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Aerodynamic Characteristics of Wings Designed With a Combined-Theory Method To Cruise at a Mach Number of 4.5

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Summary

A wind-tunnel study has been conducted to determine the capability of a method combining linear theory and shock-expansion theory to design optimum camber surfaces for wings that will fly at high-supersonic/low-hypersonic speeds. Three force models (a flat-plate reference wing and two cambered and twisted wings) as well as a surface-pressure-measurement model were used to obtain aerodynamic lift, drag, pitching-moment, and pressure coefficient data at Mach numbers of 3.5, 4.0, and the design Mach number of 4.5. An analysis of these data showed that the three force models had about the same levels of aerodynamic performance and efficiency even though the camber surfaces of the three wing models were markedly different. The camber surfaces of the two warped-wing models were dissimilar because wing airfoil-thickness ratio was a design constraint for one but not the other. However, the two wings were similarly modified to rid each of root-chord singularities. Thus, the similarities in aerodynamic performance and efficiency that were observed indicated that thickness ratio was not a significant theoretical constraint in the combined-theory optimization method at the design conditions selected for this study. However, the force and pressure data have value independently as a data base for comparison with appropriate theory for wing performance analysis.

Introduction

The quest for aerodynamically efficient, supersonic cruise aircraft has led to the development of several computer-implemented, linear-theory methods for calculating optimum wing camber and twist. An example of such methods is reported in reference 1. These linear-theory methods proved to be useful in the design of wings for high-speed aircraft and in the predictions of aerodynamic performance at low-supersonic Mach numbers (approximately 1.5 to 2.0). Refinements, such as those found in reference 2, made these linear-theory methods more flexible and applicable to wings meeting a variety of design requirements. However, the wing flow field modeled by these early methods had simplified characteristics. Finite-strength shocks, near-vacuum limited expansions, separated flow, and other nonlinear phenomena could not be represented. The results of these limitations manifested themselves when wings designed with linear-theory methods did not always achieve the predicted levels of lift-drag ratio and/or zero-lift pitching moment. (Refs. 3, 4, and 5 are typical.) This result was often observed at test Mach numbers above 2.5 and at design-lift coefficients above 0.05 for wings that required moderate-to-severe camber and twist.

Somewhat different approaches for predicting wing characteristics at high-supersonic/low-hypersonic Mach numbers were concurrently under study and development. These methods computed aerodynamic characteristics from wing thickness, surface slope, and finite-strength shock effects; they left out the aerodynamic influence from surface-pressure interactions because the computational Mach cone narrowed as the Mach number increased. Such methods were useful at very high Mach numbers but did not always give satisfactory predictions at the middle range of Mach number (approximately 2.0 to 3.0) as shown, for example, in reference 4.

The need for a single method that would successfully predict wing performance across the range of Mach number from low-supersonic to high-supersonic/low-hypersonic speeds prompted researchers to combine the key features of both the high and low Mach number methods into a single computer-implemented method. Three examples of this combined-theory methodology were reported and described in references 6, 7, and 8, all of which appeared at about the same time. Along with other similar methods under concurrent study, they verified the idea that a generalized, combined-theory method was both promising and feasible. The study reported in reference 8 led to the combined-theory design and analysis method presented and described in reference 9.

A validation program was initiated with the design of a set of wing models using this new combined-theory method. These wings were predicted to have high aerodynamic efficiency at Mach numbers beyond the range of linear-theory application but within the operating range of available supersonic wind tunnels. The data from subsequent tests in the high-speed leg of the Langley Unitary Plan Wind Tunnel were evaluated to determine the merits of the combined-theory wing design method as a design tool at high-supersonic/low-hypersonic Mach numbers. These data are also significant individually in describing the aerodynamic characteristics of wings designed for flight at very high-supersonic/low-hypersonic speeds.

Symbols

b	wing span, 14.0 in.
C_A	axial-force coefficient
C_D	drag coefficient
$C_{D,o}$	drag coefficient at zero lift
$C_{D,o,F}$	drag coefficient of flat-wing model at zero lift
C_L	lift coefficient
$C_{L,c}$	camber lift coefficient (lift coefficient at zero angle of attack)
$C_{L,\mathrm{DES}}$	design-lift coefficient
$C_{L_{\alpha,o}}$	$= \Delta C_L/\Delta\alpha$ per degree at zero angle of attack
C_m	pitching-moment coefficient about $0.25\bar{c}$ ($x = 19.818$ in.)
$C_{m,o}$	pitching-moment coefficient at zero lift
$(\Delta C_m/\Delta C_L)_o$	longitudinal stability derivative at zero lift
C_N	normal-force coefficient
C_p	wing surface-pressure coefficient, $(p - p_\infty)/q_\infty$
$C_{p,u}$	pressure coefficient on wing upper surface, $(p - p_\infty)/q_\infty$
c	wing chord, in.
$\bar{c}$	mean geometric chord, 26.909 in.
L/D	lift-drag ratio
l	maximum wing model length, 40.0 in.
M	free-stream Mach number
P_s	stagnation pressure, lb/ft^2
p	pressure, lb/ft^2
p_∞	free-stream pressure, lb/ft^2
q_∞	dynamic pressure in free stream, $\frac{\gamma}{2} p_\infty M^2$, lb/ft^2

R	Reynolds number per foot
r	body radius, in.
T_s	stagnation temperature, °F
t	wingtip length, 4.0 in.
x	longitudinal axis coordinate, in.
x'	x-distance aft of wing leading edge
y	lateral or spanwise axis coordinate, in.
z	coordinate axis normal to xy-plane, in.
α	angle of attack, deg
ALPHA	angle of attack used in computer tables (tables III, IV, and V), deg
β	$= (M^2 - 1.0)^{1/2}$
γ	ratio of specific heats for air, 1.4
Δ	increment
Λ	leading-edge sweep angle, $\tan^{-1}(36.0/7.0) \approx 79.0°$

Wing Design and Analysis

Design Criteria

Several constraints were imposed on the design of the wind-tunnel wing models obtained by employing the combined-theory method: (1) a Mach number in the range from 4.0 to 4.5, (2) a subsonic leading edge ($\beta \cot \Lambda < 1.0$), (3) a cruise lift coefficient in the range $0.05 \leq C_{L,\mathrm{DES}} \leq 0.10$, (4) a wing maximum thickness-chord ratio sufficient to test the combined-theory-method capabilities but within small disturbance limits, (5) a "reasonable" zero-lift pitching-moment coefficient, and (6) a smooth wing-balance-body junction (which would eliminate or minimize thickness-induced lift, drag, and moment effects of the balance body on the wing):

A design Mach number of 4.5 was chosen since it exceeded the accepted range of linear-theory applicability but was within the cruise Mach number range considered for several high-speed research aircraft. (The conceptual configurations reported in ref. 10 were typical examples of these potential aircraft.) A leading-edge sweep angle of about 79.0° ($\tan^{-1}(36.0/7.0)$) was selected because at a Mach number of 4.5, it provided a subsonic leading edge ($\beta \cot \Lambda = 0.853$) with the attendant possibilities of favorable camber and twist benefits. Cruise lift coefficients in the range $0.08 \leq C_L \leq 0.10$ have been considered for high-speed aircraft. Experience has shown, however, that the theoretical camber surfaces which produced such high lift coefficients at high Mach numbers and had subsonic leading edges were usually severely warped. Thus, a value of $C_{L,\mathrm{DES}} = C_{L,c} = 0.05$ was selected as an input parameter likely to yield a reasonable camber surface. An airfoil maximum thickness-chord ratio from 0.025 to 0.030 and a circular-arc airfoil shape were chosen for the wing models. Even though this airfoil-thickness range provided sufficient volume for structural strength, it was thin enough to minimize thickness-induced drag penalties that were evident in the tests reported in references 3 and 5. This wing model is referred to as the "combined-theory wing" since a finite airfoil-thickness ratio was specified.

To determine the effect of a finite wing-thickness constraint on the combined-theory wing design process, a second wing with optimum camber and twist was obtained from a zero-thickness input. This wing model is referred to as the "linear-theory wing" (even though it was designed with the combined-theory program) because the combined-theory program was used to simulate typical linear-theory design programs that provide zero-thickness camber surfaces under the assumption that the thickness is usually small enough to be ignored.

A negligible value of zero-lift pitching-moment coefficient ($C_{m,o} \approx 0$) was chosen although a positive, nonzero $C_{m,o}$ is desired on a real wing design. Camber-surface modifications in the region of the root chord were anticipated to smooth out singularities caused by theoretical and numerical methods and to provide a practical wing that could readily be built. Thus, the $C_{m,o} = 0$ value for the theoretical wings was chosen as a convenient reference point from which changes were noted in zero-lift pitching-moment characteristics as camber-surface modifications were made.

Method and Application

The aforementioned design criteria were input to the combined-theory wing design program and applied to a clipped-tip delta wing having an aspect ratio of 0.636 and a taper ratio of 0.10. Two cambered and twisted wings (occasionally referred to as "warped wings") were obtained. The first, the combined-theory wing, was designed for optimum performance with a finite-thickness airfoil constraint. Difficulties noted in reference 11 concerning the calculation of a reasonably smooth camber surface with good aerodynamic performance characteristics were encountered during the preliminary design phases. The interaction of thickness-chord ratio with Mach number, leading-edge sweep angle, and design-lift and zero-lift pitching-moment coefficients within the numerical method resulted in camber surfaces that often had singularities both in the z-ordinates and in the drag-due-to-lift parameter. These were reduced and removed, respectively, by using a 2.5-percent-thick, circular-arc airfoil. The second, the linear-theory wing, was designed for optimum performance with a zero-thickness constraint. No computational difficulties were found in obtaining a reasonable camber surface.

A third wing with a zero-camber surface and the same planform as the cambered and twisted wings was added to the wing set to serve as a reference for performance comparisons. All three wings had a reference area of 308.0 in^2; their planform and centerbody are shown in figure 1.

All the factors that have been discussed were used to obtain a set of optimum camber surfaces from the combined-theory design code. These computed optimum camber surfaces are represented by their trailing-edge shapes in figure 2(a). Differences in the two camber surfaces due to the finite-thickness constraint of the combined-theory wing are readily seen in the respective trailing edges. However, the effect of the finite-thickness constraint was evident in the leading-edge region as well. Although the leading edges of both the cambered and twisted wings lay in the xy-plane, the leading-edge slopes ($\tan^{-1}(\Delta z/\Delta x)$ at $x' = 0$) were as unique as respective trailing edges (fig. 2(b)).

The three leading- and trailing-edge sketches in figure 1(a) suggest the overall features and characteristics of the model shapes. These surfaces evolved through several stages. The process originated with the theoretically optimum camber-surface trailing edges and concluded with the model camber-surface trailing edges shown in figure 3. Root-chord-region tailoring removed the singularity features of both wings and permitted a smooth junction of the balance body and wing surface for minimum aerodynamic interference. Numerical descriptions of the wing planform and camber surfaces of the models, as well as airfoil-thickness distributions, are presented in table I, which uses the format of reference 12. The balance body, centered along the root-chord camber lines of the models, is shown in figures 1 and 3 and is described by

$$
\begin{aligned}
r &= x(64.0 - x)/1280.0 \qquad (0.0 \leq x \leq 32.0) \\
r &= 0.80 \qquad\qquad\qquad\qquad (32.0 \leq x \leq 40.0)
\end{aligned}
$$

Verification Analysis

The theoretical $C_{L,c}$ and $C_{m,o}$ obtained from the combined-theory computer code and the method of reference 7 for the unmodified cambered and twisted wings are presented for comparison as follows:

Purpose or method	Linear-theory method		Combined-theory method	
	$C_{L,c}$	$C_{m,o}$	$C_{L,c}$	$C_{m,o}$
Design goal	0.05	0	0.05	0
Combined-theory design program	0.0457	−0.0001	0.0453	0
Method of reference 7[a]	0.0514	−0.0001	0.0506	−0.0023

[a]Values were calculated from combined-theory ordinates with extrapolated root and tip coordinates.

The method of reference 7 was used to check the values predicted by the combined-theory code because it also employed corrected linear theory and could represent a wing surface with about 1900 area elements (as compared with the 180 area elements in the combined-theory code wing description). Both methods estimated $C_{L,c}$ and $C_{m,o}$ values that were close to all the design goals. However, the lower $C_{L,c}$ values predicted by the combined-theory code were assumed to be due to the reduced number of wing area elements.

The camber-surface tailoring, indicated in figure 3, changed the $C_{L,c}$ and $C_{m,o}$ values, as is seen in the following table:

Camber surface[a]	Linear-theory method		Combined-theory method	
	$C_{L,c}$	$C_{m,o}$	$C_{L,c}$	$C_{m,o}$
Original camber surface	0.0514	−0.0001	0.0506	−0.0023
Tailored camber surface	0.0377	−0.0031	0.0374	−0.0047

[a]Values were obtained from method of reference 7.

Tailoring not only removed the root-chord-region singularities but also reduced the value of $C_{L,c}$. It also added a negative increment to both values of $C_{m,o}$, thus changing them from virtually zero to slightly negative. Since one purpose of this study was to determine the effect of the tailoring procedures, no reoptimizing or redesigning was undertaken. Alternate techniques (ref. 13) could have preserved the design $C_{L,c}$ and $C_{m,o}$, the design $C_{m,o}$, or even added a positive increment to the $C_{m,o}$ value. However, these alternatives might have introduced geometry problems in obtaining a smooth low-interference junction of the wing and the balance body.

Models

Four wing models were built and tested in the wind tunnel for this study. Three of them, each corresponding to one shown in figure 1, were force models for obtaining measurements of lift, drag, and pitching-moment data. A fourth wing model (a copy of the combined-theory wing model) was built to provide pressure data. The upper and lower surfaces were fitted with 294 orifices: 147 on the upper surface of the right side, and 147 on the lower surface of the left side. These orifice locations are shown and tabulated in figure 4 along with comments on their operational status.

The four wing models were machined from aluminum. Stainless-steel inserts were fitted in a recessed body cavity so that a six-element strain-gauge balance and support sting could be installed in each force model. Pressure tubing housed in a cylindrical body extension connected surface orifices to pressure-scanning instruments outside the wind-tunnel test section. An accelerometer that measured angle of attack was also mounted in the pressure-model body cavity.

Test Conditions and Procedures

Force Tests

Wind-tunnel tests were conducted in the 4-ft by 4-ft high-supersonic-speed test section of the Langley Unitary Plan Wind Tunnel. Aerodynamic force and pitching-moment data were taken with the models at Mach numbers of 3.5, 4.0, and 4.5 and at Reynolds number conditions of 2.0×10^6 per foot. No. 35 size carborundum grit was applied in a 0.08-in-wide band that was 0.125 in. behind the leading edge of the wings to promote turbulent boundary-layer conditions over the model surfaces. This grit application was based both on experience with wind-tunnel testing at high Mach numbers and on the data in reference 14.

Stagnation temperatures and pressures at test Mach numbers were as follows:

M	T_s, °F	P_s, lb/ft^2
3.5	125	2703
4.0	150	3698
4.5	150	4656

Base pressures were measured and recorded so that force and pitching-moment data could be corrected to free-stream conditions. Strain-gauge accuracy and test-data repeatability set average force and pitching-moment data limits as follows:

Coefficient	Typical accuracy at $M = 4.5$
C_N	±0.0031
C_A	±.0003
C_m	±.0004

Similarly, angle-of-attack measurements used to correct force and moment coefficients were made through the model-support mechanism and were accurate to about ±0.01°.

Pressure Tests

As before, the test Mach numbers were 3.5, 4.0, and 4.5. However, Reynolds number conditions of both 2.0×10^6 and 4.0×10^6 per foot were applied to check the pressure coefficient data. Surface pressures were measured by a scanivalve system with a gauge of 720.0-lb/ft^2 capacity. Scanivalve-gauge accuracy, based on measured repeatability of about ±2.0 lb/ft^2, gave C_p limits that were computed from

$$\Delta C_p = \pm 2.0/q_\infty$$

At the test Mach number and Reynolds number conditions, these C_p limits were as follows:

		$R = 2.0 \times 10^6$ per foot		$R = 4.0 \times 10^6$ per foot	
M	T_s, °F	P_s, lb/ft^2	C_p	P_s, lb/ft^2	C_p
3.5	125	2703	±0.0066	5406	±0.0033
4.0	150	3698	±.0073	7396	±.0037
4.5	150	4656	±.0088	9312	±.0044

Repeatability derived from experience suggested that the accelerometer used to set the pressure-model angle of attack had accuracy limits of about ±0.01°.

No grit was used on the pressure model because it could have affected the integrity of the surface pressures from orifices near the grit strips in an unpredictable manner.

Flow Visualization

To supplement the force and pressure measurements, shadowgraphs and oil-flow and vapor-screen photographs were taken. As a preparation for the oil-flow and vapor-screen photographs, the three force models were painted with flat black paint and white reference dots were painted at 4-in. intervals along the root chord. The models needed no special preparation for the shadowgraphs, which were taken during the force tests. Vapor-screen and oil-flow photographs were taken at the design Mach number of 4.5 and at a Reynolds number of 2.0×10^6 per foot. Details concerning the methods and apparatus used to obtain these photographs are described in references 15 and 16, respectively.

Experimental Results

Force Data

Wind-tunnel force and pitching-moment data from the three force models are presented in figures 5 to 7 and are given in table II. The data were corrected for flow angularity and base drag; grit drag was assumed to be negligibly small.

A high degree of linearity is found in the measurements of α versus C_L and C_m versus C_L (figs. 5(a), 6(a), and 7(a)). The C_D versus C_L polars and the L/D versus C_L curves were virtually identical across the range $0 < C_L < 0.12$ (figs. 5(b), 6(b), and 7(b)).

A summary of zero-lift aerodynamic performance data has been obtained from figures 5 through 7 and is presented in figure 8. Since the wing models had the same planform, airfoil, and balance-body shape, it was predicted and observed that $C_{L_{\alpha,o}}$ and $(\Delta C_m/\Delta C_L)_o$ were identical. Topographical differences in the wing surfaces of the two cambered and twisted models were reflected in the small but definite differences in the data showing $C_{m,o}$ and $C_{L,c}$ versus Mach number. Figures 5(a), 6(a), 7(a), and 8(b) show that the measured $C_{m,o}$ of both warped-wing models was very small but negative at the test Mach numbers. As a result of the camber-surface tailoring shown in figure 3, the linear-theory wing model $C_{m,o}$ suffered a decrement of 0.0028 at the design Mach number of 4.5; and that of the combined-theory wing model, a decrement of 0.0046. However, the data showing $C_{L,c}$ versus Mach number showed decreasing differences rather than almost constant differences between the Mach numbers of 3.5 and 4.5. In the same Mach number range, there were virtually only two $C_{D,o}$ data curves: the curve for the flat wing and the curve for the cambered and twisted wings. Thus, the two cambered and twisted wing models had almost the same camber drag, even though the camber and twist distributions were markedly different on each wing.

Another measure of wing performance was the drag-due-to-lift factor $\Delta C_D/C_L^2$ computed from

$$\frac{\Delta C_D}{C_L^2} = \frac{C_D - C_{D,o,F}}{C_L^2}$$

for $C_L > 0$, or from the linear-theory relationship

$$\frac{\Delta C_D}{C_L^2} \approx \frac{1}{C_{L_{\alpha,o}}}$$

at $C_L = 0$ and for zero leading-edge thrust. Figure 9 shows $\Delta C_D/C_L^2$ derived from the experimental data of the three wing models at the design Mach number of 4.5.

At zero lift, all three wing models had the same value of $\Delta C_D/C_L^2$. For $C_L > 0$, the combined-theory wing model had a slightly higher $\Delta C_D/C_L^2$ than the linear-theory wing model in the range $0.02 < C_L < 0.10$. The reverse was true in the range $0.10 < C_L < 0.22$. All three wing models had about the same values of $\Delta C_D/C_L^2$ in the range $0.05 < C_L < 0.09$. At about $C_L = 0.056$, the $\Delta C_D/C_L^2$ data of the linear-theory and combined-theory wing models passed through a sharply defined minimum and then paralleled in magnitude and trend that of the flat-wing model. Beyond $C_L \approx 0.08$, the warped-wing $\Delta C_D/C_L^2$ data curves continue to increase toward values that were about 0.04 to 0.06 higher than the values of $\Delta C_D/C_L^2$ in the flat-wing model data.

Pressure Data

Surface-pressure data measured at the test Mach numbers are presented in tables III, IV, and V. These data were obtained at a Reynolds number of 4.0×10^6 per foot rather than at the force-data Reynolds number of 2.0×10^6 per foot. The low static pressures present at the high-supersonic test Mach numbers made it difficult for the pressure gauge to respond satisfactorily when the pressure coefficients approached the vacuum limit at a Reynolds number of 2.0×10^6 per foot. A sample of these data at a Mach number of 4.5 is shown in figure 10.

Flow-Visualization Data

Oil-flow and vapor-screen photographs obtained at a Mach number of 4.5 with the combined-theory wing model are shown in figure 11. Similar photographs taken with the other wing models lacked enough contrast to make them publishable. In figure 12 a photograph showing the combined-theory wing model at a Mach number of 4.5 and an angle of attack of 5.58° is presented as a typical example of the weak shock waves that appeared in the shadowgraphs.

Analysis

The wing analysis method of reference 7 was used to check the aerodynamic characteristics of both the theoretically optimum and the tailored wings. Camber lift coefficients (lift coefficients at zero angle of attack) of about 0.038 and 0.037 were predicted for the tailored linear-theory and combined-theory wing models, respectively. Both of these values were larger than but in reasonably good agreement with the measured value of about 0.036 obtained from both the cambered and twisted wing models at the design Mach number of 4.5.

Also important were the changes in $C_{m,o}$ and the corresponding changes in center of lift on both warped-wing models due to the tailoring employed on the original optimum camber surfaces. The change from a desired zero $C_{m,o}$ to the measured values of $C_{m,o}$ at the design Mach number of 4.5 indicated that the center of lift had moved aft 12.8 percent of $\bar{c}$ on the combined-theory wing and 7.8 percent of $\bar{c}$ on the linear-theory wing. Aftward, center-of-lift changes predicted by the method of reference 7 were 12.6 percent of $\bar{c}$ and 8.2 percent of $\bar{c}$, respectively, for the two models showing reasonably good agreement, as in the predictions of camber lift coefficients.

The comparisons of lift, drag, and L/D performance data in figures 5, 6, and 7 showed that the cambered and twisted wing models had no significant advantages over the flat-wing model in the lift coefficient range $0.0 < C_L < 0.12$. Any performance differences should be found in the drag-due-to-lift data. The results presented in figure 9 suggested that any camber and twist effects present, other than a nonzero $C_{m,o}$, were lost near $C_L = 0.056$ and a corresponding $\alpha = 1.5°$.

In figure 13 theoretical predictions of $\Delta C_D/C_L^2$ from the method of reference 7 were compared with $\Delta C_D/C_L^2$ data derived from force coefficient measurements on the combined-theory and linear-theory models. Linear theory was overly optimistic in predicting $\Delta C_D/C_L^2$ levels, but did reasonably well in predicting trends (especially in the lift coefficient range where the minimum $\Delta C_D/C_L^2$ occurred). The two nonlinear-theory predictions agreed better with experimental data in magnitude and trends ahead of the minimum, whereas the nonlinear theory without leading-edge thrust and vortex-analogy corrections did better overall since it predicted a minimum close to that obtained from force coefficient measurements. However, all three prediction curves had smooth, gradual trend changes near the minimum, whereas the measured data from both wing models indicated that much more rapid changes in flow structure had occurred between $0.05 < C_L < 0.07$.

A set of isobar plots was made to examine the hypothesis that upper-surface vortex and/or separated flow was the cause of the $\Delta C_D/C_L^2$ minimum at $C_L = 0.056$. The plots (fig. 14) were drawn from the upper-surface pressure coefficient data (presented in fig. 10), which were measured at a Mach number of 4.5 and at a Reynolds number of 4.0×10^6 per foot.

From apex to trailing edge, the isobar contours for $\alpha = -0.37°$ have a smoothness, continuity, and regularity in spacing and pattern that suggest mostly attached upper-surface flow. At $\alpha = 1.64°$ isobar contours have changed to a less-ordered pattern of curves (new from apex to midlength; reminiscent of the $\alpha = -0.37°$ isobars from midlength to the trailing edge) that suggest a leading-edge vortex had formed.

Conclusions

A wind-tunnel study using three force models and a pressure-orifice model has been made to determine the capability of a method combining linear theory and shock-expansion theory for designing optimum camber surfaces at high-supersonic/low-hypersonic Mach numbers. Aerodynamic force and surface-pressure measurements were taken and flow-visualization photographs were obtained. The conclusions reached from an analysis and evaluation of the data are given as follows:

1. The flat-plate reference model, the warped-wing model (cambered and twisted wing) designed with a zero-thickness constraint, and the warped-wing model designed with a finite-thickness constraint showed about the same overall levels of aerodynamic lift, drag, and lift-drag ratio.
2. The effects due to leaving the leading edge unchanged while smoothing the root-chord singularities in the theoretical camber surfaces were more detrimental to the zero-lift pitching moment of the combined-theory wing than to that of the linear-theory wing even though the camber lift coefficients of both warped-wing models were about equally changed.
3. For the flat-plate wing, the drag penalties accruing to camber lift and zero-lift pitching moment were relatively modest compared with the magnitude of the drag coefficient at zero lift.

From these conclusions, the evaluation can be made that the combined-theory design method has limited applicability in generating optimal cambered and twisted wing surfaces at the Mach numbers used in this study.

