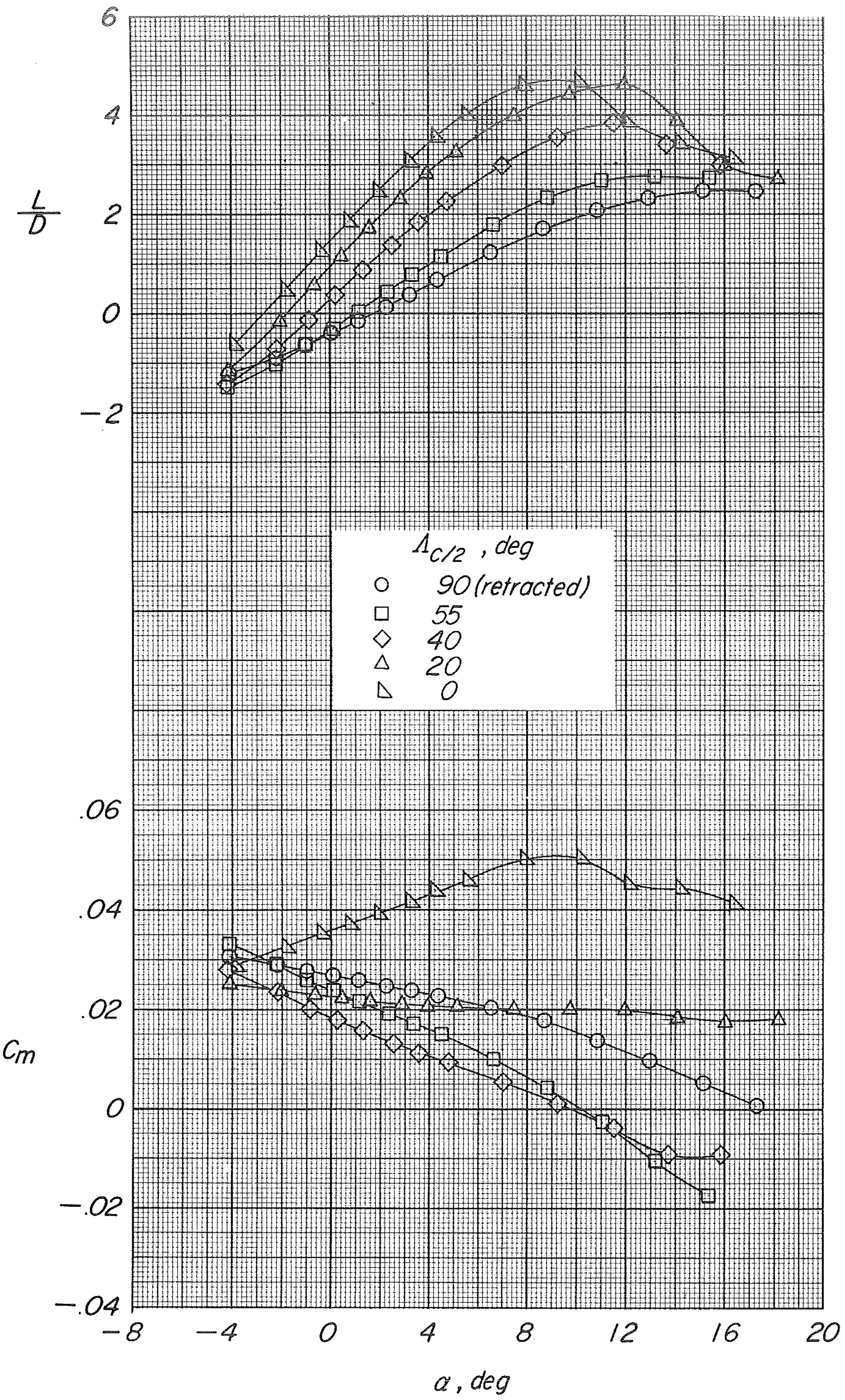

Figure 7.- Continued.

