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# FULL-SCALE WIND-TUNNEL INVESTIGATION OF THE LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF THE M2-F1 LIFTING BODY FLIGHT VEHICLE

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# FULL-SCALE WIND-TUNNEL INVESTIGATION OF THE LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF THE M2-F1 LIFTING BODY FLIGHT VEHICLE

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## SUMMARY

The investigation was performed in the Ames 40- by 80-Foot Wind Tunnel. The aerodynamic characteristics were determined for an angle-of-attack range of $-8^{\circ}$ to $24^{\circ}$, for several control settings, and for dynamic pressures ranging from about 14 to 56 psf. The vehicle was longitudinally stable (the static margin $dC_m/dC_L$ ranged from about -0.08 to -0.13). For the range of control settings examined and at a given angle of attack, the control effectiveness, $\partial C_m/\partial \delta_f$, was equal to about -0.006/deg. The maximum untrimmed lift-to-drag ratio was 2.9. A comparison of trimmed aerodynamic characteristics was made between wind-tunnel and flight determined results which show good agreement in view of the differences in test conditions.

## INTRODUCTION

Many studies have been conducted in developing lifting body reentry configurations capable of gliding to a specified recovery site and making a conventional horizontal landing. A representative configuration is the M-2 lifting body. (See refs. 1 through 4.) To examine handling qualities during landing of this type of vehicle a large-scale light-weight (1250 lb) M-2 was built. This vehicle (designated the M2-F1) has been flight tested at NASA's Flight Research Center (ref. 5). Tests of this same vehicle were performed in the Ames 40- by 80-Foot Wind Tunnel to obtain basic longitudinal aerodynamic characteristics and to produce results which would allow comparison with those obtained from flight tests. The results of this wind-tunnel investigation are presented herein.

## NOTATION

$c$ vehicle length, 20 ft

$C_D$ drag coefficient, $\frac{D}{qS}$

$C_L$ lift coefficient, $\frac{L}{qS}$

$C_m$ pitching-moment coefficient, $\frac{\text{pitching moment}}{qSc}$

D drag force, lb

L lift force, lb

q free-stream dynamic pressure, $lb/ft^2$

S body planform area, 138.9 $ft^2$

$V_\infty$ free-stream velocity, knots

$\alpha$ angle of attack, angle of body cone axis with respect to the free stream, deg

$\delta_e$ elevon deflection (see fig. 2), deg

$\delta_f$ flap deflection (see fig. 2), deg

The data presented are referred to the wind axis.

## MODEL DESCRIPTION

Photographs of the model installed in the test section of the Ames 40- by 80-Foot Wind Tunnel are shown in figure 1. Basic model dimensions and geometry are given in figure 2. The elevons and flaps were interconnected by mechanical linkages to the control stick. The elevon incidence is expressed as a function of the flap incidence in figure 3. This control system, though entirely adequate for flight, was flexible enough to allow the elevon surface deflection for a given flap position to vary with dynamic pressure and angle of attack. This elevon deflection was not measured during the flight tests; however, it was estimated in reference 5 that the elevons would deviate as much as $2^\circ$ to $5^\circ$ from the no load setting. The flap position was measured directly at the surface and hence was not in question during the flight tests. To reduce the control surface deflection during the wind-tunnel tests, the elevons and flaps were positioned with locking pins directly at the control surface. Only the flap incidence will be referenced in the remaining figures.

## TEST PROCEDURE

The tests were performed by setting the control position and then varying the angle of attack for several dynamic pressures ranging from 14 to 56 psf. The test dynamic pressures for the different flap settings were chosen (based on a preliminary estimate) to correspond approximately to the dynamic pressures for trimmed 1g flight. The angle of attack was varied from $-8^\circ$ to $24^\circ$ except when restricted by model structural limitations.

## REDUCTION OF DATA

### Corrections

No tunnel-wall corrections were applied to the basic data presented because estimates indicated that such effects on the data were well within the indicated accuracy.

The data were corrected for tares obtained for the unshielded strut tips. These tares were obtained without the model and hence are subject to errors from differences due to interaction with the model. For dynamic pressures greater than or equal to 28 psf[1] the tare values used were: drag coefficient, 0.014, and pitching-moment coefficient, -0.005.

### Accuracy of Measurements

The various quantities measured in the wind tunnel were accurate within the following limits. The values given include error limits due to calibrations, corrections, and recording methods. The force, pressure, and moment measurements for each data point were obtained by averaging 10 samples. Hence, the accuracy limits listed for these items are for the average values.

| | |
|---|---|
| Angle of attack | $\pm 0.3^\circ$ |
| Lift | ±10 lb |
| Drag | ±3 lb |
| Pitching moment | ±300 ft-lb |
| Free-stream dynamic pressure | ±1/2 percent above 20 psf, ±0.1 psf below 20 psf |
| Flap and elevon settings | $\pm 0.5^\circ$ |

The accuracy of the flight data with which the wind-tunnel test results were compared is discussed in reference 5.

## RESULTS AND DISCUSSION

The basic aerodynamic characteristics obtained in the wind tunnel are presented in figures 4 and 5. From these data the results at trimmed pitching moments ($C_m = 0$) were obtained and are compared with the flight-test results in figure 6.

[1]The tares were significantly greater at the lower dynamic pressures tested because of Reynolds number effects.