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Table I. Camber-Surface and Thickness Ordinates

[Data given in format of ref. 12]

(a) Linear-theory wing

```
  1   1                 20  13
308.                                                                                          REFA
0.0     5.0     10.0    15.0    20.0    30.0    40.0    50.0    60.0    70.0                  XAF 10
80.0    90.0    100.0                                                                         XAF 13
0.0     0.0     0.0     40.0                                                                  WAFORG 1
1.0     .1944   0.0     39.0                                                                  WAFORG 2
3.0     .5833   0.0     37.0                                                                  WAFORG 3
5.0     .9722   0.0     35.0                                                                  WAFORG 4
7.0     1.3611  0.0     33.0                                                                  WAFORG 5
9.0     1.75    0.0     31.0                                                                  WAFORG 6
11.0    2.1389  0.0     29.0                                                                  WAFORG 7
13.0    2.5278  0.0     27.0                                                                  WAFORG 8
15.0    2.9167  0.0     25.0                                                                  WAFORG 9
17.0    3.3056  0.0     23.0                                                                  WAFORG10
19.0    3.6944  0.0     21.0                                                                  WAFORG11
21.0    4.0833  0.0     19.0                                                                  WAFORG12
23.0    4.4722  0.0     17.0                                                                  WAFORG13
25.0    4.8611  0.0     15.0                                                                  WAFORG14
27.0    5.25    0.0     13.0                                                                  WAFORG15
29.0    5.6388  0.0     11.0                                                                  WAFORG16
31.0    6.0278  0.0     9.0                                                                   WAFORG17
33.0    6.4167  0.0     7.0                                                                   WAFORG18
35.0    6.8056  0.0     5.0                                                                   WAFORG19
36.0    7.0     0.0     4.0                                                                   WAFORG20
0.0     -.020   -.050   -.100   -.160   -.300   -.480   -.680   -.900   -1.125                TZORD 1
-1.350  -1.575  -1.800                                                                        TZ 1
0.0     -.020   -.050   -.100   -.160   -.300   -.480   -.680   -.900   -1.125                TZORD 2
-1.350  -1.575  -1.800                                                                        TZ 2
0.0     -.020   -.050   -.100   -.160   -.300   -.480   -.680   -.900   -1.125                TZORD 3
-1.350  -1.575  -1.800                                                                        TZ 3
0.0     -.020   -.050   -.100   -.160   -.300   -.480   -.680   -.900   -1.125                TZORD 4
-1.350  -1.575  -1.800                                                                        TZ 4
0.0     -.020   -.050   -.096   -.150   -.289   -.459   -.651   -.855   -1.060                TZORD 5
-1.290  -1.500  -1.735                                                                        TZ 5
0.0     -.020   -.047   -.089   -.133   -.268   -.430   -.605   -.787   -.980                 TZORD 6
-1.200  -1.400  -1.645                                                                        TZ 6
0.0     -.019   -.045   -.079   -.115   -.236   -.389   -.558   -.721   -.900                 TZORD 7
-1.100  -1.300  -1.515                                                                        TZ 7
0.0     -.015   -.037   -.065   -.100   -.206   -.342   -.495   -.651   -.816                 TZORD 8
-1.000  -1.188  -1.370                                                                        TZ 8
0.0     -.010   -.029   -.050   -.081   -.178   -.304   -.441   -.580   -.732                 TZORD 9
-.900   -1.075  -1.245                                                                        TZ 9
0.0     -.006   -.019   -.037   -.065   -.149   -.264   -.393   -.520   -.650                 TZORD10
-.800   -.960   -1.102                                                                        TZ10
0.0     .000    -.010   -.025   -.050   -.120   -.225   -.339   -.450   -.567                 TZORD11
-.701   -.850   -.983                                                                         TZ11
0.0     .003    .000    -.014   -.034   -.093   -.180   -.281   -.381   -.485                 TZORD12
-.602   -.730   -.850                                                                         TZ12
0.0     .007    .008    -.004   -.020   -.066   -.140   -.231   -.319   -.402                 TZORD13
-.502   -.615   -.720                                                                         TZ13
0.0     .010    .014    .006    -.006   -.042   -.106   -.179   -.246   -.320                 TZORD14
-.403   -.500   -.580                                                                         TZ14
```

Table I. Continued

(a) Concluded

0.0	.012	.018	.015	.006	-.025	-.069	-.121	-.179	-.240	TZORD15
-.310	-.390	-.460								TZ15
0.0	.014	.022	.022	.017	.001	-.032	-.066	-.110	-.158	TZORD16
-.215	-.275	-.330								TZ16
0.0	.015	.025	.028	.029	.023	.001	-.019	-.040	-.070	TZORD17
-.120	-.160	-.200								TZ17
0.0	.015	.025	.032	.036	.042	.040	.039	.027	.012	TZORD18
-.011	-.040	-.075								TZ18
0.0	.015	.025	.036	.042	.059	.075	.090	.099	.097	TZORD19
.090	.070	.051								TZ19
0.0	.014	.023	.037	.046	.069	.090	.117	.132	.140	TZORD20
.142	.140	.124								TZ 20
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD 1
.80	.45	0.0								WAF 1
0.0	.2375	.450	.6375	.800	1.05	1.20	1.25	1.20	1.05	WAFORD 2
.80	.45	0.0								WAF 2
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD 3
.80	.45	0.0								WAF 3
0.0	.2375	.450	.6375	.800	1.05	1.20	1.25	1.20	1.05	WAFORD 4
.80	.45	0.0								WAF 4
0.0	.2375	.450	.6375	.800	1.05	1.20	1.25	1.20	1.05	WAFORD 5
.80	.45	0.0								WAF 5
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD 6
.80	.45	0.0								WAF 6
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD 7
.80	.45	0.0								WAF 7
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD 8
.80	.45	0.0								WAF 8
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD 9
.80	.45	0.0								WAF 9
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD10
.80	.45	0.0								WAF10
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD11
.80	.45	0.0								WAF11
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD12
.80	.45	0.0								WAF12
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD13
.80	.45	0.0								WAF13
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD14
.80	.45	0.0								WAF14
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD15
.80	.45	0.0								WAF15
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD16
.80	.45	0.0								WAF16
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD17
.80	.45	0.0								WAF17
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD18
.80	.45	0.0								WAF18
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD19
.80	.45	0.0								WAF19
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD20
.80	.45	0.0								WAF 20

Table I. Continued

(b) Combined-theory wing

1 1			20 13							
308.										REFA
0.0	5.0	10.0	15.0	20.0	30.0	40.0	50.0	60.0	70.0	XAF 10
80.0	90.0	100.0								XAF 13
0.0	0.0	0.0	40.0							WAFORG 1
1.0	.1944	0.0	39.0							WAFORG 2
3.0	.5833	0.0	37.0							WAFORG 3
5.0	.9722	0.0	35.0							WAFORG 4
7.0	1.3611	0.0	33.0							WAFORG 5
9.0	1.75	0.0	31.0							WAFORG 6
11.0	2.1389	0.0	29.0							WAFORG 7
13.0	2.5278	0.0	27.0							WAFORG 8
15.0	2.9167	0.0	25.0							WAFORG 9
17.0	3.3056	0.0	23.0							WAFORG10
19.0	3.6944	0.0	21.0							WAFORG11
21.0	4.0833	0.0	19.0							WAFORG12
23.0	4.4722	0.0	17.0							WAFORG13
25.0	4.8611	0.0	15.0							WAFORG14
27.0	5.25	0.0	13.0							WAFORG15
29.0	5.6388	0.0	11.0							WAFORG16
31.0	6.0278	0.0	9.0							WAFORG17
33.0	6.4167	0.0	7.0							WAFORG18
35.0	6.8056	0.0	5.0							WAFORG19
36.	7.0	0.0	4.0							WAFORG20
0.0	-.015	-.035	-.065	-.100	-.195	-.300	-.420	-.575	-.75	TZORD 1
-.950	-1.15	-1.35								TZ 1
0.0	-.015	-.035	-.065	-.100	-.195	-.300	-.420	-.575	-.750	TZORD 2
-.950	-1.15	-1.35								TZ 2
0.0	-.015	-.035	-.065	-.100	-.195	-.300	-.420	-.575	-.750	TZORD 3
-.950	-1.15	-1.35								TZ 3
0.0	-.013	-.035	-.065	-.101	-.201	-.307	-.422	-.580	-.755	TZORD 4
-.955	-1.155	-1.355								TZ 4
0.0	-.011	-.034	-.065	-.102	-.208	-.319	-.445	-.593	-.770	TZORD 5
-.970	-1.17	-1.395								TZ 5
0.0	-.009	-.033	-.065	-.106	-.221	-.351	-.499	-.652	-.827	TZORD 6
-1.03	-1.25	-1.495								TZ 6
0.0	-.007	-.032	-.065	-.112	-.234	-.379	-.540	-.707	-.895	TZORD 7
-1.113	-1.315	-1.57								TZ 7
0.0	-.004	-.028	-.063	-.111	-.235	-.383	-.540	-.720	-.906	TZORD 8
-1.125	-1.325	-1.570								TZ 8
0.0	-.002	-.024	-.058	-.104	-.222	-.360	-.526	-.692	-.866	TZORD 9
-1.08	-1.275	-1.495								TZ 9
0.0	.001	-.020	-.052	-.092	-.200	-.325	-.480	-.640	-.804	TZORD10
-.995	-1.185	-1.385								TZ10
0.0	.005	-.013	-.039	-.076	-.172	-.284	-.422	-.568	-.715	TZORD11
-.875	-1.070	-1.245								TZ11
0.0	.009	-.004	-.025	-.057	-.138	-.238	-.356	-.484	-.613	TZORD12
-.755	-.917	-1.085								TZ12
0.0	.011	.002	-.013	-.036	-.102	-.192	-.294	-.398	-.512	TZORD13
-.635	-.770	-.905								TZ13
0.0	.013	.007	-.002	-.018	-.071	-.146	-.228	-.316	-.411	TZORD14
-.510	-.625	-.735								TZ14

Table I. Concluded

(b) Concluded

0.0	.013	.013	.009	-.003	-.042	-.099	-.161	-.230	-.308	TZORD15
-.385	-.485	-.575								TZ15
0.0	.013	.015	.017	.010	-.015	-.053	-.094	-.144	-.204	TZORD16
-.265	-.340	-.400								TZ16
0.0	.012	.017	.023	.022	.012	-.007	-.030	-.056	-.102	TZORD17
-.145	-.195	-.240								TZ17
0.0	.011	.019	.027	.032	.036	.038	.038	.028	.005	TZORD18
-.020	-.050	-.085								TZ18
0.0	.010	.020	.031	.042	.062	.082	.102	.112	.115	TZORD19
.110	.095	.076								TZ19
0.0	.009	.021	.032	.047	.075	.104	.138	.158	.164	TZORD20
.163	.158	.150								TZ 20
0.0	.2375	.450	.6375	.800	1.05	1.20	1.25	1.20	1.05	WAFORD 1
.80	.45	0.0								WAF 1
0.0	.2375	.450	.6375	.800	1.05	1.20	1.25	1.20	1.05	WAFORD 2
.80	.45	0.0								WAF 2
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD 3
.80	.45	0.0								WAF3
0.0	.2375	.450	.6375	.800	1.05	1.20	1.25	1.20	1.05	WAFORD 4
.80	.45	0.0								WAF 4
0.0	.2375	.450	.6375	.800	1.05	1.20	1.25	1.20	1.05	WAFORD 5
.80	.45	0.0								WAF 5
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD 6
.80	.45	0.0								WAF 6
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.0	1.05	WAFORD 7
.80	.45	0.0								WAF 7
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD 8
.80	.45	0.0								WAF 8
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD 9
.80	.45	0.0								WAF 9
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD10
.80	.45	0.0								WAF10
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD11
.80	.45	0.0								WAF11
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD12
.80	.45	0.0								WAF12
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD13
.80	.45	0.0								WAF13
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD14
.80	.45	0.0								WAF14
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD15
.80	.45	0.0								WAF15
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD16
.80	.45	0.0								WAF16
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD17
.80	.45	0.0								WAF17
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD18
.80	.45	0.0								WAF18
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD19
.80	.45	0.0								WAF19
0.0	.2375	.45	.6375	.80	1.05	1.2	1.25	1.2	1.05	WAFORD20
.80	.45	0.0								WAF 20

Table II. Lift, Drag, and Pitching-Moment Coefficients at Mach Numbers of 3.5, 4.0, and 4.5

(a) Flat-plate wing model

M = 3.5

α, deg	C_L	C_D	C_m
-5.61	-.0896	.0133	.0203
-4.63	-.0739	.0105	.0167
-3.64	-.0570	.0081	.0129
-2.64	-.0406	.0064	.0091
-1.62	-.0241	.0053	.0053
-.63	-.0093	.0047	.0020
.36	.0050	.0047	-.0012
1.35	.0196	.0051	-.0045
2.38	.0364	.0061	-.0083
3.36	.0532	.0077	-.0121
4.35	.0699	.0099	-.0159
5.37	.0871	.0128	-.0198
6.35	.1035	.0162	-.0235
8.35	.1368	.0248	-.0310
10.36	.1702	.0359	-.0388
12.36	.2035	.0495	-.0466
14.35	.2371	.0658	-.0548
.34	.0056	.0048	-.0013

M = 4.0

α, deg	C_L	C_D	C_m
-5.68	-.0823	.0124	.0185
-4.71	-.0682	.0098	.0154
-3.73	-.0533	.0076	.0120
-2.72	-.0385	.0060	.0086
-1.72	-.0239	.0049	.0052
-.71	-.0096	.0044	.0020
.34	.0044	.0043	-.0011
1.33	.0185	.0047	-.0042
2.30	.0331	.0056	-.0075
3.28	.0480	.0070	-.0109
4.28	.0635	.0091	-.0143
5.28	.0785	.0117	-.0177
6.27	.0936	.0147	-.0211
8.28	.1238	.0226	-.0278
10.27	.1540	.0326	-.0346
12.29	.1857	.0455	-.0420
14.28	.2172	.0606	-.0494
.28	.0044	.0044	-.0011

M = 4.5

α, deg	C_L	C_D	C_m
-5.54	-.0745	.0113	.0159
-4.60	-.0615	.0089	.0131
-3.61	-.0481	.0069	.0103
-2.58	-.0341	.0054	.0072
-1.59	-.0205	.0044	.0043
-.61	-.0072	.0041	.0015
.39	.0056	.0042	-.0012
1.41	.0192	.0044	-.0041
2.42	.0331	.0053	-.0071
3.39	.0463	.0067	-.0100
4.40	.0603	.0087	-.0130
5.42	.0744	.0112	-.0161
6.40	.0881	.0141	-.0190
8.43	.1160	.0216	-.0252
10.40	.1438	.0311	-.0314
12.40	.1728	.0430	-.0381
14.40	.2039	.0578	-.0456
.40	.0062	.0042	-.0013

Table II. Continued

(b) Linear-theory wing model

M = 3.5

α, deg	C_L	C_D	C_m
-6.41	-.0599	.0095	.0104
-5.43	-.0433	.0076	.0065
-4.42	-.0260	.0062	.0026
-3.44	-.0098	.0055	-.0012
-2.43	.0064	.0053	-.0049
-1.47	.0209	.0055	-.0082
-.42	.0361	.0063	-.0116
.59	.0511	.0075	-.0148
1.57	.0665	.0093	-.0183
2.57	.0820	.0118	-.0217
3.58	.0974	.0150	-.0251
4.58	.1128	.0187	-.0285
5.56	.1279	.0228	-.0318
7.58	.1582	.0330	-.0386
9.57	.1891	.0456	-.0458
11.59	.2203	.0607	-.0532
13.63	.2536	.0792	-.0615
-.42	.0373	.0063	-.0119

M = 4.0

α, deg	C_L	C_D	C_m
-6.48	-.0567	.0090	.0099
-5.49	-.0414	.0072	.0064
-4.50	-.0263	.0059	.0029
-3.48	-.0107	.0051	-.0008
-2.46	.0042	.0049	-.0042
-1.46	.0185	.0051	-.0074
-.45	.0320	.0058	-.0104
.52	.0456	.0068	-.0133
1.52	.0595	.0085	-.0164
2.53	.0743	.0108	-.0197
3.50	.0879	.0136	-.0227
4.51	.1021	.0170	-.0257
5.54	.1163	.0210	-.0288
7.52	.1439	.0302	-.0349
9.52	.1720	.0417	-.0414
11.57	.2028	.0563	-.0487
13.56	.2337	.0733	-.0564
-.44	.0331	.0059	-.0107

M = 4.5

α, deg	C_L	C_D	C_m
-6.36	-.0511	.0083	.0082
-5.38	-.0373	.0067	.0052
-4.39	-.0235	.0055	.0022
-3.36	-.0092	.0048	-.0009
-2.36	.0046	.0046	-.0039
-1.33	.0184	.0049	-.0068
-.36	.0306	.0056	-.0094
.62	.0434	.0065	-.0121
1.63	.0565	.0080	-.0148
2.62	.0695	.0102	-.0175
3.62	.0824	.0129	-.0203
4.64	.0954	.0162	-.0231
5.62	.1076	.0197	-.0258
7.61	.1337	.0285	-.0316
9.65	.1609	.0396	-.0378
11.61	.1884	.0528	-.0444
13.62	.2183	.0691	-.0519
-.34	.0313	.0056	-.0096

Table II. Concluded

(c) Combined-theory wing model

M = 3.5

α, deg	C_L	C_D	C_m
-6.43	-.0604	.0095	.0083
-5.43	-.0430	.0076	.0043
-4.41	-.0256	.0062	.0003
-3.45	-.0097	.0055	-.0034
-2.45	.0070	.0053	-.0071
-1.44	.0221	.0056	-.0105
-.44	.0366	.0064	-.0138
.58	.0517	.0076	-.0171
1.58	.0674	.0095	-.0206
2.54	.0823	.0120	-.0238
3.54	.0978	.0152	-.0272
4.56	.1138	.0190	-.0307
5.60	.1296	.0234	-.0342
7.57	.1601	.0336	-.0410
9.59	.1924	.0466	-.0486
11.59	.2243	.0619	-.0563
13.58	.2577	.0803	-.0647
-.44	.0377	.0065	-.0140

M = 4.0

α, deg	C_L	C_D	C_m
-6.49	-.0568	.0089	.0080
-5.52	-.0415	.0071	.0044
-4.52	-.0265	.0059	.0010
-3.47	-.0106	.0051	-.0027
-2.51	.0037	.0049	-.0059
-1.52	.0181	.0051	-.0091
-.50	.0321	.0058	-.0122
.50	.0461	.0068	-.0153
1.50	.0600	.0086	-.0183
2.54	.0754	.0111	-.0217
3.49	.0886	.0138	-.0246
4.50	.1027	.0172	-.0277
5.47	.1165	.0211	-.0307
7.49	.1455	.0306	-.0372
9.50	.1751	.0424	-.0441
11.50	.2056	.0569	-.0515
13.48	.2372	.0740	-.0594
-.48	.0331	.0059	-.0124

M = 4.5

α, deg	C_L	C_D	C_m
-6.42	-.0529	.0084	.0069
-5.39	-.0381	.0066	.0037
-4.41	-.0241	.0055	.0006
-3.41	-.0098	.0048	-.0025
-2.42	.0038	.0046	-.0055
-1.41	.0174	.0048	-.0083
-.37	.0309	.0056	-.0111
.60	.0434	.0066	-.0137
1.59	.0565	.0081	-.0164
2.63	.0702	.0104	-.0193
3.58	.0826	.0130	-.0220
4.56	.0951	.0161	-.0247
5.58	.1085	.0199	-.0276
7.58	.1355	.0288	-.0337
9.58	.1632	.0400	-.0402
11.60	.1924	.0539	-.0474
13.63	.2241	.0710	-.0555
-.37	.0313	.0056	-.0112

Table III. Pressure Coefficients on Combined-Theory Wing at $M = 3.5$ and $R = 4.0 \times 10^6$ Per Foot

(a) $\alpha = -4.40^\circ$ and -2.40°

C_p at 2y/b of :

X'/C	0.0		.15		.30		.45		.60		.75		.90		X'/C
	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	
							ALPHA =	-4.40							
.025	.0453	-.0052	.0546	-.0405	.0546	-.0391	.0634	-.0351		-.0335		-.0360	.0393		.025
.050	.0445	-.0038	.0496	-.0356	.0497	-.0394	.0526	-.0350	.0469	-.0314	.0452		.0570	-.0340	.050
.075	.0410	-.0056	.0450	-.0176	.0422	-.0374	.0465	-.0347	.0453	-.0341	.0486	-.0375	.0500	-.0345	.075
.100	.0392	-.0052	.0421	-.0070	.0406	-.0356	.0410	-.0340	.0392	-.0333	.0436	-.0366	.0483	-.0371	.100
.150	.0393	-.0053	.0357	-.0006	.0340	-.0263	.0313	-.0338	.0305	-.0341	.0365	-.0358	.0395	-.0395	.150
.200	.0356	-.0034	.0300	-.0013		-.0149	.0251	-.0319	.0236		.0225	-.0357	.0337	-.0410	.200
.250	.0322	-.0032	.0267	-.0018	.0228	-.0041	.0208	-.0254	.0190	-.0367	.0196	-.0353	.0288	-.0416	.250
.300	.0305	-.0043	.0247	-.0044		-.0008	.0177	-.0201	.0165	-.0353	.0126	-.0356	.0247	-.0429	.300
.350	.0288	-.0052	.0228	-.0063	.0141	-.0014	.0128	-.0147	.0090	-.0332	.0069	-.0363	.0209	-.0438	.350
.400	.0259	-.0055	.0184	-.0076	.0106	-.0035	.0072	-.0079	.0045	-.0313	.0046	-.0377	.0181	-.0454	.400
.450	.0231	-.0050	.0139	-.0058	.0076	-.0051	.0034	-.0032	-.0003	-.0282	.0020	-.0393	.0157	-.0467	.450
.500	.0154	-.0048	.0072	-.0039	.0042	-.0063	.0024	-.0015	-.0029	-.0256	-.0007	-.0402	.0116	-.0482	.500
.550	.0139	-.0061	.0043	-.0044	.0011	-.0062	.0008	-.0039	-.0048	-.0230	-.0032	-.0413	.0051	-.0488	.550
.600	.0084	-.0047	.0011	-.0056		-.0068		-.0066	-.0069	-.0213	-.0073	-.0406	-.0060	-.0488	.600
.650	.0040	-.0043	-.0005	-.0063	-.0052	-.0062	-.0065	-.0067	-.0085	-.0188	-.0099	-.0404	-.0124	-.0506	.650
.700	-.0003	-.0053	-.0059	-.0061	-.0101	-.0065	-.0135	-.0040	-.0126	-.0170	-.0111	-.0413	-.0135	-.0517	.700
.750	-.0004	-.0068	-.0092	-.0068	-.0139	-.0064	-.0178	-.0052	-.0176	-.0140	-.0138	-.0410	-.0121	-.0523	.750
.800		-.0078		-.0078		-.0092	-.0159	-.0105		-.0122	-.0182	-.0394	-.0148	-.0520	.800
.850	-.0135	-.0081	-.0143	-.0097	-.0159	-.0124	-.0165	-.0147	-.0251	-.0118	-.0239	-.0364	-.0170	-.0517	.850
.900	-.0087	-.0078	-.0167	-.0110	-.0193	-.0111	-.0214	-.0141	-.0261	-.0144	-.0257	-.0363		-.0499	.900
.950	-.0119	-.0082	-.0193	-.0119	-.0253	-.0103	-.0262	-.0139	-.0261	-.0190		-.0395	-.0487	-.0477	.950

C_p at 2y/b of :

X'/C	0.0		.15		.30		.45		.60		.75		.90		X'/C
	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	
							ALPHA =	-2.40							
.025	.0296	.0049	.0368	-.0001	.0406	-.0114	.0458	-.0106		-.0081		-.0113	.0361		.025
.050	.0281	.0063	.0333	.0108	.0325	-.0038	.0339	-.0086	.0289	.0022	.0393		.0425	-.0136	.050
.075	.0230	.0041	.0290	.0102	.0251	.0094	.0268	-.0000	.0247	-.0027	.0288	-.0097	.0344	-.0113	.075
.100	.0233	.0040	.0254	.0087	.0235	.0091	.0215	.0079	.0177	.0010	.0229	-.0070	.0312	-.0138	.100
.150	.0244	.0064	.0197	.0084	.0167	.0106	.0124	.0128	.0093	.0049	.0133	-.0009	.0191	-.0148	.150
.200	.0205	.0074	.0156	.0071		.0112	.0064	.0127	.0033		.0003	.0014	.0124	-.0148	.200
.250	.0173	.0068	.0122	.0072	.0063	.0097	.0026	.0135	-.0000	.0047	-.0030	.0041	.0063	-.0139	.250
.300	.0164	.0049	.0092	.0054		.0070	.0001	.0106	-.0021	.0068	-.0091	.0054	.0012	-.0143	.300
.350	.0147	.0037	.0075	.0035	-.0007	.0056	-.0035	.0079	-.0086	.0078	-.0138	.0052	-.0033	-.0153	.350
.400	.0108	.0043	.0040	.0028	-.0040	.0055	-.0074	.0081	-.0130	.0074	-.0154	.0042	-.0065	-.0163	.400
.450	.0082	.0048	-.0001	.0044	-.0067	.0042	-.0099	.0070	-.0173	.0066	-.0175	.0016	-.0091	-.0179	.450
.500	.0015	.0049	-.0063	.0063	-.0087	.0029	-.0107	.0056	-.0189	.0046	-.0197	.0005	-.0124	-.0190	.500
.550	-.0003	.0030	-.0086	.0050	-.0109	.0027	-.0127	.0031	-.0200	.0023	-.0216	-.0014	-.0183	-.0174	.550
.600	-.0045	.0037	-.0101	.0029		.0024		.0009	-.0209	-.0013	-.0248	-.0021	-.0275	-.0150	.600
.650	-.0074	.0047	-.0119	.0033	-.0173	.0035	-.0191	.0018	-.0221	-.0022	-.0266	-.0037	-.0339	-.0153	.650
.700	-.0120	.0041	-.0177	.0034	-.0219	.0028	-.0250	.0043	-.0256	-.0033	-.0273	-.0079	-.0352	-.0170	.700
.750	-.0129	.0022	-.0206	.0024	-.0249	.0033	-.0281	.0031	-.0298	-.0023	-.0292	-.0092	-.0340	-.0197	.750
.800		.0009		.0006		-.0002	-.0264	-.0023		-.0023	-.0328	-.0090	-.0361	-.0188	.800
.850	-.0236	.0003	-.0247	-.0011	-.0260	-.0040	-.0272	-.0062	-.0361	-.0034	-.0370	-.0067	-.0372	-.0173	.850
.900	-.0192	.0004	-.0268	-.0027	-.0295	-.0028	-.0317	-.0058	-.0370	-.0073	-.0387	-.0093		-.0156	.900
.950	-.0218	-.0004	-.0286	-.0039	-.0344	-.0017	-.0358	-.0058	-.0371	-.0123		-.0162	-.0470	-.0186	.950

Table III. Continued

(b) $\alpha = -0.39^\circ$ and 1.63°

C_p at $2y/b$ of :