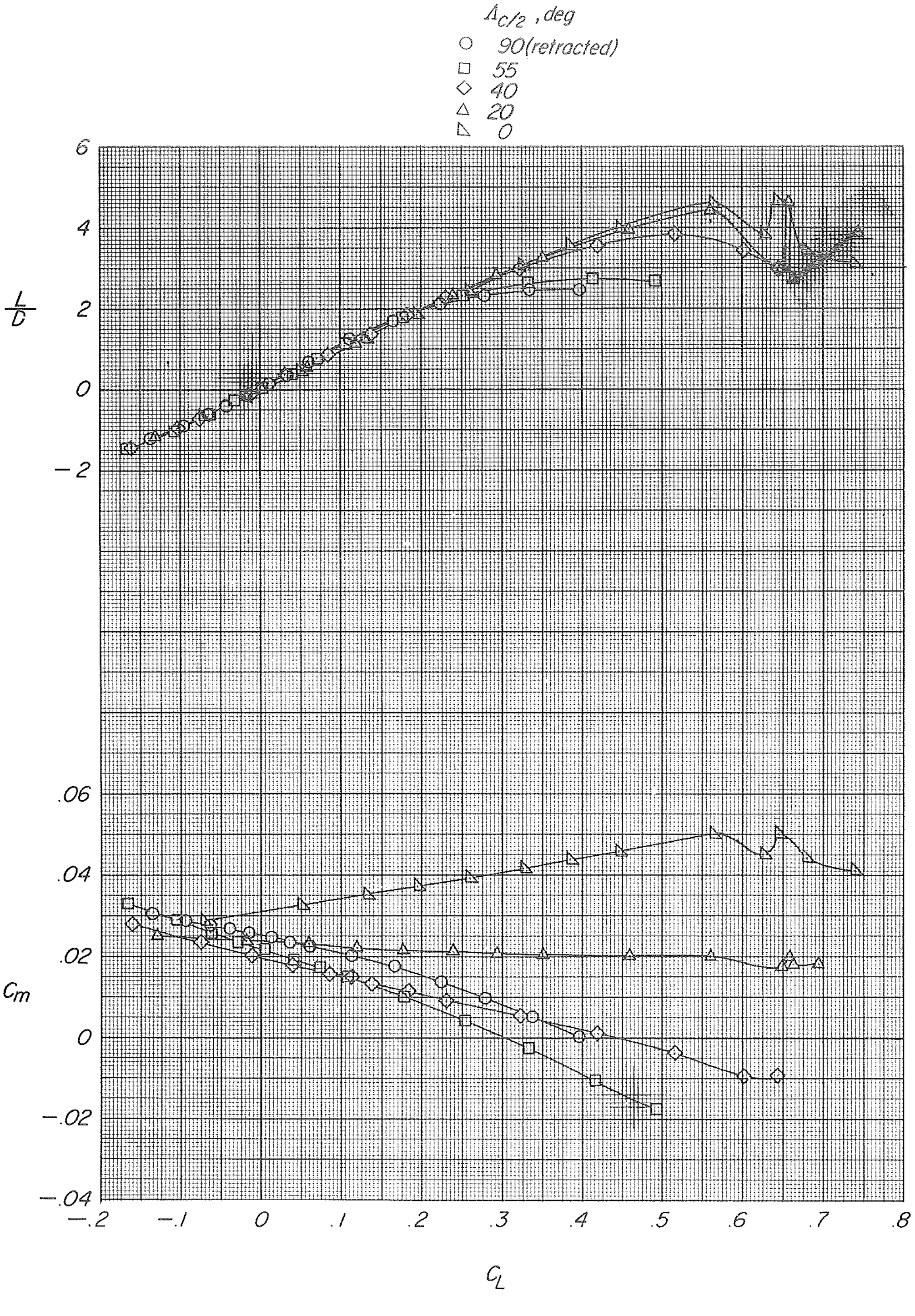

Figure 7.- Concluded.