## Basic Wind-Tunnel Results

Figure 4 shows the effect of dynamic pressure on the aerodynamic characteristics with the control flaps set at -18.4°. It is apparent that as dynamic pressure is reduced from 28 to 14 psf, there are significant increases in the pitching-moment coefficient. In addition, the accuracy in the pitching-moment coefficient is reduced as the dynamic pressure is reduced. This reduced accuracy resulted in a noticeable increase in scatter at 14 psf.

In view of this scatter, the control position data in figure 5 are presented only for dynamic pressures greater than or equal to about 28 psf. The vehicle was longitudinally stable and controllable over the range of lift coefficients investigated. The static margin, $dC_m/dC_L$, which was essentially constant with $C_L$ for each control setting except -18.4°, ranged from about -0.08 to -0.13. The nonlinear variation evident for the -18.4° control setting could be attributed reasonably to separation of the air flow on the lower surface of the elevons at the low angles of attack. For the range of control settings examined and at a given angle of attack it was determined from the results of figure 5 that the control effectiveness, $\partial C_m/\partial \delta_f$, was equal to about -0.006/deg.

From the lift-to-drag ratio results presented in figure 5 the maximum untrimmed value was about 2.9.

## Comparison of Wind-Tunnel and Flight Results

The wind-tunnel results for trimmed conditions were obtained from figure 5 and are presented in figure 6 along with the flight-test results. The basic coefficients are presented in figure 6(a), the required control position results are presented in figure 6(b), and the forward velocity results (computed using the data of fig. 6(a) and the 1250 pound weight of the vehicle) are presented in figure 6(c).

It is apparent that the lift coefficient obtained from the wind-tunnel test results is linear with angle of attack while that obtained from the flight-test results is slightly nonlinear. At low angles of attack the lift coefficients and slopes agree very well, but at the high angles of attack the slope of the curve obtained from the flight-test results decreases slightly, with the result that at 20° angle of attack the lift coefficient is about 7 percent less than that obtained from the wind-tunnel test results. It is also apparent from figure 6(a) that the minimum drag coefficient obtained from the wind-tunnel test results is about 10 percent greater than that obtained from the flight-test results. At the higher lift coefficients the difference in drag decreased until at about the maximum test lift coefficient, the drag coefficients are about the same.

Generally, the agreement between the data from flight and from the wind-tunnel tests was considered good, especially in view of the following differences in test conditions:

a. The dynamic pressures in the wind tunnel were from 4 to 16 psf higher than those at which the vehicle was flown, for particular trimmed lift coefficients. With the previously noted variation of the pitching-moment coefficient with dynamic pressure for $q < 28$ psf and the inaccuracy of measurement of the pitching-moment coefficient, the difference in dynamic pressure could be expected to adversely affect the agreement between flight and wind-tunnel results, particularly for lift coefficients above 0.3.

b. The elevon linkage was flexible during the flight tests allowing the elevon to deflect under aerodynamic loading. But during the wind-tunnel tests this was prevented by positioning the elevon with locking pins directly at the surface. The resulting differences in elevon angle at a given angle of attack and forward speed could adversely affect the comparison of flight and wind-tunnel data.

c. As previously mentioned, the presence of the wind-tunnel model-support struts could affect the wind-tunnel test results. This of course could also adversely affect the agreement between the flight and wind-tunnel test results.

The difference in drag coefficient due to the possible presence of greater turbulence in the wind tunnel than in flight was discounted. An estimate of the difference in drag that could result from the vehicle experiencing completely laminar and completely turbulent flow indicated that the maximum drag difference could be only about 5 percent. Since even under ideal conditions the vehicle could never experience completely laminar flow in flight, the drag difference is believed to be much less.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., Dec. 22, 1965