ALPHA = -.39

X'/C	0.0 UPPER	0.0 LOWER	.15 UPPER	.15 LOWER	.30 UPPER	.30 LOWER	.45 UPPER	.45 LOWER	.60 UPPER	.60 LOWER	.75 UPPER	.75 LOWER	.90 UPPER	.90 LOWER	X'/C
.025	.0161	.0186	.0171	.0259	.0177	.0294	.0177	.0322		.0358		.0291	-.0056		.025
.050	.0160	.0196	.0160	.0255	.0126	.0286	.0103	.0326	-.0014	.0428	.0013		.0011	.0337	.050
.075	.0126	.0155	.0143	.0241	.0078	.0282	.0047	.0319	-.0034	.0339	-.0066	.0315	-.0031	.0328	.075
.100	.0099	.0105	.0119	.0226	.0070	.0248	.0003	.0329	-.0069	.0331	-.0094	.0301	-.0043	.0295	.100
.150	.0120	.0174	.0067	.0214	.0009	.0249	-.0071	.0299	-.0141	.0301	-.0169	.0308	-.0139	.0266	.150
.200	.0091	.0189	.0015	.0202		.0245	-.0122	.0276	-.0191		-.0258	.0279	-.0223	.0243	.200
.250	.0058	.0189	-.0013	.0195	-.0085	.0222	-.0147	.0273	-.0216	.0216	-.0298	.0272	-.0276	.0221	.250
.300	.0040	.0172	-.0036	.0166		.0194	-.0150	.0238	-.0224	.0222	-.0345	.0252	-.0318	.0178	.300
.350	.0021	.0150	-.0048	.0149	-.0142	.0187	-.0171	.0215	-.0266	.0230	-.0374	.0231	-.0358	.0139	.350
.400	-.0016	.0148	-.0084	.0140	-.0162	.0185	-.0205	.0218	-.0298	.0216	-.0384	.0200	-.0391	.0098	.400
.450	-.0040	.0161	-.0117	.0163	-.0175	.0176	-.0228	.0207	-.0329	.0198	-.0391	.0164	-.0410	.0060	.450
.500	-.0099	.0160	-.0163	.0180	-.0195	.0155	-.0236	.0186	-.0337	.0170	-.0395	.0146	-.0439	.0026	.500
.550	-.0104	.0153	-.0178	.0168	-.0219	.0153	-.0248	.0153	-.0337	.0148	-.0401	.0123	-.0484	.0039	.550
.600	-.0138	.0160	-.0203	.0146		.0138		.0129	-.0342	.0112	-.0426	.0114	-.0543	.0071	.600
.650	-.0177	.0157	-.0226	.0138	-.0281	.0148	-.0295	.0141	-.0351	.0101	-.0434	.0091	-.0584	.0053	.650
.700	-.0223	.0150	-.0275	.0145	-.0317	.0146	-.0345	.0165	-.0379	.0093	-.0433	.0046	-.0593	.0002	.700
.750	-.0226	.0133	-.0300	.0136	-.0342	.0148	-.0372	.0147	-.0413	.0100	-.0443	.0030	-.0595	-.0062	.750
.800		.0115		.0114		.0111	-.0358	.0090		.0099	-.0469	.0039	-.0608	-.0081	.800
.850	-.0319	.0108	-.0334	.0090	-.0352	.0064	-.0367	.0049	-.0460	.0080	-.0502	.0062	-.0607	-.0088	.850
.900	-.0276	.0103	-.0351	.0073	-.0381	.0076	-.0409	.0052	-.0466	.0038	-.0516	.0031		-.0088	.900
.950	-.0300	.0095	-.0367	.0058	-.0424	.0089	-.0442	.0048	-.0466	-.0017		-.0053	-.0619	-.0127	.950

C_p at $2y/b$ of :

ALPHA = 1.63

X'/C	0.0 UPPER	0.0 LOWER	.15 UPPER	.15 LOWER	.30 UPPER	.30 LOWER	.45 UPPER	.45 LOWER	.60 UPPER	.60 LOWER	.75 UPPER	.75 LOWER	.90 UPPER	.90 LOWER	X'/C
.025	.0050	.0336	-.0165	.0463	-.0288	.0502	-.0398	.0493		.0511		.0360	-.0620		.025
.050	.0058	.0347	-.0146	.0437	-.0293	.0454	-.0416	.0491	-.0574	.0774	-.0422		-.0691	.0409	.050
.075	.0037	.0299	.0013	.0413	-.0206	.0441	-.0367	.0475	-.0559	.0500	-.0673	.0469	-.0712	.0492	.075
.100	.0030	.0255	.0002	.0390	-.0147	.0406	-.0324	.0485	-.0528	.0486	-.0684	.0459	-.0713	.0449	.100
.150	.0037	.0331	-.0054	.0373	-.0154	.0409	-.0302	.0448	-.0469	.0452	-.0644	.0470	-.0789	.0414	.150
.200	-.0013	.0349	-.0097	.0352		.0405	-.0297	.0422	-.0443		-.0607	.0443	-.0776	.0392	.200
.250	-.0045	.0345	-.0124	.0347	-.0213	.0377	-.0300	.0427	-.0439	.0369	-.0581	.0436	-.0765	.0365	.250
.300	-.0065	.0322	-.0146	.0313		.0341	-.0303	.0392	-.0435	.0377	-.0574	.0410	-.0743	.0319	.300
.350	-.0079	.0299	-.0154	.0289	-.0246	.0339	-.0318	.0369	-.0451	.0385	-.0574	.0385	-.0710	.0283	.350
.400	-.0118	.0291	-.0175	.0276	-.0265	.0340	-.0340	.0372	-.0460	.0370	-.0569	.0349	-.0694	.0241	.400
.450	-.0129	.0293	-.0198	.0300	-.0280	.0329	-.0353	.0360	-.0472	.0347	-.0562	.0309	-.0673	.0200	.450
.500	-.0177	.0302	-.0250	.0323	-.0303	.0309	-.0361	.0340	-.0477	.0315	-.0561	.0292	-.0674	.0167	.500
.550	-.0186	.0290	-.0272	.0307	-.0320	.0302	-.0364	.0302	-.0482	.0286	-.0560	.0266	-.0681	.0173	.550
.600	-.0224	.0291	-.0293	.0288		.0290		.0272	-.0486	.0254	-.0575	.0259	-.0693	.0201	.600
.650	-.0262	.0299	-.0310	.0278	-.0372	.0290	-.0404	.0280	-.0498	.0243	-.0583	.0233	-.0698	.0175	.650
.700	-.0301	.0287	-.0355	.0276	-.0402	.0288	-.0443	.0309	-.0519	.0234	-.0586	.0187	-.0694	.0119	.700
.750	-.0304	.0270	-.0383	.0273	-.0429	.0293	-.0466	.0287	-.0544	.0241	-.0600	.0173	-.0694	.0051	.750
.800		.0252		.0250		.0250	-.0452	.0224		.0236	-.0612	.0174	-.0698	.0026	.800
.850	-.0389	.0239	-.0407	.0219	-.0433	.0194	-.0468	.0180	-.0567	.0210	-.0635	.0196	-.0703	.0002	.850
.900	-.0347	.0232	-.0423	.0195	-.0458	.0206	-.0505	.0185	-.0573	.0162	-.0648	.0159		-.0025	.900
.950	-.0370	.0221	-.0441	.0179	-.0503	.0215	-.0536	.0176	-.0580	.0103		.0064	-.0698	-.0091	.950

Table III. Concluded

(c) $\alpha = 3.62^\circ$ and 5.62°

C_p at 2y/b of :

X'/C	0.0		.15		.30		.45		.60		.75		.90		X'/C
	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	
							ALPHA =	3.62							
.025	-.0027	.0495	-.0446	.0653	-.0514	.0662	-.0557	.0631		.0616		.0430	-.0738		.025
.050	-.0027	.0520	-.0445	.0625	-.0528	.0628	-.0576	.0643	-.0662	.0931	-.0659		-.0749	.0430	.050
.075	-.0051	.0500	-.0400	.0605	-.0532	.0622	-.0584	.0635	-.0658	.0645	-.0716	.0598	-.0762	.0586	.075
.100	-.0061	.0433	-.0297	.0577	-.0532	.0587	-.0586	.0646	-.0665	.0636	-.0722	.0596	-.0753	.0559	.100
.150	-.0074	.0524	-.0190	.0562	-.0541	.0587	-.0593	.0613	-.0674	.0606	-.0729	.0617	-.0777	.0536	.150
.200	-.0105	.0538	-.0185	.0536		.0584	-.0603	.0583	-.0675		-.0739	.0594	-.0778	.0518	.200
.250	-.0135	.0538	-.0203	.0526	-.0518	.0558	-.0618	.0590	-.0681	.0529	-.0736	.0588	-.0779	.0499	.250
.300	-.0159	.0505	-.0218	.0489		.0517	-.0643	.0561	-.0687	.0539	-.0740	.0561	-.0780	.0457	.300
.350	-.0163	.0474	-.0219	.0464	-.0407	.0510	-.0670	.0539	-.0702	.0549	-.0746	.0534	-.0768	.0423	.350
.400	-.0190	.0473	-.0250	.0444	-.0329	.0514	-.0686	.0541	-.0719	.0533	-.0747	.0497	-.0773	.0380	.400
.450	-.0201	.0468	-.0281	.0466	-.0327	.0505	-.0675	.0530	-.0743	.0510	-.0748	.0453	-.0766	.0339	.450
.500	-.0255	.0470	-.0329	.0493	-.0348	.0485	-.0655	.0512	-.0764	.0476	-.0748	.0435	-.0773	.0307	.500
.550	-.0266	.0457	-.0348	.0478	-.0372	.0479	-.0617	.0468	-.0789	.0443	-.0749	.0409	-.0778	.0311	.550
.600	-.0298	.0472	-.0368	.0459		.0463		.0439	-.0803	.0410	-.0766	.0406	-.0780	.0335	.600
.650	-.0336	.0471	-.0389	.0448	-.0443	.0466	-.0511	.0441	-.0828	.0401	-.0777	.0378	-.0788	.0304	.650
.700	-.0374	.0461	-.0428	.0446	-.0466	.0453	-.0494	.0473	-.0840	.0392	-.0778	.0331	-.0784	.0247	.700
.750	-.0378	.0429	-.0455	.0432	-.0491	.0464	-.0507	.0447	-.0860	.0398	-.0794	.0319	-.0784	.0180	.750
.800		.0419		.0414		.0416	-.0486	.0378		.0389	-.0807	.0322	-.0789	.0160	.800
.850	-.0462	.0402	-.0482	.0376	-.0502	.0351	-.0496	.0333	-.0855	.0357	-.0820	.0343	-.0792	.0133	.850
.900	-.0426	.0391	-.0500	.0346	-.0532	.0363	-.0544	.0340	-.0834	.0305	-.0843	.0300		.0104	.900
.950	-.0448	.0378	-.0519	.0328	-.0571	.0368	-.0587	.0327	-.0796	.0241		.0194	-.0778	.0029	.950

C_p at 2y/b of :

X'/C	0.0		.15		.30		.45		.60		.75		.90		X'/C
	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	
							ALPHA =	5.62							
.025	-.0110	.0703	-.0607	.0842	-.0639	.0842	-.0663	.0781		.0730		.0495	-.0772		.025
.050	-.0108	.0739	-.0617	.0827	-.0658	.0823	-.0688	.0813	-.0751	.1095	-.0721		-.0789	.0469	.050
.075	-.0137	.0708	-.0650	.0819	-.0665	.0824	-.0695	.0809	-.0743	.0795	-.0788	.0724	-.0809	.0679	.075
.100	-.0146	.0652	-.0658	.0800	-.0680	.0795	-.0698	.0827	-.0746	.0795	-.0791	.0735	-.0799	.0669	.100
.150	-.0173	.0763	-.0603	.0786	-.0728	.0800	-.0713	.0799	-.0756	.0773	-.0800	.0773	-.0836	.0658	.150
.200	-.0193	.0770	-.0311	.0757		.0794	-.0729	.0774	-.0757		-.0806	.0752	-.0834	.0651	.200
.250	-.0208	.0768	-.0256	.0746	-.0793	.0767	-.0741	.0781	-.0772	.0707	-.0808	.0746	-.0836	.0638	.250
.300	-.0227	.0733	-.0284	.0705		.0730	-.0769	.0751	-.0784	.0723	-.0810	.0722	-.0837	.0603	.300
.350	-.0235	.0694	-.0295	.0677	-.0758	.0724	-.0805	.0736	-.0803	.0736	-.0818	.0692	-.0825	.0570	.350
.400	-.0270	.0690	-.0326	.0658	-.0651	.0721	-.0831	.0738	-.0813	.0720	-.0821	.0654	-.0832	.0529	.400
.450	-.0280	.0686	-.0355	.0674	-.0560	.0717	-.0824	.0726	-.0826	.0697	-.0826	.0611	-.0824	.0489	.450
.500	-.0331	.0680	-.0407	.0696	-.0511	.0693	-.0815	.0706	-.0838	.0662	-.0838	.0590	-.0834	.0457	.500
.550	-.0342	.0661	-.0428	.0686	-.0489	.0691	-.0785	.0662	-.0860	.0628	-.0839	.0567	-.0839	.0462	.550
.600	-.0373	.0675	-.0448	.0666		.0677		.0631	-.0875	.0589	-.0859	.0565	-.0843	.0481	.600
.650	-.0408	.0680	-.0468	.0656	-.0539	.0678	-.0738	.0633	-.0900	.0582	-.0867	.0539	-.0851	.0449	.650
.700	-.0449	.0672	-.0505	.0652	-.0566	.0661	-.0717	.0666	-.0913	.0574	-.0866	.0491	-.0847	.0393	.700
.750	-.0460	.0631	-.0534	.0627	-.0592	.0666	-.0687	.0635	-.0934	.0579	-.0881	.0478	-.0847	.0326	.750
.800		.0617		.0610		.0611	-.0644	.0557		.0567	-.0888	.0488	-.0848	.0308	.800
.850	-.0538	.0597	-.0573	.0565	-.0599	.0536	-.0644	.0509	-.0937	.0529	-.0895	.0510	-.0852	.0278	.850
.900	-.0501	.0585	-.0592	.0527	-.0626	.0549	-.0672	.0519	-.0919	.0471	-.0912	.0459		.0245	.900
.950	-.0525	.0563	-.0610	.0502	-.0668	.0552	-.0701	.0502	-.0903	.0400		.0342	-.0827	.0160	.950

Table IV. Pressure Coefficients on Combined-Theory Wing at $M = 4.0$ and $R = 4.0 \times 10^6$ Per Foot

(a) $\alpha = -4.45°$ and $-2.45°$

C_p at 2y/b of :

X'/C	0.0		.15		.30		.45		.60		.75		.90		X'/C
	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	
							ALPHA =	-4.45							
.025	.0470	-.0030	.0536	-.0241	.0549	-.0291	.0628	-.0288		-.0268		-.0262	.0483		.025
.050	.0455	-.0004	.0490	-.0268	.0491	-.0298	.0524	-.0289	.0479	-.0283	.0536		.0639	-.0231	.050
.075	.0420	-.0022	.0438	-.0235	.0424	-.0295	.0463	-.0290	.0459	-.0290	.0498	-.0310	.0571	-.0247	.075
.100	.0387	-.0003	.0401	-.0143	.0409	-.0270	.0413	-.0279	.0405	-.0282	.0457	-.0302	.0557	-.0290	.100
.150	.0396	-.0038	.0335	-.0006	.0339	-.0167	.0317	-.0231	.0318	-.0285	.0386	-.0295	.0458	-.0320	.150
.200	.0335	-.0013	.0287	-.0000		-.0102	.0256	-.0194	.0256		.0270	-.0297	.0403	-.0345	.200
.250	.0303	-.0015	.0255	-.0011	.0223	-.0050	.0218	-.0141	.0214	-.0267	.0236	-.0290	.0353	-.0347	.250
.300	.0284	-.0031	.0238	-.0038		-.0035	.0191	-.0105	.0187	-.0233	.0173	-.0286	.0309	-.0355	.300
.350	.0278	-.0045	.0228	-.0057	.0149	-.0024	.0156	-.0080	.0124	-.0206	.0125	-.0284	.0274	-.0364	.350
.400	.0246	-.0052	.0189	-.0060	.0120	-.0024	.0107	-.0042	.0076	-.0182	.0100	-.0287	.0243	-.0373	.400
.450	.0230	-.0043	.0152	-.0045	.0103	-.0037	.0078	-.0027	.0032	-.0165	.0076	-.0292	.0222	-.0386	.450
.500	.0169	-.0036	.0094	-.0021	.0076	-.0047	.0064	-.0022	.0010	-.0153	.0050	-.0287	.0185	-.0394	.500
.550	.0154	-.0036	.0073	-.0028	.0050	-.0048	.0053	-.0039	-.0002	-.0144	.0028	-.0293	.0125	-.0404	.550
.600	.0116	-.0031	.0053	-.0041		-.0050		-.0059	-.0012	-.0148	-.0008	-.0286	.0031	-.0401	.600
.650	.0080	-.0030	.0036	-.0045	-.0009	-.0042	-.0011	-.0056	-.0028	-.0138	-.0034	-.0280	-.0038	-.0415	.650
.700	.0044	-.0033	-.0011	-.0047	-.0040	-.0049	-.0066	-.0038	-.0058	-.0137	-.0040	-.0288	-.0050	-.0424	.700
.750	.0032	-.0045	-.0041	-.0048	-.0075	-.0044	-.0102	-.0041	-.0102	-.0120	-.0065	-.0280	-.0045	-.0412	.750
.800		-.0056		-.0061		-.0075	-.0086	-.0085		-.0115	-.0102	-.0277	-.0067	-.0416	.800
.850	-.0069	-.0064	-.0082	-.0080	-.0089	-.0104	-.0095	-.0120	-.0171	-.0115	-.0145	-.0257	-.0083	-.0414	.850
.900	-.0037	-.0067	-.0108	-.0094	-.0124	-.0098	-.0140	-.0119	-.0185	-.0135	-.0169	-.0261		-.0380	.900
.950	-.0065	-.0072	-.0130	-.0108	-.0171	-.0090	-.0177	-.0112	-.0183	-.0163		-.0278	-.0151	-.0315	.950

C_p at 2y/b of :

X'/C	0.0		.15		.30		.45		.60		.75		.90		X'/C
	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	
							ALPHA =	-2.45							
.025	.0303	.0065	.0350	.0016	.0414	-.0036	.0461	-.0071		-.0039		-.0053	.0425		.025
.050	.0284	.0079	.0318	.0064	.0337	-.0037	.0359	-.0057	.0316	-.0027	.0424		.0488	-.0063	.050
.075	.0241	.0062	.0281	.0091	.0264	.0029	.0282	.0073	.0290	-.0026	.0316	-.0065	.0409	-.0040	.075
.100	.0221	.0067	.0246	.0101	.0241	.0114	.0233	.0127	.0218	.0010	.0275	-.0054	.0375	-.0078	.100
.150	.0237	.0060	.0196	.0096	.0173	.0121	.0146	.0149	.0126	.0068	.0188	.0001	.0277	-.0106	.150
.200	.0194	.0084	.0151	.0079		.0117	.0087	.0136	.0068		.0074	.0041	.0201	-.0123	.200
.250	.0172	.0079	.0119	.0076	.0069	.0102	.0053	.0138	.0030	.0080	.0031	.0074	.0143	-.0118	.250
.300	.0156	.0061	.0096	.0055		.0072	.0033	.0113	.0007	.0100	-.0025	.0085	.0097	-.0115	.300
.350	.0148	.0045	.0086	.0034	.0018	.0055	.0006	.0089	-.0044	.0108	-.0068	.0082	.0055	-.0118	.350
.400	.0109	.0037	.0057	.0025	-.0008	.0051	-.0030	.0097	-.0082	.0102	-.0088	.0071	.0018	-.0123	.400
.450	.0095	.0043	.0028	.0037	-.0025	.0045	-.0048	.0091	-.0116	.0092	-.0104	.0046	-.0003	-.0134	.450
.500	.0044	.0045	-.0021	.0060	-.0048	.0040	-.0059	.0082	-.0133	.0067	-.0128	.0035	-.0037	-.0144	.500
.550	.0031	.0045	-.0038	.0059	-.0066	.0042	-.0066	.0058	-.0139	.0047	-.0144	.0015	-.0088	-.0132	.550
.600	.0004	.0053	-.0057	.0049		.0039		.0033	-.0144	.0016	-.0176	.0009	-.0165	-.0106	.600
.650	-.0031	.0055	-.0079	.0045	-.0123	.0047	-.0122	.0037	-.0159	.0004	-.0196	-.0005	-.0230	-.0110	.650
.700	-.0072	.0052	-.0120	.0042	-.0148	.0040	-.0171	.0056	-.0183	-.0009	-.0197	-.0044	-.0244	-.0125	.700
.750	-.0084	.0039	-.0146	.0041	-.0177	.0046	-.0200	.0049	-.0220	-.0001	-.0215	-.0057	-.0245	-.0145	.750
.800		.0028		.0027		.0015	-.0186	.0002		-.0001	-.0241	-.0056	-.0262	-.0141	.800
.850	-.0170	.0019	-.0183	.0007	-.0193	-.0018	-.0199	-.0035	-.0274	-.0008	-.0272	-.0039	-.0274	-.0134	.850
.900	-.0142	.0013	-.0208	-.0010	-.0227	-.0014	-.0237	-.0037	-.0284	-.0040	-.0294	-.0058		-.0126	.900
.950	-.0160	.0005	-.0224	-.0026	-.0265	-.0006	-.0268	-.0033	-.0284	-.0078		-.0109	-.0311	-.0137	.950

Table IV. Continued

(b) $\alpha = -0.45^{\circ}$ and 1.55°

C_p at 2y/b of :

ALPHA = -.45

X'/C	0.0 UPPER	0.0 LOWER	.15 UPPER	.15 LOWER	.30 UPPER	.30 LOWER	.45 UPPER	.45 LOWER	.60 UPPER	.60 LOWER	.75 UPPER	.75 LOWER	.90 UPPER	.90 LOWER	X'/C
.025	.0167	.0184	.0181	.0245	.0191	.0301	.0213	.0339		.0359		.0315	.0148		.025
.050	.0159	.0192	.0161	.0248	.0141	.0290	.0140	.0336	.0058	.0359	.0174		.0180	.0352	.050
.075	.0137	.0163	.0141	.0234	.0096	.0289	.0089	.0330	.0035	.0345	.0031	.0324	.0118	.0357	.075
.100	.0106	.0133	.0118	.0226	.0085	.0251	.0050	.0337	-.0000	.0335	.0002	.0322	.0098	.0310	.100
.150	.0131	.0182	.0072	.0219	.0034	.0249	-.0018	.0309	-.0076	.0309	-.0066	.0326	-.0003	.0285	.150
.200	.0091	.0188	.0026	.0201		.0241	-.0069	.0279	-.0126		-.0149	.0305	-.0080	.0265	.200
.250	.0068	.0185	.0000	.0197	-.0051	.0225	-.0095	.0275	-.0156	.0224	-.0198	.0303	-.0142	.0237	.250
.300	.0041	.0171	-.0016	.0170		.0197	-.0103	.0242	-.0164	.0231	-.0247	.0282	-.0173	.0203	.300
.350	.0040	.0157	-.0019	.0146	-.0094	.0185	-.0119	.0214	-.0198	.0237	-.0280	.0258	-.0210	.0169	.350
.400	.0003	.0144	-.0043	.0136	-.0115	.0178	-.0147	.0217	-.0224	.0232	-.0286	.0231	-.0248	.0136	.400
.450	-.0004	.0151	-.0064	.0148	-.0126	.0160	-.0156	.0207	-.0251	.0218	-.0289	.0193	-.0270	.0097	.450
.500	-.0046	.0151	-.0109	.0167	-.0144	.0150	-.0162	.0200	-.0260	.0193	-.0294	.0176	-.0303	.0067	.500
.550	-.0056	.0142	-.0131	.0159	-.0165	.0152	-.0163	.0178	-.0264	.0171	-.0298	.0152	-.0345	.0073	.550
.600	-.0084	.0152	-.0149	.0152		.0152		.0156	-.0261	.0139	-.0322	.0141	-.0394	.0101	.600
.650	-.0124	.0157	-.0167	.0152	-.0209	.0162	-.0211	.0159	-.0272	.0126	-.0333	.0122	-.0436	.0089	.650
.700	-.0160	.0156	-.0204	.0152	-.0232	.0155	-.0257	.0178	-.0289	.0113	-.0328	.0078	-.0444	.0047	.700
.750	-.0172	.0143	-.0230	.0148	-.0259	.0160	-.0279	.0167	-.0318	.0121	-.0338	.0064	-.0448	-.0004	.750
.800		.0131		.0131		.0125	-.0269	.0114		.0116	-.0358	.0065	-.0459	-.0024	.800
.850	-.0246	.0122	-.0264	.0111	-.0277	.0087	-.0282	.0072	-.0357	.0103	-.0378	.0082	-.0459	-.0033	.850
.900	-.0216	.0113	-.0283	.0090	-.0302	.0090	-.0313	.0070	-.0363	.0066	-.0396	.0059		-.0032	.900
.950	-.0233	.0101	-.0298	.0073	-.0335	.0096	-.0340	.0071	-.0365	.0024		-.0003	-.0428	-.0054	.950

C_p at 2y/b of :

ALPHA = 1.55

X'/C	0.0 UPPER	0.0 LOWER	.15 UPPER	.15 LOWER	.30 UPPER	.30 LOWER	.45 UPPER	.45 LOWER	.60 UPPER	.60 LOWER	.75 UPPER	.75 LOWER	.90 UPPER	.90 LOWER	X'/C
.025	.0062	.0322	-.0091	.0432	-.0203	.0490	-.0261	.0506		.0521		.0411	-.0352		.025
.050	.0062	.0334	-.0083	.0419	-.0213	.0456	-.0289	.0495	-.0410	.0519	-.0244		-.0433	.0480	.050
.075	.0045	.0287	-.0046	.0395	-.0191	.0444	-.0291	.0483	-.0396	.0495	-.0485	.0468	-.0444	.0532	.075
.100	.0034	.0267	.0004	.0376	-.0097	.0411	-.0247	.0488	-.0390	.0485	-.0488	.0463	-.0437	.0480	.100
.150	.0027	.0323	-.0023	.0367	-.0087	.0406	-.0199	.0458	-.0349	.0450	-.0465	.0469	-.0518	.0434	.150
.200	.0008	.0333	-.0067	.0350		.0398	-.0208	.0428	-.0323		-.0465	.0445	-.0508	.0410	.200
.250	-.0017	.0332	-.0090	.0343	-.0155	.0374	-.0215	.0423	-.0320	.0368	-.0446	.0444	-.0510	.0383	.250
.300	-.0044	.0313	-.0103	.0314		.0344	-.0223	.0389	-.0322	.0373	-.0447	.0423	-.0515	.0341	.300
.350	-.0040	.0296	-.0102	.0289	-.0190	.0336	-.0232	.0363	-.0340	.0377	-.0453	.0401	-.0510	.0305	.350
.400	-.0075	.0283	-.0125	.0271	-.0209	.0328	-.0248	.0361	-.0351	.0366	-.0451	.0369	-.0523	.0267	.400
.450	-.0076	.0290	-.0149	.0286	-.0218	.0313	-.0249	.0347	-.0363	.0356	-.0445	.0333	-.0517	.0230	.450
.500	-.0120	.0288	-.0192	.0306	-.0235	.0289	-.0259	.0334	-.0367	.0329	-.0443	.0313	-.0532	.0197	.500
.550	-.0135	.0275	-.0209	.0295	-.0247	.0288	-.0256	.0313	-.0369	.0307	-.0432	.0286	-.0540	.0203	.550
.600	-.0162	.0278	-.0228	.0277		.0288		.0293	-.0370	.0275	-.0447	.0275	-.0546	.0228	.600
.650	-.0198	.0285	-.0245	.0277	-.0291	.0297	-.0303	.0297	-.0382	.0261	-.0452	.0252	-.0553	.0206	.650
.700	-.0233	.0286	-.0280	.0285	-.0311	.0296	-.0340	.0317	-.0394	.0250	-.0447	.0207	-.0556	.0160	.700
.750	-.0245	.0272	-.0306	.0277	-.0336	.0295	-.0355	.0297	-.0417	.0253	-.0459	.0190	-.0562	.0099	.750
.800		.0259		.0258		.0258	-.0343	.0241		.0246	-.0469	.0191	-.0564	.0074	.800
.850	-.0306	.0248	-.0332	.0235	-.0350	.0213	-.0365	.0197	-.0438	.0225	-.0483	.0209	-.0569	.0055	.850
.900	-.0279	.0237	-.0346	.0213	-.0369	.0217	-.0390	.0197	-.0440	.0184	-.0499	.0180		.0038	.900
.950	-.0296	.0221	-.0364	.0190	-.0404	.0219	-.0417	.0193	-.0451	.0135		.0107	-.0503	-.0001	.950

