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AERODYNAMIC CHARACTERISTICS OF A MODIFIED CONE—CONICAL-FRUSTUM ENTRY CONFIGURATION AT MACH 6.0

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SUMMARY

An investigation of the internal arrangement and the stability and control of a modified cone—conical-frustum entry vehicle has been conducted. The internal arrangement was made to house eight men in orbit for 24 hours and included a propulsive lift system for hover and landing. The experimental tests were conducted at Mach 6.0 and a Reynolds number based on model length of 6.3×10^6. Trailing-edge flaps symmetrically arranged were used to trim the vehicle. The results show that the configuration is stable about all axes and can be trimmed about a center of gravity at 60 percent of the length with a maximum lift-drag ratio of 1.57 and a static margin of 3.5 percent. Calculations made by using a basic Newtonian computer program predicted the forces very well but overestimated the moments.

INTRODUCTION

Some manned lifting-entry-vehicle concepts are designed to fly the complete trajectory to a conventional horizontal landing. In such designs, either the low-speed or the high-speed aerodynamic characteristics are usually compromised, because the aerodynamic design requirements in the low-speed and high-speed ranges are in conflict. To avoid such compromises, Love (ref. 1) suggested that more attention be devoted to lifting-vehicle concepts in which the entry flight mode and the landing mode were decoupled. That is, the vehicle would be designed for the hypersonic-supersonic portion of the trajectory, and the landing would be accomplished by an auxiliary system such as a limp paraglider, a stowed rotor, or a propulsive lift system. Love also points out that other possible advantages of decoupling, especially with propulsive lift, are brief hover time for landing-site selection or close-in decision reversals, suitability for emergency landing at unprepared sites, near-zero landing velocities (vertical and horizontal), and no major night landing problems.

As a preliminary step in evaluating the feasibility of using propulsive lift in the decoupled concept, realistic packaging requirements for manned orbital flight including a propulsive lift system have been investigated for several configurations. In addition, hypersonic wind-tunnel studies are being conducted to trim and stabilize these configurations for the center-of-gravity locations found in the packaging studies. This report presents the aerodynamic data for an early design concept with lift fans. The vehicle can be compactly packaged to provide for an eight-man crew in orbit for 24 hours. The data were obtained in the Langley 20-inch Mach 6 tunnel at a Reynolds number 6.3×10^6 (based on model length).

SYMBOLS

The longitudinal data are referenced to the stability-axis system and the lateral and directional data to the body-axis system. The moment coefficients were taken about the longitudinal center of gravity (60 percent l) along the center line determined in the preliminary packaging studies.

b	span, cm
C_D	drag coefficient, $\frac{\text{Drag}}{qS}$
C_L	lift coefficient, $\frac{\text{Lift}}{qS}$
C_l	rolling-moment coefficient, $\frac{\text{Rolling moment}}{qbS}$
C_{l_β}	effective dihedral parameter, negative for positive dihedral effect, $\frac{\Delta C_l}{\Delta\beta}$
C_m	pitching-moment coefficient about center of gravity, $\frac{\text{Pitching moment}}{qSl}$
C_{m_α}	longitudinal-stability parameter, negative for longitudinal stability, $\frac{dC_m}{d\alpha}$
C_N	normal-force coefficient, $\frac{\text{Normal force}}{qS}$
$C_{m_{C_{N,\text{trim}}}}$	static margin, $\left(\frac{dC_m}{dC_N}\right)_{\alpha,\text{trim}}$
C_n	yawing-moment coefficient, $\frac{\text{Yawing moment}}{qSb}$
C_{n_β}	directional-stability parameter, positive for directional stability, $\frac{\Delta C_n}{\Delta\beta}$
C_Y	side-force coefficient, $\frac{\text{Side force}}{qS}$

C_{Y_β}	rate of change of side-force coefficient with sideslip angle, $\frac{\Delta C_Y}{\Delta\beta}$
d	maximum diameter of basic conical afterbody (fig. 1)
L/D	lift-drag ratio
l	model length, cm
q	dynamic pressure, newtons/meter^2
S	model base area, meters^2
x_{cg}	location of center of gravity from nose
z_{cg}	vertical distance of center of gravity from center line, positive downward
α	angle of attack, deg
β	angle of sideslip, deg
δ	flap deflection angle measured from plane of vehicle surface (sign opposite to that of moment produced), deg

Subscripts:

1,2	lower flaps	shown in figure 1; subscripts omitted for controls at 0°
3,4	upper flaps	

CONFIGURATION CONCEPT

The configuration presented in figure 1 is representative of a possible entry vehicle in the class providing L/D of 1.5. This design evolved from a basic body of revolution (15° conical forebody and 11.3° conical afterbody) during a packaging study (unpublished) of an arrangement with provision for eight crewmen in orbit for 24 hours (fig. 2). The lift fans were selected as the propulsive lift system because at the time of the packaging studies, hover-time requirements were thought to be on the order of 10 minutes; and for hover times beyond about 8 minutes, the low fuel consumption of these lift fans gives them a total fuel and system weight advantage over turbojets and turbofans. More recent information has indicated that hover-time requirements are on the order of only 2 minutes or less. The lift fans were placed in the base, and the tail-sitter entry mode was selected because of system space requirements and the fan deployment advantages. Accommodation of the four lift fans in the base of the model required that the gas generators be placed exterior to the basic configuration. The half-cone fairing forward of the gas generator and the tangential fairing between the basic model and the gas generator housing were added to make the configuration more streamlined.