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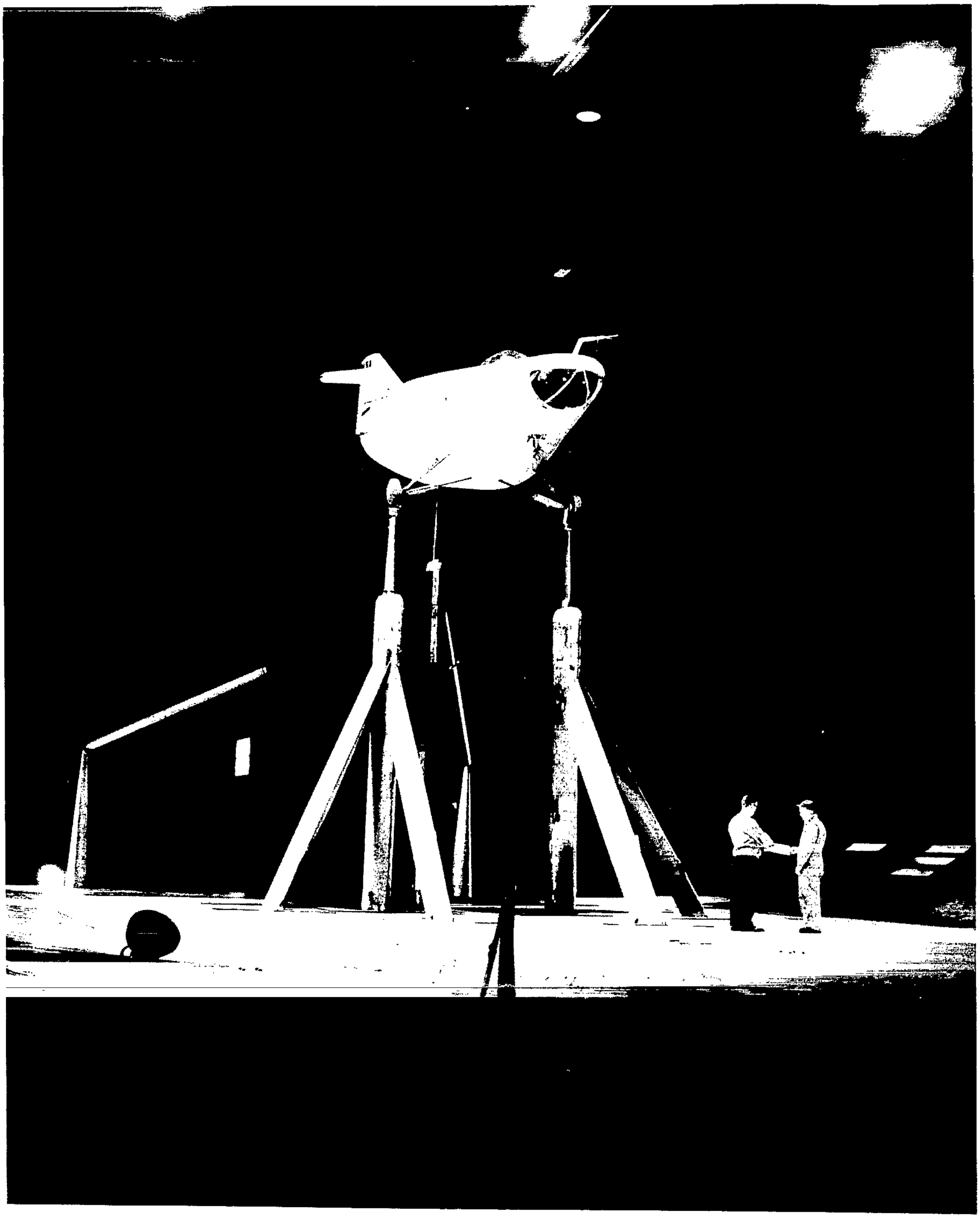
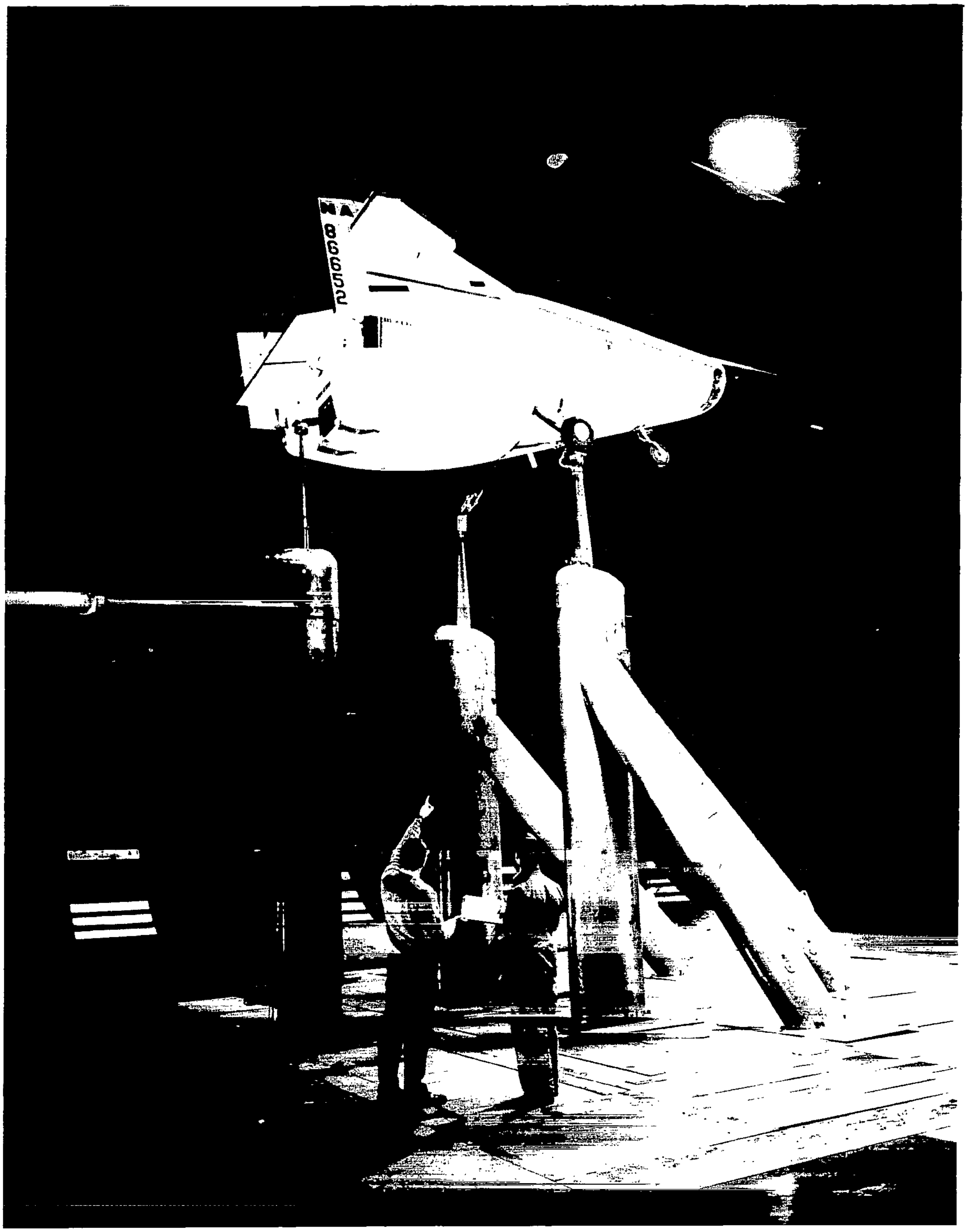


(a) 3/4 front view. A-33718

Figure 1.- M2-F1 lifting body flight vehicle mounted in the Ames 40- by 80-Foot Wind Tunnel.