Table IV. Concluded

(c) $\alpha = 3.55°$ and $5.57°$

C_P at 2y/b of :

X'/C	0.0		.15		.30		.45		.60		.75		.90		X'/C
	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	
							ALPHA = 3.55								
.025	-.0044	.0488	-.0292	.0619	-.0370	.0648	-.0391	.0644		.0633		.0496	-.0469		.025
.050	-.0011	.0506	-.0312	.0597	-.0400	.0617	-.0428	.0650	-.0498	.0656	-.0418		-.0513	.0532	.050
.075	-.0029	.0479	-.0319	.0572	-.0399	.0614	-.0435	.0643	-.0487	.0639	-.0548	.0602	-.0532	.0637	.075
.100	-.0039	.0438	-.0266	.0550	-.0393	.0579	-.0438	.0649	-.0492	.0631	-.0549	.0600	-.0524	.0596	.100
.150	-.0052	.0506	-.0199	.0542	-.0377	.0584	-.0439	.0621	-.0498	.0600	-.0548	.0619	-.0583	.0564	.150
.200	-.0081	.0511	-.0152	.0521		.0574	-.0438	.0588	-.0493		-.0554	.0596	-.0581	.0541	.200
.250	-.0091	.0509	-.0158	.0518	-.0372	.0549	-.0425	.0588	-.0502	.0521	-.0552	.0596	-.0584	.0516	.250
.300	-.0114	.0490	-.0170	.0490		.0518	-.0433	.0556	-.0501	.0534	-.0553	.0577	-.0583	.0477	.300
.350	-.0108	.0467	-.0174	.0461	-.0370	.0508	-.0448	.0528	-.0516	.0536	-.0569	.0553	-.0572	.0439	.350
.400	-.0143	.0463	-.0196	.0445	-.0348	.0506	-.0459	.0530	-.0521	.0523	-.0567	.0524	-.0581	.0402	.400
.450	-.0146	.0463	-.0217	.0455	-.0315	.0487	-.0451	.0511	-.0532	.0505	-.0570	.0483	-.0573	.0361	.450
.500	-.0191	.0464	-.0259	.0474	-.0294	.0461	-.0456	.0493	-.0540	.0479	-.0571	.0461	-.0584	.0328	.500
.550	-.0206	.0435	-.0276	.0462	-.0298	.0455	-.0446	.0468	-.0557	.0460	-.0559	.0436	-.0585	.0334	.550
.600	-.0229	.0444	-.0296	.0441		.0447		.0446	-.0562	.0426	-.0573	.0425	-.0586	.0355	.600
.650	-.0265	.0444	-.0311	.0430	-.0352	.0462	-.0474	.0455	-.0576	.0415	-.0579	.0401	-.0594	.0330	.650
.700	-.0297	.0449	-.0338	.0442	-.0364	.0459	-.0479	.0479	-.0583	.0404	-.0573	.0355	-.0592	.0282	.700
.750	-.0308	.0431	-.0363	.0437	-.0386	.0461	-.0457	.0453	-.0602	.0407	-.0586	.0340	-.0594	.0219	.750
.800		.0417		.0415		.0418	-.0406	.0389		.0398	-.0593	.0334	-.0594	.0197	.800
.850	-.0364	.0403	-.0390	.0387	-.0401	.0365	-.0397	.0343	-.0617	.0370	-.0597	.0353	-.0594	.0177	.850
.900	-.0343	.0392	-.0407	.0361	-.0427	.0370	-.0423	.0345	-.0618	.0322	-.0619	.0317		.0156	.900
.950	-.0357	.0373	-.0421	.0333	-.0453	.0371	-.0454	.0338	-.0620	.0269		.0234	-.0524	.0104	.950

C_P at 2y/b of :

X'/C	0.0		.15		.30		.45		.60		.75		.90		X'/C
	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	
							ALPHA = 5.57								
.025	-.0077	.0688	-.0429	.0813	-.0448	.0827	-.0456	.0795		.0759		.0571	-.0496		.025
.050	-.0074	.0720	-.0452	.0801	-.0486	.0806	-.0500	.0818	-.0555	.0802	-.0471		-.0528	.0585	.050
.075	-.0092	.0699	-.0468	.0787	-.0491	.0809	-.0507	.0823	-.0546	.0798	-.0591	.0729	-.0567	.0747	.075
.100	-.0102	.0669	-.0449	.0767	-.0499	.0778	-.0509	.0837	-.0549	.0798	-.0601	.0742	-.0555	.0723	.100
.150	-.0121	.0732	-.0404	.0756	-.0512	.0785	-.0518	.0807	-.0558	.0768	-.0601	.0772	-.0624	.0698	.150
.200	-.0151	.0733	-.0355	.0733		.0782	-.0526	.0774	-.0557		-.0607	.0757	-.0623	.0684	.200
.250	-.0150	.0730	-.0294	.0728	-.0525	.0758	-.0513	.0781	-.0567	.0696	-.0602	.0765	-.0624	.0664	.250
.300	-.0177	.0704	-.0247	.0699		.0724	-.0526	.0748	-.0568	.0712	-.0604	.0738	-.0625	.0626	.300
.350	-.0169	.0682	-.0234	.0670	-.0557	.0720	-.0542	.0723	-.0584	.0721	-.0622	.0717	-.0612	.0592	.350
.400	-.0207	.0679	-.0252	.0649	-.0546	.0712	-.0554	.0723	-.0588	.0703	-.0620	.0689	-.0621	.0551	.400
.450	-.0210	.0677	-.0277	.0662	-.0523	.0695	-.0547	.0705	-.0596	.0682	-.0626	.0654	-.0613	.0511	.450
.500	-.0255	.0677	-.0320	.0682	-.0470	.0670	-.0551	.0686	-.0602	.0658	-.0627	.0635	-.0625	.0479	.500
.550	-.0271	.0642	-.0338	.0664	-.0427	.0656	-.0541	.0649	-.0623	.0636	-.0614	.0597	-.0626	.0480	.550
.600	-.0287	.0648	-.0356	.0643		.0647		.0632	-.0630	.0604	-.0631	.0591	-.0627	.0501	.600
.650	-.0320	.0647	-.0373	.0625	-.0435	.0660	-.0572	.0644	-.0642	.0596	-.0638	.0565	-.0636	.0472	.650
.700	-.0354	.0646	-.0401	.0632	-.0445	.0655	-.0578	.0668	-.0647	.0581	-.0631	.0521	-.0635	.0419	.700
.750	-.0372	.0627	-.0427	.0631	-.0467	.0662	-.0559	.0638	-.0663	.0586	-.0644	.0507	-.0635	.0361	.750
.800		.0609		.0606		.0611	-.0525	.0566		.0573	-.0647	.0497	-.0634	.0339	.800
.850	-.0421	.0593	-.0453	.0574	-.0471	.0547	-.0524	.0516	-.0672	.0540	-.0646	.0515	-.0634	.0313	.850
.900	-.0399	.0580	-.0471	.0540	-.0491	.0554	-.0532	.0521	-.0672	.0486	-.0668	.0474		.0291	.900
.950	-.0408	.0557	-.0484	.0506	-.0514	.0549	-.0541	.0511	-.0675	.0424		.0378	-.0554	.0228	.950

Table V. Pressure Coefficients on Combined-Theory Wing at $M = 4.5$ and $R = 4.0 \times 10^6$ Per Foot

(a) $\alpha = -4.35^\circ$ and -2.36°

C_p at 2y/b of :

X'/C	0.0		.15		.30		.45		.60		.75		.90		X'/C
	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	
							ALPHA =	-4.35							
.025	.0504	.0004	.0575	-.0146	.0593	-.0214	.0642	-.0205		-.0166		-.0136	.0475		.025
.050	.0489	.0025	.0538	-.0159	.0530	-.0227	.0542	-.0209	.0485	-.0212	.0476		.0625	-.0087	.050
.075	.0458	.0011	.0487	-.0174	.0458	-.0222	.0477	-.0206	.0464	-.0222	.0509	-.0247	.0559	-.0135	.075
.100	.0424	.0026	.0451	-.0130	.0431	-.0191	.0423	-.0200	.0408	-.0214	.0466	-.0238	.0542	-.0192	.100
.150	.0443	.0001	.0389	-.0022	.0356	-.0105	.0332	-.0158	.0325	-.0228	.0397	-.0241	.0450	-.0249	.150
.200	.0385	.0014	.0325	.0002		-.0053	.0265	-.0111	.0258		.0292	-.0244	.0394	-.0277	.200
.250	.0359	.0023	.0281	.0009	.0228	-.0026	.0223	-.0072	.0214	-.0195	.0248	-.0238	.0344	-.0280	.250
.300	.0323	.0010	.0249	-.0010		-.0021	.0198	-.0050	.0185	-.0160	.0190	-.0223	.0305	-.0286	.300
.350	.0315	-.0004	.0227	-.0024	.0151	-.0012	.0162	-.0040	.0126	-.0132	.0140	-.0201	.0271	-.0289	.350
.400	.0261	-.0011	.0191	-.0036	.0124	-.0019	.0123	-.0024	.0084	-.0118	.0115	-.0207	.0241	-.0297	.400
.450	.0237	-.0010	.0157	-.0028	.0105	-.0024	.0104	-.0016	.0044	-.0106	.0091	-.0201	.0223	-.0306	.450
.500	.0178	-.0014	.0101	-.0014	.0076	-.0032	.0084	-.0013	.0019	-.0101	.0062	-.0194	.0185	-.0309	.500
.550	.0156	-.0017	.0076	-.0021	.0054	-.0039	.0080	-.0026	.0007	-.0103	.0048	-.0200	.0135	-.0321	.550
.600	.0121	-.0015	.0052	-.0027		-.0038		-.0039	-.0001	-.0110	.0007	-.0192	.0056	-.0308	.600
.650	.0076	-.0014	.0031	-.0030	-.0006	-.0037	.0014	-.0037	-.0021	-.0113	-.0018	-.0192	-.0010	-.0319	.650
.700	.0039	-.0015	-.0009	-.0032	-.0026	-.0042	-.0039	-.0025	-.0043	-.0115	-.0020	-.0200	-.0025	-.0324	.700
.750	.0021	-.0022	-.0038	-.0025	-.0061	-.0024	-.0071	-.0017	-.0085	-.0093	-.0045	-.0177	-.0027	-.0288	.750
.800		-.0030		-.0046		-.0056	-.0059	-.0066		-.0093	-.0075	-.0187	-.0047	-.0299	.800
.850	-.0060	-.0038	-.0078	-.0063	-.0080	-.0075	-.0077	-.0099	-.0146	-.0094	-.0105	-.0175	-.0059	-.0296	.850
.900	-.0043	-.0042	-.0101	-.0070	-.0110	-.0077	-.0112	-.0098	-.0163	-.0108	-.0134	-.0180		-.0233	.900
.950	-.0064	-.0045	-.0120	-.0082	-.0146	-.0070	-.0145	-.0075	-.0168	-.0132		-.0177	-.0096	-.0122	.950

C_p at 2y/b of :

X'/C	0.0		.15		.30		.45		.60		.75		.90		X'/C
	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	
							ALPHA =	-2.36							
.025	.0355	.0093	.0409	.0040	.0442	.0001	.0482	-.0015		-.0021		.0003	.0438		.025
.050	.0326	.0099	.0361	.0068	.0356	.0008	.0380	-.0004	.0330	-.0021	.0452		.0488	.0022	.050
.075	.0291	.0085	.0324	.0082	.0287	.0009	.0310	.0002	.0308	-.0030	.0333	-.0027	.0418	.0042	.075
.100	.0266	.0091	.0285	.0090	.0260	.0045	.0257	.0070	.0253	.0031	.0293	-.0017	.0392	-.0010	.100
.150	.0290	.0083	.0228	.0126	.0186	.0148	.0169	.0174	.0150	.0103	.0213	.0018	.0279	-.0043	.150
.200	.0235	.0101	.0174	.0108		.0143	.0111	.0174	.0091		.0116	.0058	.0211	-.0070	.200
.250	.0212	.0102	.0136	.0100	.0089	.0127	.0080	.0172	.0052	.0100	.0065	.0085	.0157	-.0072	.250
.300	.0174	.0089	.0108	.0083		.0100	.0056	.0147	.0025	.0118	.0005	.0102	.0117	-.0068	.300
.350	.0173	.0079	.0099	.0062	.0034	.0081	.0032	.0123	-.0018	.0124	-.0040	.0097	.0094	-.0067	.350
.400	.0122	.0060	.0071	.0046	.0008	.0072	.0002	.0122	-.0050	.0116	-.0062	.0087	.0057	-.0069	.400
.450	.0113	.0067	.0040	.0056	-.0011	.0070	-.0008	.0113	-.0086	.0109	-.0083	.0070	.0032	-.0074	.450
.500	.0061	.0066	-.0002	.0073	-.0028	.0058	-.0018	.0096	-.0100	.0086	-.0100	.0059	.0003	-.0085	.500
.550	.0039	.0062	-.0026	.0067	-.0051	.0052	-.0019	.0071	-.0112	.0065	-.0111	.0037	-.0044	-.0082	.550
.600	.0012	.0063	-.0047	.0058		.0051		.0054	-.0116	.0039	-.0144	.0035	-.0105	-.0056	.600
.650	-.0028	.0063	-.0066	.0051	-.0098	.0048	-.0075	.0054	-.0129	.0019	-.0160	.0022	-.0160	-.0068	.650
.700	-.0064	.0060	-.0103	.0052	-.0117	.0047	-.0125	.0071	-.0148	.0008	-.0159	-.0010	-.0182	-.0080	.700
.750	-.0080	.0055	-.0125	.0058	-.0139	.0061	-.0145	.0074	-.0180	.0018	-.0177	-.0014	-.0186	-.0086	.750
.800		.0046		.0037		.0027	-.0132	.0018		.0015	-.0194	-.0021	-.0200	-.0092	.800
.850	-.0147	.0036	-.0160	.0017	-.0160	.0004	-.0156	-.0018	-.0228	.0011	-.0216	-.0009	-.0215	-.0090	.850
.900	-.0130	.0033	-.0176	.0006	-.0181	.0001	-.0182	-.0020	-.0233	-.0012	-.0241	-.0024		-.0070	.900
.950	-.0144	.0025	-.0191	-.0006	-.0212	.0009	-.0209	-.0007	-.0239	-.0041		-.0057	-.0192	-.0033	.950

Table V. Continued

(b) $\alpha = -0.37^\circ$ and 1.64°

C_P at 2y/b of :

X'/C	0.0		.15		.30		.45		.60		.75		.90		X'/C
	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	
							ALPHA =	-.37							
.025	.0222	.0208	.0227	.0255	.0226	.0305	.0255	.0346		.0356		.0347	.0204		.025
.050	.0196	.0207	.0185	.0250	.0163	.0293	.0169	.0342	.0097	.0361	.0215		.0223	.0371	.050
.075	.0174	.0181	.0163	.0251	.0124	.0295	.0122	.0340	.0078	.0345	.0078	.0334	.0167	.0378	.075
.100	.0136	.0160	.0136	.0239	.0104	.0264	.0082	.0342	.0039	.0341	.0045	.0334	.0148	.0325	.100
.150	.0165	.0198	.0093	.0227	.0055	.0254	.0021	.0324	-.0031	.0311	-.0015	.0337	.0052	.0292	.150
.200	.0108	.0203	.0049	.0213		.0252	-.0028	.0301	-.0075		-.0090	.0320	-.0010	.0273	.200
.250	.0093	.0200	.0019	.0205	-.0034	.0234	-.0055	.0292	-.0112	.0236	-.0143	.0307	-.0066	.0249	.250
.300	.0061	.0187	.0002	.0180		.0208	-.0066	.0260	-.0124	.0240	-.0183	.0290	-.0110	.0214	.300
.350	.0070	.0173	-.0008	.0161	-.0076	.0201	-.0085	.0233	-.0157	.0246	-.0227	.0270	-.0130	.0185	.350
.400	.0020	.0164	-.0028	.0147	-.0092	.0186	-.0103	.0228	-.0177	.0237	-.0237	.0239	-.0167	.0152	.400
.450	.0017	.0164	-.0051	.0156	-.0106	.0172	-.0101	.0219	-.0201	.0226	-.0248	.0206	-.0187	.0119	.450
.500	-.0031	.0160	-.0093	.0171	-.0126	.0162	-.0110	.0209	-.0213	.0204	-.0257	.0191	-.0220	.0092	.500
.550	-.0052	.0154	-.0112	.0161	-.0136	.0157	-.0099	.0181	-.0219	.0179	-.0248	.0163	-.0252	.0089	.550
.600	-.0073	.0157	-.0133	.0154		.0156		.0159	-.0218	.0148	-.0275	.0154	-.0295	.0118	.600
.650	-.0111	.0159	-.0150	.0150	-.0178	.0155	-.0153	.0162	-.0229	.0131	-.0284	.0137	-.0334	.0105	.650
.700	-.0142	.0154	-.0177	.0147	-.0185	.0145	-.0194	.0178	-.0236	.0115	-.0274	.0094	-.0342	.0070	.700
.750	-.0160	.0145	-.0201	.0150	-.0210	.0157	-.0211	.0175	-.0265	.0124	-.0289	.0084	-.0351	.0032	.750
.800		.0139		.0131		.0124	-.0198	.0121		.0121	-.0298	.0082	-.0356	.0017	.800
.850	-.0209	.0130	-.0225	.0113	-.0225	.0098	-.0222	.0080	-.0294	.0114	-.0308	.0096	-.0361	.0006	.850
.900	-.0194	.0123	-.0241	.0098	-.0248	.0098	-.0247	.0077	-.0299	.0085	-.0335	.0079		.0015	.900
.950	-.0204	.0115	-.0252	.0083	-.0270	.0103	-.0267	.0086	-.0303	.0049		.0033	-.0285	.0030	.950

C_P at 2y/b of :

X'/C	0.0		.15		.30		.45		.60		.75		.90		X'/C
	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	UPPER	LOWER	
							ALPHA =	1.64							
.025	.0108	.0328	.0001	.0426	-.0074	.0502	-.0111	.0517		.0522		.0460	-.0127		.025
.050	.0082	.0333	-.0008	.0417	-.0112	.0472	-.0157	.0505	-.0255	.0522	-.0071		-.0183	.0513	.050
.075	.0069	.0294	-.0005	.0399	-.0112	.0452	-.0163	.0488	-.0240	.0493	-.0344	.0476	-.0227	.0545	.075
.100	.0049	.0280	-.0001	.0382	-.0091	.0417	-.0167	.0493	-.0242	.0486	-.0330	.0473	-.0222	.0486	.100
.150	.0050	.0323	-.0015	.0371	-.0071	.0404	-.0174	.0468	-.0253	.0450	-.0326	.0474	-.0335	.0440	.150
.200	.0011	.0329	-.0041	.0354		.0394	-.0177	.0439	-.0251		-.0342	.0445	-.0336	.0411	.200
.250	.0014	.0337	-.0063	.0348	-.0121	.0382	-.0162	.0436	-.0258	.0372	-.0344	.0437	-.0346	.0390	.250
.300	-.0018	.0322	-.0078	.0318		.0351	-.0165	.0402	-.0257	.0376	-.0354	.0420	-.0355	.0350	.300
.350	-.0003	.0301	-.0086	.0293	-.0160	.0340	-.0176	.0372	-.0276	.0378	-.0382	.0398	-.0355	.0315	.350
.400	-.0054	.0292	-.0106	.0276	-.0170	.0336	-.0184	.0369	-.0281	.0372	-.0379	.0370	-.0373	.0284	.400
.450	-.0057	.0291	-.0128	.0284	-.0184	.0317	-.0176	.0350	-.0291	.0357	-.0386	.0331	-.0371	.0244	.450
.500	-.0103	.0287	-.0164	.0304	-.0199	.0297	-.0184	.0336	-.0296	.0333	-.0389	.0311	-.0393	.0213	.500
.550	-.0123	.0277	-.0181	.0295	-.0203	.0291	-.0171	.0314	-.0305	.0313	-.0372	.0286	-.0400	.0214	.550
.600	-.0138	.0279	-.0198	.0275		.0284		.0289	-.0303	.0277	-.0389	.0271	-.0409	.0235	.600
.650	-.0175	.0280	-.0214	.0272	-.0240	.0288	-.0224	.0290	-.0315	.0259	-.0396	.0250	-.0423	.0216	.650
.700	-.0203	.0279	-.0236	.0276	-.0241	.0283	-.0257	.0311	-.0317	.0247	-.0387	.0210	-.0423	.0181	.700
.750	-.0218	.0264	-.0256	.0269	-.0261	.0282	-.0267	.0301	-.0337	.0250	-.0398	.0195	-.0421	.0130	.750
.800		.0255		.0250		.0248	-.0257	.0243		.0243	-.0407	.0201	-.0418	.0109	.800
.850	-.0255	.0248	-.0274	.0228	-.0277	.0214	-.0281	.0199	-.0353	.0229	-.0405	.0214	-.0407	.0092	.850
.900	-.0243	.0239	-.0290	.0213	-.0298	.0218	-.0302	.0195	-.0355	.0197	-.0429	.0191		.0084	.900
.950	-.0251	.0227	-.0305	.0195	-.0323	.0225	-.0322	.0199	-.0364	.0154		.0137	-.0309	.0081	.950

Table V. Concluded

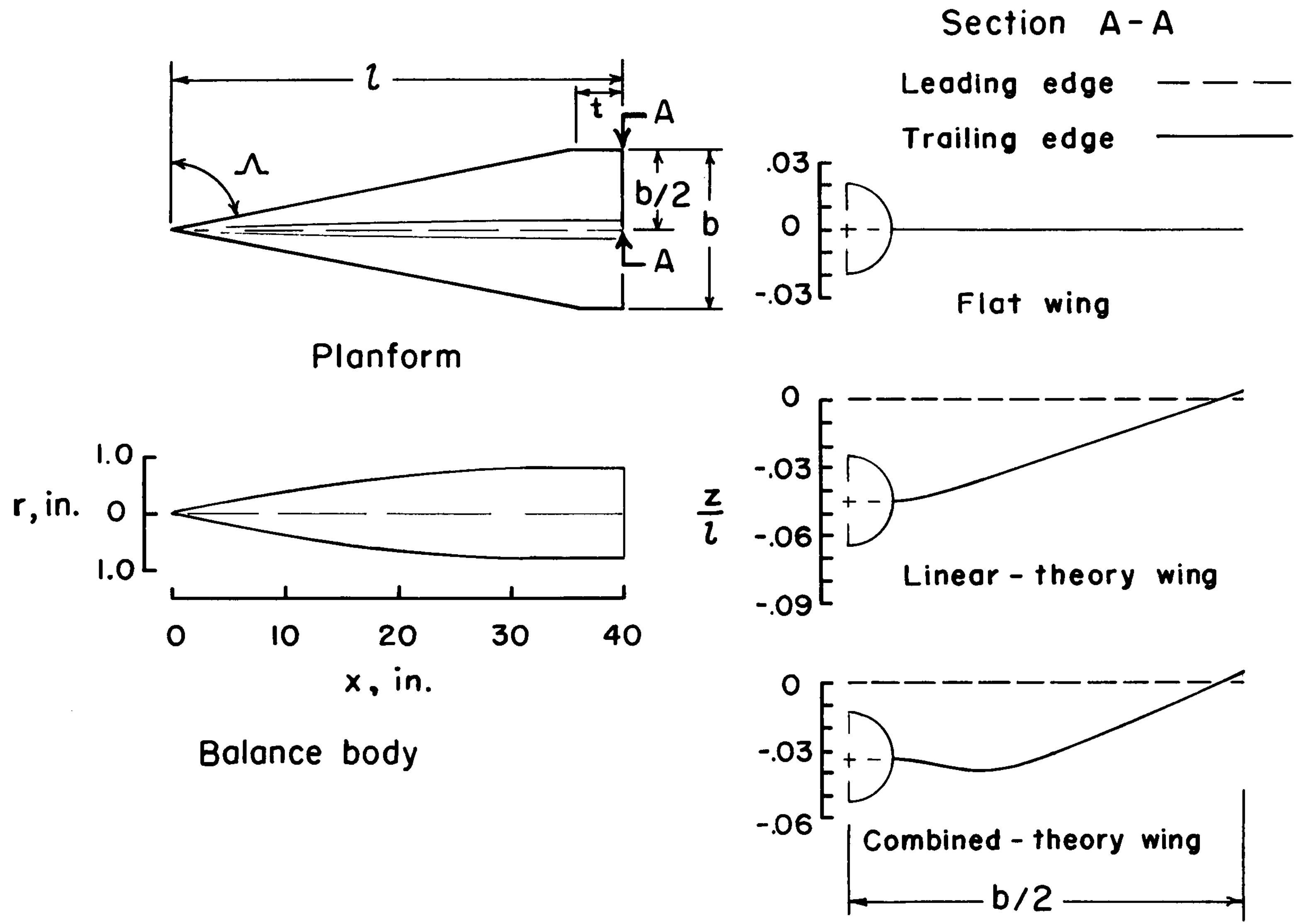
(c) $\alpha = 3.65°$ and $5.66°$

C_p at 2y/b of :

X'/C	0.0 UPPER	0.0 LOWER	.15 UPPER	.15 LOWER	.30 UPPER	.30 LOWER	.45 UPPER	.45 LOWER	.60 UPPER	.60 LOWER	.75 UPPER	.75 LOWER	.90 UPPER	.90 LOWER	X'/C
							ALPHA =	3.65							
.025	.0002	.0490	-.0168	.0611	-.0239	.0651	-.0252	.0657		.0643		.0551	-.0276		.025
.050	.0001	.0499	-.0205	.0602	-.0291	.0625	-.0311	.0661	-.0373	.0661	-.0257		-.0321	.0575	.050
.075	-.0001	.0473	-.0214	.0578	-.0290	.0614	-.0315	.0649	-.0359	.0639	-.0386	.0613	-.0373	.0656	.075
.100	-.0022	.0447	-.0211	.0558	-.0299	.0582	-.0316	.0655	-.0361	.0633	-.0418	.0623	-.0361	.0610	.100
.150	-.0015	.0500	-.0174	.0543	-.0297	.0588	-.0325	.0630	-.0373	.0599	-.0417	.0637	-.0453	.0572	.150
.200	-.0065	.0508	-.0153	.0521		.0574	-.0325	.0594	-.0366		-.0418	.0606	-.0444	.0544	.200
.250	-.0050	.0510	-.0149	.0524	-.0280	.0556	-.0305	.0598	-.0380	.0520	-.0414	.0598	-.0449	.0525	.250
.300	-.0088	.0496	-.0152	.0492		.0522	-.0307	.0563	-.0378	.0529	-.0417	.0580	-.0447	.0485	.300
.350	-.0074	.0474	-.0157	.0458	-.0296	.0512	-.0314	.0535	-.0391	.0534	-.0438	.0559	-.0426	.0449	.350
.400	-.0127	.0458	-.0173	.0441	-.0296	.0504	-.0319	.0534	-.0394	.0525	-.0439	.0534	-.0443	.0415	.400
.450	-.0120	.0459	-.0189	.0447	-.0296	.0486	-.0300	.0513	-.0400	.0507	-.0445	.0495	-.0428	.0374	.450
.500	-.0165	.0453	-.0223	.0468	-.0294	.0469	-.0305	.0494	-.0406	.0483	-.0446	.0477	-.0446	.0343	.500
.550	-.0184	.0437	-.0239	.0459	-.0281	.0456	-.0290	.0465	-.0421	.0461	-.0435	.0447	-.0446	.0341	.550
.600	-.0194	.0441	-.0254	.0439		.0442		.0443	-.0423	.0425	-.0456	.0435	-.0446	.0362	.600
.650	-.0225	.0439	-.0265	.0428	-.0300	.0453	-.0338	.0449	-.0434	.0411	-.0445	.0413	-.0460	.0341	.650
.700	-.0250	.0439	-.0284	.0429	-.0296	.0441	-.0363	.0466	-.0434	.0393	-.0432	.0365	-.0461	.0297	.700
.750	-.0265	.0421	-.0305	.0426	-.0312	.0446	-.0362	.0454	-.0451	.0398	-.0445	.0354	-.0461	.0247	.750
.800		.0409		.0403		.0403	-.0342	.0392		.0390	-.0443	.0338	-.0457	.0226	.800
.850	-.0296	.0398	-.0323	.0377	-.0324	.0362	-.0363	.0343	-.0460	.0369	-.0439	.0352	-.0455	.0206	.850
.900	-.0286	.0391	-.0335	.0357	-.0342	.0369	-.0373	.0342	-.0458	.0330	-.0464	.0325		.0196	.900
.950	-.0295	.0376	-.0346	.0336	-.0363	.0373	-.0378	.0342	-.0465	.0283		.0259	-.0338	.0181	.950

