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SUMMARY

An investigation has been conducted in the Langley Unitary Plan wind tunnel to determine the effects of wing planform modifications on the longitudinal aerodynamic characteristics of a maneuverable missile configuration. The wing span and root chord of the configuration were held constant but the tip chord was progressively increased so that the planform was varied from a delta planform to two alternate trapezoidal planforms.

Although it is not possible to make direct comparisons of the configurations because of the differing geometric characteristics, some significant aerodynamic effects were noted. In particular, nonlinear variations in pitching moment occurred at low angles of attack for roll angles of either 0° or 45° when the tip chord was increased and at high angles of attack for a roll angle of 45°, with this effect also being more pronounced for the trapezoidal planforms. The larger trapezoidal wing did provide greater lifting potential but was restricted by the pitching-moment nonlinearities. In general, the basic delta wing with its more linear characteristics appears to be suitable for highly maneuverable flight over a wide angle-of-attack range, whereas the larger trapezoidal wing with its high lift potential might be suitable for other missions where high lift at low angles of attack would be beneficial.

INTRODUCTION

The National Aeronautics and Space Administration is conducting research on the aerodynamic characteristics of various missile configurations in order to enlarge the data bank available to missile designers for determining the potential for improved maneuverability and performance. One area of interest concerns the restrictions which are often imposed on the dimensions of the missile due to launcher and/or logistic constraints. One of the critical components, in terms of sizing, is the wing, particularly for configurations relying on aerodynamic lift for maneuverability and/or range-payload requirements.

The purpose of this study was to determine some of the effects of the wing planform on the aerodynamics of missile configurations with a constrained wing span. For this study, the wing root chord was also held constant. The basic wing was a delta planform with a leading-edge sweep angle of 79.9°. Area was systematically added to the leading edge of the delta planform to form two trapezoidal planform wings having ratios of tip chord to root chord of 0.20 and 0.40. The configurations were cruciform with in-line tail controls. Wind-tunnel data were obtained at model roll angles of 0° and 45° for tail pitch-control deflections of 0° and -20°. The angle-of-attack range was from approximately -4° to 32° at Mach numbers from 1.60 to 2.86. The Reynolds number was 6.6×10^6 per meter. Theoretical predictions are compared with the experimental drag-due-to-lift values. Results of related investigations are reported in references 1 to 7.

SYMBOLS

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

$C_{D,o}$ drag coefficient at $C_L = 0$

ΔC_D drag-due-to-lift parameter, $C_D - C_{D,o}$

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

C_m pitching-moment coefficient about centroid of wing area, $\frac{\text{Pitching moment}}{qSd}$

c wing root chord, cm

d maximum body diameter, m

l body length, cm

M Mach number

q dynamic pressure, Pa

S wing area, including that of body bounded by extending wing leading and trailing edges to body center line, m^2 (When used with subscript 1, denotes wing area of wing 1.)

t wing root maximum thickness, cm

W_1 delta wing ($\lambda = 0$)

W_2 small trapezoidal wing ($\lambda = 0.20$)

W_3 large trapezoidal wing ($\lambda = 0.40$)

x moment reference center aft of nose, cm

α angle of attack, degrees

δ_m tail deflection to provide pitch, negative deflection for positive moment, all tails deflected for $\phi = 45^{\circ}$, degrees

Λ wing leading-edge sweep angle, degrees

λ ratio of tip chord to root chord

ϕ model roll angle about body center line, degrees

APPARATUS

Model

Details of the model are shown in figure 1. The configuration consisted of an ogive nose, a cylindrical afterbody, cruciform wings, and all-movable in-line tail controls. The three wing planforms used were a 79.9° delta wing and two trapezoidal shapes having ratios of tip chord to root chord of 0.20 and 0.40. The exposed wing root thickness-chord ratios were 0.040, 0.045, and 0.050, respectively. The wing and tail airfoil sections were hexagonal and the overall body length-diameter ratio was 15.

Wind Tunnel

The investigation was conducted in the low Mach number test section of the Langley Unitary Plan wind tunnel, which is a variable-pressure, continuous-flow facility. The test section is approximately 1.2 meters square by 2.1 meters long. The nozzle leading to the test section is of the asymmetric sliding-block type which permits a continuous variation in Mach number from about 1.5 to 2.9. A more detailed description of the facility is presented in reference 8.

MEASUREMENTS, CORRECTIONS, AND TEST CONDITIONS

Aerodynamic forces and moments were measured by a sting-supported, six-component strain-gage balance mounted within the model. The tests were conducted at Mach numbers from 1.60 to 2.86 for angles of attack to approximately 32° and for model roll angles of 0° and 45°. The Reynolds number was 6.6×10^{6} per meter.

The angles of attack have been corrected for tunnel flow angularity and deflection of the model support system due to load. The dew point was sufficiently low to prevent condensation effects.

Boundary-layer transition strips composed of carborundum grains embedded in a plastic adhesive were affixed to the wing and tail surfaces and to the nose. The strips were 0.15 cm wide and consisted of No. 50 grains located 1.02 cm rearward of the wing and tail leading edges (measured streamwise), and 3.05 cm rearward of the nose apex.

The aerodynamic coefficients are based on the respective area of each wing projected to the body center line; the reference length is the body diameter; and the pitching moments are referred to the center-line body station corresponding to the centroid of the reference area for each wing. The following table may be useful in comparing coefficients for the three models:

	W_1	W_2	W_3
S, cm^2	442.24	480.26	518.35
d, cm	5.08	5.08	5.08
x/l	0.582	0.591	0.595
t/c	0.040	0.045	0.050
$\frac{S}{S_1}, \frac{Sd}{S_1 d}$	1.0	1.09	1.17
Λ, deg	79.9	77.4	73.4

PRESENTATION OF RESULTS

The results are presented as follows:

	Figure
Longitudinal aerodynamic characteristics for $\phi = 0^{o}$ at –	
M = 1.60	2
M = 2.36	3
M = 2.86	4
Longitudinal aerodynamic characteristics for $\phi = 45^{o}$ at –	
M = 1.60	5
M = 2.36	6
M = 2.86	7
Experimental and theoretical drag due to lift	8

DISCUSSION

It is not possible to make direct comparisons of the configurations because of differing geometric characteristics; however, some pertinent observations can be made. Through proper location of the moment center, each of the three configurations can be made stable and controllable within certain limits. A fundamental configuration effect that can be pointed out from the data for $\phi = 0^{\circ}$ and 45° (figs. 2 to 7) is the nonlinearity that occurs in the variation of C_m with C_L at low angles of attack as the wing tip chord is increased. This effect is probably caused by the interference of the wing flow field on the tail as the wing tip chord increases and the tip Mach cone effects become stronger. The effect tends to disappear as the tail emerges from the flow field of the wing. The largest wing, W_3, indicates the possibility of sustaining a greater lift for a constant angle of attack; however, the change in moment center required to provide low angle stability would tend to nullify this greater lift potential for highly maneuverable flight because of the greater trimming requirements that would be imposed.

In addition to the low angle moment nonlinearities, the results for $\phi = 45^{\circ}$ (figs. 5 to 7) indicate the added complexity of a pitch-up tendency at higher angles of attack. This higher angle-of-attack pitch-up, which imposes a static stability limitation for all of the wings, probably results from interference flow-field effects on the tail surfaces.

In general it can be said that the delta wing, W_1, with its lower lifting capability also provides the most linear moment characteristics because of the smaller flow-field effects on the tail; thus it may provide good maneuvering characteristics over a wider range of angle of attack and Mach number. On the other hand, the larger wing, W_3, demonstrates the capability of producing much higher lift within the fixed-span constraint but with the resulting onset of undesirable nonlinear moment characteristics. This type of arrangement might be best suited for missions where high angles of attack are not required, such as in the low altitude regime where the lift could be generated from high dynamic pressure rather than from high angle of attack. The lifting capability of the larger wing might also be utilized in supporting heavier payloads rather than in providing high maneuverability, a characteristic that might be desirable for an air-to-surface missile or a cruise missile, for example.

An examination of the data indicates an increasingly wide disparity between the stability characteristics at $\phi = 0^{\circ}$ and 45° as the wing tip chord is increased. In addition, the changes in control effectiveness between the 45° plane (four controls) and the 0° plane (two controls) are substantial and tend to result in missile maneuvering capability that must be limited to the lower level of control power ($\phi = 0^{\circ}$). This condition has added some impetus to studies of nonsymmetric missile configurations, including monoplanar types (ref. 9, for example).

The experimental and theoretical values of the drag-due-to-lift parameter for $\delta_m = 0^{\circ}$ are presented in figure 8. At $M = 1.60$, a change in roll angle from 0° to 45° is accompanied by a substantial increase in the experimental drag due to lift; however, this difference diminishes as Mach number is increased. The data also exhibit the characteristic increase in drag due to lift with increasing Mach number. The theoretical drag-due-to-lift data are based on linear theory and were computed according to the method described in reference 10 with modifications to the computer program to include the effects of the horizontal tail. The theoretical method is limited to the case for $\phi = 0^{\circ}$. With the exception of W_2 at $M = 2.86$, the theory predicts ΔC_D values higher than the experimental values for $\phi = 0^{\circ}$ although there is a convergence of theory and experiment as Mach number is increased.