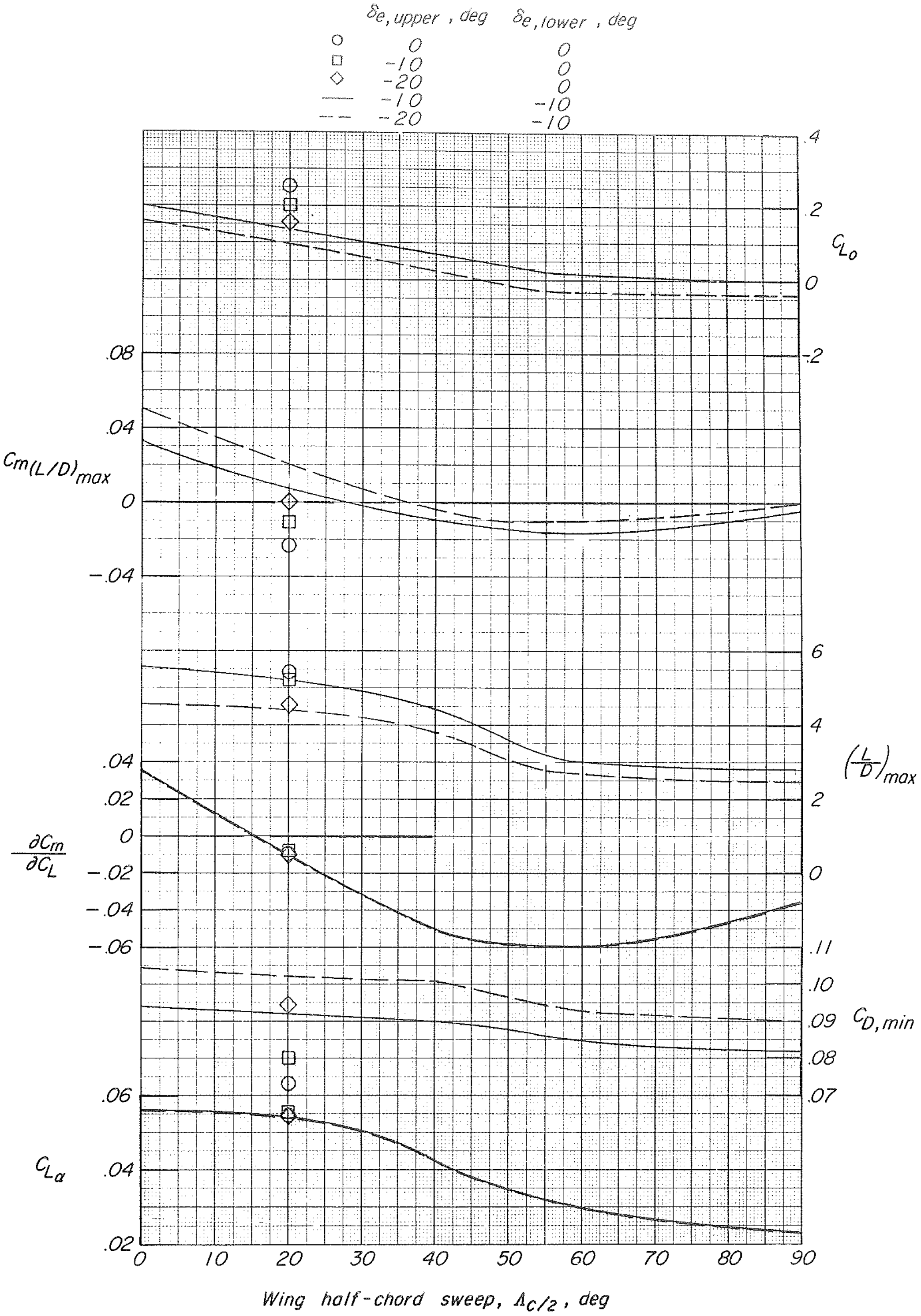

Figure 8.- Summary of various longitudinal aerodynamic parameters as affected by wing sweep and elevon deflection. Moment reference location, $0.456l_{ref}$.

NASA-Langley, 1971 —— 1 L-7357

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