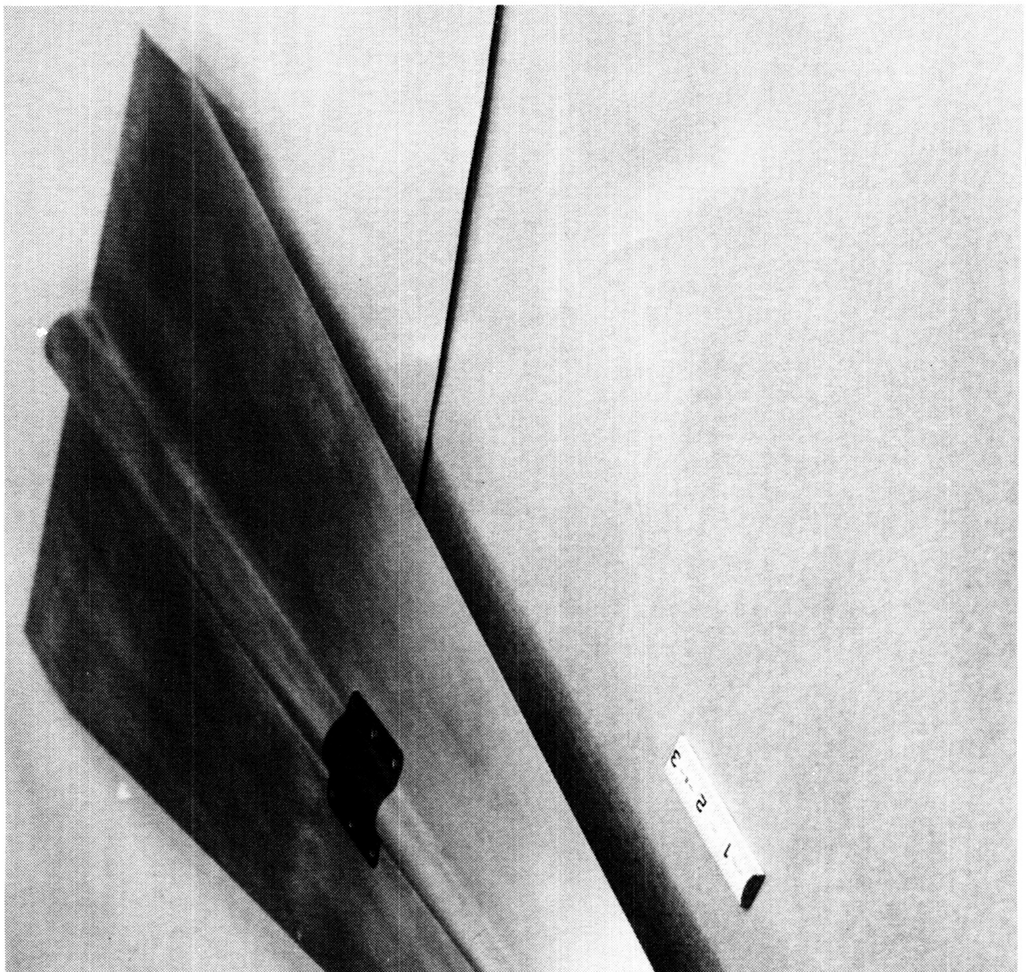
C_p at 2y/b of :

X'/C	0.0 UPPER	0.0 LOWER	.15 UPPER	.15 LOWER	.30 UPPER	.30 LOWER	.45 UPPER	.45 LOWER	.60 UPPER	.60 LOWER	.75 UPPER	.75 LOWER	.90 UPPER	.90 LOWER	X'/C
							ALPHA =	5.66							
.025	-.0055	.0675	-.0248	.0798	-.0300	.0821	-.0292	.0810		.0771		.0637	-.0295		.025
.050	-.0053	.0701	-.0300	.0791	-.0362	.0804	-.0357	.0828	-.0404	.0810	-.0285		-.0339	.0640	.050
.075	-.0059	.0675	-.0315	.0774	-.0362	.0798	-.0363	.0829	-.0394	.0799	-.0406	.0744	-.0393	.0766	.075
.100	-.0074	.0660	-.0315	.0761	-.0373	.0764	-.0364	.0839	-.0398	.0798	-.0454	.0754	-.0382	.0732	.100
.150	-.0073	.0704	-.0316	.0756	-.0386	.0777	-.0371	.0816	-.0408	.0766	-.0449	.0781	-.0475	.0707	.150
.200	-.0130	.0715	-.0317	.0725		.0776	-.0379	.0779	-.0403		-.0455	.0753	-.0474	.0685	.200
.250	-.0114	.0727	-.0280	.0723	-.0373	.0760	-.0353	.0787	-.0415	.0690	-.0446	.0749	-.0475	.0671	.250
.300	-.0150	.0699	-.0240	.0694		.0722	-.0364	.0750	-.0416	.0703	-.0451	.0729	-.0478	.0632	.300
.350	-.0131	.0671	-.0221	.0661	-.0394	.0715	-.0371	.0722	-.0427	.0714	-.0473	.0708	-.0454	.0598	.350
.400	-.0181	.0646	-.0223	.0637	-.0393	.0706	-.0378	.0722	-.0431	.0706	-.0474	.0683	-.0471	.0561	.400
.450	-.0174	.0658	-.0235	.0645	-.0406	.0684	-.0358	.0702	-.0437	.0686	-.0481	.0643	-.0457	.0518	.450
.500	-.0214	.0655	-.0263	.0668	-.0400	.0667	-.0356	.0681	-.0437	.0660	-.0479	.0626	-.0472	.0487	.500
.550	-.0233	.0627	-.0282	.0653	-.0381	.0652	-.0346	.0644	-.0463	.0634	-.0461	.0593	-.0477	.0484	.550
.600	-.0237	.0633	-.0291	.0635		.0638		.0621	-.0460	.0599	-.0479	.0582	-.0471	.0505	.600
.650	-.0266	.0632	-.0308	.0620	-.0379	.0642	-.0395	.0629	-.0472	.0583	-.0479	.0558	-.0487	.0479	.650
.700	-.0291	.0629	-.0327	.0616	-.0362	.0632	-.0416	.0650	-.0469	.0565	-.0465	.0509	-.0486	.0432	.700
.750	-.0308	.0610	-.0347	.0613	-.0372	.0636	-.0411	.0632	-.0483	.0569	-.0475	.0496	-.0482	.0379	.750
.800		.0591		.0586		.0588	-.0392	.0565		.0555	-.0475	.0493	-.0481	.0358	.800
.850	-.0336	.0581	-.0363	.0554	-.0377	.0537	-.0409	.0511	-.0488	.0530	-.0466	.0510	-.0475	.0336	.850
.900	-.0332	.0571	-.0380	.0530	-.0395	.0548	-.0418	.0512	-.0487	.0486	-.0494	.0478		.0321	.900
.950	-.0334	.0553	-.0392	.0504	-.0407	.0550	-.0420	.0506	-.0491	.0431		:97	-.0356	.0285	.950



(a) Model planform, balance-body, and camber-surface leading- and trailing-edge descriptions.

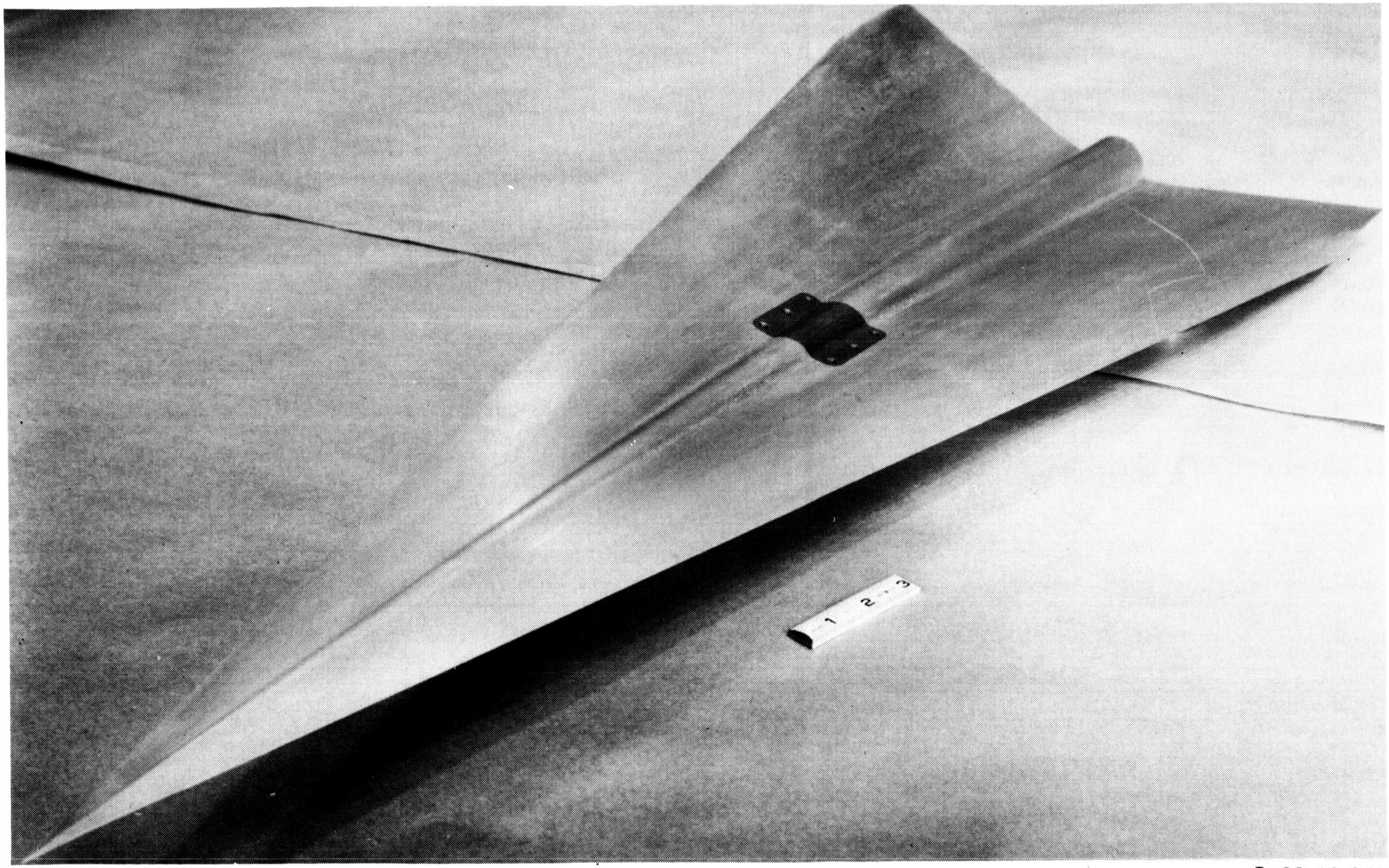
Figure 1. Wind-tunnel models.



L-83-10,838

(b) Photograph of flat-wing model.

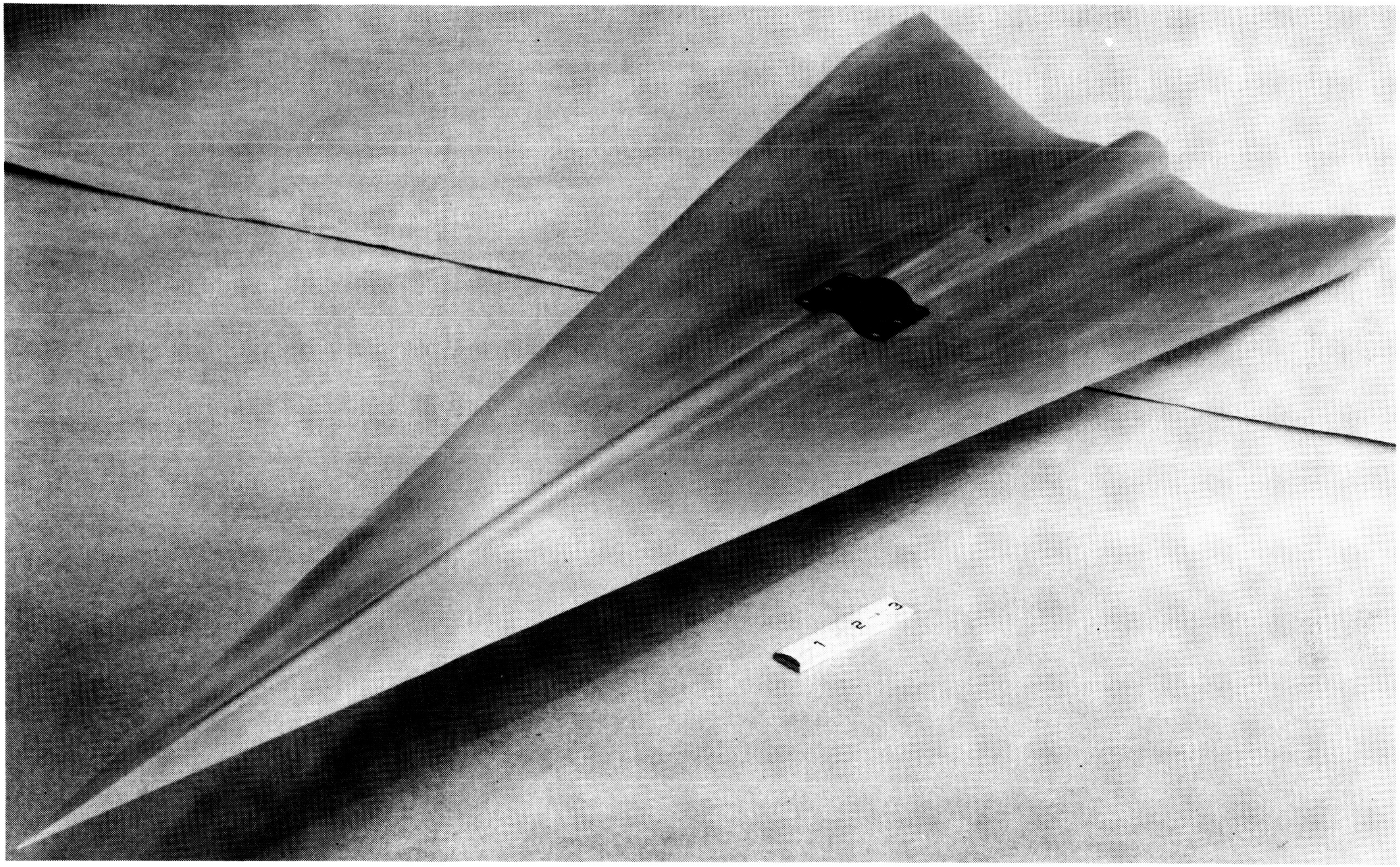
Figure 1. Continued.



L-83-10,840

(c) Photograph of linear-theory wing model.

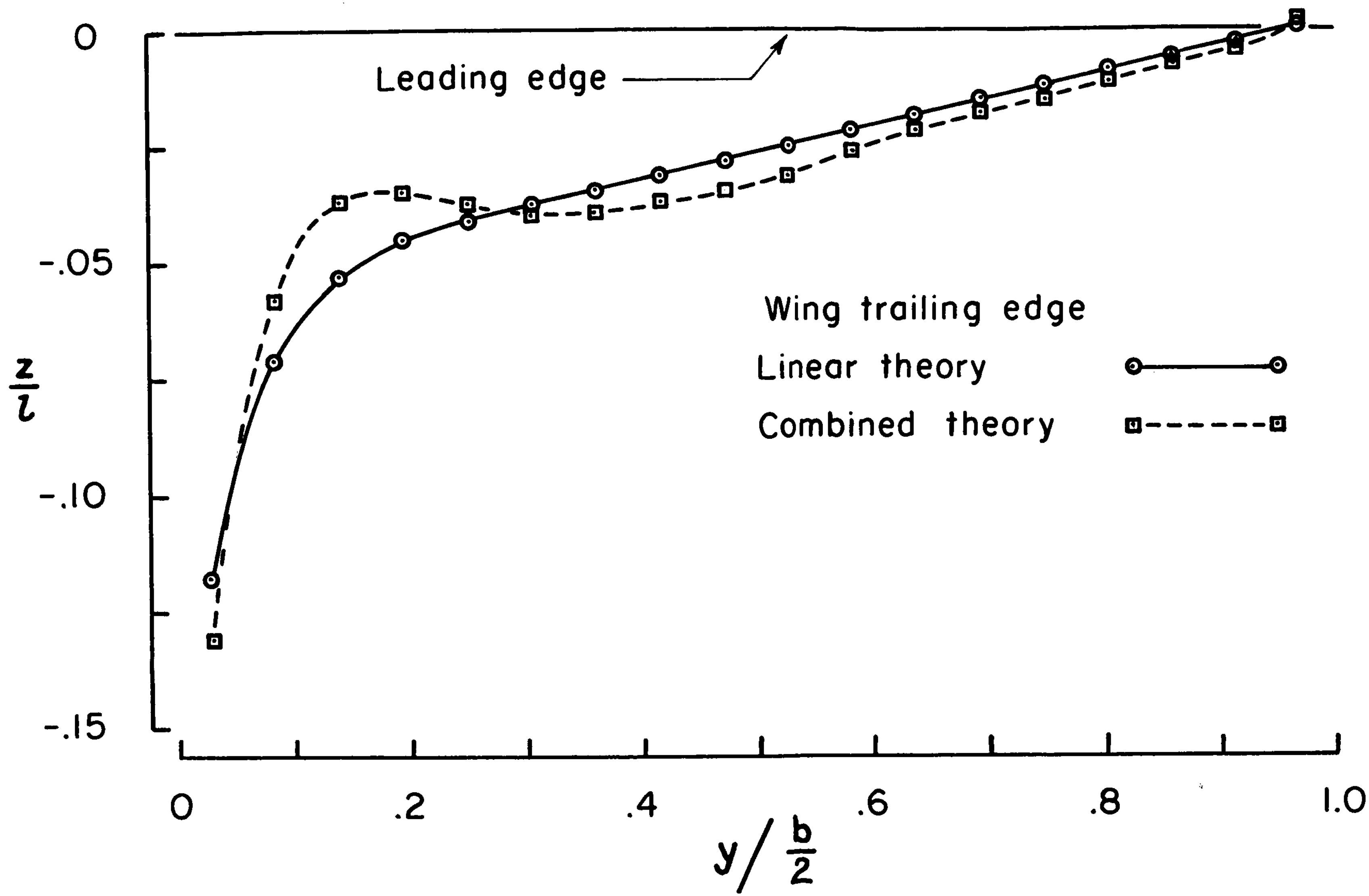
Figure 1. Continued.



L-83-10,839

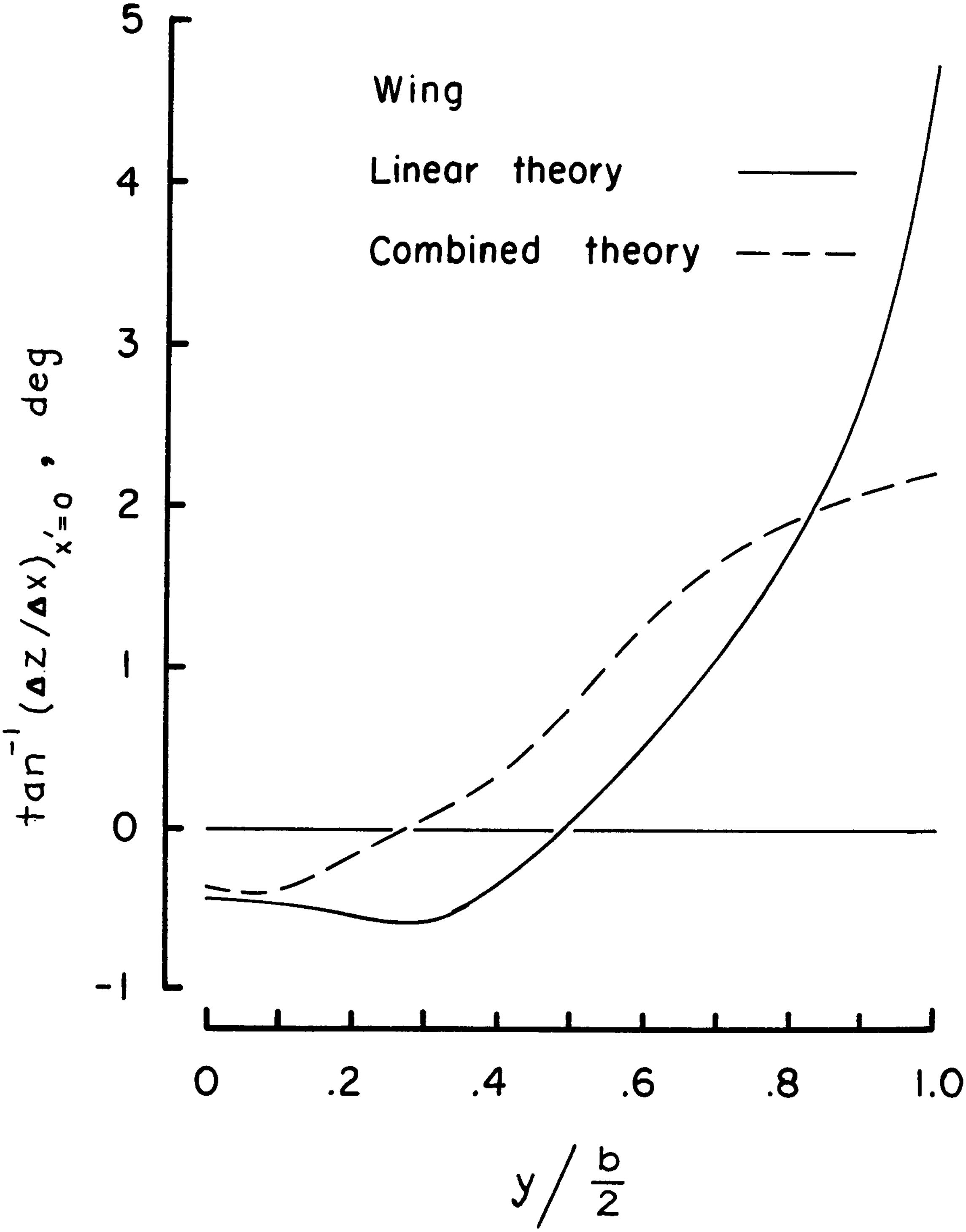
(d) Photograph of combined-theory wing model.

Figure 1. Concluded.



(a) Leading and trailing edges.

Figure 2. Comparison of computed optimum wings.



(b) Leading-edge, camber-surface slopes.

Figure 2. Concluded.

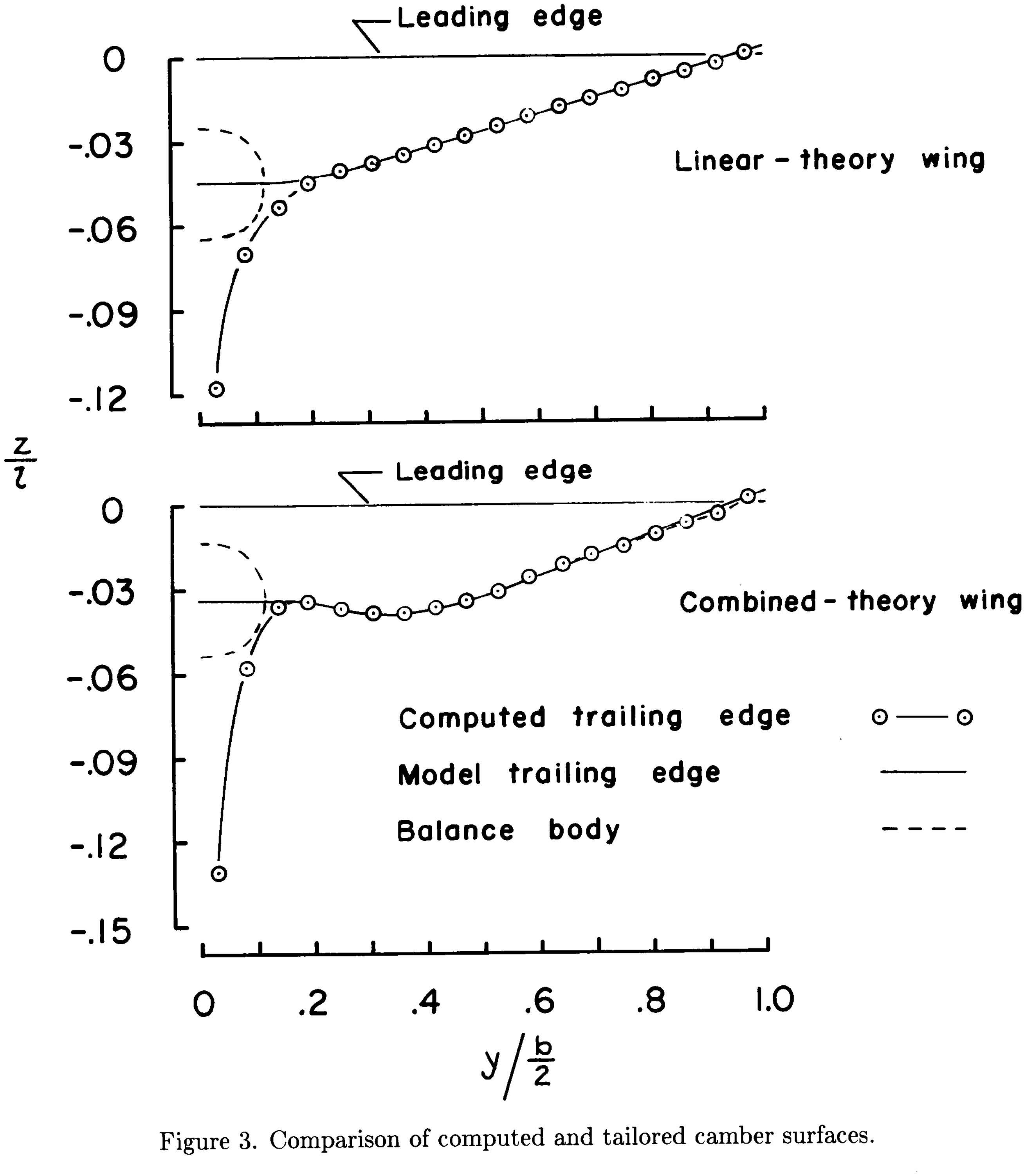
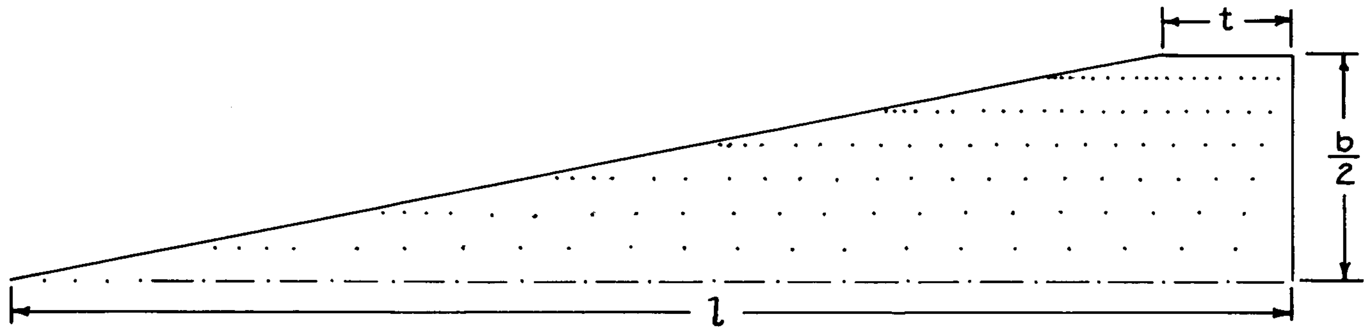


Figure 3. Comparison of computed and tailored camber surfaces.



