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FINAL TECHNICAL REPORT:
AUTOMATIC GUIDANCE FOR
VTOL AIRCRAFT

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FOREWORD

This report was prepared by the Kaman AviDyne Division of Kaman Sciences Corporation, Burlington, Massachusetts. It presents the final documentation of the effort conducted for the NASA Electronics Research Center, Cambridge, Massachusetts, under Contract NAS 12-2097, as modified. The work reported in this document was performed in the period from March, 1969 through February, 1970 and was monitored for the National Aeronautics and Space Administration by Miss Ann Muzyka.

The study was performed under the direction of Dr. N. P. Hobbs, General Manager of Kaman AviDyne. Mr. John Zvara acted as Program Manager, and Mr. William C. Hoffman served as Project Leader and Principal Investigator. Prof. A. E. Bryson of Stanford University and Prof. N. D. Ham of the Massachusetts Institute of Technology were Technical Consultants for the study.

ABSTRACT

A simple perturbation feedback scheme is developed for automatic guidance of a VTOL aircraft with a velocity-command flight control system. By neglecting the delay required to attain a commanded velocity and by using ground range to touchdown rather than time as the independent variable, a reduced model having two state variables - altitude and crossrange - and three control variables - components of commanded velocity - was obtained. The model was linearized by taking first-order perturbations about a nominal trajectory. By minimizing a performance index which was quadratic in both the state and the control variables, an effective linear feedback guidance law was developed.

To implement the guidance scheme, the nominal state variables, the nominal control variables, and the feedback gains would be pre-calculated and stored as functions of range to go in the on-board computer. During flight, the actual state variables would be measured and their deviations from nominal used to calculate optimal corrections to the stored nominal control variables.

The performance of the guidance concept was evaluated by means of a six-degree-of-freedom digital simulation of the NASA/LaRC YHC-1A tandem rotor helicopter with the NASA/ERC velocity-command flight control system. A simple nominal trajectory was

used, consisting of piecewise-constant vertical and forward acceleration segments. Simulation results indicate that the scheme can successfully handle a variety of off-nominal conditions, including initial condition errors, winds and uncertainties in the aircraft characteristics.

TABLE OF CONTENTS

<u>SECTION</u>	<u>TITLE</u>	<u>PAGE</u>
I	INTRODUCTION	1-1
	1.1 Background	1-1
	1.2 Scope of Investigation	1-2
II	ANALYTICAL DEVELOPMENT	2-1
	2.1 Simplified Model of Controlled Vehicle	2-1
	2.2 Perturbation Equations	2-4
	2.3 Quadratic Synthesis	2-5
	2.4 Implementation of the Guidance Concept	2-7
III	DIGITAL SIMULATION	3-1
	3.1 Vehicle Model	3-1
	3.2 Flight Control System	3-4
	3.3 Guidance System	3-9
IV	SYSTEM PERFORMANCE	4-1
	4.1 Nominal Trajectory	4-1
	4.2 Guidance Feedback Gains	4-6
	4.3 Simulation Results	4-12
V	CONCLUSIONS AND RECOMMENDATIONS	5-1
	5.1 Summary and Conclusions	5-1
	5.2 Recommendations for Further Research	5-4
App. A	— LISTING OF THE SIMULATION PROGRAM	A-1
App. B	— THREE-DIMENSIONAL ANALYTICAL MODEL FOR THE MASS CENTER MOTIONS OF A HELICOPTER	B-1
App. C	— PHYSICAL AND AERODYNAMIC CHARACTERISTICS OF NASA/LaRC YHC-1A HELICOPTER	C-1
	NOMENCLATURE	N-1
	REFERENCES	R-1

SECTION I

INTRODUCTION

1.1 BACKGROUND

In the past few years, the possible commercial use of V/STOL aircraft to help relieve the national air traffic problem has received wide attention. Responding to this interest, the NASA Electronics Research Center began its V/STOL Avionics Program, which has an overall objective to "develop and demonstrate the avionics system technologies that would make V/STOL aircraft all-weather operations both technically and economically feasible on civil air route structures and in air traffic environments representative of the 1975 to 1985 time period" (Ref. 1).

During Phase 1 of the program, the feasibility of using an IGS*/nav-aid system for terminal guidance and navigation of V/STOL aircraft was evaluated. In subphases 1a and 1b of this effort, use was made of a Gemini inertial platform and computer onboard an H-19 helicopter. Flights were made both with and without position updates from a ground-based radar, and test results were used to determine update requirements as a function of sensor performance. Phase 1c has involved flight test of the Gemini system onboard a CH-46C helicopter to provide velocity and position determination in support of a Langley Research Center investigation of variable stability helicopter and V/STOL characteristics.

*Inertial Guidance System.

The objective of Phase 2 of the program now in progress is to evaluate and demonstrate the technical and commercial feasibility of using integrated, digital strapdown/nav-aid system concepts for flight control, guidance and navigation of V/STOL aircraft. Whereas Phase 1 of the program explored a particular technical concept (aided inertial guidance system terminal navigation), the concern in Phase 2 is with a total (integrated) guidance, navigation and control system concept applied to the enroute problem as well as the terminal problem. Navigation and guidance is to be accomplished in three dimensions. (In Phase 1, navigation only was done in three dimensions.) Program activity will consist of analysis, simulation, development of an experimental flight system and flight test. Major outputs are planned to be new V/STOL avionics system and subsystem technology, and test data verifying performance estimates based on analysis and simulation.

1.2 SCOPE OF INVESTIGATION

This report describes a study of the guidance subsystem that was carried out in support of Phase 2 of the V/STOL Avionics Program. The study objective was to develop and evaluate automatic guidance modes and associated software for V/STOL aircraft. The initial part of the effort, which was reported in Ref. 2, was restricted to the longitudinal axis of the guidance system, i.e., the vertical plane. The present report describes the

three-dimensional guidance analysis and documents the entire investigation.

Fig. 1 is a block diagram of the automatic V/STOL avionics system showing the flow of information and the relationships of the three principal subsystems (navigation, guidance, and flight

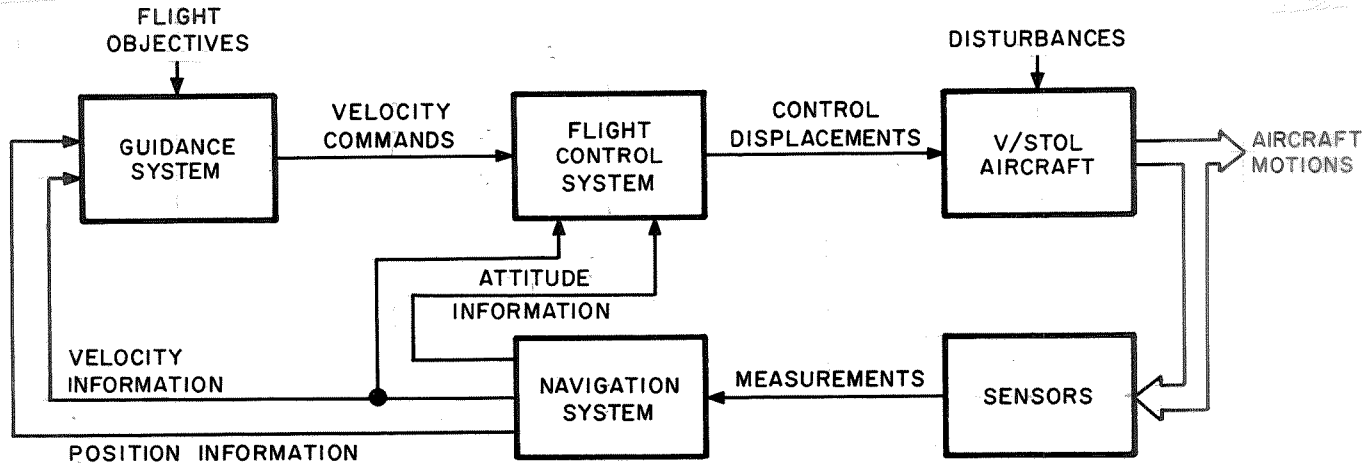


Fig. 1. Block Diagram of V/STOL Avionics Systems

control). The function of the guidance system is to control the position and velocity of the aircraft in order to achieve certain specified flight objectives, e.g., to transport passengers from one airport to another under zero visibility conditions. To perform this task, the guidance system requires position and velocity information from the navigation system. It uses these data to generate velocity commands for the flight control system, which provides the direct control of the vehicle maneuvers by displacement of the appropriate aircraft controls.

In the development of the guidance concept, both the navigation system and the flight control system were assumed to be ideal, i.e., the exact position and velocity were always known and the response to velocity commands was immediate. The simulation used to evaluate the guidance system's performance included a detailed representation of the flight control system and the aircraft dynamics, but neglected imperfections in the navigation system.

SECTION II

ANALYTICAL DEVELOPMENT

This section presents the analytical development of an automatic guidance concept for a VTOL aircraft which has a velocity-command flight control system. A simplified mathematical model of the controlled aircraft is formulated, and linearized about a nominal trajectory. A linear, feedback guidance law is then synthesized for this simplified system.

2.1 SIMPLIFIED MODEL OF CONTROLLED VEHICLE

As mentioned in the Introduction, the purpose of the guidance system is to generate velocity commands to the flight control system. The dynamics of the flight control system and the aircraft introduce delays in the response to these velocity commands. However, the response time of the controlled vehicle (on the order of a few seconds*), is generally short in comparison to the characteristic time of the guidance function (on the order of tens of seconds). Thus, relative to the time scale of the guidance system, velocity commands are very nearly instantly achieved.

The guidance analysis commenced with the simplest possible representation of the controlled vehicle - a perfect autopilot. That is, the aircraft's true velocity components were assumed always to be equal to their respective commanded values, i.e.

*From NASA/ERC velocity-command flight control system studies.

$$\dot{x} = V_x = V_{x_c} \quad (1)$$

$$\dot{y} = V_y = V_{y_c} \quad (2)$$

$$\dot{z} = V_z = V_{z_c} \quad (3)$$

where x , y and z are the position coordinates of the aircraft in the inertial coordinate system illustrated in Fig. 2. The

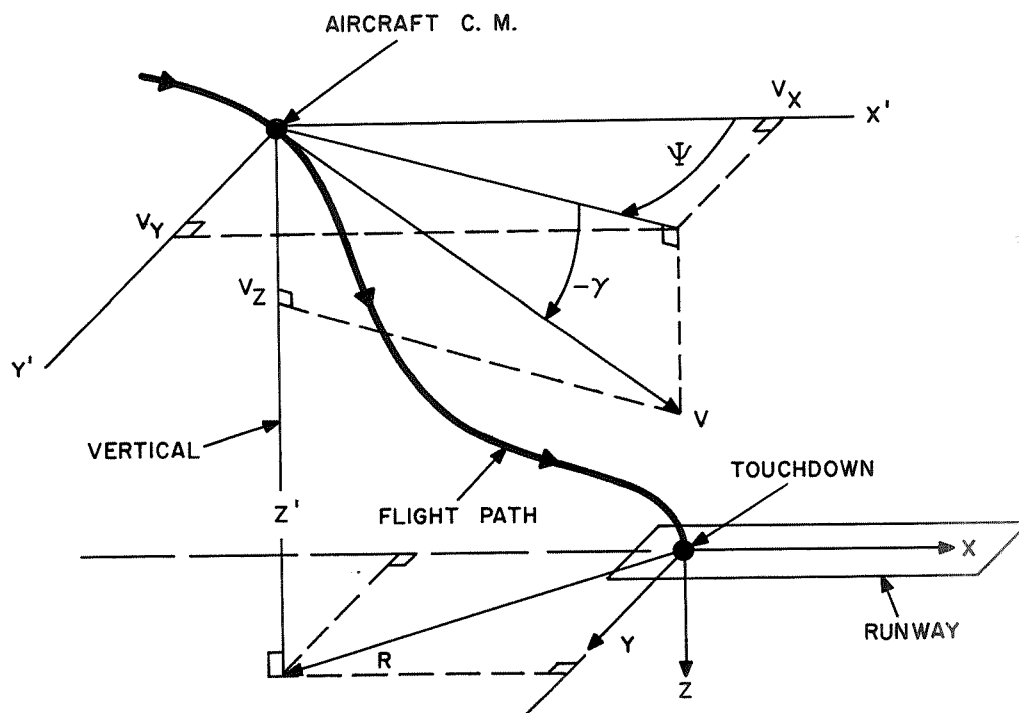


Fig. 2. Coordinate System and Nomenclature for Guidance Analysis

origin of the coordinate system is at the runway touchdown point; the x -axis is in the horizontal plane, parallel to the runway and positive in the landing direction; the z -axis is positive down along the local vertical; and the y -axis forms a right-hand

orthogonal system. V_x , V_y and V_z are the three components of inertial velocity; V_{x_c} , V_{y_c} and V_{z_c} are the corresponding velocity commands. Eqs. (1) through (3) describe a simple dynamic system with three state variables (x , y , z) and three control variables (V_{x_c} , V_{y_c} , V_{z_c}), with time being the independent variable.

The vehicle model can be reduced further (since time is not of great importance) by using a monotonic function of the position coordinates as the independent variable. For most trajectories, the ground range to go, R , is convenient for this purpose

$$R = \sqrt{x^2 + y^2} \quad (4)$$

Differentiating Eq. (4) with respect to time and using Eqs. (1) and (2) gives*

$$\dot{R} = (xV_{x_c} + yV_{y_c})/R \quad (5)$$

Dividing Eqs. (2) and (3) by Eq. (5), we obtain*

$$dy/dR = RV_{y_c} / (xV_{x_c} + yV_{y_c}) \quad (6)$$

$$dz/dR = RV_{z_c} / (xV_{x_c} + yV_{y_c}) \quad (7)$$

where x is determined by

$$x = -\sqrt{R^2 - y^2} \quad (8)$$

from the definition of the coordinate system.

*Since the right hand sides of Eqs. (5) - (7) become indeterminate for $R = \dot{R} = 0$, this simplified model is not valid for the final hover and touchdown.

Thus, Eqs. (6) through (8) completely describe the approximate motion of the controlled aircraft. The two state variables are y and z ; the three control variables are V_{x_c} , V_{y_c} and V_{z_c} ; R is the independent variable; and the third position coordinate x is a dependent parameter given by Eq. (8).

2.2 PERTURBATION EQUATIONS

The simplified equations of motion, Eqs. (6) and (7), are nonlinear; however, the synthesis technique to be applied later requires the equations of motion to be linear in both the state and control variables. This may be accomplished by taking first-order perturbations of the equations about a nominal trajectory.

Using vector-matrix notation, the perturbation form of Eqs. (6) and (7) may be written in the standard form

$$d\underline{x}/dR = F\underline{x} + G\underline{u} \quad (9)$$

where the state vector $\underline{x}$ and the control vector $\underline{u}$ are defined by

$$\underline{x} = \begin{bmatrix} \delta y \\ \delta z \end{bmatrix} \quad (10)$$

$$\underline{u} = \begin{bmatrix} \delta V_{x_c} \\ \delta V_{y_c} \\ \delta V_{z_c} \end{bmatrix} \quad (11)$$

and the matrices F and G are given by

$$F = \frac{R(y_N^V x_{c_N} - x_N^V y_{c_N})}{x_N(x_N^V x_{c_N} + y_N^V y_{c_N})^2} \begin{bmatrix} v_{y_{c_N}}, 0 \\ v_{z_{c_N}}, 0 \end{bmatrix} \quad (12)$$

$$G = \frac{R}{(x_N^V x_{c_N} + y_N^V y_{c_N})^2} \begin{bmatrix} -x_N^V y_{c_N}, x_N^V x_{c_N}, 0 \\ -x_N^V z_{c_N}, -y_N^V z_{c_N}, x_N^V x_{c_N} + y_N^V y_{c_N} \end{bmatrix} \quad (13)$$

In the above equations, the perturbation quantities are defined as

$$\delta(\) = (\) - (\)_N \quad (14)$$

where the subscript N denotes the nominal value of the indicated quantity.

2.3 QUADRATIC SYNTHESIS

Having described the approximate motion of the controlled aircraft in the vicinity of the nominal trajectory, we may now apply the quadratic synthesis technique (Ref. 3) to find a linear feedback guidance law. A convenient performance index to choose for this purpose is one which is a quadratic function of the control and state variable perturbations:

$$J = \frac{1}{2}(\underline{x}^T S_f \underline{x})_{R=R_f} + \frac{1}{2} \int_{R_i}^{R_f} [\underline{x}^T A \underline{x} + \underline{u}^T B \underline{u}] dR \quad (15)$$

where R_i and R_f are, respectively, the initial and final range. The matrices S_f and A weight the penalties associated with terminal and enroute state variable errors, and the matrix B penalizes control deviations during the flight:

$$S_f = \begin{bmatrix} \delta y_f^{-2} & , & 0 \\ 0 & , & \delta z_f^{-2} \end{bmatrix} \quad (16)$$

$$A = \frac{1}{R_f - R_i} \begin{bmatrix} \delta y_m^{-2} & , & 0 \\ 0 & , & \delta z_m^{-2} \end{bmatrix} \quad (17)$$

$$B = \frac{1}{R_f - R_i} \begin{bmatrix} \delta V_{x_{c_m}}^{-2} & , & 0 & 0 \\ 0 & , & \delta V_{y_{c_m}}^{-2} & , & 0 \\ 0 & , & 0 & \delta V_{z_{c_m}}^{-2} \end{bmatrix} \quad (18)$$

The parameters δy_f , δz_f , δy_m , δz_m , $\delta V_{x_{c_m}}$, $\delta V_{y_{c_m}}$ and $\delta V_{z_{c_m}}$ must be chosen to provide satisfactory enroute and terminal guidance within acceptable limitations on δV_{x_c} , δV_{y_c} and δV_{z_c} .

The minimization of the performance criterion, Eq. (15), subject to the perturbation equations of motion, Eq. (9), yields the linear feedback guidance law

$$\delta \underline{u} = -C(R) \delta \underline{x} \quad (19)$$

where the feedback gain matrix $C(R)$ is defined by

$$C = B^{-1}G^TS \quad (20)$$

and B^{-1} is the inverse of B [Eq. (18)], G^T is the transpose of G [Eq. (13)] and S is the solution of the matrix Riccati equation

$$\frac{dS}{dR} = -SF - F^TS + SGB^{-1}G^TS - A \quad (21)$$

with the boundary condition

$$S(R_f) = S_f \quad (22)$$

2.4 IMPLEMENTATION OF THE GUIDANCE CONCEPT

In expanded form the guidance law, Eq. (19), is

$$V_{x_c} = V_{x_{c_N}} - C_{V_x,y} (y - y_N) - C_{V_x,z} (z - z_N) \quad (23)$$

$$V_{y_c} = V_{y_{c_N}} - C_{V_y,y} (y - y_N) - C_{V_y,z} (z - z_N) \quad (24)$$

$$V_{z_c} = V_{z_{c_N}} - C_{V_z,y} (y - y_N) - C_{V_z,z} (z - z_N) \quad (25)$$

Figure 3 is a block diagram showing the configuration of the velocity-command guidance system with the simple model of the controlled aircraft used in the analysis. In the simulation described in the next section, and in actual implementation, the contents of the dashed block "Controlled Aircraft" are replaced by the flight control system and the actual ("bare") helicopter dynamics.

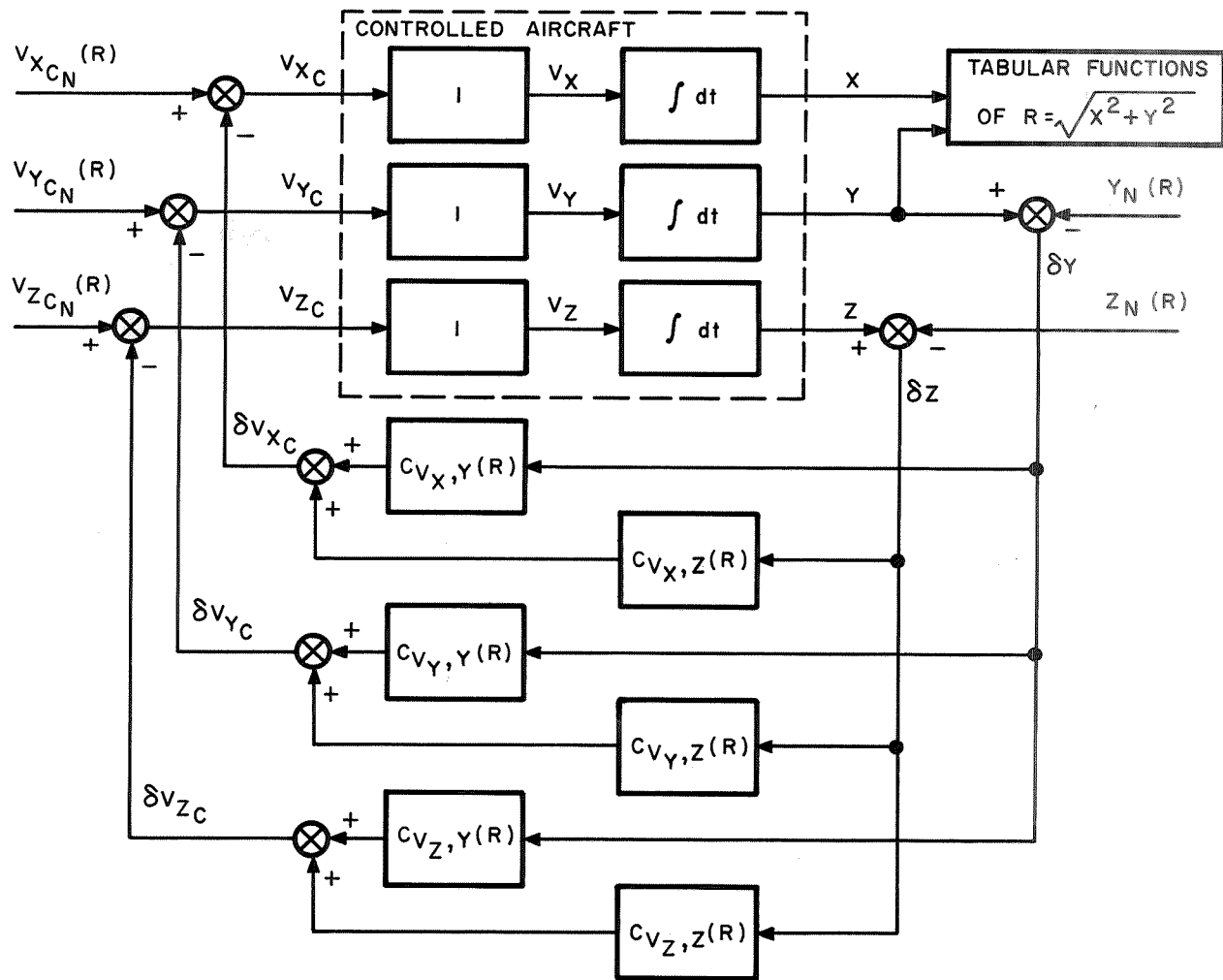


Fig. 3. Velocity-Command Guidance System With Simple Model of Controlled Aircraft

In addition to Eqs. (23) through (25), the guidance function must include the necessary calculations to comply with the guidance/flight control interface specification. Consequently, the guidance system outputs must be the components of the "velocity-to-be-gained" (i.e., difference between the desired and actual velocity components) resolved into a "Vertical Heading" reference frame, which was selected by the flight control system

designers for the convenience of a manually operated mode. The "Vertical Heading" frame has its origin at the aircraft center of mass and is defined as follows: the x axis is the projection of the body-fixed x axis onto the local horizontal plane; the z axis is vertical and directed downward; and the y axis completes the orthogonal triad. Thus, the transformation from the inertial frame to the "Vertical Heading" frame involves a rotation through the yaw (or heading) angle ψ about the z axis. As a result, the guidance system outputs are given by

$$V_{x_G} = (V_{x_c} - V_x) \cos \psi + (V_{y_c} - V_y) \sin \psi \quad (26)$$

$$V_{y_G} = -(V_{x_c} - V_x) \sin \psi + (V_{y_c} - V_y) \cos \psi \quad (27)$$

$$V_{z_G} = V_{z_c} - V_z \quad (28)$$

Figure 4 is a flow diagram for the implementation of the guidance algorithm, Eqs. (23) through (28). The inputs required are the three inertial position coordinates (x, y, z), the three inertial velocity components (V_x , V_y , V_z) and the yaw angle ψ . The outputs are the three components of velocity-to-be-gained in the Vertical Heading frame (V_{x_G} , V_{y_G} , V_{z_G}). Fixed data storage is required for twelve guidance quantities: the independent variable (R); the five nominal trajectory histories (y_N , z_N , $V_{x_{c_N}}$, $V_{y_{c_N}}$, $V_{z_{c_N}}$); and the six feedback gains ($C_{V_x,y}$, $C_{V_y,y}$, $C_{V_z,y}$, $C_{V_x,z}$, $C_{V_y,z}$, $C_{V_z,z}$). From the results of the simulations

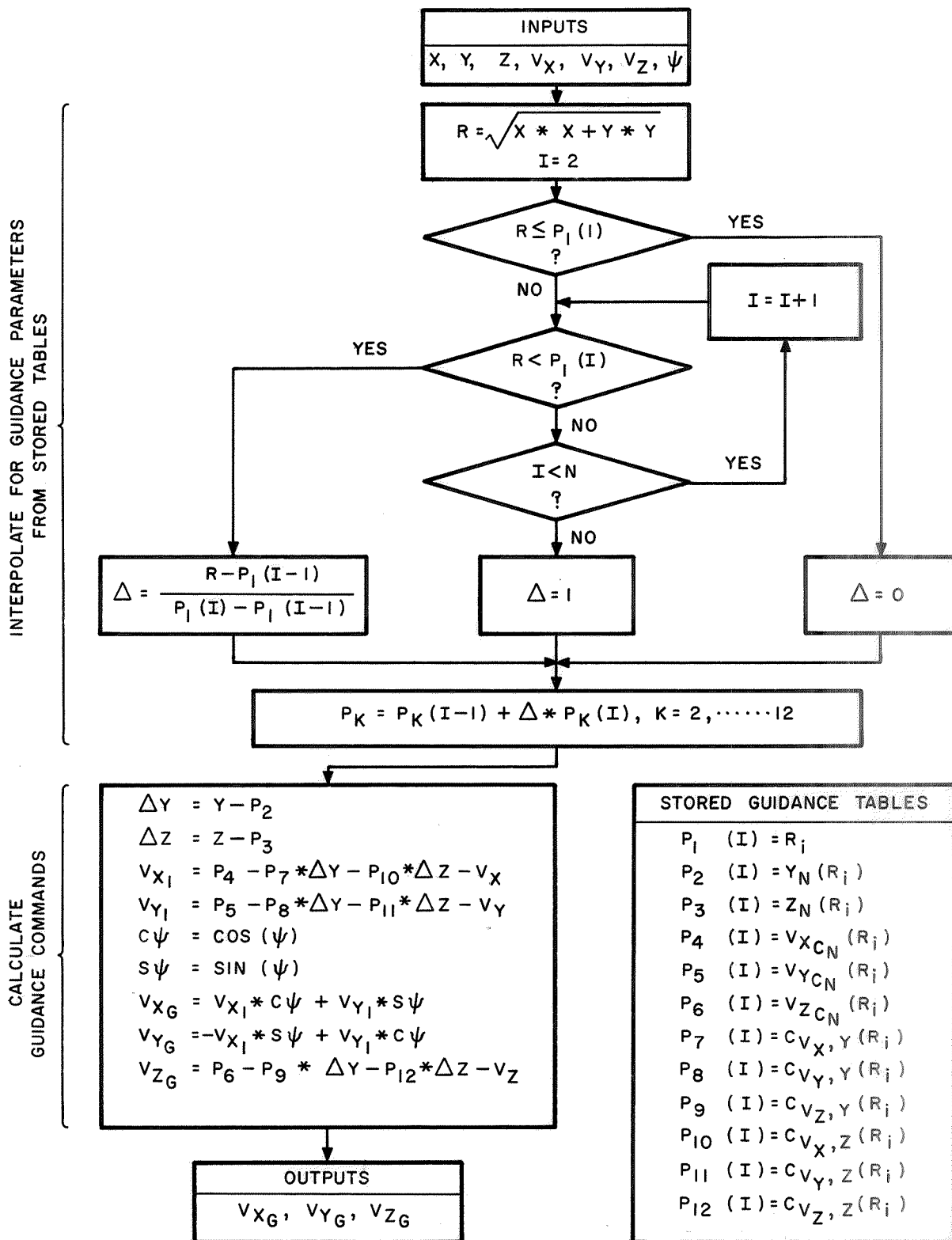


Fig. 4. Computer Flow Diagram for Guidance Scheme

described in Section IV, it is estimated that approximately 25 sets of data points should be sufficient to represent most realistic nominal trajectories.

Table 1 provides a summary of the estimated computer requirements for the guidance scheme -- including computation time, storage, and resolution and maximum expected values of important quantities. The data in Table 1 are based on the flow chart of Fig. 4 and the simulation experience gathered during this investigation. As indicated in Section IV, possible savings in storage requirements might be realized for certain nominal trajectories (e.g., one with no turns), although with some loss of flexibility. However, from Table 1 it is apparent that the storage requirements for a single nominal trajectory are very modest, so that a number of different nominals might be carried along for greater flexibility or contingency situations. In fact, six nominals would require only about 2000 words of memory for the entire guidance function. The maximum time required for the guidance calculations is approximately 2 milliseconds*; hence a sample rate of 8 to 10 per second would consume less than 5% of the computer's time.

*Based on operation speeds of IBM 4 π /CP-2 computer.
(See Table 1.)

Table 1. Estimated Computer Requirements

Data Specifications				Storage (Words)	Speed (μ sec)	
Quantity (Units)	Min.	Max.	Resolution*		Operation**	No. Time
x, y, x_N, y_N (km)	-500	500	0.1 or 0.05%	Permanent	$\pm$ @ 3.8	204 775.2
z, z_N (m)	-50	1500	0.1	Guidance Tables (1 nominal)	$\times$ @ 11.5	23 264.5
R (km)	0	700	0.1 or 0.05%	Program	$\div$ @ 46.3	1 46.3
$V_x, V_y, V_{x_{CN}}, V_{y_{CN}}$ (m/sec)	-75	75	0.02	Temporary	$\sqrt$ @ 250	1 250
$V_z, V_{z_{CN}}$ (m/sec)	-8	8	0.02	Margin ($\sim 10\%$)	sin @ 244	1 244
$V_{x_G}, V_{y_G}, V_{z_G}$ (m/sec)	-1	1	0.02	Total	cos @ 230	1 230
ψ (deg)	-180	180	0.1		store @ 2.5	54 135
$C_{V_{x,y}}$ (sec^{-1})	-0.5	0.5	10^{-5}		Margin ($\sim 10\%$)	195
$C_{V_{y,y}}, C_{V_{z,z}}$ (sec^{-1})	0	1	10^{-5}		Total	2140
$C_{V_{z,y}}, C_{V_{x,z}}, C_{V_{y,z}}$ (sec^{-1})	-0.01	0.01	10^{-6}			

*If two quantities are given, the larger of the two applies.

**Times for IBM 4 π /CP-2 computer.

SECTION III

DIGITAL SIMULATION

To evaluate the performance of the guidance law formulated in the previous section, a six-degree-of-freedom digital computer simulation of the tandem-rotor YHC-1A helicopter was developed by modifying Program LIFT (Ref. 4). The important changes made in LIFT are discussed below.*

3.1 VEHICLE MODEL

The most significant modification of LIFT required the development of a mathematical model which adequately describes the aerodynamics of the helicopter. Two possibilities were investigated:

1. An Analytical Model. This approach would utilize an approximate analytical model which describes the aerodynamic forces acting on the vehicle as functions of its position, velocity, pitch and roll attitudes, and collective stick displacement, where the last three variables are the control inputs to the model. An analytical model which was developed for this purpose is described in Appendix B.
2. A Near-Trim Model. The alternative approach would utilize the trim and stability derivative data contained in Reference 5 to calculate the aerodynamic forces and moments as functions of altitude; velocity; all three vehicle attitudes (yaw, pitch, roll) and their

*A complete listing of the modified version of LIFT is contained in Appendix A.

rates; and the four control displacements (differential collective, gang collective, roll cyclic, yaw cyclic).

The advantages of the analytical model for guidance studies are (1) it is simpler, in that it does not include the pitching dynamics of the vehicle, and (2) it is not a linearized model which relies on a near-trim assumption for validity. On the other hand, the near-trim model has the advantage of allowing a more complete simulation of the vehicle dynamics, both translational and rotational, and of including the complete flight control system as well.

The near-trim model was eventually selected for the simulation since it was anticipated that the aircraft would be flown in the vicinity of trim to maintain reasonably comfortable flights. Thus, in a body axis frame, the aerodynamic forces and moments acting on the vehicle are represented in LIFT in the following manner:

$$F_x = mg \sin \theta_o + X_u \Delta u + X_w \Delta w + X_q q + X_{\delta_e} \Delta \delta_e + X_{\delta_c} \Delta \delta_c \quad (29)$$

$$F_y = Y_v \Delta v + Y_p p + Y_r r + Y_{\delta_a} \Delta \delta_a + Y_{\delta_r} \Delta \delta_r \quad (30)$$

$$F_z = -mg \cos \theta_o + Z_u \Delta u + Z_w \Delta w + Z_q q + Z_{\delta_e} \Delta \delta_e + Z_{\delta_c} \Delta \delta_c \quad (31)$$

$$F_\ell = L_v v + L_p p + L_r r + L_{\delta_a} \Delta \delta_a + L_{\delta_r} \Delta \delta_r \quad (32)$$

$$F_m = M_u \Delta u + M_w \Delta w + M_q q + M_{\delta_e} \Delta \delta_e + M_{\delta_c} \Delta \delta_c \quad (33)$$

$$F_n = N_v v + N_p p + N_r r + N_{\delta_a} \Delta \delta_a + N_{\delta_r} \Delta \delta_r \quad (34)$$

where

$$\Delta() = () - ()_o \quad (35)$$

and the subscript o denotes the trim value of the indicated quantity. The trim values θ_o , δ_{e_o} , δ_{c_o} , δ_{a_o} , δ_{r_o} and the stability derivatives X_u , X_w , etc., are linearly interpolated from data tables as functions of the horizontal and vertical velocity components relative to the air, V_H and V_V :

$$V_H = \sqrt{(V_x - w_x)^2 + (V_y - w_y)^2} \quad (36)$$

$$V_V = V_z - w_z \quad (37)$$

where w_x , w_y and w_z are the inertial wind components. The stored data tables for the YHC-1A helicopter were obtained from Reference 5 for the operating conditions shown in Table 2.

Table 2. Operating Conditions for YHC-1A
Trim and Stability Derivative Data in
Program LIFT

Gross weight	13,400 lbs
c.m. Position	normal
I_{xx}	9203 slug-ft ²
I_{yy}	75,914 slug-ft ²
I_{zz}	71,786 slug-ft ²
J_{xz}	-7114 slug-ft ²
Rate of Descent, V_V	-1500, 0, +1500 ft/min
Altitude	sea level
Forward Velocity, V_H	0, 20, 40, 60, 80, 100, 120, 140 kts

The tables themselves and other pertinent vehicle data are contained in Appendix C. Only sea level data were used since (1) complete data for other altitudes were not available, and (2) all flight tests will be restricted to low altitudes (~ 1000 ft) where the data are just slightly different from sea level values.

Another modification to Program LIFT was the addition of a variable mass capability to account for fuel consumption. This requires the integration of another differential equation:

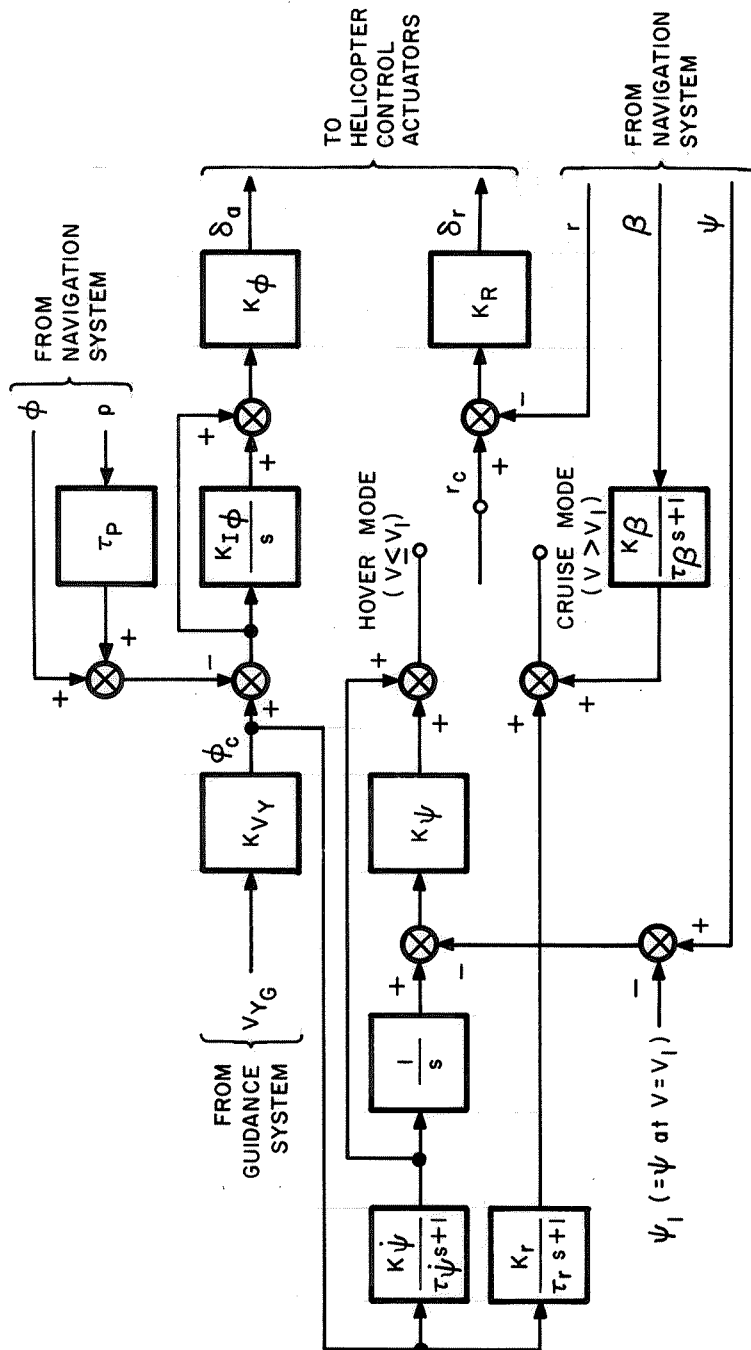
$$\frac{dm}{dt} = -f(V_H, V_V) \quad (38)$$

The rate of fuel flow f is interpolated from a stored table of trim values obtained from Reference 6 (see Appendix C).

3.2 FLIGHT CONTROL SYSTEM

The second major change made in LIFT involved the inclusion of the velocity-command flight control system which has been developed by NASA/ERC. The longitudinal and lateral-directional channels of this system are shown in Figs. 5 and 6, respectively. The addition of eight state variables to the program was required to implement the flight control system, as defined below.

$$\frac{dV_{x_{GI}}}{dt} = V_{x_G} \quad (39)$$



$K_{VY} = 0.13123 \text{ RAD-SEC/M}$	$K_{\dot{\psi}} = 1.0 \text{ SEC}^{-1}$	$K_R = 38.10 \text{ CM-SEC/RAD}$
$\tau_p = 0.50 \text{ SEC}$	$\tau_{\dot{\psi}} = 20.0 \text{ SEC}$	$K_{\beta} = 0.30 \text{ SEC}^{-1}$
$K_{I\phi} = 0.35 \text{ SEC}^{-1}$	$K_{\psi} = 1.0 \text{ SEC}^{-1}$	$\tau_{\beta} = 0.50 \text{ SEC}$
$K_{\phi} = 38.10 \text{ CM/RAD}$	$K_r = 0.3 \text{ SEC}^{-1}$	$V_l = 18.0 \text{ M/SEC}$
	$\tau_r = 0.5 \text{ SEC}$	

Fig. 6. Lateral-Directional Channels of Velocity-Command Flight Control System

$$\frac{d\theta_{E_I}}{dt} = \theta_E \quad (40)$$

$$\frac{dV_{z_{G_I}}}{dt} = V_{z_G} \quad (41)$$

$$\frac{d\phi_{E_I}}{dt} = \phi_E \quad (42)$$

$$\frac{d\phi_{c_{I_1}}}{dt} = \frac{K_{\psi} \phi_c - \phi_{c_{I_1}}}{\tau_{\psi}} \quad (43)$$

$$\frac{d\psi_c}{dt} = \phi_{c_{I_1}} \quad (44)$$

$$\frac{d\phi_{c_{I_2}}}{dt} = \frac{K_r \phi_c - \phi_{c_{I_2}}}{\tau_r} \quad (45)$$

$$\frac{d\beta_I}{dt} = \frac{\beta - \beta_I}{\tau_{\beta}} \quad (46)$$

where

$$\theta_E = \theta_c - \theta - \tau_Q q \quad (47)$$

$$\theta_c = K_{v_x} (V_{x_G} + K_{I_{v_x}} V_{x_{E_I}}) \quad (48)$$

$$\phi_E = \phi_c - \phi - \tau_p p \quad (49)$$

$$\phi_c = K_{v_y} V_{y_G} \quad (50)$$

With the above definitions, the flight control system commands are given by

$$\delta_e = K_\theta (\theta_E + K_{I_\theta} \theta_{E_I}) \quad (51)$$

$$\delta_c = K_{V_z} (V_{z_G} + K_{V_z} V_{z_{G_I}}) \quad (52)$$

$$\delta_a = K_\phi (\phi_E + K_{I_\phi} \phi_{E_I}) \quad (53)$$

$$\delta_r = \begin{cases} K_R [\phi_{c_{I_1}} + K_\psi (\psi_c - \psi + \psi_1) - r] , & V \leq V_1 \\ K_R [\phi_{c_{I_2}} - K_\beta \beta_I - r] , & V > V_1 \end{cases} \quad (54a)$$

$$(54b)$$

V_1 is the true airspeed at which the flight control system switches from a hover mode, Eq. (54a), to a cruise mode, Eq. (54b). To prevent large transients when switching from cruise to hover mode, the yaw angle feedback is biased by the value which existed at mode switch, ψ_1 .

The initial conditions for the additional state variables introduced by the flight control system were chosen to correspond to trim flight at the initial velocity and altitude, i.e.

$$V_{x_{G_I}}(t_i) = \frac{\theta_o(V_{x_i}, V_{z_i})}{K_{V_x} K_{V_{x_I}}} \quad (55)$$

$$\theta_{E_I}(t_i) = \frac{\delta_{e_o}(V_{x_i}, V_{z_i})}{K_\theta K_{I_\theta}} \quad (56)$$

$$V_{z_{G_I}}(t_i) = \frac{\delta_{c_o}(V_{x_i}, V_{z_i})}{K_v K_z} \quad (57)$$

$$\phi_{E_I}(t_i) = \frac{\delta_{a_o}(V_{x_i}, V_{z_i})}{K_\phi K_{I_\phi}} \quad (58)$$

$$\phi_{c_{I_1}}(t_i) = 0 \quad (59)$$

$$\psi_c(t_i) = \frac{\delta_{r_o}(V_{x_i}, V_{z_i})}{K_R K_\psi} + \psi(t_i) \quad (60)$$

$$\phi_{c_{I_2}}(t_i) = 0 \quad (61)$$

$$\beta_I(t_i) = 0 \quad (62)$$

3.3 GUIDANCE SYSTEM

The last important modification of LIFT was the implementation of the guidance scheme developed in Section II. This requires storing eleven pre-calculated quantities as functions of the independent variable, range to go. The stored histories are the nominal crossrange and vertical positions, the three nominal velocity commands and the six feedback gains. At each integration step, the current range is used to interpolate for the appropriate value of each of these quantities, and the velocity commands are generated via Eqs. (23) through (28).

SECTION IV

SYSTEM PERFORMANCE

The performance of the guidance concept developed in Section II was evaluated by means of the digital simulation described in Section III. This section discusses the nominal trajectory which was used in the simulations, the corresponding feedback gains and the results obtained for a variety of off-nominal conditions.

4.1 NOMINAL TRAJECTORY

One of the more difficult tasks in applying this type of a guidance concept is the selection of an appropriate nominal trajectory about which to linearize the equations. A number of approaches are possible. One could somewhat arbitrarily select a set of nominal control histories and exercise the simulation with these as open-loop guidance commands to obtain a nominal. Then, by trial and error, the control histories could be adjusted until a satisfactory nominal trajectory is obtained. This is generally a very tedious process. A more sophisticated approach would be to automate this iterative process by using optimization techniques to calculate a nominal trajectory which extremalizes a specified performance criterion (e.g., minimum fuel) and satisfies a given set of terminal conditions (e.g., position and velocity), without violating any enroute constraints (e.g., noise or air traffic control

restrictions). Unfortunately, the calculation of such an optimum trajectory is a major effort in itself and was not feasible during the present study.*

A third alternative, the one used here, consists of generating a simple, analytical nominal which, although it may violate some physical constraints (e.g., instant accelerations), at least approximates a reasonable a priori trajectory. This approach was felt to be adequate for the present study, since the primary purpose was the preliminary verification by simulation of a guidance concept, and not the calculation of recommended experimental or operational flight profiles.

Fig. 7 shows the nominal trajectory used in the study. It consists of several piece-wise-constant vertical and horizontal acceleration segments, which are indicated on the figure. The selected nominal is a planar flight covering a horizontal distance of 10 km (~ 5.4 nmi), which has been subdivided into three phases; takeoff, cruise and approach. The choice of the takeoff phase of the trajectory was based on conversations held with the NASA/LaRC test pilots of the YHC-1A helicopter. It begins with a vertical lift-off to hover at 10 m (~ 30 ft) above the runway, followed by a constant horizontal acceleration to 5 m/sec (~ 10 kts) which is maintained for 20 seconds to provide the pilot an opportunity to verify system performance. The forward velocity is then increased to 25 m/sec (~ 50 kts), at

*The calculation of optimum VTOL trajectories has been the subject of some inhouse NASA/ERC research.

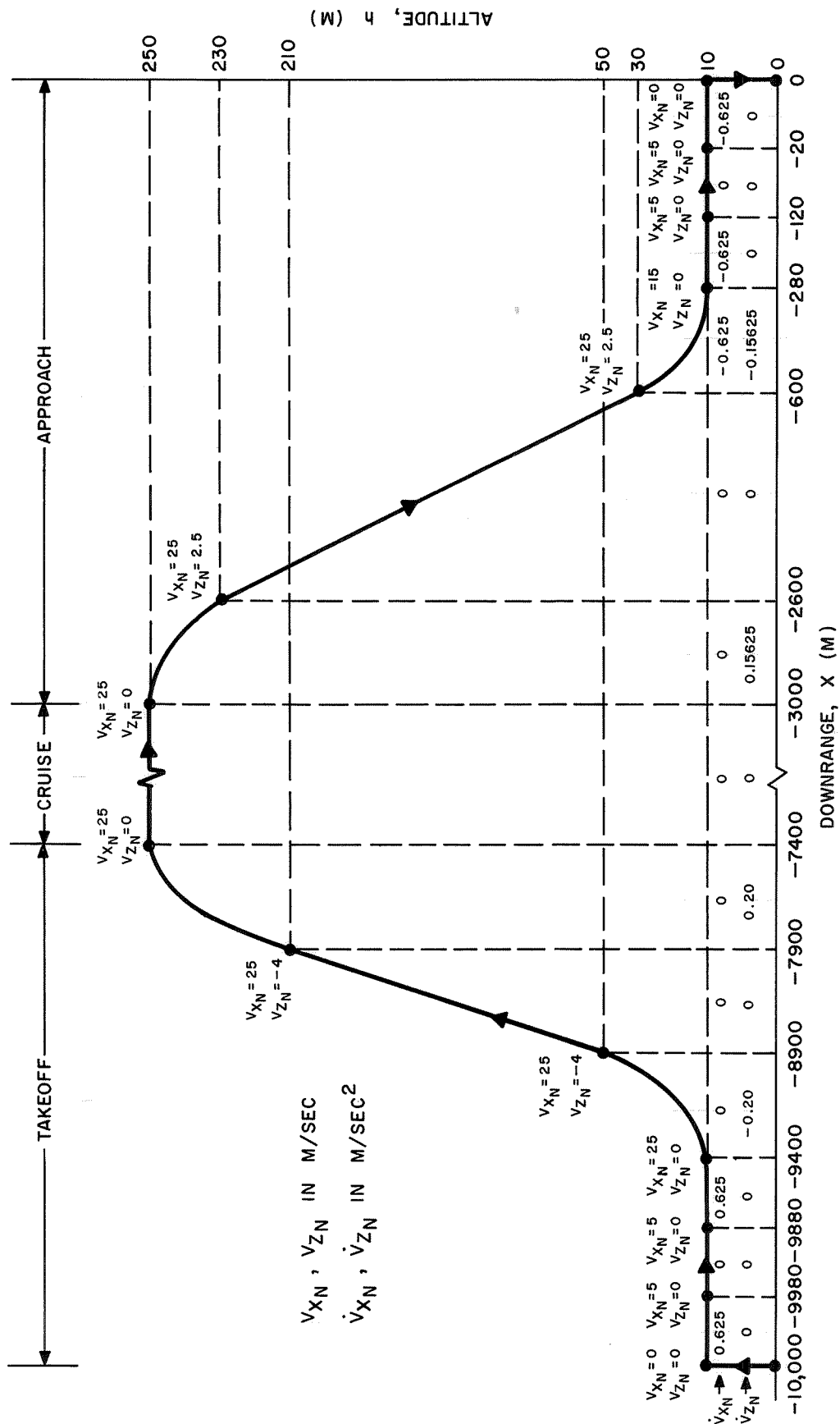


Fig. 7. Nominal VTOL Planar Trajectory

which point the transition to a steady climb rate of 4 m/sec (~800 ft/min) is initiated. The steady rate of ascent is held until an altitude of 210 m (~700 ft), where the leveling off maneuver begins. The beginning of the cruise phase occurs when the aircraft has attained level flight at an altitude of 250 m (~800 ft). This cruise condition is maintained until the aircraft is 3000 m (~10,000 ft) from touchdown, where the approach phase begins.

