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SUMMARY OF LONGITUDINAL STABILITY AND CONTROL PARAMETERS AS DETERMINED FROM SPACE SHUTTLE CHALLENGER FLIGHT TEST DATA

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SUMMARY

Estimates of longitudinal stability and control parameters for the space shuttle were determined by applying a maximum likelihood parameter estimation technique to Challenger flight test data. The parameters C_{m_α}, $C_{m_{\delta_e}}$, and C_{Z_α} describe 90 percent of the response to longitudinal inputs during Space Shuttle Challenger flights with $C_{m_{\delta_e}}$ being the dominant parameter. The values of C_{Z_α} were found to be input dependent for these tests. However, when C_{Z_α} was set at preflight predictions, the values determined for $C_{m_{\delta_e}}$ changed less than 10 percent from the values obtained when C_{Z_α} was estimated as well.

The preflight predictions for C_{Z_α} and C_{m_α} are acceptable values, while the values of $C_{m_{\delta_e}}$ should be about 30 percent less negative than the preflight predictions near Mach 1 and 10 percent less negative, otherwise.

INTRODUCTION

The space shuttle vehicle has received one of the most extensive preflight analyses of any aircraft that has ever flown. Thousands of wind-tunnel hours went into its development and refinement. Results from wind-tunnel tests and analytical studies provided a detailed description of the aerodynamic characteristics of the shuttle vehicle over a flight envelope covering a Mach number range from 27 to .5 (reference 1). In an effort to verify the preflight aerodynamics, a flight test program was established. The program was planned as an on-going process based on the analysis of measurement data from each succeeding flight. Since only a limited number of maneuvers could be performed during a given shuttle descent, these were planned to examine different aspects of the shuttle aerodynamics so that as much of the flight envelope as possible could be verified. The difficulty with this plan-of-attack was that the types of maneuvers that could be performed, within the constraints of safety and limitations imposed by the shuttle flight control system, were not ideal maneuvers for identifying the shuttle aerodynamic parameters. However, since these maneuvers represent the only available data, each data set was examined in extreme detail.

This paper will present the results of analyzing the longitudinal maneuvers from five Challenger flights (STS-6, 7, 8, 11, 13). These results will be compared with those of references 2 and 3. The results of the Challenger flights are a significant addition to the shuttle aerodynamic data base and constitute the final phase of efforts to obtain aerodynamic parameters for the shuttle vehicle.

SYMBOLS

a_X, a_Y, a_Z	acceleration measured along X, Y, and Z body axes, respectively, g units
b	wing span, m (ft)
C_m	pitching-moment coefficient, $M_Y/\bar{q}S\bar{c}$
C_X	axial-force coefficient, $F_X/\bar{q}S$
C_Z	normal-force coefficient, $F_Z/\bar{q}S$
$\bar{c}$	wing mean geometric chord, m (ft)
F_X, F_Y, F_Z	force along X, Y, and Z body axes, respectively, N (lb)
M_X, M_Y, M_Z	rolling, pitching, and yawing moments, respectively, N-m (ft-lb)
p, q, r	rate of roll, pitch and yaw, rad/sec or deg/sec
$\bar{q}$	dynamic pressure, N/m^2 ($slug/ft^2$)
S	wing area, m^2 (ft^2)
u, v, w	velocity along X, Y, and Z body axes, respectively, m/sec (ft/sec)
V	airplane total velocity, m/sec (ft/sec)
X, Y, Z	body coordinate axes through airplane center of gravity
α	angle of attack, rad or deg.
α_T	value of angle of attack at start of maneuver, rad or deg
δ_e	elevator deflection, rad or deg.
δ_r	rudder deflection, rad or deg.
δ_{SB}	speedbrake deflection, rad or deg.
θ, ϕ	pitch angle, roll angle, rad or deg.
ρ	air density, kg/m^3 ($slug/ft^3$)

The following derivations are referenced to a body axis system with origin at the aircraft center of gravity:

$$C_{m_q} = \frac{\partial C_m}{\partial \frac{q\bar{c}}{2V}} \qquad C_{m_\alpha} = \frac{\partial C_m}{\partial \alpha} \qquad C_{m_{\delta e}} = \frac{\partial C_m}{\partial \delta_e} \qquad C_{X_\alpha} = \frac{\partial C_x}{\partial \alpha}$$

$$C_{Z_q} = \frac{\partial C_z}{\partial \frac{q\bar{c}}{2V}} \qquad C_{Z_\alpha} = \frac{\partial C_z}{\partial \alpha} \qquad C_{Z_{\delta_e}} = \frac{\partial C_z}{\partial \delta_e}$$

Subscripts:

O coefficient at trimmed conditions

Superscripts:

$(\dot{\cdot})$ time derivative of (.)

Abbreviations:

ACIP	Aerodynamic Coefficient Identification Package
BET	Best Estimated Trajectory
IMU	Inertial Measurement Unit
PTI	Programmed Test Input
RCS	Reaction Control System
RGA, AA	Rate Gyro Assembly, Accelerometer Assembly
STS	Space Transportation System

TEST VEHICLE

The orbiter configuration is shown in figure 1, and key physical characteristics are given in Table I. The thick, double delta wing is configured with fullspan elevons, comprising two panels per side. Each elevon panel is independently actuated. All four panels are deflected symmetrically as an elevator (δ_e) for pitch control and left and right elevons are deflected differentially as an aileron (δ_α) for roll control (figure 2). The body flap is used as the primary longitudinal trim device. The elevons are programmed as a function of Mach number to follow a set schedule with the body flap deflection to provide a desired aileron effectiveness.

The vertical tail consists of the fin and split rudder. The rudder panels are deflected together for yaw control and are separated symmetrically to act as a speedbrake (δ_{SB}) to provide subsonic energy modulation (figure 2). The speedbrake opens fully (87.2 degrees) just below Mach 10 and then follows a predetermined schedule until Mach 0.9 is reached. The rudder is not activated until Mach 3.5.

Stability augmentation is provided by the aft Reaction Control System (RCS) jets and aerodynamic control surfaces, with the forward jets reserved for on-orbit attitude control and for aborts. The aft yaw jets are active until Mach 1 and the pitch and roll jets are terminated at dynamic pressures of 20 and 10 psf, respectively. Additional details on the shuttle vehicle and its systems are given in reference 1.

MANEUVERS

During the first five Challenger flights (STS-6, 7, 8, 11, and 13), specially designed maneuvers were performed to obtain data for use in the parameter extraction programs. These maneuvers were performed to obtain data at specific points during the descent trajectory. The test points were chosen so that aerodynamic parameters could be determined along the descent trajectory to verify the aerodynamic model obtained from the wind tunnel tests. This verification procedure will add confidence to the assumed aerodynamics of the shuttle where there is agreement and will point to areas of potential inaccuracy where there is no agreement.

The excitation inputs performed during the flight tests were developed using a shuttle simulation to generate responses for various inputs and then extracting parameters from these responses. The control inputs that gave the best definition of the parameters of interest were used for the flight tests. These inputs were programmed as a function of Mach number and implemented through the automatic control system. In this paper, two elevon input forms were used to excite the vehicle (figure 3). Input form 1 resulted from a pulse programmed input and input form 2 resulted from a doublet programmed input.

In spite of the care taken to design effective inputs, since the automatic control system was active as soon as the vehicle responded to the input, the resulting responses were reduced in magnitude and the input form was altered to suppress the response. This led to identifiability problems and correlation of parameters during the extraction process. Additional details on the maneuver design are given in reference 4.

INSTRUMENTATION AND DATA PROCESSING

As a development vehicle, the shuttle is fully instrumented and has a number of redundant systems for measuring various vehicle states and controls. Several instrument packages were utilized. In particular. the major source of data was the Aerodynamic Coefficient Identification Package (ACIP), an instrumentation package specifically designed to measure rates, accelerations, and control surface positions required for parameter identification. The ACIP data were recorded at 172 samples per second. Another source of acceleration and rate measurements was the instrumentation for the flight guidance and control system (RGA, AA). The RGA, AA data were recorded at 25 samples per second, but are very noisy. A third source of flight measurements is the Inertial Measurement Unit (IMU). The primary measurements taken from the IMU were accelerations. The IMU measurements are high fidelity, but were only recorded at one sample per second which limited their usefulness.

The ACIP data were the primary source for the linear and angular accelerations, angular rates, and control surface deflections. The RCS chamber pressures were used to determine the jet thrust, and these measurements came from the vehicle operational instrumentation.

The most reliable data considered were used to generate a Best Estimated Trajectory (BET) for the shuttle vehicle. The data prepared for parameter extraction consisted of those maneuvers considered appropriate for parameter extraction (i.e., those which demonstrated sufficient excitation of the vehicle). The linear and angular accelerations, angular rates, and control surface deflections came from the ACIP instrumentation. The BET angular rates and linear accelerations at the start of a maneuver were taken as initial conditions, and the rates and accelerations were integrated over time to obtain angular positions and vehicle velocities. The velocities were then corrected for the effect of winds and the resulting components were used to calculate the vehicle total velocity, angle-of-attack, and angle-of-sideslip. Additional details on the instrumentation and data processing can be found in references 5, 6, and 7.

PARAMETER EXTRACTION PROCEDURE

A Maximum Likelihood Parameter Extraction Program was used to examine the flight test data. This program is described in reference 8. A linear aerodynamic model describing a rigid airplane was assumed (references 1 and 2). The coefficients included in the model used for this study were: Cm_q, Cm_α, Cm_{δ_e}, Cx_α, Cz_q, Cz_α, and Cz_{δ_e}. These coefficients are referenced to the body axis system of figure 1 and are defined in the symbol list. The parameter values obtained using the extraction programs are given in tables that include the parameter value and the estimated standard deviations for each parameter. The estimated standard deviation is an indicator of the identifiability of the different parameters. If the estimated standard deviation is less than 10 percent of the extracted value for the parameter, then the parameter is identified.