The mission operation could be as follows: The configuration would be boosted into orbit; upon completion of the orbital phase and deorbit the vehicle would descend by using reaction controls and aerodynamic controls, when they become effective, through the hypersonic and high supersonic speed phases. When low supersonic speeds were achieved, drogue parachutes would be deployed to slow and stabilize the vehicle through the transonic and subsonic speed ranges until the supporting main parachutes were deployed. After deployment of the main parachute, the vehicle would assume a tail-sitter attitude, and the pilot would rotate to a vertical position. The inlets to the gas generators would be opened, and the engine would be started at about 3 kilometers. After engine checkout, engine thrust would be increased until hover was achieved; then, transition from support by parachute to support by the deployed lift fan would be made, and the vehicle would be maneuvered to a vertical landing on the base struts.

APPARATUS AND METHODS

Wind Tunnel and Tests

The tests were conducted in the Langley 20-inch Mach 6 tunnel. This tunnel, which is described in detail in reference 2, is a blowdown tunnel exhausting to the atmosphere. For these tests the stagnation pressure was 21 atmospheres and the stagnation temperature 477° K. These conditions give a Reynolds number (based on model length) of 6.3×10^6. Test angles of attack were from -3° to 12° and sideslip angles were 0° and -5°.

Methods

A water-cooled six-component strain-gage balance was used to measure the forces and moments. The model support system traverses in the vertical plane and an optical system was used to set the model angle of attack. A combination lens and right-angle prism with a focal length of 1.52 meters was imbedded in the model surface. The light from a point source was reflected from the prism onto a screen and the location of the reflected light was calibrated against angle of attack. Model base pressures were measured above and below the sting and the average of these values was used to adjust the axial-force coefficient to the condition for free-stream static pressure on the base. Mach number was measured for each test point with a total-pressure probe. Lateral and directional stability derivatives were calculated by assuming a linear variation of sideslip angle between 0^{o} and -5^{o}.

Accuracy

On the basis of balance calibrations, readout accuracy, and dynamic pressure accuracy, the measured quantities are estimated to be accurate within the following limits:

C_D	±0.0017
C_L	±0.0062
C_m	±0.0008
L/D	±0.0258
C_{l_β}	±0.0002
C_{n_β}	±0.0002
C_{Y_β}	±0.0018
α, deg	±0.1
β, deg	±0.1
δ, deg	±0.05
Mach number	±0.02

RESULTS AND DISCUSSION

Longitudinal Data

Figure 3(a) presents the longitudinal aerodynamic characteristics of the configuration with and without trailing-edge flaps. The data of the basic cone—conical-frustum (model 1 of ref. 3) are also included for comparison. As expected, the higher aspect ratio of the present configuration resulted in larger C_L, C_D, and L/D. (Compare flagged circle with filled circle.) The opposite is true for the longitudinal stability parameter $-C_{m_\alpha}$. Both configurations are stable about the realistic center-of-gravity location of 60 percent l; however, the basic configuration has the higher value of $-C_{m_\alpha}$.

Figure 3(b) compares the calculated values of the longitudinal data with the measured values. For the basic body the Newtonian computer program (ref. 4) was used for the calculations with the following innovations: (1) the Newtonian pressure coefficient was replaced by the tangent-cone value on each windward surface element and (2) the zero pressure coefficient was replaced by the Prandtl-Meyer expansion value on each surface element in the shadowed region. For the controls the tangent-cone theory was used to determine the flow conditions immediately ahead of the control, and oblique shock theory was used to determine the pressures on the controls. The calculated values of C_L and C_D were found to agree very well with the measured values; however, the calculated and measured values of C_m were not in very good agreement.

The configuration is symmetrical about the pitch axis and therefore trims at $\alpha = 0^o$. The simple flaps were designed to trim the present configuration at angles of attack up to $(L/D)_{max}$. Figure 3 shows that this trim capability was provided and that the control increased the stability. The arrangement of the controls was selected to allow for their possible use about other axes as well as the pitch axis. However, if roll control was desired, the hinge line of the controls should be skewed so that the plane of the resultant force of each control passes through the vehicle center of gravity to avoid roll-yaw cross coupling.

A summary of the longitudinal trim characteristics is presented in figure 4 along with the maximum L/D data for the basic cone—conical-frustum model from reference 3. The maximum trimmed L/D is 1.57 which is about 10 percent higher than that of the basic configuration. The static margin at $(L/D)_{max}$ is 3.5 percent – approximately double that of the basic configuration. If the center of gravity were moved rearward to 61 percent l, a flap deflection of -10^o will provide trim at $(L/D)_{max} = 1.63$ with a static margin of 1.9 percent. This $(L/D)_{max}$ is 14 percent higher than that of the basic configuration. As noted previously, the center of gravity was assumed to be on the center line of the body; however, with vertical center-of-gravity offset, tradeoffs of trimmed aerodynamic parameters with flap deflections and center-of-gravity location are possible. Figure 5 shows the effect of the vertical location of the center of gravity on the trimmed longitudinal aerodynamic characteristics for a longitudinal center-of-gravity location at 60 percent l. The maximum L/D (1.63) and highest trimmed C_L (0.475) are obtained with δ_3 and $\delta_4 = -10^o$ and $z_{cg}/l = 0.04$. For a uniform wall structure, the maximum lower limit of z_{cg}/l would be approximately 0.026; however, with structural asymmetry between the windward and leeward surfaces commensurate with the asymmetric aerodynamic heating, the center of gravity can be moved to $z_{cg}/l = 0.04$. As noted earlier, the maximum L/D can be obtained with a rearward shift of the center of gravity; however, some downward shift of the center-of-gravity location may be desirable because of the accompanying increase of static margin. If so, the condition of $(L/D)_{max}$ and $C_{L,max}$ could be obtained with a combination of downward and rearward shift of the center of gravity. Since the predicted values of the pitching moment miss the trim angle of attack by 2^o to 3^o (fig. 3(b)), the predicted trim values of the aerodynamic characteristics were not plotted.