The approach phase of the trajectory, which is the most crucial in terms of accuracy requirements, was modeled after the nominal approach used by NASA/ERC personnel for the flight control system analysis. At 3000 m (~10,000 ft) from touchdown, a constant vertical acceleration transition is initiated, which is completed when a flight path angle of -0.1 rad has been achieved. The constant rate of descent of 2.5 m/sec (~500 ft/min) is maintained until an altitude of 30 m (~100 ft) is reached, at which point the flare maneuver is commenced. The flare itself consists of constant vertical and horizontal accelerations such that the aircraft levels off at an altitude of 10 m (~30 ft). The horizontal deceleration is maintained until the velocity has been reduced to 5 m/sec (~10 kts). This condition is held for 20 seconds to again provide the pilot an opportunity to verify system performance. The remainder of the trajectory consists of a final deceleration to hover above the runway followed by a vertical descent to touchdown.

Fig. 8 shows the nominal takeoff and approach paths on a speed vs altitude plot. The shaded areas indicate the "dead man" curves which have been assumed for the YHC-1A. These are the areas from which a safe recovery could not be affected in the event of a single engine failure. Since actual data for the YHC-1A vehicle were unavailable, the "avoid" areas in Fig. 8 were approximated from corresponding curves for the Vertol CH-46D vehicle (Reference 7).

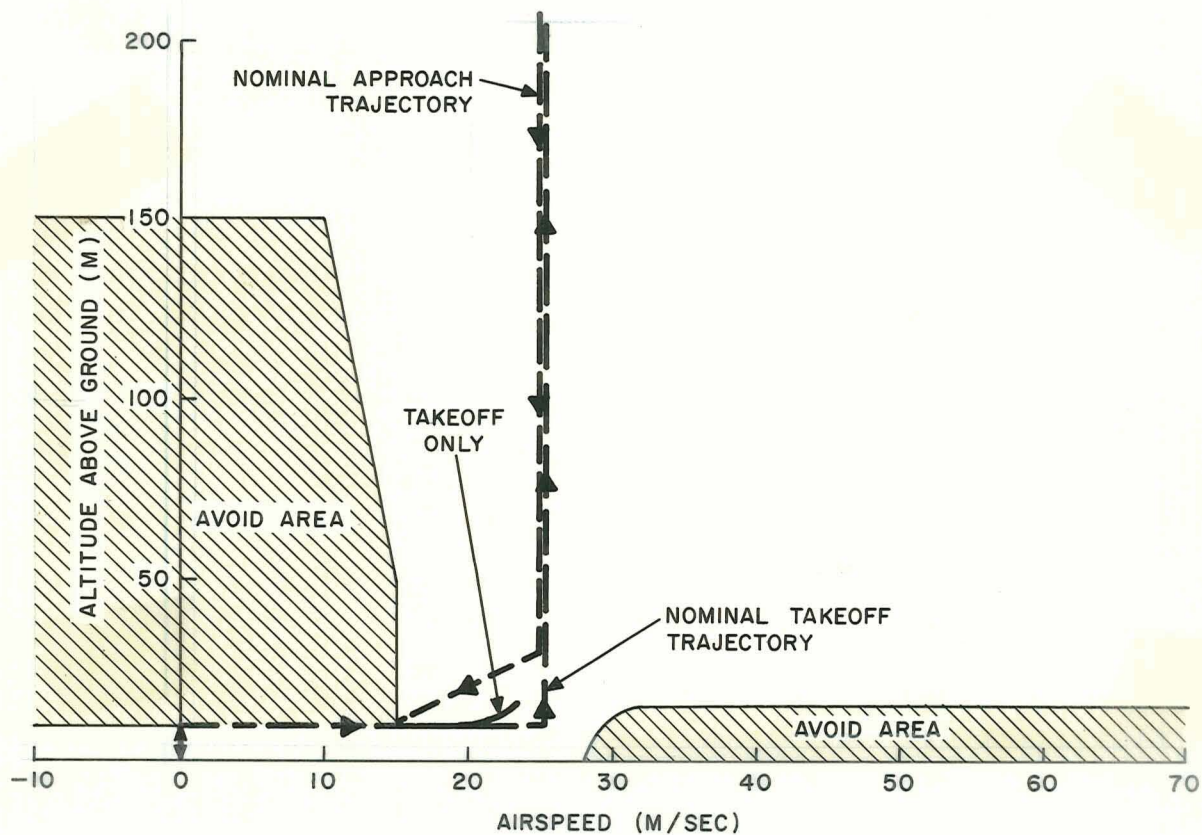


Fig. 8. YHC-1A Height for Safe Landing After Single Engine Failure (Assumed) With Nominal Takeoff and Approach Paths Indicated

In addition to the complete planar nominal just described, a 90° approach phase nominal was also devised to briefly examine

the system performance during a turning maneuver. This 90° approach nominal, whose ground track is shown in Fig. 9, was simply obtained from the straight-in approach of Fig. 7 by "wrapping" it around a 500 m radius vertical cylinder, beginning at $x = -1200$ m. Thus, the two approaches are identical for $R \leq 1200$ m.

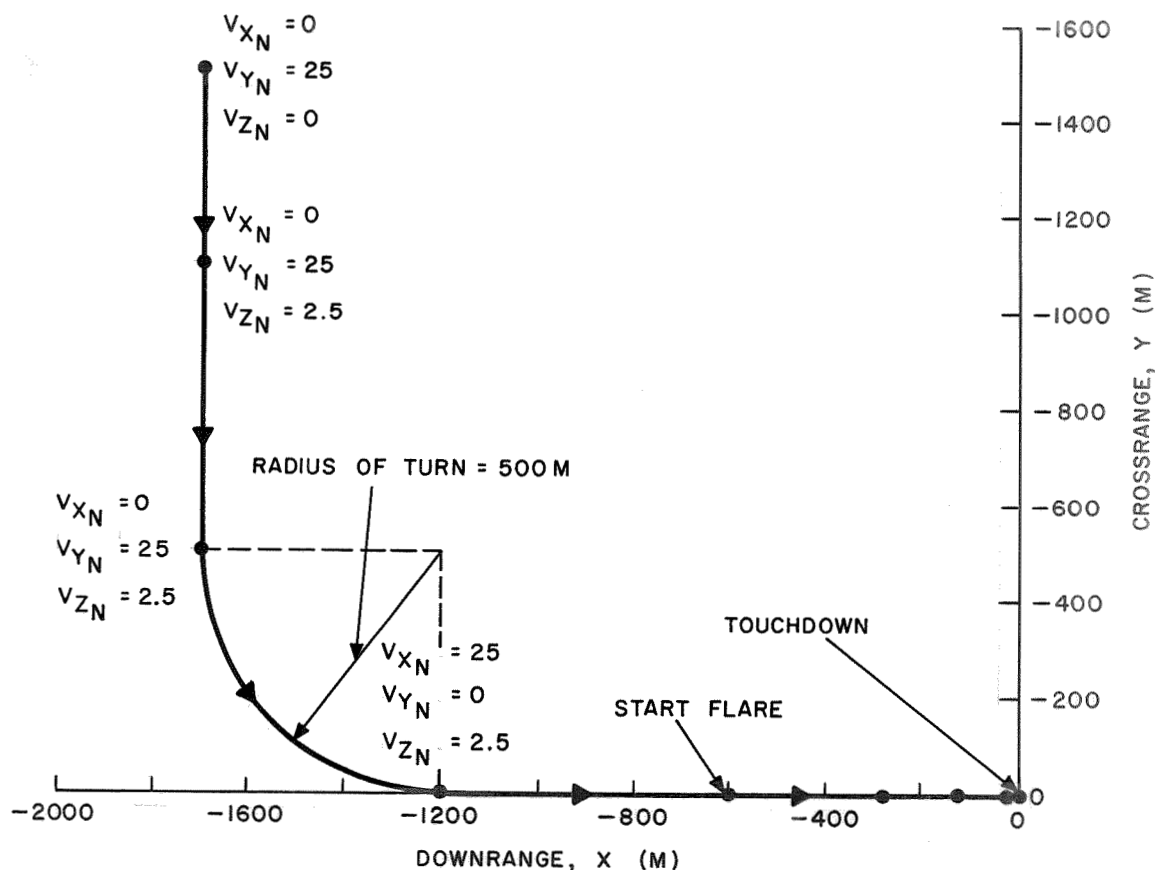


Fig. 9. Nominal 90° Approach Trajectory

4.2 GUIDANCE FEEDBACK GAINS

Using the nominal trajectories just described, the guidance feedback gains were calculated for each phase by integrating

Eq. (21) backwards, i.e., away from the touchdown point. The weighting parameters which were used in these calculations are given in Table 3. The values of δy_f and δz_f for the takeoff phase were selected such that the gains at the end of this phase matched the (constant) cruise gains. Except for the cruise phase, which is a steady-state flight condition, the weighting parameters penalize both enroute and terminal deviations from the nominal trajectory.

At either end of the nominal trajectory, the aircraft velocity goes to zero. As a result, the rate of change of the independent variable becomes zero, while the nonzero feedback

Table 3. Weighting Parameters Used to Calculate Guidance Feedback Gains

	TAKEOFF	CRUISE	APPROACHES
δy_m	10.0 m	15.0 m	15.0 m
δz_m	10.0 m	15.0 m	15.0 m
δy_f	27.8 m	∞	5.0 m
δz_f	27.8 m	∞	5.0 m
$\delta V_{x_{c_m}}$	0.5 m/sec	0.5 m/sec	0.5 m/sec
$\delta V_{y_{c_m}}$	0.5 m/sec	0.5 m/sec	0.5 m/sec
$\delta V_{z_{c_m}}$	0.5 m/sec	0.5 m/sec	0.5 m/sec

gains become infinite. To avoid these difficulties, the initial and final ranges used in the calculations were 20 m from the actual ends of the trajectory (i.e., $R_i = 9980$ m and $R_f = 20$ m), where in both cases, $V_{x_N} = 5$ m/sec. The resulting feedback gains are shown in Fig. 10. For a planar nominal trajectory, ($V_{y_{c_N}} = y_N = 0$), three of the six gains are always zero: $C_{V_{x,y}}$, $C_{V_{z,y}}$ and $C_{V_{y,z}}$. Furthermore, during level flight ($V_{z_{c_N}} = 0$) $C_{V_{x,z}}$ also vanishes. It is also interesting that for these weighting parameters, the remaining two gains, $C_{V_{y,y}}$ and $C_{V_{z,z}}$, are nearly identical throughout the entire flight. Consequently, a significant savings in computer storage might be realized during a straight flight since only two gain histories are required.

To simulate the guidance system's performance, the nominal trajectory histories and the feedback gains had to be stored as functions of the range to go. The values of these quantities which were used to obtain the results discussed in the remainder of this section are presented in Tables 4 and 5. The small symbols in Fig. 10 indicate the stored gain values for the planar nominal. To prevent numerical interpolation difficulties at either end of the trajectory, the guidance tables include entries at $R = 0$ m and 10,000 m, which assume the gains to be constant during the first and last 20 m of the flight.

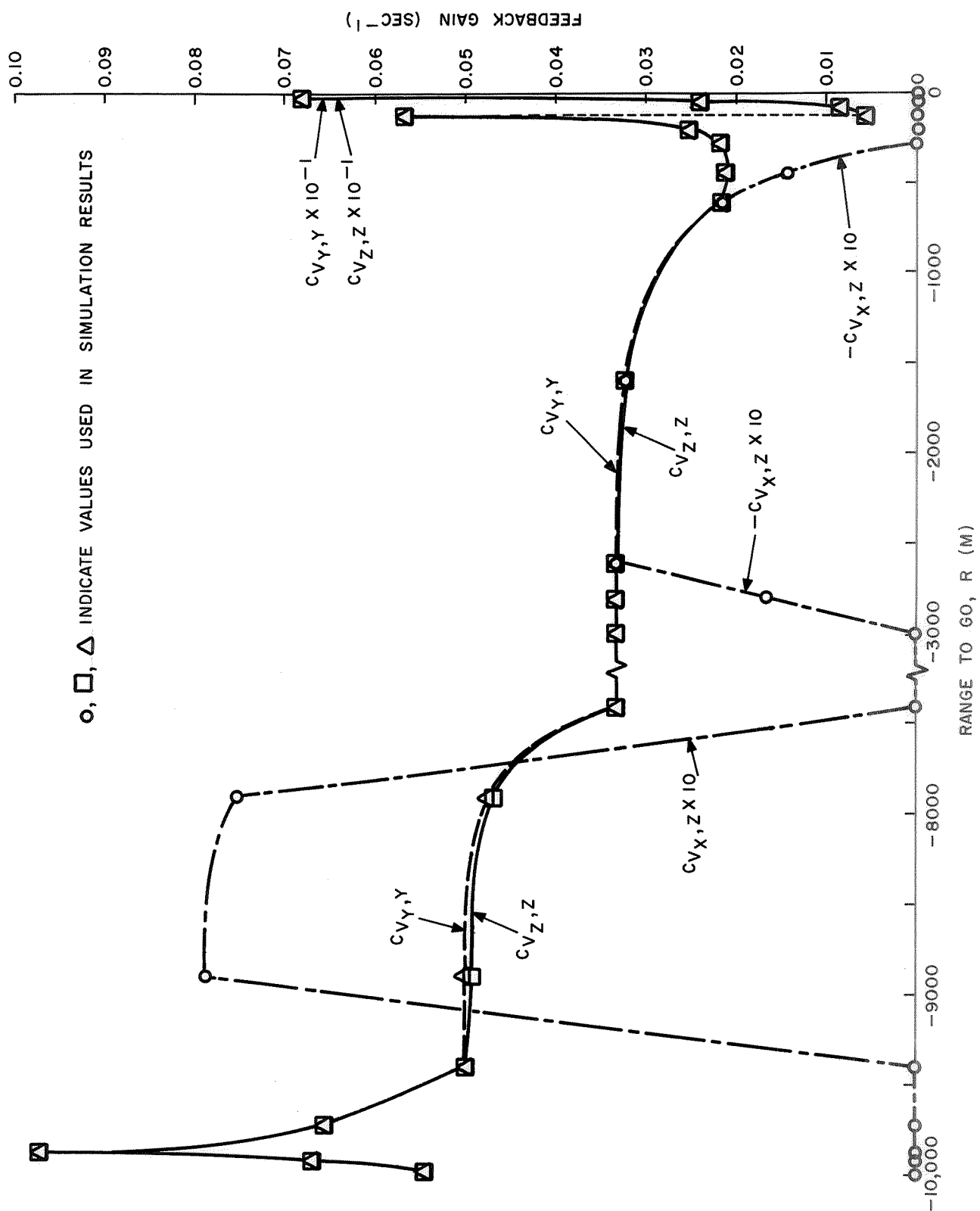


Fig. 10. Feedback Gains for Planar Nominal Trajectory

Table 4. Stored Guidance Quantities for Planar Nominal

R (m)	z_N (m)	$V_{x_{C_N}}$ (m/sec)	$V_{z_{C_N}}$ (m/sec)	$C_{V_{y,y}}$ (sec ⁻¹)	$C_{V_{x,z}}$ (sec ⁻¹)	$C_{V_{z,z}}$ (sec ⁻¹)	
0	-10	0	0	0.6827	0	0.6827	APPROACH
20	-10	5	0	0.6827	0	0.6827	
40	-10	5	0	0.2415	0	0.2415	
80	-10	5	0	0.08664	0	0.08664	
120	-10	5	0	0.05684	0	0.05684	
200	-10	11.18	0	0.02498	0	0.02498	
280	-10	15	0	0.02173	0	0.02173	
440	-16.31	20.62	1.4	0.02097	-0.001428	0.02097	
600	-30.0	25	2.5	0.02153	-0.002150	0.02150	
1,600	-130.0	25	2.5	0.03235	-0.003221	0.03221	
2,600	-230	25	2.5	0.03326	-0.003310	0.03310	CRUISE
2,800	-243.94	25	1.38	0.03329	-0.001658	0.03316	
3,000	-250	25	0	0.03333	0	0.03333	
7,400	-250	25	0	0.03333	0	0.03333	TAKEOFF
7,900	-210	25	-4	0.04737	0.007540	0.04713	
8,900	-50	25	-4	0.04995	0.007893	0.04933	
9,400	-10	25	0	0.04999	0	0.04981	
9,720	-10	15	0	0.06554	0	0.06550	
9,880	-10	5	0	0.09732	0	0.09731	
9,920	-10	5	0	0.06687	0	0.06686	
9,980	-10	5	0	0.05454	0	0.05454	
10,000	-10	0	0	0.05454	0	0.05454	

($y_N = 0$ m; $V_{y_{C_N}} = 0$ m/sec; $C_{V_{x,y}} = C_{V_{z,y}} = C_{V_{y,z}} = 0$ sec⁻¹)

Table 5. Stored Guidance Quantities for 90° Approach

R (m)	y _N (m)	z _N (m)	V _x C _N (m/sec)	V _y C _N (m/sec)	V _z C _N (m/sec)	C _{V_x,y} (sec ⁻¹)	C _{V_y,y} (sec ⁻¹)	C _{V_z,y} × 100 (sec ⁻¹)	C _{V_x,z} (sec ⁻¹)	C _{V_y,z} × 100 (sec ⁻¹)	C _{V_z,z} (sec ⁻¹)
0	0	-10	0	0	0	0	0.8750	0	0	0	0.8750
20	0	-10	5	0	0	0	0.8750	0	0	0	0.8750
40	0	-10	5	0	0	0	0.2384	0	0	0	0.2384
80	0	-10	5	0	0	0	0.08630	0	0	0	0.08630
120	0	-10	5	0	0	0	0.05672	0	0	0	0.05672
280	0	-10	15	0	0	0	0.02171	0	0	0	0.02171
600	0	-30	25	0	2.5	0	0.02152	0	-0.002150	0	0.02150
1200	0	-90	25	0	2.5	0	0.03056	0	-0.003045	0	0.03045
1300	-10.09	-100.06	24.5	5	2.5	-0.006465	0.03169	-0.001365	-0.003218	-0.003864	0.03161
1400	-41.47	-110.51	22.93	9.97	2.5	-0.01450	0.03336	-0.007019	-0.003586	-0.01765	0.03359
1500	-97.63	-121.78	20.12	14.84	2.5	-0.02573	0.03491	-0.02233	-0.004165	-0.04950	0.03646
1600	-186.05	-134.60	15.70	19.46	2.5	-0.04298	0.03476	-0.06280	-0.004992	-0.1212	0.04078
1772	-500.0	-168.54	0	25	2.5	-0.1025	0.000529	-0.5287	-0.005421	-0.6882	0.06882
2030	-1109.46	-229.49	0	25	2.5	-0.03595	0.000176	-0.1760	-0.001706	-0.2873	0.02873
2277	-1514.6	-250	0	25	0	-0.03629	0	-0.09182	0.001031	0	0.02825
3000	-2470.0	-250	0	25	0	-0.03629	0	-0.09182	0.001031	0	0.02825

4.3 SIMULATION RESULTS

A large number of flights were simulated with various off-nominal initial conditions and winds. Figs. 11 through 33 are included to present representative results of these simulations. Table 6 is a key to these results, indicating the phase of the trajectory and the off-nominal condition for each of the figures. In addition to the off-nominal initial conditions mentioned in Table 6, the effects of initial errors in forward velocity (± 10 m/sec), vertical velocity (± 5 m/sec), mass ($\pm 10\%$), and moments and product of inertia ($\pm 10\%$) were also investigated. Besides the lateral wind results included here, constant (10 m/sec) headwinds and tailwinds, constant-shear ($5-z/50$ m/sec) headwinds and tailwinds, constant (± 5 m/sec) vertical winds, and constant (± 10 m/sec) crosswinds combined with constant (± 10 m/sec) headwinds and tailwinds were also considered. In these situations, as well as the ones illustrated in Figs. 11 through 33, the guidance scheme performed satisfactorily. (Reference 2 contains many other plots for the vertical response during the approach phase.)

The small symbols shown on the actual histories indicate successive time intervals of 10 seconds in Fig. 11, and 5 seconds in Figs. 12 through 33. In many of the plots, the (automatically selected) ordinate scale is greatly magnified, which at first glance tends to exaggerate the size of a variable's excursions. Finally, it should be noted that neither the magnitudes nor the

Table 6. Key to Simulation Results

Figure No.	Trajectory Phase	Initial Conditions	Winds
11	Entire	Nominal	None
12	0° Approach	$\delta z_i = +50$ m	None
13	0° Approach	$\delta z_i = -50$ m	None
14	0° Approach	$\delta y_i = -100$ m	None
15	0° Approach	$\delta \psi_i = \delta \psi_i = 20^\circ$	None
16	0° Approach	Nominal	$w_y = 10$ m/sec
17	0° Approach	Nominal	$w_y = 5-z/50$ m/sec
18	Takeoff	$\delta z_i = +10$ m	None
19	Takeoff	$\delta z_i = -10$ m	None
20	Takeoff	$\delta y_i = -100$ m	None
21	Takeoff	$\delta \psi_i = \delta \psi_i = 20^\circ$	None
22	Takeoff	Nominal	$w_y = 10$ m/sec
23	Takeoff	Nominal	$w_y = 5-z/50$ m/sec
24	Cruise	$\delta z_i = +50$ m	None
25	Cruise	$\delta z_i = -50$ m	None
26	Cruise	$\delta y_i = -100$ m	None
27	Cruise	$\delta \psi_i = \delta \psi_i = 20^\circ$	None
28	Cruise	Nominal	$w_y = 10$ m/sec
29	90° Approach	Nominal	None
30	90° Approach	$\delta z_i = +50$ m	None
31	90° Approach	$\delta z_i = -50$ m	None
32	90° Approach	$\delta x_i = +100$ m	None
33	90° Approach	$\delta x_i = -100$ m	None

rates of change of the guidance commands were limited in the simulations as they would be in the airborne computer by word size and sampling rate. Hence, the large initial transients which are evident in some of the results presented would not occur during an actual flight of the system.

The vertical and horizontal profiles of the entire straight-in trajectory with nominal initial conditions and no winds are shown in Fig. 11a. Figs. 11b through 11e present the corresponding time histories of the commanded and actual inertial velocity components (V_X , V_Y , V_Z); the commanded and actual vehicle attitudes (θ , ϕ , ψ); the angle of attack (α), sideslip angle (β) and normal acceleration (a_z); and the control displacements (δ_E , δ_C , δ_A , δ_R). The upper portion of Fig. 11a shows that, even for entirely nominal conditions, small lateral motions are induced by coupling between the lateral and longitudinal dynamics and by the change of trim conditions with vertical and forward velocity.

Figs. 12 and 13 show the effects of initial altitude errors of ± 50 m at the beginning of the approach phase. In each case, the guidance scheme smoothly funnels the aircraft back toward the nominal path and into the nominal final conditions. The effects of a cross range error of -100 m and a heading error of 20° at the beginning of the straight-in approach are presented in Figs. 14 and 15, respectively. In both cases, the guidance

scheme performs very well. Approaches through lateral winds are examined in Figs. 16 and 17. Fig. 16 is for a constant lateral wind of 10 m/sec, while Fig. 17 compares a constant shear of 0.02 sec^{-1} superimposed on a constant wind of 5 m/sec (i.e., $w_y = 5 - 0.02 z \text{ m/sec}$). The lateral response which begins at $x = -600 \text{ m}$ ($t \cong 97 \text{ sec}$) is caused by the helicopter's changing trim conditions and aerodynamics during the flare and forward deceleration.

Figs. 18 through 23 illustrate the guidance system's performance during the takeoff phase for the same off-nominal conditions just discussed, except the initial altitude errors are only $\pm 10 \text{ m}$ (to remain above ground level). In all cases, the system performs satisfactorily. Similar results are presented for the cruise phase in Figs. 24 through 28, where the guidance scheme smoothly returns the helicopter to the nominal path regardless of the off-nominal conditions.

A few simulations were run with the 90° approach nominal discussed previously. Fig. 29 presents the flight profiles and the time histories of various quantities for nominal initial conditions and no winds (c.f., Fig. 11). The effects of errors of $\pm 50 \text{ m}$ in altitude and $\pm 100 \text{ m}$ in downrange at the beginning of the approach are shown in Figs. 30 through 33. These results illustrate that the guidance scheme performs satisfactorily for a turning approach as well as a straight one. The nominal

profiles y_N and z_N shown in these figures appear to differ since they are plotted vs the actual downrange $x = -\sqrt{R^2 - y^2}$, rather than the nominal downrange $x_N = -\sqrt{R^2 - y_N^2}$.

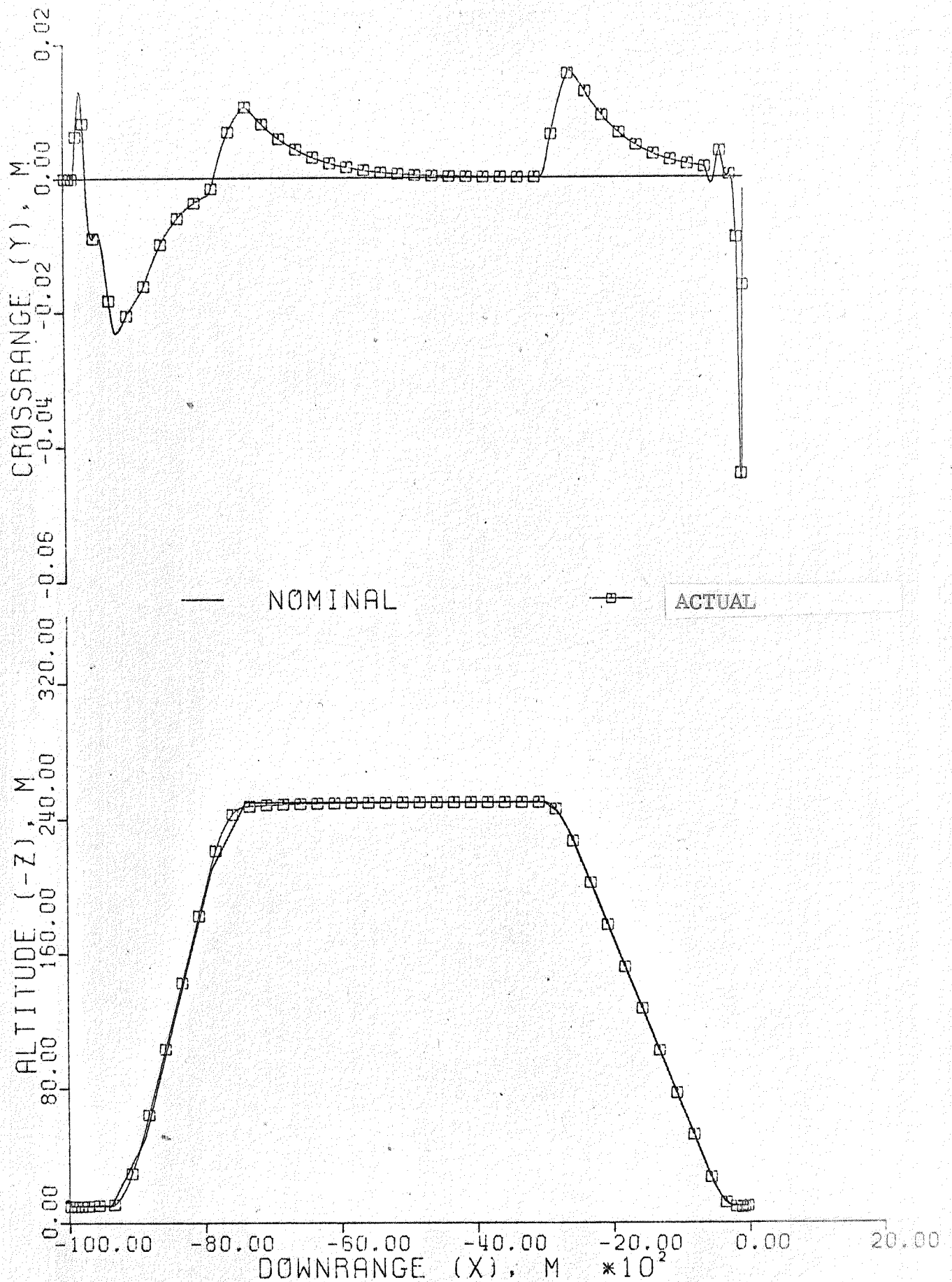


Fig. 11a. Entire Flight With Nominal Conditions - Flight Profiles

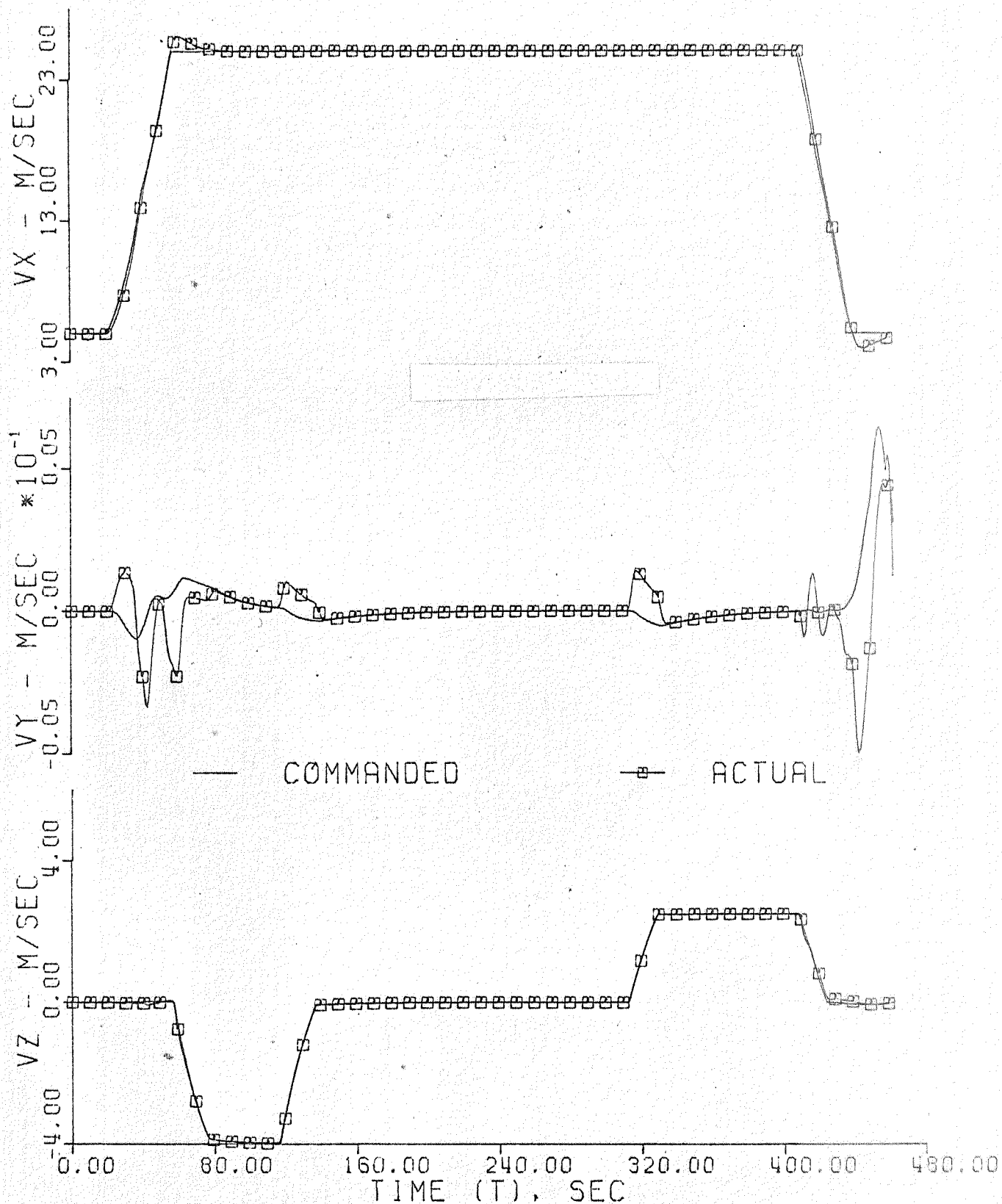


Fig. 11b. Entire Flight With Nominal Conditions - Velocity Histories

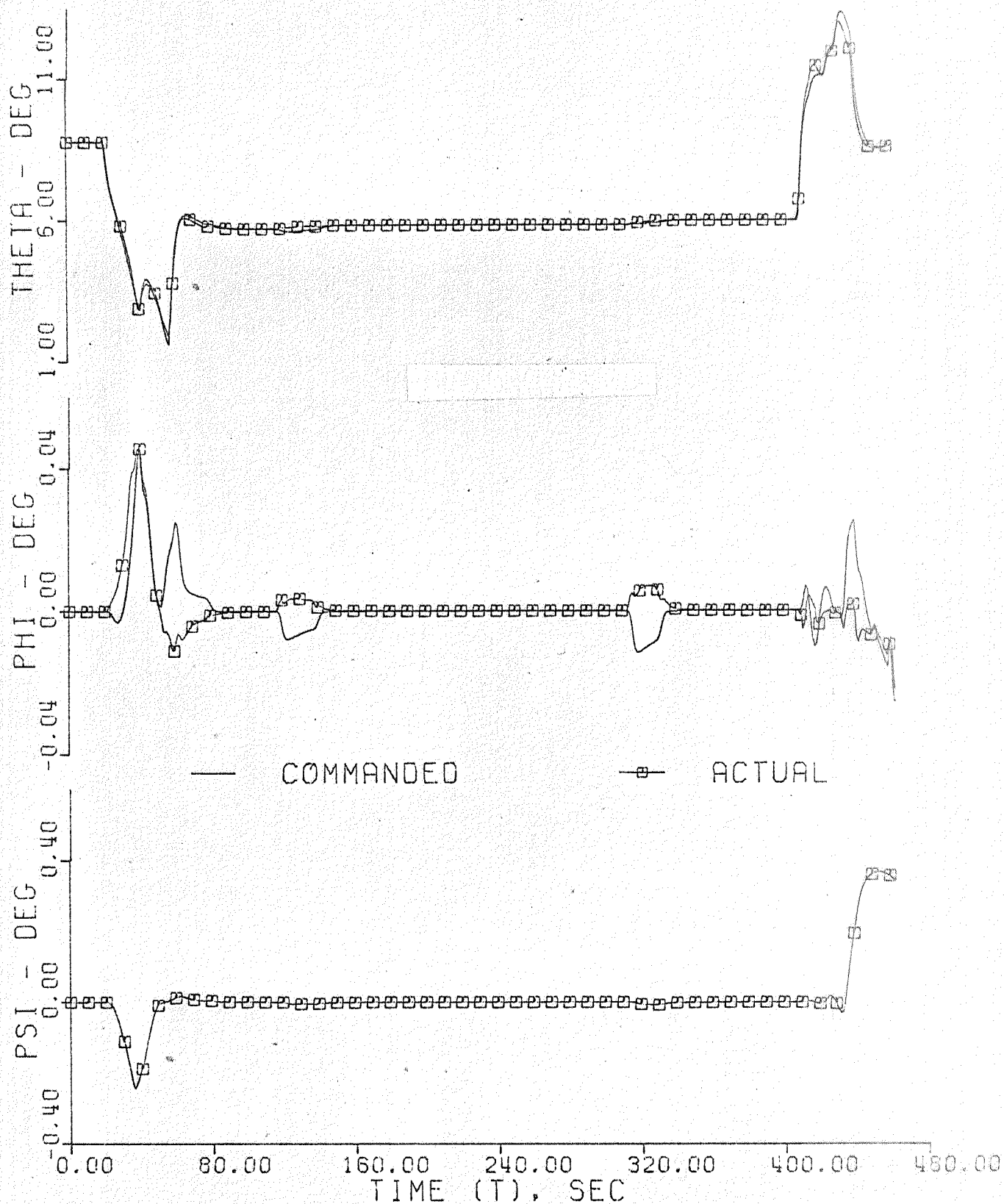


Fig. 11c. Entire Flight With Nominal Conditions - Attitude Histories

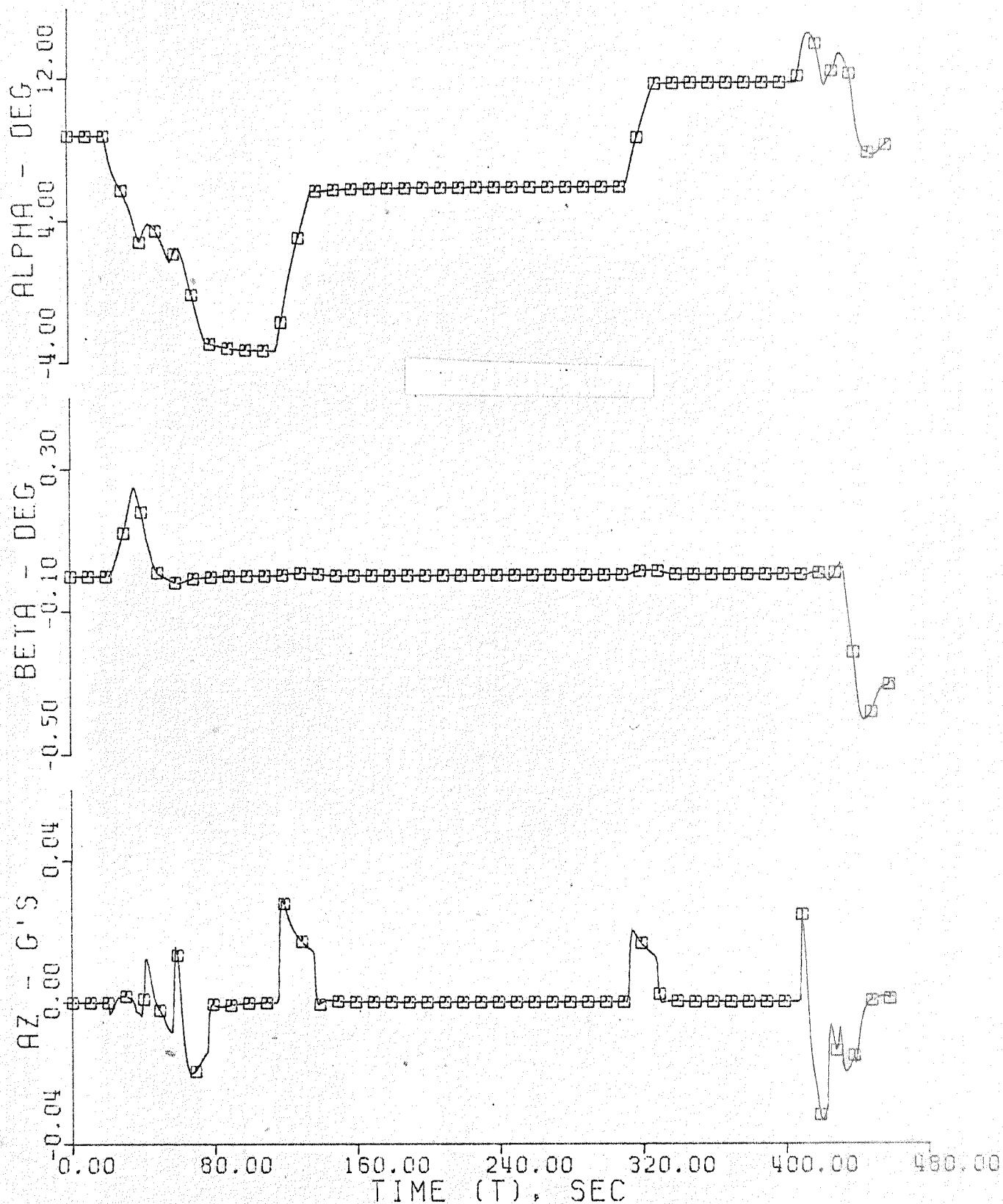


Fig. 11d. Entire Flight With Nominal Conditions - Angle of Attack, Sideslip Angle and Normal Acceleration Histories