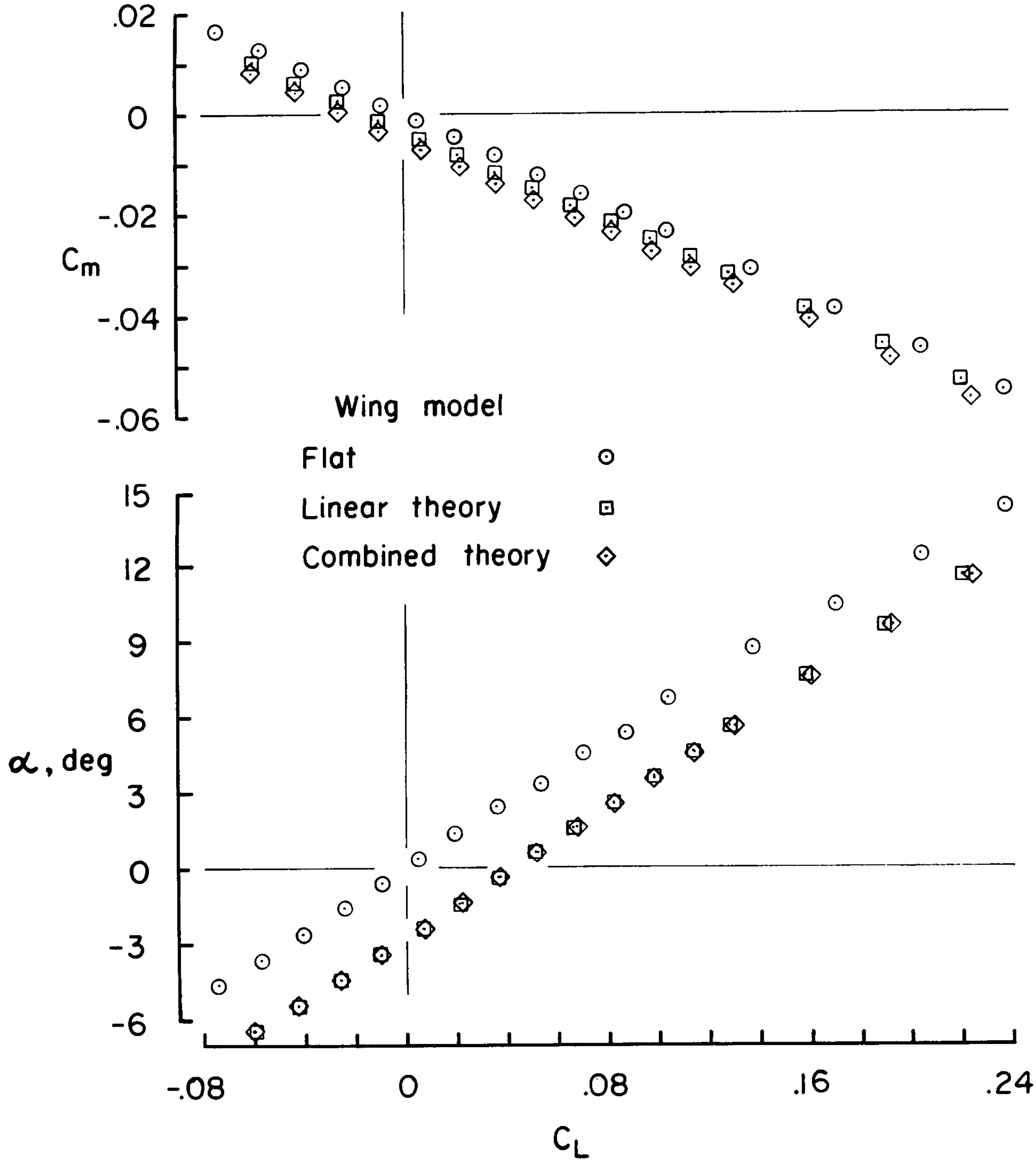
$y/\frac{b}{2}$	x'/c																				
	.025	.050	.075	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	.75	.80	.85	.90	.95
0																		U			
.15																		U			
.30						U		U						U				U			
.45														U							
.60	U					L												U			
.75	U	L																			U
.90	L																			U	

Empty box : upper and lower orifices were operable

U : upper orifice was inoperable

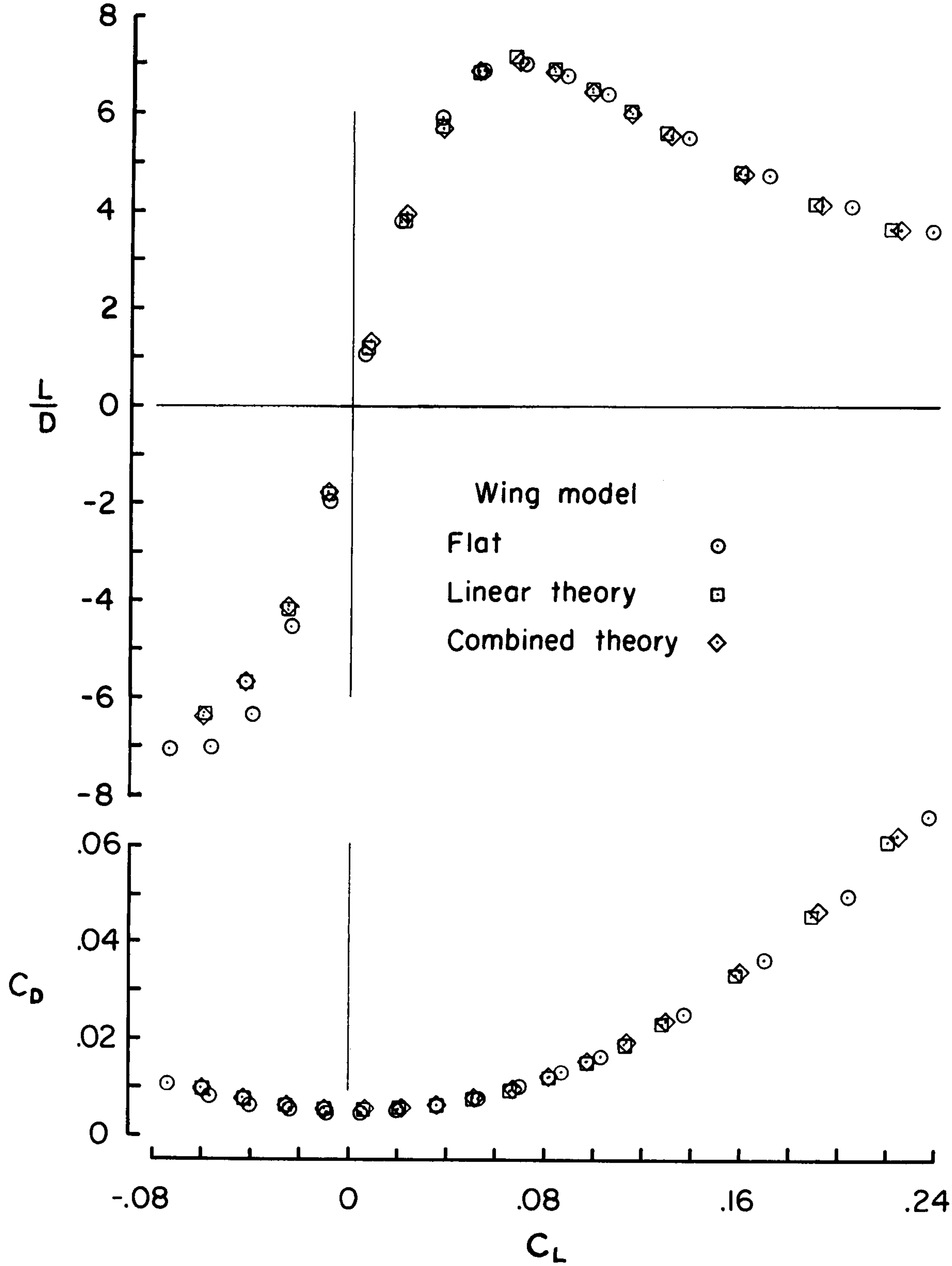
L : lower orifice was inoperable

Figure 4. Pressure-model orifice locations and condition during test runs.



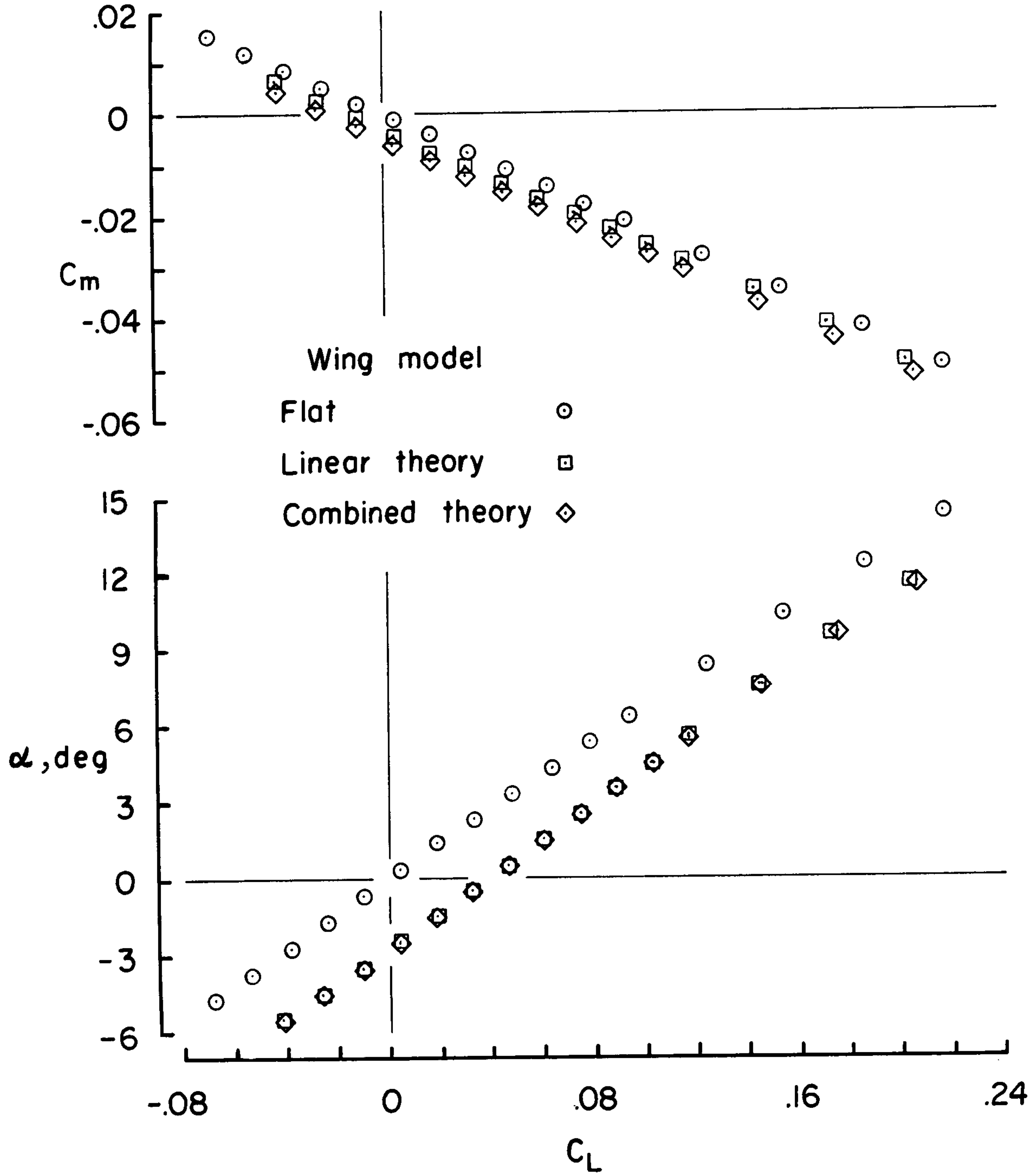
(a) C_m and α versus C_L.

Figure 5. Measured aerodynamic characteristics with $M = 3.5$ and $R = 2.0 \times 10^6$ per foot.



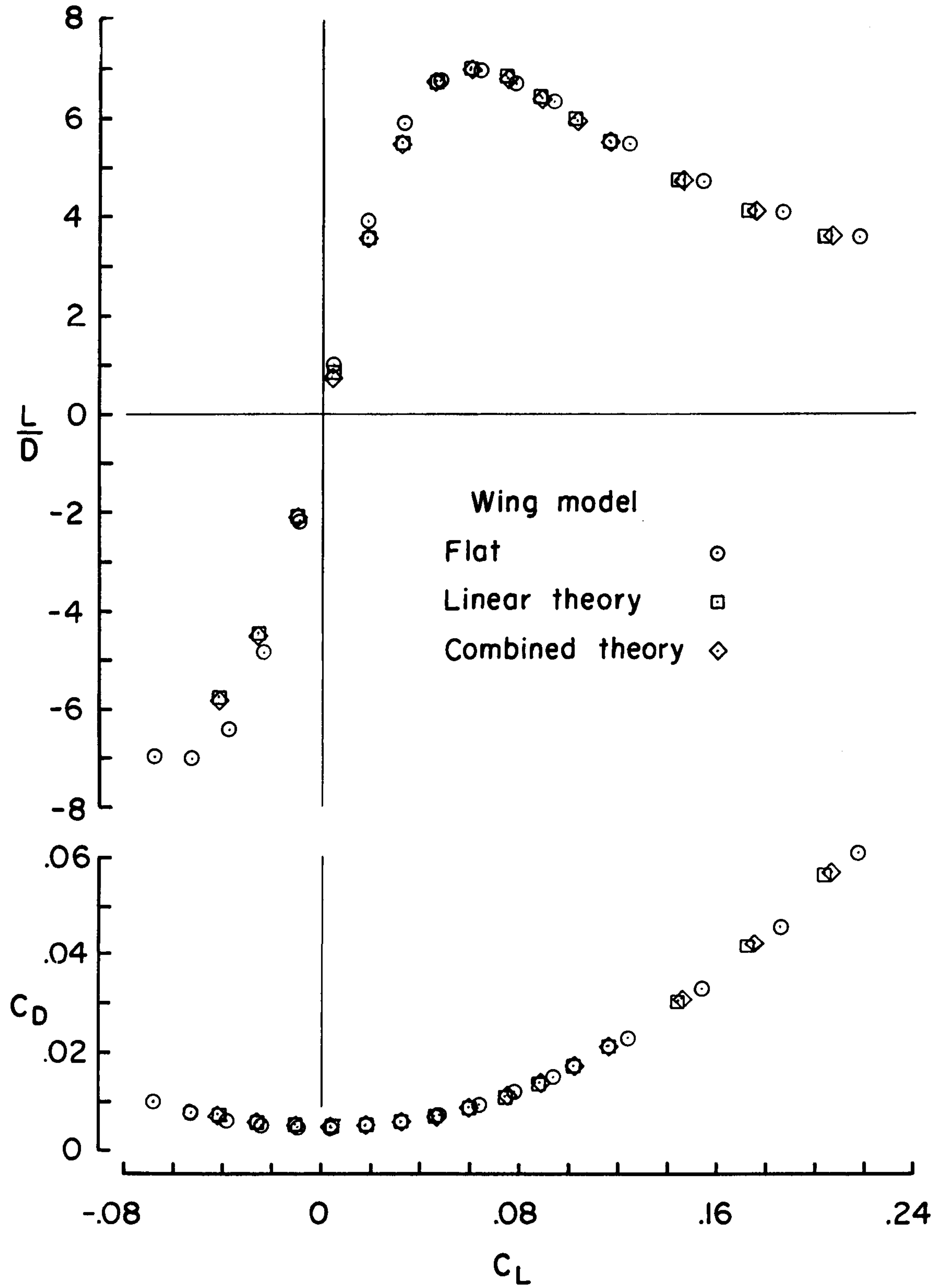
(b) L/D and C_D versus C_L.

Figure 5. Concluded.



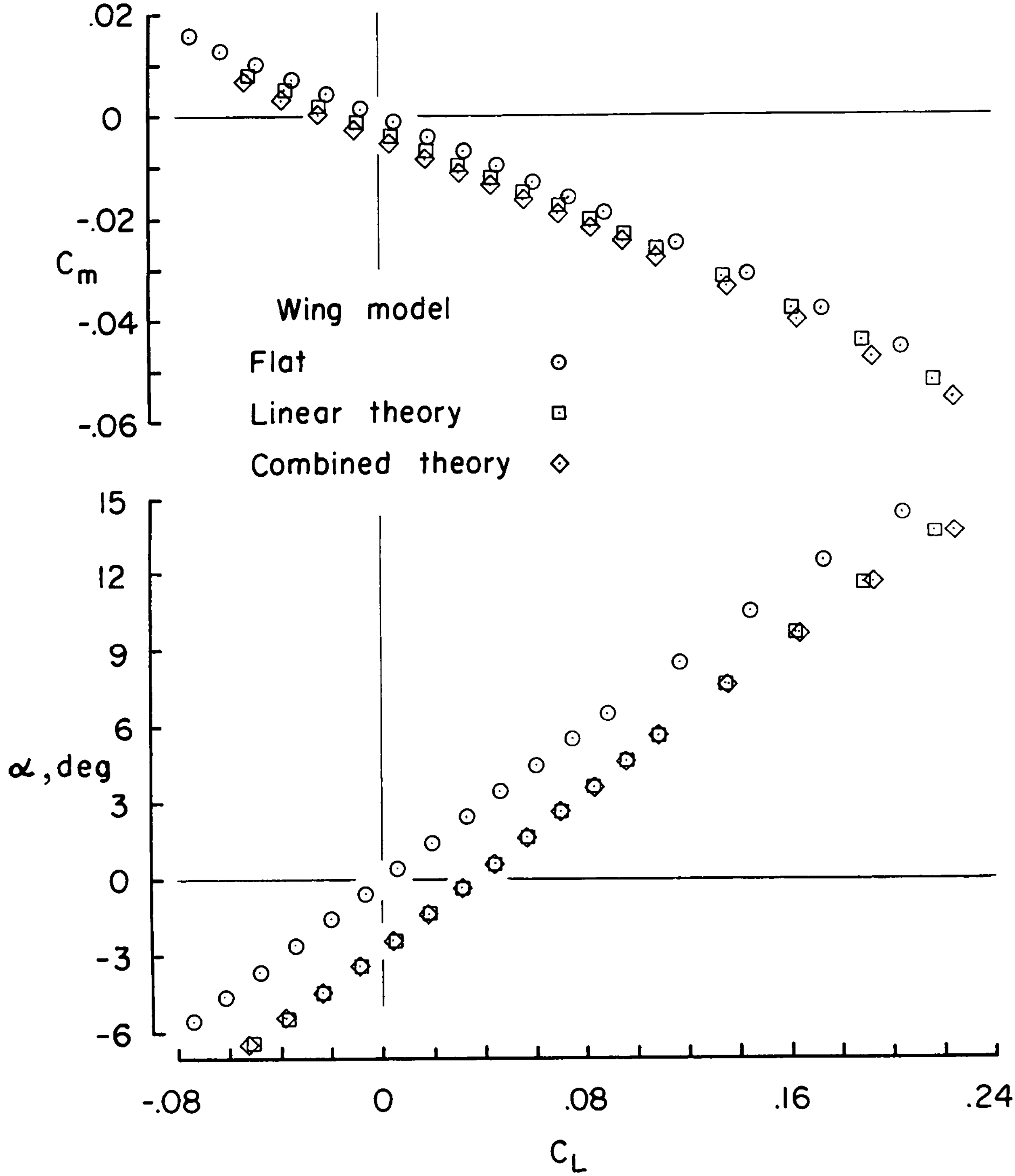
(a) C_m and α versus C_L.

Figure 6. Measured aerodynamic characteristics with $M = 4.0$ and $R = 2.0 \times 10^6$ per foot.



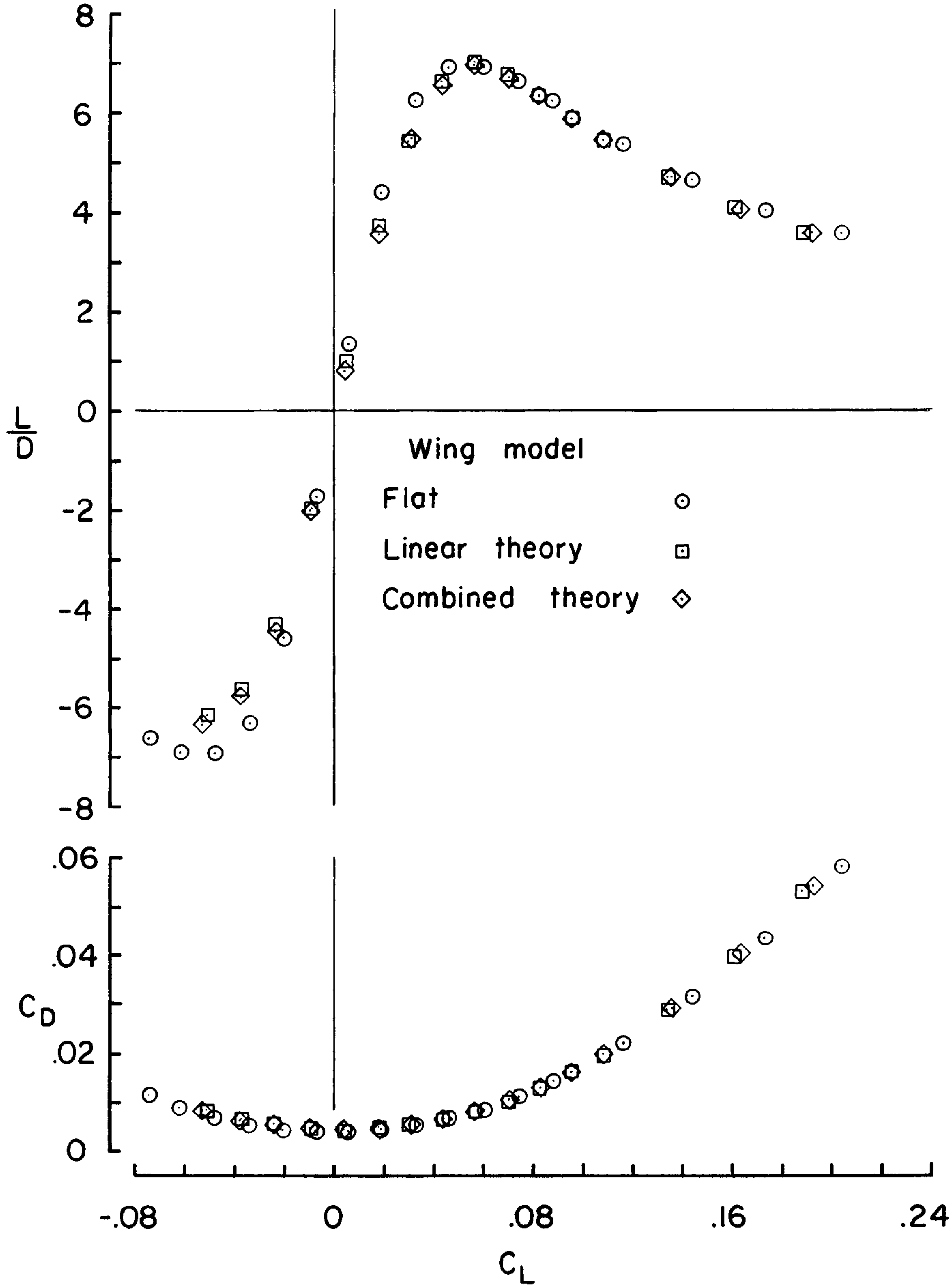
(b) L/D and C_D versus C_L.

Figure 6. Concluded.