RESULTS AND DISCUSSION

The analysis used to examine the flight data was performed using a

Maximum Likelihood Method. Only a limited number of the longitudinal maneuvers were appropriate for parameter extraction. For the model chosen the parameters C_{Z_α}, C_{m_α}, and $C_{m_{\delta_e}}$ describe approximately 90 percent of the response to a control input. Of the active parameters, $C_{m_{\delta_e}}$ has the most influence. The values determined for C_{Z_α}, C_{m_α}, and $C_{m_{\delta_e}}$ are given in Table II for various Mach numbers. The estimated standard deviations are also given in the table. These values are an indication of confidence in the extracted parameter value as discussed in the parameter extractions procedure section. The results of estimating the parameters C_{Z_α}, C_{m_α}, and $C_{m_{\delta_e}}$ will now be discussed in more detail.

C_{Z_α}

The variation of normal force with angle-of-attack parameter is plotted versus Mach number in figure 4. The extended values are fairly well identified in most cases as indicated by the small standard deviations (Table II). However, the values tended to vary considerably from the predicted preflight values of (reference 1). This trend was also seen with the results from the Discovery flight tests (reference 3).

The values of C_{Z_α} obtained from the second Discovery flight (STS-19) and the Challenger flight (STS-13) were consistently less negative than the majority of the values determined from earlier Challenger flights. An examination of the different data sets showed that when type 1 commands were used to excite the vehicle for longitudinal parameter extraction, more negative values of C_{Z_α} were obtained (figure 4). When type 2 elevon commands were used, less negative values were obtained (figure 4). The type 2 input had a form similar to the push-over, pull-up maneuver that gave the most identifiable parameters from flight tests of Columbia (references 2 and 3). However, the extracted values of C_{Z_a} from Challenger flight test data were more negative than the preflight predictions. Therefore, even though the type 2 input was considered to be a good maneuver, the resulting C_{Z_α} values did not agree with previous results (references 2 and 3).

An examination of the a_Z and $\dot{w}$ equations shows that C_{Z_α} is strongly affected by variations in a_Z. The power spectrum of the normal acceleration response to the two inputs was examined and the pulse inputs resulted in greater excitation of the normal acceleration. However, many of the values obtained using the pulse inputs were more than twice as negative as the preflight predictions and, therefore, seem too negative.

Because of the variations in the C_{Z_α} values determined, the true impact of the different parameter values should be examined. (For selected runs, the value of C_{Z_α} was set at the preflight value and the run repeated with only C_{m_α} and $C_{m_{\delta_e}}$ identified.) This meant that the value of C_{Z_α} was changed by over 50 percent, in some cases. The results can be seen by examining the solid symbols in figures 3, 5, and 6. The values of C_{m_α}

changed by at most 10 percent while the changes in Cm_{δ_e} were less than 5 percent. With these changes the data fit was essentially the same with the model describing at least 90 percent of the response to the input. Even though Cz_α was identifiable, the effect of Cm_{δ_e} was dominant so that the value chosen for Cz_α had very little effect on the resulting model of vehicle motions. In this situation using the preflight values for Cz_α seems appropriate.

Cm_α

The static stability parameter, Cm_α, obtained during this study is plotted versus Mach number in figure 5. The values of Cm_α from reference 1 are designated by a solid line. The estimated values of Cm_α for Mach numbers greater than 15 showed considerable scatter about the preflight predictions. Between Mach 15 and Mach 1.5, the estimated values show the same trends as those of reference 1 and a majority were within 20 percent of the predicted Cm_α values. Again the preflight predictions would be appropriate values for Cm_α.

$Cm_{\delta e}$

The elevon control effectiveness parameter is plotted versus Mach number in figure 6. The extracted values tend to indicate less control effectiveness, but follow the same trends as the preflight predictions. The reduced effectiveness when compared to the preflight predictions was particularly noticeable in the vicinity of Mach 1. As with Cm_α, these trends are similar to those from the other shuttle vehicles (ref. 2 and 3). The results obtained indicate that the values for $Cm_{\delta e}$ should be 10 percent less than the preflight predictions except in the Mach range 1.2 to .8 where they should be 30 percent less.

TEST OF SUGGESTED MODEL

The preceding discussion has suggested that a longitudinal model for the shuttle vehicle using values of Cz_α and Cm_α from reference 1, and values for $Cm_{\delta e}$ that were 10 percent less than reference 1 (except near Mach 1 where they should be 30 percent less than reference 1 values) could describe 90 percent of the response of the vehicle to a control input. To check this supposition the model was used with a data set that had not been used for extraction of parameter values. The results are shown for various Mach numbers in figure 7.

The calculated fit error for each of the parameters estimated was less than 10 percent of the peak-to-peak variation for that variable. In the case of normal acceleration, the fit appeared poor, but in terms of percent of the measured variable the fit error was within 10 percent of the measured variable. Apparently, however, angle-of-attack, pitch rate, and vertical acceleration cannot be totally fitted with the model used. In general, when the fit was good on angle-of-attack and pitch rate, vertical acceleration was underestimated. When the fit of vertical acceleration was good, angle-of-attack and pitch rate were overestimated. Comparing the Mach 4 and 5 runs where two different input forms were used, the Mach 5 run expected a less negative Cz_α and underestimated vertical acceleration. On the other hand, the Mach 4 run expected a more negative Cz_α and overestimated pitch rate. However, as a general conclusion, when choosing a model that varied only with Mach number, the procedure showed that the assumed models gave time histories whose fit errors were within 10 percent of the flight data for the majority of the runs.

CONCLUDING REMARKS

Three parameters (Cm_{δ_e}, Cz_α, Cm_α) described 90 percent of the response to longitudinal inputs for the Challenger vehicle. Of these Cm_{δ_e} was the dominant parameter. The estimated values of Cz_α tended to scatter between 30 percent more negative than the preflight predictions for pulse type inputs and 30 percent less negative for doublet type inputs. When Cz_α was set at the preflight predictions, the values extracted for Cz_α and Cm_{δ_e} varied less than 10 percent from the values obtained when Cz_α was also estimated. The values determined for Cm_α were reasonably consistent between Mach 1.5 and Mach 15 and generally followed the trends of the preflight predictions. The values extracted for Cm_{δ_e} followed the trends of the preflight predictions but tended to show less elevon effectiveness.

The preflight estimates of Cz_α and Cm_α are acceptable values for these parameters, but the Cm_{δ_e} values should be about 10 percent less negative than the preflight estimates except near Mach 1 where they should be 30 percent less negative.

REFERENCES

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6. Findlay, J. T.; Kelly, G. M.; and McConnell, J. G.: An AEROdynamic Best Estimate Trajectory File (AEROBET) for NASA Langley Research Center Shuttle Investigations. AMA Report No. 82-9, March 1982.

7. Flanagan, P. F.: FINAL REPORT/GTFILE Generation - Definition and Development. AMA Report No. 81-20, July 1981.

8. Murphy, Patrick C.: An Algorithm for Maximum Likelihood Estimation Using a Efficient Method for Approximating Sensitivities. NASA TP-2311, June 1984.

TABLE I. ENTRY PHYSICAL CHARACTERISTICS OF SPACE SHUTTLE ORBITER

Mass properties (range for five flights):

Mass, kg . . . . 91,917 - 100,309

Moments of Inertia (range for five flights):

I_X, kg-m^2 . . . . 1,171,428 - 1,313,633

I_Y, kg-m^2 . . . . 9,228,939 - 9,614,705

I_Z, kg-m^2 . . . . 9,584,958 - 10,031,878

I_Z, kg-m^2 . . . . 205,832 - 223,189

$I_{XY} = I_{YZ} = 0$

Wing:

Reference area, m^2 . . . . 249.91

Mean aerodynamic chord, m 12.06

Span, m 23.79

Elevon (per side):

Reference area, m^2 . . . . 19.51

Mean aerodynamic chord, m 2.30

Rudder (per side panel):

Reference area, m^2 . . . . 9.30

Mean aerodynamic chord, m 1.86

Body Flap:

Reference area, m^2 . . . . 12.54

Mean aerodynamic chord, m 2.06

TABLE II.- EXTRACTED PARAMETERS

	$\alpha_T = 40$		$\alpha_T = 40$		$\alpha_T = 40$	
	M = 22		M = 21		M = 19	
Parameter	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation
C_{Z_0}	-1.16	.0027	-1.17	.0026	-1.15	.0025
C_{Z_α}	-3.47	.16	-1.73	.14	-1.35	.35
$C_{Z_{\delta_e}}$	-.377	.025	-.51	.014	-.38	.025
C_{m_α}	-.40	.0027	-.072	.015	-.13	.0057
C_{m_q}	-2.2	---	-2.2	---	-2.2	0
$C_{m_{\delta_e}}$	-.23	.003	-.31	.0044	-.21	.0095

	$\alpha_T = 40$		$\alpha_T = 39$		$\alpha_T = 39$	
	M = 19		M = 18		M = 18	
Parameter	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation
C_{Z_0}	-1.1	.0025	-1.18	.0027	-1.2	.019
C_{Z_α}	-3.53	.20	-3.9	.19	-1.7	1.2
$C_{Z_{\delta_e}}$	-.26	.024	-.29	.031	-.47	.18
C_{m_α}	-.20	.017	-.21	.013	-.27	.018
C_{m_q}	-2.2	---	-2.2	---	-2.2	---
$C_{m_{\delta_e}}$	-.25	.0053	-.30	.0056	-.25	.0032