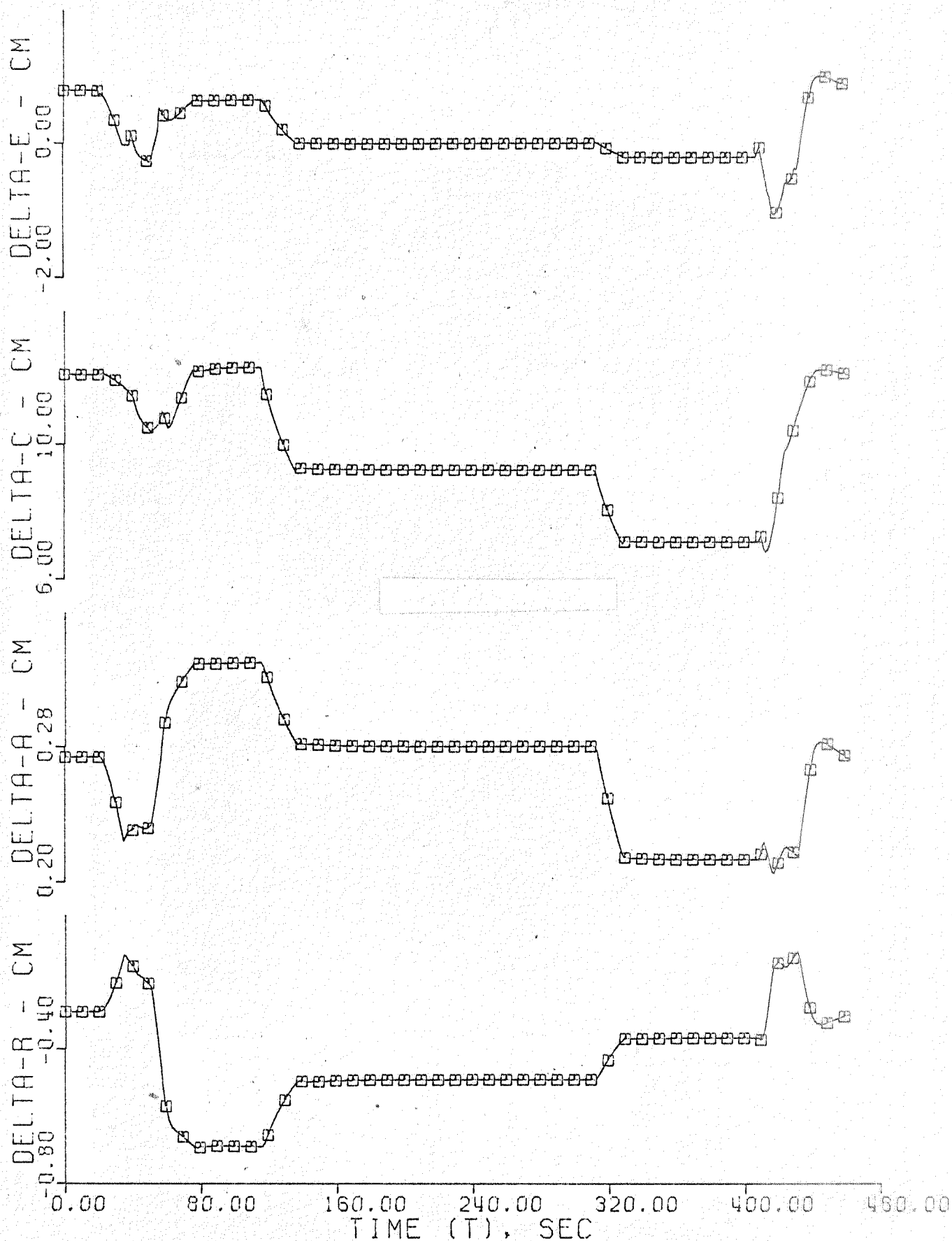


Fig. 11e. Entire Flight With Nominal Conditions - Control Histories

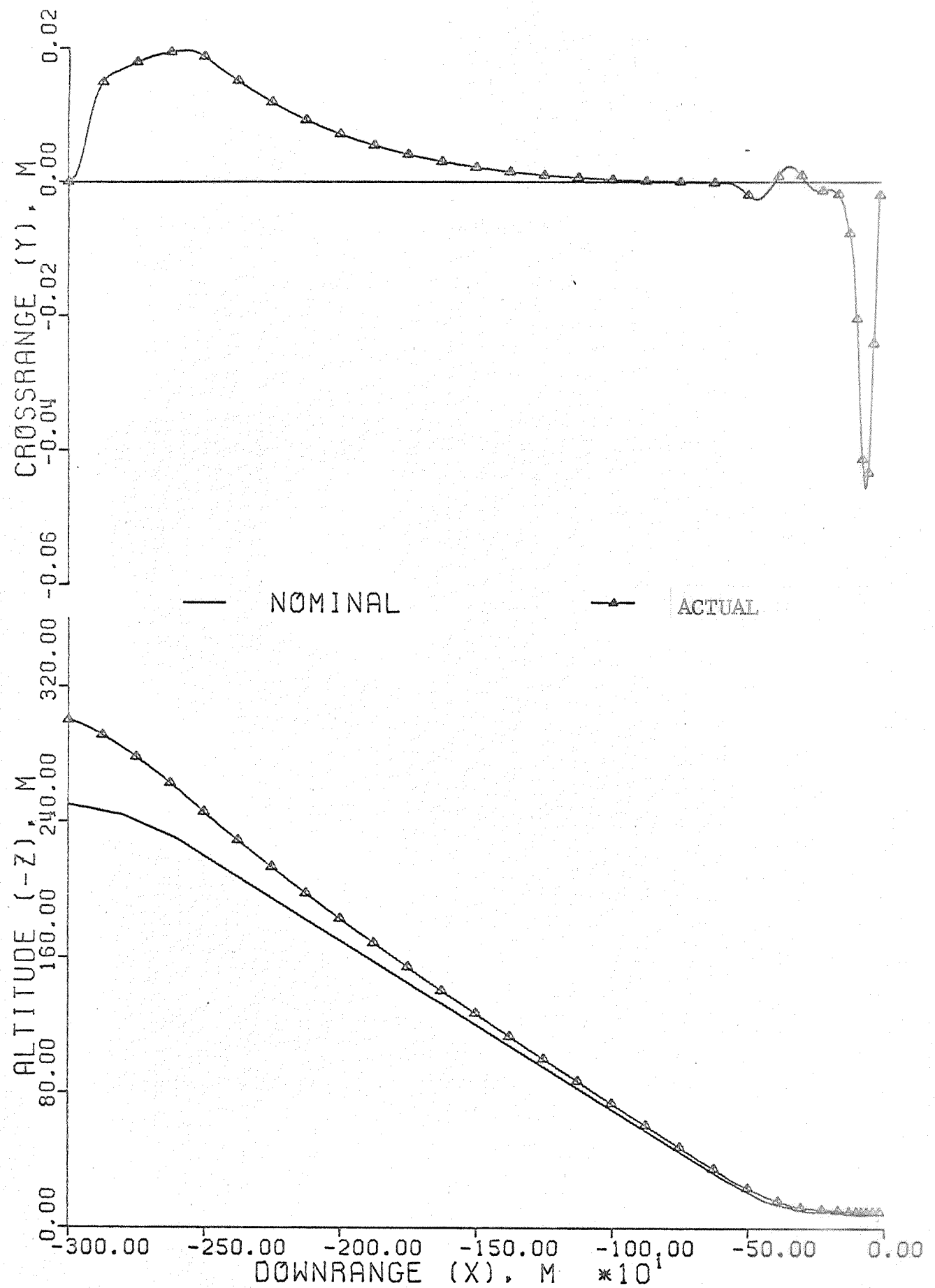


Fig. 12a. Straight Approach With $\delta z_i = +50$ m - Flight Profiles

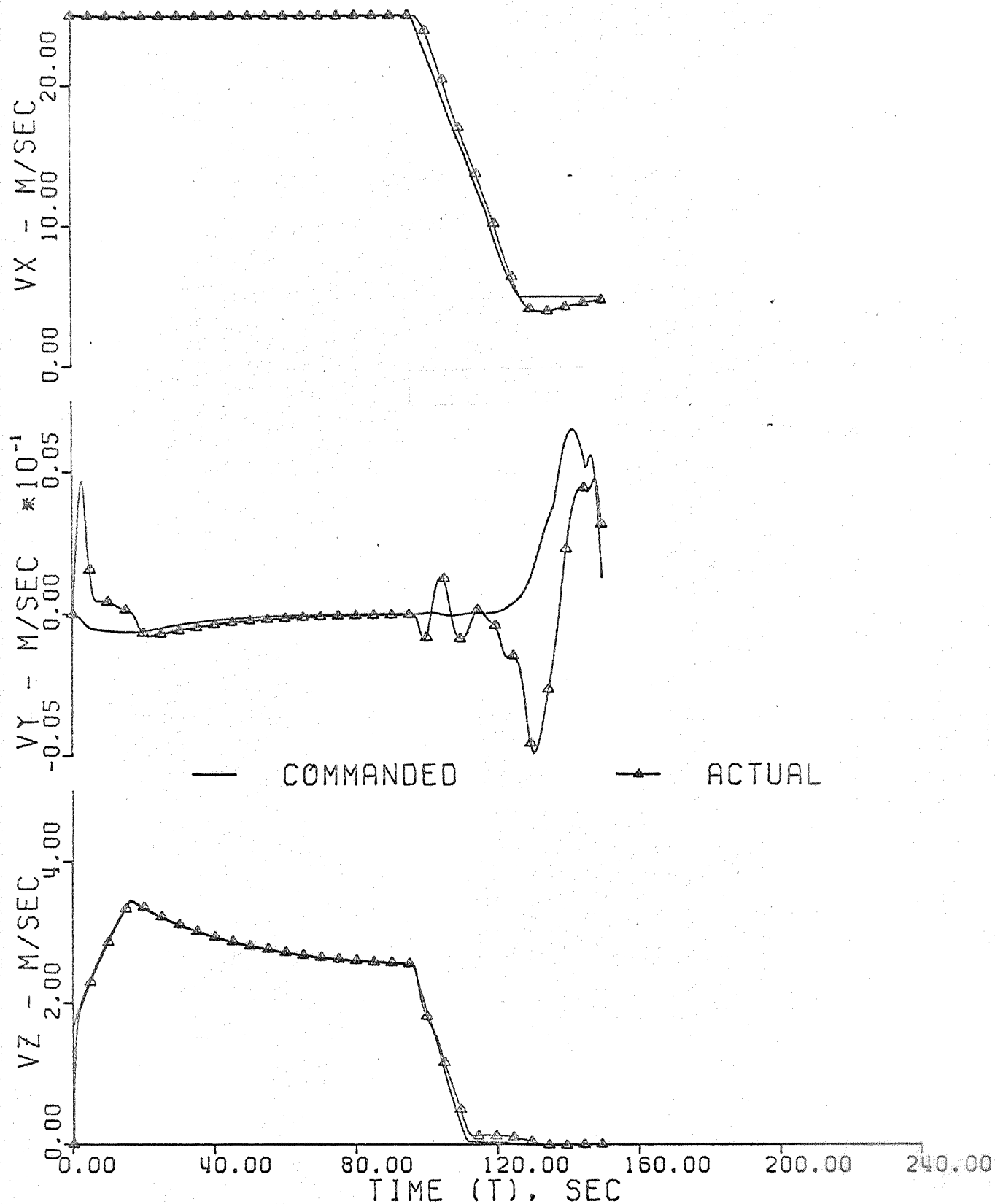


Fig. 12b. Straight Approach With $\delta z_i = +50$ m - Velocity Histories

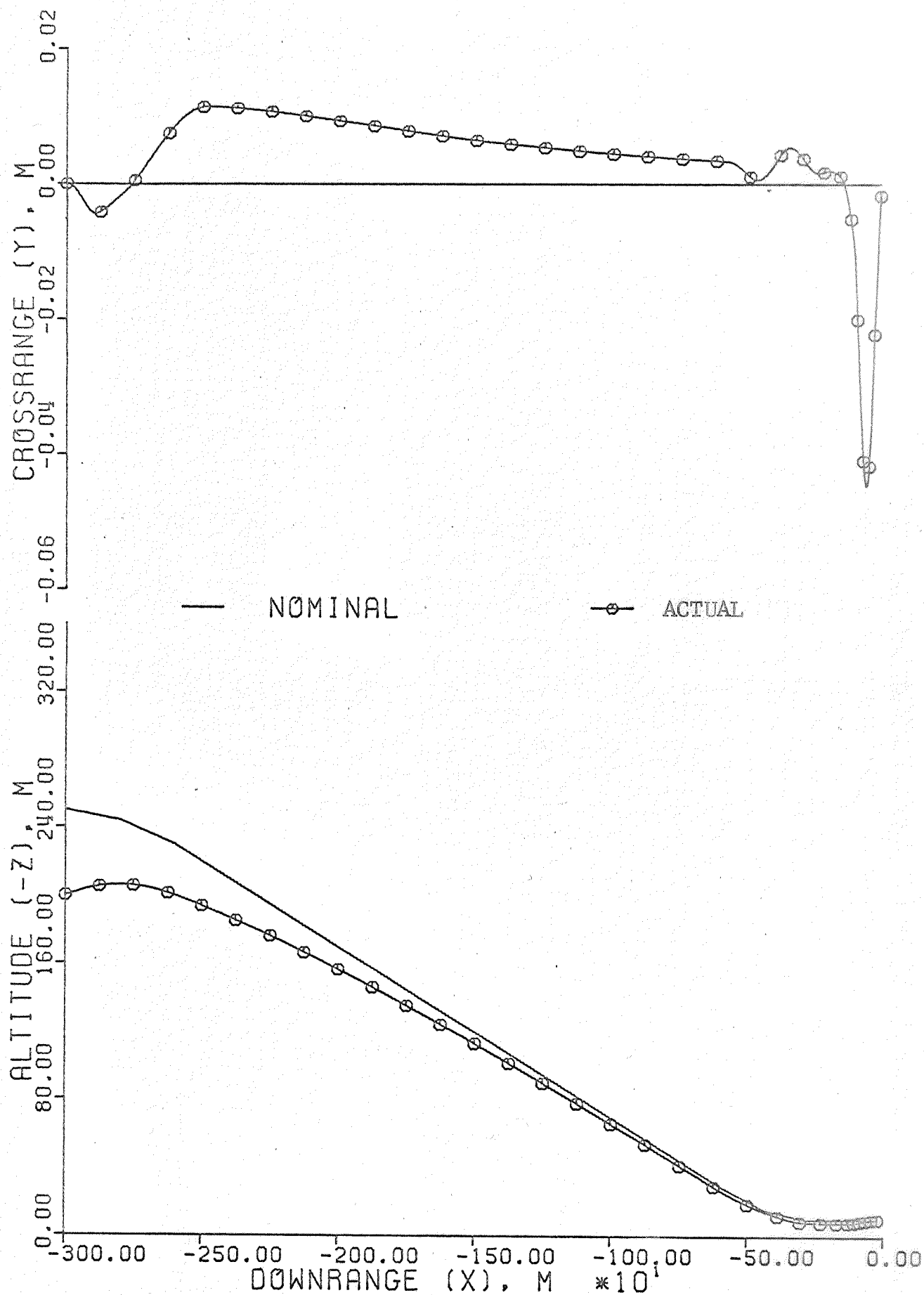


Fig. 13a. Straight Approach With $\delta z_i = -50$ m — Flight Profiles

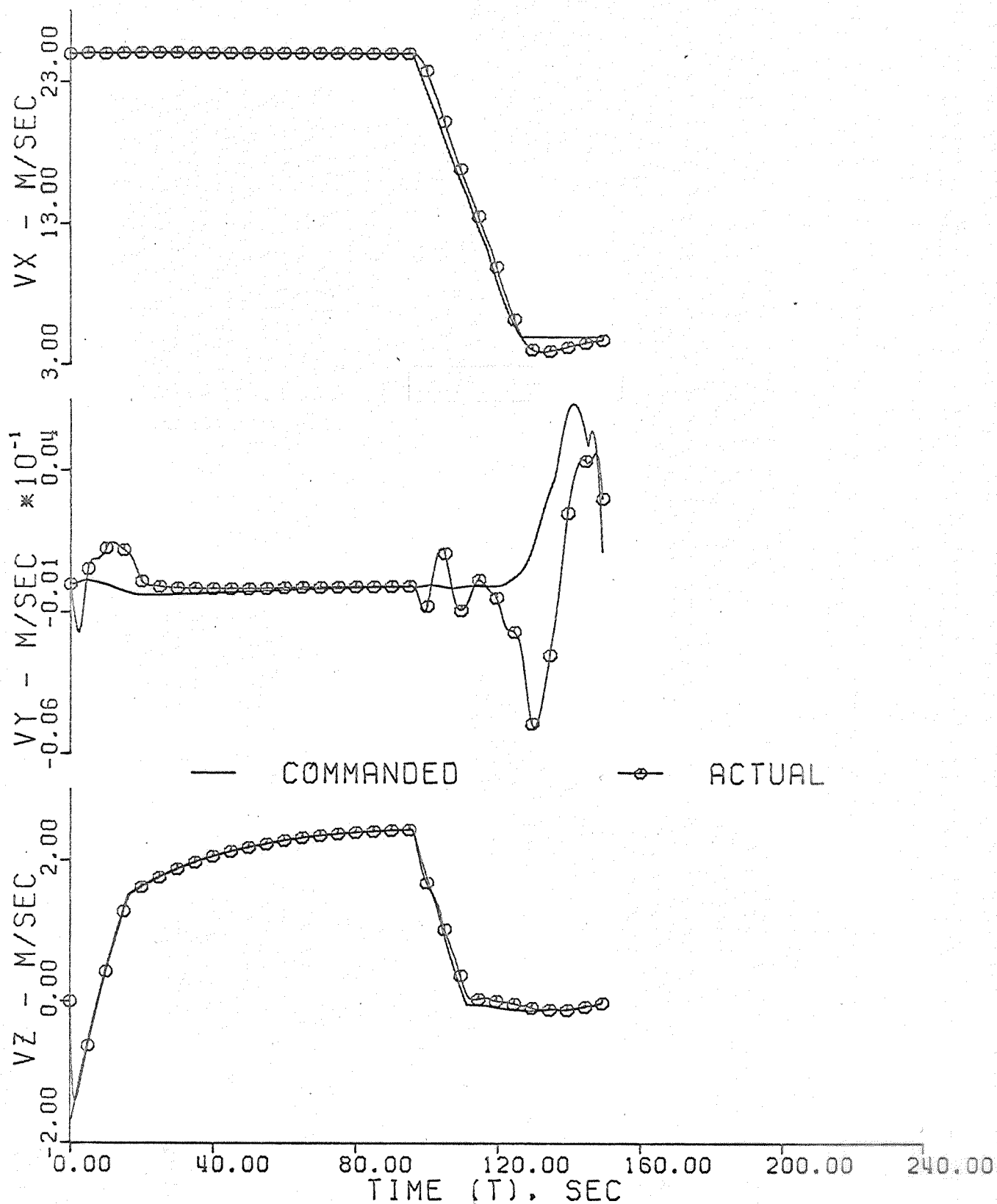


Fig. 13b. Straight Approach With $\delta z_i = -50$ m - Velocity Histories

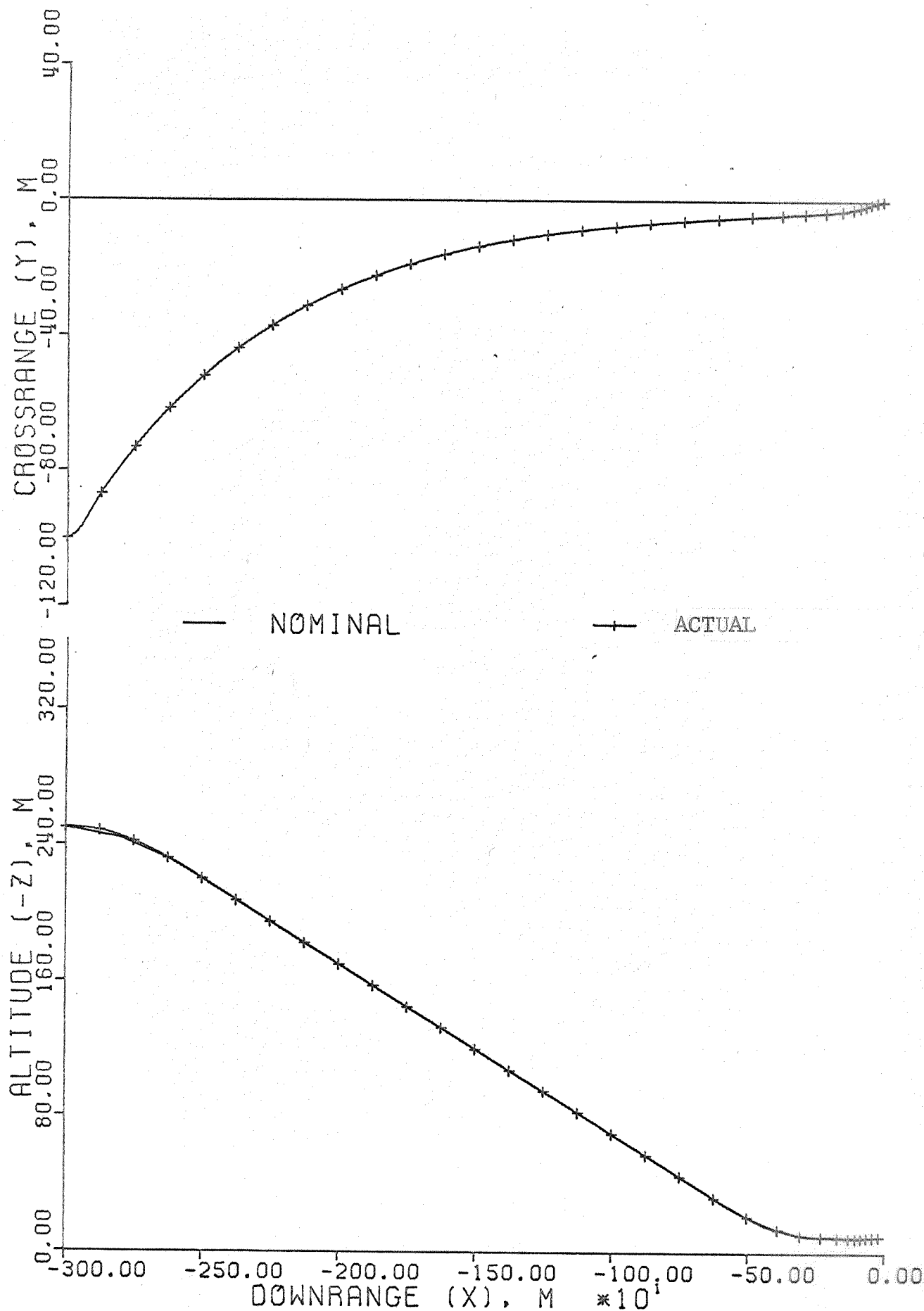


Fig. 14a. Straight Approach With $\delta y_i = -100$ m — Flight Profiles

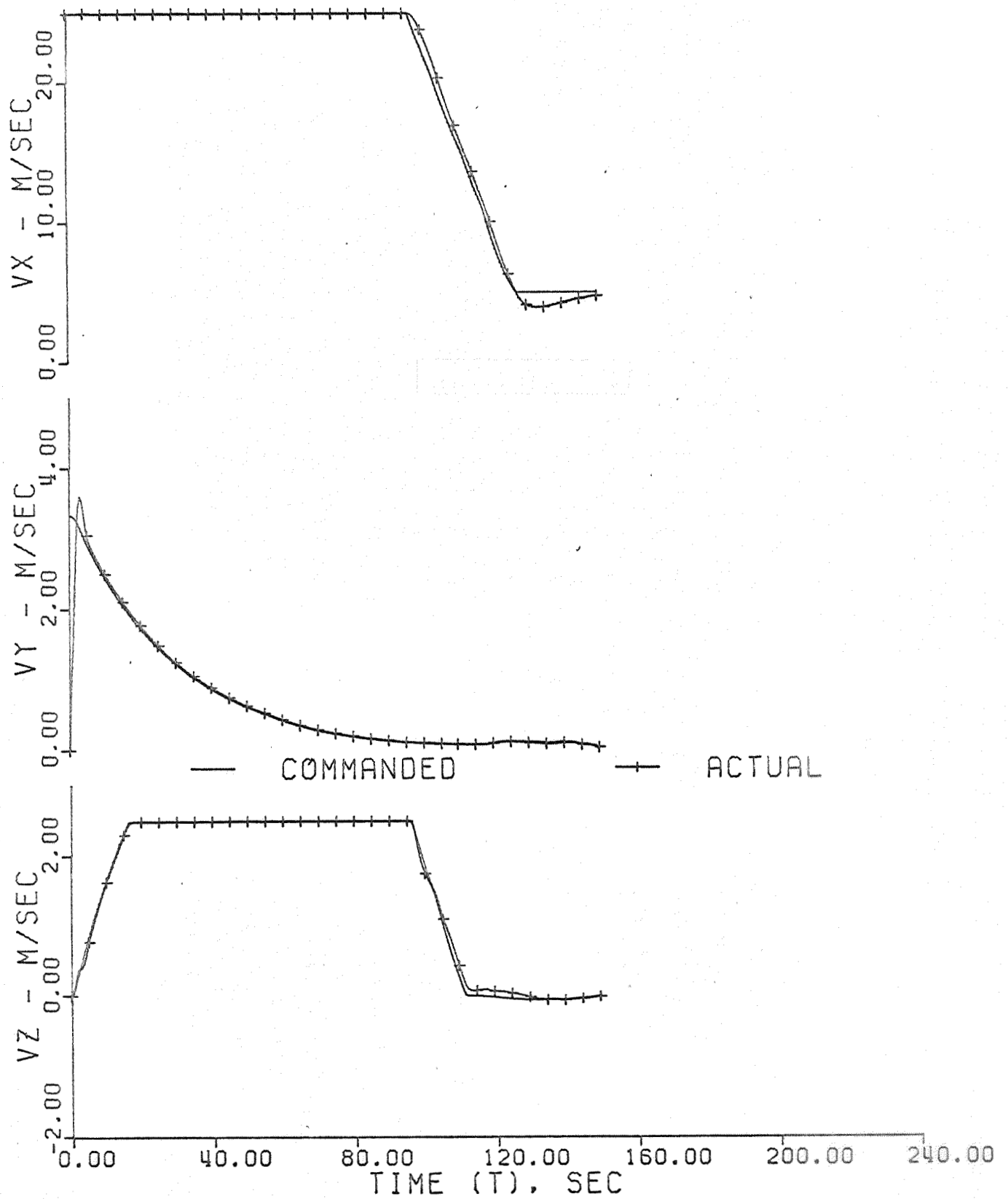


Fig. 14b. Straight Approach With $\delta y_i = -100$ m - Velocity Histories

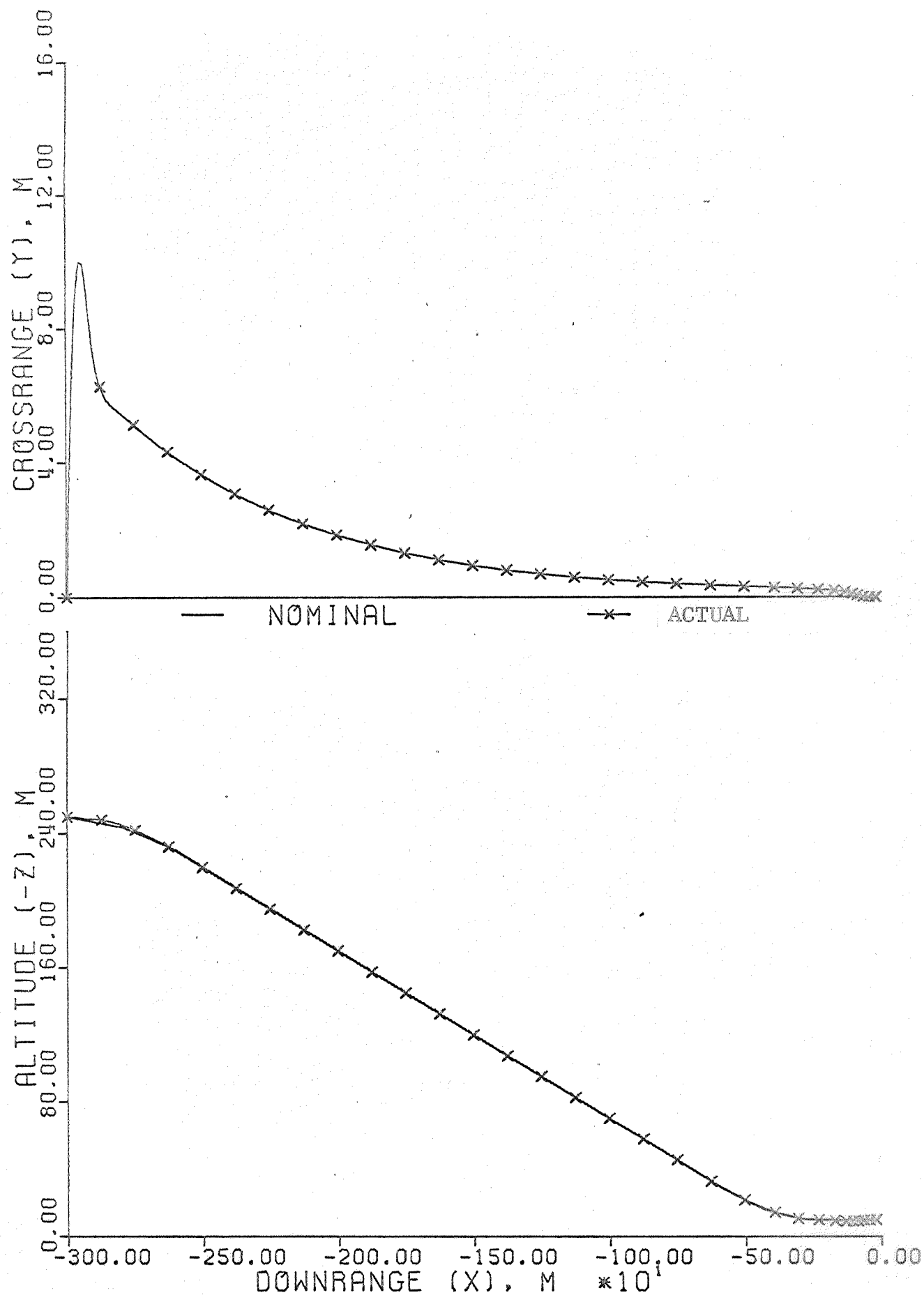


Fig. 15a. Straight Approach With $\delta\psi_i = \delta\psi_f = 20^\circ$ - Flight Profiles

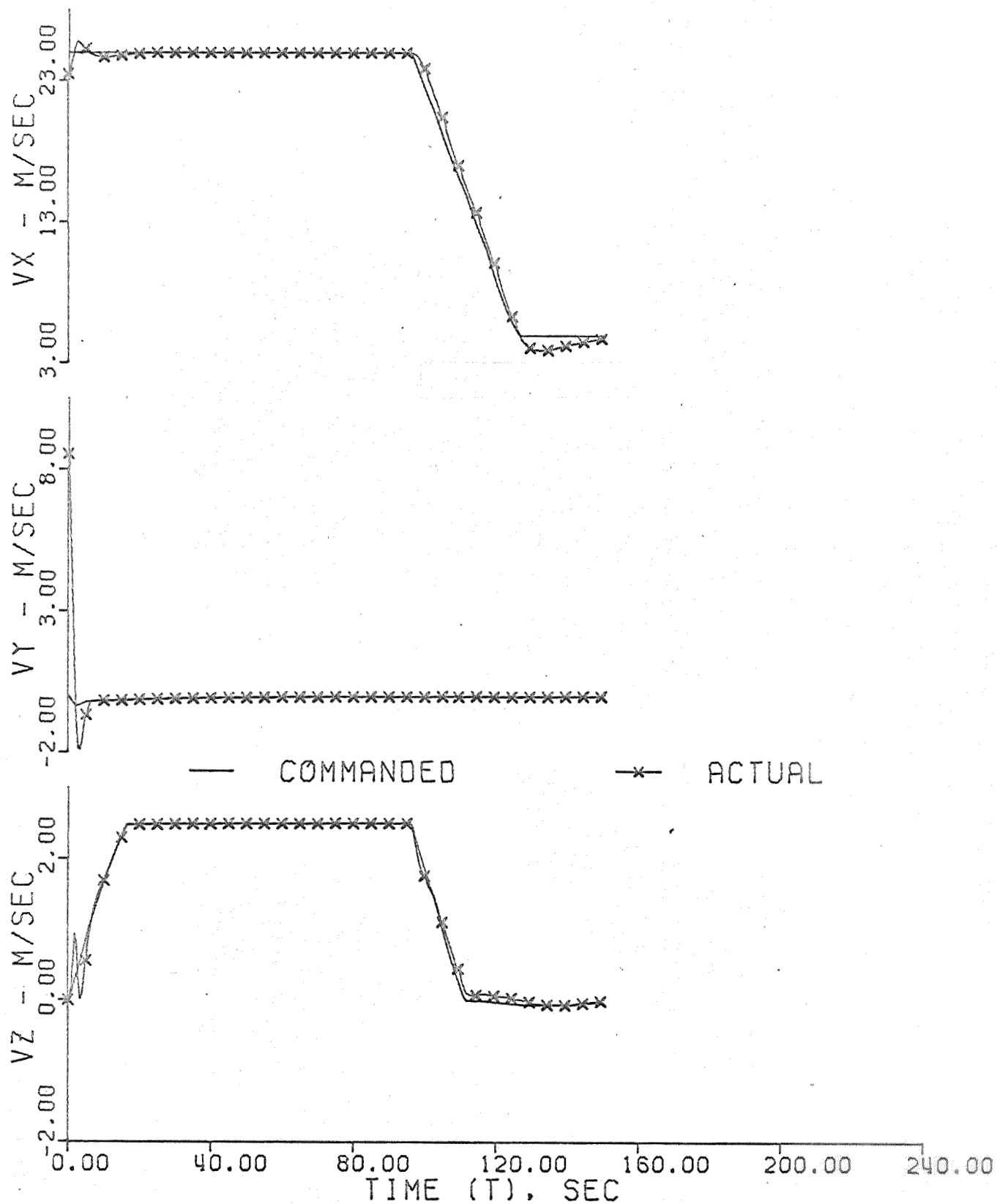


Fig. 15b. Straight Approach With $\delta\psi_i = \delta\psi_i = 20^\circ$ - Velocity Histories