Lateral and Directional Data

The configuration without controls is directionally stable $\left(C_{n_\beta}\ \text{positive}\right)$ and has positive dihedral effect $\left(C_{l_\beta}\ \text{negative}\right)$ at all positive angles of attack (fig. 6(a)). The deflected controls significantly increase the directional stability. The dihedral effect is affected only slightly by the control deflection. Figure 6(b) shows that the C_{Y_β} and C_{l_β} of the basic body are well predicted by the computer program, but the C_{n_β} is greatly overestimated. This result is consistent with the incorrect prediction of the pitching moment. The effects of the controls on the lateral-directional stability were not calculated.

CONCLUDING REMARKS

The aerodynamic characteristics of a modified cone—conical-frustum entry vehicle with compact packaging, ample space for eight men and their space-environment support equipment, and a propulsive-lift landing system have been determined at Mach 6.0 and a Reynolds number based on model length of 6.3×10^6. The experimental data show that the vehicle equipped with four symmetrically arranged trailing-edge flaps (each 4 percent of the base area) is longitudinally stable and controllable and laterally and directionally stable about the center of gravity established along the center line by the internal-systems arrangement, with center of gravity at 60 percent of the length. Trimmed maximum lift-drag ratio for this center of gravity is 1.57 at 10° angle of attack with a static margin of 3.5 percent. A slight downward and rearward shift of the center-of-gravity location will provide trim at a lift-drag ratio of 1.63 with a static margin $\geqq 1.9$ percent. Theoretical calculations made by using a basic Newtonian computer program predicted the forces very well but overestimated the moments.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., February 29, 1968,
124-07-02-77-23.

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    Part 2 – Fields of Application. Machine Design, vol. 37, no. 8, Apr. 1, 1965, pp. 94-100.

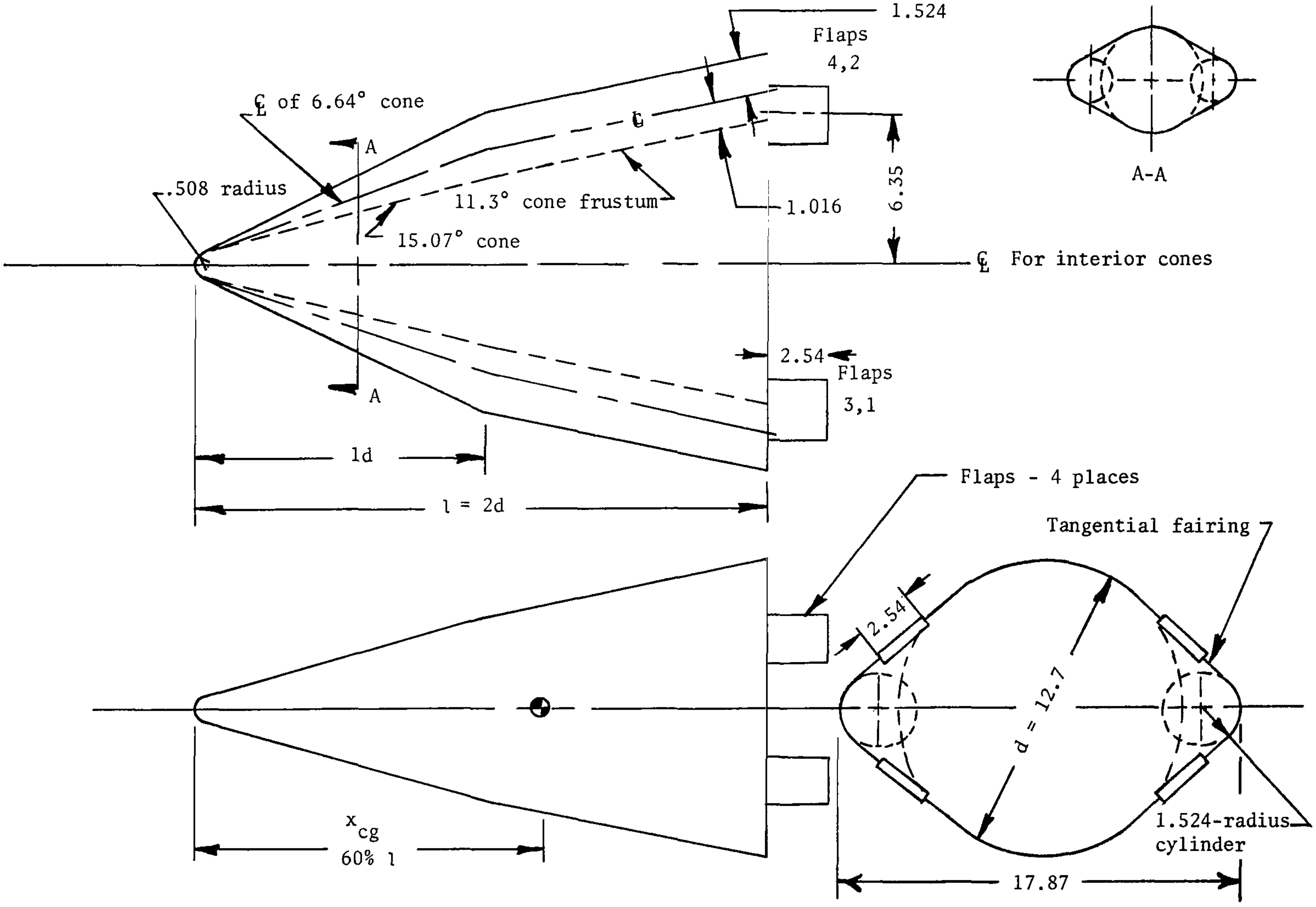


Figure 1.- Model details. (All dimensions in cm.)