TABLE II.- EXTRACTED PARAMETERS (CONTINUED)

	$\alpha_T = 39$		$\alpha_T = 38.5$		$\alpha_T = 38.5$	
	M = 18		M = 14		M = 14	
Parameter	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation
C_{Z_0}	-1.22	.003	-1.12	.0025	-1.39	.0018
C_{Z_α}	-4.1	.24	-2.8	.2	-6.01	.30
$C_{Z_{\delta e}}$	-.48	.032	-.40	.032	-.4	.03
C_{m_α}	-.446	.022	-.11	.0073	-.34	.014
C_{m_q}	-2.2	---	-2.2	---	-2.2	---
$C_{m_{\delta e}}$	-.26	.006	-.25	.0021	-.3	.003

	$\alpha_T = 38.0$		$\alpha_T = 36.0$		$\alpha_T = 35.8$	
	M = 13		M = 8.4		M = 8	
Parameter	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation
C_{Z_0}	-1.14	.0013	-1.05	.0016	-1.14	.0022
C_{Z_α}	-1.26	.19	-.58	.15	-5.20	.3
$C_{Z_{\delta e}}$	-.38	.027	-.41	.022	-.22	.030
C_{m_α}	-.27	.0056	-.045	.0073	-.08	.026
C_{m_q}	-2.2	---	-2.2	---	-2.2	---
$C_{m_{\delta e}}$	-.126	.002	-.22	.0025	-.204	.005

TABLE II.- EXTRACTED PARAMETERS (CONTINUED)

	α_T = 35.8		α_T = 25.1		α_T = 22.5	
	M = 8		M = 5.5		M = 4.5	
Parameter	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation
C_{Z_0}	1.07	.001	-.489	.0008	-.62	.9E-3
C_{Z_α}	-1.17	.13	-1.99	.18	-4.38	.22
$C_{Z_{\delta_e}}$	-.25	.021	-.12	.019	-.15	.019
C_{m_α}	-.068	.0014	-.021	.014	-.19	.014
C_{m_q}	-2.2	---	-2.2	---	-2.2	---
$C_{m_{\delta_e}}$	-.183	.0007	-.149	.0074	-.149	.0025

	α_T = 15.0		α_T = 12.0		α_T = 12.0	
	M = 3.2		M = 2.0		M = 2.0	
Parameter	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation
C_{Z_0}	-.50	.00093	-.38	.0009	-.48	.0012
C_{Z_α}	-1.06	.025	-4.53	.22	-3.5	.13
$C_{Z_{\delta_e}}$	-.40	---	-.466	.019	-.17	.022
C_{m_α}	-.023	.005	-.19	.014	-.17	.0046
C_{m_q}	-2.2	---	-2.2	---	-2.2	---
$C_{m_{\delta_e}}$	-.133	.002	-.149	.0025	-.13	.0014

TABLE II.- EXTRACTED PARAMETERS (CONTINUED)

	$\alpha_T = 9.0$		$\alpha_T = 9.5$		$\alpha_T = 6.5$	
	M = 1.6		M = 1.5		M = 1.0	
Parameter	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation
C_{Z_0}	-.56	.0027	-.40	.0013	-.38	.0008
C_{Z_α}	-7.98	.41	-4.23	.14	-4.08	.29
$C_{Z_{\delta_e}}$	-.21	.061	-.24	.024	-.49	.045
C_{m_α}	-.13	.025	-.054	.017	-.81	.018
C_{m_q}	-2.2	---	-2.2	---	-2.2	---
$C_{m_{\delta_e}}$	-.21	.0084	-.154	.0055	-.37	.0061

	$\alpha_T = 6.0$		$\alpha_T = 5.5$			
	M = .9		M = .7			
Parameter	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation
C_{Z_0}	-.366	.00054	-.435	.0021		
C_{Z_α}	-2.98	.14	-2.22	.24		
$C_{Z_{\delta_e}}$	-.8	---	-1.15	.13		
C_{m_α}	-.13	.0076	-.643	.023		
C_{m_q}	-2.2	---	-2.2	---		
$C_{m_{\delta_e}}$	-.52	.0041	-.38	.018		

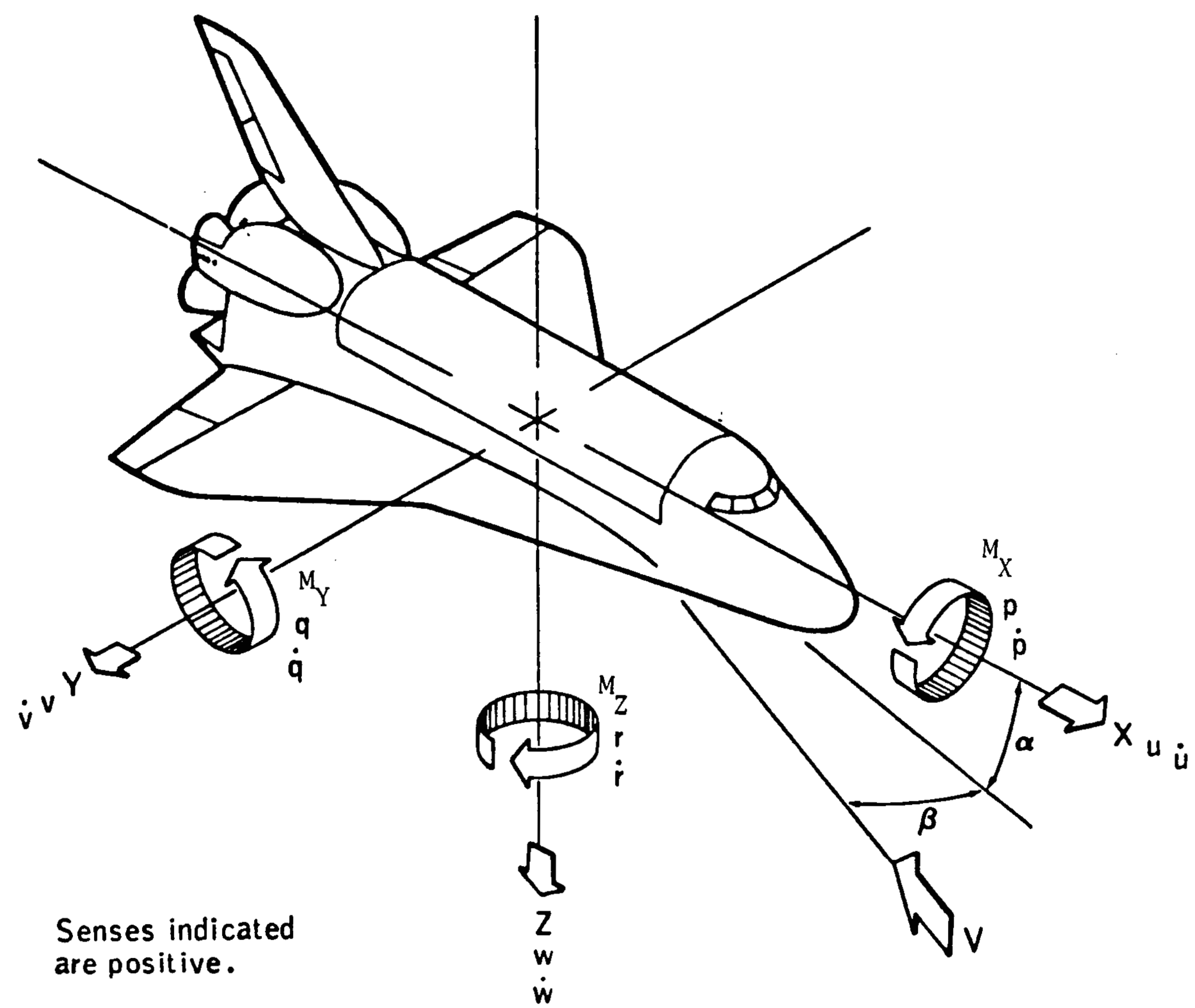


Figure 1. Schematic of shuttle vechicle showing body axes and positive senses of accelerations, rates, velocities, moments and angles.