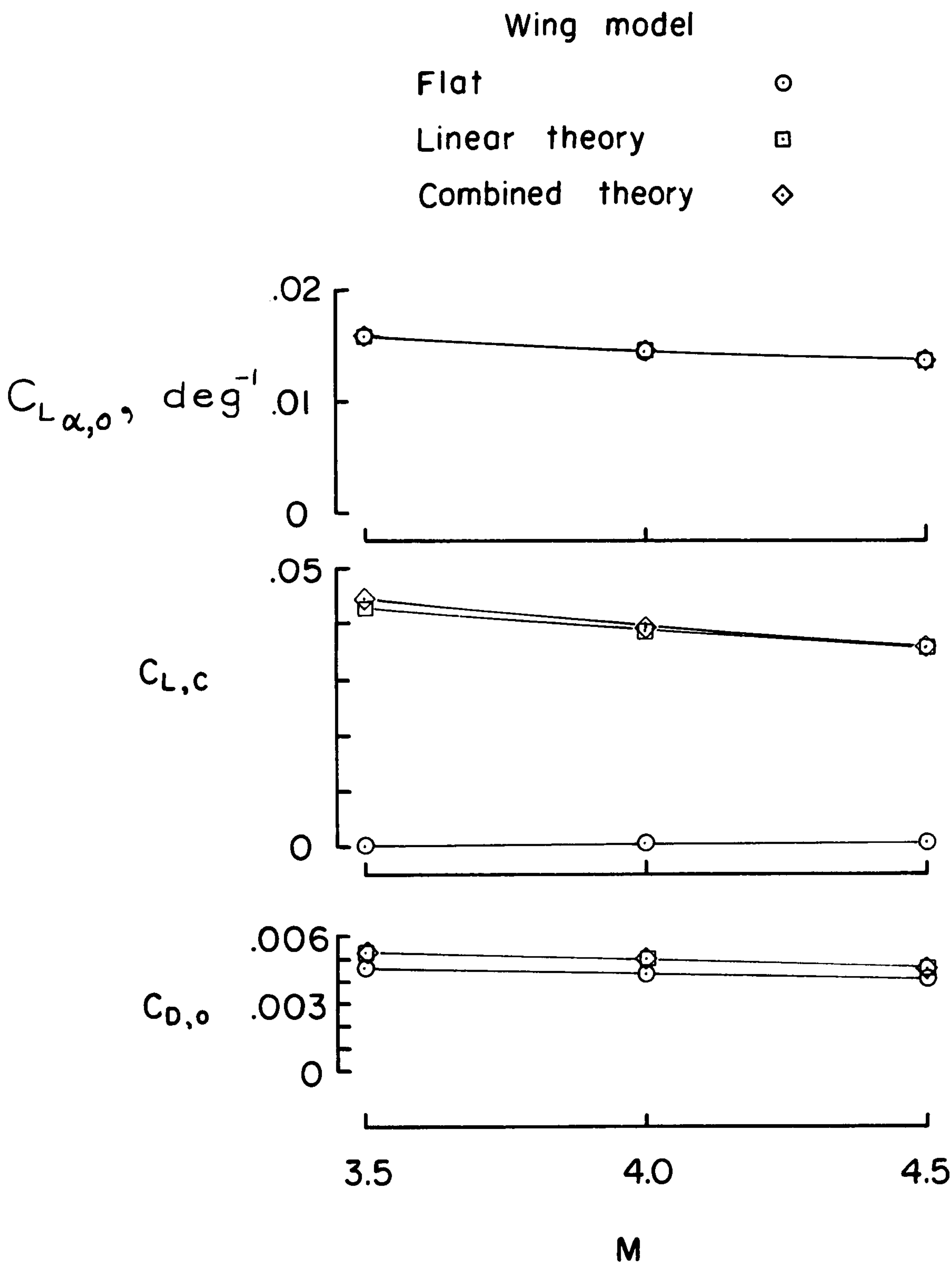
(a) C_m and α versus C_L.

Figure 7. Measured aerodynamic characteristics with $M = 4.5$ and $R = 2.0 \times 10^6$ per foot.



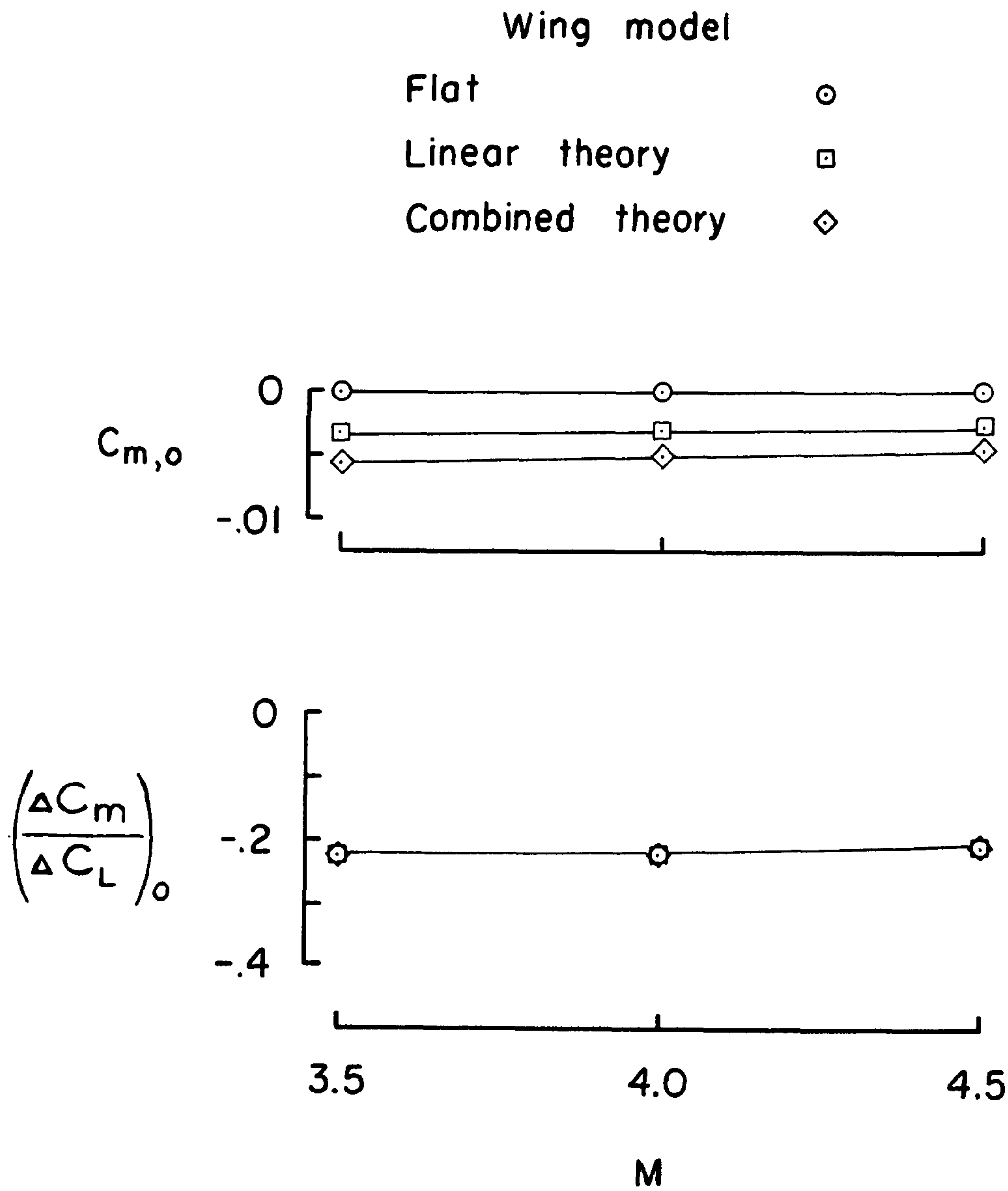
(b) L/D and C_D versus C_L.

Figure 7. Concluded.



(a) $C_{L_{\alpha,o}}$, $C_{L,c}$, and $C_{D,o}$.

Figure 8. Measured characteristics of wing and planform performance.



(b) $C_{m,o}$ and $(\Delta C_m/\Delta C_L)_o$.

Figure 8. Concluded.

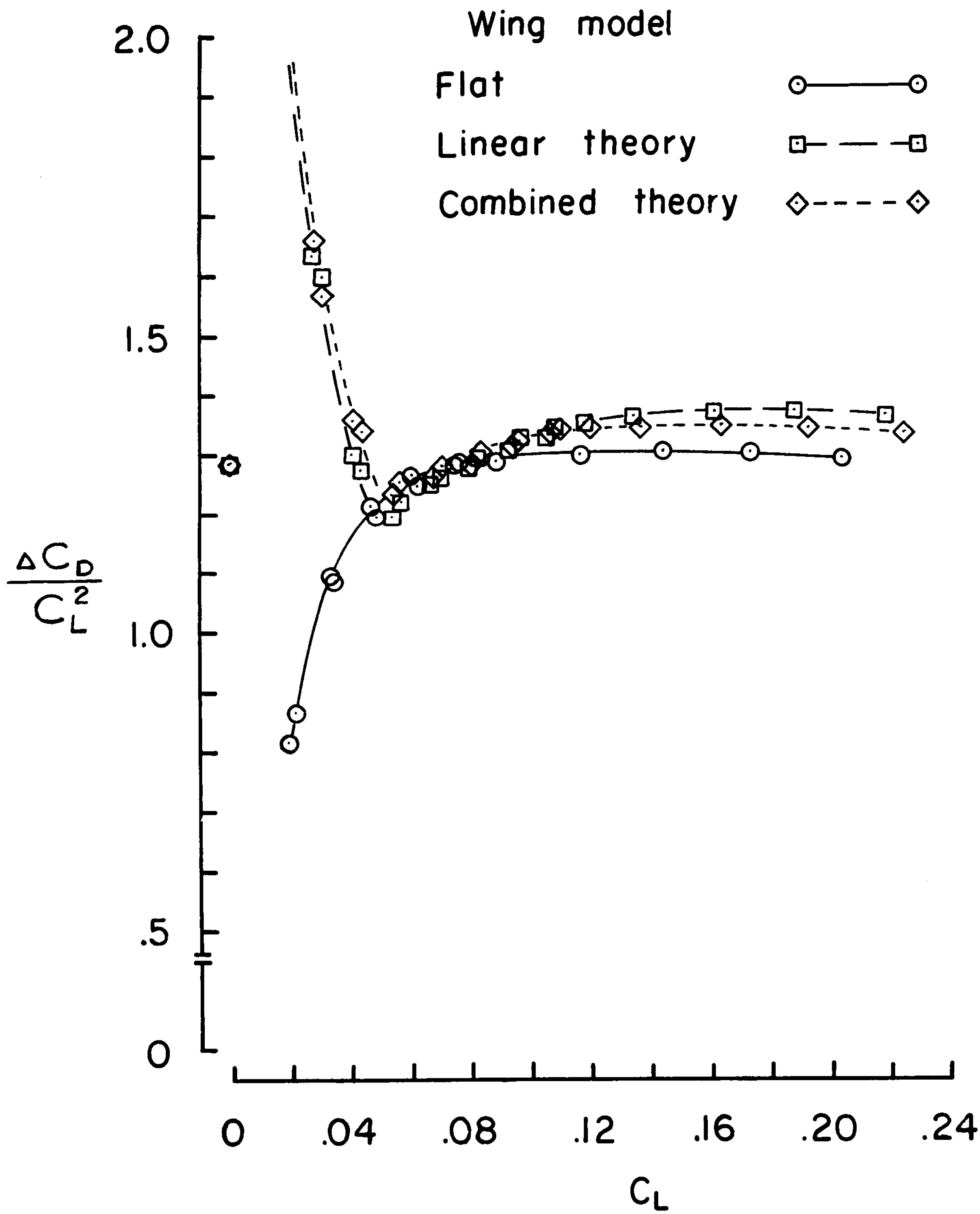
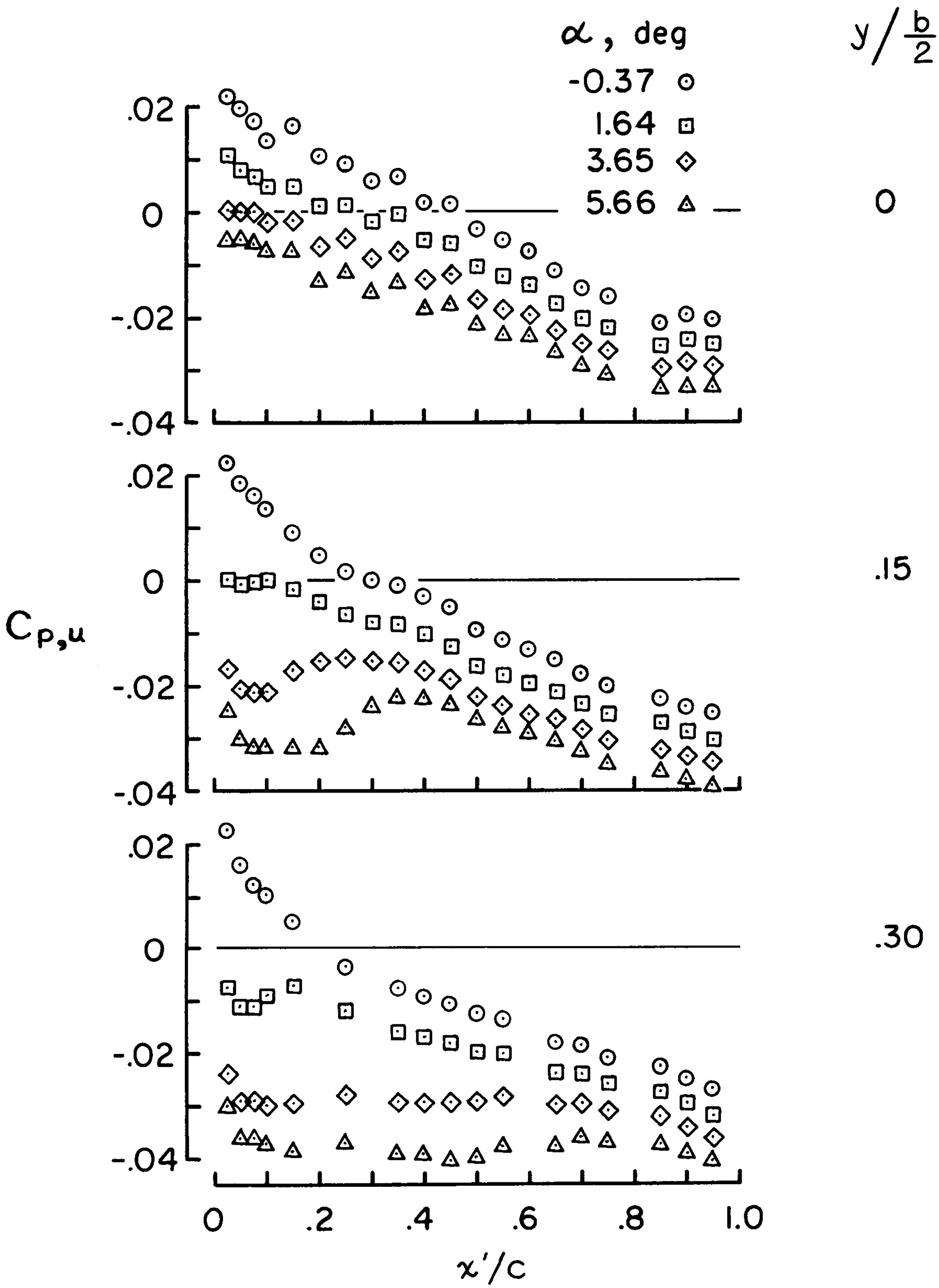
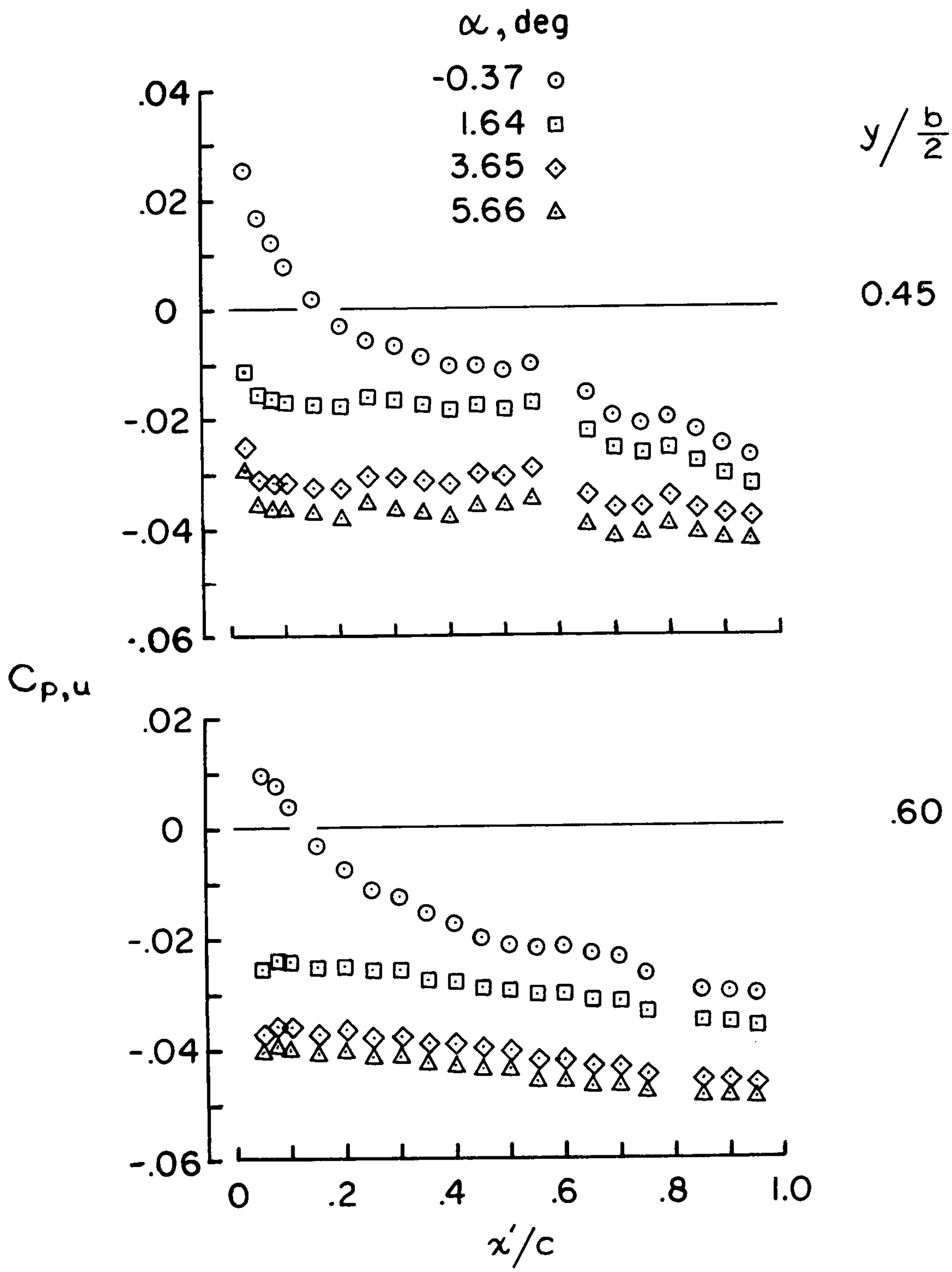


Figure 9. Drag-due-to-lift factor $\Delta C_D/C_L^2$ at $M = 4.5$ and $R = 2.0 \times 10^6$ per foot.



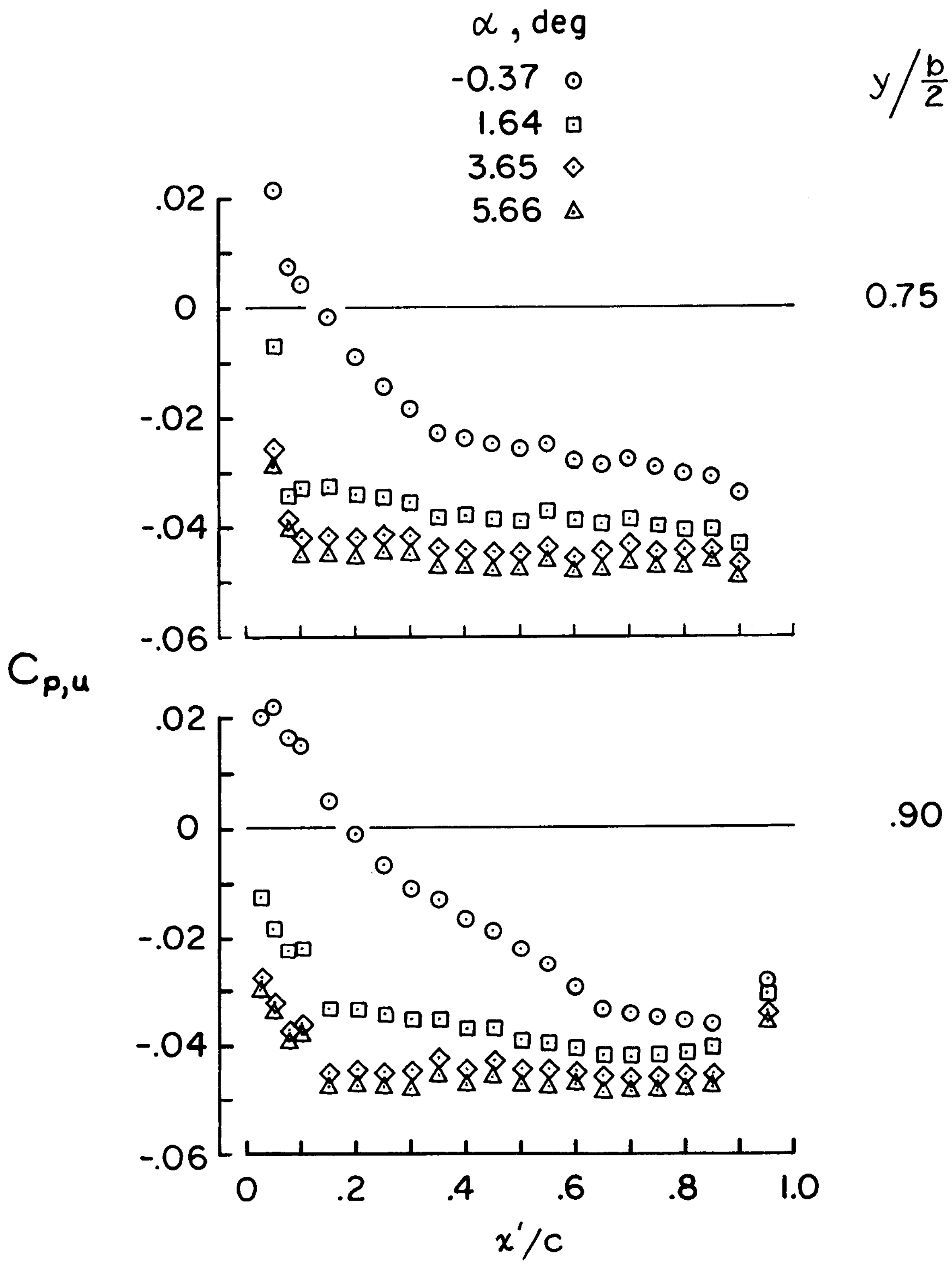
(a) $y/\frac{b}{2} = 0$, 0.15, and 0.30.

Figure 10. Pressure coefficients measured on upper surface of combined-theory wing at $M = 4.5$ and $R = 4.0 \times 10^6$ per foot.



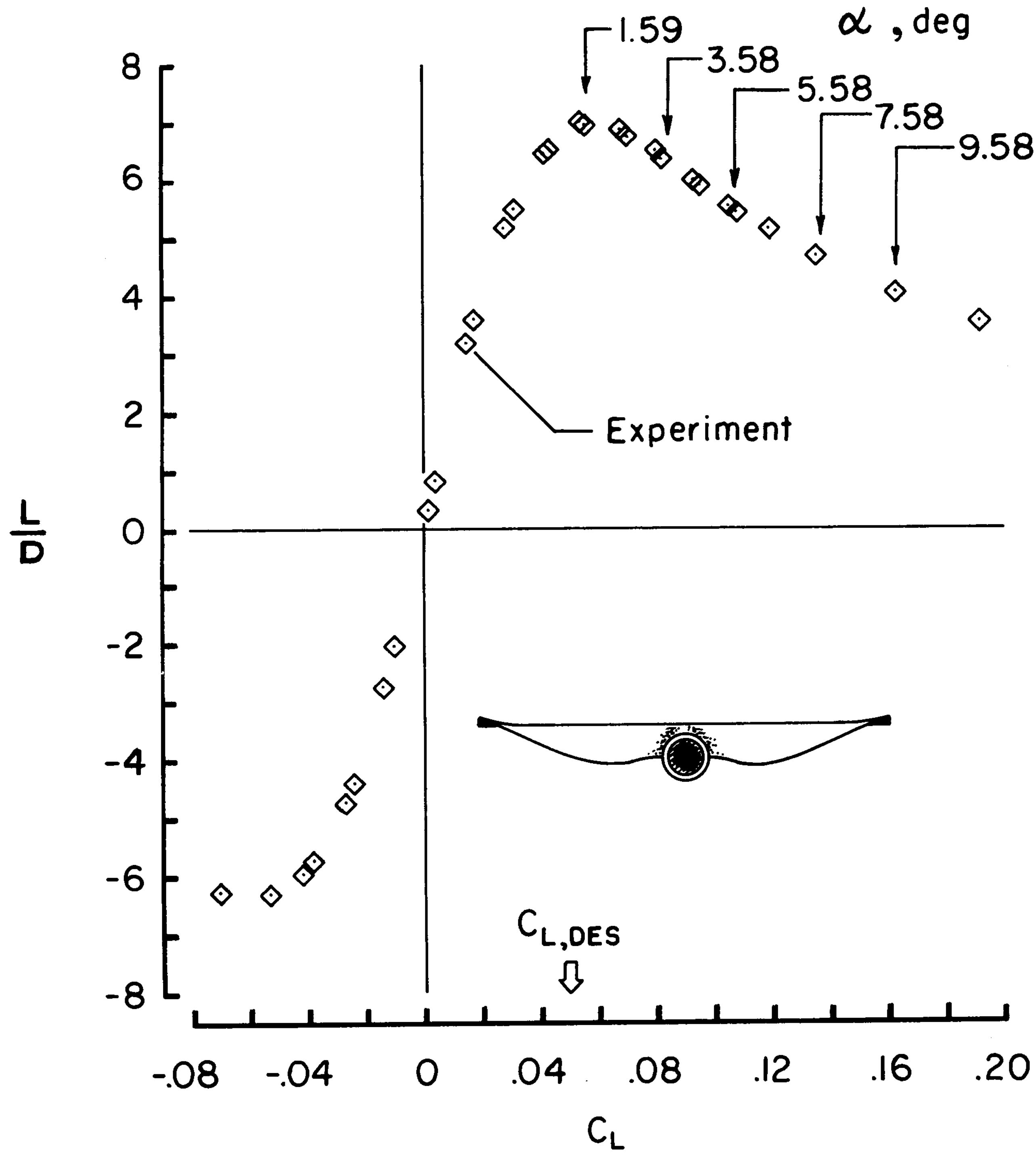
(b) $y/\frac{b}{2} = 0.45$ and 0.60.

Figure 10. Continued.