CONCLUDING REMARKS

An investigation has been conducted to determine the effects of wing planform modifications on the longitudinal aerodynamic characteristics of maneuverable missile configurations on which the wing span and root chord were constrained but the tip chord was progressively increased so that the wing shape varied from a delta planform to trapezoidal planforms.

The results indicated that, when the wing tip chord was increased, a nonlinear variation of pitching moment with lift occurred for roll angles of 0° and 45° at low angles of attack. This nonlinearity was apparently due to an increased interference field from the wing tip Mach cone affecting the tail since the effect tended to disappear at higher angles as the tail emerged from the wing flow field. An additional nonlinearity that occurred at higher angles of attack for the 45° roll plane was also apparently due to the wing interference flow field, and this effect progressively worsened as the wing tip chord was increased. Although the wing with the largest tip chord (and largest area) did indicate a substantial advantage in lift capability, the nonlinear pitch characteristics associated with the wing would tend to limit the most effective use of the wing to low angles of attack.

In general, the basic delta wing with its more linear characteristics appeared to be suitable for more highly maneuverable flight over a wide angle-of-attack range. The large trapezoidal wing with its superior lift potential might be well suited for other missions where high lift at low angles of attack would be beneficial.

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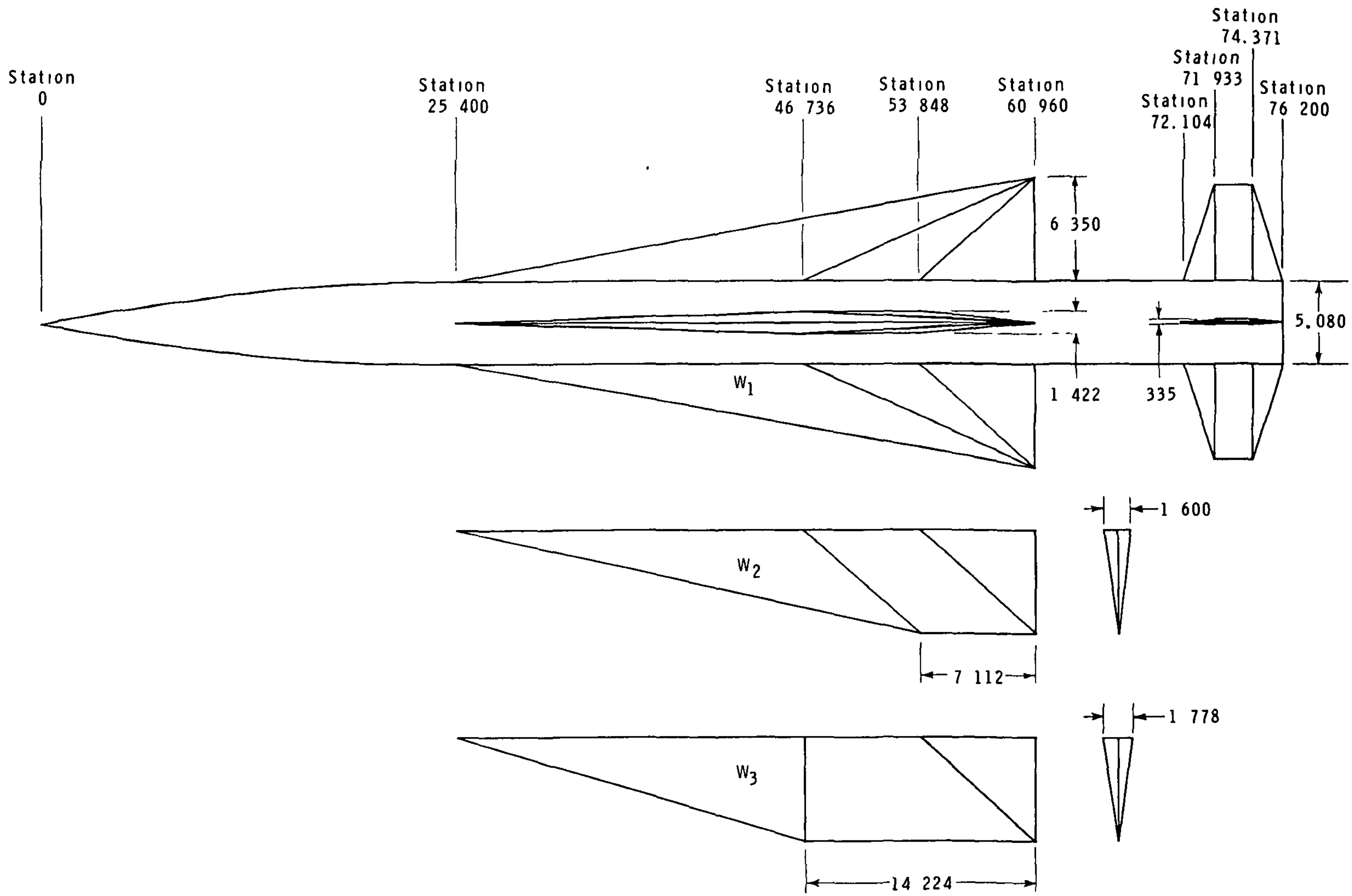
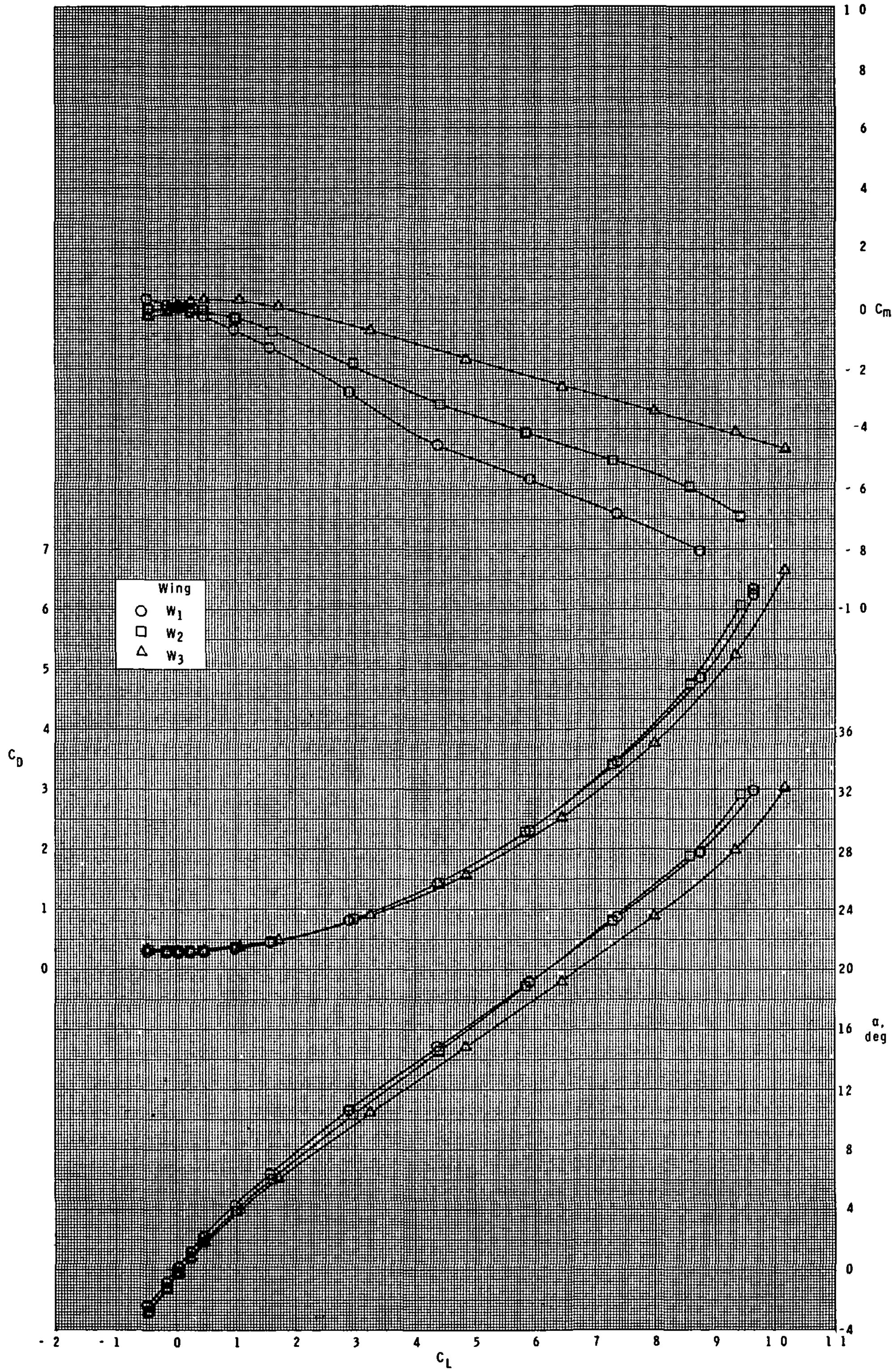
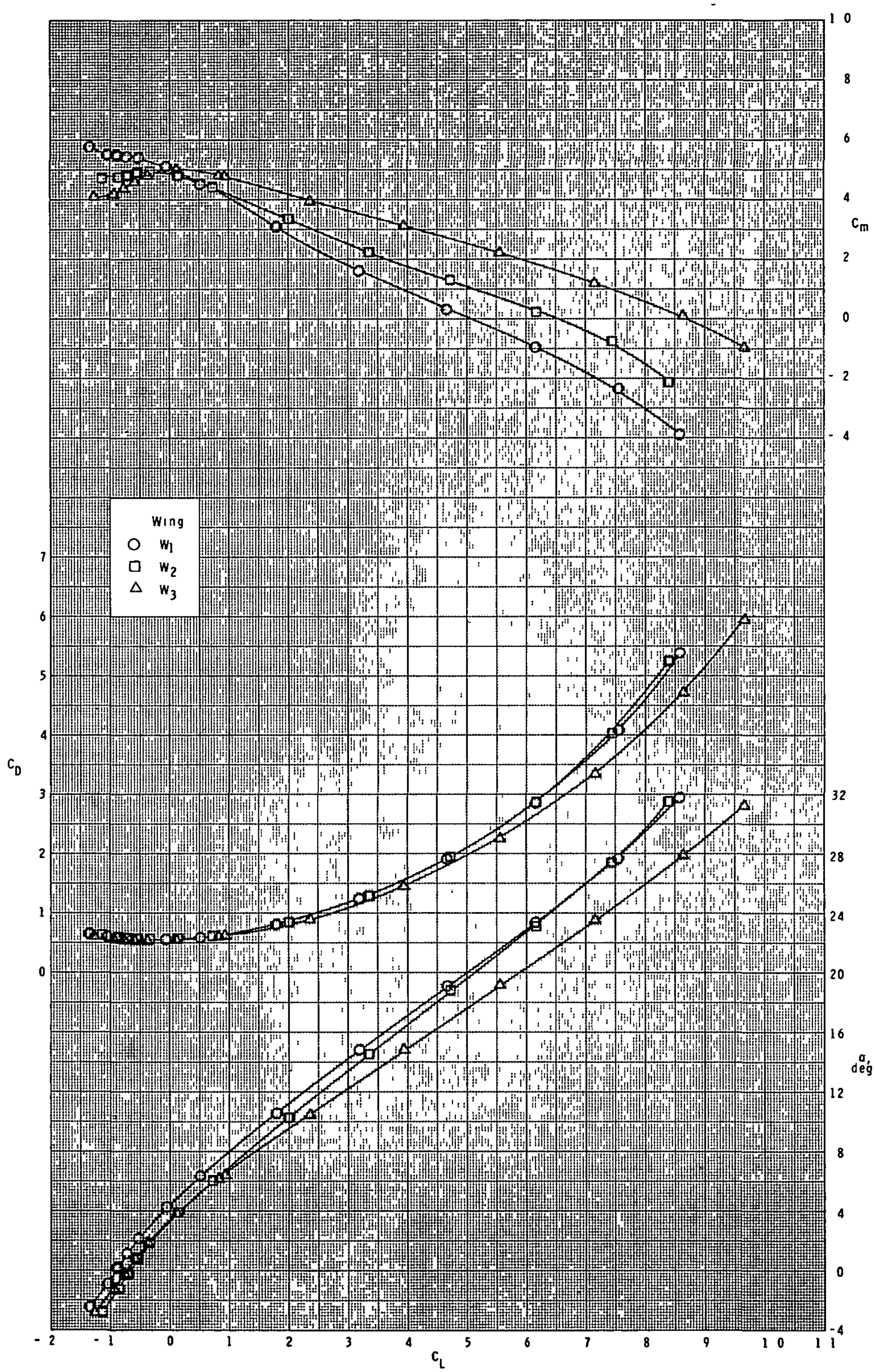