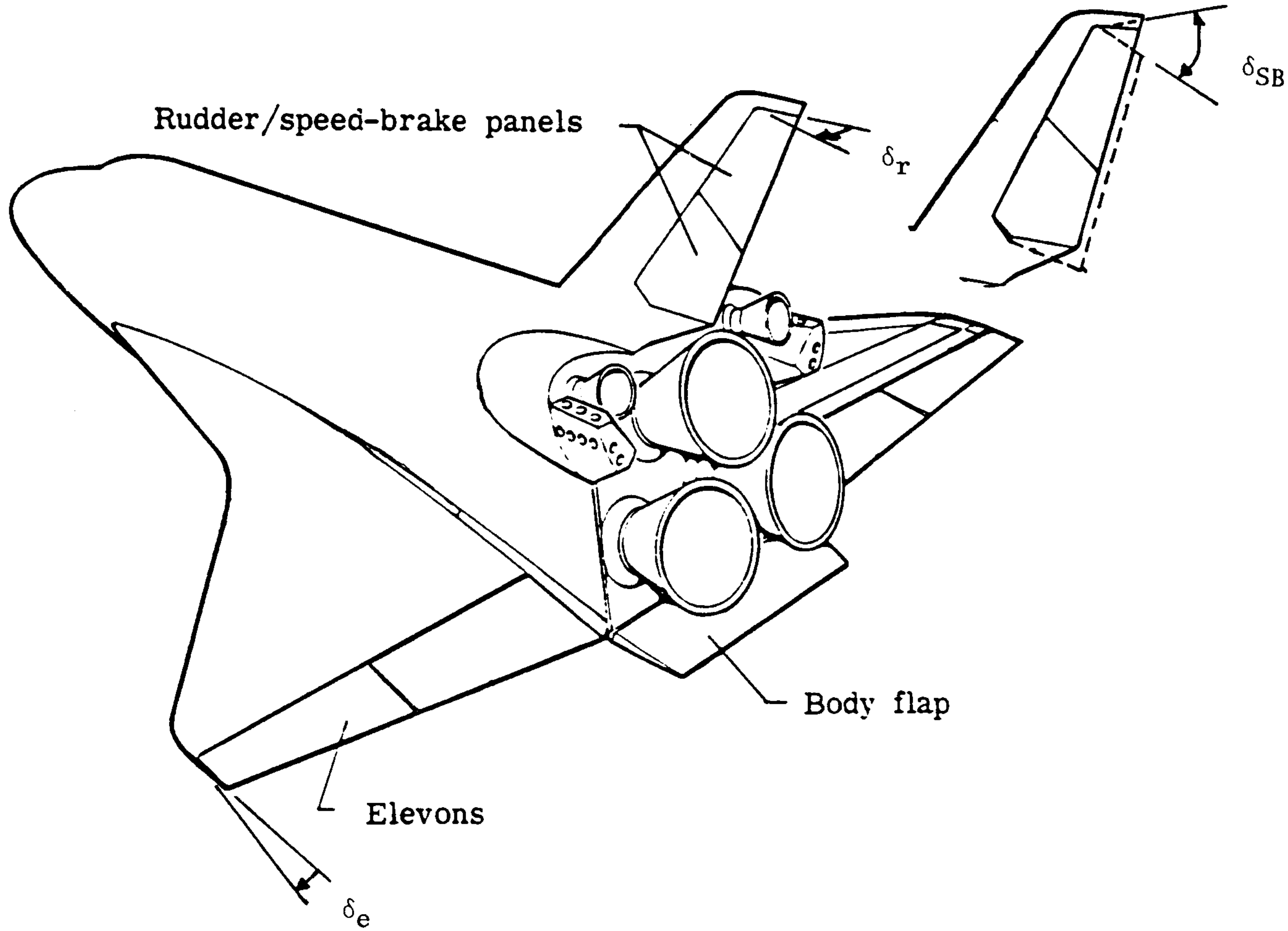
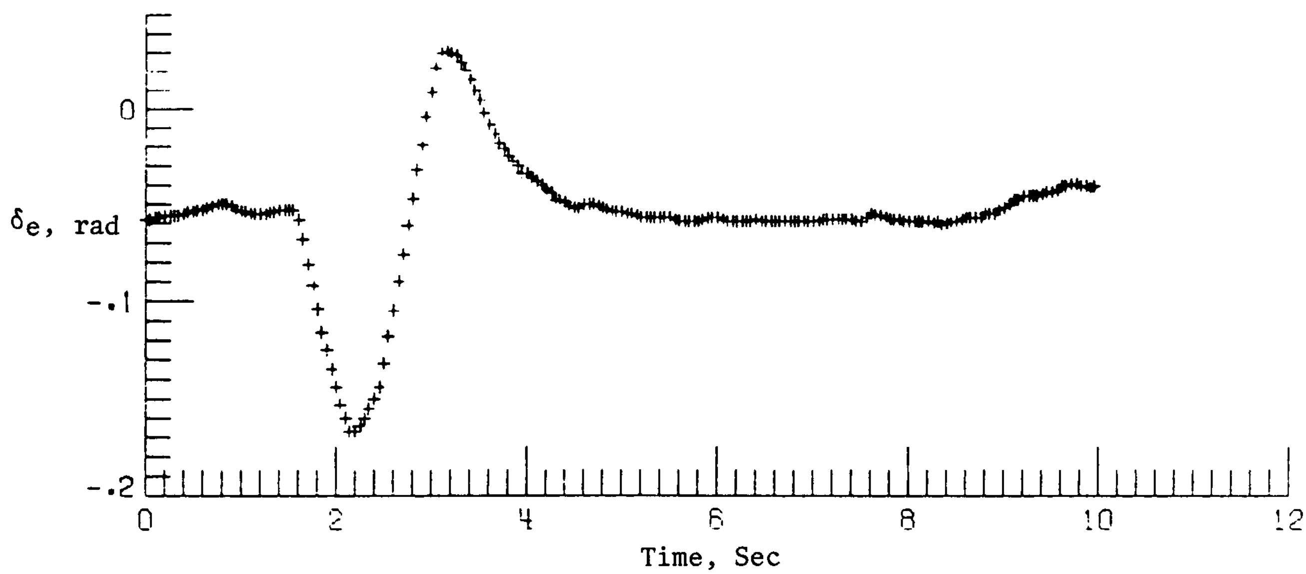
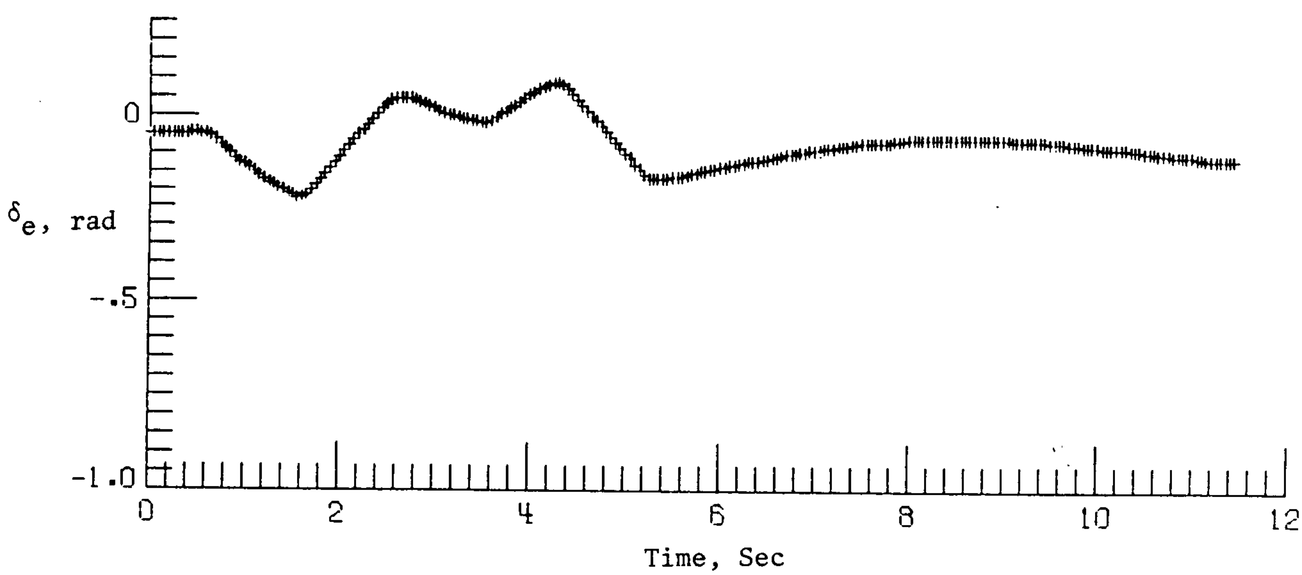


Figure 2. Sketch of space shuttle orbiter showing surface deflections.