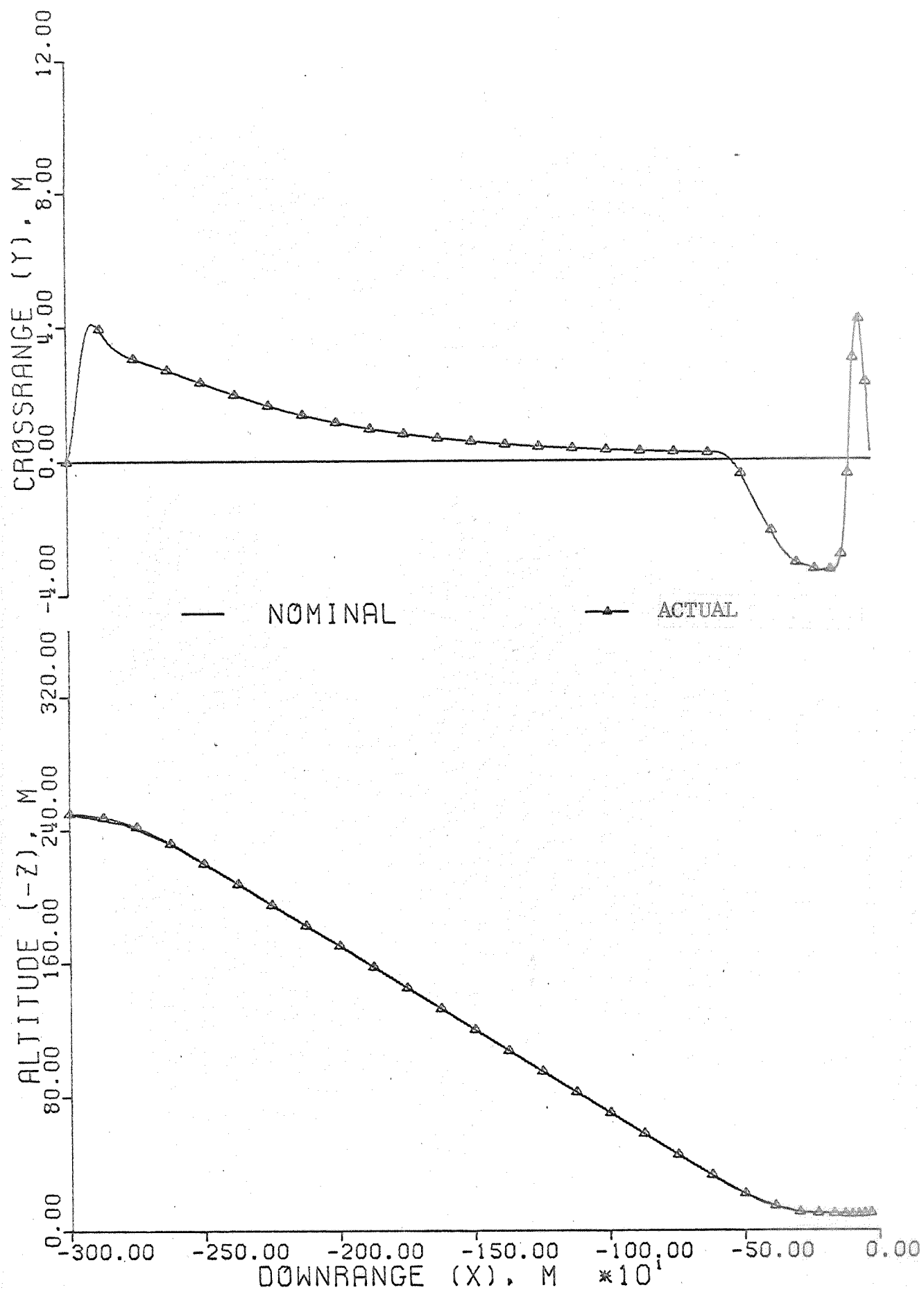


Fig. 16a. Straight Approach With $w_y = 10$ m/sec - Flight Profiles

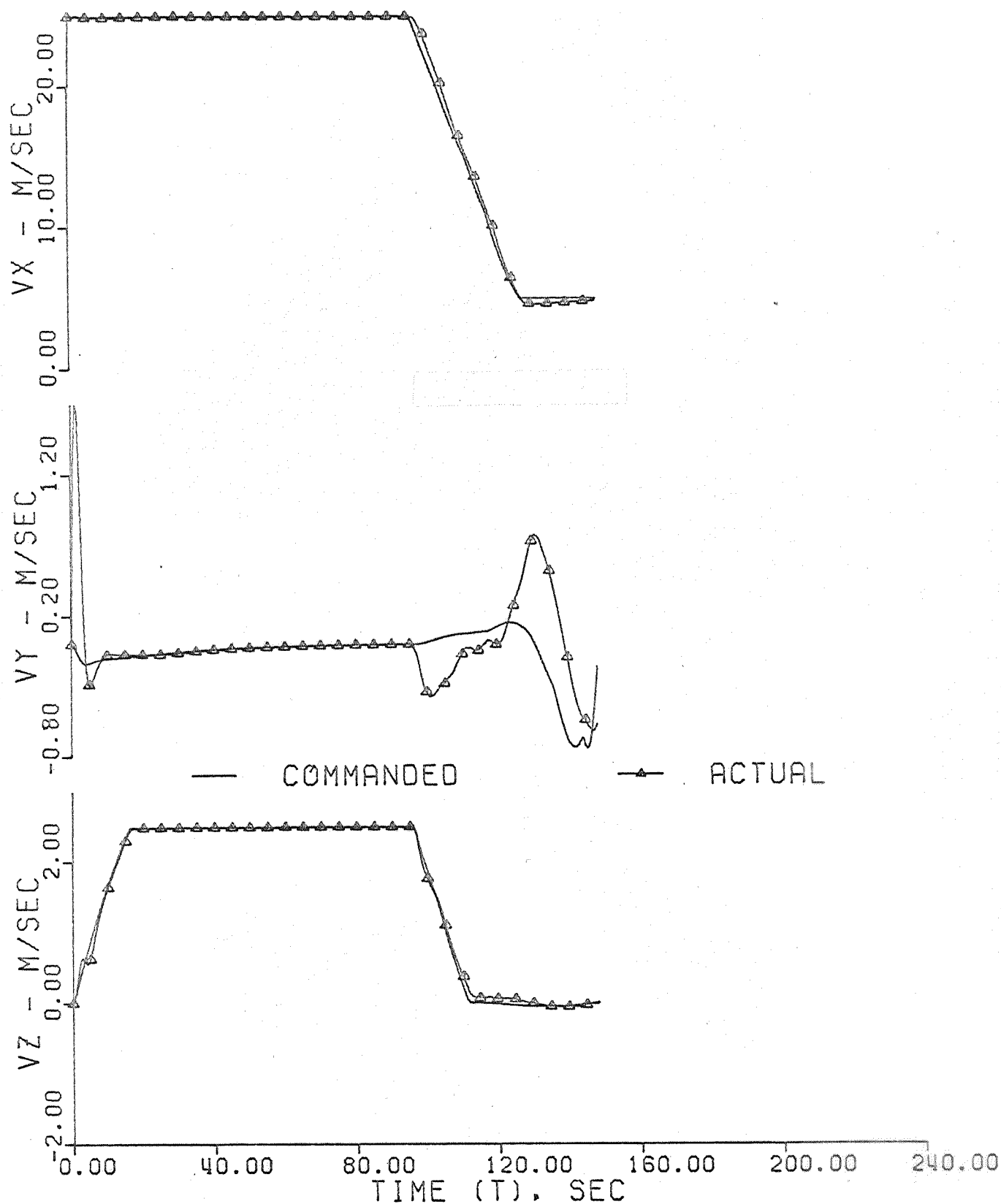


Fig. 16b. Straight Approach With $w_y = 10$ m/sec - Velocity Histories

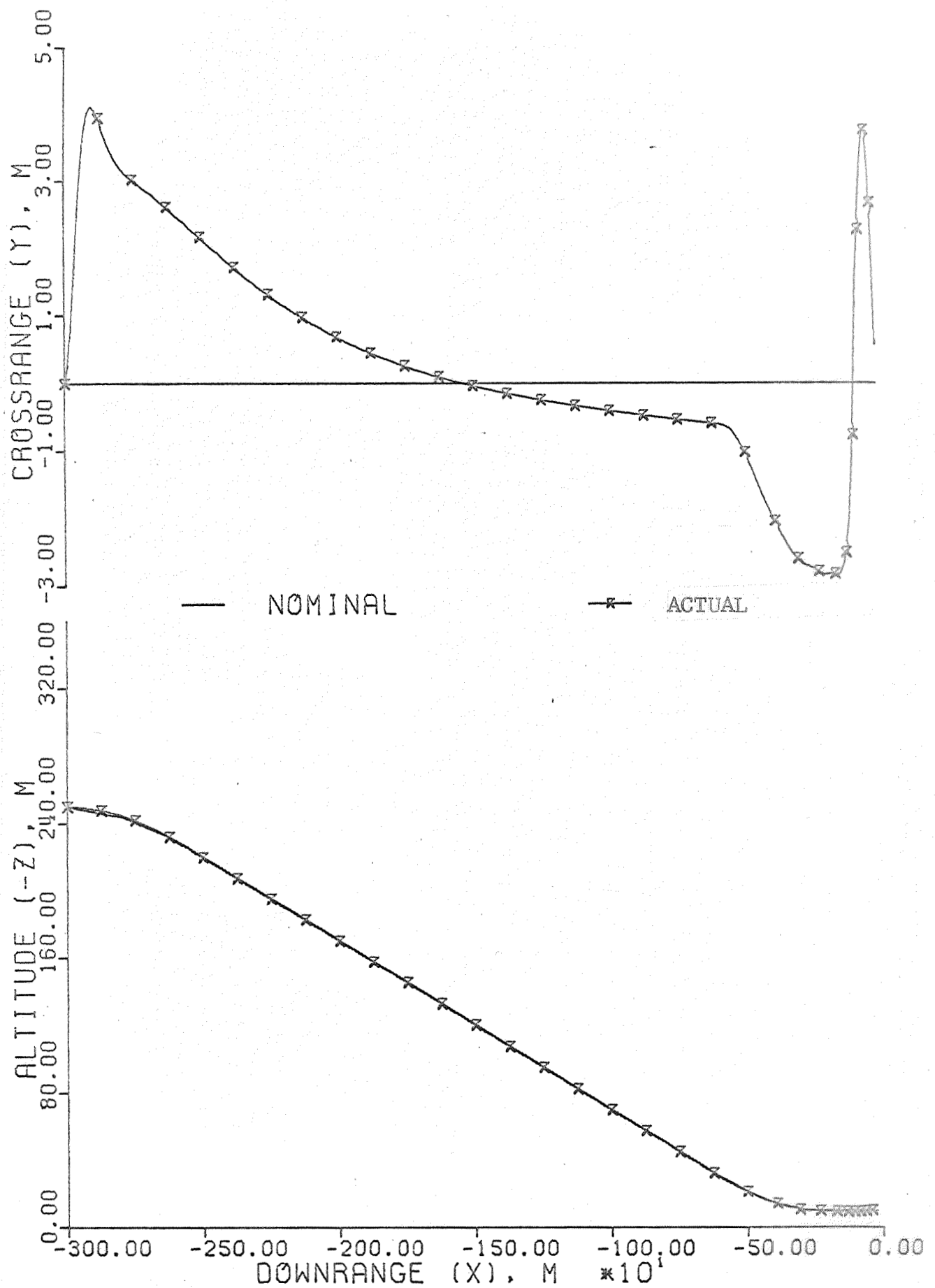


Fig. 17a. Straight Approach With $w_y = 5-z/50$ m/sec - Flight Profiles

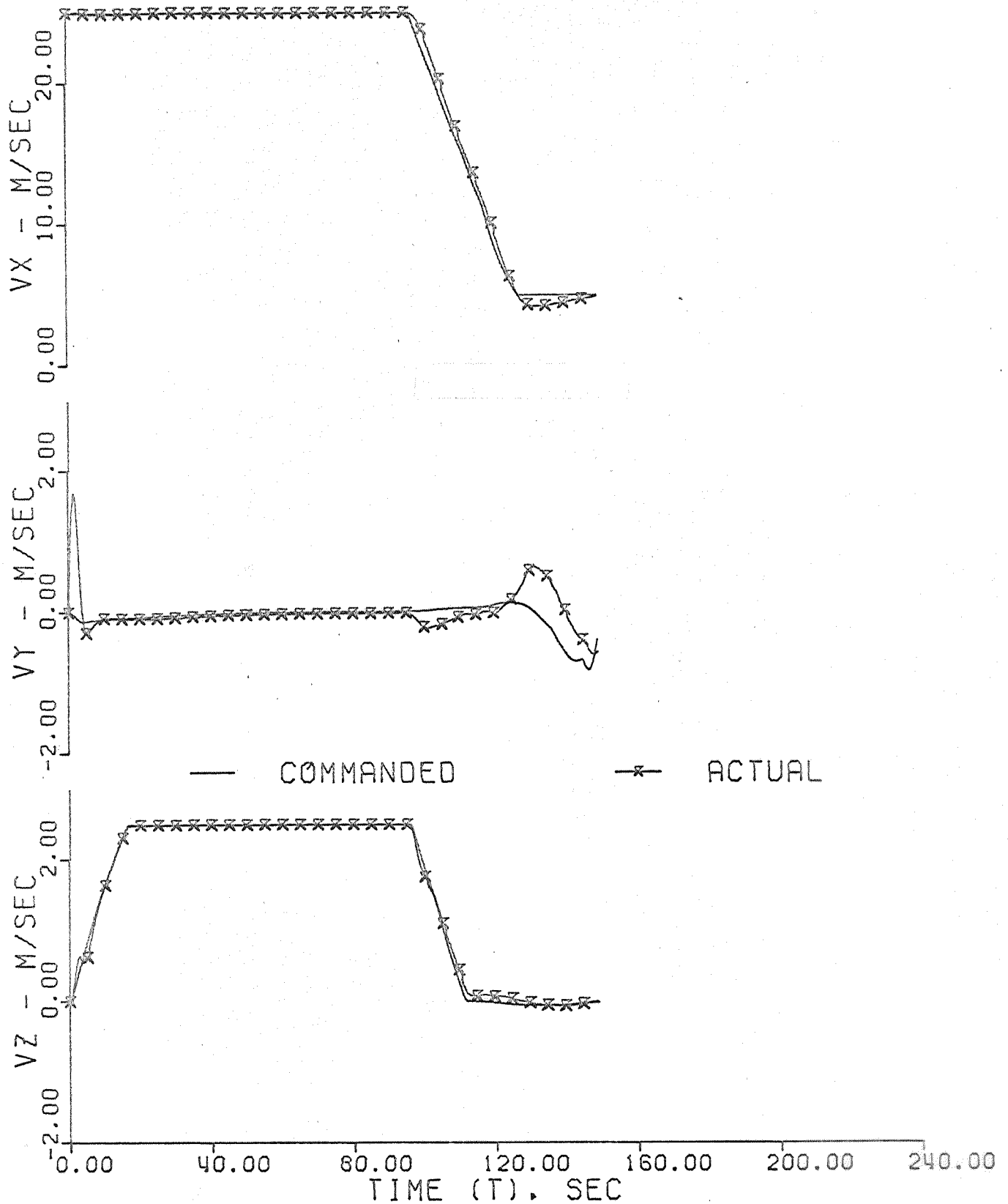


Fig. 17b. Straight Approach With $w_y = 5-z/50$ m/sec - Velocity Histories

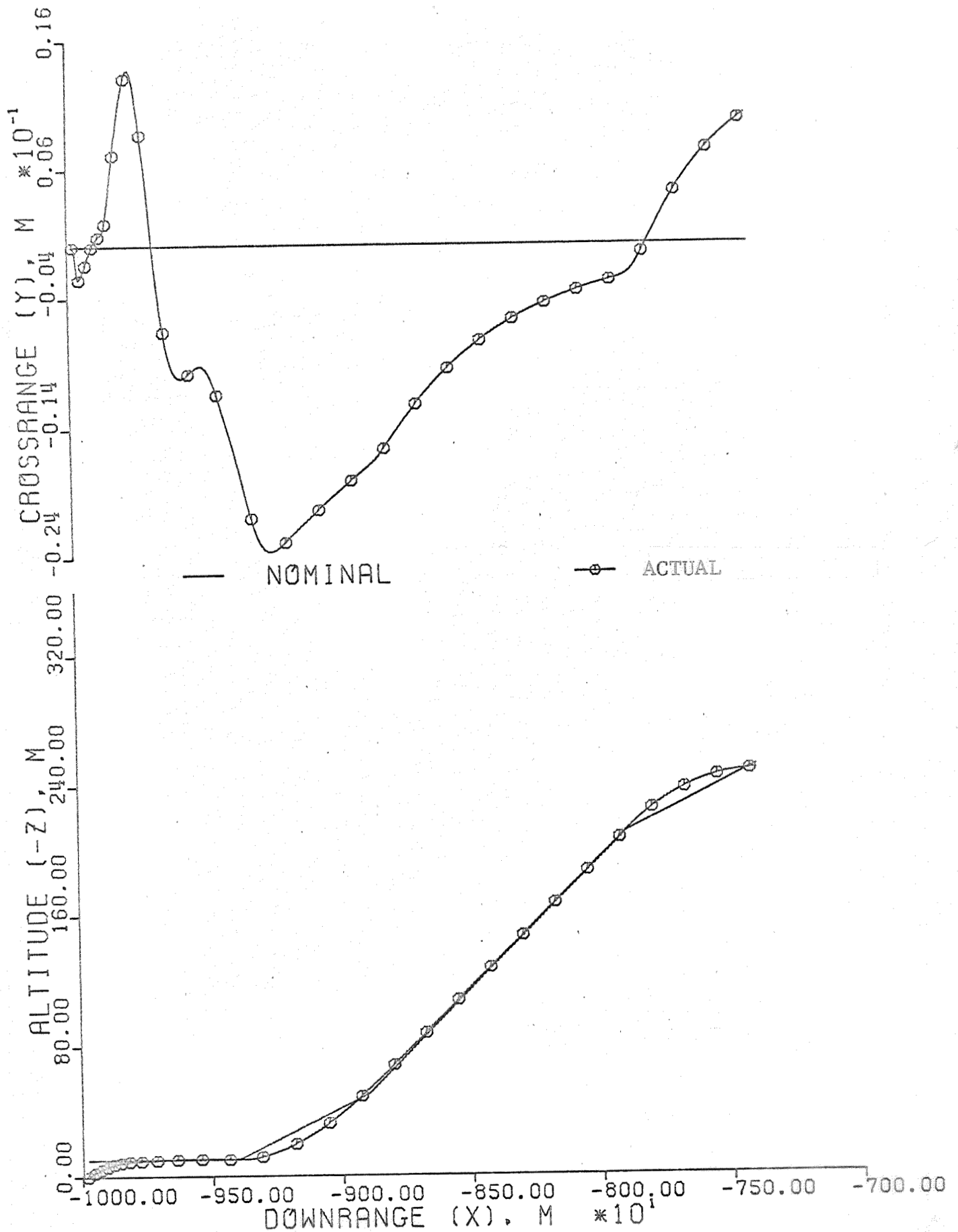


Fig. 18a. Takeoff With $\delta z_i = +10$ m - Flight Profiles

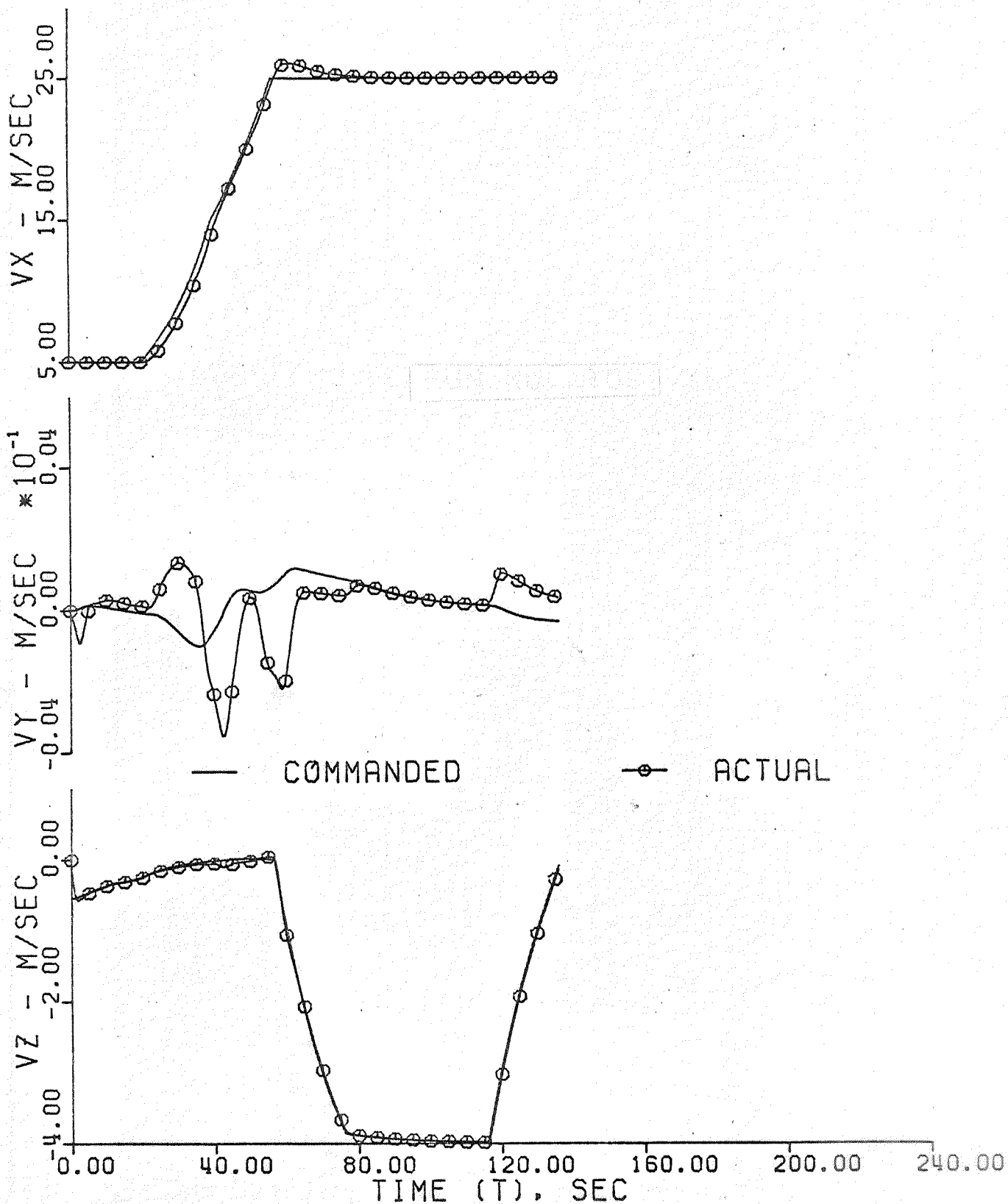


Fig. 18b. Takeoff With $\delta z_i = +10$ m - Velocity Histories

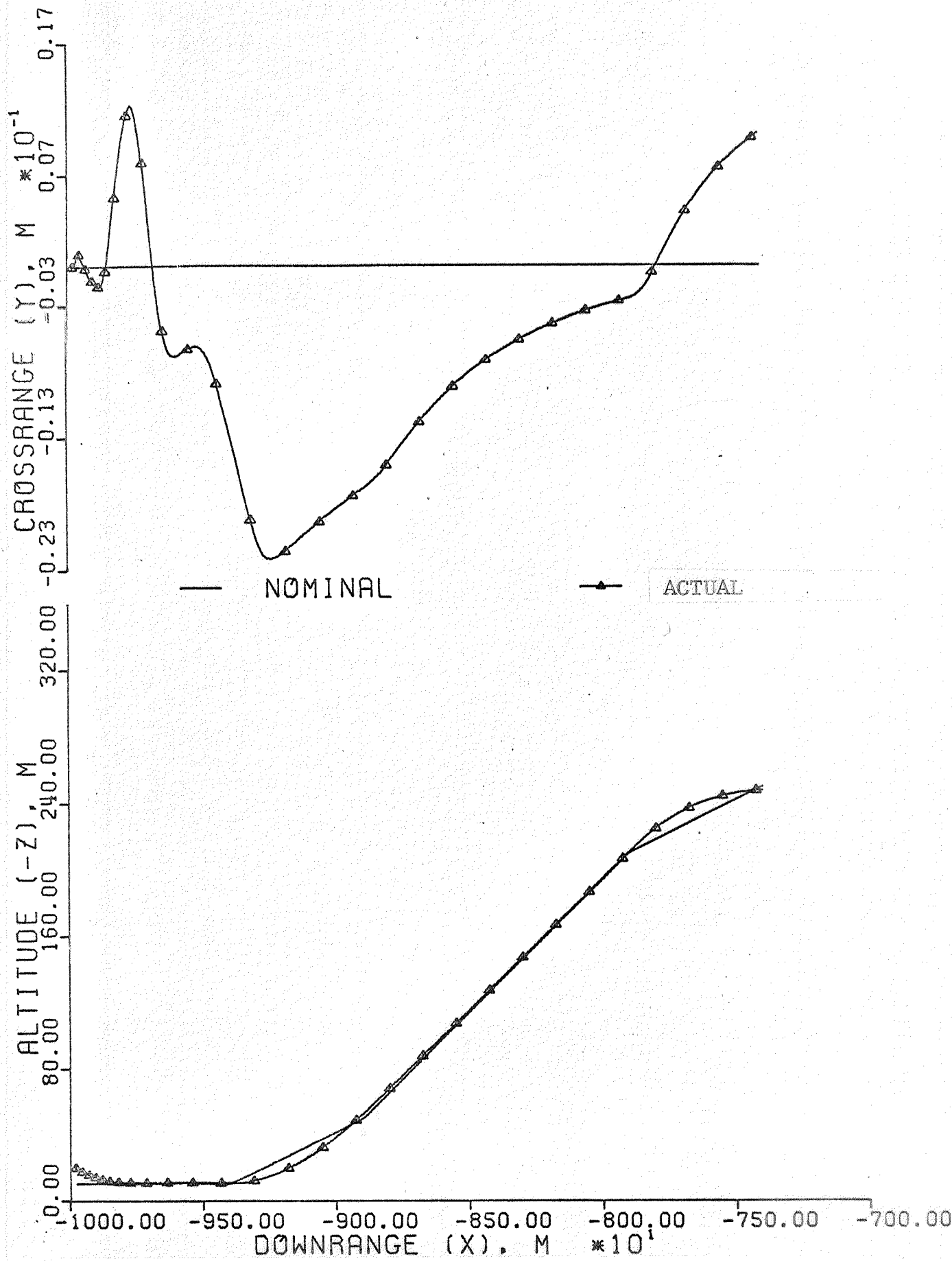


Fig. 19a. Takeoff With $\delta z_1 = -10$ m - Flight Profiles

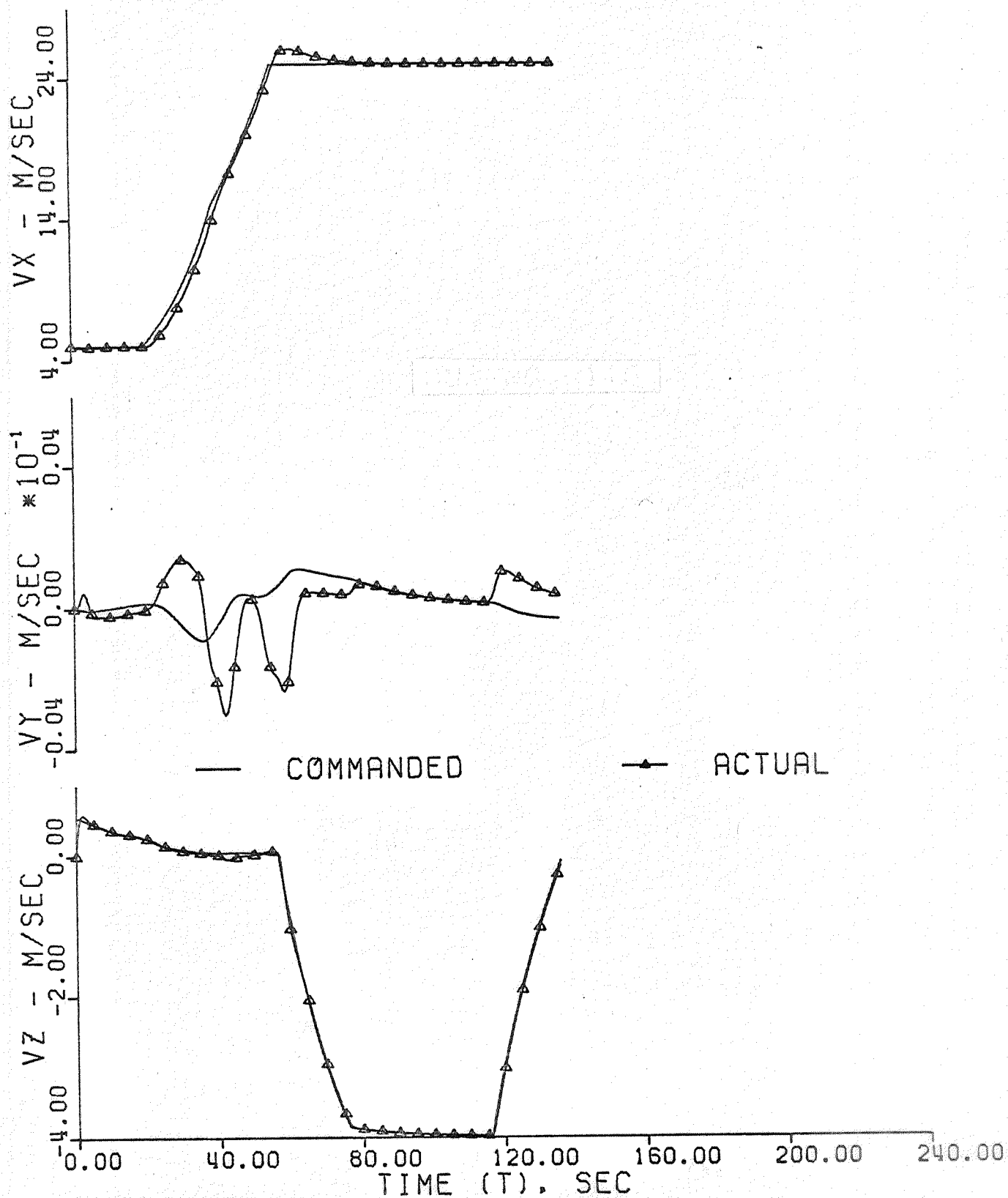


Fig. 19b. Takeoff With $\delta z_i = -10$ m - Velocity Histories

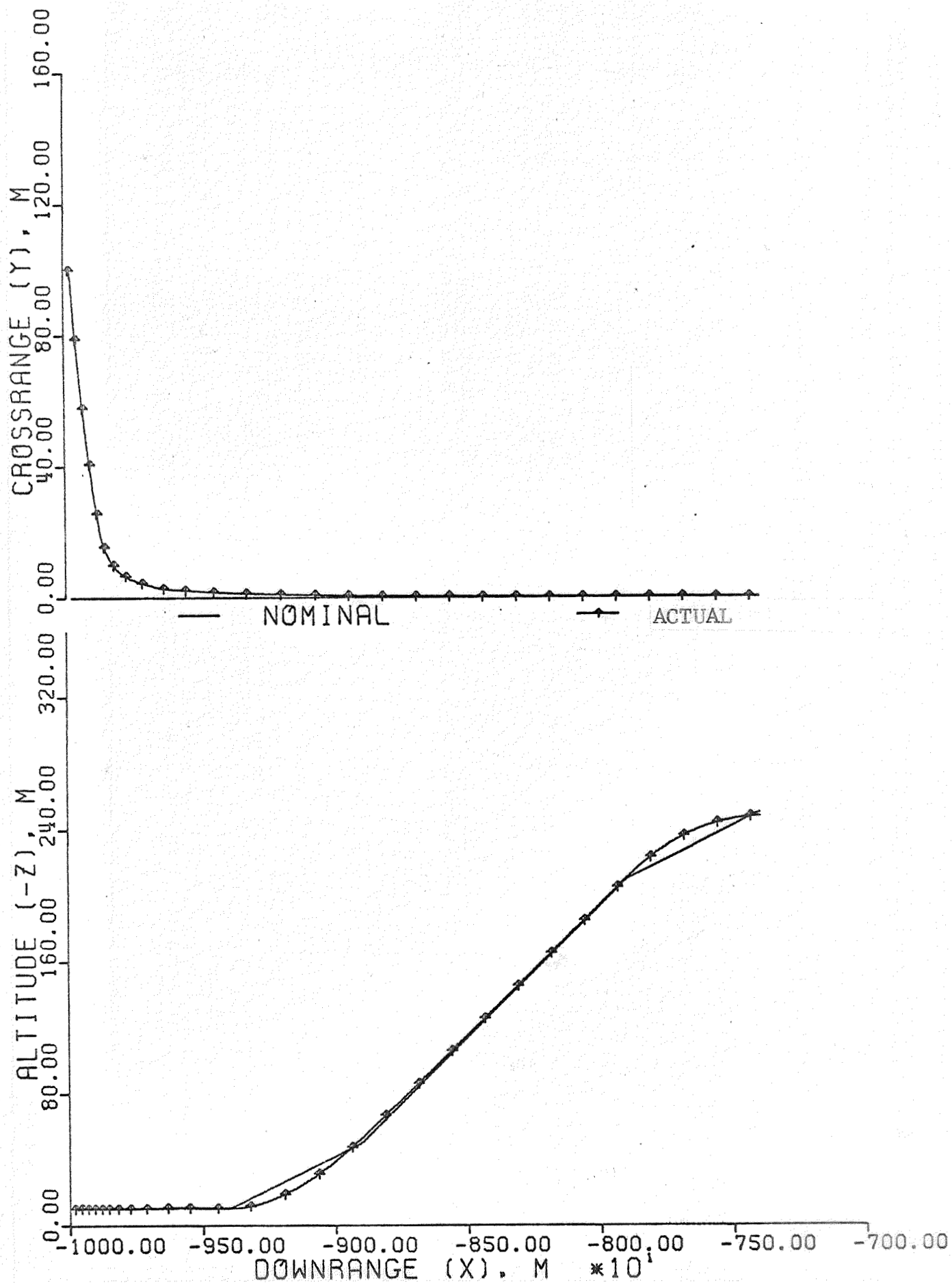


Fig. 20a. Takeoff With $\delta y_i = -100$ m - Flight Profiles

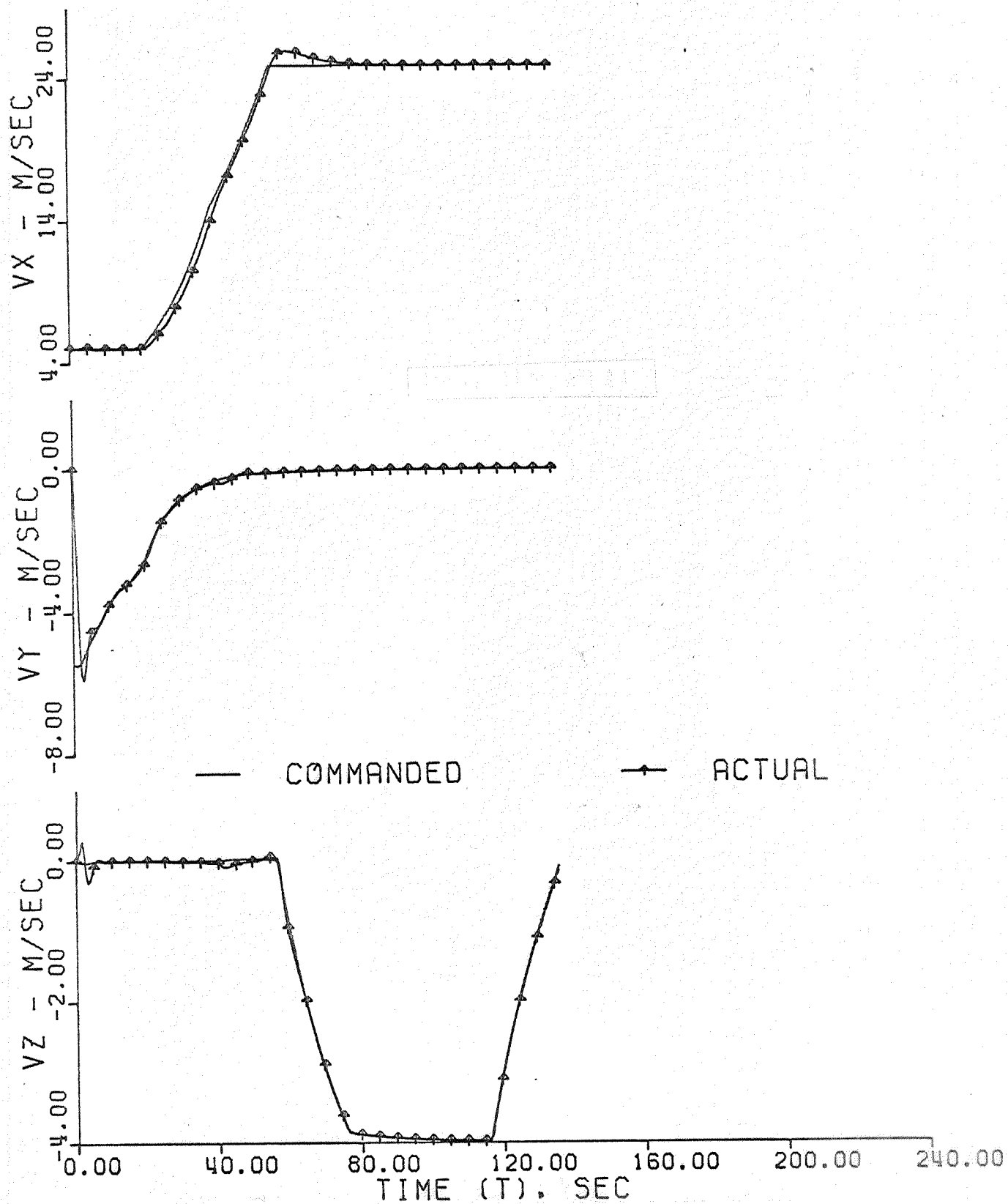


Fig. 20b. Takeoff With $\delta y_i = -100$ m - Velocity Histories

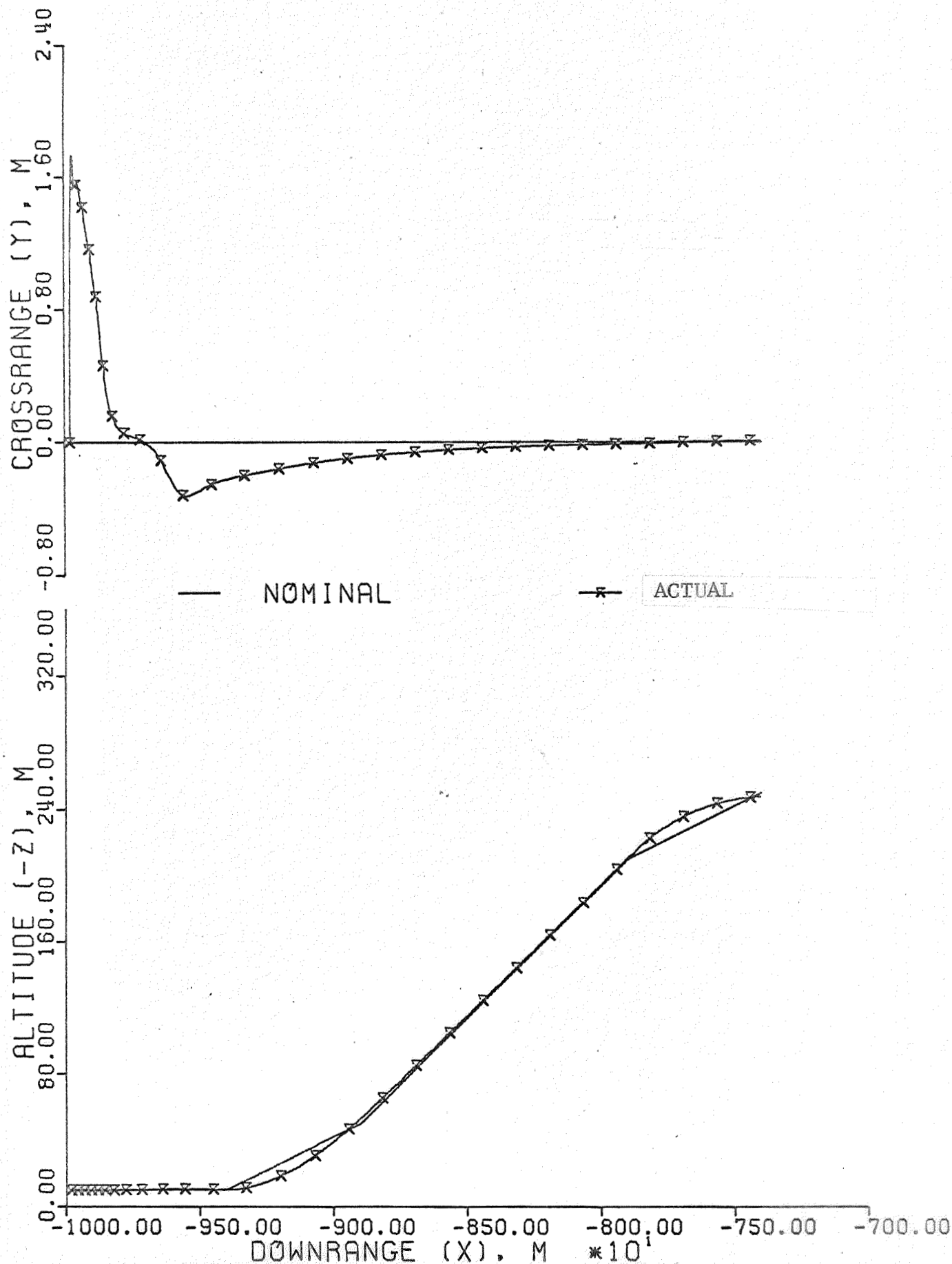


Fig. 21a. Takeoff With $\delta\psi_i = \delta\psi_i = 20^\circ$ - Flight Profiles

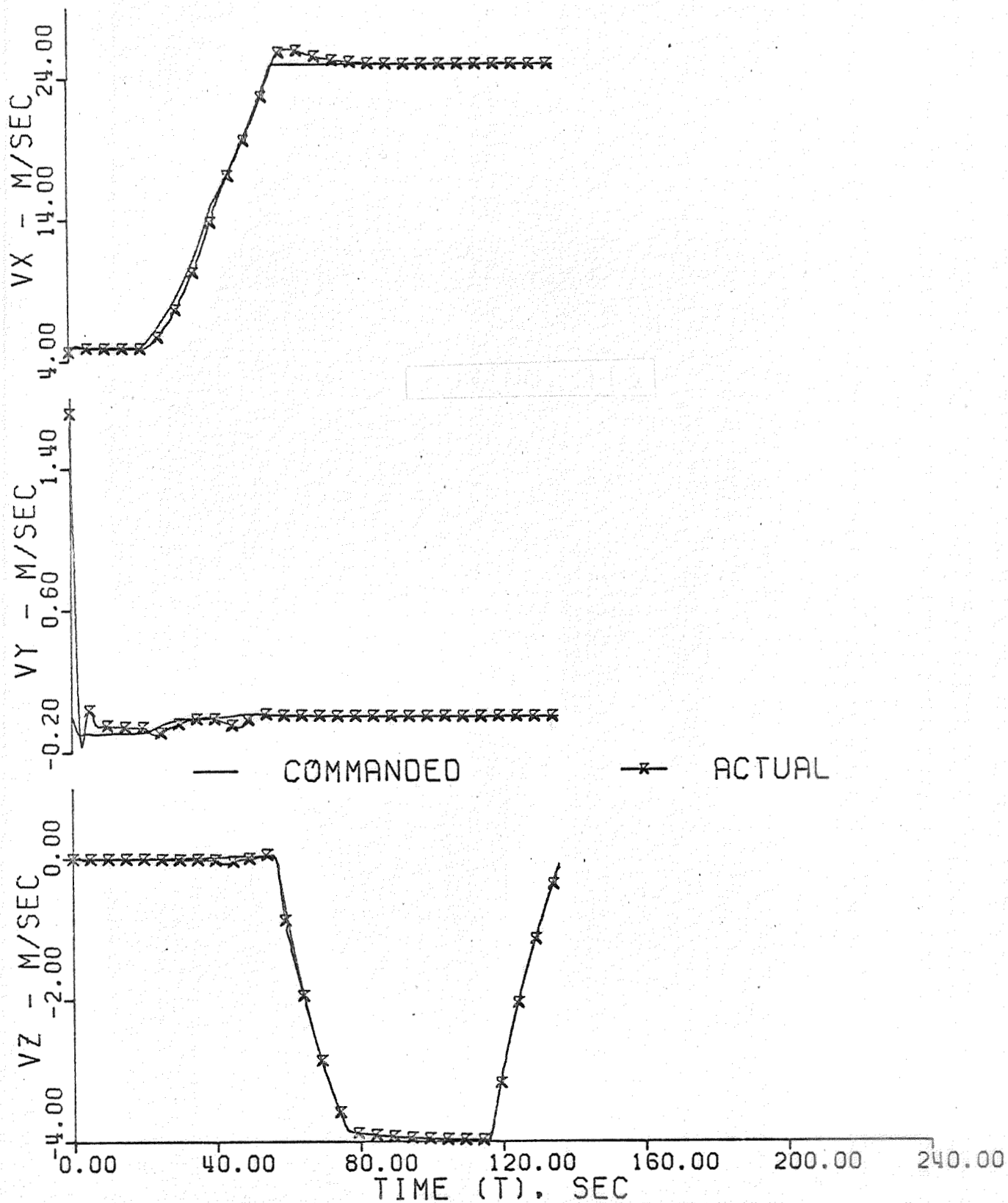


Fig. 21b. Takeoff With $\delta\psi_i = \delta\psi_i = 20^\circ$ - Velocity Histories