Figure 1.- Model details. Dimensions are in centimeters.



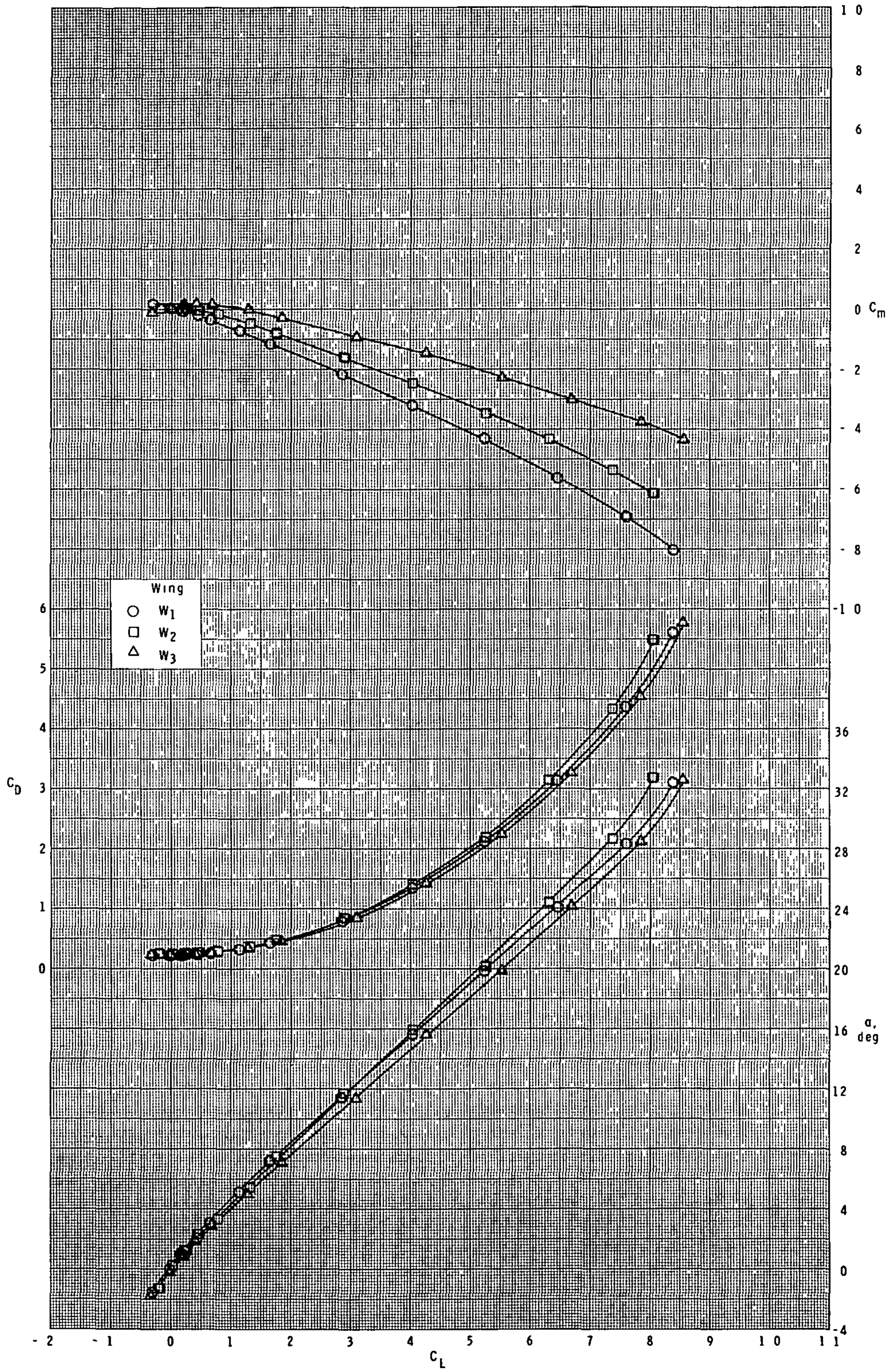
(a) $\delta_m = 0^o$.

Figure 2.- Longitudinal aerodynamic characteristics for $\phi = 0^o$ at $M = 1.60$.