(a) Input Type 1



(b) Input Type 2

Figure 3. Elevon Deflection From PTI

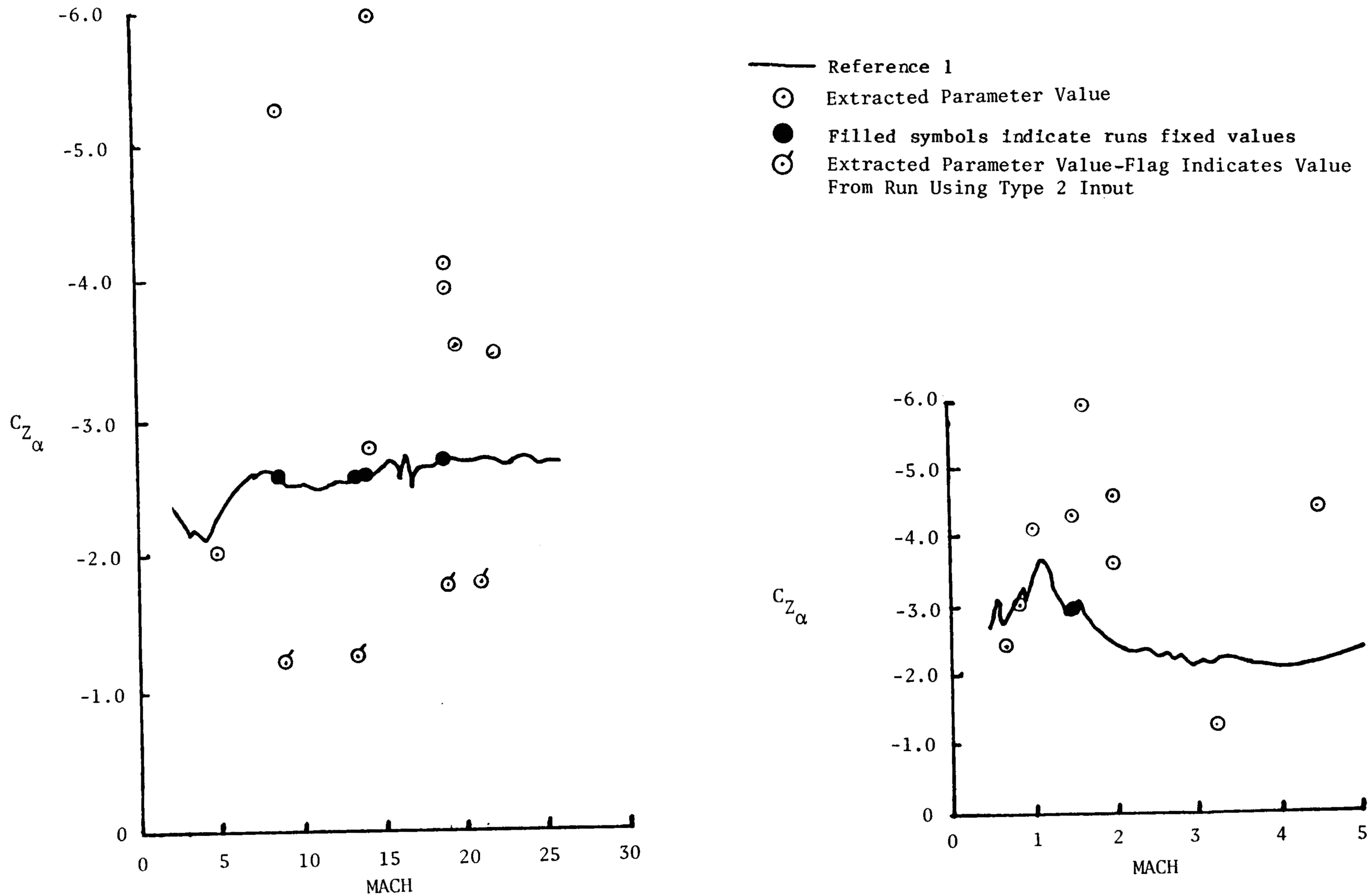
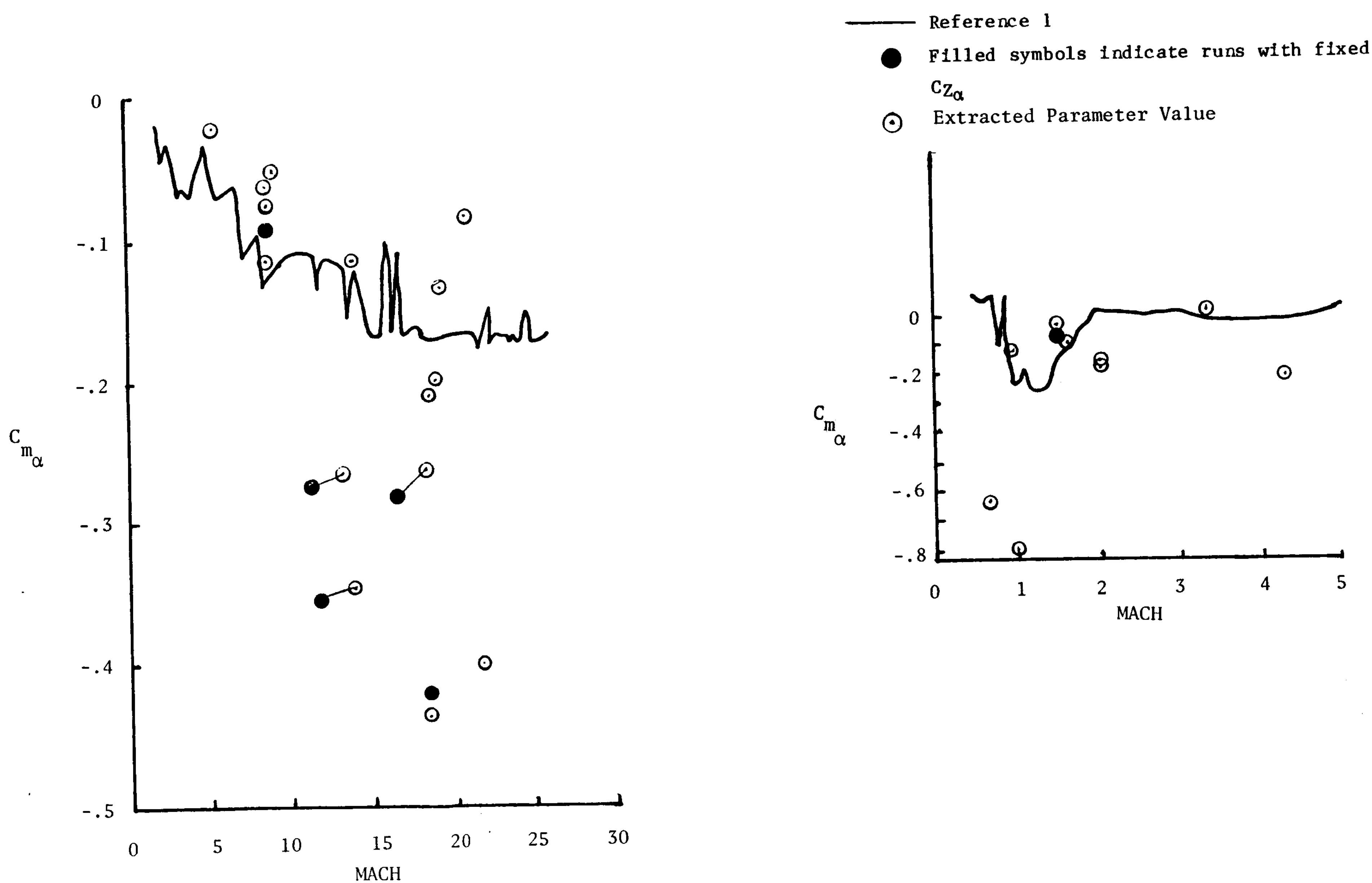
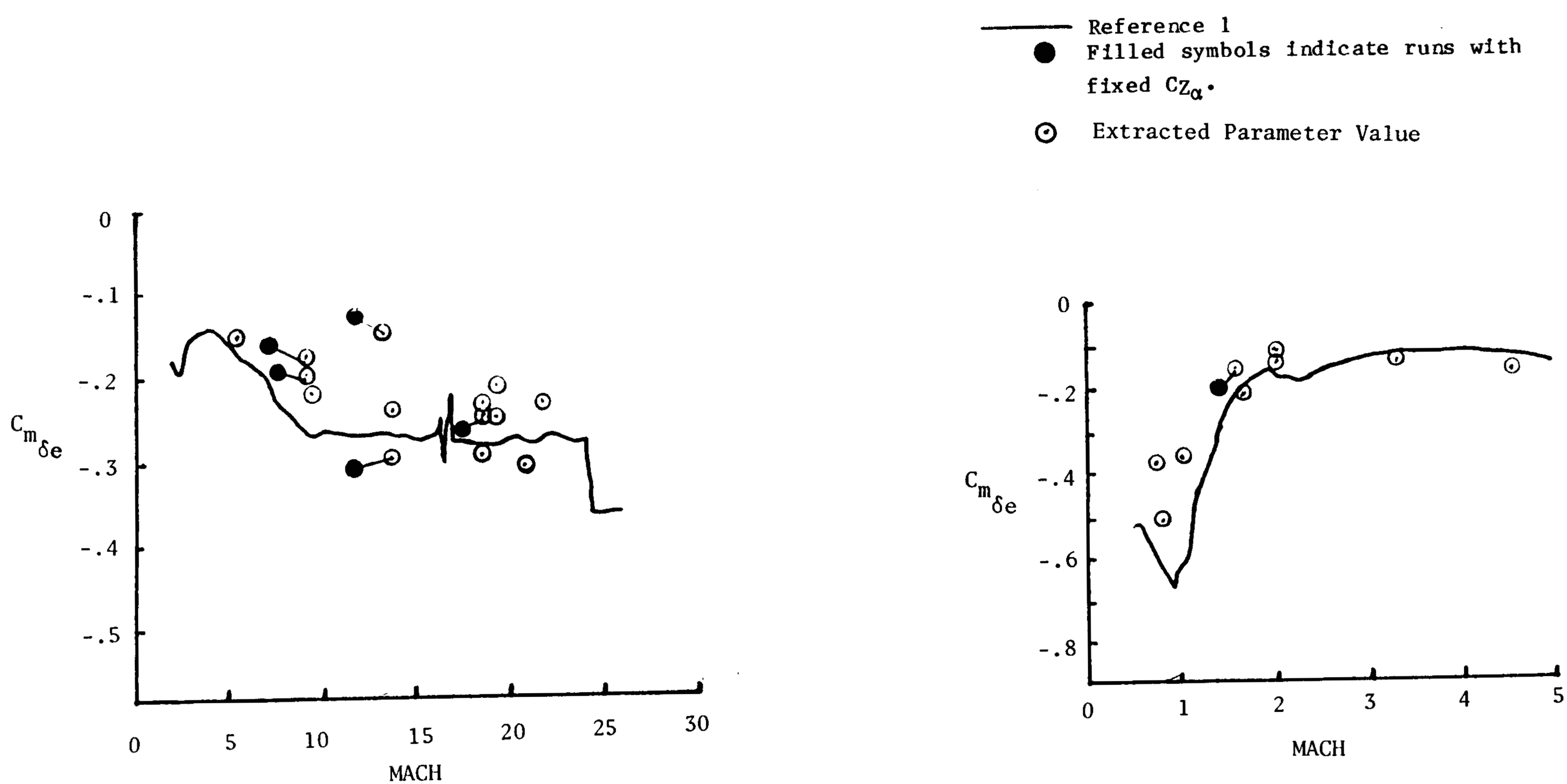


Figure 4. Change in normal force with alpha versus Mach number.