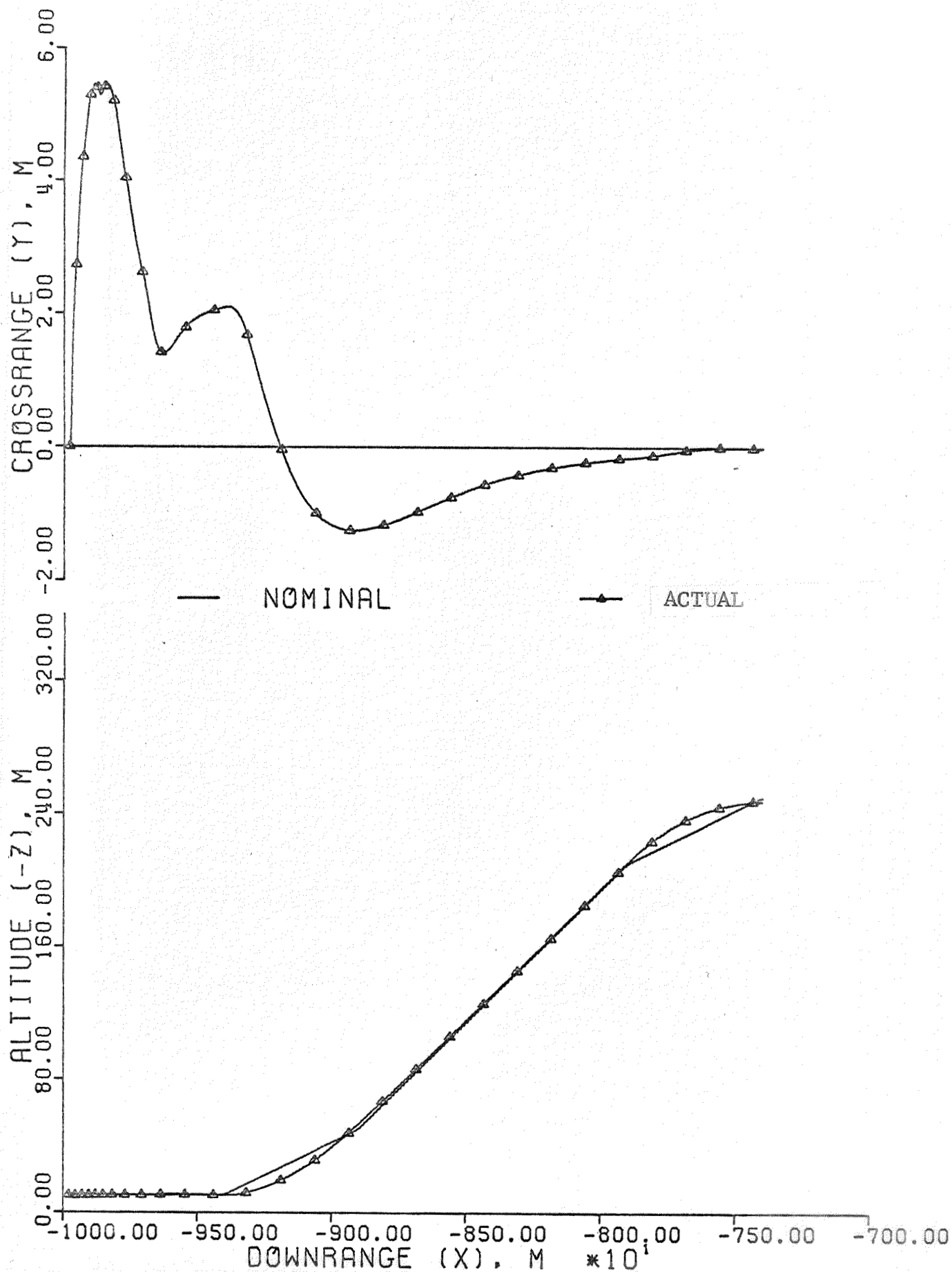


Fig. 22a. Takeoff With $w_y = 10$ m/sec - Flight Profiles

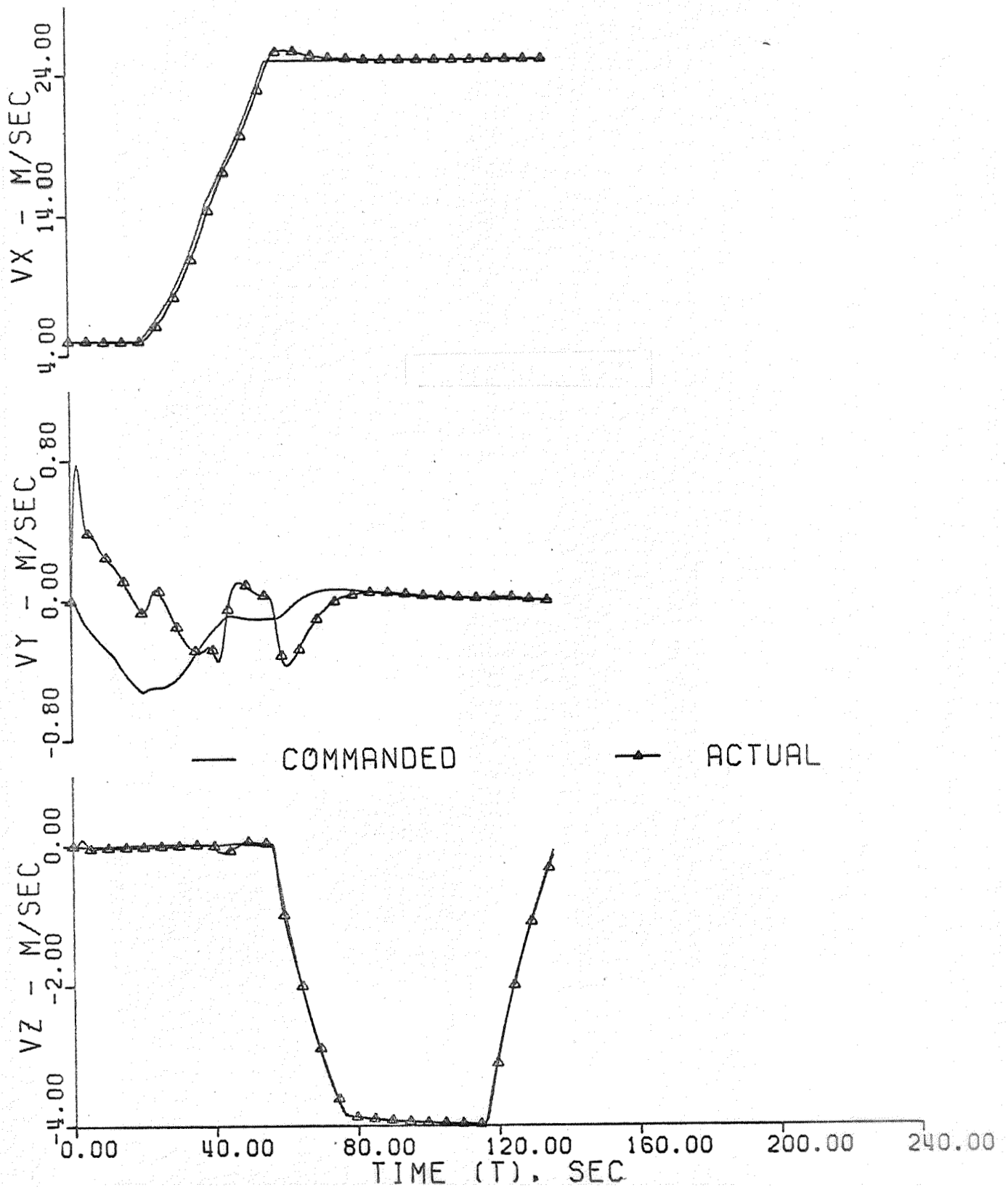


Fig. 22b. Takeoff With $w_y = 10$ m/sec - Velocity Histories

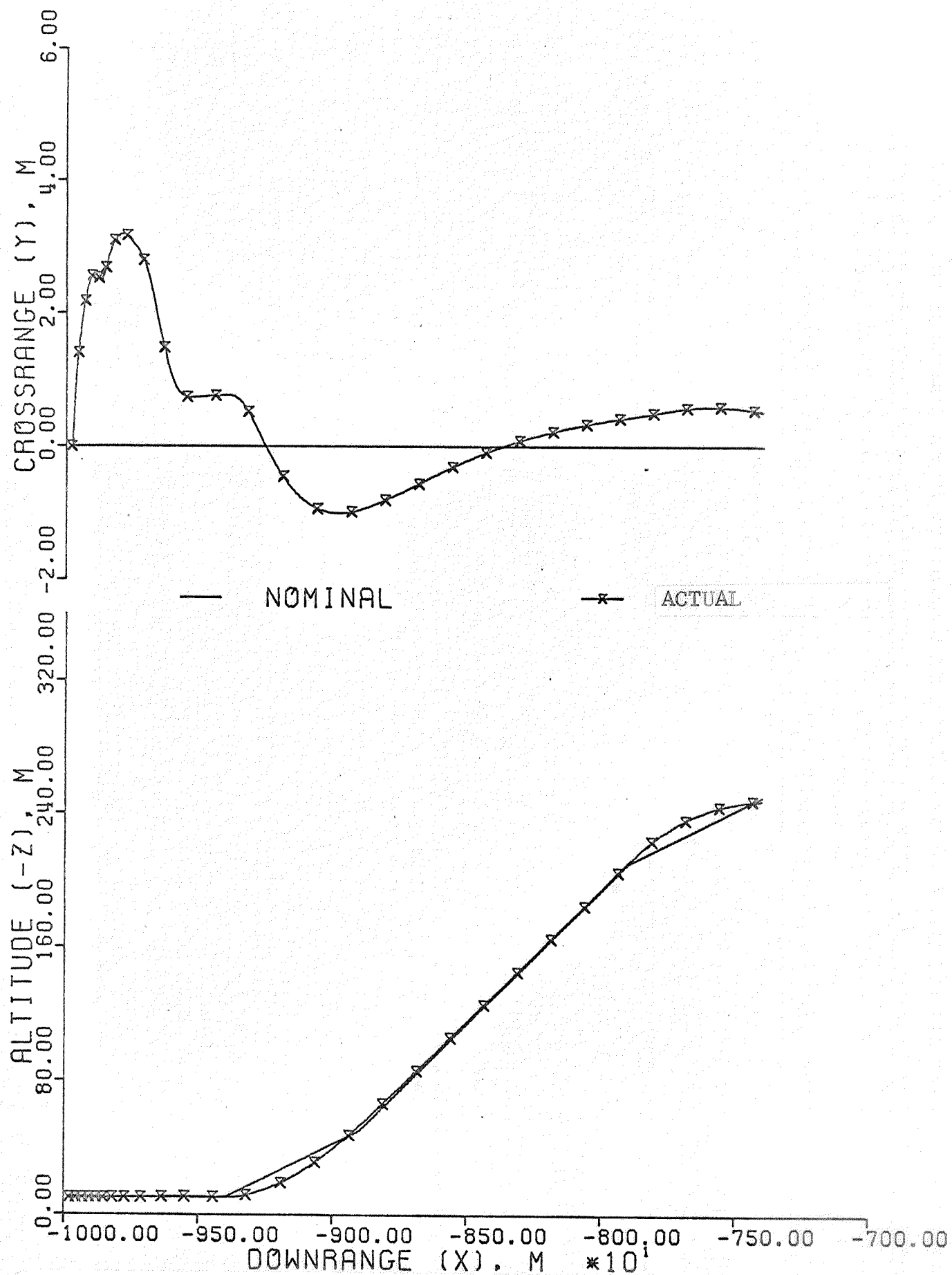


Fig. 23a. Takeoff With $w_y = 5-z/50$ m/sec - Flight Profiles

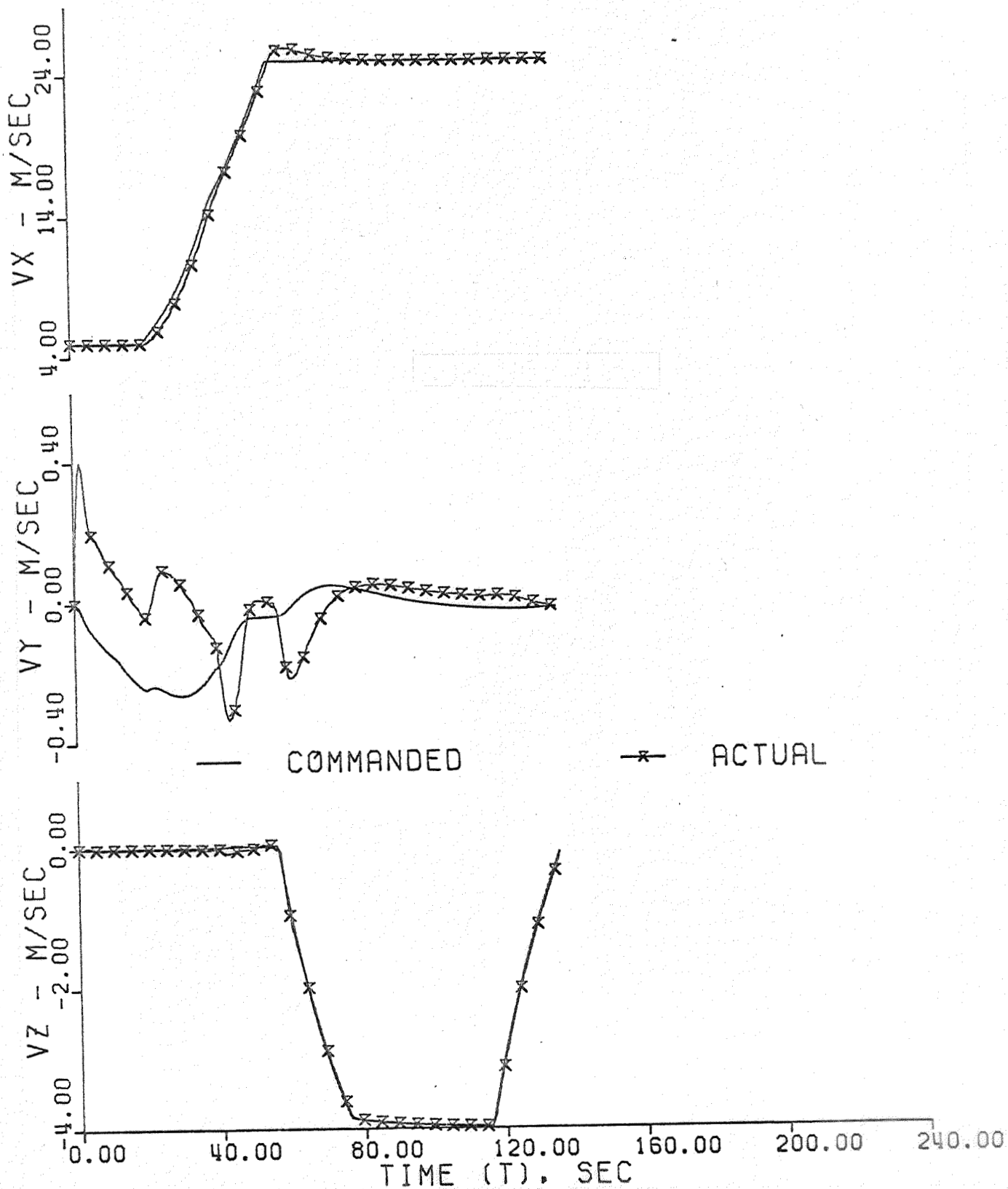


Fig. 23b. Takeoff With $w_y = 5-z/50$ m/sec - Velocity Histories

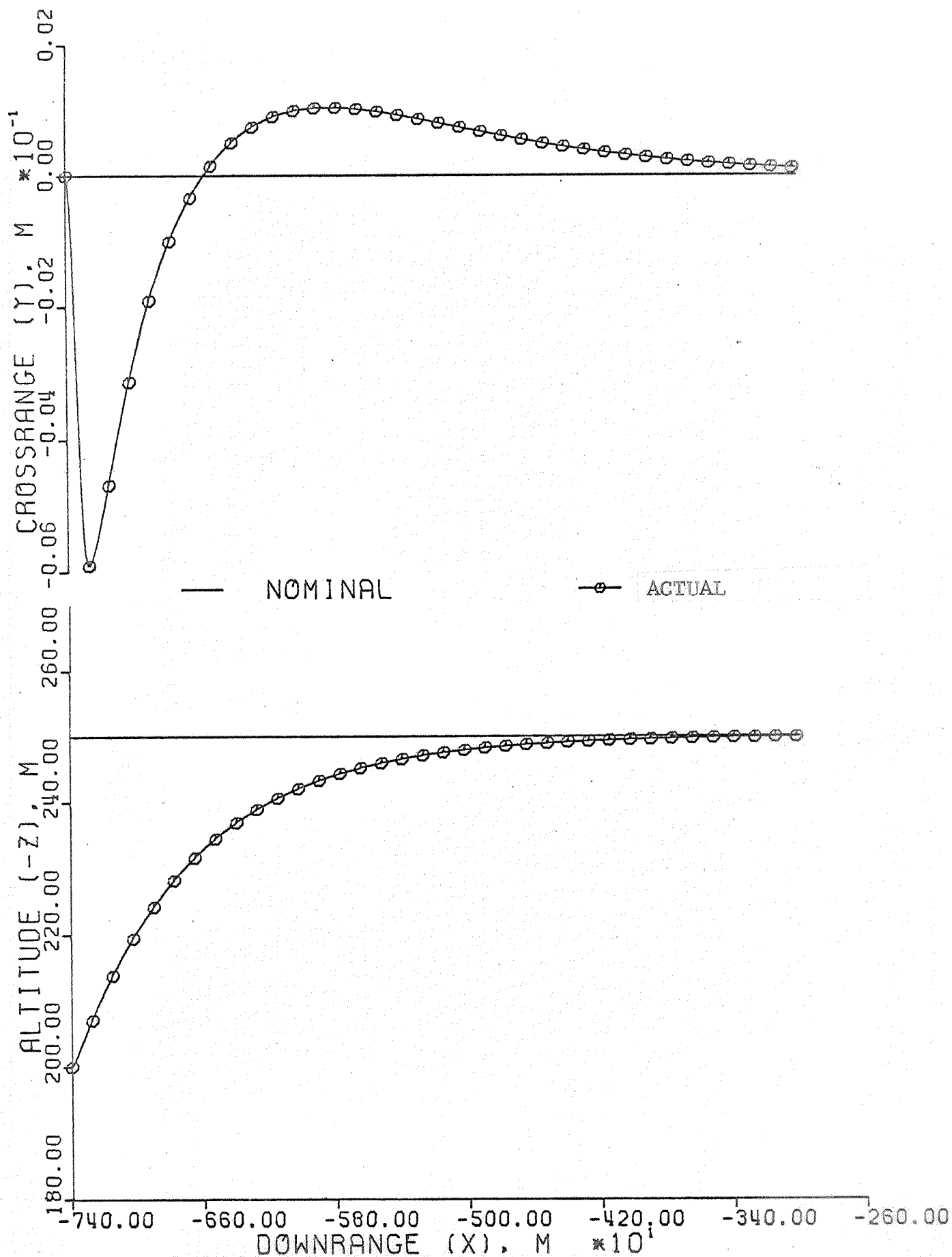


Fig. 24a. Cruise With $\delta z_i = +50$ m - Flight Profiles

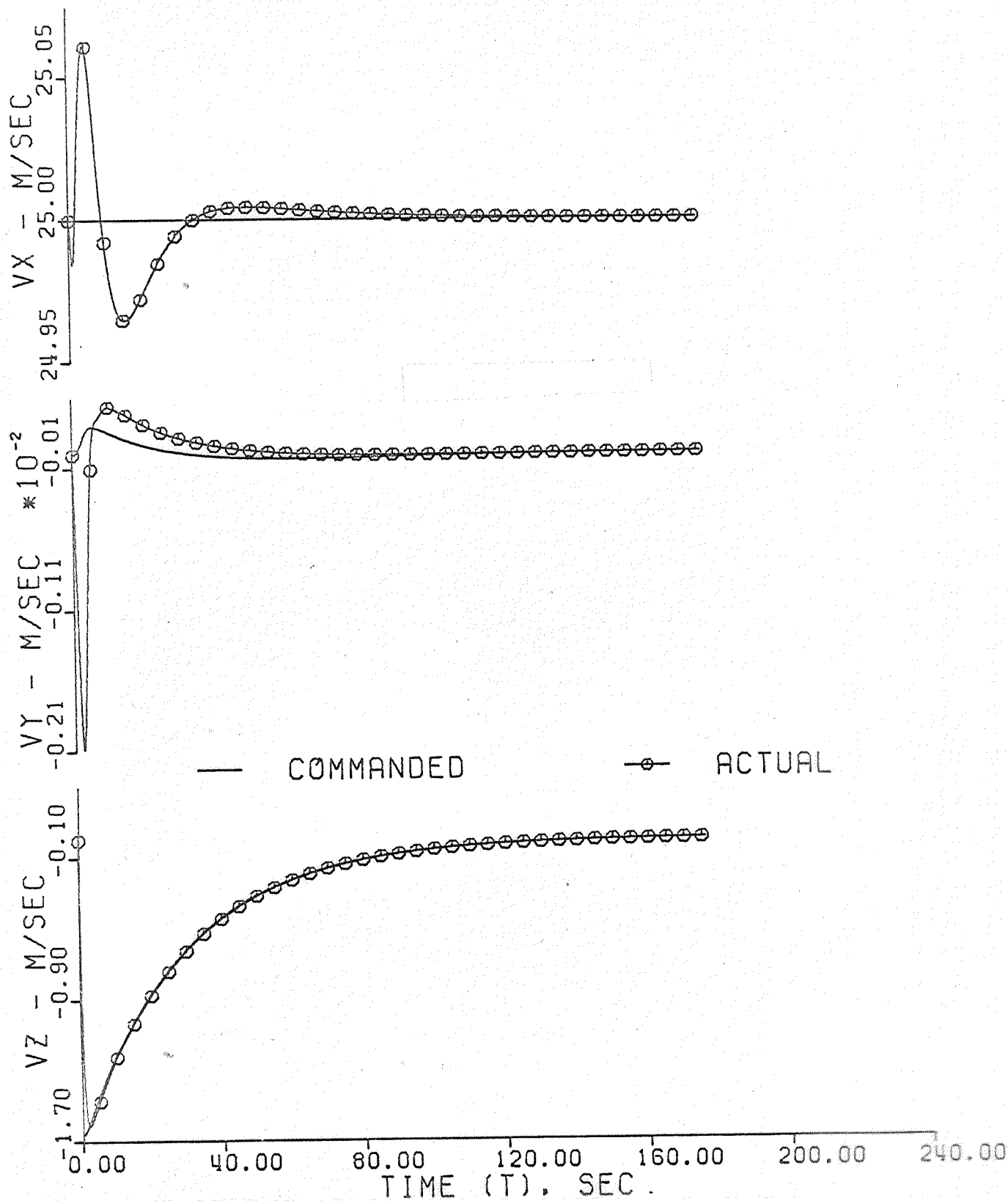


Fig. 24b. Cruise With $\delta z_i = +50$ m - Velocity Histories

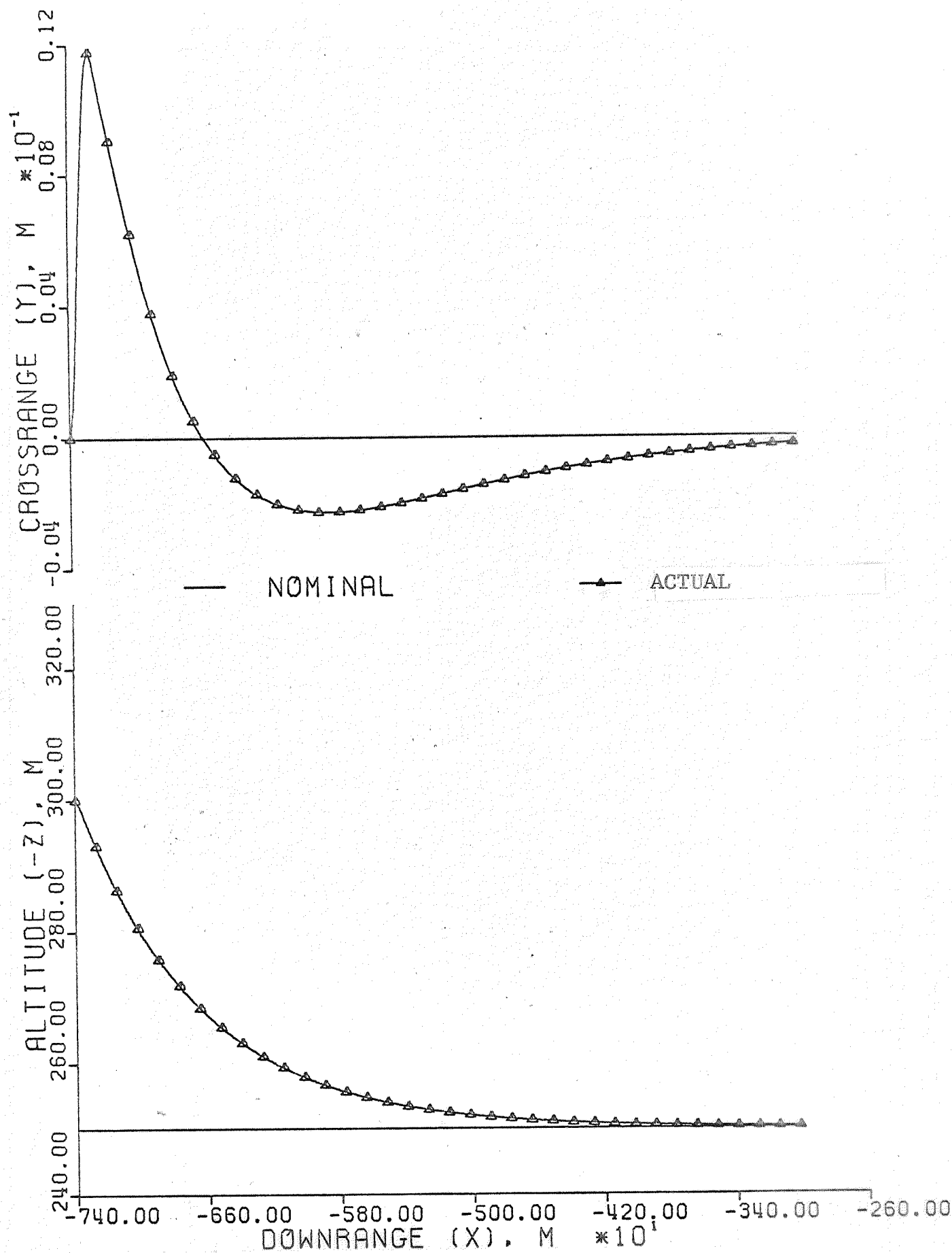


Fig. 25a. Cruise With $\delta z_i = -50$ m - Flight Profiles

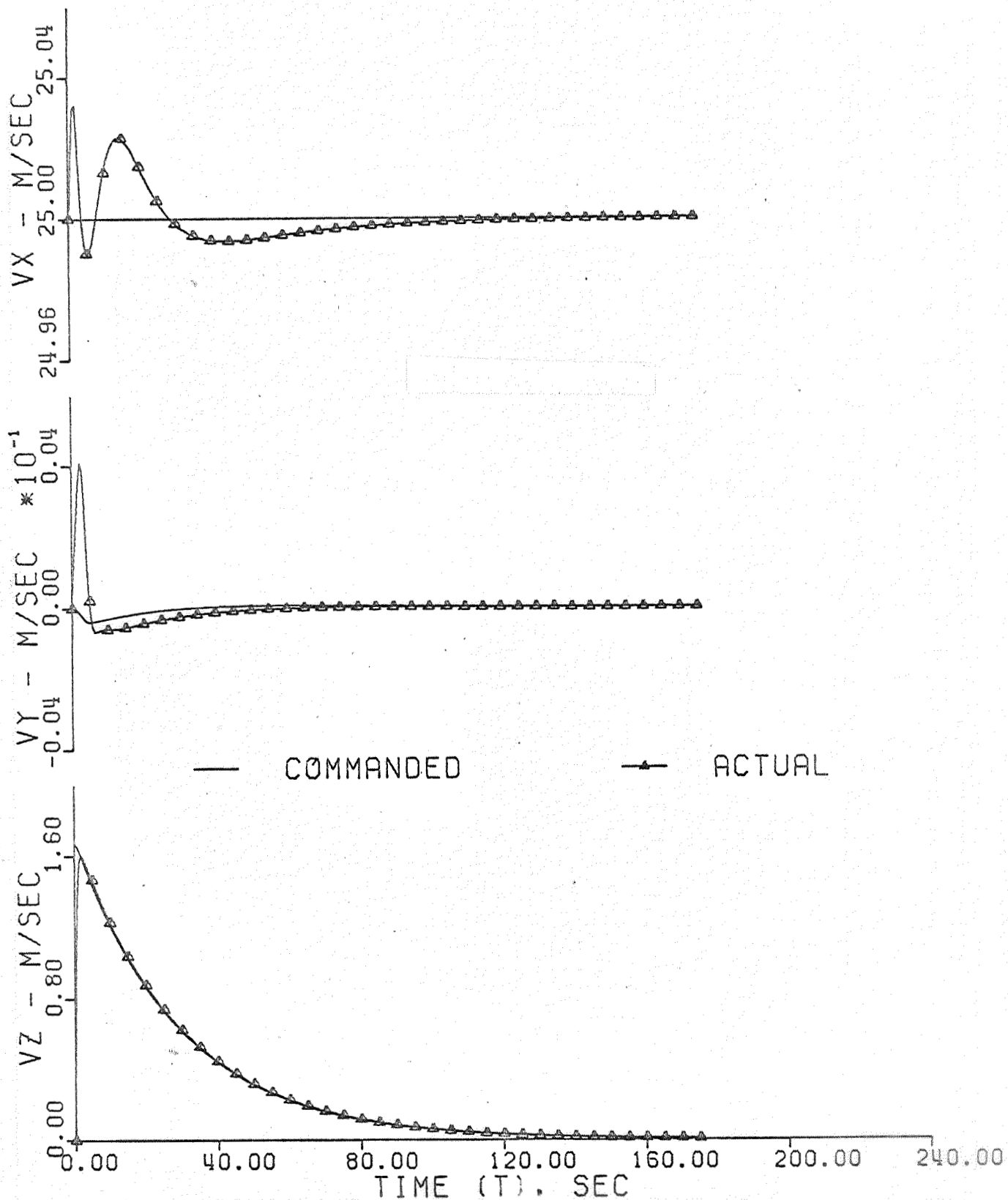


Fig. 25b. Cruise With $\delta z_i = -50$ m - Velocity Histories

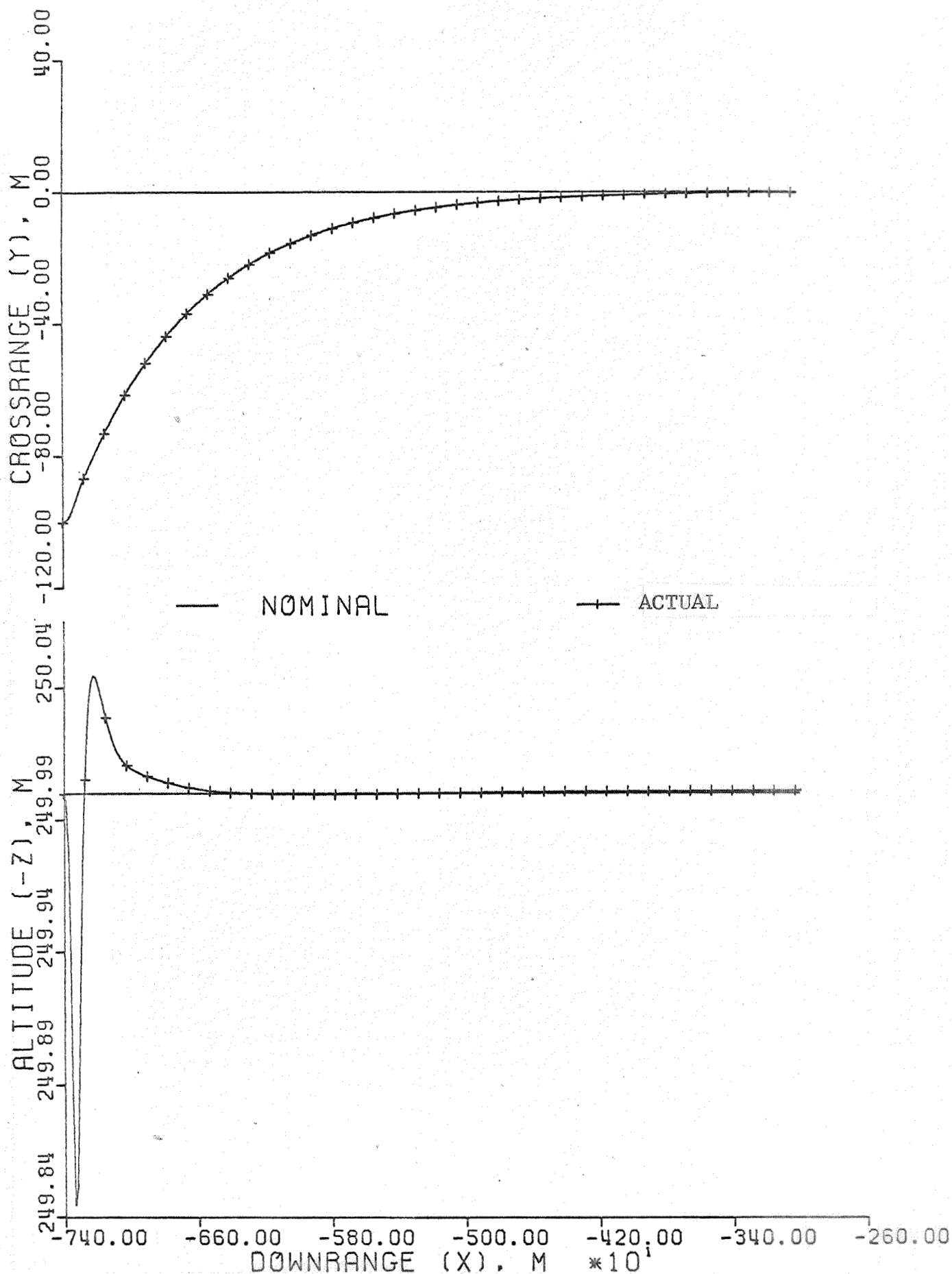


Fig. 26a. Cruise With $\delta y_i = -100$ m - Flight Profiles

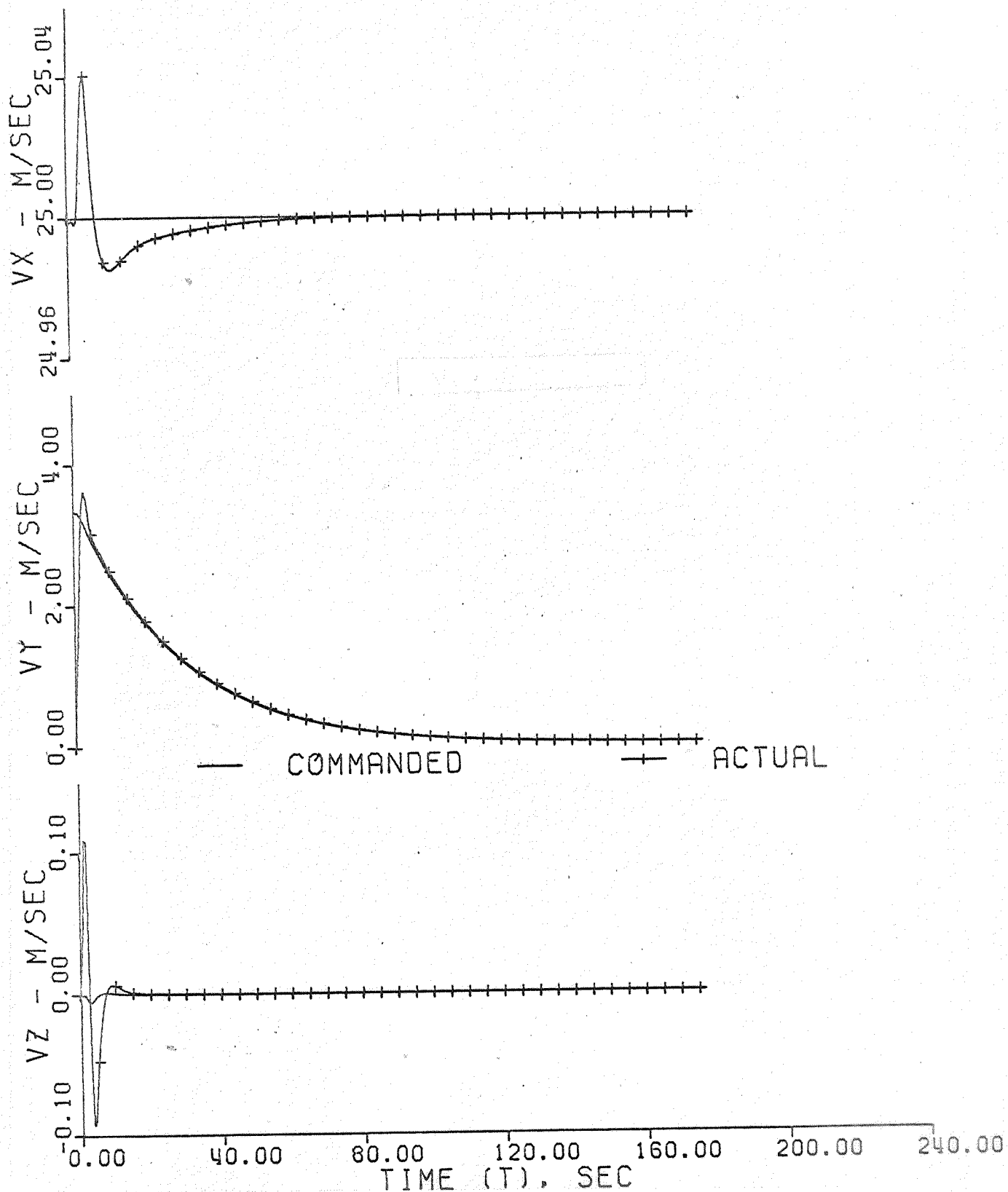


Fig. 26b. Cruise With $\delta y_i = -100$ m - Velocity Histories

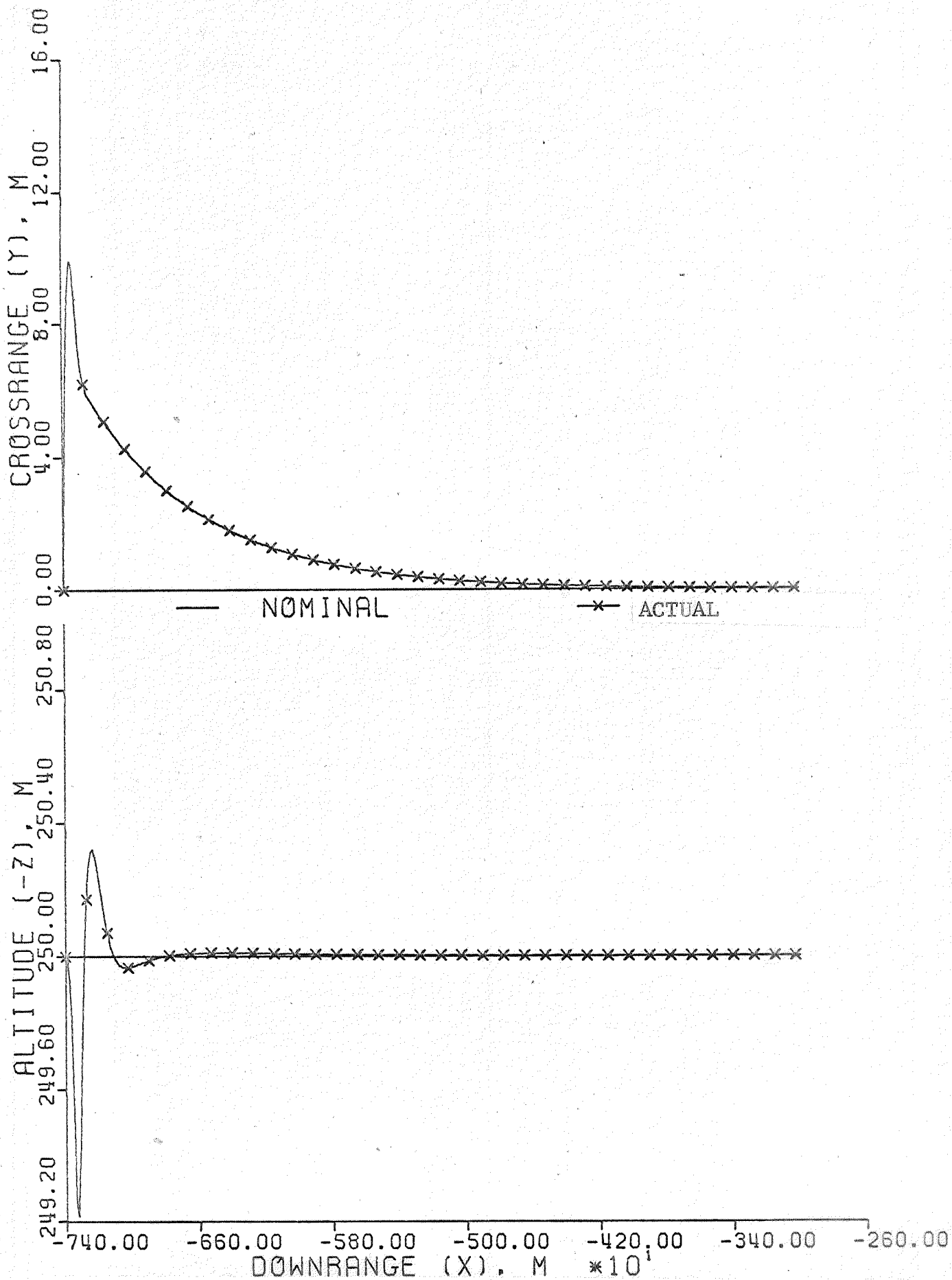


Fig. 27a. Cruise With $\delta\psi_i = \delta\psi_i = 20^\circ$ - Flight Profiles

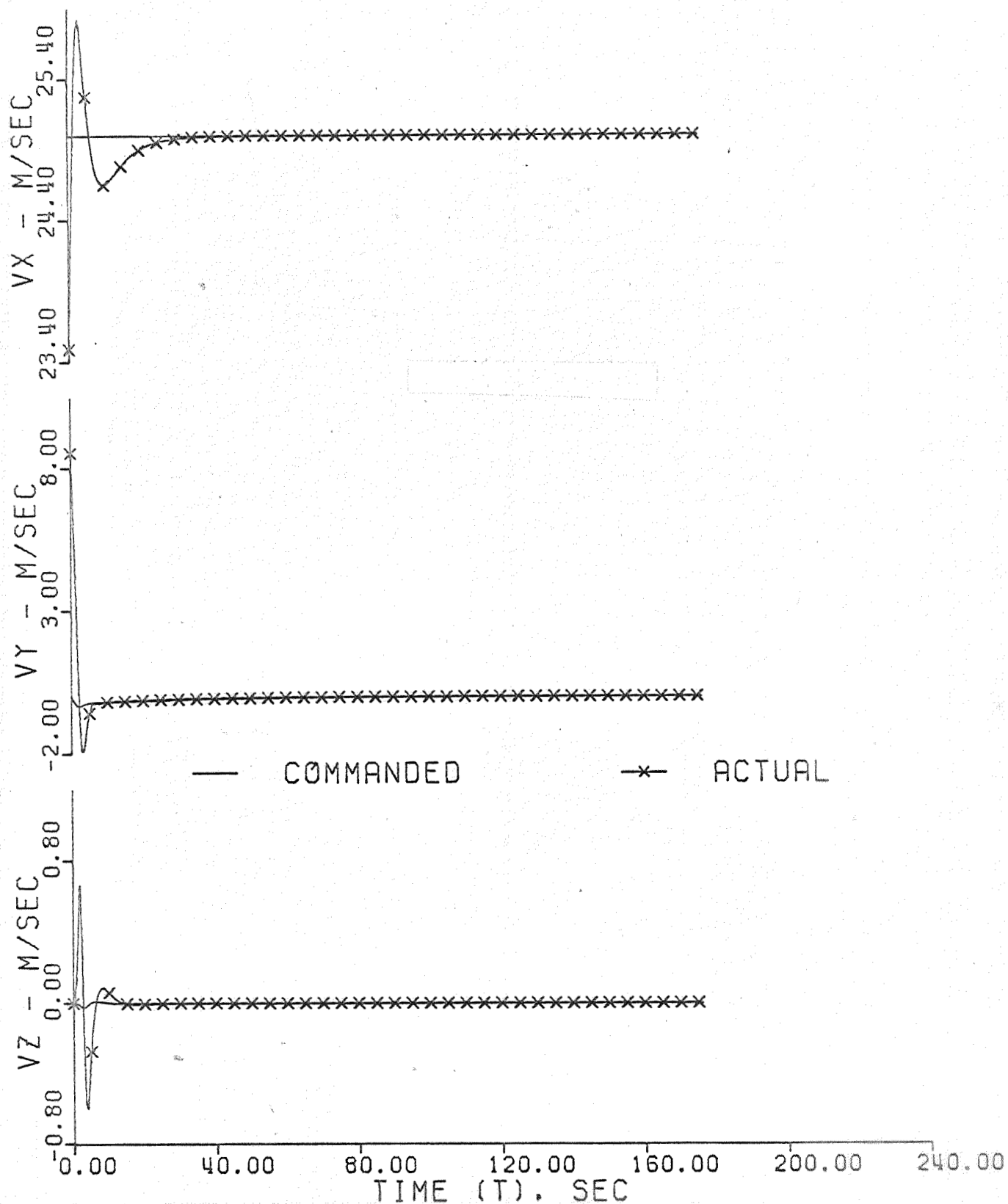


Fig. 27b. Cruise With $\delta\psi_i = \delta\psi_i = 20^\circ$ - Velocity Histories

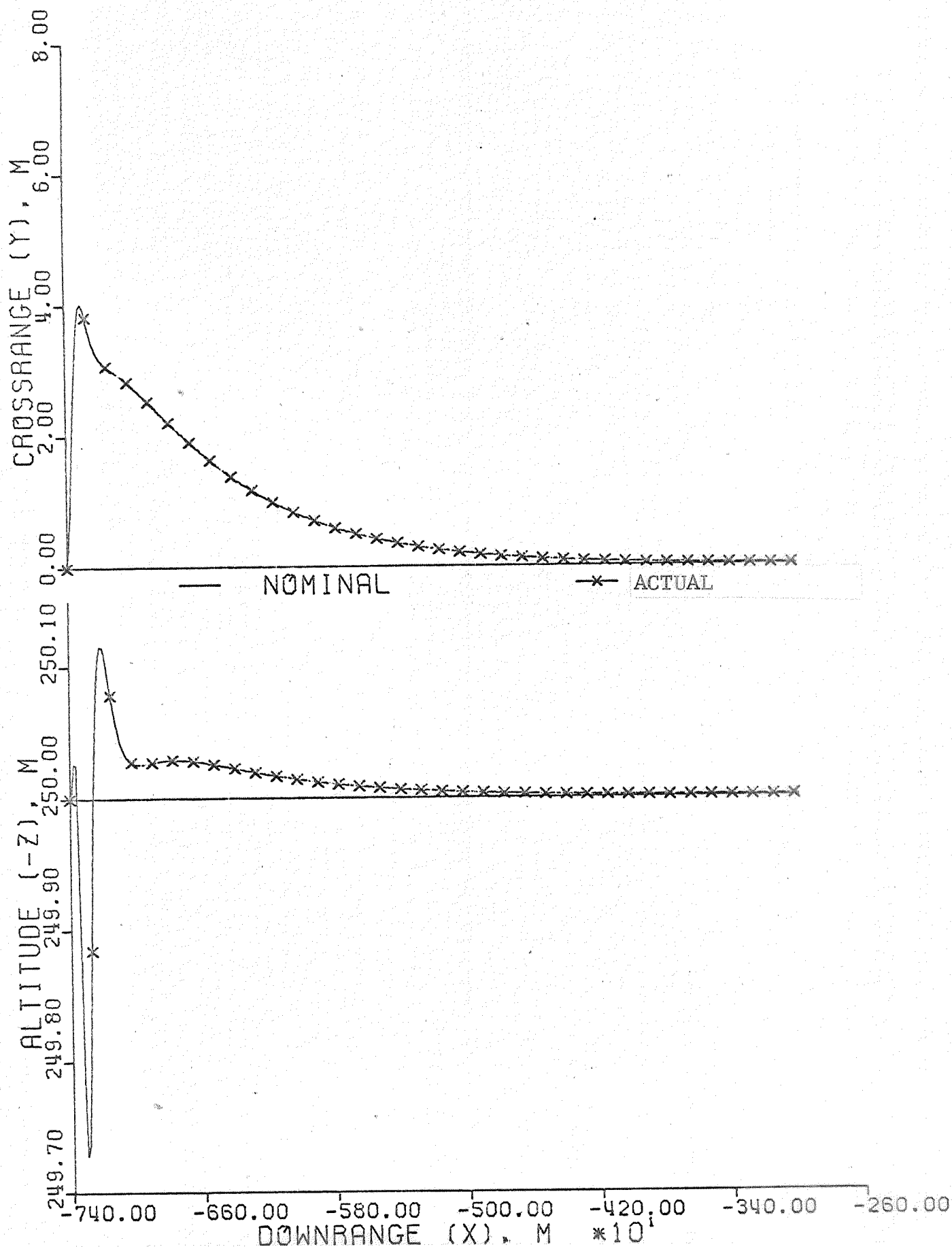


Fig. 28a. Cruise With $w_y = 10$ m/sec - Flight Profiles

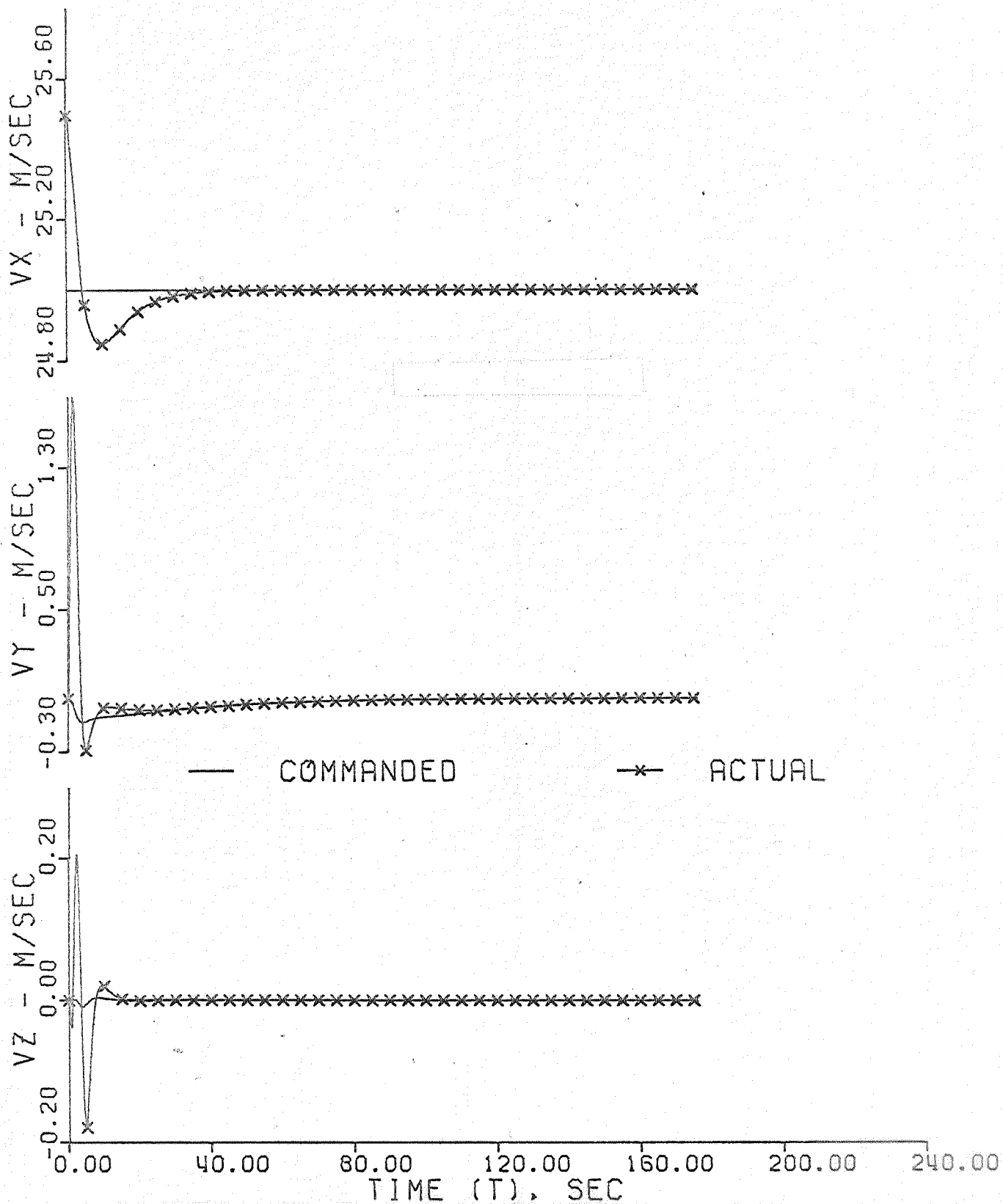


Fig. 28b. Cruise With $w_y = 10$ m/sec - Velocity Histories

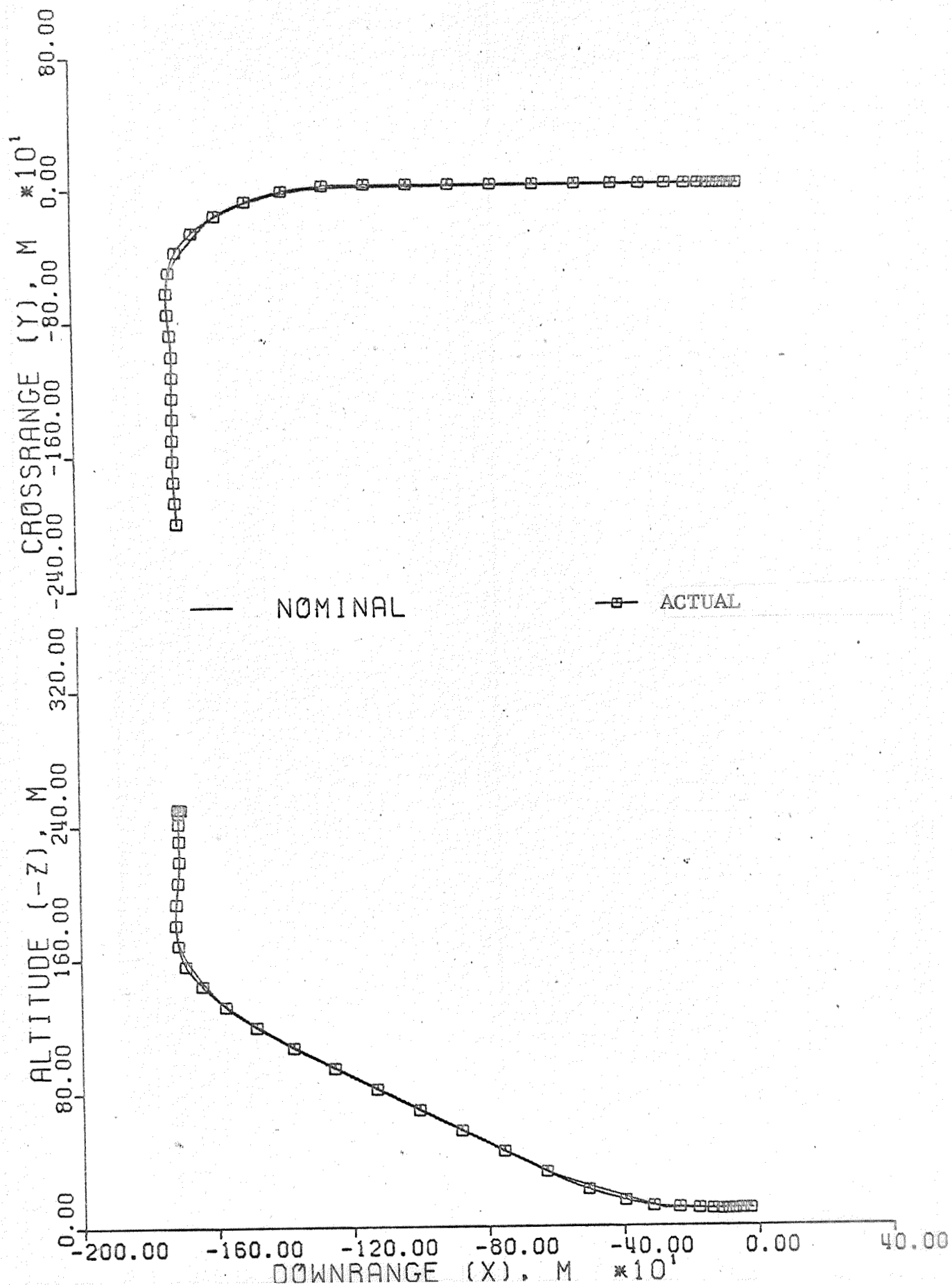


Fig. 29a. 90° Approach With Nominal Conditions - Flight Profiles

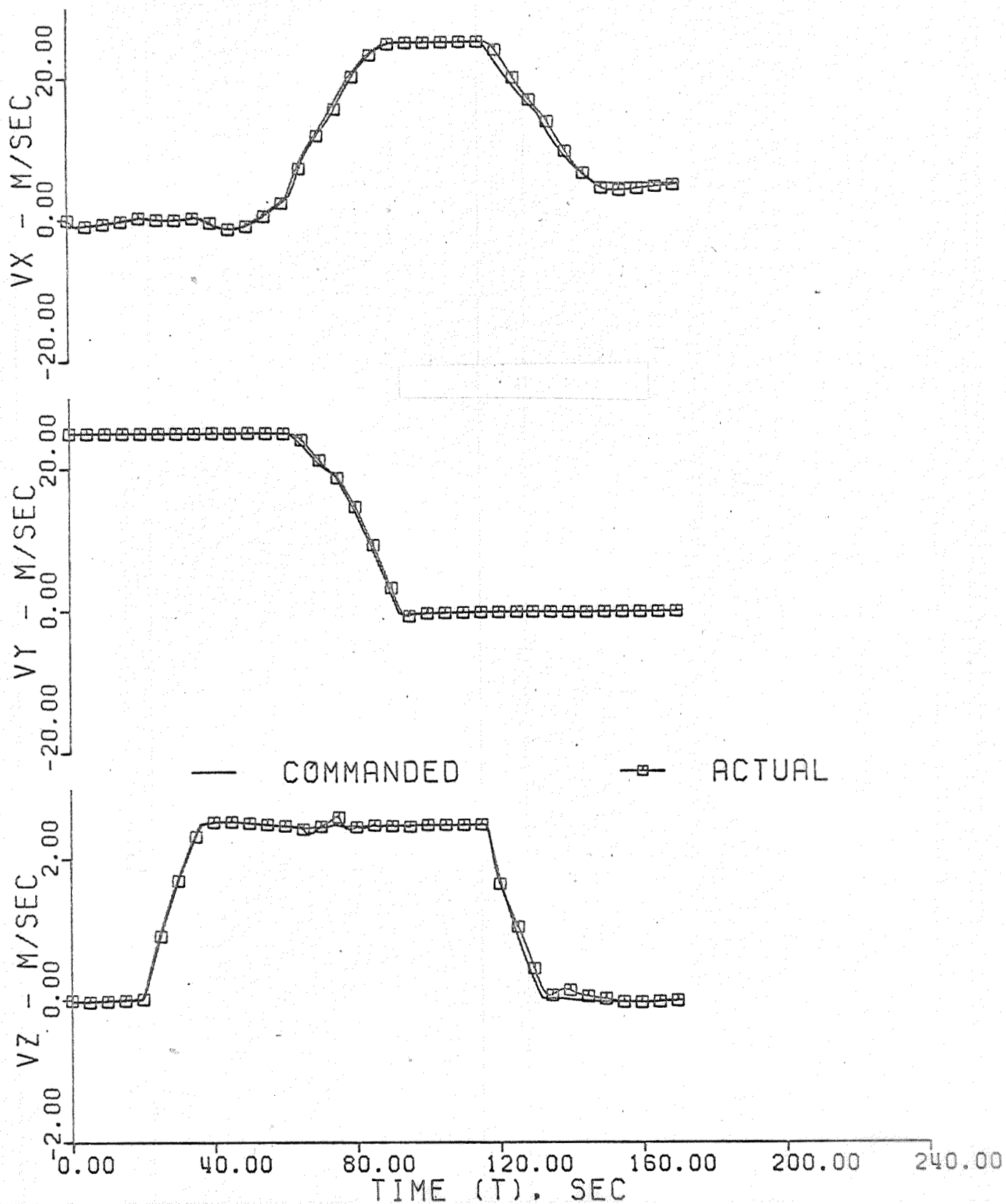


Fig. 29b. 90° Approach With Nominal Conditions - Velocity Histories

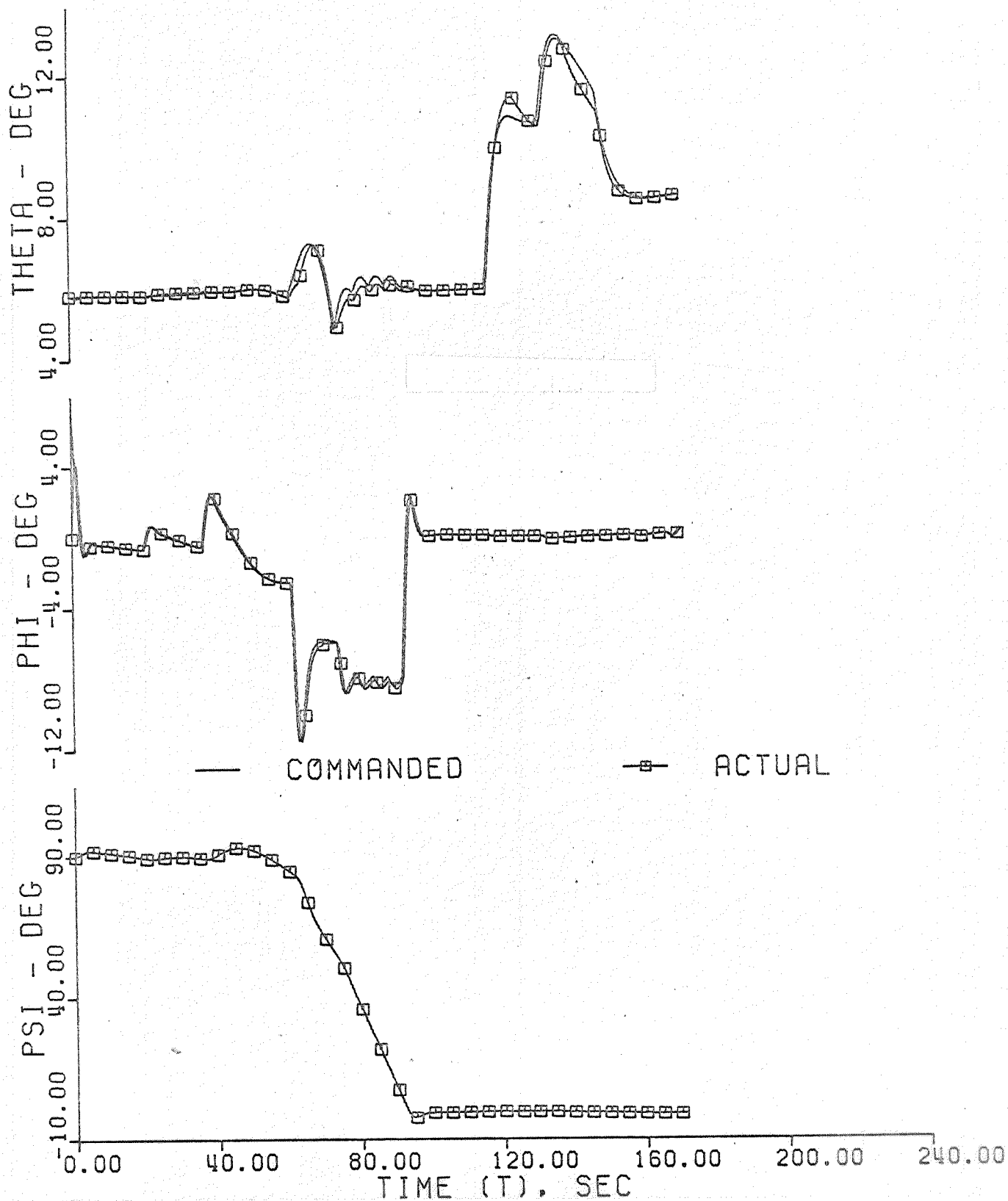


Fig. 29c. 90° Approach With Nominal Conditions - Attitude Histories

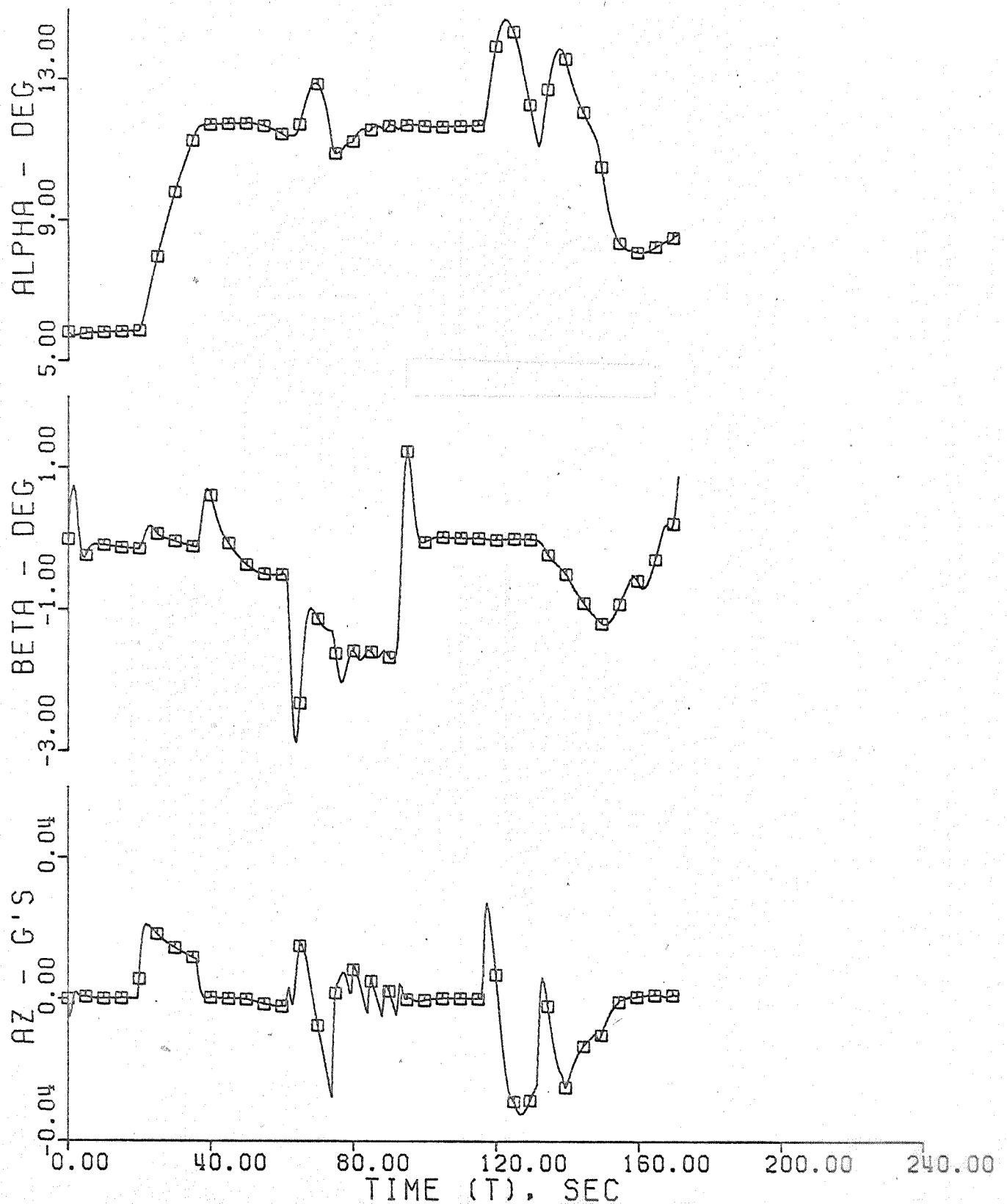


Fig. 29d. 90° Approach With Nominal Conditions - Angle of Attack, Sideslip Angle and Normal Acceleration Histories