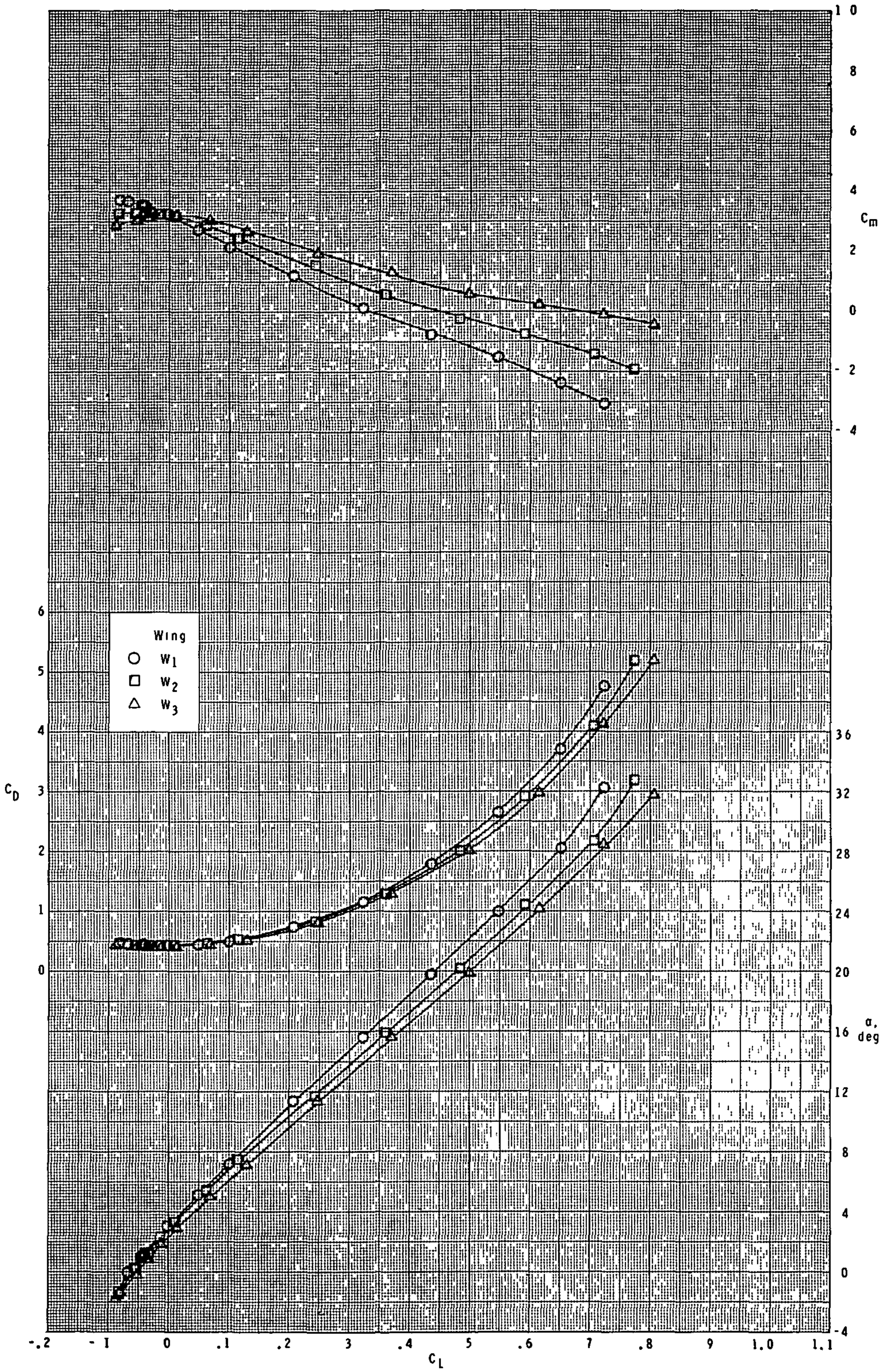
(b) $\delta_m = -20^{\circ}$.

Figure 2.- Concluded.



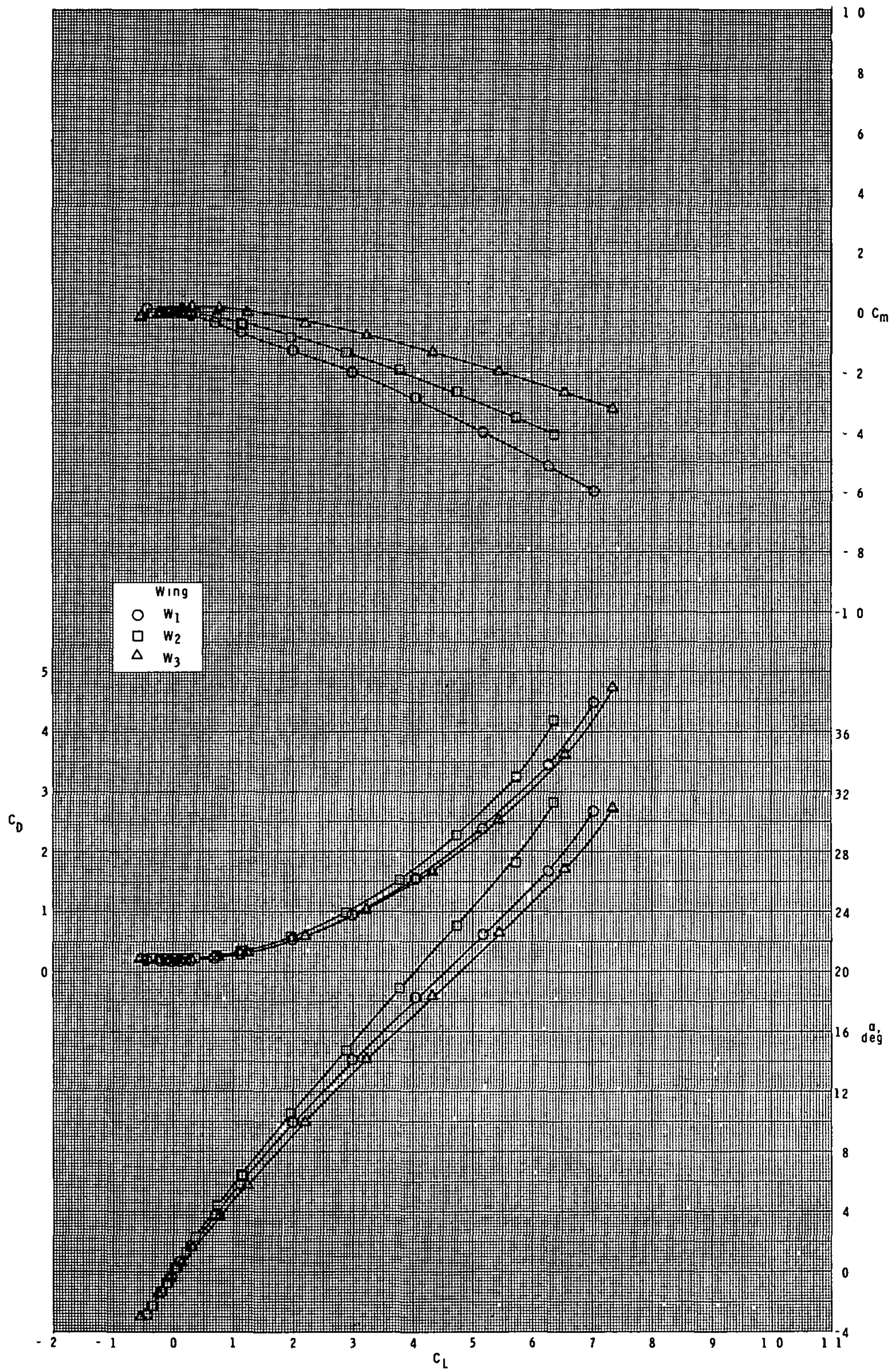
(a) $\delta_m = 0^o$.

Figure 3.- Longitudinal aerodynamic characteristics for $\phi = 0^o$ at $M = 2.36$.



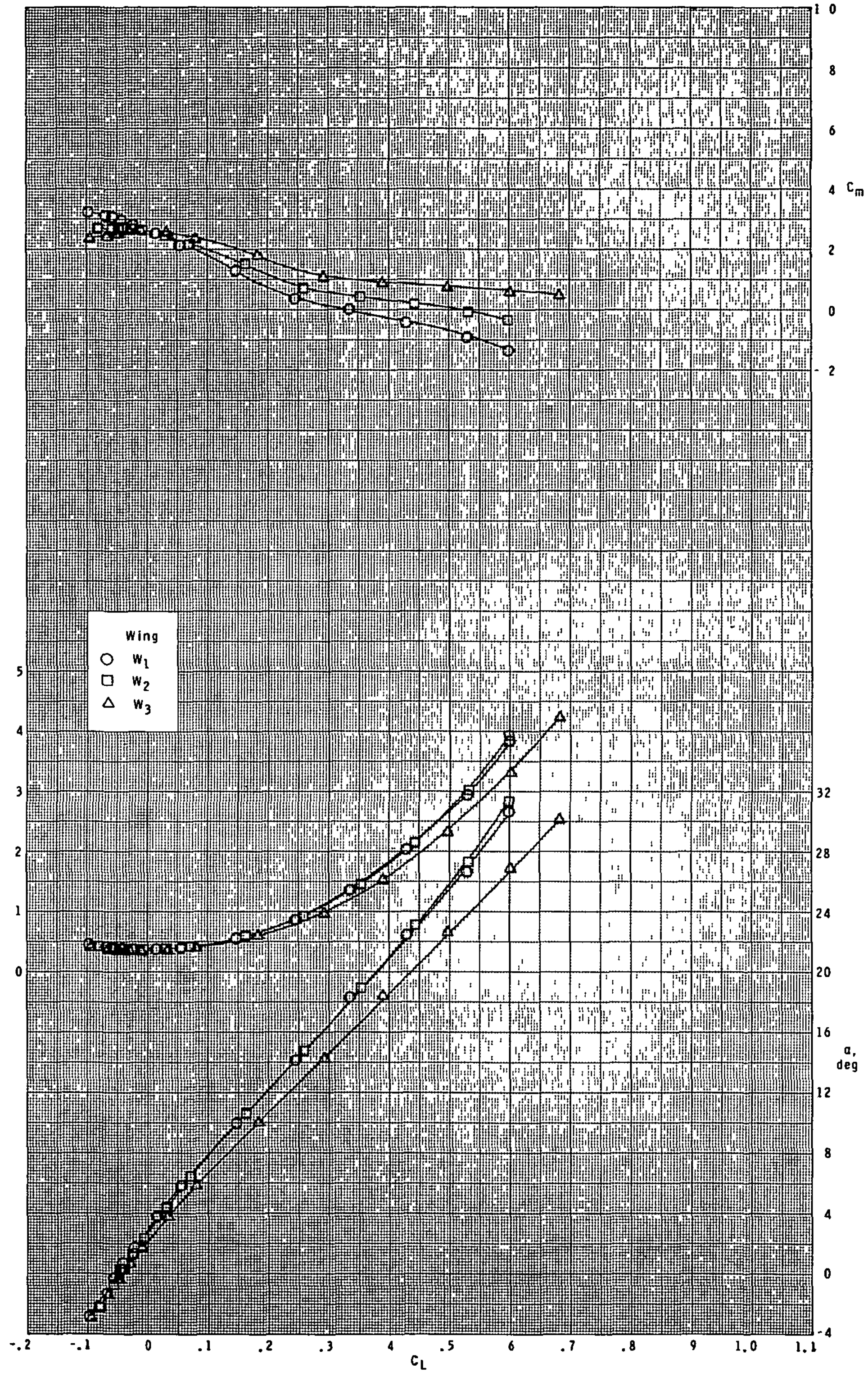
(b) $\delta_m = -20^o$.