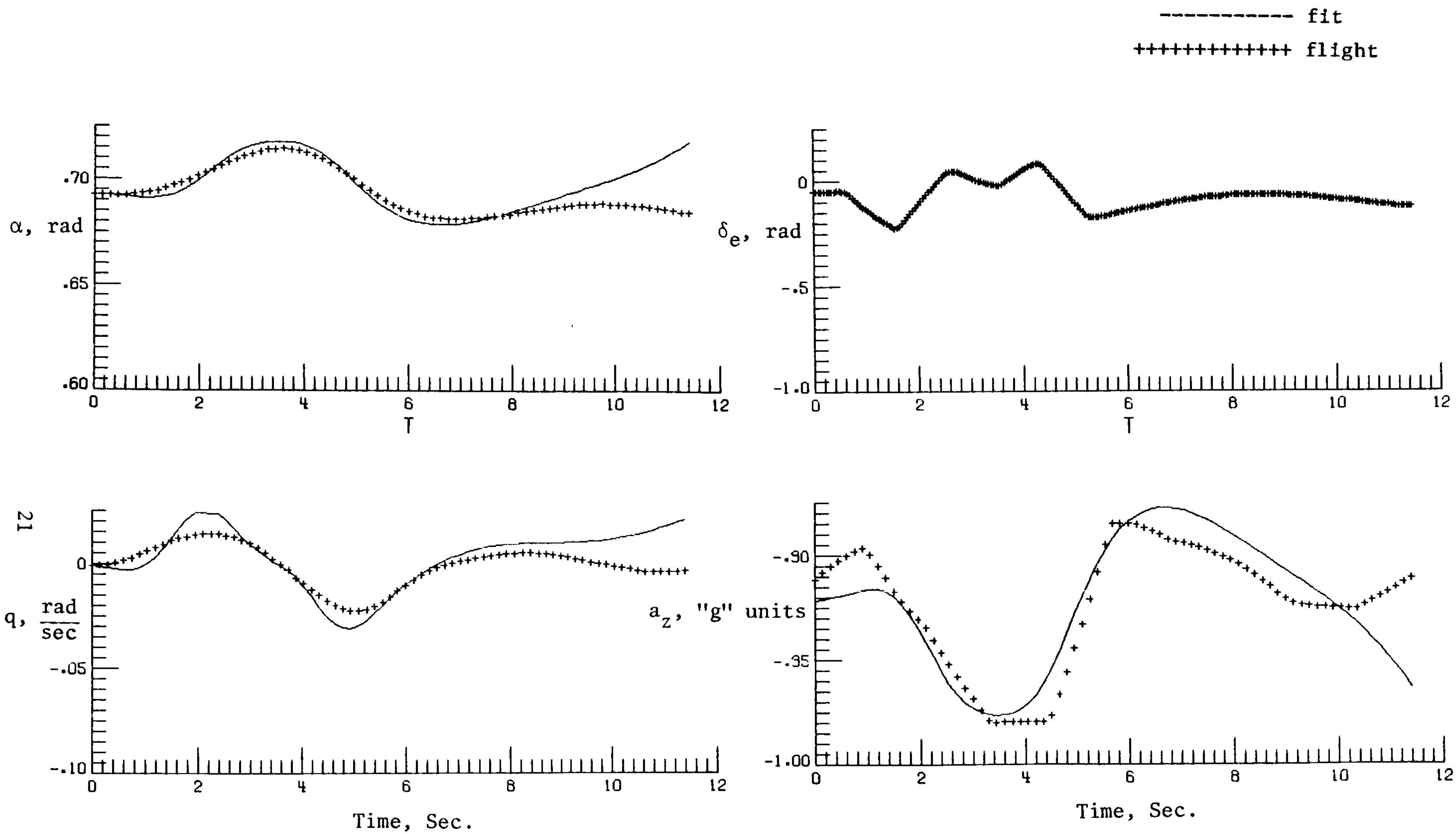
Note: Leaders indicate point represented by solid symbol.

Figure 5. Static stability versus Mach number.



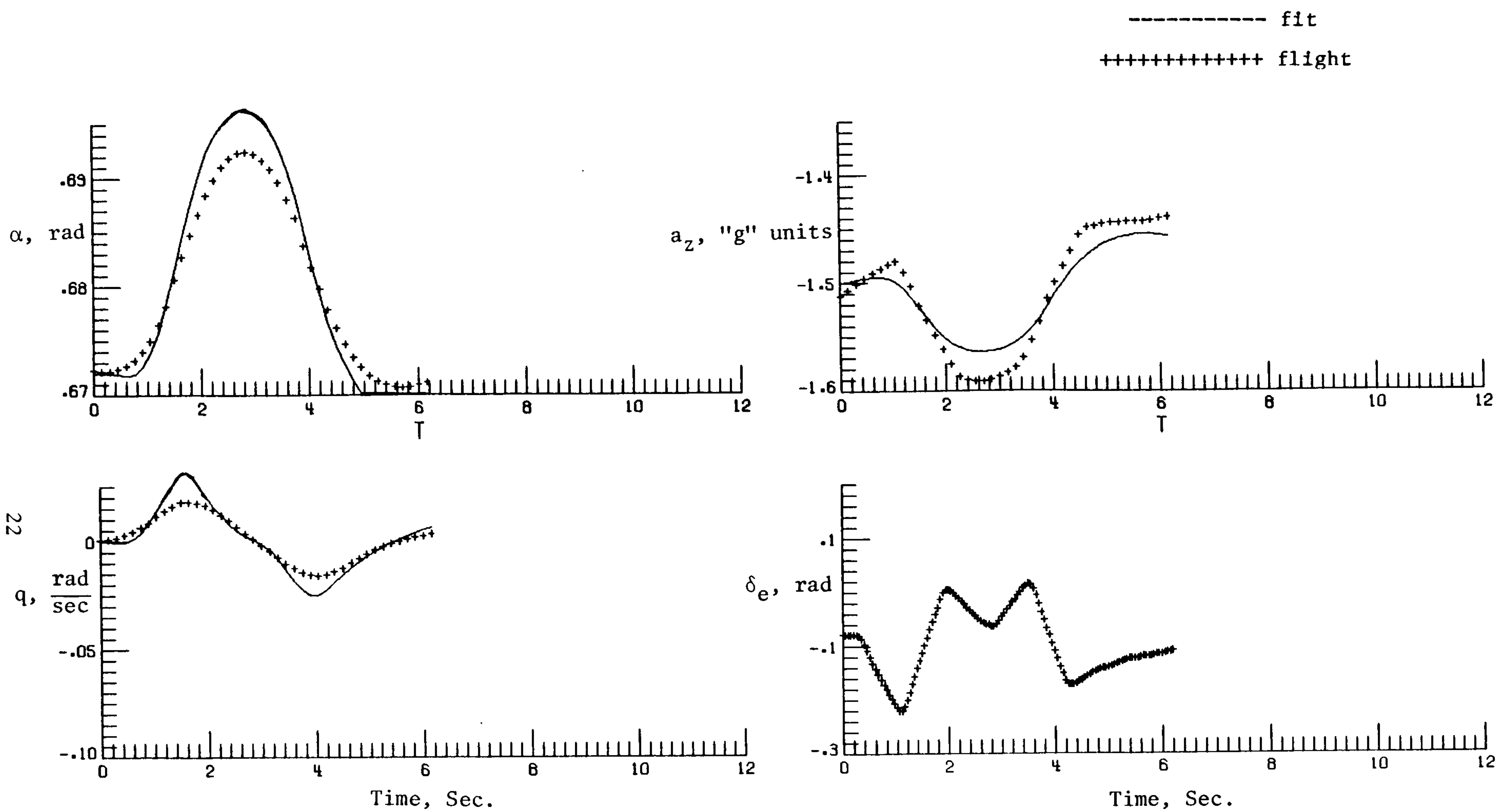
Note: Leaders indicate point represented by solid symbol.

Figure 6. Elevon effectiveness versus Mach number.