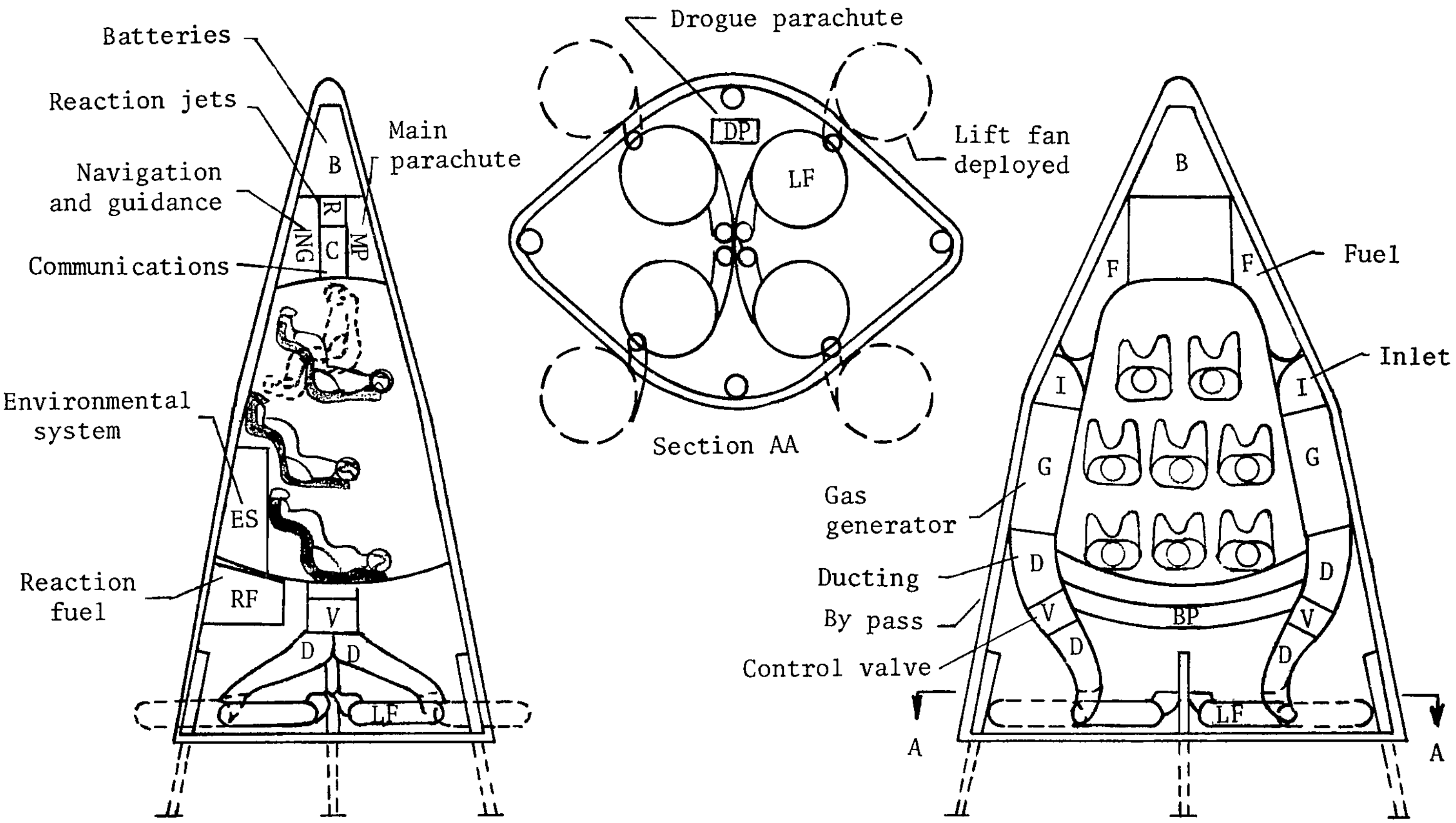
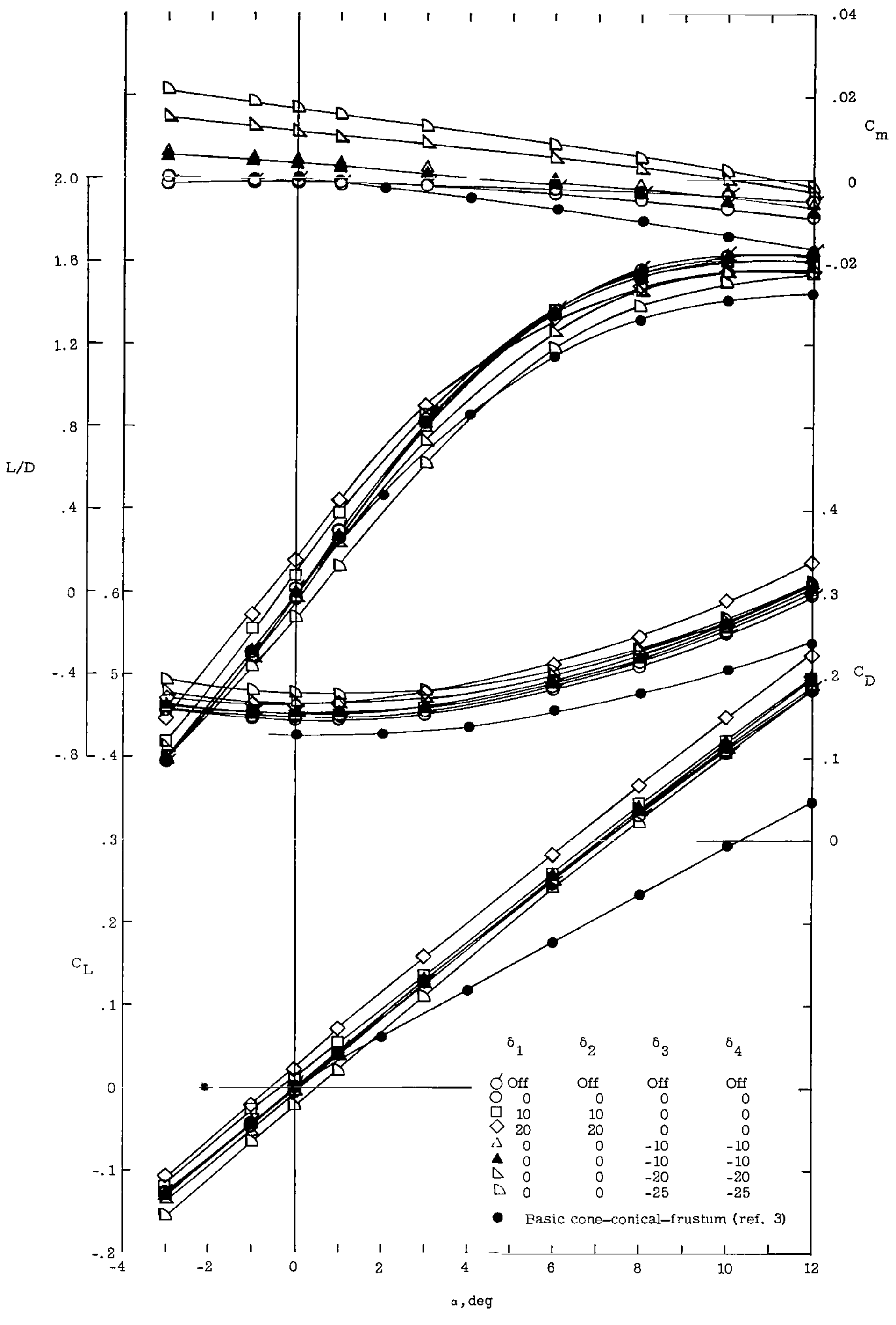