Figure 3.- Concluded.



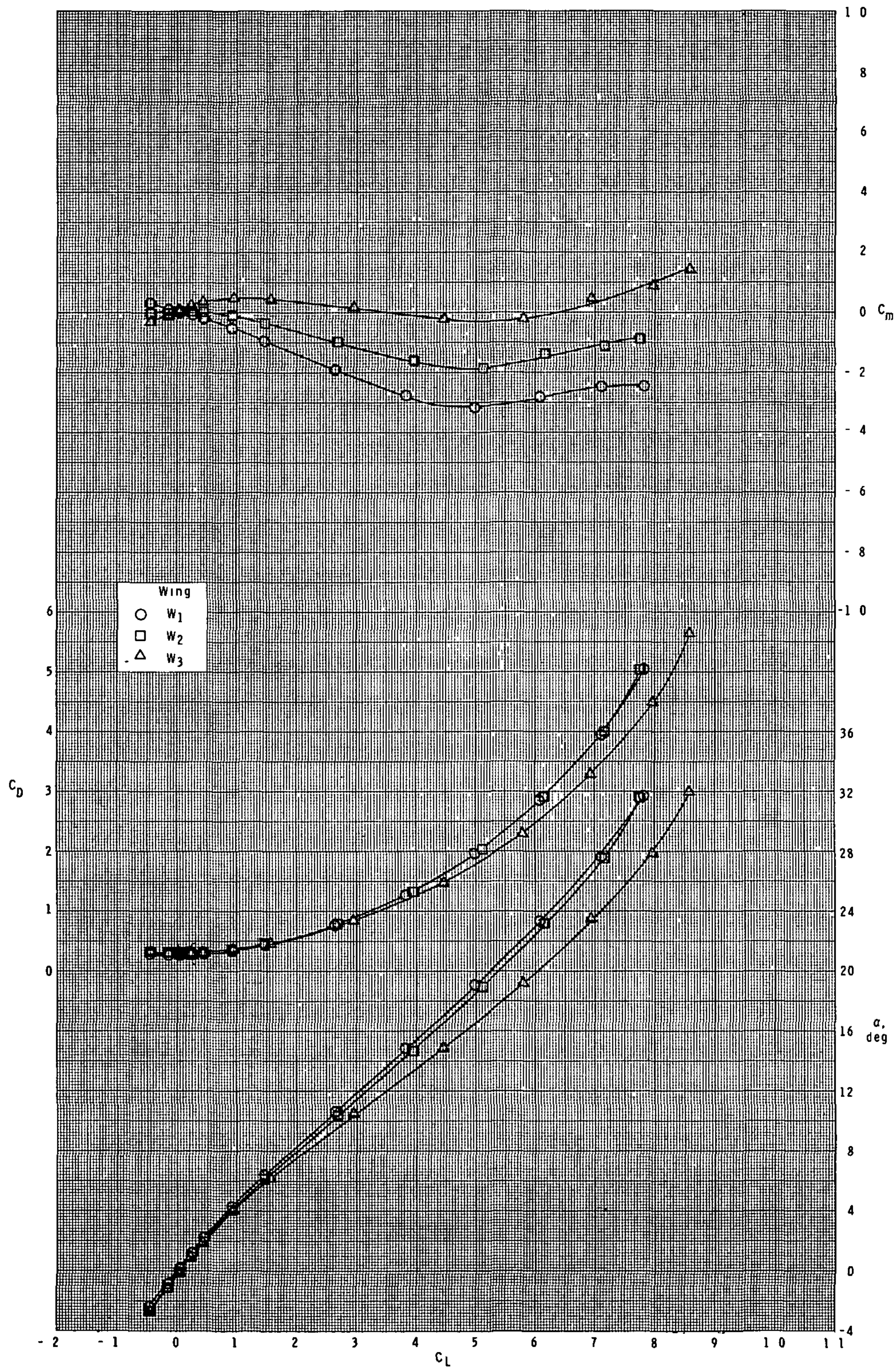
(a) $\delta_m = 0^o$.

Figure 4.- Longitudinal aerodynamic characteristics for $\phi = 0^o$ at $M = 2.86$.



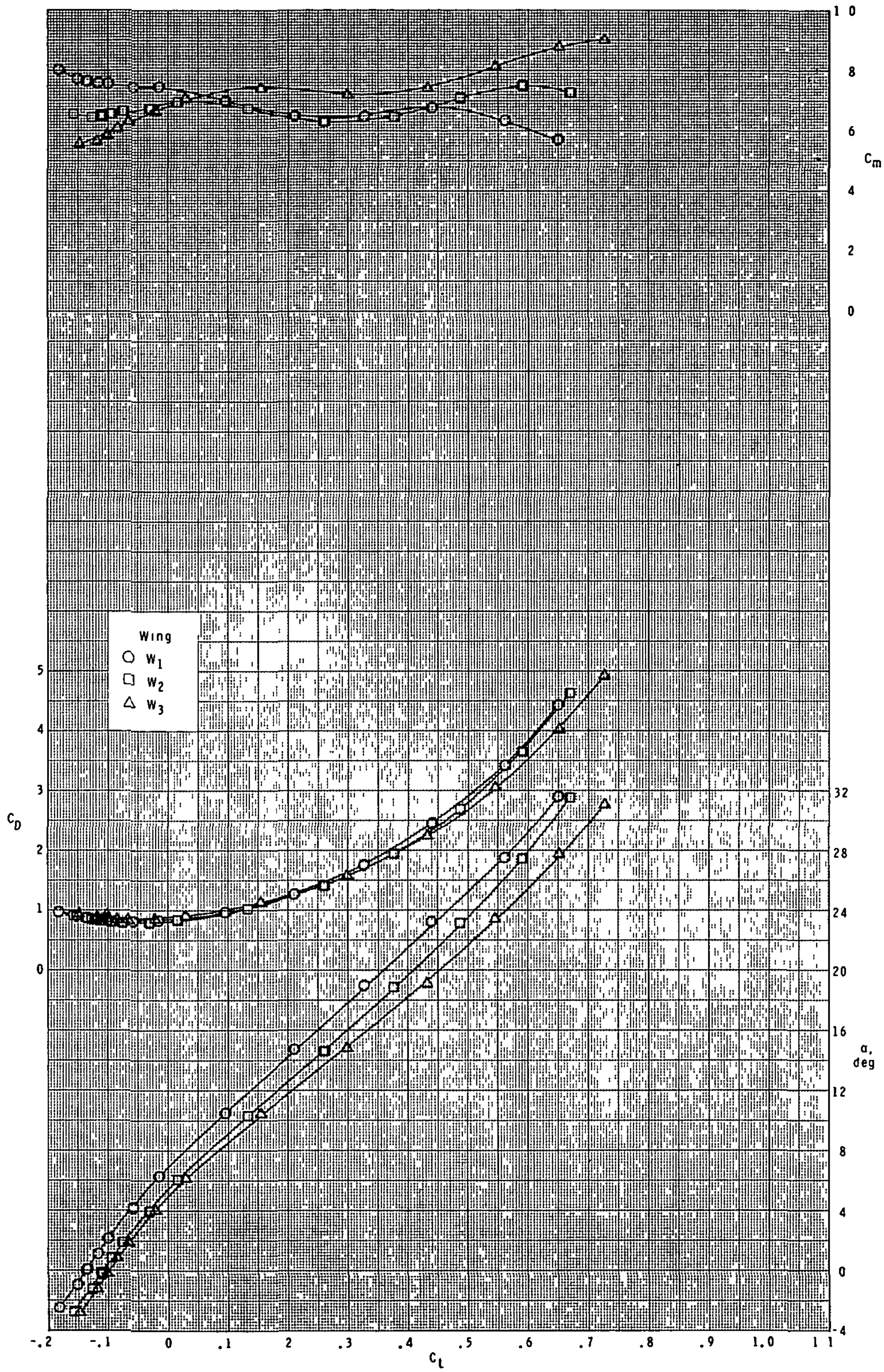
(b) $\delta_m = -20^o$.

Figure 4.- Concluded.