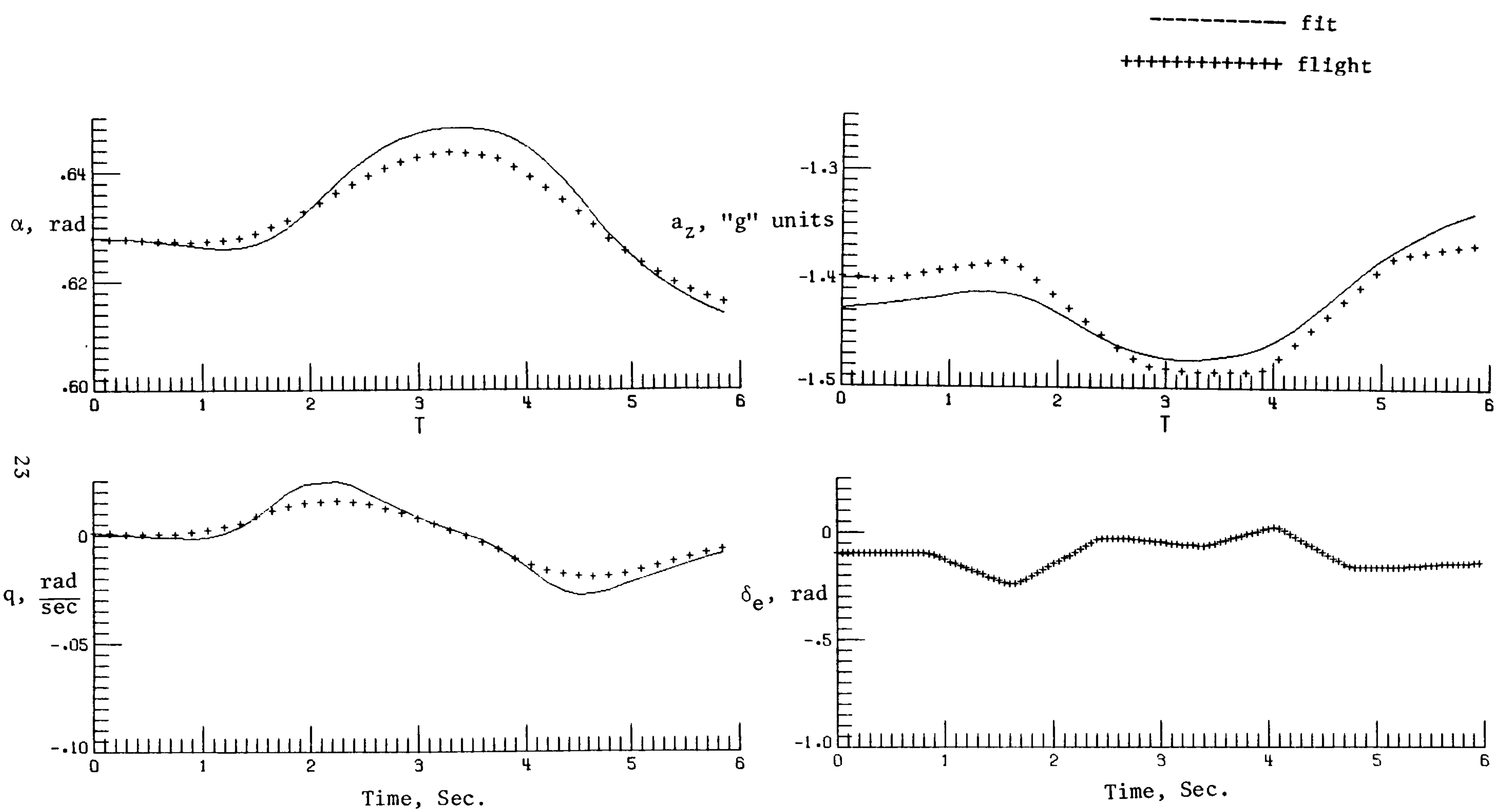
(a) Mach = 18

Figure 7. Time histories of fits to flight data at various Mach numbers using data from Figures 2-4.



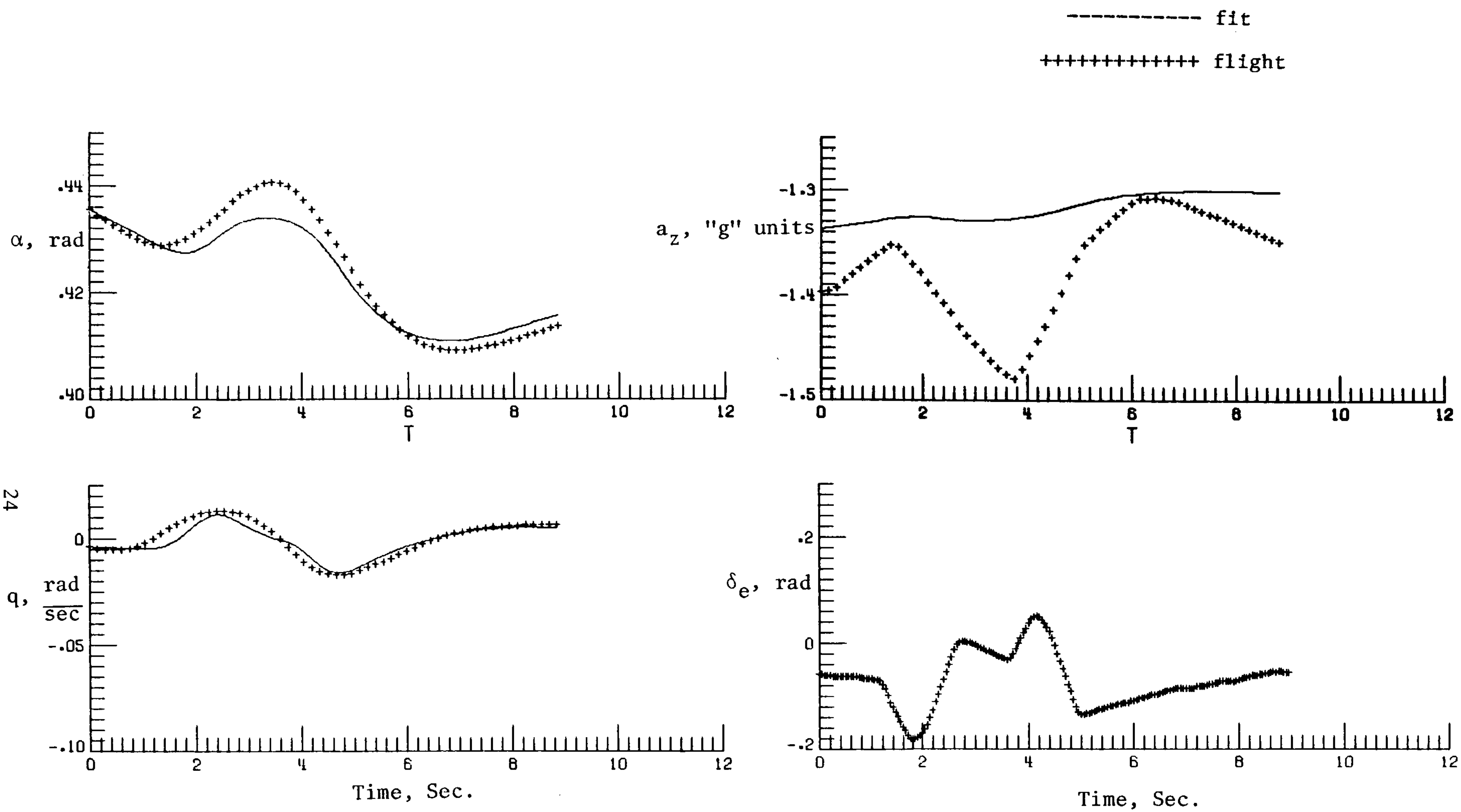
(b) Mach 13

Figure 7. Continued.



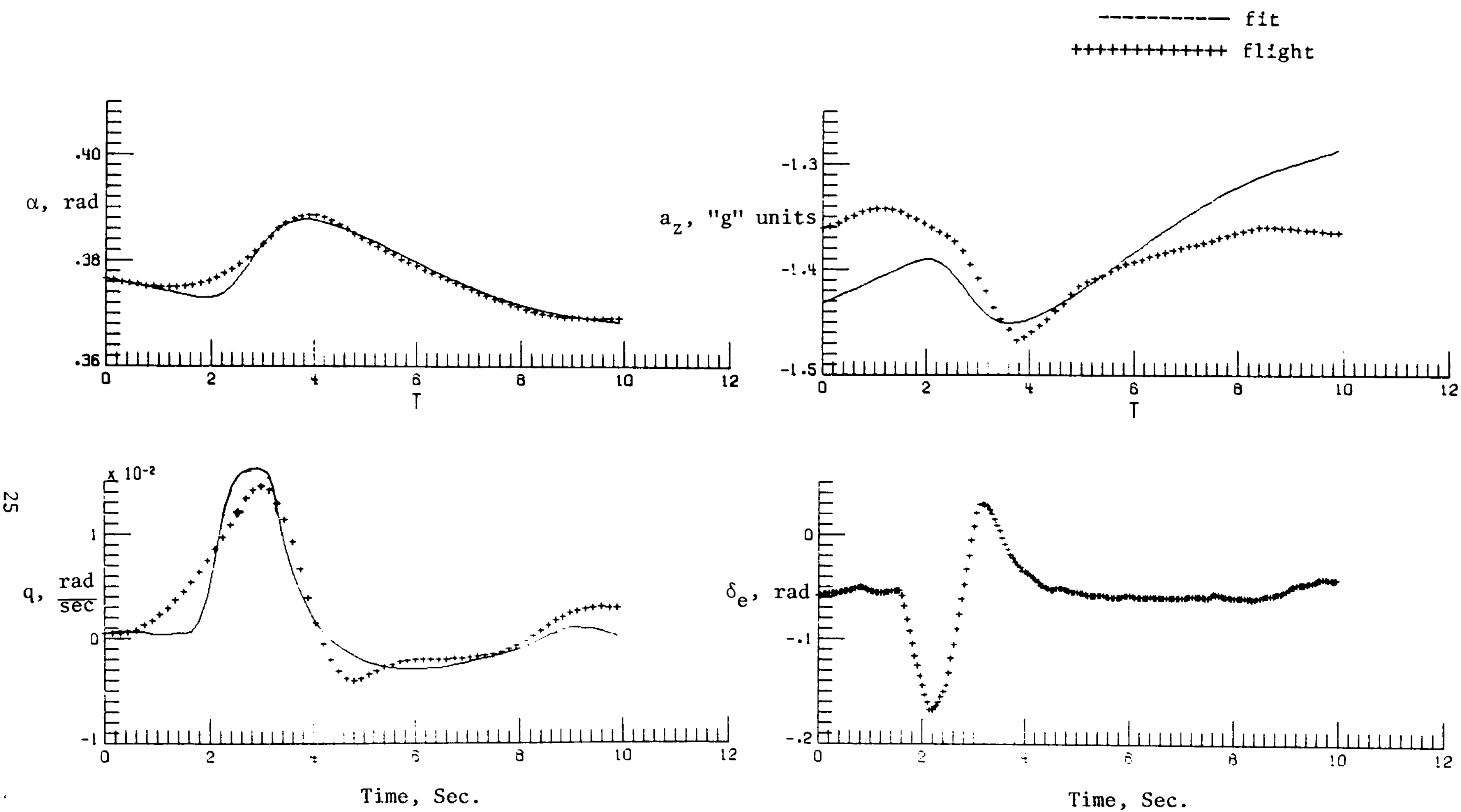
(c) Mach = 8

Figure 7. Continued.