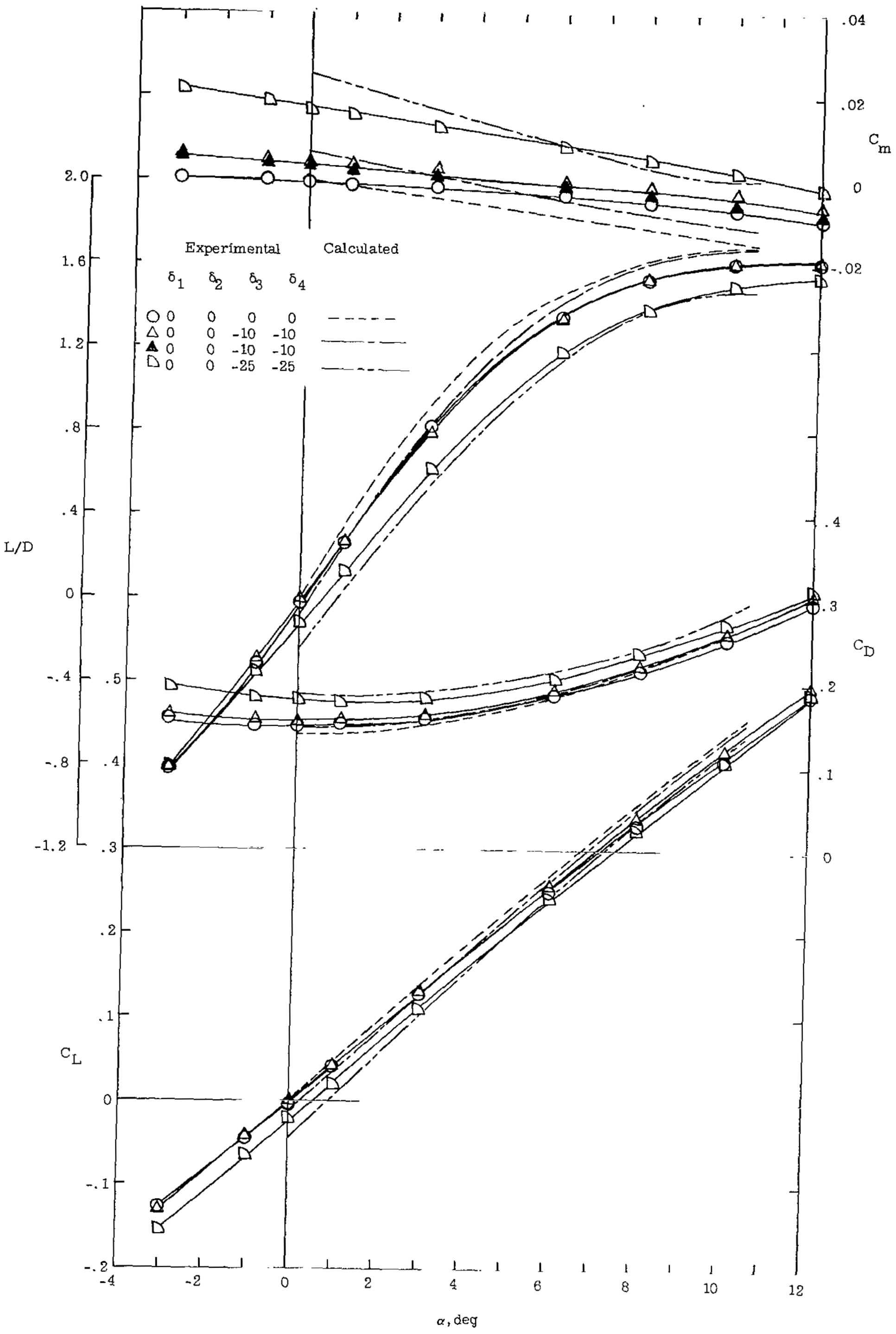