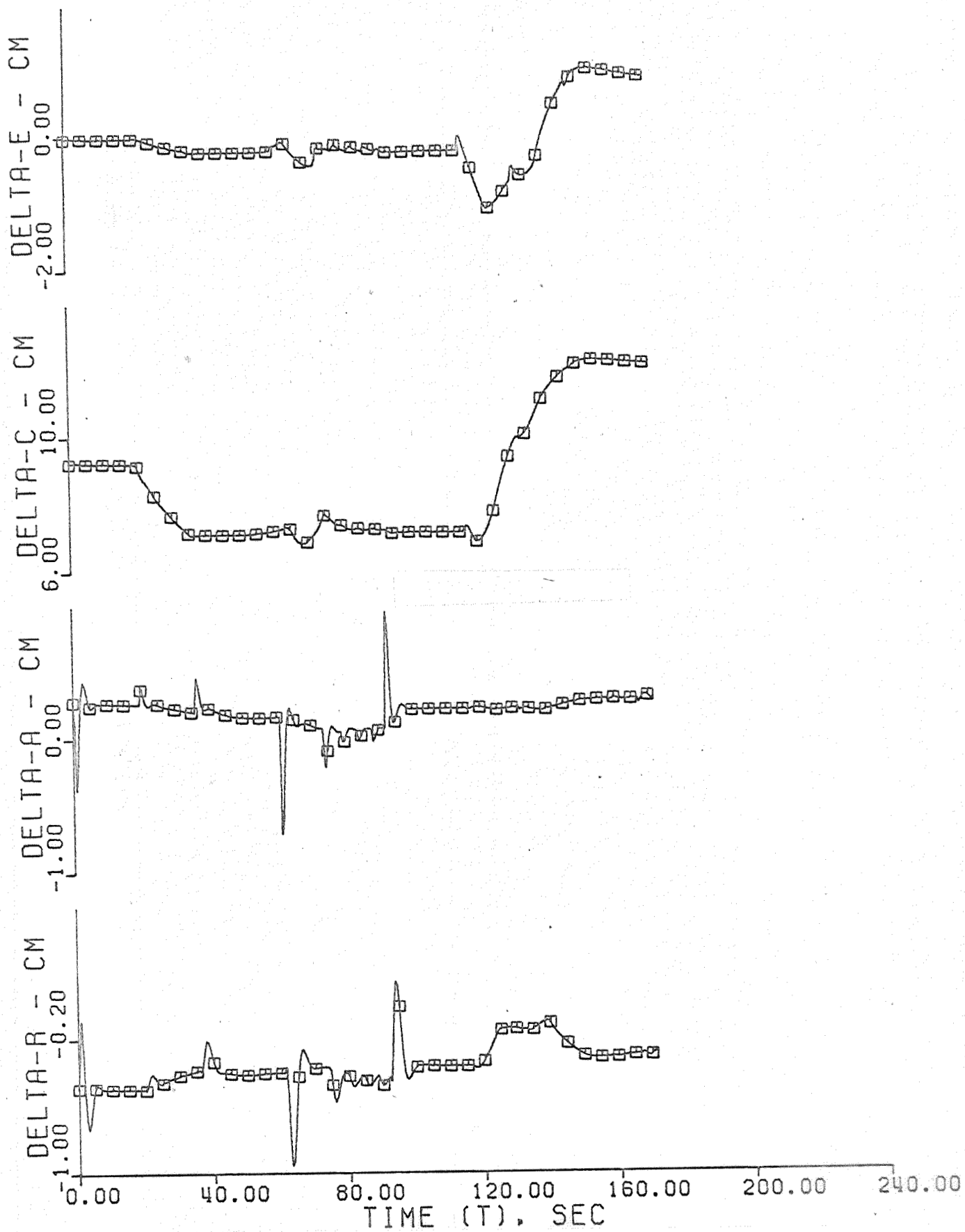


Fig. 29e. 90° Approach With Nominal Conditions - Control Histories

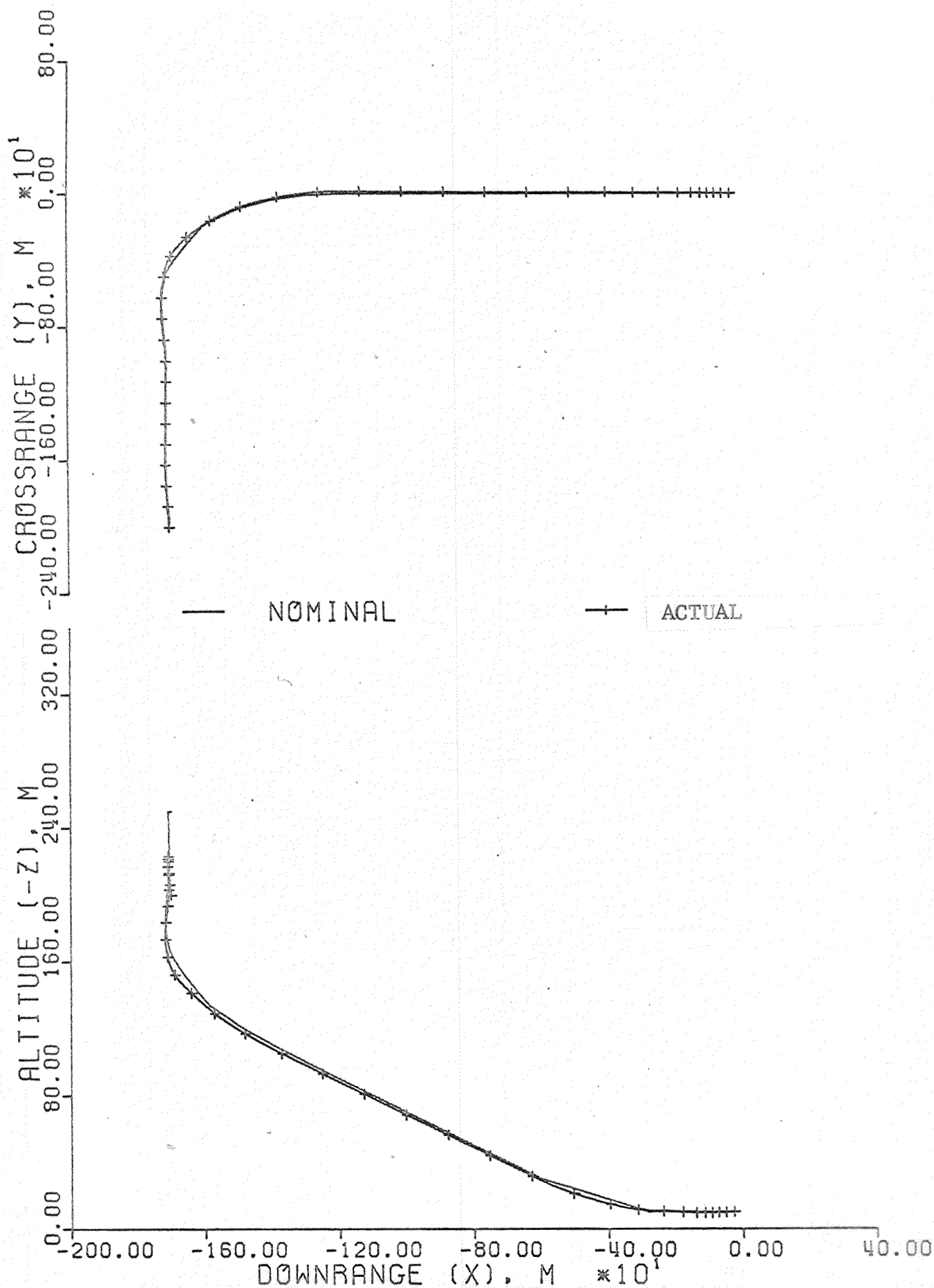


Fig. 30a. 90° Approach With $\delta z_i = +50$ m - Flight Profiles

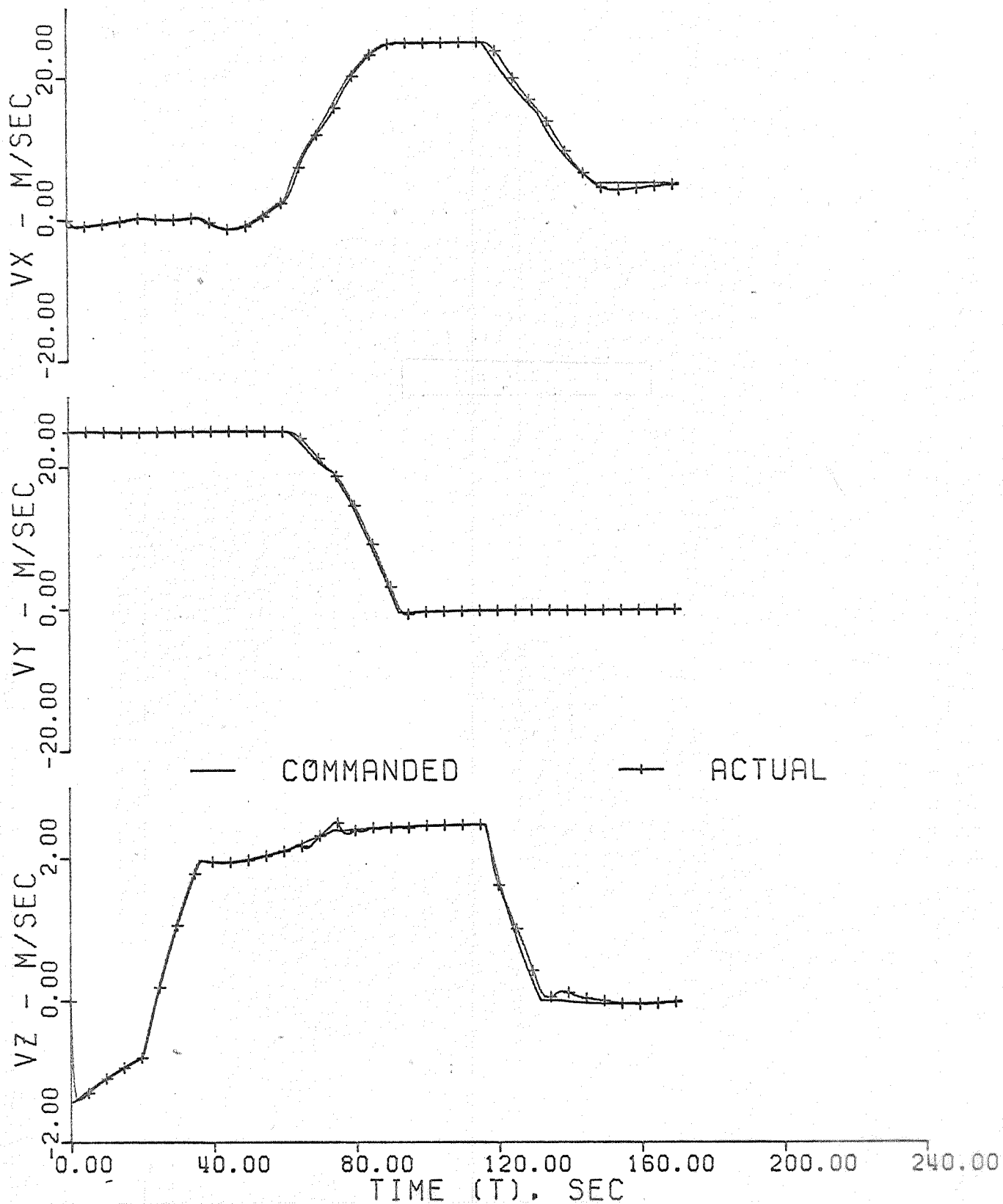


Fig. 30b. 90° Approach With $\delta z_i = +50$ m - Velocity Histories

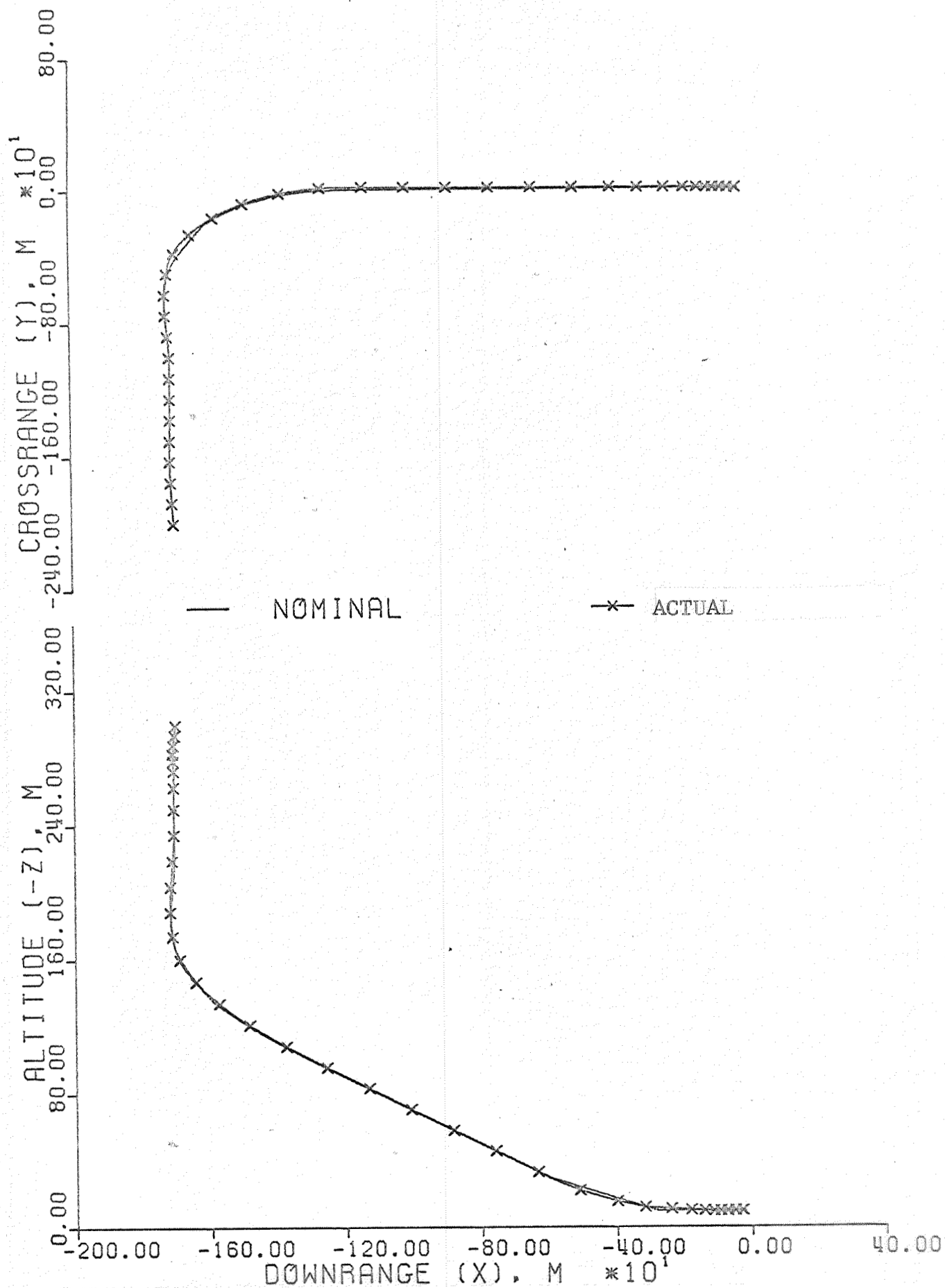


Fig. 31a. 90° Approach With $\delta z_1 = -50$ m - Flight Profiles

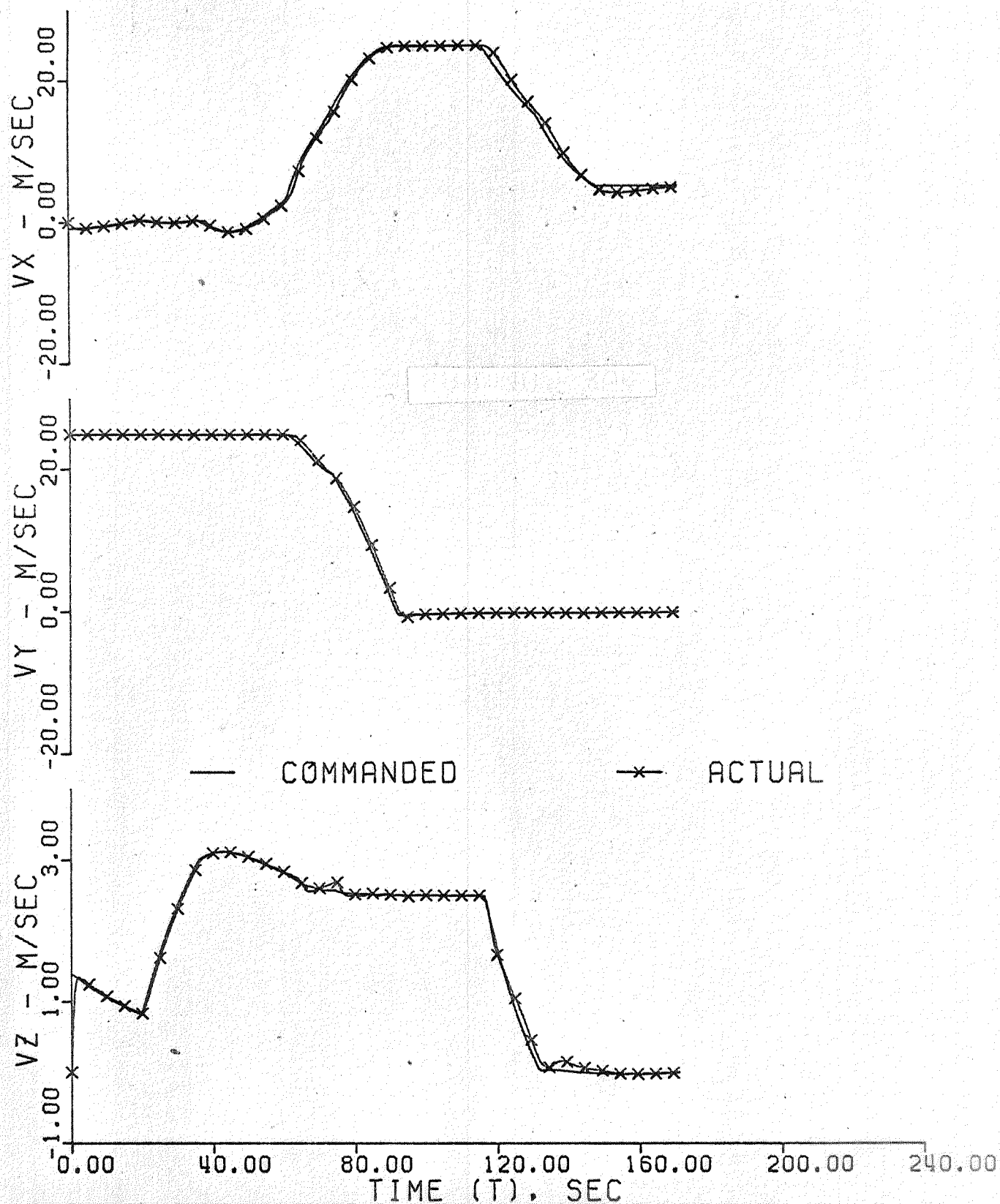


Fig. 31b. 90° Approach With $\delta z_i = -50$ m - Velocity Histories

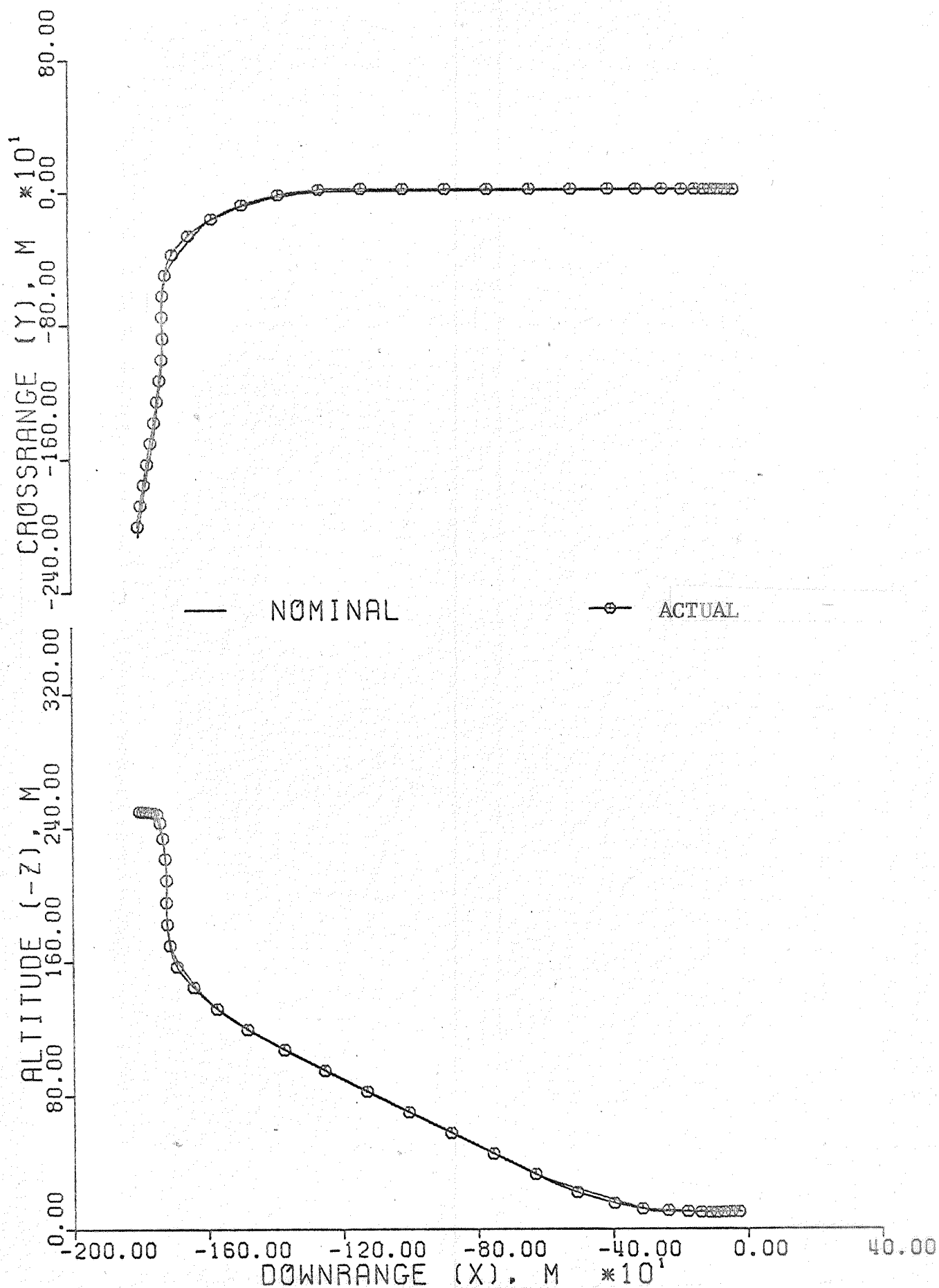


Fig. 32a. 90° Approach With $\delta x_i = +100$ m - Flight Profiles

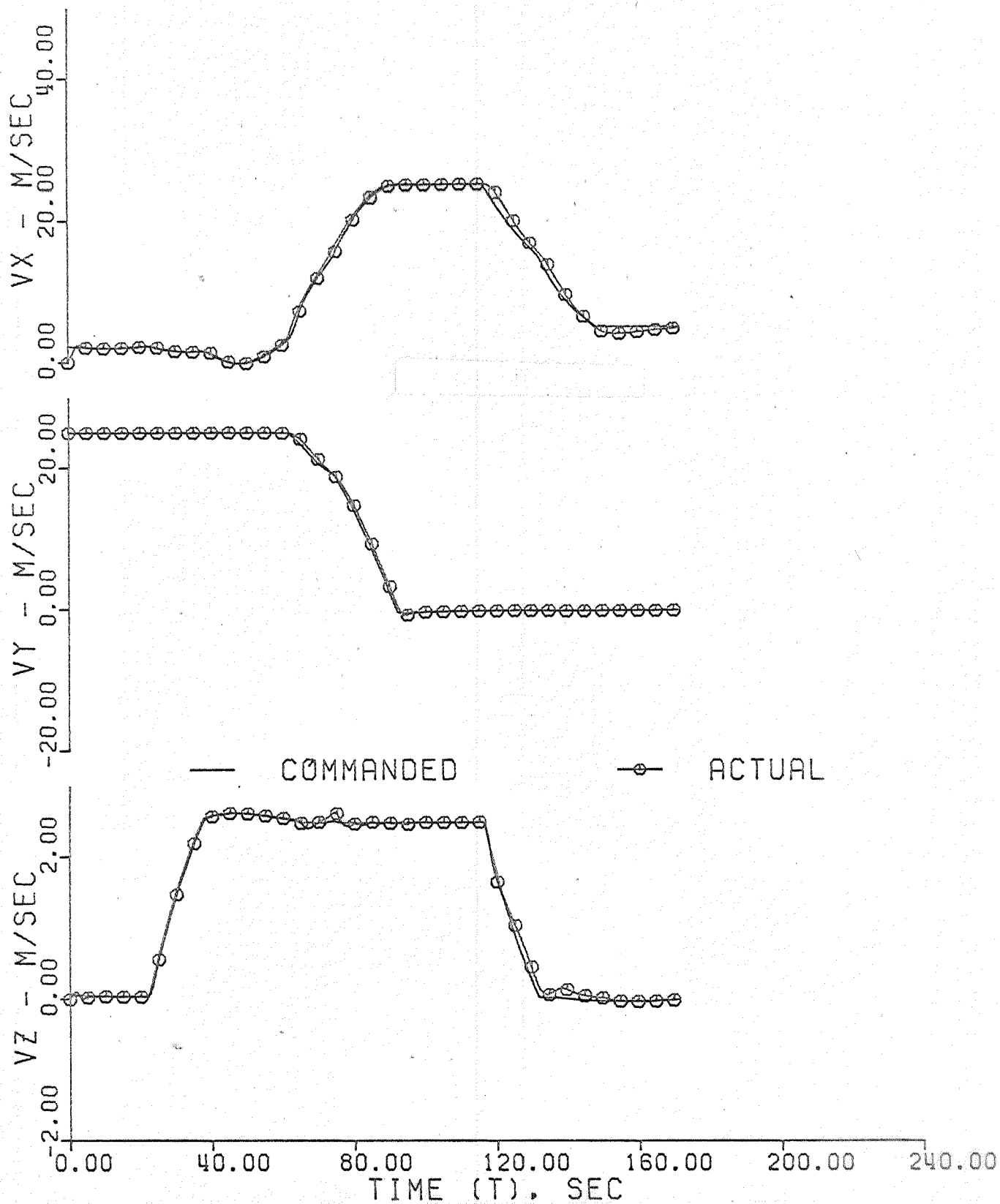


Fig. 32b. 90° Approach With $\delta x_i = +100$ m - Velocity Histories

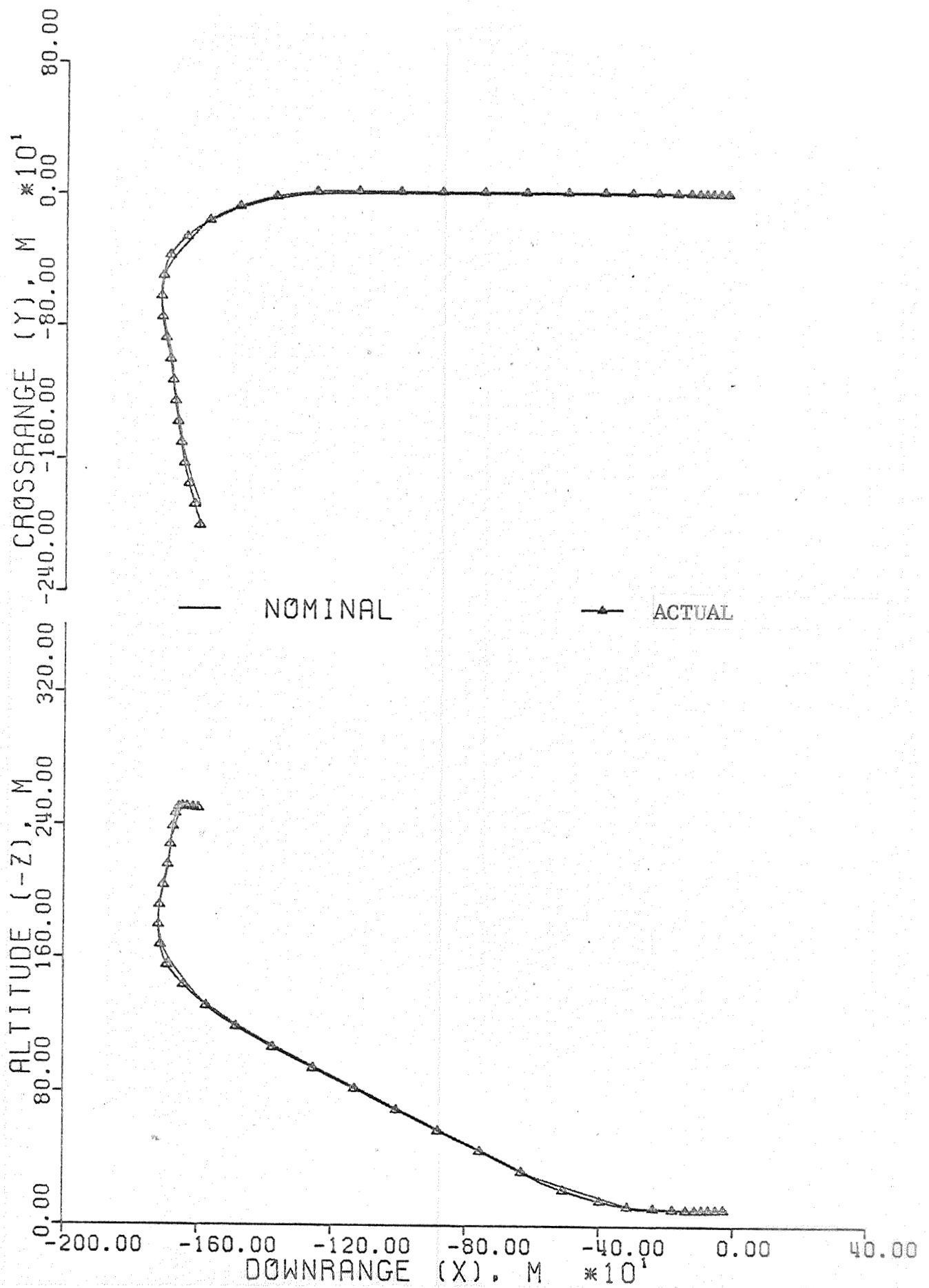


Fig. 33a. 90° Approach With $\delta x_1 = -100$ m - Flight Profiles

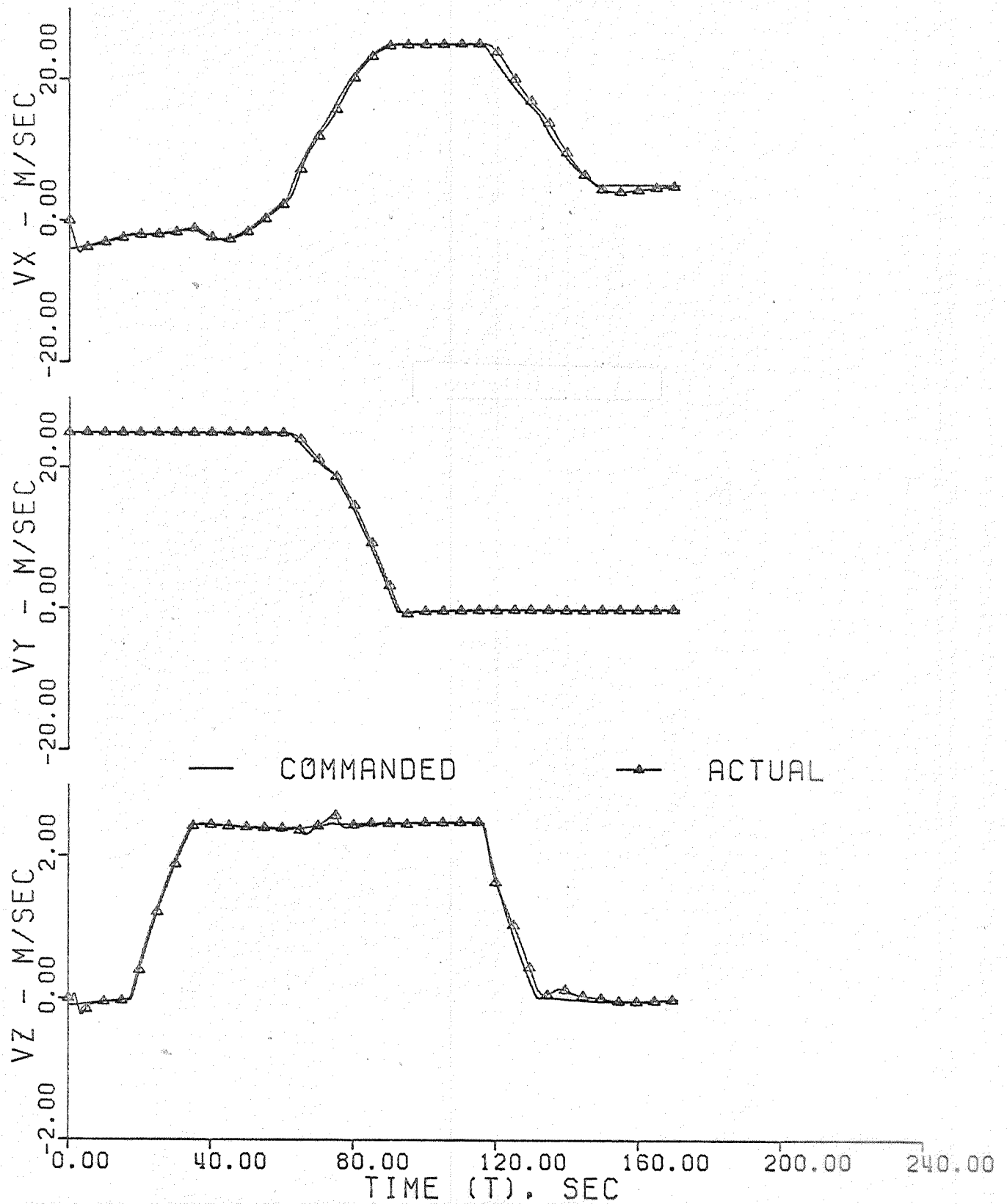


Fig. 33b. 90° Approach With $\delta x_i = -100$ m - Velocity Histories

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY AND CONCLUSIONS

A simple perturbation feedback scheme has been developed for automatic guidance of a VTOL aircraft with a velocity-command flight control system. The performance of the guidance scheme was evaluated for a variety of off-nominal conditions by means of a digital computer simulation of the NASA/LaRC YHC-1A tandem-rotor helicopter. The important results and conclusions of the study are summarized in the following paragraphs:

1. By assuming the response of the velocity-command flight control system to be rapid in comparison to the characteristic time of the guidance function, and by using range to go rather than time as the independent variable, a very simple model of the controlled aircraft was obtained. The two state variables of this model are the aircraft's altitude and its lateral displacement from the runway centerline; the three control variables are the inertial components of commanded velocity.
2. The simplified equations were linearized by taking first-order perturbations about a nominal trajectory. By minimizing a performance index which was a quadratic function of the state and control variable perturbations, a linear feedback guidance law was obtained. The six feedback gains, which are functions of the range from touchdown, must be determined by integrating a matrix-Riccati equation backwards along the nominal trajectory.

3. The guidance scheme could be easily implemented in the flight computer. The feedback gains would be pre-calculated for a selected nominal trajectory and stored as functions of range to go, along with the nominal state and control variable histories. During flight, the state variables would be estimated from measurements and their deviations from nominal would be used to compute corrections to the nominal control histories. The computational and storage requirements are very modest. It is estimated that the program and guidance tables for one nominal trajectory would require only 500 words of memory, hence tables for several nominal approaches could be carried along for greater flexibility and for contingency situations. Furthermore, the calculation time for the guidance scheme would be on the order of 2 milliseconds (based on IBM 4 π /CP-2 operation times), so that the guidance commands could be computed several times a second without using more than a small percentage (<5%) of the computer's time.
4. A simple, analytical nominal trajectory was generated by piecing together flight segments during which the forward and vertical accelerations were constant. The feedback gains calculated for this nominal were used to evaluate the guidance scheme's performance. Since this nominal contained no lateral turns, three of the six gains were always zero, and a fourth one vanished during level flight. To briefly examine the guidance concept during a turning maneuver, a 90 $^{\circ}$ approach was simply generated by "wrapping" a section of the straight-in approach about an assumed vertical cylinder. For this nominal, all six feedback gains were nonzero prior to and during the turn. Since the feedback gains

become infinite when the aircraft velocity is zero (hover) the gain calculations were commenced and terminated, respectively, immediately before the final deceleration to hover and immediately following the initial forward acceleration from hover.

5. The performance of the guidance scheme was evaluated by means of a digital simulation, which included the six-degree-of-freedom dynamics of the NASA/LaRC YHC-1A tandem-rotor helicopter and the NASA/ERC velocity-command flight control system designed for that aircraft. Each of the three phases of flight - takeoff, cruise and hover - were simulated with a variety of off-nominal conditions. The initial condition errors included: ± 50 m in altitude (± 10 m for takeoff phase); -100 m in crossrange; 20° in heading; ± 10 m/sec in forward velocity; ± 5 m/sec in vertical velocity; $\pm 10\%$ in mass; and $\pm 10\%$ in each moment of inertia and the cross-product of inertia. A number of winds were considered: constant headwinds, tailwinds and crosswinds of 10 m/sec; constant vertical winds of ± 5 m/sec; a constant crosswind of 10 m/sec plus a constant headwind or tailwind of 10 m/sec; and constant-shear headwinds, tailwinds, or crosswinds of $(5-z/50)$ m/sec. The conclusion from all these simulations is that the proposed guidance scheme can successfully handle very large initial condition errors while it is relatively insensitive to winds or uncertainties in the aircraft characteristics.
6. The mathematical model of the aircraft is a very important element in the development and analysis of the guidance system, and much effort was devoted to the definition of a satisfactory one in this study. In

fact, three separate models were utilized -- one to develop the guidance concept, another to generate the nominal trajectory and a third to simulate the system performance. A fourth model which was developed (Appendix B), analytically describes the center of mass motions of the helicopter as functions of the pitch and roll attitudes and the collective stick displacement. The favorable comparison of this model with a "near trim" model at several trim flight conditions indicates that it might be very useful for guidance analyses and performance prediction for helicopters.

5.2 RECOMMENDATIONS FOR FURTHER RESEARCH

During the course of this investigation, a number of problem areas have been identified which warrant additional research. Further study of the following items should be conducted to better establish the capabilities and requirements of the proposed VTOL automatic guidance scheme.

1. A detailed examination should be made of several aspects of the proposed guidance scheme which could not be thoroughly investigated in the present study. Among these should be a more complete analysis of turning flights and the inclusion of limits on the magnitudes and rates of the guidance commands. The latter effort would eliminate the unrealistic large transients which were exhibited in some of the simulation results obtained in this study. Another important area which warrants additional work is the guidance at either end of the flight -- liftoff and, particularly, landing. During vertical and hovering flight, the time delays of the velocity-command flight control system become

important and must be considered by the guidance system. Furthermore, the ground range to go is not satisfactory as the independent variable during these modes since both downrange and crossrange position of the aircraft should be controlled directly. A suggested approach would be the use of altitude as the independent variable during vertical flight, switching to a steady-state position regulator for hover. These modifications should not have a large impact on the computer requirements of the guidance system.

2. In the simulations conducted during the present study, the guidance calculations were performed with exact position and velocity information (i.e., from an ideal navigation system), and only deterministic disturbances were examined. A useful extension of the simulation program would include realistic navigation system error equations and random disturbances, such as sensor noise and winds.
3. The guidance system should be evaluated by means of a hybrid simulation in which the vehicle dynamics are simulated with an analog computer and the guidance, navigation and flight control systems are implemented digitally. Such simulations would facilitate the analysis of sampling rate, quantization and truncation effects. Eventually, as much flight hardware as feasible should be included in the hybrid simulation, including the airborne computer.
4. To enable the pilot to monitor the performance of the automatic system and to provide him with guidance commands during a manual control mode, an appropriate navigation/guidance display should be developed. The displayed information should include the present position of the aircraft, the target, the nominal trajectory

and the guidance (velocity-to-be-gained) commands. This display should be evaluated in real-time with the hybrid simulation discussed previously.

5. The analytical model of the center of mass motions of a helicopter which is described in Appendix B deserves further investigation. It appears to be a reasonably simple yet adequate model for guidance analyses and performance prediction, and is not restricted to "near-trim" flight conditions. A detailed evaluation of this model should be performed by programming it as a sub-routine for program LIFT, conducting simulations with it and comparing the results with those obtained during the present study. Part of the flight control system could be eliminated in these simulations, since the inputs to this model would be the commanded pitch and roll attitudes and the collective stick displacement, rather than all four control displacements.
6. As discussed in Section IV, the selection of a nominal trajectory for the guidance scheme is a difficult task, and was somewhat arbitrarily done for the present study. By applying optimal control theory, a realistic nominal trajectory could be obtained which optimizes an appropriate performance index (e.g., minimum fuel), subject to various enroute and terminal constraints (e.g., air traffic control restrictions, and final position and velocity). The point mass model described in Appendix B might be used to describe the aircraft in this type of investigation. The guidance feedback gains should be calculated for the resulting trajectory, and the performance of the guidance scheme evaluated as in the present study.

7. Finally, in order to demonstrate the versatility of the guidance scheme, it should be applied to aircraft other than the YHC-1A tandem-rotor helicopter. Reliable data should be obtained for other V/STOL aircraft and studies similar to those conducted under the present contract should be performed for those vehicles. Among others, suitable candidates are the tail rotor and synchropter helicopter types, the tilt-wing XC-142 or CL-84, the ducted-fan X-22, the vectored-thrust P.1127, the fan-in-wing XV-5A, the Breguet 941 deflected slip-stream STOL airplane or the Doernier DO-31 jet V/STOL transport.

Appendix A

LISTING OF THE SIMULATION PROGRAM

This appendix contains a complete listing of the digital computer program which was used to generate all of the simulation results presented in this report. As discussed in Section III, the program is a modified version of Program LIFT (Lifting Flight Trajectory), which is completely described in Reference 4. The program was written in FORTRAN IV and run on the IBM 7094 computer at the NASA Electronics Research Center. A typical planar approach run required approximately four minutes of computer time.

02/13/70		80/80 LIST	PAGE NO. 000001
\$IBFTC MBLOC	LIST,DECK		GLT00010
	BLOCK DATA		GLT00020
	COMMON/BEND/NEND		GLT00030
	COMMON/BINTG/N,L,INTEG,NRKG,FREQ,NSTOP,NCHAN,DEL,DEL1,KOUNT		GLT00040
	COMMON/BPLOT/NTAPE,NPEND,NPLOT		GLT00050
	COMMON/BTAP/NIN,NOUT		GLT00060
	COMMON/BTITLE/TITLE(12),NRUN,NTYPE,NPRINT,NTABL,NPAGE		GLT00070
	DATA NTAPE,NPEND,NPLOT/8,-1000.0/		GLT00080
	DATA NIN,NOUT,NEND/5,6,1/		GLT00090
	DATA L,INTEG,NRKG,FREQ,NSTOP,NCHAN,DEL,KOUNT/1,2,5,5.0,0,0,0.1,0/		GLT00100
	END		GLT00110
\$IBFTC LIFT	LIST,DECK		GLT00120
C*****			GLT00130
C	ENTRY PROGRAM		GLT00140
C	MAIN PROGRAM *** LIFT*** LIFTING FLIGHT TRAJECTORY		GLT00150
C	PROGRAM CALLS SUBROUTINE VIDE (6D SECTION)		GLT00160
C	INITIAL DATA SET IN BLOCK DATA PROGRAM		GLT00170
C	PLACED IN MAIN LINK		GLT00180
C*****			GLT00190
	COMMON/BBNTG/N,L,INTEG,NRKG,FREQ,NSTOP,NCHAN,DEL,DEL1,KOUNT		GLT00200
	COMMON/BPLOT/NTAPE,NPEND,NPLOT		GLT00210
	COMMON/BTAP/NIN,NOUT		GLT00220
	COMMON/BTITLE/TITLE(12),NRUN,NTYPE,NPRINT,NTABL,NPAGE		GLT00230
C	NAMelist		GLT00240
	NAMelist/NAME/NPRINT,NTYPE,INTEG,NTABL		GLT00250
	NRUN=1		GLT00260
	READ(NIN,NAME)		GLT00270
	READ (NIN,1) TITLE		GLT00280
1	FORMAT (12A6)		GLT00290
	CALL VIDE		GLT00300
	CALL PLOTTER (NTAPE)		GLT00310
	STOP		GLT00320
	END		GLT00330
\$ORIGIN	PLACE		GLT00340
\$IBFTC BBLOC	LIST,DECK		GLT00350
	BLOCK DATA		GLT00360
C*****			GLT00370
C	INITIAL DATA FOR MAIN PROGRAM *LIFT*		GLT00380
C	PLACED IN MAIN LINK		GLT00390
C*****			GLT00400
	COMMON/BADAM/T,VALUE(20),DERN(20),DERN3(20),DERN2(20),DERN1(20),		GLT00410
1	TPRIN		GLT00420
	COMMON/BCHAN/STOP,SDEL,ST,SVAL(20),SDER(20),STOPL,SWITCH,SC1,SC2,		GLT00430
1	S1,S2,CHANL,MSTOP,DSTOP,DCHAN		GLT00440
	COMMON/BCONST/GG,RADE,DH,QRHOS		GLT00450
	COMMON/BLABEL/SOLNO(7,2),SMOTE(8,2)		GLT00460
	COMMON/BLIMIT/UPBND(20),DNBND(20),LIM,NSPT,ZBAR(20),DERNN(20)		GLT00470
	COMMON/BPHASE/NCON,MCON(20),MPHASE,NPHASE,PHASE(20),EXTRA(20),		GLT00480
1	ADD(20),NEXT		GLT00490
	COMMON/BWIND/ALT(220),WX(220),WY(220),WZ(220),NWIN,WXX,WYY,WZZ		GLT00500
	DATA ALT,WX,WY,WZ,NWIN/0.0,100000.0,878*0.0,2/		GLT00510
	DATA VALUE,DERN,DERN3,DERN2,DERN1,T,TPRIN/102*0.0/		GLT00520
	DATA UPBND,DNBND,ZBAR,DERNN,NSPT/80*0.0,3/		GLT00530
	DATA STOP,SDEL,ST,SVAL,SDER,SWITCH,SC1,SC2,S1,S2,STOPL/48*0.,.001/		GLT00540
1	,MSTOP/2/		GLT00550
	DATA ((SMOTE(J,I),J=1,8),I=1,2)/16*6H	/	GLT00560

02/13/70	80/80 LIST	PAGE NO. 000002
DATA SOLNO(1,1),SOLNO(1,2),(SMOTE(1,I),I=1,2)/		GLT00570
1 38HNUMERICAL SOLUTION IS RUNGE KUTTA GILL,		GLT00580
2 37HNUMERICAL SOLUTION IS ADAMS-BASHFORTH,		GLT00590
3 34H6-D RIGID BODY EQUATIONS OF MOTION,		GLT00600
447HLONGITUDINAL EQUATIONS OF MOTION FOR RIGID BODY/		GLT00610
DATA NCON,NPHASE,MPHASE,MCON,PHASE,EXTRA,ADD/4*1,19*0,40*0.0,		GLT00620
1 50.8,0.5,0.2,0.1,-0.03281,-1.66675,1.0,		GLT00630
2 0.13123,0.5,38.1,0.35,1.0,0.3,20.0,0.5,1.0,0.3,38.1,0.5,18.0/		GLT00640
DATA GG,RADE,DH,QRHOS/9.8066,6.37839E+06,100.0,0.13961E-3/		GLT00650
END		GLT00660
\$IBFTC B6BLOC LIST,DECK		GLT00670
BLOCK DATA		GLT00680
C*****		GLT00690
C INITIAL ROUTINE FOR 6 DEGREES OF FREEDOM PROGRAM VIDE		GLT00700
C SUBROUTINE FOR USE WITH VIDE 6 DEGREES OF FREEDOM -KAMAN AVIDYNE		GLT00710
C PLACED IN VIDE (6-D) LINK		GLT00720
C*****		GLT00730
COMMON/BDEV6/A(3,3),ALPHA,AMACH,AMASS,B,BETA,C,CL,CM,CN,		GLT00740
1 CX,CY,CZ,DDA,DDE,DDF,DDR,DNA,FL,FM,FN,FX,FY,FZ,GAMR,P,PHI,PSI,		GLT00750
2 Q,R,RLAMB,RHO,S,SOFs,THETA,UR,VA(3),VR,VTA,VTR,WR,XI,XR,XZI,		GLT00760
3 YI,YR,ZI,ZR,WDOT,KTR		GLT00770
COMMON/BITER/DD(20),SDDE		GLT00780
COMMON/BTABL/NDD,NVC,DA(30),DE(30),DF(30),DR(30),TDD(30),		GLT00790
1 XVC(30),YVC(30),ZVC(30),VXC(30),VYC(30),VZC(30),		GLT00800
2 CVX(30),CVY(30),CVZ(30),CVXL(30),CVYL(30),CVZL(30)		GLT00810
DATA XR,YR,ZR,XI,YI,ZI,XZI,B,C,PSI,THETA,PHI,GAMR,		GLT00820
1 RLAMB,VTR,P,Q,R,KTR,WDOT,S,AMASS/		GLT00830
2 3*0.0,12474.0,102898.0,97238.0,+9683.0,7.367,0.4572,9*0.0,		GLT00840
3 1,0.0,341.0,6078.0/		GLT00850
DATA NDD,NVC,DA,DE,DF,DR,TDD,VXC,VYC,VZC,XVC,YVC,ZVC,CVX,CVY,CVZ/		GLT00860
1 2,2,121*0.0,29*10000.0,90*0.0,-100000.0,29*100000.0,150*0.0/,		GLT00870
2 CVXL,CVYL,CVZL/90*0.0/		GLT00880
END		GLT00890
\$IBFTC VIDEP LIST,DECK		GLT00900
SUBROUTINE VIDE		GLT00910
C*****		GLT00920
C KAMAN AVIDYNE SIX DEGREES OF FREEDOM STUDY		GLT00930
C SUBROUTINE IS THE MAIN CONTROLLING ROUTINE FOR THIS SUBSECTION (6-D)		GLT00940
C CONTROLS INPUT,LOOPING AND OUTPUT		GLT00950
C CALLS PINIT,SOSDE		GLT00960
C INITIAL VALUES FOR SECTION SET IN BLOCK DATA ROUTINE		GLT00970
C PLACED IN VIDE (6-D) LINK		GLT00980
C SUBROUTINE CALLED FROM LIFT		GLT00990
C VARIABLES ARE IN THE ORDER U,V,W,P,Q,R,PSI,THETA,PHI,XR,YR,ZR,AMASS		GLT01000
C WHERE VALUE(I),I=1 2 3 4 5 6 7 8 9 10 11 12 13		GLT01010
C IF NPRINT IS NEGATIVE, *VIDE* WRITES TRAJECTORY DATA ON NTAPE (8),		GLT01020
C AND AT COMPLETION OF ALL RUNS, CALLS *PLOTTER* WHICH PLOTS		GLT01030
C ON CALCOMP 763.		GLT01040
C*****		GLT01050
COMMON/BADAM/T,VALUE(20),DERN(20),DERN3(20),DERN2(20),DERN1(20),		GLT01060
1 TPRIN		GLT01070
COMMON/BAUTOP/THETE,THETC,VCOM(3),VXVH,VYVH,VXEI,VZCI,THETEI,		GLT01080
1 YNOM,ZNOM,VXNOM,VYNOM,VZNOM,GVX,GVY,GVZ,GVXL,GVYL,GVZL,		GLT01090
2 XX,PHIEI,PHIC,PHICI,PSIC,PSIR,BETAI,VXCOM,VYCOM,MODE,PHIE		GLT01100
COMMON/BCHAN/STOP,SDEL,ST,SVAL(20),SDER(20),STOPL,SWITCH,SC1,SC2,		GLT01110
1 S1,S2,CHANL,MSTOP,DSTOP,DCHAN		GLT01120

	02/13/70	80/80 LIST	PAGE NO. 000003
	COMMON/BCONST/GG,RADE,DH,QRHOS		GLT01130
	COMMON/BDEV6/A(3,3),ALPHA,AMACH,AMASS,B,BETA,C,CL,CM,CN,		GLT01140
	1 CX,CY,CZ,DDA,DDE,DDF,DDR,DNA,FL,FM,FN,FX,FY,FZ,GAMR,P,PHI,PSI,		GLT01150
	2 Q,R,RLAMB,RHO,S,SQFS,THETA,UR,VA(3),VR,VTA,VTR,WR,XI,XR,XZI,		GLT01160
	3 YI,YR,ZI,ZR,WDOT ,KTR		GLT01170
	COMMON/BEND/NEND		GLT01180
	COMMON/BINTG/N,L,INTEG,NRKG,FREQ,NSTOP,NCHAN,DEL,DEL1,KOUNT		GLT01190
	COMMON/BITER/DD(20),SDDE		GLT01200
	COMMON/BLIMIT/UPBND(20),DNBND(20),LIM,NSPT,ZBAR(20),DERNN(20)		GLT01210
	COMMON/BPHASE/NCON,MCON(20),MPHASE,NPHASE,PHASE(20),EXTRA(20),		GLT01220
	1 ADD(20),NEXT		GLT01230
	COMMON/BPLOT/NTAPE,NPEND,NPLOT		GLT01240
	COMMON/BPRIN6 /KEEP,SKEEP(50,42)		GLT01250
	COMMON/BSTAB/LOOP		GLT01260
	COMMON/BTABL/NDD,NVC,DA(30),DE(30),DF(30),DR(30),TDD(30),		GLT01270
	1 XVC(30),YVC(30),ZVC(30),VXC(30),VYC(30),VZC(30),		GLT01280
	2 CVX(30),CVY(30),CVZ(30),CVXL(30),CVYL(30),CVZL(30)		GLT01290
	COMMON/BTAP/NIN,NOUT		GLT01300
	COMMON/BTITLE/TITLE(12),NRUN,NTYPE,NPRINT,NTABL,NPAGE		GLT01310
	COMMON/BWIND/ALT(220),WX(220),WY(220),WZ(220),NWIN,WXX,WYY,WZZ		GLT01320
C	NAMELIST		GLT01330
	NAMELIST /NAM6/ DEL,FREQ,NRKG,NWIN,ALT,WX,WY,WZ,XR,YR,ZR,AMASS,S,		GLT01340
	1 VTR,GAMR,RLAMB,B,C,XI,YI,ZI,XZI,P,Q,R,PSI,THETA,PHI,		GLT01350
	2 MCON,NCON,PHASE,EXTRA,ADD,STOP,NRUN,NSPT, KTR,MSTOP,		GLT01360
	3 NDD,NVC,DA,DE,DF,DR,TDD,VXC,VYC,VZC,XVC,YVC,ZVC,		GLT01370
	4 CVX,CVY,CVZ,CVXL,CVYL,CVZL		GLT01380
	NRUN=1		GLT01390
	N=10		GLT01400
	IF (NPRINT.GT.0) GO TO 30		GLT01410
	NPLOT=1		GLT01420
	NPRINT=IABS(NPRINT)		GLT01430
	REWIND NTAPE		GLT01440
	30 READ (NIN,NAM6)		GLT01450
	IF (KTR.GT.1000) GO TO 500		GLT01460
	SWITCH=ADD(20)		GLT01470
	NPAGE=1		GLT01480
C	INITIAL CONDITIONS FROM INPUT		GLT01490
	SAMASS=AMASS		GLT01500
	SXR=XR		GLT01510
	SYR=YR		GLT01520
	SZR=ZR		GLT01530
	HVTR=VTR		GLT01540
	HGAMR=GAMR		GLT01550
	HRLAMB=RLAMB		GLT01560
	HDEL=DEL		GLT01570
	HP=P		GLT01580
	HQ=Q		GLT01590
	HR=R		GLT01600
	HPSI=PSI		GLT01610
	HTHETA=THETA		GLT01620
	HPhi=PHI		GLT01630
	SDEL=DEL		GLT01640
	LINTG=INTEG		GLT01650
	LOOP=1		GLT01660
C	LATERAL CONTROL SYSTEM MODE--HOVER=0, CRUISE=1		GLT01670
	MODE=1		GLT01680

	02/13/70	80/80 LIST	PAGE NO. 000004
	IF (VTR.LT.ADD(20)) MODE=0		GLT01690
	DO 100 NIX=14,20		GLT01700
100	VALUE(NIX)=0.0		GLT01710
	VALUE(10) = XR		GLT01720
	VALUE(11) = YR		GLT01730
	VALUE(12) = ZR		GLT01740
	VALUE(13)=AMASS		GLT01750
	VALUE(4) = P		GLT01760
	VALUE(5) = Q		GLT01770
	VALUE(6) = R		GLT01780
	VALUE(7) = PSI*0.0174533		GLT01790
	VALUE(8) = THETA*0.0174533		GLT01800
	VALUE(9) = PHI*0.0174533		GLT01810
	GAMR = GAMR*0.0174533		GLT01820
	RLAMB = RLAMB*0.0174533		GLT01830
	CGAM = COS(GAMR)		GLT01840
	UR = VTR*CGAM*COS(RLAMB)		GLT01850
	VR = VTR*CGAM*SIN(RLAMB)		GLT01860
	WR=-VTR*SIN(GAMR)		GLT01870
	T=0.0		GLT01880
	TPRIN=T		GLT01890
	MPHASE=1		GLT01900
	NPHASE=MCON(1)		GLT01910
	NEND=1		GLT01920
	DEL1=DEL		GLT01930
	L=1		GLT01940
	KEEP=0		GLT01950
	NSTOP=0		GLT01960
	CALL PINIT		GLT01970
	IF (NPRINT.NE.3) WRITE (NOUT,35)		GLT01980
35	FORMAT (/1H)		GLT01990
C	CALCULATE INTEGRAL		GLT02000
40	CALL SOSDE		GLT02010
	LOOP=2		GLT02020
C	STORAGE FOR TABLE PRINTOUT		GLT02030
	KEEP=KEEP+1		GLT02040
	SKEEP(KEEP,1)=T		GLT02050
	SKEEP(KEEP,2)=XR		GLT02060
	SKEEP(KEEP,3)=YR		GLT02070
	SKEEP(KEEP,4)=ZR		GLT02080
	SKEEP(KEEP,5)=VALUE(7)*57.29577		GLT02090
	SKEEP(KEEP,6)=VALUE(8)*57.29577		GLT02100
	SKEEP(KEEP,7)=VALUE(9)*57.29577		GLT02110
	SKEEP(KEEP,8)=VTA		GLT02120
	SKEEP(KEEP,9)=VTR		GLT02130
	SKEEP(KEEP,10)=GAMR*57.29577		GLT02140
	SKEEP(KEEP,11)=RLAMB*57.29577		GLT02150
	SKEEP(KEEP,12)=ALPHA*57.29577		GLT02160
	SKEEP(KEEP,13)=BETA*57.29577		GLT02170
	SKEEP(KEEP,14)=VALUE(13)		GLT02180
	SKEEP(KEEP,15)=UR		GLT02190
	SKEEP(KEEP,16)=VR		GLT02200
	SKEEP(KEEP,17)=WR		GLT02210
	SKEEP(KEEP,18)=VA(1)		GLT02220
	SKEEP(KEEP,19)=VA(2)		GLT02230
	SKEEP(KEEP,20)=VA(3)		GLT02240