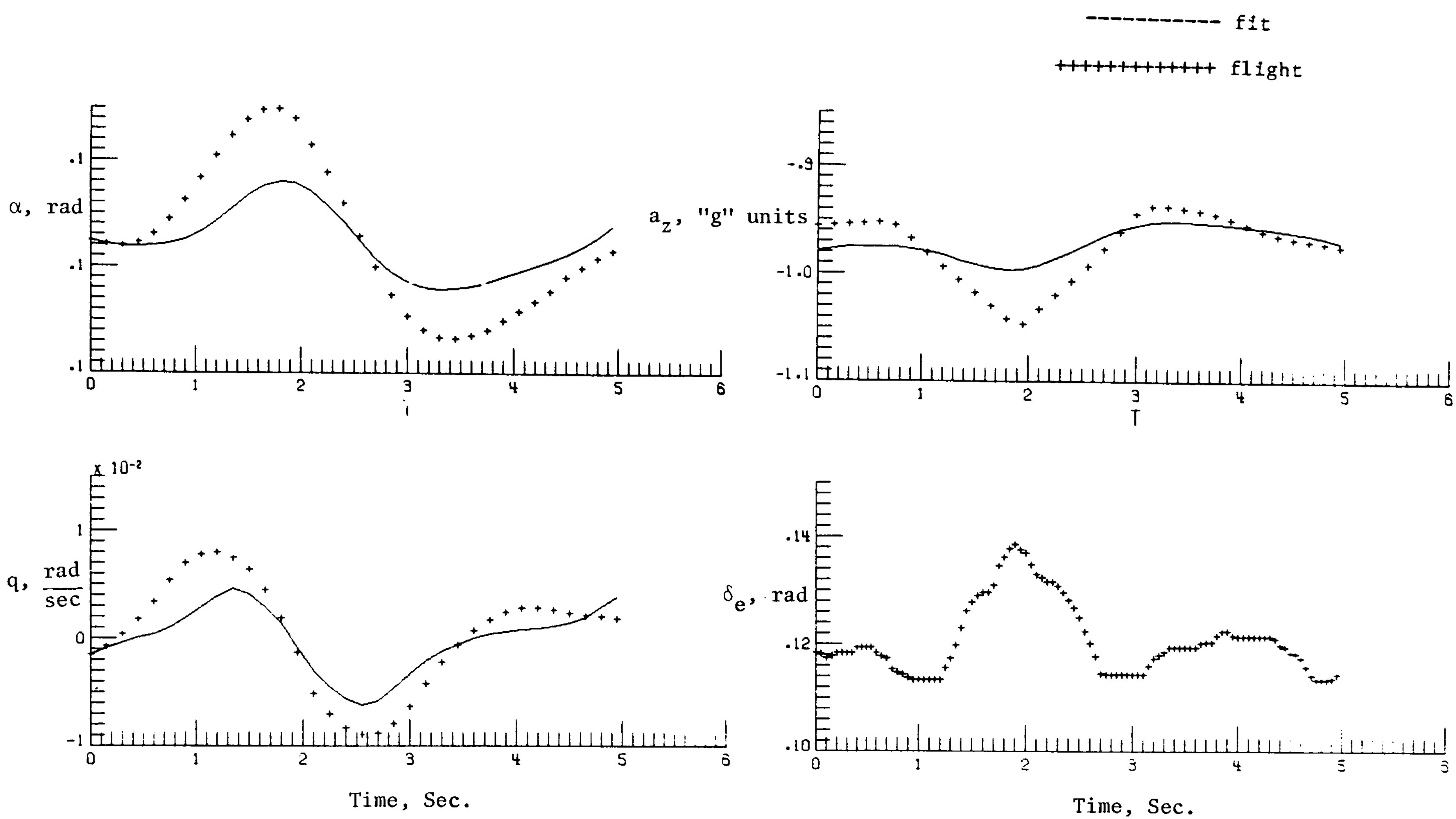
(d) Mach = 5

Figure 7. Continued.



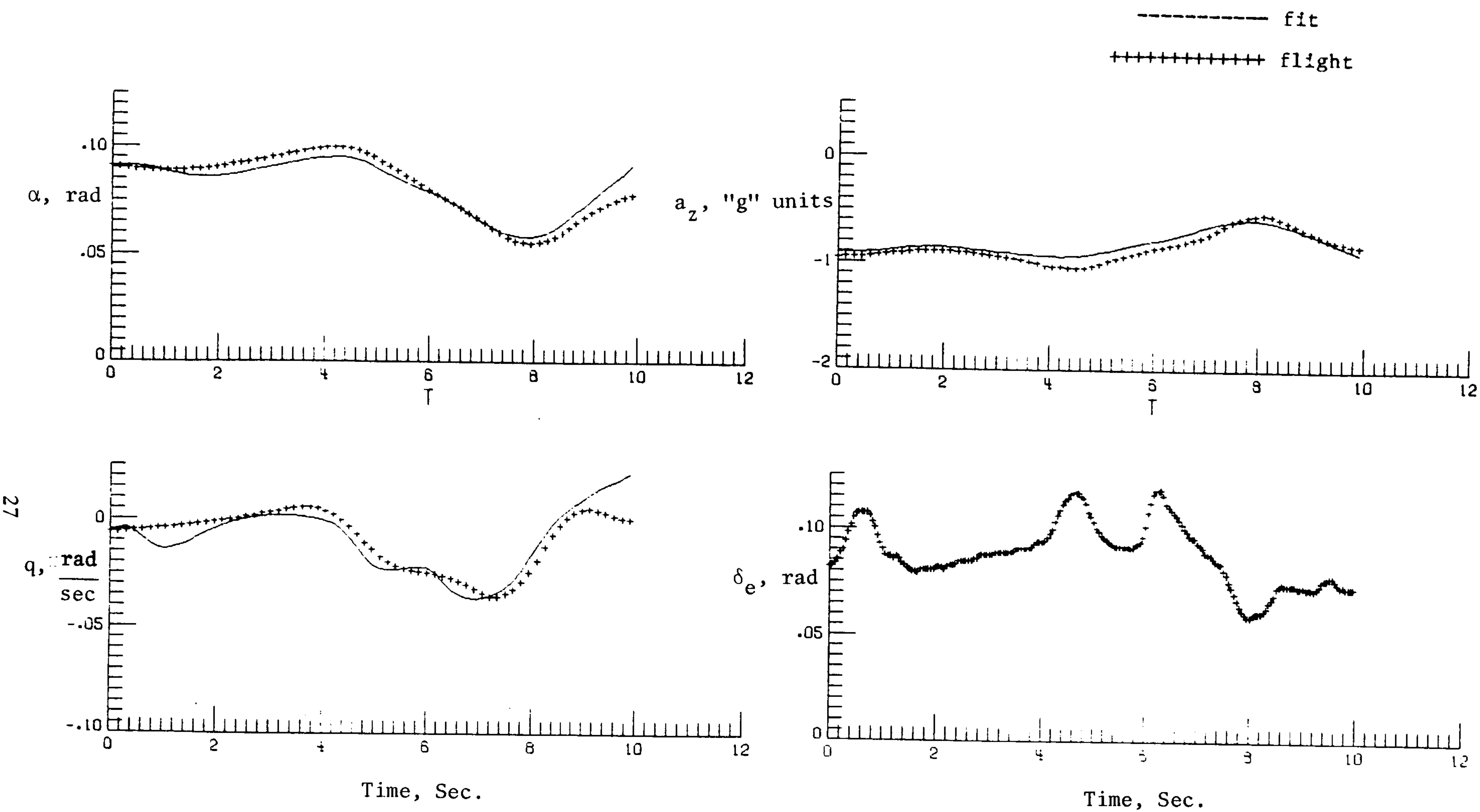
(e) Mach = 4

Figure 7. Continued.



(f) Mach 1.2

Figure 7. Continued.



(g) Mach = .5

Figure 7. Concluded.

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15. Supplementary Notes

16. Abstract

Estimates of longitudinal stability and control parameters for the space shuttle were determined by applying a maximum likelihood parameter estimation technique to Challenger flight test data. The parameters C_{m_α}, $C_{m_{\delta e}}$, and C_{Z_α} describe 90 percent of the response to longitudinal inputs during Space Shuttle Challenger flights with $C_{m_{\delta e}}$ being the dominant parameter. The values of C_{Z_α} were found to be input dependent for these tests. However, when C_{Z_α} was set at preflight predictions, the values determined for $C_{m_{\delta e}}$ changed less than 10 percent from the values obtained when C_{Z_α} was estimated as well.

The preflight predictions for C_{Z_α} and C_{m_α} are acceptable values, while the values of $C_{m_{\delta e}}$ should be about 30 percent less negative than the preflight predictions near Mach 1 and 10 percent less negative, otherwise.

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