Figure 2.- Equipment arrangement for 8 men in orbit for 24 hours.



(a) Experimental data.

Figure 3.- Longitudinal aerodynamic data, stability axis.



(b) Comparison of experimental and calculated data.

Figure 3.- Concluded.

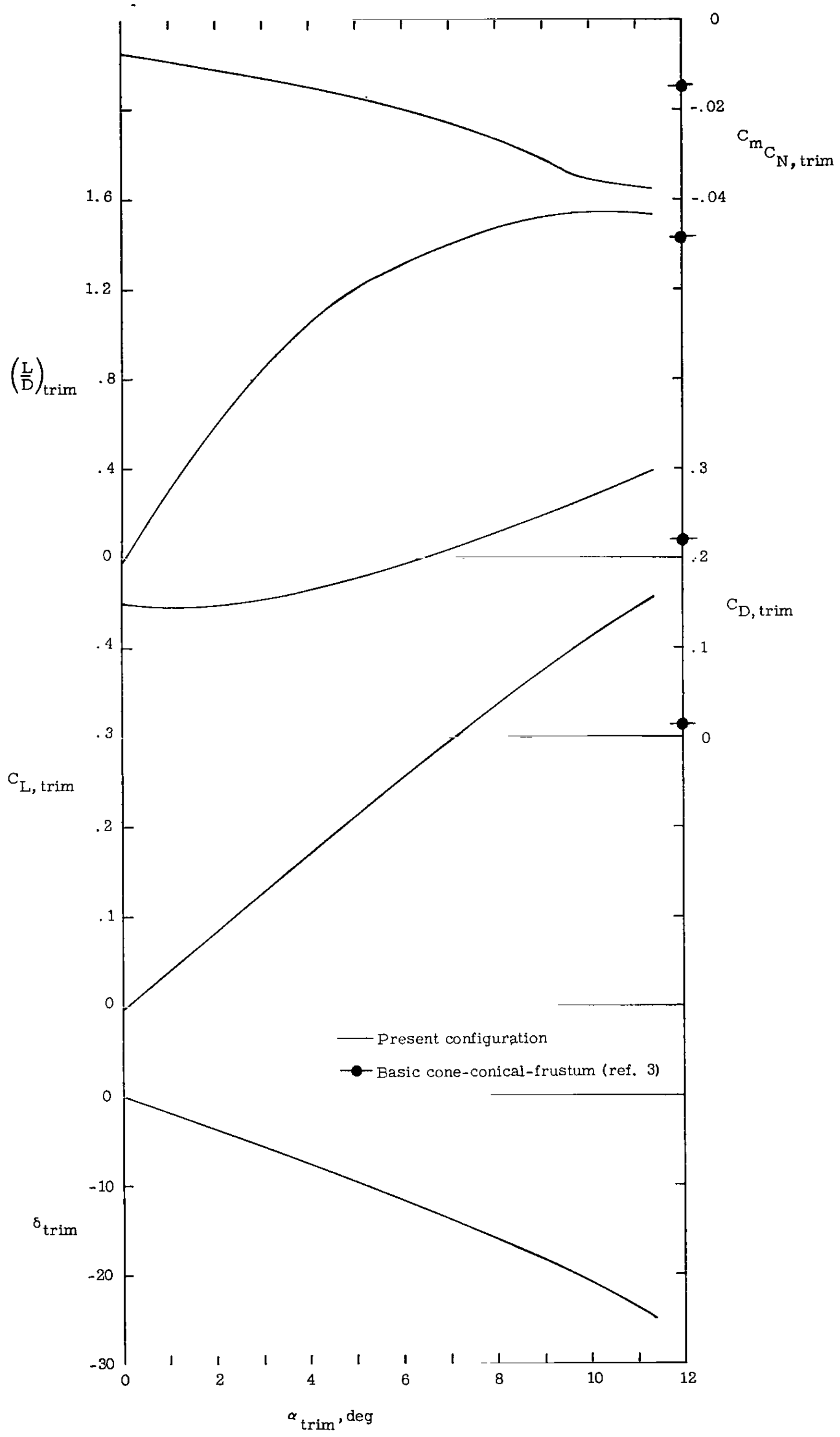


Figure 4.- Trim characteristics. x_{cp} = 60 percent l.