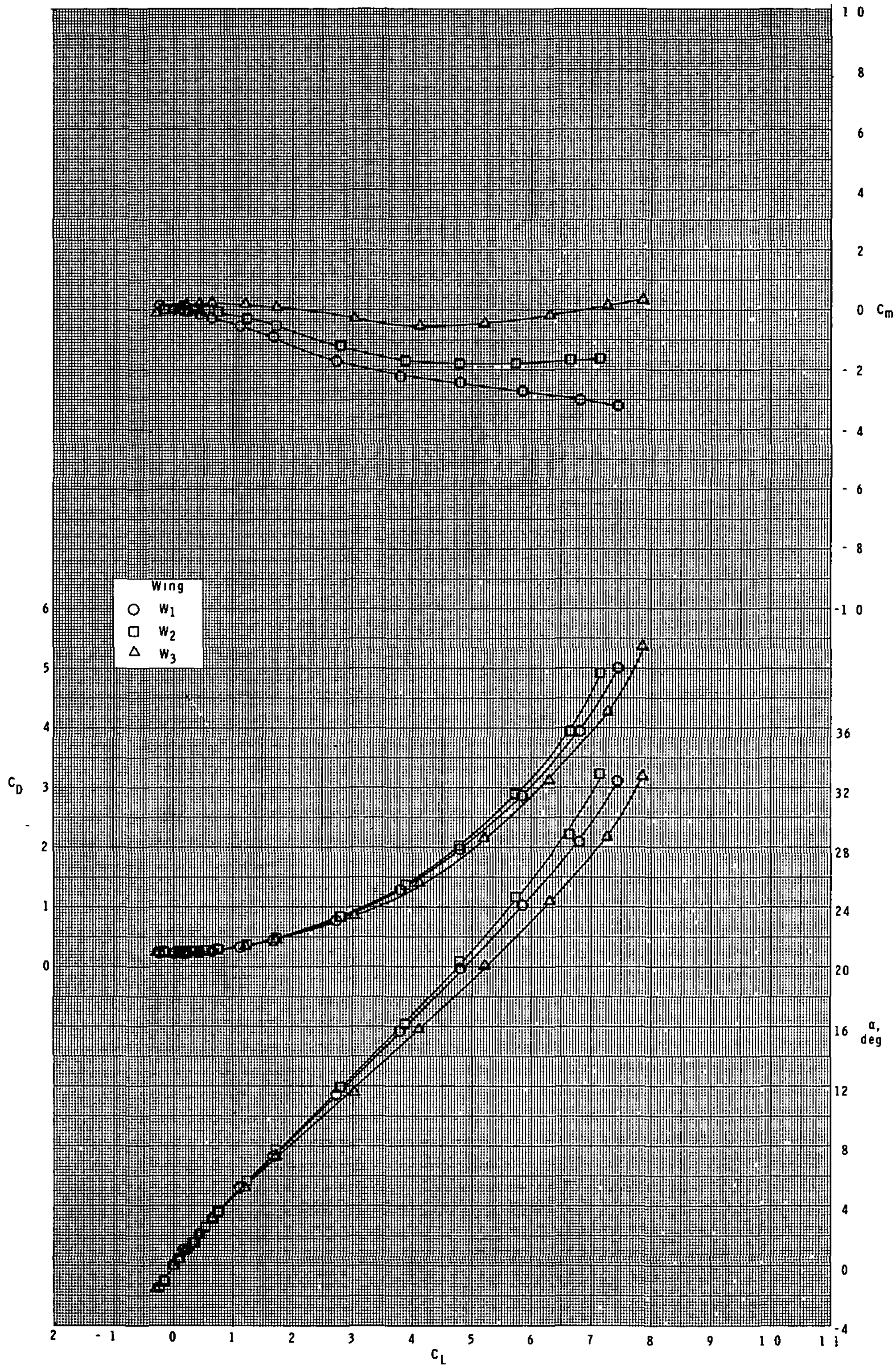
(a) $\delta_m = 0^o$.

Figure 5.- Longitudinal aerodynamic characteristics for $\phi = 45^o$ at $M = 1.60$.



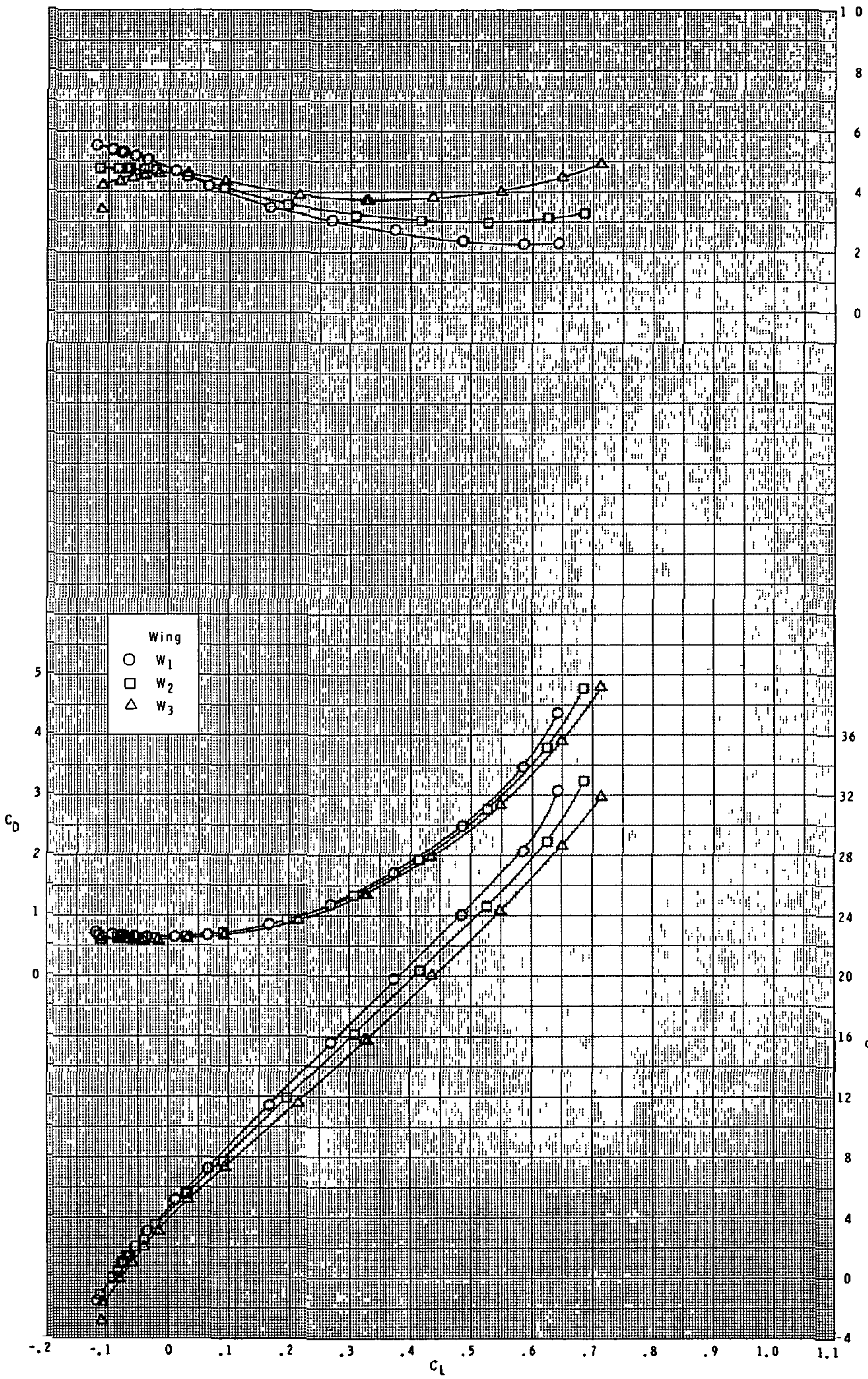
(b) $\delta_m = -20^o$.

Figure 5.- Concluded.