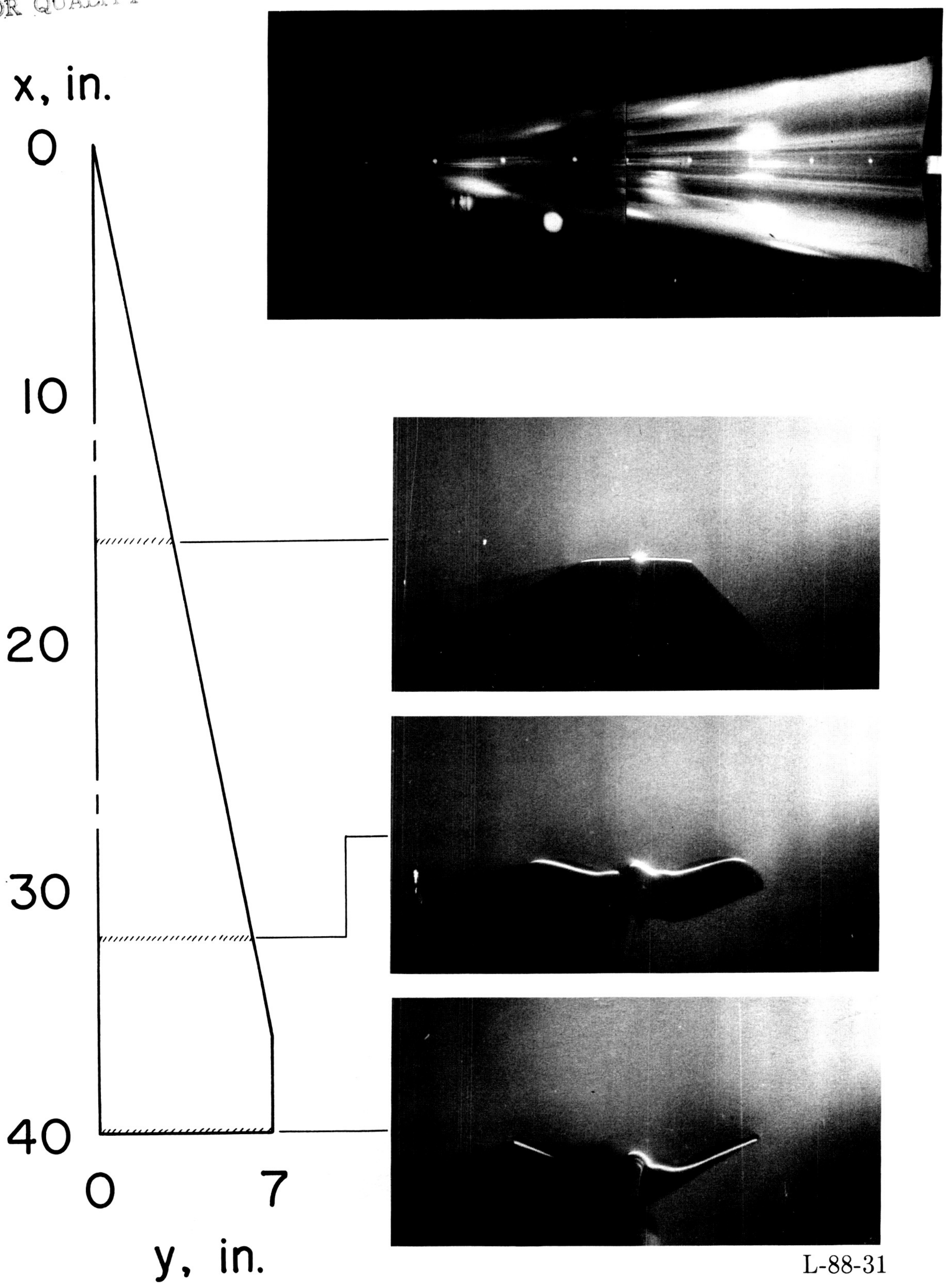
(c) $y/\frac{b}{2} = 0.75$ and 0.90.

Figure 10. Concluded.



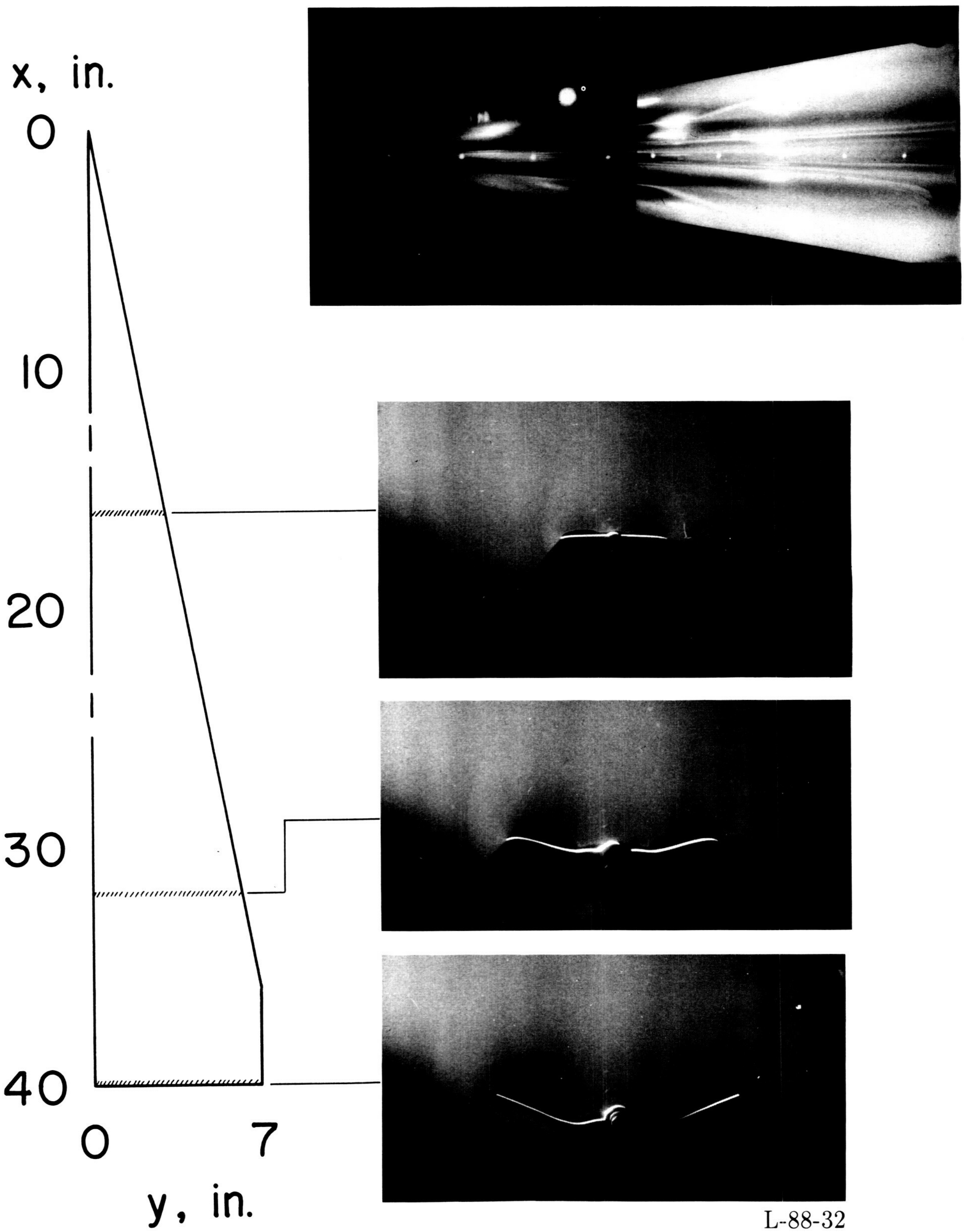
(a) Angles of attack and lift-drag ratio versus C_L at locations where photographs were obtained.

Figure 11. Oil-flow and vapor-screen photographs of combined-theory wing model at $M = 4.5$ and $R = 4.0 \times 10^6$ per foot.



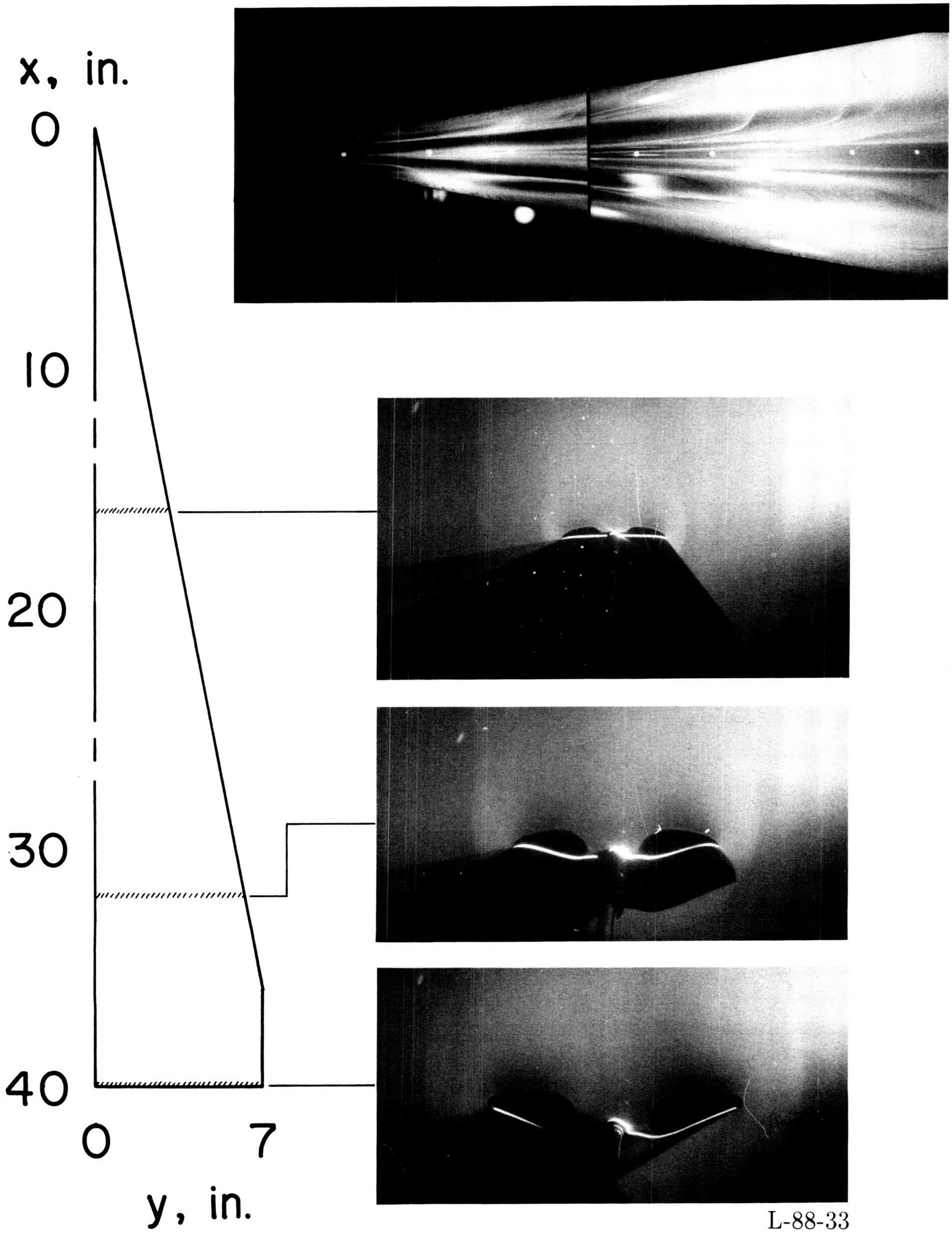
(b) $\alpha = 1.59°$.

Figure 11. Continued.



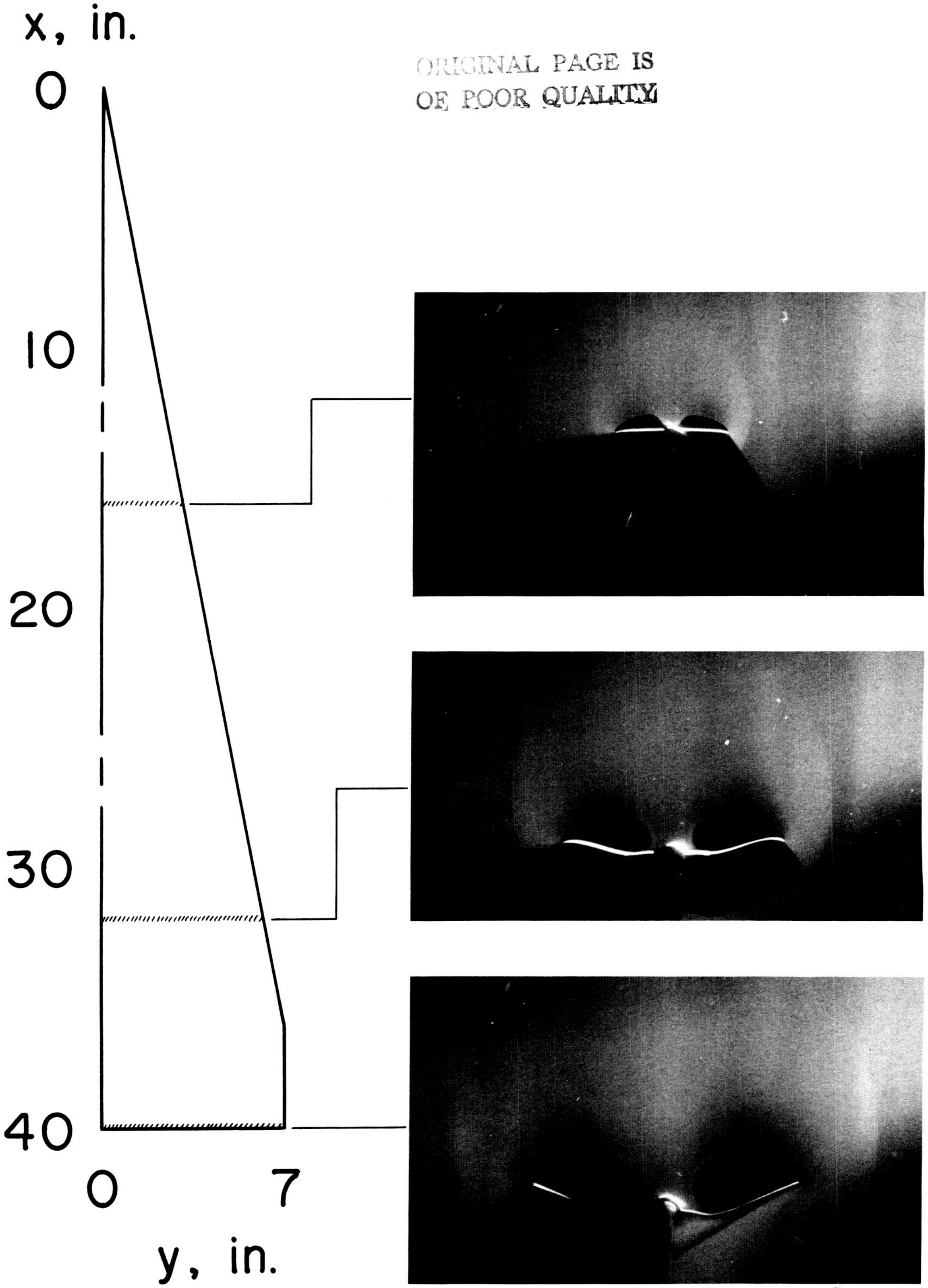
(c) $\alpha = 3.58°$.

Figure 11. Continued.



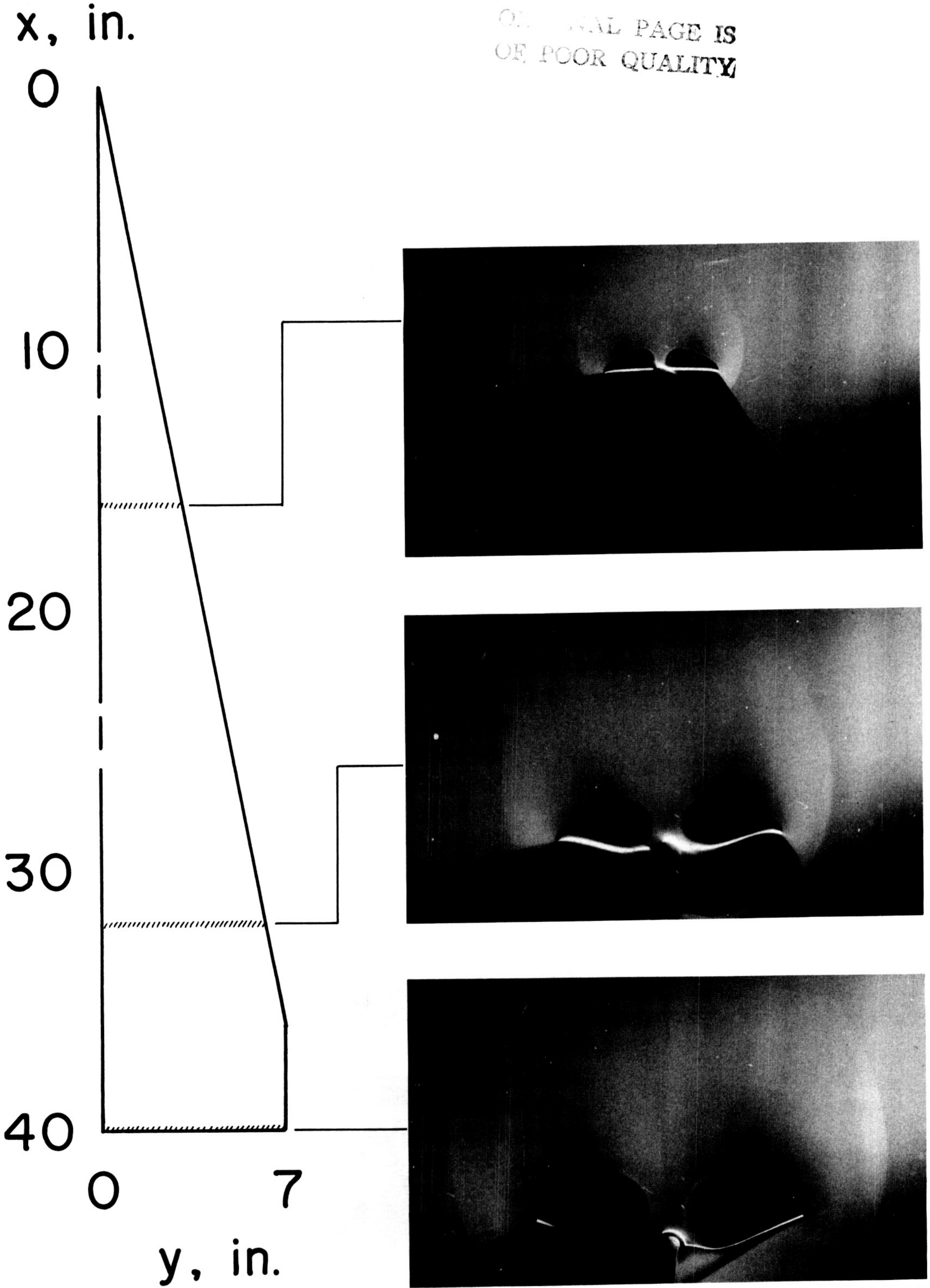
(d) $\alpha = 5.58°$.

Figure 11. Continued.



(e) $\alpha = 7.58°$.

Figure 11. Continued.



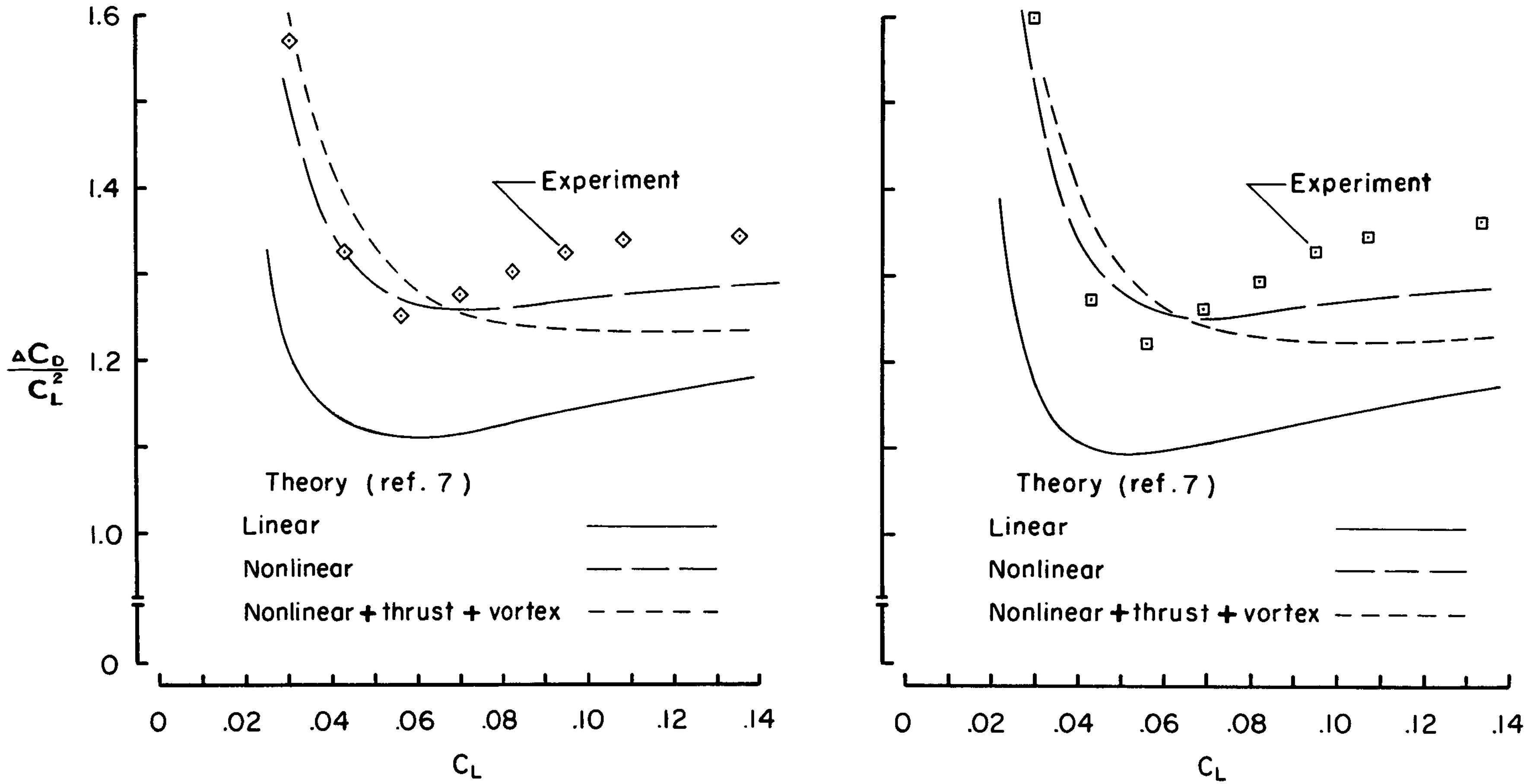
L-88-35

(f) $\alpha = 9.58°$.

Figure 11. Concluded.

L-88-36

Figure 12. Shadowgraph of combined-theory wing model at $M = 4.5$, $R = 2.0 \times 10^6$ per foot, and $\alpha = 5.58°$.



(a) Combined-theory wing model.

(b) Linear-theory wing model.

Figure 13. Comparison of theoretical and experimental $\Delta C_D/C_L^2$ at $M = 4.5$ and $R = 2.0 \times 10^6$ per foot.

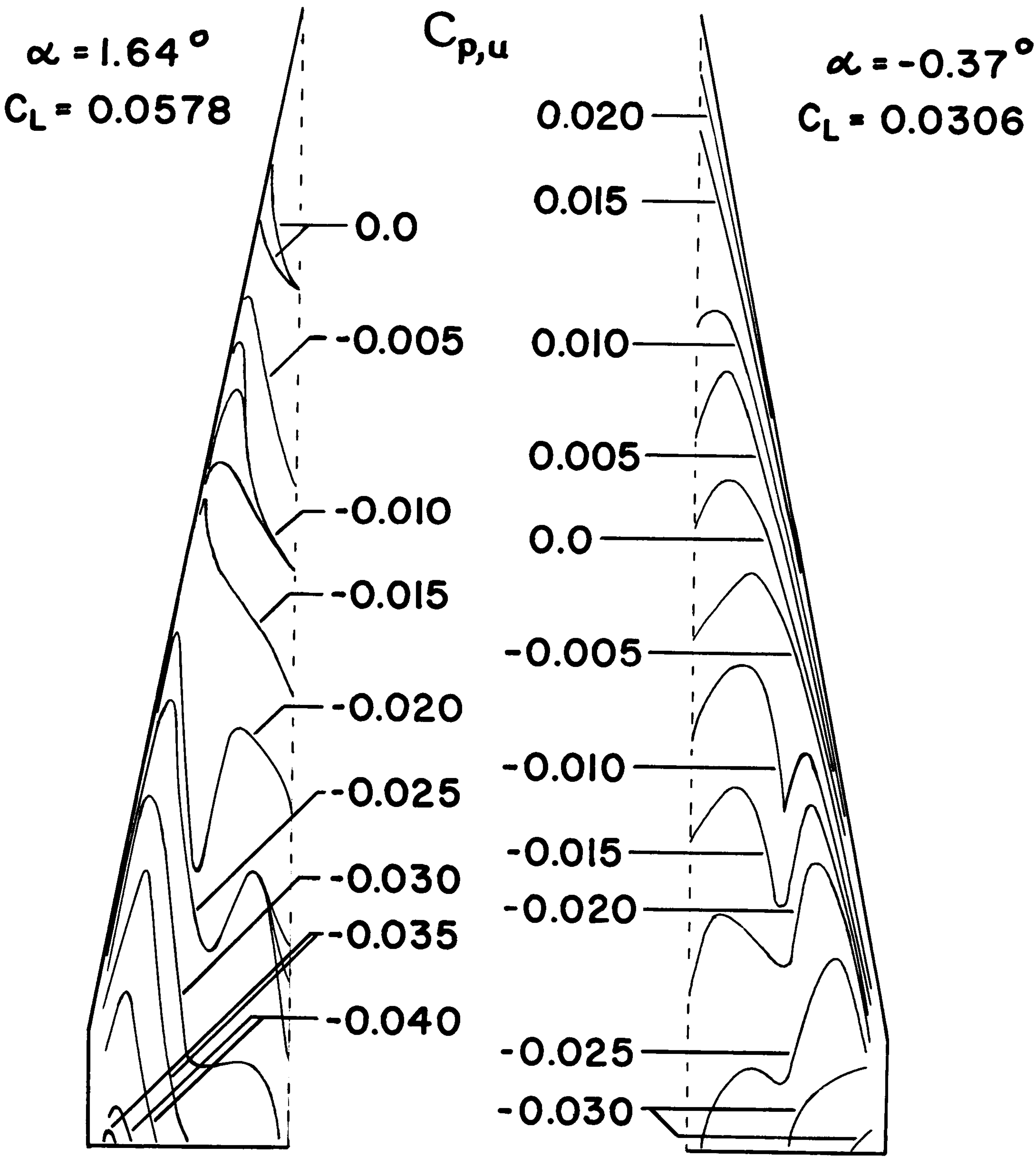


Figure 14. Upper-surface isobars on combined-theory wing model at $M = 4.5$ with $\alpha = -0.37°$ and $1.64°$.

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16. Abstract
A wind-tunnel study has been conducted to determine the capability of a method combining linear theory and shock-expansion theory to design optimum camber surfaces for wings that will fly at high-supersonic/low-hypersonic speeds. Three force models (a flat-plate reference wing and two cambered and twisted wings) were used to obtain aerodynamic lift, drag, and pitching-moment data. A fourth pressure-orifice model was used to obtain surface-pressure data. All four wing models had the same planform, airfoil section, and centerbody area distribution. The design Mach number was 4.5, but data were also obtained at Mach numbers of 3.5 and 4.0. Results of these tests indicated that the use of airfoil thickness as a theoretical optimum, camber-surface design constraint did not improve the aerodynamic efficiency or performance of a wing as compared with a wing that was designed with a zero-thickness airfoil (linear-theory) constraint.

17. Key Words (Suggested by Authors(s))
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