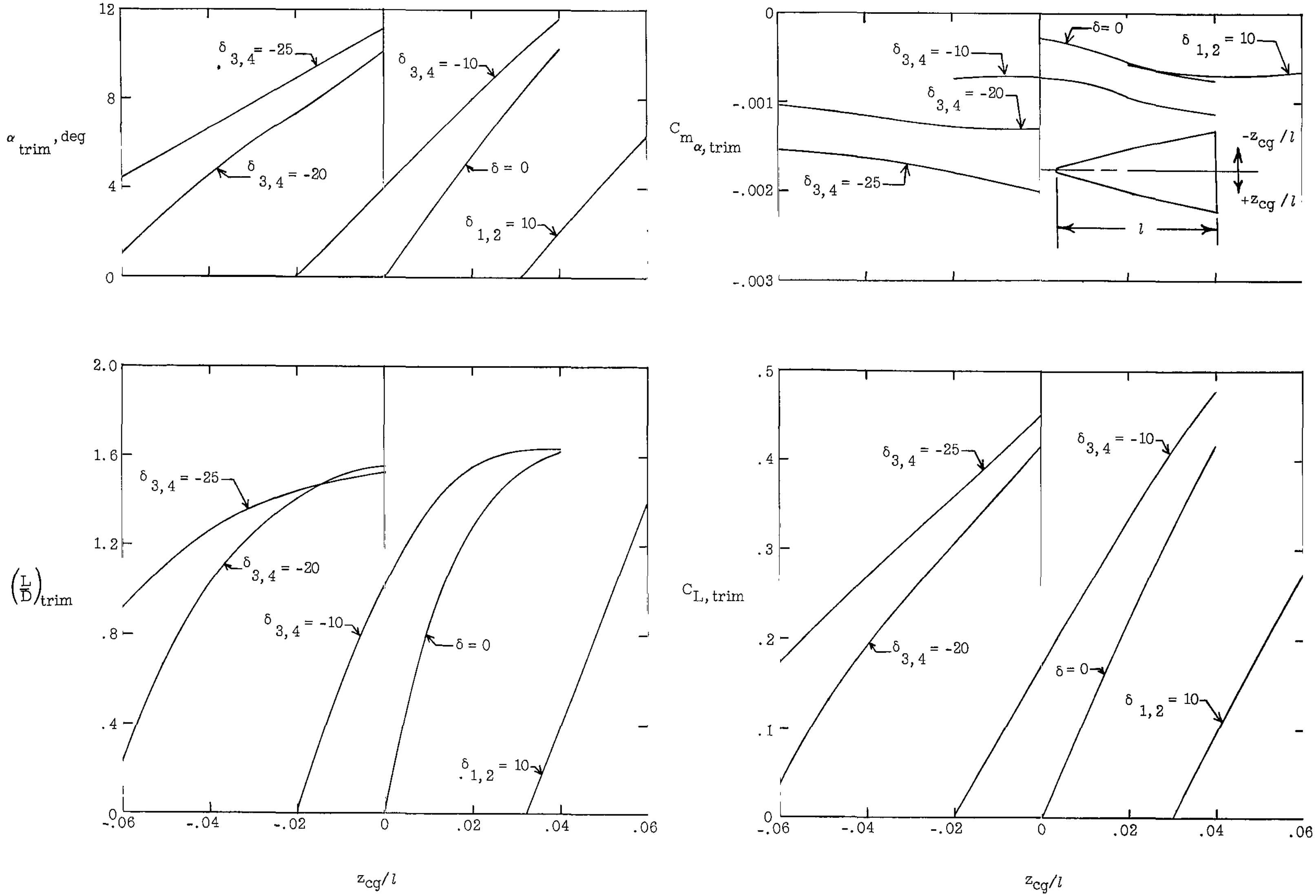
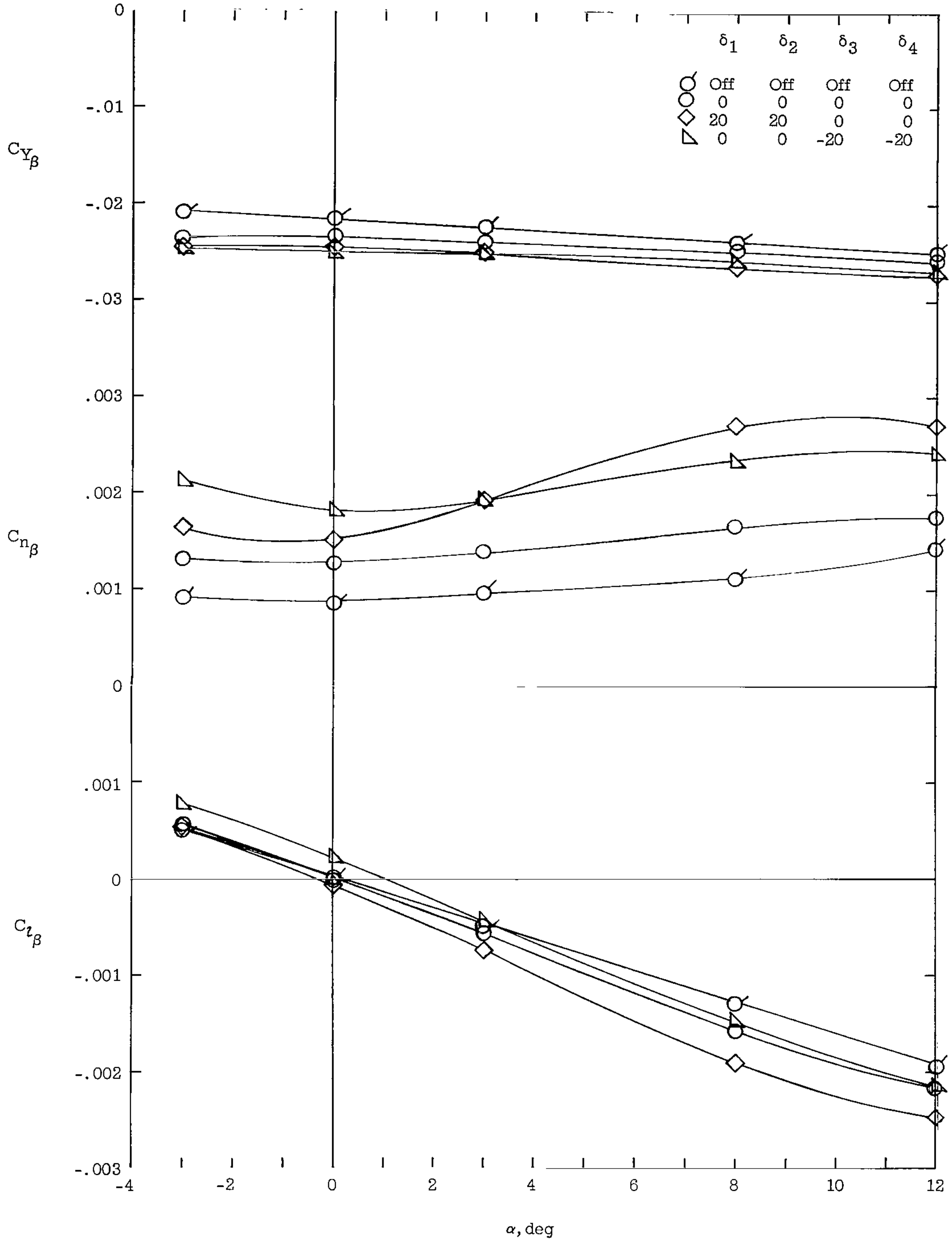
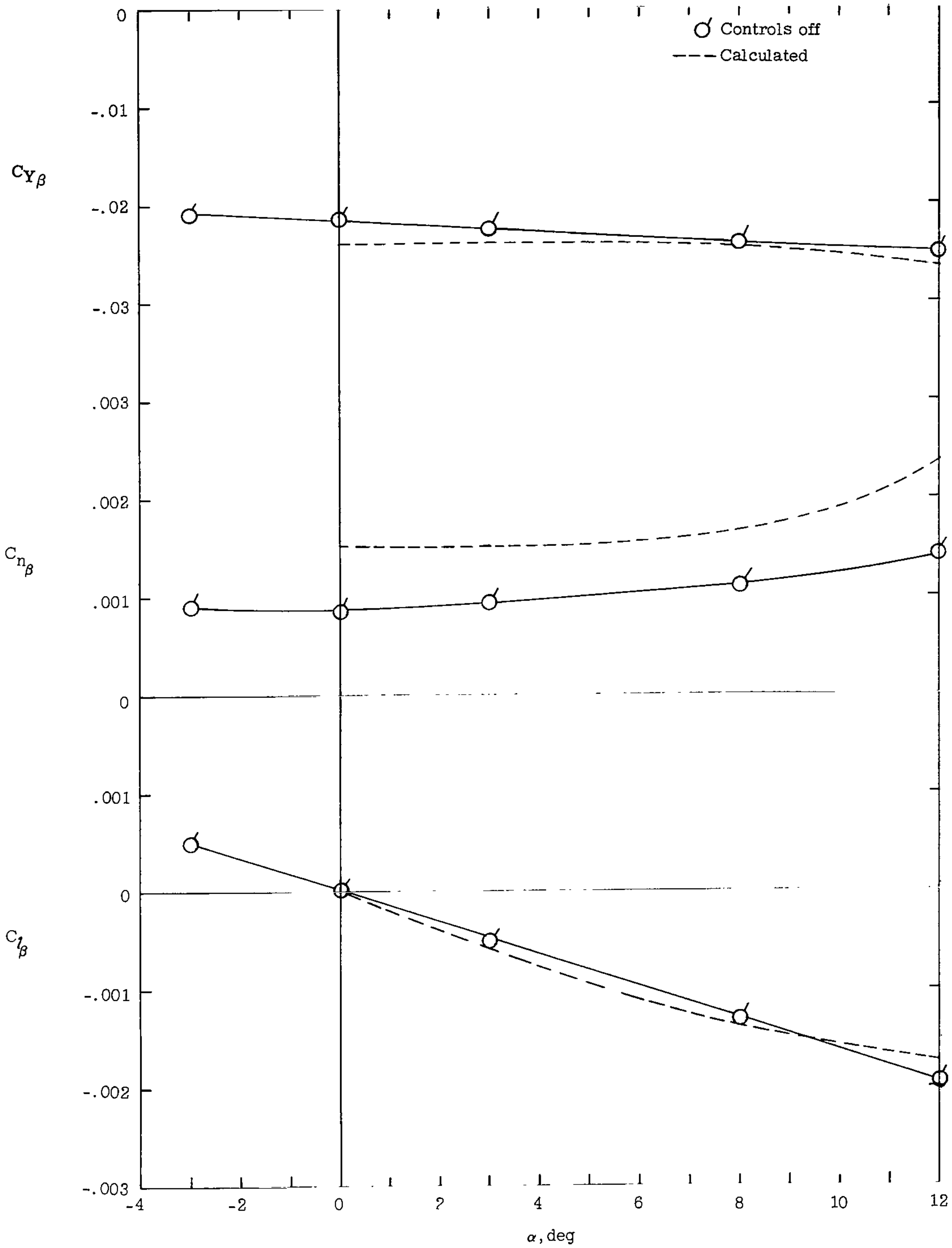


Figure 5.- Effect of vertical location of center of gravity on longitudinal trim characteristics. x_{cg} = 60 percent l.



(a) Experimental data.

Figure 6.- Lateral and directional stability derivatives, body axis.



(b) Comparison of experimental and calculated data.

Figure 6.- Concluded.

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