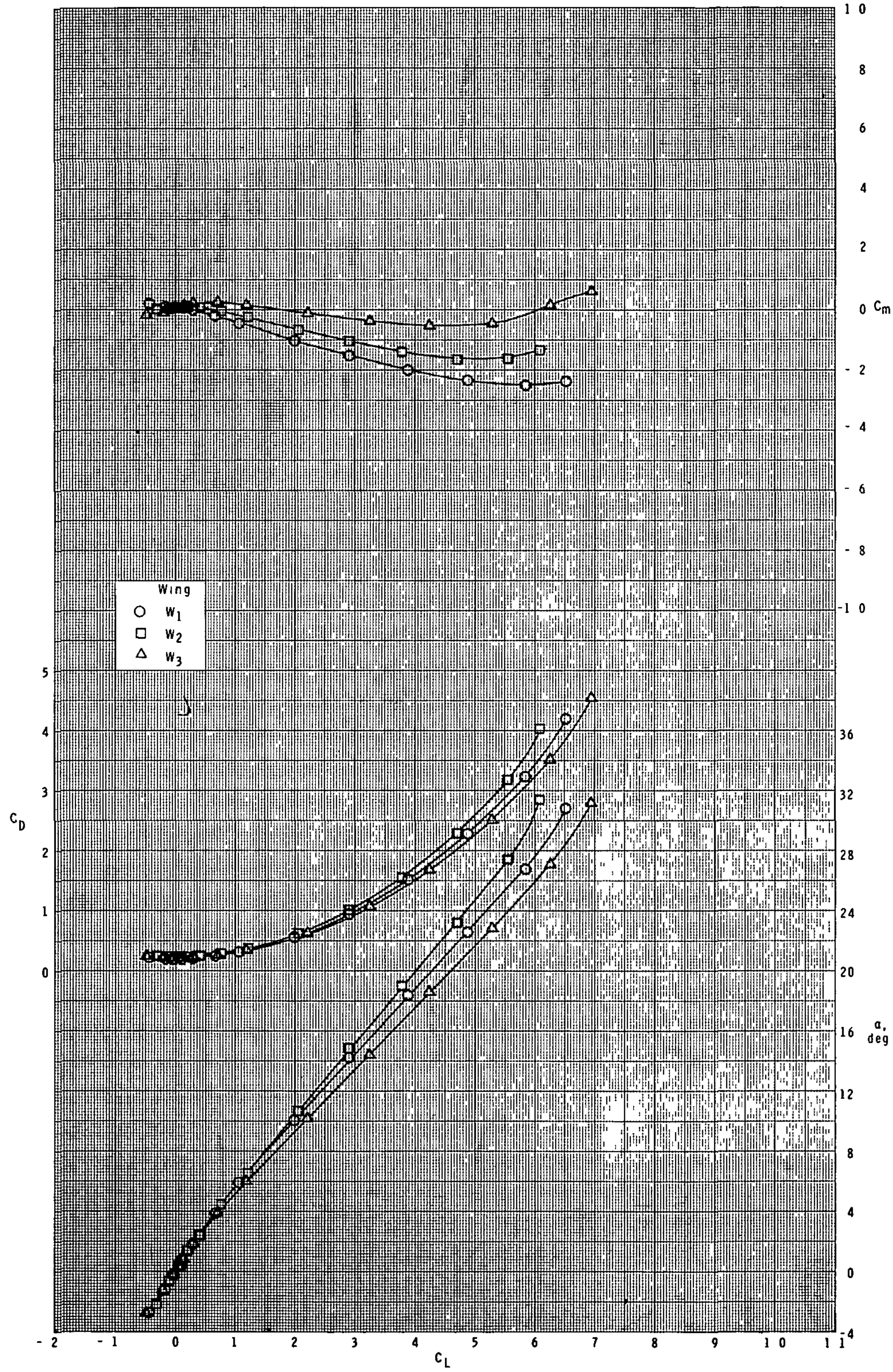
(a) $\delta_m = 0^o$.

Figure 6.- Longitudinal aerodynamic characteristics for $\phi = 45^o$ at $M = 2.36$.



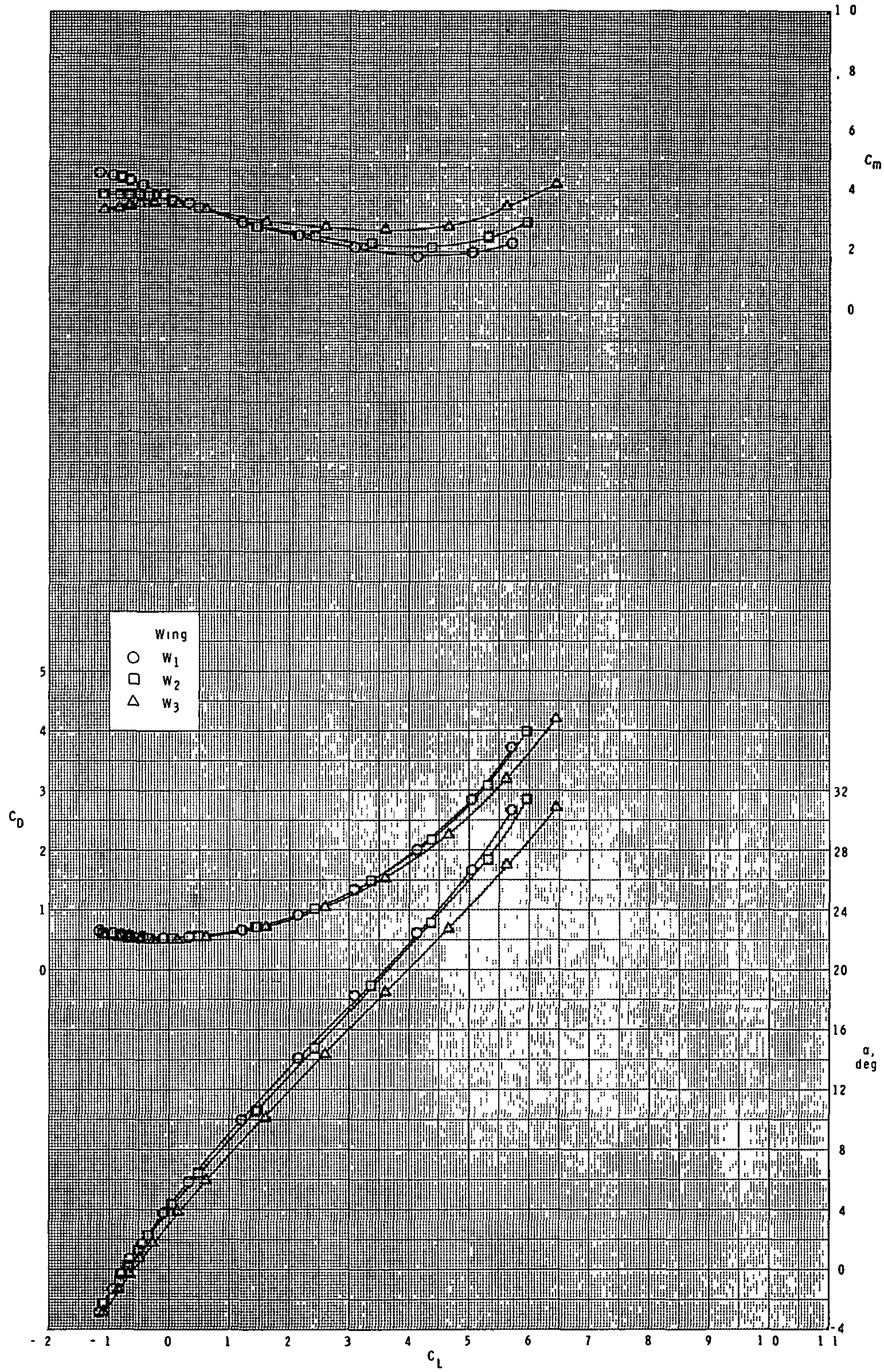
(b) $\delta_m = -20^{\circ}$.

Figure 6.- Concluded.



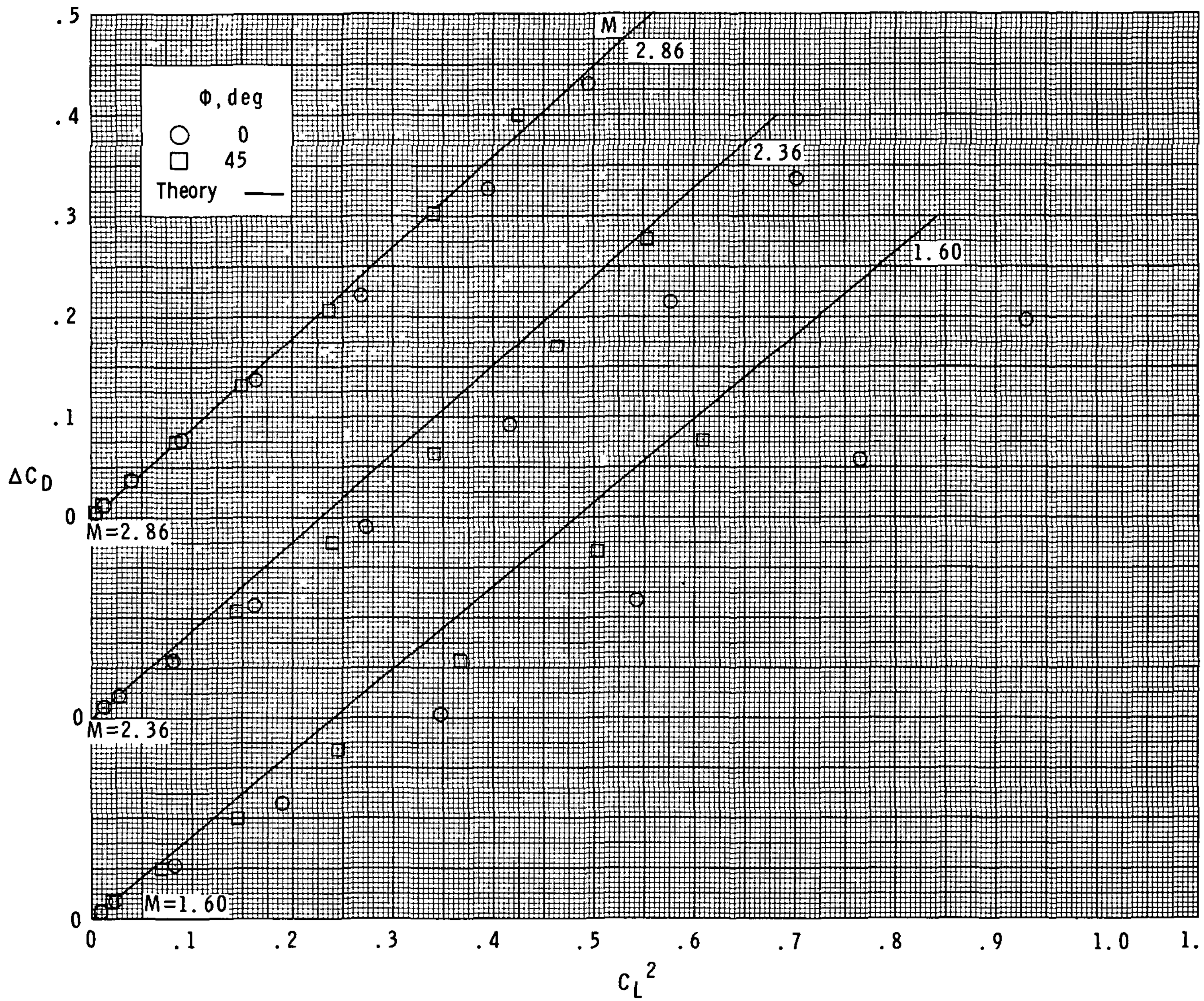
(a) $\delta_m = 0^{\circ}$.