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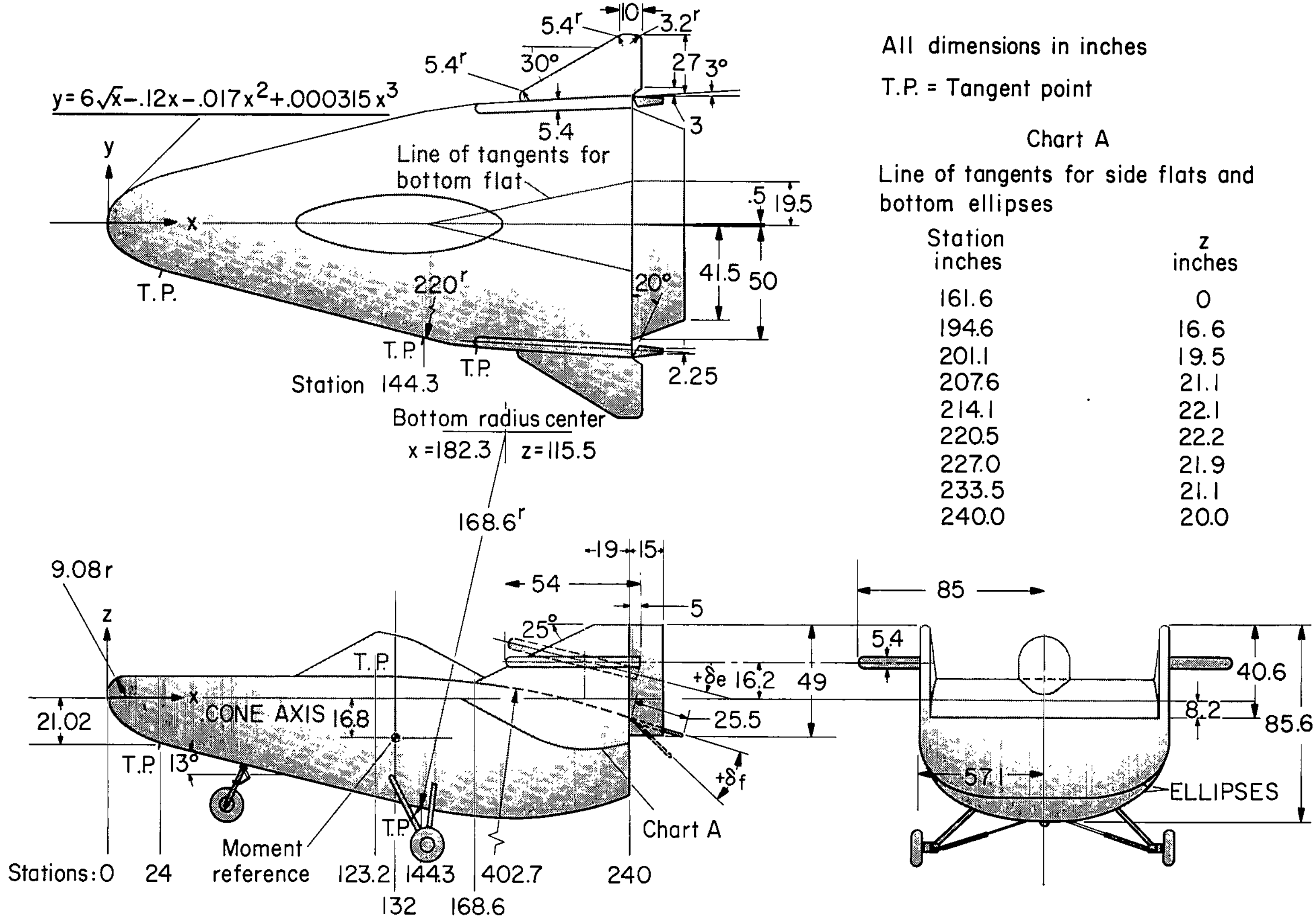
(b) 3/4 rear view.

Figure 1.- Concluded.




All dimensions in inches

T.P. = Tangent point

Chart A

Line of tangents for side flats and bottom ellipses

| Station inches | z inches |
|---|---|
| 161.6 | 0 |
| 194.6 | 16.6 |
| 201.1 | 19.5 |
| 207.6 | 21.1 |
| 214.1 | 22.1 |
| 220.5 | 22.2 |
| 227.0 | 21.9 |
| 233.5 | 21.1 |
| 240.0 | 20.0 |

Figure 2.- Basic model dimensions.