02/13/70		80/80 LIST	PAGE NO. 000005
	SKEEP(KEEP,21)=VXVH		GLT02250
	SKEEP(KEEP,22)=VYVH		GLT02260
	SKEEP(KEEP,23)=VALUE(4)*57.29577		GLT02270
	SKEEP(KEEP,24)=VALUE(5)*57.29577		GLT02280
	SKEEP(KEEP,25)=VALUE(6)*57.29577		GLT02290
	SKEEP(KEEP,26)=WDOT		GLT02300
	SKEEP(KEEP,27)=DERN(3)/GG		GLT02310
	SKEEP(KEEP,28)=DNA		GLT02320
	SKEEP(KEEP,29)=YNOM		GLT02330
	SKEEP(KEEP,30)=ZNOM		GLT02340
	SKEEP(KEEP,31)=VXNOM		GLT02350
	SKEEP(KEEP,32)=VYNOM		GLT02360
	SKEEP(KEEP,33)=VZNOM		GLT02370
	SKEEP(KEEP,34)=THETC*57.29577		GLT02380
	SKEEP(KEEP,35)=PHIC*57.29577		GLT02390
	SKEEP(KEEP,36)=VXCOM		GLT02400
	SKEEP(KEEP,37)=VYCOM		GLT02410
	SKEEP(KEEP,38)=VCOM(3)		GLT02420
	SKEEP(KEEP,39)=DDA		GLT02430
	SKEEP(KEEP,40)=DDF		GLT02440
	SKEEP(KEEP,41)=DDE		GLT02450
	SKEEP(KEEP,42)=DDR		GLT02460
	IF (NPRINT.GT.4) GO TO 90		GLT02470
C	TIME HISTORY PRINT OUT **NPRINT LT 5 **		GLT02480
	WRITE (NOUT,3) TITLE,NPAGE,NRUN		GLT02490
3	FORMAT (1H1,12A6,15X,4HPAGE I4,14H OF RUN NUMBER I5)		GLT02500
	NPAGE=NPAGE+1		GLT02510
	WRITE (NOUT,200) T,DEL,L,(VALUE(I),I=1,12),(DERN(I),I=1,12)		GLT02520
200	FORMAT (1H ,//5X,3HT =F10.3,5X,10HDEL TIME = E15.6,5X,3HL = 15///		GLT02530
1	22X,3HU = E16.8,22X3HV = E16.8,22X,3HW = E16.8/		GLT02540
2	22X,3HP = E16.8,22X3HQ = E16.8,22X,3HR = E16.8/		GLT02550
3	20X,5HPSI = E16.8,18X7HTHETA = E16.8,20X5HPHI = E16.8/		GLT02560
4	21X,4HXR = E16.8,21X4HYR = E16.8,21X4HZR = E16.8//		GLT02570
5	21X,4HDX = E16.8,21X4HDV = E16.8,21X4HDW = E16.8/		GLT02580
6	21X,4HDP = E16.8,21X4HDQ = E16.8,21X,4HDR = E16.8/		GLT02590
7	19X,6HDPSI = E16.8,17X8HDTHETA = E16.8,19X6HDPHI = E16.8/		GLT02600
8	20X,5HDXR = E16.8,20X5HDYR = E16.8,20X5HDZR = E16.8)		GLT02610
	WRITE (NOUT,203) (VALUE(I),I=13,20),(DERN(I),I=13,20)		GLT02620
203	FORMAT (/19X,6HMASS = E16.8,14X,11HVALUE(14) = E16.8,14X,		GLT02630
1	11HVALUE(15) = E16.8/14X,11HVALUE(16) = E16.8,14X,		GLT02640
2	11HVALUE(17) = E16.8,14X,11HVALUE(18) = E16.8/14X,		GLT02650
3	11HVALUE(19) = E16.8,14X,11HVALUE(20) = E16.8//19X,		GLT02660
4	6HWDOT = E16.8,15X,10HDERN(14) = E16.8,15X,		GLT02670
5	10HDERN(15) = E16.8/15X,10HDERN(16) = E16.8,15X,		GLT02680
6	10HDERN(17) = E16.8,15X,10HDERN(18) = E16.8/15X,		GLT02690
7	10HDERN(19) = E16.8,15X,10HDERN(20) = E16.8)		GLT02700
	WRITE (NOUT,201)S0FS,RHO,DNA,AMACH,VTA, VA,DDA,DDE,DDR,DDF,		GLT02710
1	ALPHA,BETA,VTR,GAMR,RLAMB		GLT02720
201	FORMAT (/ 9X,16HSPEED OF SOUND = E16.8,20X5HRHO = E16.8,15X,		GLT02730
1	10HPRESSURE = E16.8//		GLT02740
2	19X,6HMACH = E16.8,6X,19HRELATIVE VELOCITY =		GLT02750
3	E16.8/21X4HUA = E16.8,21X,4HVA = E16.8,21X,4HWA = E16.8//		GLT02760
4	16X, 9HDELTA A = E16.8,16X,9HDELTA E = E16.8,16X9HDELTA R = E16.8		GLT02770
5	/16X,9HDELTA C = E16.8,18X,7HALPHA = E16.8,19X6HBETA = E16.8//		GLT02780
6	8X,17HRUNWAY VELOCITY = E16.8,16X,9HGAMMA R = E16.8,15X,		GLT02790
7	10HLAMBDA R = E16.8)		GLT02800

02/13/70		80/80 LIST	PAGE NO. 000006
	WRITE (NOUT,202) SKEEP(KEEP,27),VXVH,VYVH,FX,FY,FZ,FL,FM,FN,		GLT02810
1	((A(I,J),J=1,3),I=1,3)		GLT02820
202	FORMAT (/20X,5HAGS = E16.8,19X,6HVXVH = E16.8,19X,6HVVYVH = E16.8/		GLT02830
1	21X,4HFX = E16.8,21X,4HFX = E16.8,21X,4HFZ = E16.8/		GLT02840
2	21X,4HFL = E16.8,21X,4HFM = E16.8,21X,4HFN = E16.8//		GLT02850
3	10X,27HTHE AXES TRANSPOSE MATRIX = /(40X,3E16.8/))		GLT02860
	IF (NPHASE.EQ.1) GO TO 90		GLT02870
	WRITE (NOUT,210) XX,YNOM,ZNOM,VXNOM,VYNOM,VZNOM,GVX,GVY,GVZ,		GLT02880
1	GVXL,GVYL,GVZL,VXCOM,VYCOM,VCOM(3),VCOM(1),VCOM(2),		GLT02890
2	THETC,PHIC		GLT02900
210	FORMAT (/9H0GUIDANCE,14X,7HRANGE = E16.8,10X,6HYNOM = E16.8,10X,		GLT02910
1	6HZNOM = E16.8,14X,3HAND,16X,7HVXNOM = E16.8,9X,7HVNOM =		GLT02920
2	E16.8,9X,7HVZNOM = E16.8/2X,7HCONTROL,16X,5HCVX =E16.8,		GLT02930
3	11X,5HCVY = E16.8,11X,5HCVZ = E16.8/3X,4HDATA,17X,6HCVXL =		GLT02940
4	E16.8,10X,6HCVYL = E16.8,10X,6HCVZL = E16.8,/25X,5HVXC =		GLT02950
5	E16.8,11X,5HVYC = E16.8,11X,5HVZC = E16.8/23X,7HVXVHC =		GLT02960
6	E16.8,9X,7HVYVHC = E16.8/23X,7HTHETC = E16.8,10X,6HPHIC =		GLT02970
7	E16.8)		GLT02980
90	CONTINUE		GLT02990
	IF (NEND.GE.2) GO TO 1000		GLT03000
	IF (KEEP.EQ.50) GO TO 1000		GLT03010
	IF (L.LT.3) GO TO 40		GLT03020
1000	IF (NPRINT.LT.3) GO TO 611		GLT03030
C	PRINTOUT TABLES		GLT03040
	NTAB=1		GLT03050
	WRITE (NOUT,6001) (TITLE(I),I=1,12),NPAGE,NRUN,NTAB		GLT03060
6001	FORMAT (1H1,12A6,15X,4HPAGE I4,14H OF RUN NUMBER I5/		GLT03070
1	/10X,5HTABLE I5)		GLT03080
	NPAGE=NPAGE+1		GLT03090
	WRITE (NOUT,600)		GLT03100
600	FORMAT (/3X,4HTIME,7X,2HXR,8X,2HYR,8X,2HZR,9X,3HPSI,5X,5HTHETA,5X,		GLT03110
1	3HPHI,5X,3HVTA,5X,2HVR,6X,5HGAMMA,4X,6HLAMBDA,4X,5HALPHA,4X,		GLT03120
2	4HBETA,6X,4HMASS/3X,5H(SEC),6X,3H(M),7X,3H(M),7X,3H(M),6X,		GLT03130
3	5H(DEG),5X,5H(DEG),5X,5H(DEG),2X,15H(M/SEC) (M/SEC),3X,5H(DEG),		GLT03140
4	5X,5H(DEG),4X,5H(DEG),4X,5H(DEG),5X,4H(KG) //)		GLT03150
	DO 601 I=1,KEEP		GLT03160
601	WRITE(NOUT,602) (SKEEP(I,J),J=1,14)		GLT03170
602	FORMAT (1X,F7.2,F11.2,2F10.2,F10.3,2F9.3,2F8.2,F9.3,F10.3,2F9.3,		GLT03180
1	F10.2)		GLT03190
	IF (NTABL.EQ.3) GO TO 610		GLT03200
	NTAB=2		GLT03210
	WRITE (NOUT,6001) (TITLE(I),I=1,12),NPAGE,NRUN,NTAB		GLT03220
	NPAGE=NPAGE+1		GLT03230
	WRITE (NOUT,603)		GLT03240
603	FORMAT (/3X,4HTIME,6X,2HUR,6X,2HVR,6X,2HWR,7X,2HUA,6X,2HVA,6X,		GLT03250
1	2HWA,6X,4HVXVH,4X,4HVVYVH,7X,1HP,8X,1HQ,8X,1HR,8X,4HMDOT,6X,		GLT03260
2	2HAZ,6X,2HQA/3X,5H(SEC),3X,2(3(7H(M/SEC),1X),1X),2(7H(M/SEC),		GLT03270
3	1X),3(9H(DEG/SEC)),2X,8H(KG/SEC),3X,5H(G'S),2X,6H(N/M2)//)		GLT03280
	DO 604 I=1,KEEP		GLT03290
604	WRITE (NOUT,605) SKEEP(I,1),(SKEEP(I,J),J=15,28)		GLT03300
605	FORMAT (1X,F7.2,2(F9.2,2F8.2),F9.2,F8.2,F10.3,2F9.3,F10.4,F9.3,		GLT03310
1	F8.1)		GLT03320
610	IF (NTABL.EQ.2) GO TO 611		GLT03330
	NTAB=3		GLT03340
	WRITE (NOUT,6001) (TITLE(I),I=1,12),NPAGE,NRUN,NTAB		GLT03350
	NPAGE=NPAGE+1		GLT03360

02/13/70		80/80 LIST	PAGE NO. 000007
	WRITE (NOUT,606)		GLT03370
606	FORMAT (/3X,4HTIME,5X,4HYNOM,6X,4HZNOM,5X,5HVXNOM,3X,5HVYNOM,3X,		GLT03380
1	5HVZNOM,3X,7HTHETA-C,3X,5HPHI-C,4X,3HVXC,5X,3HVYC,5X,3HVZC,3X,		GLT03390
2	7HDELTA-A,2X,7HDELTA-C,2X,7HDELTA-E,2X,7HDELTA-R /3X,5H(SEC),		GLT03400
3	2(5X,3H(M),2X),2X,3(7H(M/SEC),1X),2(2X,5H(DEG),2X),3(7H(M/SEC),		GLT03410
4	1X),4(3X,4H(CM),2X) //)		GLT03420
	DO 607 I=1,KEEP		GLT03430
607	WRITE (NOUT,608) SKEEP(I,1),(SKEEP(I,J),J=29,42)		GLT03440
608	FORMAT (1X,F7.2,2F10.2,3F8.2,2F9.3,3F8.2,4F9.3)		GLT03450
611	IF (NPLOT.EQ.0) GO TO 650		GLT03460
	WRITE (NTAPE) KEEP,NRUN		GLT03470
	DO 620 I=1,KEEP		GLT03480
620	WRITE (NTAPE) (SKEEP(I,J),J=1,7),(SKEEP(I,J),J=12,13),(SKEEP(I,J),		GLT03490
1	J=15,17),SKEEP(I,27),(SKEEP(I,J),J=29,30),(SKEEP(I,J),J=34,42)		GLT03500
650	KEEP=0		GLT03510
	IF (NEND.GE.2) GO TO 480		GLT03520
	GO TO (40,40,1005,40,480,480,480),L		GLT03530
480	WRITE (NOUT,481) NEND,L,LIM		GLT03540
481	FORMAT (///10X,27HTRAJECTORY ENDS WITH NEND = I5,5H L = I5,		GLT03550
1	14H FOR VARIABLE I5)		GLT03560
C	NEXT RUN		GLT03570
1011	IF (NPLOT.EQ.0) GO TO 1013		GLT03580
	WRITE (NTAPE) NPEND,NRUN		GLT03590
	WRITE (NOUT,1012)		GLT03600
1012	FORMAT (// 10X,19HTHIS RUN IS PLOTTED)		GLT03610
1013	NRUN=NRUN+1		GLT03620
1010	DEL=HDEL		GLT03630
	AMASS=SAMASS		GLT03640
	XR=SEX		GLT03650
	YR=SYR		GLT03660
	ZR=SZR		GLT03670
	VTR=HVTR		GLT03680
	GAMR=HGAMR		GLT03690
	RLAMB=HRLAMB		GLT03700
	DEL=HDEL		GLT03710
	P=HP		GLT03720
	Q=HQ		GLT03730
	R=HR		GLT03740
	PSI=HPSI		GLT03750
	THETA=HTHETA		GLT03760
	PHI=HPHI		GLT03770
	INTEG=LINTG		GLT03780
	GO TO 30		GLT03790
1005	GO TO (1020,1030,1040,1050),MSTOP		GLT03800
1020	WRITE (NOUT,1021) L		GLT03810
1021	FORMAT (//10X,27HFINAL TIME REACHED WITH L = I5)		GLT03820
	GO TO 1011		GLT03830
1030	WRITE (NOUT,1031) L		GLT03840
1031	FORMAT (//10X,32HFINAL ALTITUDE REACHED WITH L = I5)		GLT03850
	GO TO 1011		GLT03860
1040	WRITE (NOUT,1041) L		GLT03870
1041	FORMAT (//10X,28HFINAL RANGE REACHED WITH L = I5)		GLT03880
	GO TO 1011		GLT03890
1050	WRITE (NOUT,1051) L		GLT03900
1051	FORMAT (//10X,27HFINAL MASS REACHED WITH L = I5)		GLT03910
	GO TO 1011		GLT03920

02/13/70	80/80 LIST	PAGE NO. 000008
500 IF (NPLOT.EQ.0) GO TO 550		GLT03930
WRITE (NTAPE) NPEND,NPEND		GLT03940
END FILE NTAPE		GLT03950
END FILE NTAPE		GLT03960
END FILE NTAPE		GLT03970
550 RETURN		GLT03980
END		GLT03990
\$IBFTC PINI LIST,DECK		GLT04000
SUBROUTINE PINIT		GLT04010
C*****		GLT04020
C SUBROUTINE CALLED FROM VIDE OR TRIDE		GLT04030
C PRINTS OUT INITIAL TITLES, INTEGRATION SETTINGS AND WINDS		GLT04040
C PLACED IN MAIN LINK		GLT04050
C*****		GLT04060
COMMON/BCHAN/STOP,SDEL,ST,SVAL(20),SDER(20),STOPL,SWITCH,SC1,SC2,		GLT04070
1 S1,S2,CHANL,MSTOP,DSTOP,DCHAN		GLT04080
COMMON/BDEV6/A(3,3),ALPHA,AMACH,AMASS,B,BETA,C,CL,CM,CN,		GLT04090
1 CX,CY,CZ,DDA,DDE,DDF,DDR,DNA,FL,FM,FN,FX,FY,FZ,GAMR,P,PHI,PSI,		GLT04100
2 Q,R,RLAMB,RHO,S,SQFS,THETA,UR,VA(3),VR,VTA,VTR,WR,XI,XR,XZI,		GLT04110
3 YI,YR,ZI,ZR,WDOT ,KTR		GLT04120
COMMON/BINTG/N,L,INTEG,NRKG,FREQ,NSTOP,NCHAN,DEL,DEL1,KOUNT		GLT04130
COMMON/BLABEL/SOLNO(7,2),SMOTE(8,2)		GLT04140
COMMON/BLIMIT/UPBND(20),DNBND(20),LIM,NSPT,ZBAR(20),DERNN(20)		GLT04150
COMMON/BPHASE/NCON,MCON(20),MPHASE,NPHASE,PHASE(20),EXTRA(20),		GLT04160
1 ADD(20),NEXT		GLT04170
COMMON/BTABL/NDD,NVC,DA(30),DE(30),DF(30),DR(30),TDD(30),		GLT04180
1 XVC(30),YVC(30),ZVC(30),VXC(30),VYC(30),VZC(30),		GLT04190
2 CVX(30),CVY(30),CVZ(30),CVXL(30),CVYL(30),CVZL(30)		GLT04200
COMMON/BTAP/NIN,NOUT		GLT04210
COMMON/BTITLE/TITLE(12),NRUN,NTYPE,NPRINT,NTABL,NPAGE		GLT04220
COMMON/BWIND/ALT(220),WX(220),WY(220),WZ(220),NWIN,WXX,WYY,WZZ		GLT04230
DIMENSION TRUS (3,2)		GLT04240
DIMENSION SSTOP(2,4)		GLT04250
DIMENSION XNOM(30)		GLT04260
DATA TRUS(1,1),TRUS(1,2) /15HCONSTANT WEIGHT ,		GLT04270
1 16H VARIABLE WEIGHT /		GLT04280
DATA (SSTOP(1,I),I=1,4)/12H TIME =,12H ALTITUDE =,		GLT04290
1 12H RANGE =,12H MASS =/		GLT04300
WRITE (NOUT,1) TITLE,NPAGE,NRUN		GLT04310
1 FORMAT (1H1,12A6,15X,4HPAGE I4,14H OF RUN NUMBER I5)		GLT04320
NPAGE=NPAGE+1		GLT04330
WRITE (NOUT,2) (SOLNO(I,INTEG),I=1,7)		GLT04340
2 FORMAT (//10X,10A6)		GLT04350
XX=NRKG		GLT04360
IF (INTEG.EQ.1) FREQ=XX*DEL		GLT04370
WRITE (NOUT,3) NSPT,DEL,FREQ		GLT04380
3 FORMAT (/20X,I2,1X,34HSIGNIFICANT FIGURES IN INTEGRATION /		GLT04390
1 20X,24HINITIAL TIME INCREMENT = E13.5 /20X,		GLT04400
2 24HINTERVAL OF PRINT OUT = E13.5)		GLT04410
WRITE (NOUT,4) (SSTOP(I,MSTOP),I=1,2),STOP		GLT04420
4 FORMAT (/20X,13HFINAL STOP IS, 2A6,E13.5)		GLT04430
WRITE (NOUT,2) (SMOTE(I,NTYPE),I=1,8)		GLT04440
WRITE (NOUT,5) (TRUS(I,KTR),I=1,3)		GLT04450
5 FORMAT (1H0,20X,3A6)		GLT04460
WRITE (NOUT,7) S,B,C,XI,YI,ZI,XZI		GLT04470
7 FORMAT (//10X,35HPHYSICAL CHARACTERISTICS OF VEHICLE//20X,		GLT04480

	02/13/70	80/80 LIST	PAGE NO. 000009
1	32HAERODYNAMIC REFERENCE DIMENSIONS /25X,7HAREA = E13.5,10X,	GLT04490	
2	7HSPAN = E13.5,10X,7HCHORD = E13.5// 20X,	GLT04500	
3	30HMOMENTS AND PRODUCT OF INERTIA /25X,5HIXX = E13.5,5X,5HIYY =	GLT04510	
4	E13.5,5X,5HIZZ = E13.5,5X,5HIXZ = E13.5)	GLT04520	
	WRITE (NOUT, 8) XR,YR,ZR,P,Q,R,PSI,THETA,PHI,VTR,GAMR,RLAMB,AMASS	GLT04530	
8	FORMAT (///10X,14HINITIAL VALUES //	GLT04540	
1	16X,4HXR = E15.7,11X,4HYR = E15.7,11X,4HZR = E15.7/	GLT04550	
2	17X,3HP = E15.7,12X,3HQ = E15.7,12X,3HR = E15.7/	GLT04560	
3	15X,5HPSI = E15.7,8X,7HTHETA = E15.7,10X,5HPhi = E15.7/	GLT04570	
4	15X,5HVTR = E15.7,6X,9HGAMMA R = E15.7, 5X,10HLAMBDA R = E15.7/	GLT04580	
5	14X,6HMASS = E15.7)	GLT04590	
	WRITE (NOUT,9) ADD	GLT04600	
9	FORMAT (//10X,32HFLIGHT CONTROL SYSTEM PARAMETERS//	GLT04610	
1	12X,8HKTHETA = F10.5,11X,4HTQ = F10.5,6X,9HKITHETA = F10.5,	GLT04620	
2	9X,6HKIVX = F10.5,/15X,5HKVX = F10.5,10X,5HKVZ = F10.5,11X,	GLT04630	
3	4HKZ = F10.5,10X,5HKV(5/5G5V)5/16X,4HTP = F10.5,9X,6HKPhi =	GLT04640	
4	F10.5,8X,7HKIPHI = F10.5,7X,8HKCFPSI = F10.5,/14X,6HKCFR =	GLT04650	
5	F10.5,7X,8HTCFPSI = F10.5,9X,6HTCFR = F10.5,9X,6HKPSI = F10.5/	GLT04660	
6	13X,7HKBETA = F10.5,11X,4HKR = F10.5,8X,7HTBETA = F10.5,9X,	GLT04670	
7	6HTAST = F10.5)	GLT04680	
	WRITE (NOUT,10) EXTRA	GLT04690	
10	FORMAT (// 10X,7HEXTRA = 5E15.5/ (17X,5E15.5))	GLT04700	
	WRITE (NOUT,1) TITLE,NPAGE,NRUN	GLT04710	
	NPAGE=NPAGE+1	GLT04720	
	WRITE (NOUT,6) (ALT(I),WX(I),WY(I),WZ(I),I=1,NWIN)	GLT04730	
6	FORMAT (///10X,12HWIND PROFILE //	GLT04740	
1	19X,8HALTITUDE ,14X,2HWX ,18X,2HWY,18X,2HWZ/	GLT04750	
2	(15X,4(E15.8,5X)))	GLT04760	
	GO TO (20,30,40,50) ,NPHASE	GLT04770	
20	IF (EXTRA(1).GT.100.0) GO TO 25	GLT04780	
	WRITE (NOUT,21)	GLT04790	
21	FORMAT (// ,20X,27HCONTROL DEFLECTIONS VS TIME//5X,4HTIME,10X,	GLT04800	
1	7HDELTA E,8X,7HDELTA C,8X,7HDELTA A,8X,7HDELTA R/)	GLT04810	
	GO TO 27	GLT04820	
25	WRITE (NOUT,26)	GLT04830	
26	FORMAT (// ,20X,28HCONTROL DEFLECTIONS VS RANGE//4X,5HRANGE,10X,	GLT04840	
1	7HDELTA E,8X,7HDELTA C,8X,7HDELTA A,8X,7HDELTA R/)	GLT04850	
27	WRITE (NOUT,28) (TDD(I),DE(I),DF(I),DA(I),DR(I),I=1,NDD)	GLT04860	
28	FORMAT (1H ,5(E12.5,3X))	GLT04870	
	RETURN	GLT04880	
30	WRITE (NOUT, 31)	GLT04890	
31	FORMAT(// 10X50HVELOCITY COMMAND AUTOPILOT WITH OPEN-LOOP GUIDANCE	GLT04900	
1	//18X,5HRANGE,7X,3HVXC,7X,3HVYC,7X,3HVZC/)	GLT04910	
	WRITE (NOUT, 32) (XVC(I),VXC(I),VYC(I),VZC(I),I=1,NVC)	GLT04920	
32	FORMAT (13X,F11.2,3F10.2)	GLT04930	
	RETURN	GLT04940	
40	DO 41 I=1,NVC	GLT04950	
41	XNOM(I)=-SQRT(XVC(I)**2-YVC(I)**2)	GLT04960	
	WRITE (NOUT,42)	GLT04970	
42	FORMAT (//10X,43HVELOCITY COMMAND AUTOPILOT WITH CLOSED-LOOP	GLT04980	
1	9H GUIDANCE//19X,5HRANGE,8X,4HXNOM,8X,4HYNOM,8X,4HZNOM,8X,	GLT04990	
2	5HVXNOM,5X,5HVYNOM,5X,5HVZNOM)	GLT05000	
	WRITE (NOUT,43) (XVC(I),XNOM(I),YVC(I),ZVC(I),VXC(I),VYC(I),	GLT05010	
1	VZC(I),I=1,NVC)	GLT05020	
43	FORMAT (13X,4F12.2,2X,3F10.2)	GLT05030	
	WRITE (NOUT,44)	GLT05040	

	02/13/70	80/80 LIST	PAGE NO. 000010
44	FORMAT (/19X,5HRANGE,10X,5HCVX,Y,10X,5HCVY,Y,10X,5HCVZ,Y,12X,		GLT05050
1	5HCVX,Z,10X,5HCVY,Z,10X,5HCVZ,Z)		GLT05060
	WRITE (NOUT,45) (XVC(I),CVXL(I),CVYL(I),CVZL(I),CVX(I),CVY(I),		GLT05070
1	CVZ(I),I=1,NVC)		GLT05080
45	FORMAT (13X,F12.2,2X,3E15.5,2X,3E15.5)		GLT05090
	RETURN		GLT05100
50	NEND=2		GLT05110
	RETURN		GLT05120
	END		GLT05130
	\$IBFTC SOSD LIST,DECK		GLT05140
	SUBROUTINE SOSDE		GLT05150
C	*****		GLT05160
C	SUBROUTINE CALLED FROM VIDE		GLT05170
C	SUBROUTINE CONTROLS THE INTEGRATION BETWEEN ADAMS AND RUNGE-KUTTA		GLT05180
C	PLACED IN MAIN LINK		GLT05190
C	*****		GLT05200
	COMMON/BEND/NEND		GLT05210
	COMMON/BINTG/N,L,INTEG,NRKG,FREQ,NSTOP,NCHAN,DEL,DEL1,KOUNT		GLT05220
	COMMON/BPRI/LPRINT		GLT05230
	COMMON/BTAP/NIN,NOUT		GLT05240
5	GO TO (10,10,20),INTEG		GLT05250
8	L=1		GLT05260
10	CALL RKUTTA		GLT05270
	IF (NEND.EQ.3) RETURN		GLT05280
	IF (L.GT.1) GO TO 31		GLT05290
	IF (LPRINT.EQ.1) RETURN		GLT05300
20	CALL ADAM		GLT05310
30	IF (NEND.GE.2) RETURN		GLT05320
	IF (L.EQ.1) GO TO 10		GLT05330
31	IF (NEND.GE.2) RETURN		GLT05340
	IF (LPRINT.EQ.1) GO TO (1000,1000,1000,8,1000,32),L		GLT05350
	GO TO(20,1000,1000,8,1000,32),L		GLT05360
32	WRITE (NOUT,33)L		GLT05370
33	FORMAT (/10X,3HL= I3,12H IN SOLUTION)		GLT05380
C	ERROR AT THE PHASE CHANGE OR AT THE STOP VARIABLE		GLT05390
	IF (NCHAN.GT.2) GO TO 10		GLT05400
1000	RETURN		GLT05410
	END		GLT05420
	\$IBFTC RKUT LIST,DECK		GLT05430
	SUBROUTINE RKUTTA		GLT05440
C	*****		GLT05450
C	SOLUTION OF SIMULTANEOUS DIFFERENTIAL EQUATIONS BY RUNGE KUTTA GILL		GLT05460
C	SUBROUTINE IS SET FOR USE BY ITSELF OR FOR SUPPLYING ADAMS WITH		GLT05470
C	INITIAL POINTS		GLT05480
C	CALLED FROM SOSDE		GLT05490
C	PLACED IN MAIN LINK		GLT05500
C	CALLS CHANGE DEV		GLT05510
C	*****		GLT05520
	COMMON/BADAM/T,VALUE(20),DERN(20),DERN3(20),DERN2(20),DERN1(20),		GLT05530
1	TPRIN		GLT05540
	COMMON/BEND/NEND		GLT05550
	COMMON/BINTG/N,L,INTEG,NRKG,FREQ,NSTOP,NCHAN,DEL,DEL1,KOUNT		GLT05560
	COMMON/BITER/DD(20),SDDE		GLT05570
	COMMON/BLIMIT/UPBNC(20),DNBND(20),LIM,NSPT,ZBAR(20),DERNN(20)		GLT05580
	COMMON/BPHASE/NCON,MCON(20),MPHASE,NPHASE,PHASE(20),EXTRA(20),		GLT05590
1	ADD(20),NEXT		GLT05600

02/13/70		80/80 LIST	PAGE NO. 000011
	COMMON/BPRI/LPRINT		GLT05610
	COMMON/BTITLE/TITLE(12),NRUN,NTYPE,NPRINT,NTABL,NPAGE		GLT05620
	DIMENSION S(80)		GLT05630
	LPRINT=2-MOD(NPRINT,2)		GLT05640
	IF (L.EQ.6) GO TO 11		GLT05650
10	GO TO (11,120),L		GLT05660
11	IF (INTEG.EQ.1) GO TO 111		GLT05670
	INTEG=2		GLT05680
C	FOR ADAMS START		GLT05690
	F4=FREQ/4.0		GLT05700
	IF (DEL.GE.F4) DEL=F4		GLT05710
111	CALL DEV (VALUE,T,DERN)		GLT05720
	IF (NEND.EQ.3) RETURN		GLT05730
	NEXT=2		GLT05740
	DO 113 I=1,N		GLT05750
113	ZBAR(I)=VALUE(I)		GLT05760
	NCHAN=0		GLT05770
C	INITIAL SETUP FOR A NEW PHASE		GLT05780
	CALL CHANGE		GLT05790
	NCHAN=1		GLT05800
	L=2		GLT05810
	IF (INTEG.EQ.1) RETURN		GLT05820
	DO 112 I=1,N		GLT05830
112	DERN3(I)=DERN(I)		GLT05840
	RETURN		GLT05850
115	DO 121 I=1,N		GLT05860
	K=J1+I		GLT05870
	DERN(I)=S(K)		GLT05880
121	VALUE(I)=S(I)		GLT05890
120	C1=0.5*DEL		GLT05900
	C2=0.7071068*DEL		GLT05910
	C3=C2-C1		GLT05920
	C4=DEL-C2		GLT05930
	C5=DEL+C2		GLT05940
	C6=DEL/6.0		GLT05950
	C7=C4/3.0		GLT05960
	C8=C5/3.0		GLT05970
	J1=N		GLT05980
	J2=J1+N		GLT05990
	J3=J2+N		GLT06000
122	DO 200 I=1,N		GLT06010
	K=J1+I		GLT06020
	S(K)=DERN(I)		GLT06030
	S(I)=VALUE(I)		GLT06040
	DD(I)=DERN(I)		GLT06050
200	VALUE(I)=S(I)+C1*S(K)		GLT06060
	T=T+C1		GLT06070
	CALL DEV (VALUE,T,DERN)		GLT06080
	IF (NEND.GE.2) RETURN		GLT06090
	DO 300 I=1,N		GLT06100
	K=J1+I		GLT06110
	LL=J2+I		GLT06120
	S(LL)=DERN(I)		GLT06130
	DD(I)=DERN(I)		GLT06140
300	VALUE(I)=S(I)+C3*S(K)+C4*S(LL)		GLT06150
	CALL DEV (VALUE,T,DERN)		GLT06160

	02/13/70	80/80 LIST	PAGE NO. 000012
	IF (NEND.GE.2) RETURN		GLT06170
	DO 400 I=1,N		GLT06180
	LL=J2+I		GLT06190
	LM=J3+I		GLT06200
	S(LM)=DERN(I)		GLT06210
	DD(I)=DERN(I)		GLT06220
400	VALUE(I)=S(I)-C2*S(LL)+C5*S(LM)		GLT06230
	T=T+C1		GLT06240
	CALL DEV (VALUE,T,DERN)		GLT06250
	IF (NEND.GE.2) RETURN		GLT06260
	DO 500 I=1,N		GLT06270
	K=J1+I		GLT06280
	LL=J2+I		GLT06290
	LM=J3+I		GLT06300
	VALUE(I)=S(I)+C6*S(K)+C7*S(LL)+C8*S(LM)+C6*DERN(I)		GLT06310
	DD(I)=DERN(I)		GLT06320
500	ZBAR(I)=VALUE(I)		GLT06330
	CALL DEV (VALUE,T,DERN)		GLT06340
C	VALUE FOR INTEGRATED STEP		GLT06350
	L=2		GLT06360
	IF (NEND.GE.2) RETURN		GLT06370
	CALL CHANGE		GLT06380
	IF (NSTOP.GT.0.OR.NCHAN.GT.1) GO TO(11,115,800,710,800,800),L		GLT06390
	KOUNT=KOUNT+1		GLT06400
	GO TO (700,702),INTEG		GLT06410
C	RUNGE KUTTA FOR ALL POINTS		GLT06420
700	IF (KOUNT.LT.50) GO TO 701		GLT06430
	L=5		GLT06440
	RETURN		GLT06450
701	IF (KOUNT.LT.NRKG) GO TO 12		GLT06460
	L=2		GLT06470
	RETURN		GLT06480
C	ADAMS SETUP FOR INITIAL STEPS		GLT06490
702	GO TO (703,705,708),KOUNT		GLT06500
703	DO 704 I=1,N		GLT06510
704	DERN2(I)=DERN(I)		GLT06520
	GO TO 12		GLT06530
705	DO 706 I=1,N		GLT06540
706	DERN1(I)=DERN(I)		GLT06550
	GO TO 12		GLT06560
708	INTEG=3		GLT06570
710	L=1		GLT06580
800	RETURN		GLT06590
12	IF (LPRINT.EQ.2) GO TO 122		GLT06600
	RETURN		GLT06610
	END		GLT06620
\$IBFTC	ADAMS LIST,DECK		GLT06630
	SUBROUTINE ADAM		GLT06640
C*****			GLT06650
C	PLACED IN MAIN LINK		GLT06660
C	SOLUTION OF SIMULTANEOUS DIFFERENTIAL EQUATIONS BY ADAMS BASHFORTH		GLT06670
C	SUBROUTINE IS CALLED BY SOSDE AND GIVEN INITIAL VALUES BY RKUTTA		GLT06680
C*****			GLT06690
	COMMON/BADAM/T,VALUE(20),DERN(20),DERN3(20),DERN2(20),DERN1(20),		GLT06700
1	TPRIN		GLT06710
	COMMON/BCHAN/STOP,SDEL,ST,SVAL(20),SDER(20),STOPL,SWITCH,SC1,SC2,		GLT06720

02/13/70		80/80 LIST	PAGE NO. 000013
1	S1,S2,CHANL,MSTOP,DSTOP,DCHAN		GLT06730
	COMMON/BEND/NEND		GLT06740
	COMMON/BINTG/N,L,INTEG,NRKG,FREQ,NSTOP,NCHAN,DEL,DEL1,KOUNT		GLT06750
	COMMON/BITER/DD(20),SDDE		GLT06760
	COMMON/BLIMIT/UPBND(20),DNBND(20),LIM,NSPT,ZBAR(20),DERNN(20)		GLT06770
	COMMON/BPRI/LPRINT		GLT06780
	COMMON/BTITLE/TITLE(12),NRUN,NTYPE,NPRINT,NTABL,NPAGE		GLT06790
	DIMENSION VALUEN(20),DIF(20)		GLT06800
	GO TO (10,20),L		GLT06810
C	RKUTTA HAS JUST INITIALIZED		GLT06820
10	DELIMIT=DEL1/1000.0		GLT06830
	H1=DEL		GLT06840
	H2=DEL		GLT06850
	H3=DEL		GLT06860
	KOUNT=0		GLT06870
	NBOUN=0		GLT06880
	GO TO 31		GLT06890
20	L=1		GLT06900
	IF (LPRINT.EQ.1) GO TO 30		GLT06910
	DO 21 I=1,N		GLT06920
	VALUE(I)=SVAL(I)		GLT06930
21	DERN(I)=SDER(I)		GLT06940
	T=ST		GLT06950
30	TPRIN=TPRIN+FREQ		GLT06960
	IF (DEL.GT.FREQ) DEL=FREQ		GLT06970
31	IF (T.GT.TPRIN) GO TO 30		GLT06980
	DEL=SDEL		GLT06990
40	W1= H1 + H2		GLT07000
	W2 = W1 * W1		GLT07010
	W3 = W1 + H1		GLT07020
	W4 = W1 + H3		GLT07030
	W5 = W4 + W1		GLT07040
	W6 = W4 + W3		GLT07050
	W7 = W3 + H3		GLT07060
	W8 = W1 * H1		GLT07070
	W9 = W1 * H3		GLT07080
	W10= H2 + H3		GLT07090
	W11= H2 * H3		GLT07100
	W12= H1 * H2		GLT07110
	W16= W2 + W9		GLT07120
44	IF (ABS(DEL)-ABS(DELIMIT)) 401,402,402		GLT07130
401	L=5		GLT07140
	GO TO 1000		GLT07150
402	T=T+DEL		GLT07160
403	W13=DEL/2.0		GLT07170
	W14= W13 * W13 * DEL		GLT07180
	W15= DEL * DEL / 3.0		GLT07190
	W17= H1 + DEL		GLT07200
	W18= W1 + DEL		GLT07210
	W19= W1 * DEL		GLT07220
	W29 = W3 * DEL		GLT07230
	B0=DEL/W4*(W14+W15*W6+W13*(W2+2.0*H1*W4+W11))+H1*W16)/W8		GLT07240
	B1=-DEL/W10*(W14+W15*W5+W13*W16)/W12		GLT07250
	B2 = DEL / W1 * (W14 + W15 * W7 + W13 * H1 * W4)		GLT07260
	1/W11		GLT07270
	B3 = -DEL / W4 * (W14 + W15 * W3 + W13 * W8) /W10		GLT07280

02/13/70

80/80 LIST

PAGE NO. 000014

1/H3

GLT07290

DO 404 I=1,N

GLT07300

DD(I)=DERN(I)

GLT07310

C PREDICTED VALUES

GLT07320

404 ZBAR(I)=VALUE(I)+B0*DERN(I)+B1*DERN1(I)+B2*DERN2(I)+B3*DERN3(I)

GLT07330

CALL DEV (ZBAR,T,DERNN)

GLT07340

IF (NEND.GE.2) GO TO 1000

GLT07350

A = (W14 + W15 * W3 + W13 * W8) / W17 / W18

GLT07360

A0 = -(W14 + W15 * (W3- DEL) + W13*(W8 - W29) -DEL *W8)

GLT07370

1/W8

GLT07380

A1 =DEL/W17*(W14+ W15 *(W1 -DEL)- W13 * W19)/W12

GLT07390

A2 = DEL /W1 * (W14/3.0 + H1 * W15 /2.0) /H2 / W 18

GLT07400

C P-C LIMIT BOUNDS FOUND

GLT07410

CALL BOUND

GLT07420

C CORRECTED VALUES

GLT07430

DO 50 I=1,N

GLT07440

VALUEN(I)=VALUE(I)+A*DERNN(I)+A0*DERN(I)+A1*DERN1(I)+A2*DERN2(I)

GLT07450

IF (NSTOM+NCHAN.GT.1) GO TO 50

GLT07460

DIF(I) = ABS(VALUEN(I) - ZBAR(I))

GLT07470

IF (DIF(I).LE.UPBND(I)) GO TO 50

GLT07480

C P-C NOT WITHIN BOUND

GLT07490

T=T-DEL

GLT07500

DEL=DEL-.25*DEL

GLT07510

LIM=I

GLT07520

GO TO 44

GLT07530

50 CONTINUE

GLT07540

IF (L.EQ.2) GO TO 610

GLT07550

CALL CHANGE

GLT07560

IF (NCHAN.GT.1.OR.NSTOP.GT.0) GO TO (402,80,80,70,80,80),L

GLT07570

IF (T.GE.TPRIN) GO TO 64

GLT07580

60 DO 61 I=1,N

GLT07590

IF (DIF(I).GT.DNBND(I)) GO TO 62

GLT07600

61 CONTINUE

GLT07610

IF (NBOUN.GT.2) NBOUN=0

GLT07620

NBOUN=NBOUN+1

GLT07630

IF (NBOUN.NE.3) GO TO 62

GLT07640

DEL=DEL+.25*DEL

GLT07650

IF (DEL.GT.FREQ) DEL=FREQ

GLT07660

GO TO 62

GLT07670

610 DEL=SDEL

GLT07680

62 DO 63 I=1,N

GLT07690

DERN3(I)=DERN2(I)

GLT07700

DERN2(I)=DERN1(I)

GLT07710

DERN1(I)=DERN(I)

GLT07720

DERN(I)=DERNN(I)

GLT07730

63 VALUE(I)=ZBAR(I)

GLT07740

H3 = H2

GLT07750

H2 = H1

GLT07760

H1 = DEL

GLT07770

IF (LPRINT.EQ.1) GO TO 66

GLT07780

IF (L-2) 40,1000,40

GLT07790

C PRINT TIME REACHED

GLT07800

64 L=2

GLT07810

ST=T

GLT07820

SDEL=DEL

GLT07830

DEL =DEL-T+TPRIN

GLT07840

	02/13/70	80/80 LIST	PAGE NO. 000015
	T=TPRIN		GLT07850
	DO 65 I=1,N		GLT07860
	SVAL(I)=ZBAR(I)		GLT07870
65	SDER(I)=DERNN(I)		GLT07880
	GO TO 403		GLT07890
C	FOR EXIT TO PRINT EACH TIME CYCLE		GLT07900
66	L=2		GLT07910
	SDEL=DEL		GLT07920
	DEL=H1		GLT07930
	RETURN		GLT07940
C	CHANGE REACHED		GLT07950
70	INTEG=2		GLT07960
	L=1		GLT07970
	IF(DEL.GT.DEL1) DEL=DEL1		GLT07980
80	DO 71 I=1,N		GLT07990
	VALUE(I)=ZBAR(I)		GLT08000
71	DERN(I)=DERNN(I)		GLT08010
1000	RETURN		GLT08020
	END		GLT08030
\$IBFTC	BOUNDS LIST,DECK		GLT08040
	SUBROUTINE BOUND		GLT08050
C	*****		GLT08060
C	SUBROUTINE SETS INTEGRATION LIMITS FOR ADAMS METHOD		GLT08070
C	USED WITH PREDICTOR CORRECTOR SECTION OF ADAMS		GLT08080
C	PLACED IN MAIN LINK		GLT08090
C	*****		GLT08100
	COMMON/BINTG/N,L,INTEG,NRKG,FREQ,NSTOP,NCHAN,DEL,DEL1,KOUNT		GLT08110
	COMMON/BLIMIT/UPBND(20),DNBND(20),LIM,NSPT,ZBAR(20),DERNN(20)		GLT08120
	DO 10 I=1,N		GLT08130
	AVALUE=ABS(ZBAR(I))		GLT08140
	NN=1		GLT08150
	IF (AVALUE.LT.1.0) GO TO 1		GLT08160
	IF (AVALUE.GE.10.0) NN=2		GLT08170
	IF (AVALUE.GE.10.0**2) NN=3		GLT08180
	IF (AVALUE.GE.10.0**3) NN=4		GLT08190
	IF (AVALUE.GE.10.0**4) NN=5		GLT08200
	IF (AVALUE.GE.10.0**5) NN=6		GLT08210
	IF (AVALUE.GE.10.0**6) GO TO 6		GLT08220
	K=NN-NSPT		GLT08230
	UPBND(I)=10.0**K		GLT08240
	GO TO 2		GLT08250
1	IF (AVALUE.LT.10.0**(-1)) NN=2		GLT08260
	IF (AVALUE.LT.10.0**(-2)) NN=3		GLT08270
	IF (AVALUE.LT.10.0**(-3)) NN=4		GLT08280
	IF (AVALUE.LT.10.0**(-6)) GO TO 5		GLT08290
	K=NN+NSPT		GLT08300
	IF (K.GE.6) K=6		GLT08310
	UPBND(I)=10.**(-K)		GLT08320
	GO TO 2		GLT08330
5	UPBND(I)=.1		GLT08340
	GO TO 2		GLT08350
6	UPBND(I)=10.0**10		GLT08360
2	DNBND(I)=.5*UPBND(I)		GLT08370
10	CONTINUE		GLT08380
	RETURN		GLT08390
	END		GLT08400

02/13/70	80/80 LIST	PAGE NO. 000016
\$IBFTC CHANS LIST,DECK		GLT08410
SUBROUTINE CHANGE		GLT08420
C*****		GLT08430
C SUBROUTINE CALLED FROM ADAM OR RKUTTA		GLT08440
C TESTS FOR PHASE CHANGE OR TRAJECTORY END RETURNS CHANGED DEL OR L		GLT08450
C CALLS FUNCTIONS FCHAN AND FSTOP		GLT08460
C PLACED IN MAIN LINK		GLT08470
C*****		GLT08480
COMMON/BADAM/T,VALUE(20),DERN(20),DERN3(20),DERN2(20),DERN1(20),		GLT08490
1 TPRIN		GLT08500
COMMON/BAUTOP/THETE,THETC,VCOM(3),VXVH,VYVH,VXEI,VZCI,THETEI,		GLT08510
1 YNOM,ZNOM,VXNOM,VYNOM,VZNOM,GVX,GVY,GVZ,GVXL,GVYL,GVZL,		GLT08520
2 XX,PHIEI,PHIC,PHICI,PSIC,PSIR,BETAI,VXCOM,VYCOM,MODE,PHIE		GLT08530
COMMON/BCHAN/STOP,SDEL,ST,SVAL(20),SDER(20),STOPL,SWITCH,SC1,SC2,		GLT08540
1 S1,S2,CHANL,MSTOP,DSTOP,DCHAN		GLT08550
COMMON/BDEV6/A(3,3),ALPHA,AMACH,AMASS,B,BETA,C,CL,CM,CN,		GLT08560
1 CX,CY,CZ,DDA,DDE,DDF,DDR,DNA,FL,FM,FN,FX,FY,FZ,GAMR,P,PHI,PSI,		GLT08570
2 Q,R,RLAMB,RHO,S,SOFS,THETA,UR,VA(3),VR,VTA,VTR,WR,XI,XR,XZI,		GLT08580
3 YI,YR,ZI,ZR,WDOT ,KTR		GLT08590
COMMON/BINTG/N,L,INTEG,NRKG,FREQ,NSTOP,NCHAN,DEL,DEL1,KOUNT		GLT08600
COMMON/BLIMIT/UPBND(20),DNBND(20),LIM,NsPT,ZBAR(20),DERNN(20)		GLT08610
COMMON/BPHASE/NCON,MCON(20),MPHASE,NPHASE,PHASE(20),EXTRA(20),		GLT08620
1 ADD(20),NEXT		GLT08630
IF (NCHAN.GT.0) GO TO 1		GLT08640
C INITIAL TIME SETUP		GLT08650
100 S1=FSTOP(MSTOP)-STOP		GLT08660
SC1=FCHAN(VTA)-SWITCH		GLT08670
IF (ABS(SC1).GT.CHANL) RETURN		GLT08680
SC1=1.0		GLT08690
IF (MODE.EQ.0) SC1=-1.0		GLT08700
RETURN		GLT08710
C STOP CONDITION CHECK		GLT08720
1 S2=FSTOP(MSTOP)-STOP		GLT08730
SS=S2*S1		GLT08740
IF (NSTOP.GT.0) GO TO 5		GLT08750
IF (SS.GT.0.0) GO TO 20		GLT08760
C STOP CONDITION REACHED		GLT08770
5 IF (ABS(S2).GT.STOPL) GO TO 10		GLT08780
C STOP CONDITION SATISFIED		GLT08790
L=3		GLT08800
RETURN		GLT08810
10 T=T-DEL		GLT08820
DEL=DEL-S2/DSTOP		GLT08830
NSTOP=NSTOP+1		GLT08840
IF (NSTOP.LT.50) RETURN		GLT08850
L=6		GLT08860
RETURN		GLT08870
20 S1=S2		GLT08880
SC2=FCHAN(VTA)-SWITCH		GLT08890
SSC=SC1*SC2		GLT08900
IF (NCHAN.LE.1.AND.SSC.GT.0.0) GO TO 40		GLT08910
C CHANGE CONDITION REACHED		GLT08920
25 IF (ABS(SC2).GT.CHANL) GO TO 30		GLT08930
C CHANGE CONDITION SATISFIED		GLT08940
L=4		GLT08950
IF (MODE.EQ.0) GO TO 27		GLT08960