Figure 7.- Longitudinal aerodynamic characteristics for $\phi = 45^{\circ}$ at $M = 2.86$.



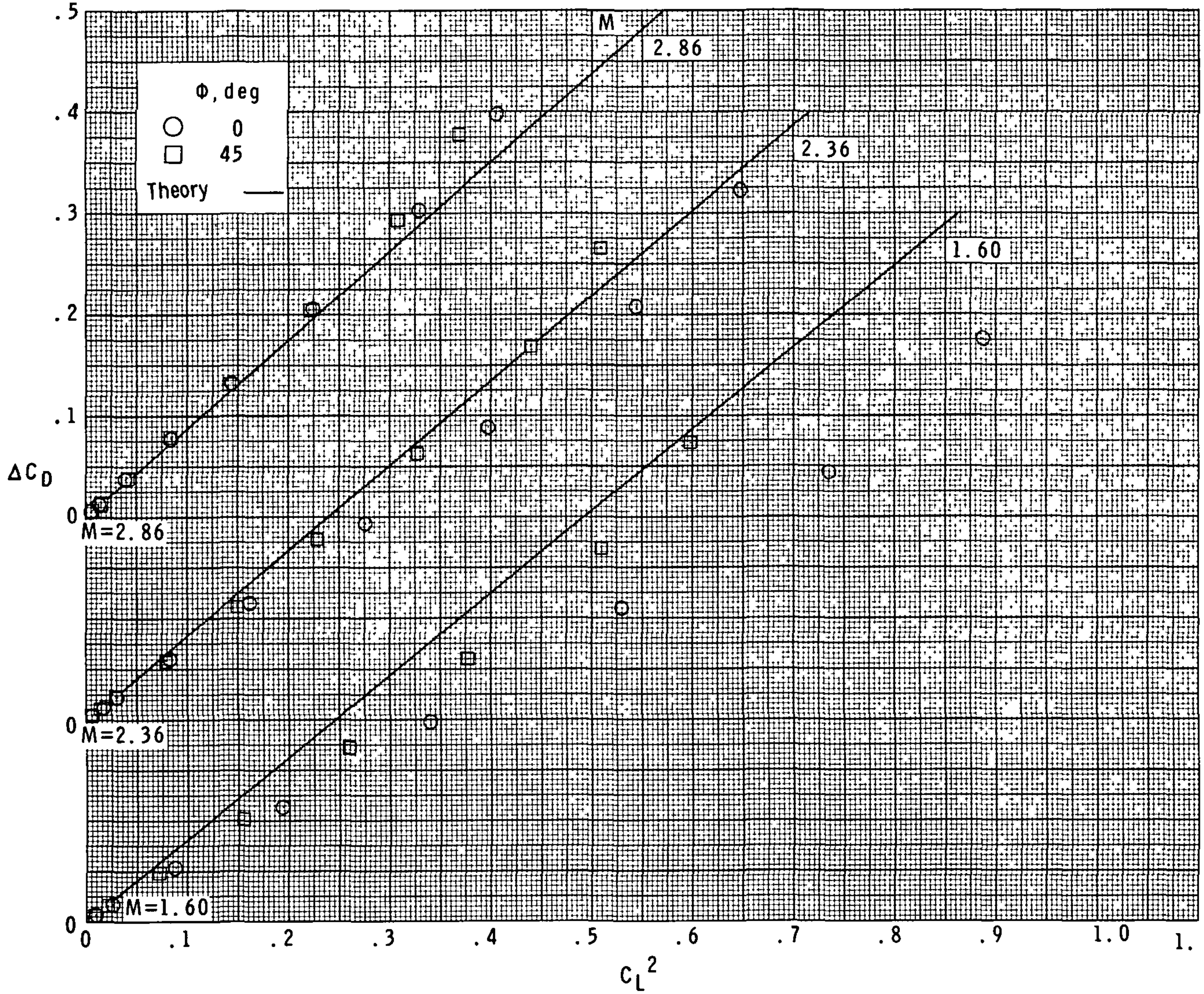
(b) $\delta_m = -20^o$.

Figure 7.- Concluded.



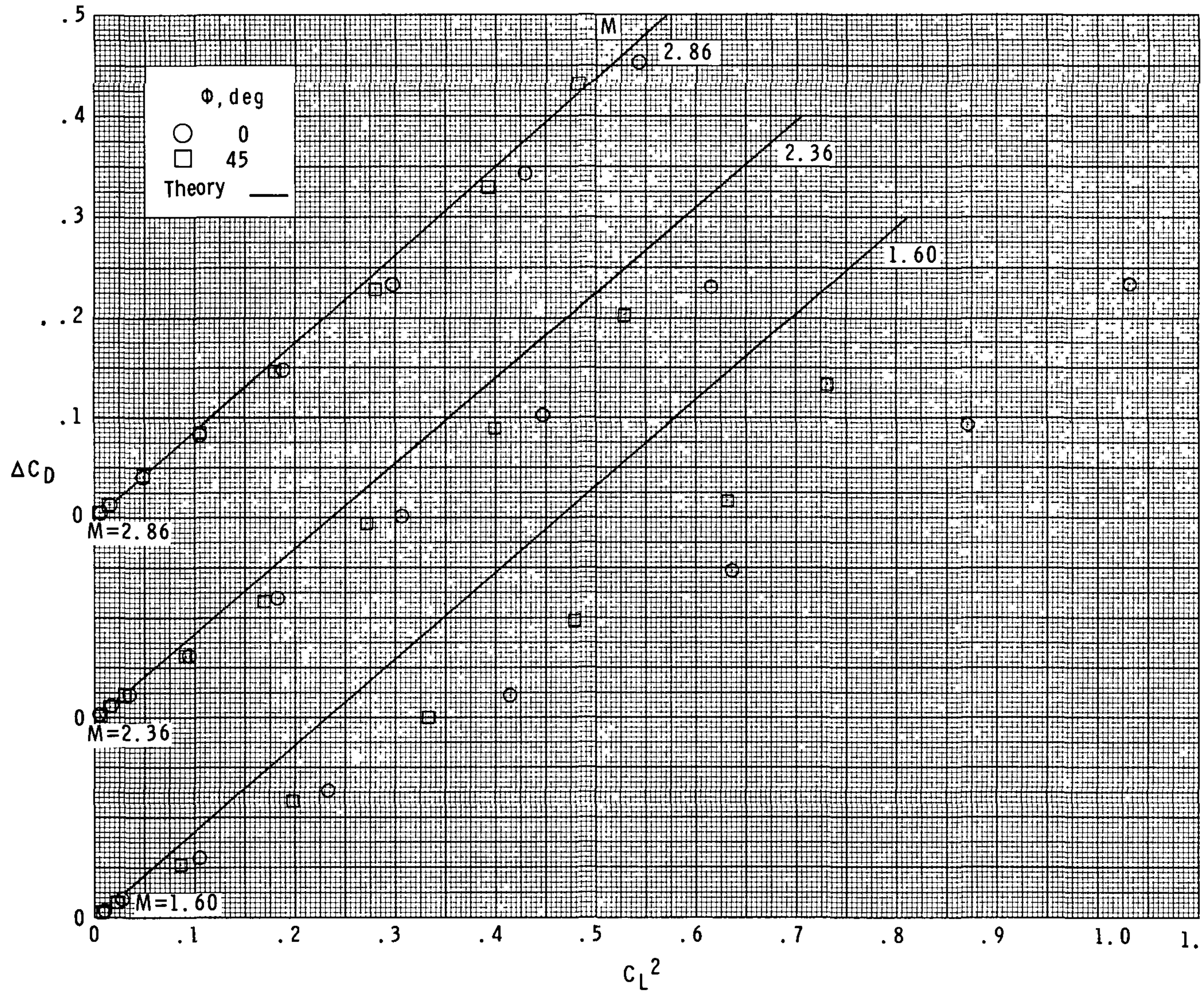
(a) W_1.

Figure 8.- Experimental and theoretical drag due to lift.



(b) W_2.

Figure 8.- Continued.



(c) W_3.

Figure 8.- Concluded.

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15 Supplementary Notes

16 Abstract

A study was made to determine the effects of wing planform modifications on the longitudinal aerodynamic characteristics of a fixed-span, maneuverable cruciform missile configuration. Three wing shapes, a basic delta planform and two alternate trapezoidal planforms having progressively increasing tip chords, were included. Data were obtained in the Langley Unitary Plan wind tunnel for angles of attack up to approximately -32°, model roll angles of 0° to 45°, and tail control deflections of 0° and -20°. The experimental drag due to lift was compared with linear theory values.

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