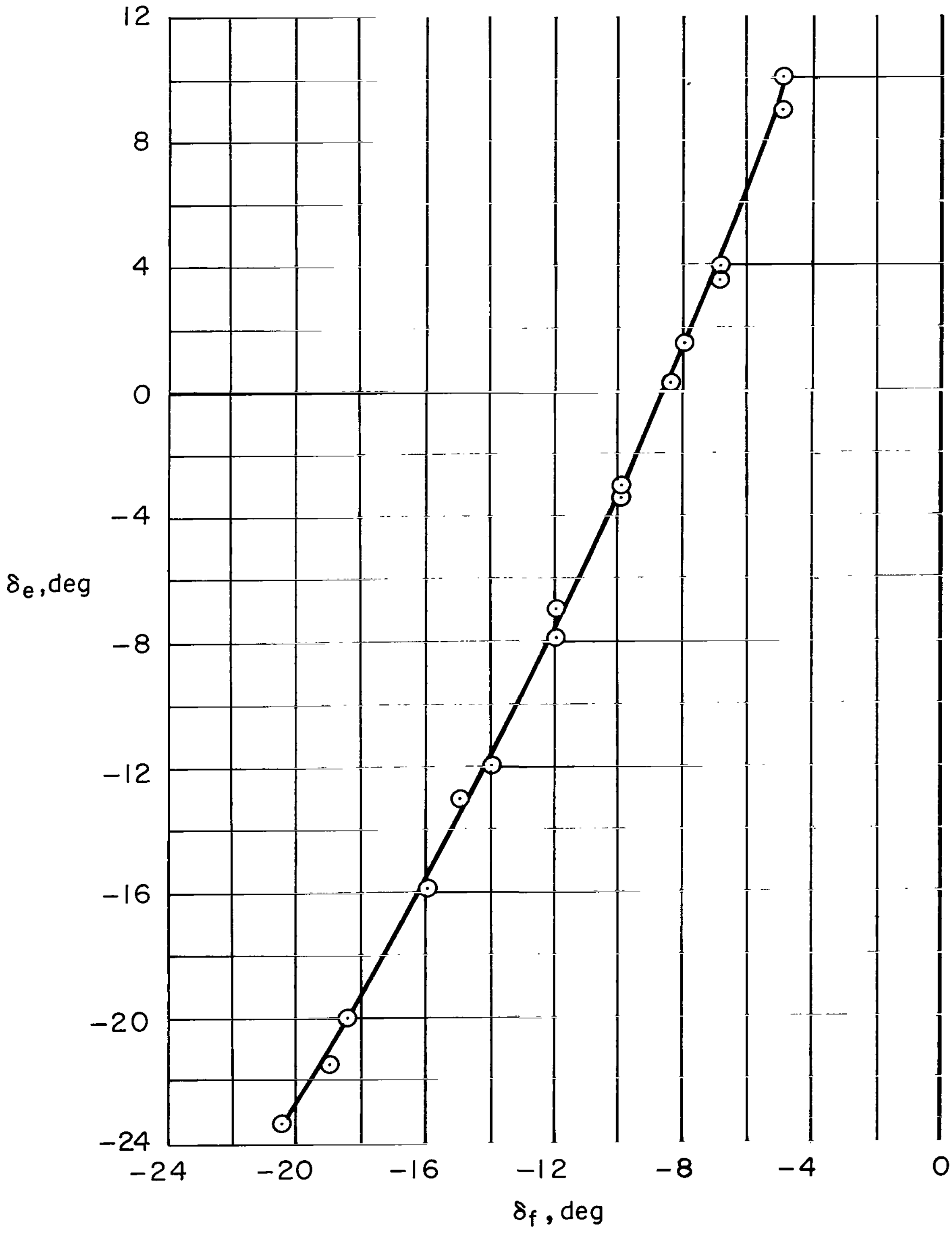



Figure 3.- Elevon position as a function of flap setting.

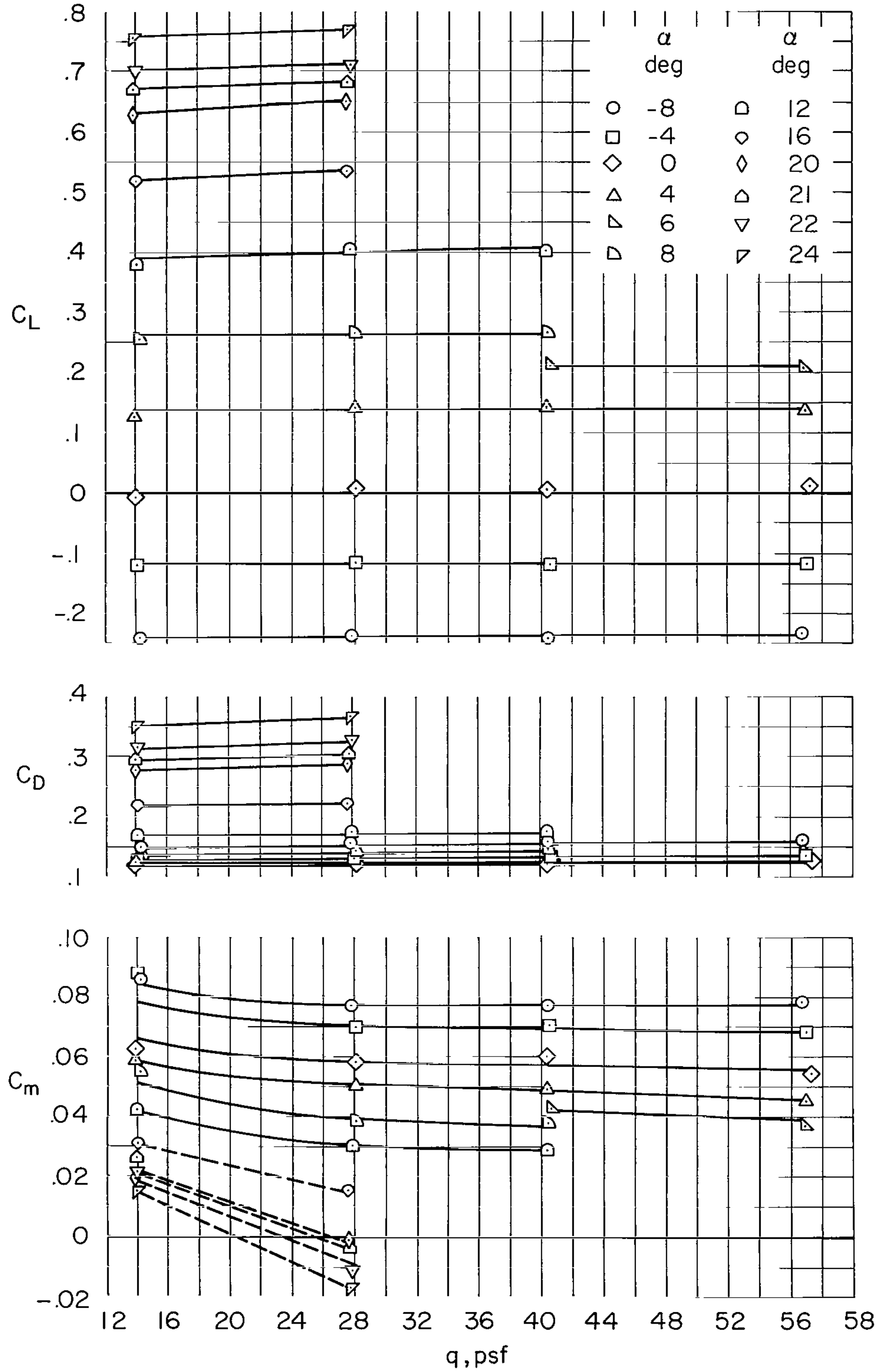



Figure 4.- Effect of dynamic pressure on aerodynamic characteristics; $\delta_f = -18.4^\circ$

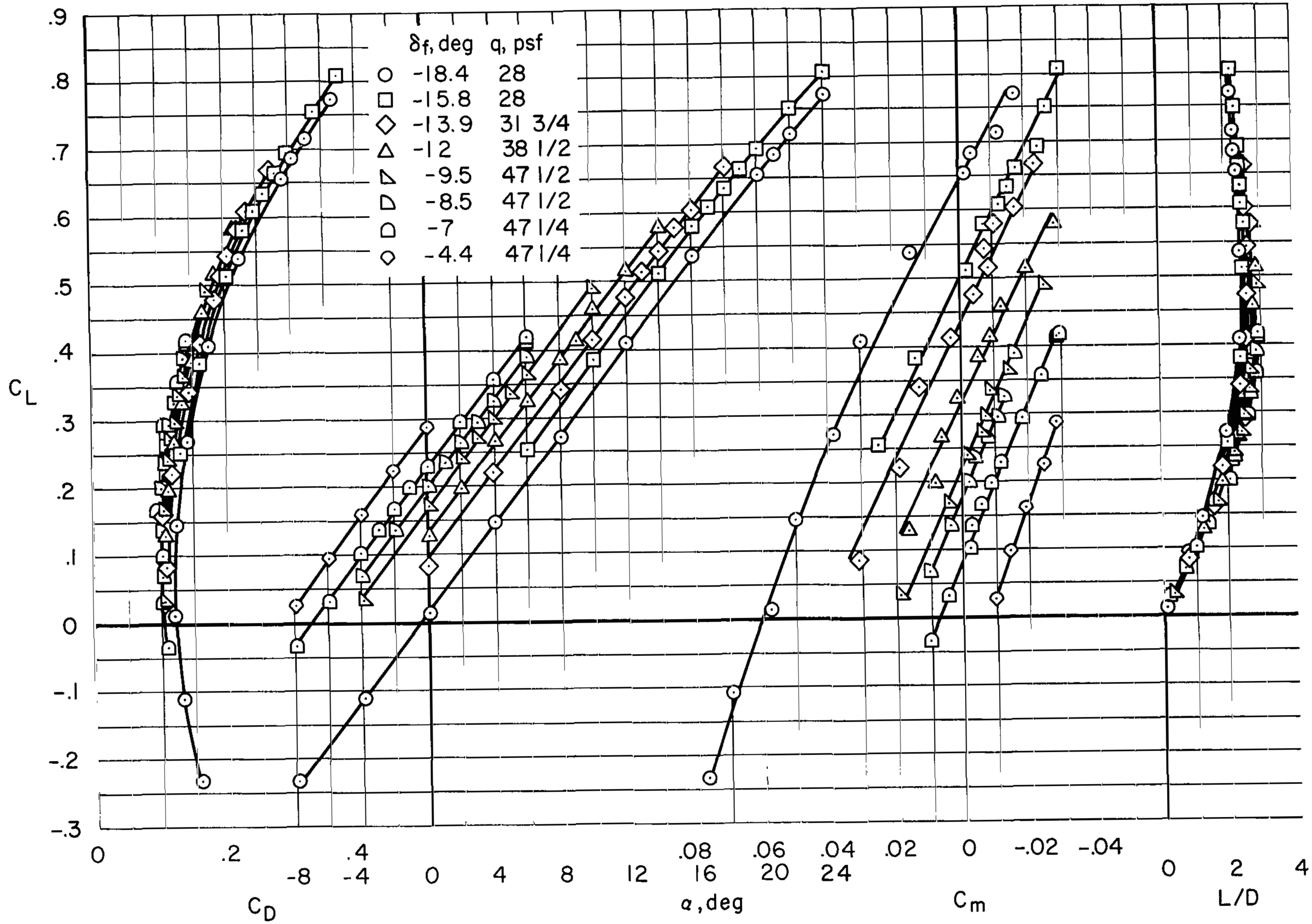
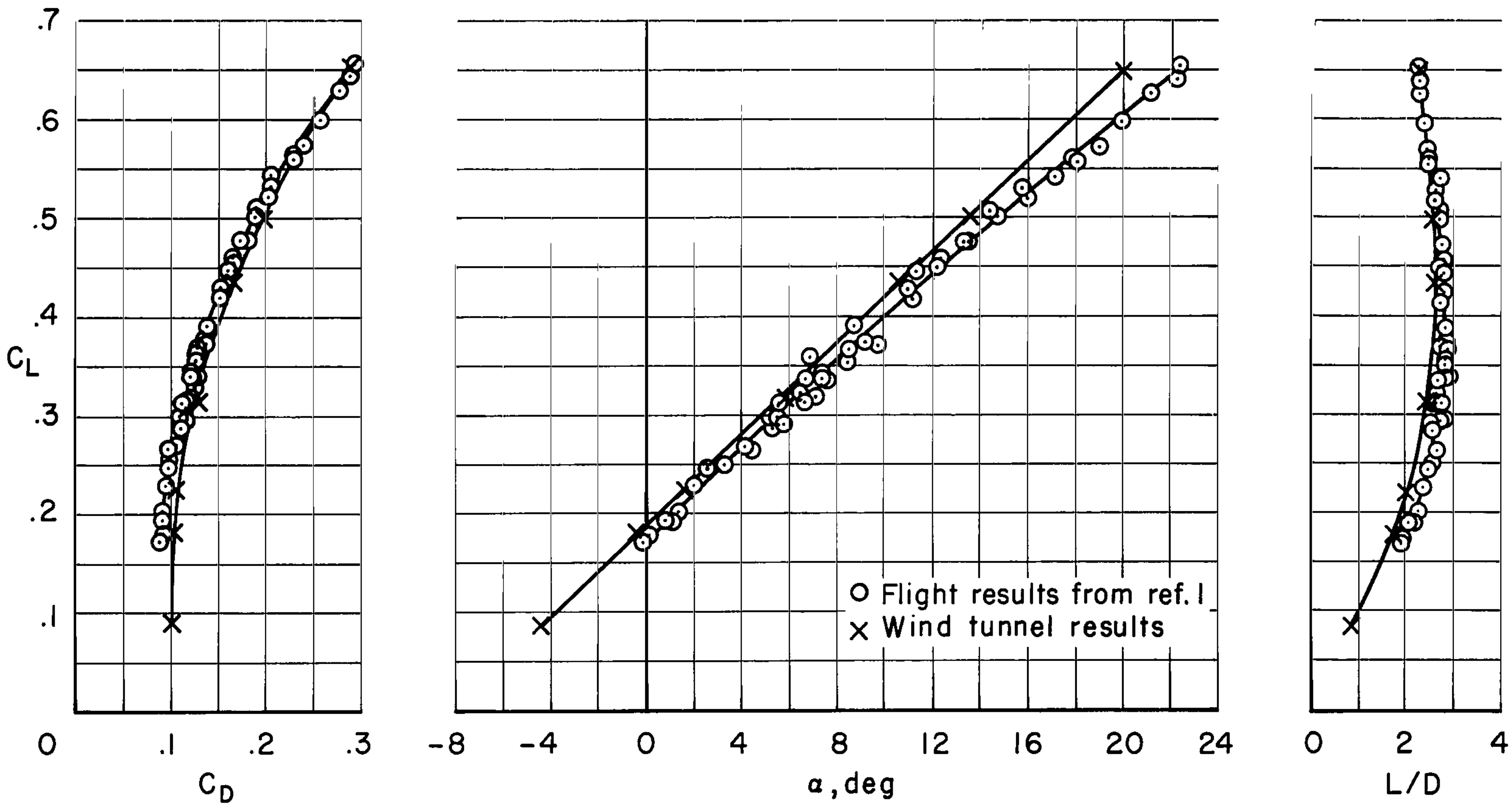
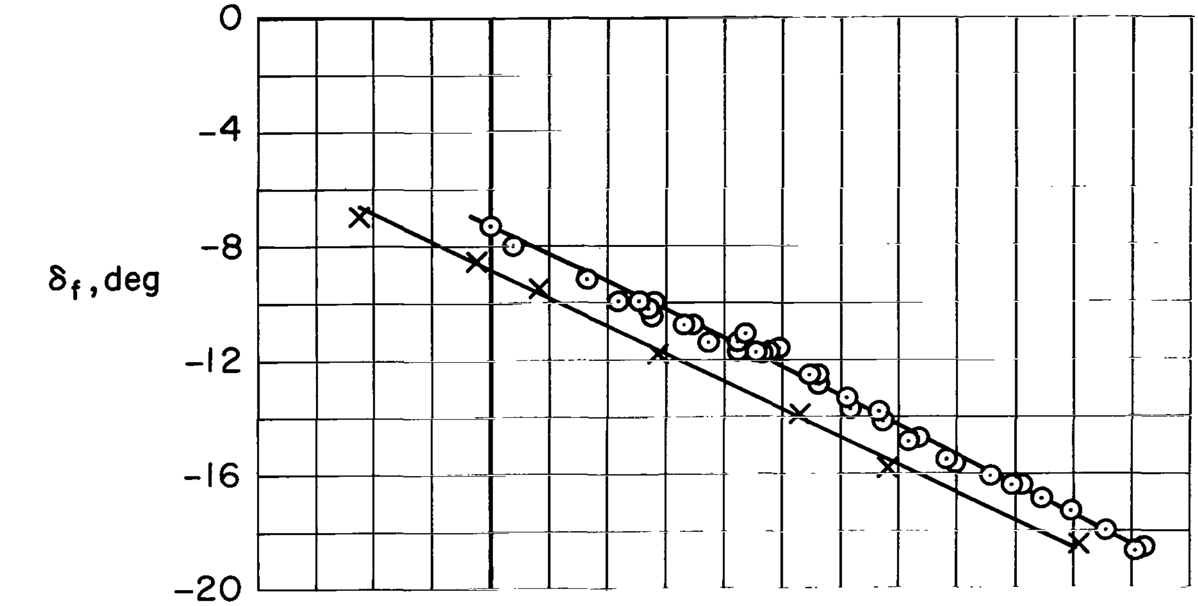



Figure 5.- Aerodynamic characteristics for several flap settings.

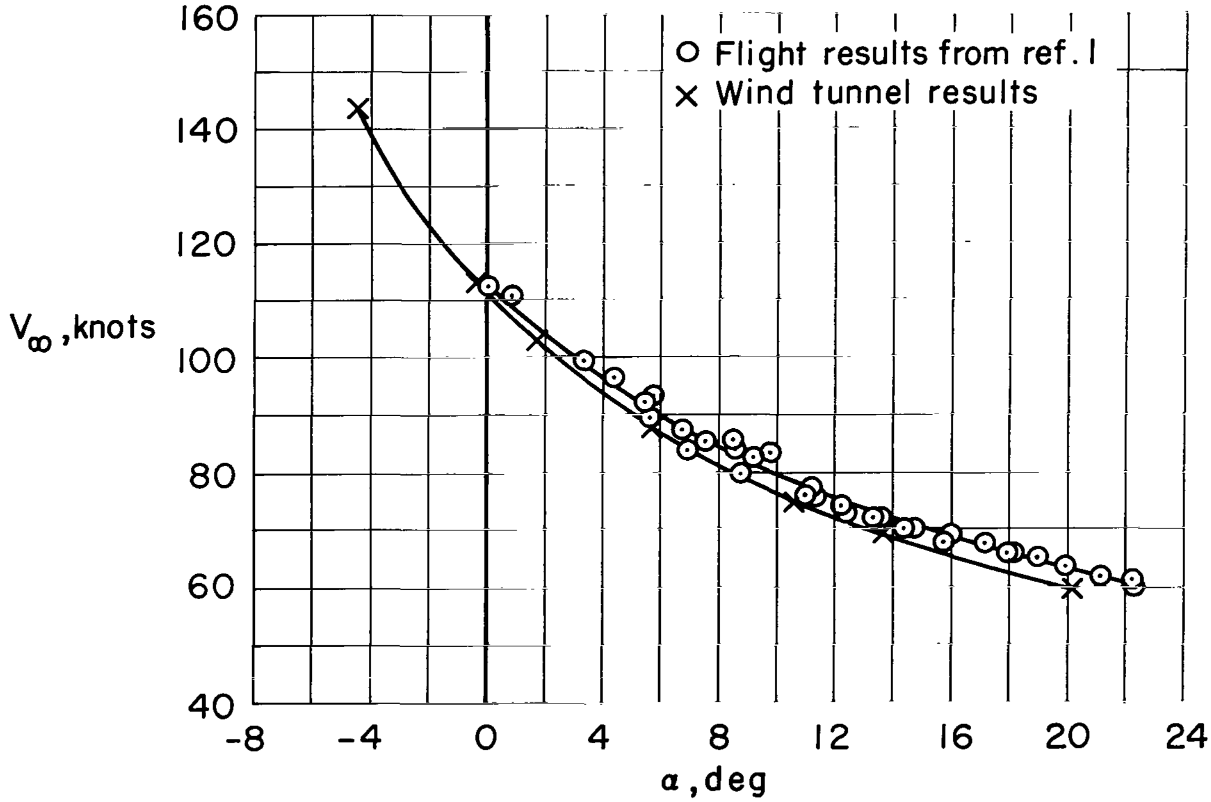



(a) Basic aerodynamic characteristics.

Figure 6.- Comparison of trimmed wind-tunnel results ($C_m$ = 0) with flight results.




(b) Control position required.




(c) Forward velocity for a vehicle weight of 1250 lb.

Figure 6.- Concluded.



NASA-Langley, 1966 A-2120