	02/13/70	80/80 LIST	PAGE NO. 000017
	MODF=0		GLT08970
	PSIR=ZBAR(7)		GLT08980
	ZBAR(19)=DDR/(ADD(16)*ADD(18))		GLT08990
	RETURN		GLT09000
27	MODE=1		GLT09010
	PSIR=0.0		GLT09020
	ZBAR(19)=0.0		GLT09030
	RETURN		GLT09040
30	T=T-DEL		GLT09050
	DEL=DEL-SC2/DCHAN		GLT09060
	NCHAN=NCHAN+1		GLT09070
	IF (NCHAN.GE.50) L=6		GLT09080
	RETURN		GLT09090
40	SC1=SC2		GLT09100
	RETURN		GLT09110
	END		GLT09120
	\$IBFTC FCHANF LIST,DECK		GLT09130
	FUNCTION FCHAN(TAS)		GLT09140
	C*****		GLT09150
	C FUNCTION CALLED BY SUBROUTINE CHANGE		GLT09160
	C CALCULATES THE VALUE OF THE VARIABLE AT EACH TIME POINT TO BE TESTED		GLT09170
	C FOR THE CHANGE OF PHASE		GLT09180
	C PLACED IN MAIN LINK		GLT09190
	C*****		GLT09200
	COMMON/BCHAN/STOP,SDEL,ST,SVAL(20),SDER(20),STOPL,SWITCH,SC1,SC2,		GLT09210
1	S1,S2,CHANL,MSTOP,DSTOP,DCHAN		GLT09220
	COMMON/BLIMIT/UPBND(20),DNBND(20),LIM,NSPT,ZBAR(20),DERNN(20)		GLT09230
	FCHAN=TAS		GLT09240
	DCHAN=(ZBAR(1)*DERNN(1)+ZBAR(2)*DERNN(2)+ZBAR(3)*DERNN(3))/TAS		GLT09250
	CHANL=UPBND(1)		GLT09260
	DO 10 I=2,3		GLT09270
	IF (UPBND(I).GT.CHANL) CHANL=UPBND(I)		GLT09280
10	CONTINUE		GLT09290
	CHANL=CHANL*10.0*(-NSPT)		GLT09300
	RETURN		GLT09310
	END		GLT09320
	\$IBFTC FSTOF LIST,DECK		GLT09330
	FUNCTION FSTOP(MSTOP)		GLT09340
	C*****		GLT09350
	C FUNCTION CALLED BY SUBROUTINE CHANGE		GLT09360
	C CALCULATES THE VALUE AT EACH POINT TO BE TESTED AGAINST FOR END		GLT09370
	C STOPS ARE ON ALTITUDE (NEGATIVE ABOVE GROUND)		GLT09380
	C PLACED IN MAIN LINK		GLT09390
	C*****		GLT09400
	COMMON/BADAM/T,VALUE(20),DERN(20),DERN3(20),DERN2(20),YDERN1(20),		GLT09410
1	TPRIN		GLT09420
	COMMON/BCHAN/STOP,SDEL,ST,SVAL(20),SDER(20),STOPL,SWITCH,SC1,SC2,		GLT09430
1	S1,S2,CHANL,MSTOP,DSTOP,DCHAN		GLT09440
	COMMON/BLIMIT/UPBND(20),DNBND(20),LIM,NSPT,ZBAR(20),DERNN(20)		GLT09450
6	GO TO (7,8,9,10,8),MSTOP		GLT09460
C	TIME STOP		GLT09470
7	FSTOP=T		GLT09480
	DSTOP=1.0		GLT09490
	RETURN		GLT09500
C	ALTITUDE STOP		GLT09510
8	JSTOP=12		GLT09520

02/13/70	80/80 LIST	PAGE NO. 000018
GO TO 20		GLT09530
C RANGE STOP		GLT09540
9 JSTOP=10		GLT09550
GO TO 20		GLT09560
C MASS STOP		GLT09570
10 JSTOP=13		GLT09580
20 FSTOP=ZBAR(JSTOP)		GLT09590
STOPL=UPBND(JSTOP)*10.0*(-NSPT)		GLT09600
DSTOP=DERNN(JSTOP)		GLT09610
RETURN		GLT09620
END		GLT09630
\$IBFTC DEVS LIST,DECK		GLT09640
SUBROUTINE DEV (VALUE,T,DERN)		GLT09650
C*****		GLT09660
C DERIVATIVE SUBROUTINE FOR USE WITH VIDE (6-D SECTION)		GLT09670
C CALLED FROM RKUTTA OR ADAM		GLT09680
C PLACED IN MAIN LINK		GLT09690
C*****		GLT09700
COMMON/BAUTOP/THETE,THETC,VCOM(3),VXVH,VYVH,VXEI,VZCI,THETEI,		GLT09710
1 YNOM,ZNOM,VXNOM,VYNOM,VZNOM,GVX,GVY,GVZ,GVXL,GVYL,GVZL,		GLT09720
2 XX,PHIEI,PHIC,PHICI,PSIC,PSIR,BETAI,VXCOM,VYCOM,MODE,PHIE		GLT09730
COMMON/BCONST/GG,RADE,DH,QRHOS		GLT09740
COMMON/BDEV6/A(3,3),ALPHA,AMACH,AMASS,B,BETA,C,CL,CM,CN,		GLT09750
1 CX,CY,CZ,DDA,DDE,DDF,DDR,DNA,FL,FM,FN,FX,FY,FZ,GAMR,P,PHI,PSI,		GLT09760
2 Q,R,RLAMB,RHO,S,SOFS,THETA,UR,VA(3),VR,VTA,VTR,WR,XI,XR,XZI,		GLT09770
3 YI,YR,ZI,ZR,WDOT ,KTR		GLT09780
COMMON/BEND/NEND		GLT09790
COMMON/BITER/DD(20),SDDE		GLT09800
COMMON/BPHASE/NCON,MCON(20),MPHASE,NPHASE,PHASE(20),EXTRA(20),		GLT09810
1 ADD(20),NEXT		GLT09820
COMMON/BSTAB/LOOP		GLT09830
COMMON/BTITLE/TITLE(12),NRUN,NTYPE,NPRINT,NTABL,NPAGE		GLT09840
COMMON/BWIND/ALT(220),WX(220),WY(220),WZ(220),NWIN,WXX,WYY,WZZ		GLT09850
DIMENSION VALUE(20),DERN(20)		GLT09860
H=-VALUE(12)		GLT09870
T=T		GLT09880
AMASS=VALUE(13)		GLT09890
C ATMOSHPERIC TABLES		GLT09900
H=H/3.28083		GLT09910
CALL ATMOS(H,DUM1,DUM2,RHO,DUM3,DUM4,SOFS,DUM5,KDUM)		GLT09920
H=H*3.28083		GLT09930
SOFS=SOFS*3.28083		GLT09940
RHO=RHO*514.073		GLT09950
CTHE = COS(VALUE(8))		GLT09960
STHE = SIN(VALUE(8))		GLT09970
CPSI = COS(VALUE(7))		GLT09980
SPSI = SIN(VALUE(7))		GLT09990
CPHI = COS(VALUE(9))		GLT10000
SPHI = SIN(VALUE(9))		GLT10010
C TRANSPOSE MATRIX		GLT10020
A(1,1)=CTHE*CPSI		GLT10030
A(1,2)=CTHE*SPSI		GLT10040
A(1,3)=-STHE		GLT10050
A(2,1)=SPHI*STHE*CPSI-CPHI*SPSI		GLT10060
A(2,2)=SPHI*STHE*SPSI+CPHI*CPSI		GLT10070
A(2,3)=SPHI*CTHE		GLT10080

	02/13/70	80/80 LIST	PAGE NO. 000019
	A(3,1)=CPHI*STHE*CPSI+SPHI*SPSI		GLT10090
	A(3,2)=CPHI*STHE*SPSI-SPHI*CPSI		GLT10100
	A(3,3)=CPHI*CTHE		GLT10110
	IF (LOOP.GT.1) GO TO 15		GLT10120
10	DO 11 I=1,3		GLT10130
	11 VALUE(I)=A(I,1)*UR+A(I,2)*VR+A(I,3)*WR		GLT10140
C	WIND COMPONENTS INTERPOLATED		GLT10150
15	CALL ALINE (NWIN,WX,ALT,WXX,H)		GLT10160
	CALL ALINE (NWIN,WY,ALT,WYY,H)		GLT10170
	CALL ALINE (NWIN,WZ,ALT,WZZ,H)		GLT10180
	IF (NTYPE.LT.2) GO TO 23		GLT10190
C	LONGITUDINAL CASE		GLT10200
	VALUE(2)=0.0		GLT10210
	VALUE(4)=0		GLT10220
	VALUE(6)=0.0		GLT10230
	VALUE(9)=0.0		GLT10240
23	U=VALUE(1)		GLT10250
	V=VALUE(2)		GLT10260
	W=VALUE(3)		GLT10270
C	VA(1)=UA,VA(2)=VA,VA(3)=WA		GLT10280
19	DO 22 I=1,3		GLT10290
22	VA(I)=VALUE(I)-(A(I,1)*WXX+A(I,2)*WYY+A(I,3)*WZZ)		GLT10300
	UR=VALUE(1)*A(1,1)+VALUE(2)*A(2,1)+VALUE(3)*A(3,1)		GLT10310
	VR=VALUE(1)*A(1,2)+VALUE(2)*A(2,2)+VALUE(3)*A(3,2)		GLT10320
	WR=VALUE(1)*A(1,3)+VALUE(2)*A(2,3)+VALUE(3)*A(3,3)		GLT10330
	P=VALUE(4)		GLT10340
	Q=VALUE(5)		GLT10350
	R=VALUE(6)		GLT10360
	PSI=VALUE(7)		GLT10370
	THETA=VALUE(8)		GLT10380
	PHI=VALUE(9)		GLT10390
	XR=VALUE(10)		GLT10400
	YR=VALUE(11)		GLT10410
	ZR=VALUE(12)		GLT10420
	VXVH=UR*CPSI+VR*SPSI		GLT10430
	VYVH=-UR*SPSI+VR*CPSI		GLT10440
	VXEI=VALUE(14)		GLT10450
	THETEI=VALUE(15)		GLT10460
	VZCI=VALUE(16)		GLT10470
	PHIEI=VALUE(17)		GLT10480
	PHICI=VALUE(18)		GLT10490
	PSIC=0.0		GLT10500
	BETAI=VALUE(19)		GLT10510
	IF (MODE.EQ.1) GO TO 30		GLT10520
	PSIC=VALUE(19)		GLT10530
	BETAI=0.0		GLT10540
30	VTA=SQRT(VA(1)**2+VA(2)**2+VA(3)**2)		GLT10550
	VTR=SQRT(VALUE(1)*VALUE(1)+VALUE(2)*VALUE(2)+VALUE(3)*VALUE(3))		GLT10560
	BETA=ATAN4(VA(2),VA(1))		GLT10570
	ALPHA=ATAN4(VA(3),VA(1))		GLT10580
	AMACH = VTA/SOFS		GLT10590
	DNA=0.5*RHO*VTA*VTA		GLT10600
	QS= DNA*S		GLT10610
	GAMR=ARSIN(-WR/VTR)		GLT10620
	RLAMB=ATAN4(VR,UR)		GLT10630
	CALL STAB (T)		GLT10640

	02/13/70	80/80 LIST	PAGE NO. 000020
	IF (NEND.GE.2) RETURN		GLT10650
C	STAB RETURNS FX,FY,FZ,FL,FM,FN,WDOT,VCOM,(I),THETE		GLT10660
	IF (LOOP.GT.1) GO TO 24		GLT10670
	THETA=VALUE(8)		GLT10680
	VALUE(14)=VXEI		GLT10690
	VALUE(15)=THETEI		GLT10700
	VALUE(16)=VZCI		GLT10710
	VALUE(17D=PHIEI		GLT10720
	VALUE(18)=0.0		GLT10730
	VALUE(19)=0.0		GLT10740
	IF (MODEHEQ.0) VALUE(19)=PSIC		GLT10750
	24 G=GG*((RADE/(RADE+H))*2)		GLT10760
C	D-U		GLT10770
	DERN(1)=-G*STHE+R*V-Q*W+FX/AMASS		GLT10780
C	D-V		GLT10790
	DERN(2)= G*CTHE*SPHI+P*W-R*U+FY/AMASS		GLT10800
C	D-W		GLT10810
	DERN(3)=G*CTHE*CPhi+Q*U-P*V+FZ/AMASS		GLT10820
C	D-R		GLT10830
	XIZI=XI*ZI		GLT10840
	PQ = P*Q		GLT10850
	QR = Q*R		GLT10860
	DERN(6)=XI /(XIZI-XZI*XZI)*(XZI/XI *((YI-ZI)*		GLT10870
	1QR+XZI*PQ+FL))+((XI-YI)*PQ-XZI*QR+FN))		GLT10880
C	D-P		GLT10890
	DERN(4)=((YI-ZI)*QR+XZI*(DERN(6)+PQ)+FL)/XI		GLT10900
C	D-Q		GLT10910
	DERN(5)=((ZI-XI)*P*R+XZI*(R*R-P*P)+FM)/YI		GLT10920
	X= Q*SPHI+R*CPhi		GLT10930
C	D-PSI		GLT10940
	DERN(7)= X/CTHE		GLT10950
C	D-THETA		GLT10960
	DERN(8)=Q*CPhi-R*SPHI		GLT10970
C	D-PHI		GLT10980
	DERN(9)=P+X*STHE/CTHE		GLT10990
C	D-XR		GLT11000
	DERN(10)=UR		GLT11010
C	D-YR		GLT11020
	DERN(11)=VR		GLT11030
C	D-ZR		GLT11040
	DERN(12)=WR		GLT11050
C	D-M		GLT11060
	DERN(13)=-WDOT		GLT11070
	DERN(14)=VCOM(1)-VXVH		GLT11080
	DERN(15)=THETE		GLT11090
	DERN(16)=VCOM(3)		GLT11100
	IF (NTYPE.LT.2) GO TO 35		GLT11110
C	LONGITUDINAL CASE		GLT11120
	DERN(2)=0.0		GLT11130
	DERN(4)=0.0		GLT11140
	DERN(6)=0.0		GLT11150
	DERN(9)=0.0		GLT11160
	DERN(17)=0.0		GLT11170
	DERN(18)=0.0		GLT11180
	DERN(19)=0.0		GLT11190
	RETURN		GLT11200

	02/13/70	80/80 LIST	PAGE NO. 000021
	35 DERN(17)=PHIE		GLT11210
	IF (MODE.EQ.1) GO TO 40		GLT11220
	DERN(18)=(ADD(12)*PHIC-PHICI)/ADD(14)		GLT11230
	DERN(19)=PHICI		GLT11240
	RETURN		GLT11250
	40 DERN(18)=(ADD(13)*PHIC-PHICI)/ADD(15)		GLT11260
	DERN(19)=(BETA-BETAI)/ADD(19)		GLT11270
	RETU-N		GLT11280
	END		GLT11290
	\$IBFTC ATMOS LIST,DECK		GLT11300
	SUBROUTINE ATMOS(Z,TM,SIGMA,RHO,THETA,DELTA,CA,AMU,K)		GLT11310
C	CALLING SEQUENCE		GLT11320
C	CALL ATMOS(Z,TM,SIGMA,RHO,THETA,DELTA,CA,AMU,K)		GLT11330
C	Z = GEOMETRIC ALTITUDE (FT)		GLT11340
C	TM = MOLECULAR SCALE TEMPERATURE (DEGREES RANKIN)		GLT11350
C	THETA = RATIO OF TEMPERATURE TO THAT AT SEA LEVEL		GLT11360
C	DELTA = RATIO OF PRESSURE TO THAT AT SEA LEVEL		GLT11370
C	CA = SPEED OF SOUND (FT/SEC)		GLT11380
C	AMU = VISCOSITY COEFFICIENT (LB-SEC-FT**2)		GLT11390
C	K = 1 NORMAL,		GLT11400
C	= 2 ALTITUDE GREATER THAN 300000. FT.,		GLT11410
C	= 3 ALTITUDE NEGATIVE,		GLT11420
C	= 4 FLOATING POINT OVERFLOW,		GLT11430
C	= 5 ALTITUDE GREATER THAN 300000. FT. AND FLOATING POINT OVERFL.		GLT11440
			GLT11450
	DIMENSION HPRIMB(11),TMB(11),SIGMAB(11),ALM(11)		GLT11460
	DATA HPRIMB/0.0,36089.239,82020.997,154199.480,173884.510,		GLT11470
	1259186.350,295275.590,344488.190,524934.380,557742.780,656167.980/		GLT11480
	2,TMB/518.688,389.988,389.988,508.788,508.788,298.188,298.188,		GLT11490
	3406.188,2386.188,2566.188,2836.188/,SIGMAB/1.00,2.9706958E-01,		GLT11500
	43.2665751E-02,1.2117870E-03,5.8677311E-04,1.7329156E-05,		GLT11510
	51.7928595E-06,9.3921519E-08,7.7658593E-10,5.6324877E-10,		GLT11520
	62.5726771E-10/,ALM/-0.00356616,0.0,0.00164592,0.0,-0.00246888,0.0,		GLT11530
	70.00219456,0.01097280,0.00548640,0.00274320,0.00192024/		GLT11540
	DATA Q/0.018744176/,RE/2.0855531E07/,S/198.72/,		GLT11550
	1AMUZ/3.7372998E-07/,RHOZ/0.0023769/,TMZ/518.688/		GLT11560
	K=1		GLT11570
	IF(Z)26,18,17		GLT11580
26	K=3		GLT11590
	GO TO 13		GLT11600
17	IF(Z.GT.300000.) K=K+1		GLT11610
18	HPRIM=(RE/(RE+Z))*Z		GLT11620
9	DO 10 M=1,11		GLT11630
	IF(HPRIM-HPRIMB(M))11,12,10		GLT11640
10	CONTINUE		GLT11650
	M=12		GLT11660
11	M=M-1		GLT11670
12	IF(ALM(M))14,15,14		GLT11680
14	TM=TMB(M)+ALM(M)*(HPRIM-HPRIMB(M))		GLT11690
	SIGMA=EXP((1.0+(Q/ALM(M)))*(ALOG(TMB(M)/TM)))*SIGMAB(M)		GLT11700
	GO TO 20		GLT11710
15	TM=TMB(M)		GLT11720
	SIGMA=SIGMAB(M)*EXP(-(Q*(HPRIM-HPRIMB(M)))/TMB(M))		GLT11730
20	RHO=RHOZ*SIGMA		GLT11740
	THETA=TM/TMZ		GLT11750
	DELTA=SIGMA*THETA		GLT11760

02/13/70	80/80 LIST	PAGE NO. 000022
CA=49.02177*SQRT(TM)		GLT11770
AMU=AMUZ/SQRT(THETA**3)*((TMZ+S)/(TM+S))		GLT11780
CALL OVEKFL(J)		GLT11790
GO TO(16,13),J		GLT11800
16 K=K+3		GLT11810
13 RETURN		GLT11820
END		GLT11830
\$IBFTC ALINL LIST,DECK		GLT11840
SUBROUTINE ALINE(N,X,Y, XNEW,YNEW)		GLT11850
C*****		GLT11860
C SUBROUTINE CALCULATES A XNEW VALUE USING LINEAR INTERPOLATION		GLT11870
C PLACED IN MAIN LINK		GLT11880
COMMON/BEND/NEND		GLT11890
COMMON/BTAP/NIN,NOUT		GLT11900
DIMENSION X(2),Y(2)		GLT11910
DO 1 I=2,N		GLT11920
J=I		GLT11930
IF(Y(I).GT.YNEW) GO TO 2		GLT11940
1 CONTINUE		GLT11950
XNEW=X(J)		GLT11960
NEND=2		GLT11970
WRITE (NOUT,3) YNEW,Y(N)		GLT11980
3 FORMAT (10X,34H THE VALUE FOR LINEAR INTERPOLATION E15.8,		GLT11990
1 25H EXCEEDS THE ARRAY VALUE E15.8)		GLT12000
RETURN		GLT12010
2 XNEW=X(J)-(Y(J)-YNEW)/(Y(J)-Y(J-1))*(X(J)-X(J-1))		GLT12020
RETURN		GLT12030
END		GLT12040
\$IBFTC A4TAN LIST,DECK		GLT12050
FUNCTION ATAN4(X,Y)		GLT12060
C SUBROUTINE CALCULATES ARCTANGENT VALUES FOR ALL VALUES IN 4 QUADRANT		GLT12070
C USES ATAN2		GLT12080
C PLACED IN MAIN LINK		GLT12090
C*****		GLT12100
DATA PI2/1.5707963/		GLT12110
IF (Y.NE.0.0) GO TO 5		GLT12120
ATAN4=SIGN (PI2,X)		GLT12130
RETURN		GLT12140
5 ATAN4=ATAN2(X,Y)		GLT12150
RETURN		GLT12160
END		GLT12170
\$IBFTC STABC LIST,DECK		GLT12180
SUBROUTINE STAB (T)		GLT12190
C*****		GLT12200
C SUBROUTINE FOR USE WITH VIDE 6 DEGREES OF FREEDOM -KAMAN AVIDYNE		GLT12210
C CALCULATE CONTROL ANGLES AND CALLS VEHICLE SUBROUTINES		GLT12220
C PLACED IN VIDE (6-D) LINK		GLT12230
C SUBROUTINE CALLED FROM DEV6		GLT12240
C*****		GLT12250
COMMON/BAUTOP/THETE,THETC,VCOM(3),VXVH,VYVH,VXEI,VZCI,THETEI,		GLT12260
1 YNOM,ZNOM,VXNOM,VYNOM,VZNOM,GVX,GVY,GVZ,GVXL,GVYL,GVZL,		GLT12270
2 XX,PHIEI,PHIC,PHICI,PSIC,PSIR,BETAI,VXCOM,VYCOM,MODE,PHIE		GLT12280
COMMON/BDEV6/A(3,3),ALPHA,AMACH,AMASS,B,BETA,C,CL,CM,CN,		GLT12290
1 CX,CY,CZ,DDA,DDE,DDF,DDR,DNA,FL,FM,FN,FX,FY,FZ,GAMR,P,PHI,PSI,		GLT12300
2 Q,R,RLAMB,RHO,S,SOFs,THETA,UR,VA(3),VR,VTA,VTR,WR,XI,XR,XZI,		GLT12310
3 YI,YR,ZI,ZR,WDOT ,KTR		GLT12320

02/13/70		80/80 LIST	PAGE NO. 000023
	COMMON/BPHASE/NCON,MCON(20),MPHASE,NPHASE,PHASE(20),EXTRA(20),		GLT12330
1	ADD(20),NEXT		GLT12340
	COMMON/BSTAB/LOOP		GLT12350
	COMMON/BTABL/NDD,NVC,DA(30),DE(30),DF(30),DR(30),TDD(30),		GLT12360
1	XVC(30),YVC(30),ZVC(30),VXC(30),VYC(30),VZC(30),		GLT12370
2	CVX(30),CVY(30),CVZ(30),CVXL(30),CVYL(30),CVZL(30)		GLT12380
	COMMON/BTAP/NIN,NOUT		GLT12390
	COMMON/BTITLE/TITLE(12),NRUN,NTYPE,NPRINT,NTABL,NPAGE		GLT12400
	XX=SQRT(XR*XR+YR*YR)		GLT12410
	IF (NPHASE.NE.1) GO TO 200		GLT12420
	IF (EXTRA(1).LT.100.0) XX=T		GLT12430
	CALL ALINE(NDD,DE,TDD,DDE,XX)		GLT12440
	CALL ALINE(NDD,DF,TDD,DDF,XX)		GLT12450
	IF (NTYPE.EQ.2) GO TO 390		GLT12460
	CALL ALINE(NDD,DA,TDD,DDA,XX)		GLT12470
	CALL ALINE(NDD,DR,TDD,DDR,XX)		GLT12480
	GO TO 400		GLT12490
200	IF (NPHASE.NE.2) GO TO 300		GLT12500
120	CALL ALINE(NVC,VXC,XVC,VXCOM,XX)		GLT12510
	CALL ALINE(NVC,VYC,XVC,VYCOM,XX)		GLT12520
	CALL ALINE(NVC,VZC,XVC,VCOM(3),XX)		GLT12530
150	CPSI=COS(PSI)		GLT12540
	SPSI=SIN(PSI)		GLT12550
	VCOM(1)=VXCOM*CPSI+VYCOM*SPSI		GLT12560
	VCOM(2)=-VXCOM*SPSI+VYCOM*CPSI		GLT12570
	THETC=ADD(5)*(VCOM(1)-VXVH+ADD(4)*VXEI)		GLT12580
	THETE=THETC-THETA-ADD(2)*Q		GLT12590
	DDE=ADD(1)*(THETE+ADD(3)*THETEI)		GLT12600
	DDF=ADD(6)*(VCOM(3)-WR+ADD(7)*(VZCI-ZR))		GLT12610
	IF (NTYPE.EQ.2) GO TO 390		GLT12620
	PHIC=ADD(8)*(VCOM(2)-VYVH)		GLT12630
	PHIE=PHIC-PHI-ADD(9)*P		GLT12640
	DDA=ADD(10)*(PHIE+ADD(11)*PHIEI)		GLT12650
	IF (MODE.EQ.1) GO TO 250		GLT12660
	DDR=ADD(18)*(PHICI+ADD(16)*(PSIC-PSI+PSIR)-R)		GLT12670
	GO TO 400		GLT12680
250	DDR=ADD(18)*(PHICI+ADD(17)*BETAI-R)		GLT12690
	GO TO 400		GLT12700
300	IF (NPHASE.NE.3) GO TO 500		GLT12710
320	CALL ALINE (NVC,ZVC,XVC,ZNOM,XX)		GLT12720
	CALL ALINE (NVC,VXC,XVC,VXNOM,XX)		GLT12730
C	HOVER MODE FOR RANGE LESS THAN EXTRA(2)		GLT12740
	IF (XX.LT.EXTRA(2)) VXNOM=-SIGN(VXNOM,XR)		GLT12750
	CALL ALINE (NVC,VZC,XVC,VZNOM,XX)		GLT12760
	CALL ALINE (NVC,CVX,XVC,GVX,XX)		GLT12770
	CALL ALINE (NVC,CVZ,XVC,GVZ,XX)		GLT12780
	DELZ=ZR-ZNOM		GLT12790
	VXCOM = VXNOM-GVX*DELZ		GLT12800
	VYCOM = 0.0		GLT12810
	VCOM(3)=VZNOM-GVZ*DELZ		GLT12820
	IF (NTYPE.EQ.2) GO TO 150		GLT12830
	CALL ALINE (NVC,YVC,XVC,YNOM,XX)		GLT12840
	CALL ALINE (NVC,VYC,XVC,VYNOM,XX)		GLT12850
	CALL ALINE (NVC,CVY,XVC,GVY,XX)		GLT12860
	DELY=YR-YNOM		GLT12870
	CALL ALINE (NVC,CVXL,XVC,GVXL,XX)		GLT12880

	02/13/70	80/80 LIST	PAGE NO. 000024
	CALL ALINE (NVC,CVYL,XVC,GVYL,XX)		GLT12890
	CALL ALINE (NVC,CVZL,XVC,GVZL,XX)		GLT12900
	VXCOM=VXCOM-GVXL*DELY		GLT12910
	VYCOM=VYNOM-GVY*DELZ-GVYL*DELY		GLT12920
	VCOM(3)=VCOM(3)-GVZL*DELY		GLT12930
	GO TO 150		GLT12940
390	DDA=0.0		GLT12950
	DDR=0.0		GLT12960
400	CALL VEAD4		GLT12970
	IF (LOOP.NE.1) RETURN		GLT12980
	THETC=THETA		GLT12990
	THETE=0.0		GLT13000
	THETEI=DDE/(ADD(1)*ADD(3))		GLT13010
	VXEI=THETA/(ADD(4)*ADD(5))		GLT13020
	VZCI=DDF/(ADD(6)*ADD(7))+ZR		GLT13030
	IF (NTYPE.EQ.2) RETURN		GLT13040
	PHIEI=DDA/(ADD(10)*ADD(11))		GLT13050
	PHICI=0.0		GLT13060
	BETAI=0.0		GLT13070
	PSIR=0.0		GLT13080
	PSIC=0.0		GLT13090
	IF (MODE.EQ.1) RETURN		GLT13100
	PSIR=PSI		GLT13110
	PSIC=DDR/(ADD(18)*ADD(16))		GLT13120
	RETURN		GLT13130
500	WRITE (NOUT,510) NPHASE		GLT13140
510	FORMAT (1H1,45HNPHASE GREATER THAN 3 NOT ALLOWED -- NPHASE =,I3)		GLT13150
	NEND=2		GLT13160
	RETURN		GLT13170
	END		GLT13180
\$IBFTC V4	LIST,DECK		GLT13190
	SUBROUTINE VEAD4		GLT13200
	COMMON/BAUTOP/THETE,THETC,VCOM(3),VXVH,VYVH,VXEI,VZCI,THETEI,		GLT13210
1	YNOM,ZNOM,VXNOM,VYNOM,VZNOM,GVX,GVY,GVZ,GVXL,GVYL,GVZL,		GLT13220
2	XX,PHIEI,PHIC,PHICI,PSIC,PSIR,BETAI,VXCOM,VYCOM,MODE,PHIE		GLT13230
	COMMON/BBLOC4/STG(1296)		GLT13240
	COMMON/BCONST/GG,RADE,DH,QRHOS		GLT13250
	COMMON/BDEV6/A(3,3),ALPHA,AMACH,AMASS,B,BETA,C,CL,CM,CN,		GLT13260
1	CX,CY,CZ,DDA,DDE,DDF,DDR,DNA,FL,FM,FN,FX,FY,FZ,GAMR,P,PHI,PSI,		GLT13270
2	Q,R,RLAMB,RHO,S,SOF5,THETA,UR,VA(3),VR,VTA,VTR,WR,XI,XR,XZI,		GLT13280
3	YI,YR,ZI,ZR,WDOT ,KTR		GLT13290
	COMMON/BEND/NEND		GLT13300
	COMMON/BPHASE/NCON,MCON(20),MPHASE,NPHASE,PHASE(20),EXTRA(20),		GLT13310
1	ADD(20),NEXT		GLT13320
	COMMON/BSTAB/LOOP		GLT13330
	COMMON/BSUB/SAVE(36),II,ARG1,ARG2,ARG3,MINTBL,MAXTBL		GLT13340
	COMMON/BTAP/NIN,NOUT		GLT13350
	COMMON/BTITLE/TITLE(12),NRUN,NTYPE,NPRINT,NTABL,NPAGE		GLT13360
	COMMON/BWIND/ALT(220),WX(220),WY(220),WZ(220),NWIN,WXX,WYY,WZZ		GLT13370
	COMMON/V4ARBL/L1(36),L2(36),NUMPTS(37)		GLT13380
C	CON1	M/SEC TO KNOTS	GLT13390
C	CON2	DEG TO RAD	GLT13400
C	CON3	FT TO M	GLT13410
C	CON4	IN TO CM	GLT13420
C	CON5	M/SEC TO FT/MIN	GLT13430
C	CON6	NORMAL MASS	GLT13440

02/13/70		80/80 LIST	PAGE NO. 000025
	DATA CON1,CON2,CON3,CON4,CON5/1.9428,0.01745,0.3048,2.54,196.8504/GLT13450		
	1	,CON6/6078.0/	GLT13460
		G=GG*(RADE/(RADE-ZR))*2	GLT13470
		VXVHA=(UR-WXX)*COS(PSI)+(VR-WYY)*SIN(PSI)	GLT13480
		VZA=WR-WZZ	GLT13490
		ARG1=CON1*ABS(VXVHA)	GLT13500
		IF (ARG1.GT.140.0) GO TO 33	GLT13510
		ARG2=CON5*VZA	GLT13520
		IF (ABS(ARG2).GT.1500.0) GO TO 34	GLT13530
		ARG3=0.0	GLT13540
		CALL THRS4	GLT13550
		II=1	GLT13560
30		MINTBL=II	GLT13570
		MAXTBL=II	GLT13580
		CALL TABLES(STG,L1,L2,NUMPTS)	GLT13590
		IF (II.EQ.18) GO TO 31	GLT13600
		IF (II.EQ.36) GO TO 8	GLT13610
		II=II+1	GLT13620
		GO TO 30	GLT13630
31		THETO=CON2*SAVE(1)	GLT13640
		STHEO=SIN(THETO)	GLT13650
		CTHEO=COS(THETO)	GLT13660
		IF (NPHASE.EQ.1) GO TO 315	GLT13670
		IF (LOOP.EQ.1) GO TO 40	GLT13680
315		IF (DDE.GT.5.5*CON4) DDE=5.5*CON4	GLT13690
		IF (DDE.LT.-5.5*CON4) DDE=-5.5*CON4	GLT13700
		IF (DDF.GT.12.8*CON4) DDF=12.8*CON4	GLT13710
		IF (DDF.LT.0.0) DDF=0.0	GLT13720
32		DELE=DDE/CON4-SAVE(17)	GLT13730
		DC=DDF/CON4-SAVE(18)	GLT13740
		DU=(VA(1)-VXVHA*CTHEO+VZA*STHEO)/CON3	GLT13750
		DW=(VA(3D-VXVHA*STHEO-VZA*CTHEO)/CON3	GLT13760
		FX=CON6*(G*STHEO+CON3*(SAVE(2)*DU+SAVE(3)*DW+SAVE(4)*Q	GLT13770
	1	+SAVE(5)*DELE+SAVE(6)*DC))	GLT13780
		FZ=CON6*U-G*CTHEO+CON3*(SAVE(7)*DU+SAVE(8)*DW+SAVE(9)*Q	GLT13790
	1	+SAVE(10)*DELE+SAVE(11)*DC)	GLT13800
		FM=YI*(SAVE(12)*DU+SAVE(13)*DW+SAVE(14)*Q+SAVE(15)*DELE	GLT13810
	1	+SAVE(16)*DC)	GLT13820
		IF (NTYPE.NE.2) GO TO 7	GLT13830
		FY=0.0	GLT13840
		FL=0.0	GLT13850
		FN=0.0	GLT13860
		RETURN	GLT13870
40		DDE=SAVE(17)*CON4	GLT13880
		DDF=SAVE(18)*CON4	GLT13890
		THETA=THETO	GLT13900
		GO TO 32	GLT13910
50		DDA=SAVE(35)*CON4	GLT13920
		DDR=SAVE(36)*CON4	GLT13930
		GO TO 90	GLT13940
7		II=II+2	GLT13950
		GO TO 30	GLT13960
8		IF (NPHASE.EQ.1) GO TO 85	GLT13970
		IF (LOOP.EQ.1) GO TO 50	GLT13980
85		IF (MODE.EQ.1) DDR=DDR+CON4*SAVE(36)	GLT13990
		IF (DDA.GT.3.6*CON4) DDA=3.6*CON4	GLT14000

	80/80 LIST	PAGE NO. 000026
02/13/70	IF (DDA.LT.-3.6*CON4) DDA=-3.6*CON4	GLT14010
	IF (DDR.GT.2.3*CON4) DDR=2.3*CON4	GLT14020
	IF (DDR.LT.-2.3*CON4) DDR=-2.3*CON4	GLT14030
90	DALF=DDA/CON4-SAVE(35)	GLT14040
	DELR=DDR/CON4-SAVE(36)	GLT14050
	VPRIME=VA(2)/CON3	GLT14060
	FY = CON6 * (SAVE(20)*VPRIME+SAVE(21)*P+SAVE(22)*R+SAVE(23)*DALF	GLT14070
1	+SAVE(24)*DELR)	GLT14080
	FL = XI*(SAVE(25)*VPRIME+SAVE(26)*P+SAVE(27)*R+SAVE(28)*DALF+	GLT14090
1	SAVE(29)*DELR)	GLT14100
	FN = ZI*(SAVE(30)*VPRIME+SAVE(31)*P+SAVE(32)*R+SAVE(33)*DALF+	GLT14110
1	SAVE(34)*DELR)	GLT14120
	GO TO 500	GLT14130
33	WRITE (NOUT,35) ARG1	GLT14140
35	FORMAT (1H ,29HARG1 OFF TABLE WITH VALUE OF E14.6)	GLT14150
	GO TO 499	GLT14160
34	WRITE (NOUT,36) ARG2	GLT14170
36	FORMAT (1H ,29HARG2 OFF TABLE WITH VALUE OF E14.6)	GLT14180
499	NEND=3	GLT14190
500	RETURN	GLT14200
	END	GLT14210
\$IBFTC	TRS4 LIST,DECK	GLT14220
	SUBROUTINE THRS4	GLT14230
	COMMON/BBLOC4/STG(1296)	GLT14240
	COMMON/BDEV6/A(3,3),ALPHA,AMACH,AMASS,B,BETA,C,CL,CM,CN,	GLT14250
1	CX,CY,CZ,DDA,DDE,DDF,DDR,DNA,FL,FM,FN,FX,FY,FZ,GAMR,P,PHI,PSI,	GLT14260
2	Q,R,RLAMB,RHO,S,SOFs,THETA,UR,VA(3),VR,VTA,VTR,WR,XI,XR,XZI,	GLT14270
3	YI,YR,ZI,ZR,WDOT ,KTR	GLT14280
	COMMON/BSUB/SAVE(36),II,ARG1,ARG2,ARG3,MINTBL,MAXTBL	GLT14290
	COMMON/V4ARBL/L1(36),L2(36),NUMPTS(37)	GLT14300
	GO TO (1,2),KTR	GLT14310
1	WDOT=0.0	GLT14320
	RETURN	GLT14330
2	II=19	GLT14340
	MINTBL=II	GLT14350
	MAXTBL=II	GLT14360
	CALL TABLES(STG,L1,L2,NUMPTS)	GLT14370
	WDOT=SAVE(II)*.4536/3600.0	GLT14380
	RETURN	GLT14390
	END	GLT14400
\$IBFTC	TABLE LIST,DECK	GLT14410
	SUBROUTINE TABLES(STG,L1,L2,NUMPTS)	GLT14420
C*****		GLT14430
C	SUBROUTINE INTERPOLATES TABLES IN VEHICLE SUBROUTINE FOR THE 6-D SEC	GLT14440
C	PLACED IN VIDE (6-D) LINK	GLT14450
C		GLT14460
C*****		GLT14470
	COMMON/BEND/NEND	GLT14480
	COMMON/BSUB/SAVE(36),II,ARG1,ARG2,ARG3,MINTBL,MAXTBL	GLT14490
	COMMON/BTAP/NIN,NOUT	GLT14500
	DIMENSION STG(1),L1(1),L2(1),NUMPTS(1)	GLT14510
	IF (MINTBL-MAXTBL) 41,100,73	GLT14520
41	DO 43 IITLU1=MINTBL,MAXTBL	GLT14530
	IJTLU1=NUMPTS(IITLU1)+1	GLT14540
	IF (ARG3-STG(IJTLU1)) 42,44,43	GLT14550
42	IF (IITLU1-MINTBL) 73,74,45	GLT14560

	02/13/70	80/80 LIST	PAGE NO. 000027
43	CONTINUE		GLT14570
	GO TO 74		GLT14580
45	IKTLU1=1		GLT14590
	ILTLU1=2		GLT14600
	IMTLU1=IJTLU1		GLT14610
	GO TO 101		GLT14620
100	IITLU1=MINTBL		GLT14630
44	IKTLU1=3		GLT14640
	ILTLU1=3		GLT14650
101	DO 97 IFTLU1=IKTLU1,ILTLU1		GLT14660
	IJTLU1=NUMPTS(IITLU1)+1		GLT14670
	IOTLU1=L1(IITLU1)		GLT14680
	IPTLU1=IOTLU1+IJTLU1		GLT14690
	DO 77 IQTLU1=1,IOTLU1		GLT14700
	INTLU1=IJTLU1+IQTLU1		GLT14710
	IF (ARG1-STG(INTLU1)) 76,78,77		GLT14720
76	IF (IQTLU1-1) 73,74,79		GLT14730
77	CONTINUE		GLT14740
	GO TO 74		GLT14750
78	IGTLU1=-1		GLT14760
	GO TO 80		GLT14770
79	IGTLU1=+1		GLT14780
80	IBTLU1=L2(IITLU1)		GLT14790
	DO 82 IATLU1=1,IBTLU1		GLT14800
	ISTLU1=IPTLU1+IATLU1		GLT14810
	IF (ARG2-STG(ISTLU1)) 81,83,82		GLT14820
81	IF (IATLU1-1) 73,74,84		GLT14830
82	CONTINUE		GLT14840
	GO TO 74		GLT14850
83	IHTLU1=-1		GLT14860
	GO TO 85		GLT14870
84	IHTLU1=+1		GLT14880
85	IETLU1=IPTLU1+L2(IITLU1)+IQTLU1+IOTLU1*IATLU1-IOTLU1		GLT14890
	IRTLU1=IETLU1-IOTLU1		GLT14900
	IF (IGTLU1+IHTLU1) 86,88,91		GLT14910
86	IF (STG(IETLU1)-99999.E9) 87,75,75		GLT14920
87	FCT=STG(IETLU1)		GLT14930
	GO TO 95		GLT14940
88	IF (IGTLU1) 89,73,93		GLT14950
89	IF (AMAX1(STG(IETLU1),STG(IRTLU1))-99999.E9) 90,75,75		GLT14960
90	FCT=STG(IETLU1)-(STG(ISTLU1)-ARG2)*((STG(IETLU1)-STG(IRTLU1))/(STG(ISTLU1)-STG(ISTLU1-1)))		GLT14970
	GO TO 95		GLT14980
91	IF (AMAX1(STG(IETLU1),STG(IRTLU1),STG(IETLU1-1),STG(IRTLU1-1))-99999.E9) 92,75,75		GLT14990
92	FCT=((STG(ISTLU1)-ARG2)*((STG(INTLU1)-ARG1)*STG(IRTLU1-1)-(STG(INTLU1-1)-ARG1)*STG(IRTLU1))-(STG(ISTLU1-1)-ARG2)*((STG(INTLU1)-ARG1)*STG(IETLU1-1)-(STG(INTLU1-1)-ARG1)*STG(IETLU1))))/((STG(ISTLU1)-STG(ISTLU1-1))*((STG(INTLU1)-STG(INTLU1-1))))		GLT15000
	GO TO 95		GLT15010
93	IF (AMAX1(STG(IETLU1),STG(IETLU1-1))-99999.E9) 94,75,75		GLT15020
94	FCT=STG(IETLU1)-(STG(INTLU1)-ARG1)*((STG(IETLU1)-STG(IETLU1-1))/(STG(INTLU1)-STG(INTLU1-1)))		GLT15030
95	GO TO (93,98,99),IFTLU1		GLT15040
96	DUMSTG=FCT		GLT15050
97	IITLU1=IITLU1-1		GLT15060
			GLT15070
			GLT15080
			GLT15090
			GLT15100
			GLT15110
			GLT15120

02/13/70		80/80 LIST		PAGE NO. 000028	
98	CONTINUE			GLT15130	
	FCT=DUMSTG-(STG(IMTLU1)-ARG3)*(DUMSTG-FCT)/(STG(IMTLU1)-STG(IJTLU1			GLT15140	
	1))			GLT15150	
99	SAVE(II)=FCT			GLT15160	
	GO TO 1001			GLT15170	
73	WRITE (NOUT,13)			GLT15180	
13	FORMAT (34H CALLING SEQUENCE STATEMENTS ERROR)			GLT15190	
	GO TO 1000			GLT15200	
74	WRITE (NOUT,14)MINTBL,MAXTBL,ARG1,ARG2,ARG3			GLT15210	
14	FORMAT (17H OFF TABLE(S) NO.I2,2H -I2,7H ARG1=1PE15.7,7H ARG2=E1			GLT15220	
	1 5.7,7H ARG3=E15.7)			GLT15230	
	GO TO 1000			GLT15240	
75	WRITE (NOUT,15) MINTBL,MAXTBL,ARG1,ARG2,ARG3			GLT15250	
15	FORMAT (37H DISCONTINUOUS FUNCTION. TABLE(S) NO.I2,2H -I2,			GLT15260	
	17H ARG1=1PE15.7,7H ARG2=E15.7,7H ARG3=E15.7)			GLT15270	
1000	NEND=2			GLT15280	
1001	RETURN			GLT15290	
	END			GLT15300	
\$IBFTC DA40	LIST,DECK			GLT15310	
	BLOCK DATA			GLT15320	
	COMMON/V4ARBL/L1(36),L2(36),NUMPTS(37)			GLT15330	
	DATA L1/36*8/			GLT15340	
	DATA L2/36*3/			GLT15350	
	DATA NUMPTS/0,36,72,108,144,180,216,252,288,324,360,396,432,468,			GLT15360	
	1 504,540,576,612,648,684,720,756,792,828,864,900,936,972,1008,			GLT15370	
	2 1044,1080,1116,1152,1188,1224,1260,1296/			GLT15380	
	END			GLT15390	
\$IBFTC DA41	LIST,DECK			GLT15400	
	BLOCK DATA			GLT15410	
	COMMON/BBLOC4/STG(1296)			GLT15420	
	DATA (STG(I),I=1,108)/			GLT15430	
	*0.000000 ,0.000000 ,20.000000 ,40.000000 ,60.000000 ,80.000000 ,			GLT15440	
	*100.0000 ,120.0000 ,140.0000 ,-1500.00 ,0.000000 ,1500.000 ,			GLT15450	
	*9.096150 ,8.245610 ,6.518040 ,4.346800 ,1.747070 ,0.858000 ,			GLT15460	
	*-2.84258 ,-7.20897 ,9.306270 ,8.198340 ,6.622350 ,4.752270 ,			GLT15470	
	*2.322940 ,1.433870 ,-2.26671 ,-6.63310 ,8.988100 ,8.138670 ,			GLT15480	
	*6.994710 ,5.343400 ,3.213520 ,2.324450 ,-1.37613 ,-5.74252 ,			GLT15490	
	*0.000000 ,0.000000 ,20.000000 ,40.000000 ,60.000000 ,80.000000 ,			GLT15500	
	*100.0000 ,120.0000 ,140.0000 ,-1500.00 ,0.000000 ,1500.000 ,			GLT15510	
	*-0.02649 ,-0.01935 ,-0.03260 ,-0.04491 ,-0.05277 ,-0.05277 ,			GLT15520	
	*-0.05277 ,-0.05277 ,-0.02540 ,-0.00181 ,-0.02156 ,-0.03604 ,			GLT15530	
	*-0.04642 ,-0.05579 ,-0.06456 ,-0.07206 ,0.011430 ,0.022370 ,			GLT15540	
	*-0.01281 ,-0.03179 ,-0.04306 ,-0.04306 ,-0.04306 ,-0.04306 ,			GLT15550	
	*0.000000 ,0.000000 ,20.000000 ,40.000000 ,60.000000 ,80.000000 ,			GLT15560	
	*100.0000 ,120.0000 ,140.0000 ,-1500.00 ,0.000000 ,1500.000 ,			GLT15570	
	*0.075050 ,0.081220 ,0.082090 ,0.075210 ,0.065680 ,0.065680 ,			GLT15580	
	*0.065680 ,0.065680 ,0.054490 ,0.068180 ,0.082550 ,0.089440 ,			GLT15590	
	*0.085480 ,0.103430 ,0.085230 ,0.056660 ,0.043680 ,0.051110 ,			GLT15600	
	*0.106370 ,0.109190 ,0.106530 ,0.106530 ,0.106530 ,0.106530 /			GLT15610	
	DATA (STG(I),I=109,216)/			GLT15620	
	*0.000000 ,0.000000 ,20.000000 ,40.000000 ,60.000000 ,80.000000 ,			GLT15630	
	*100.0000 ,120.0000 ,140.0000 ,-1500.00 ,0.000000 ,1500.000 ,			GLT15640	
	*0.156330 ,0.208750 ,0.266900 ,0.170580 ,.0971700 ,.6151000 ,			GLT15650	
	*.1423900 ,-0.38179 ,0.601850 ,0.749150 ,0.875080 ,0.849570 ,			GLT15660	
	*0.730790 ,1.248720 ,0.776010 ,0.251830 ,1.025360 ,0.939030 ,			GLT15670	
	*1.555340 ,1.459650 ,1.370430 ,1.888360 ,1.415650 ,0.891470 ,			GLT15680	

02/13/70	80/80 LIST						PAGE NO. 000030
*0.002280	,0.004690	,0.006830	,0.006830	,0.006830	,0.006830	,	GLT16250
*0.000000	,0.000000	,20.00000	,40.00000	,60.00000	,80.00000	,	GLT16260
*100.0000	,120.0000	,140.0000	,1500.00	,0.000000	,1500.000	,	GLT16270
*-0.93433	, -1.03020	, -1.24040	, -1.37428	, -1.42430	, -1.52214	,	GLT16280
*-1.49278	, -1.41781	, -0.73173	, -0.96002	, -1.31158	, -1.45996	,	GLT16290
*-1.52219	, -1.62003	, -1.59067	, -1.51570	, -0.58241	, -0.81810	,	GLT16300
*-1.48310	, -1.56553	, -1.62309	, -1.72093	, -1.69157	, -1.61660	,	GLT16310
*0.000000	,0.000000	,20.00000	,40.00000	,60.00000	,80.00000	,	GLT16320
*100.0000	,120.0000	,140.0000	,1500.00	,0.000000	,1500.000	,	GLT16330
*0.374720	,0.379300	,0.400950	,0.438150	,0.465580	,0.499950	,	GLT16340
*0.517580	,0.529880	,0.354470	,0.353640	,0.401440	,0.450220	,	GLT16350
*0.481350	,0.515720	,0.533350	,0.545650	,0.343630	,0.306120	,	GLT16360
*0.438610	,0.471660	,0.503380	,0.537750	,0.555380	,0.567680	/	GLT16370
DATA (STG(I),I=541,648)/							GLT16380
*0.000000	,0.000000	,20.00000	,40.00000	,60.00000	,80.00000	,	GLT16390
*100.0000	,120.0000	,140.0000	,1500.00	,0.000000	,1500.000	,	GLT16400
*-0.04570	, -0.03118	,0.019090	,0.036370	,0.042120	,0.021940	,	GLT16410
*0.014350	,0.009920	, -0.04765	, -0.04252	,0.045560	,0.067760	,	GLT16420
*0.067250	,0.047070	,0.039480	,0.035050	, -0.05591	, -0.16472	,	GLT16430
*0.153680	,0.116200	,0.108840	,0.096020	,0.088430	,0.084000	,	GLT16440
*0.000000	,0.000000	,20.00000	,40.00000	,60.00000	,80.00000	,	GLT16450
*100.0000	,120.0000	,140.0000	,1500.00	,0.000000	,1500.000	,	GLT16460
*0.566110	,0.452490	,0.381660	,0.631830	,1.021150	,0.181790	,	GLT16470
*0.406900	,0.585960	,0.665230	, -0.06503	, -0.23516	,0.288880	,	GLT16480
*0.778170	, -0.06119	,0.163920	,0.342980	,0.030600	, -1.69234	,	GLT16490
*-0.56815	,0.115500	,0.605650	, -0.23371	, -0.00860	,0.170460	,	GLT16500
*0.000000	,0.000000	,20.00000	,40.00000	,60.00000	,80.00000	,	GLT16510
*100.0000	,120.0000	,140.0000	,1500.00	,0.000000	,1500.000	,	GLT16520
*6.513010	,6.301310	,5.941680	,5.948450	,6.388860	,7.217460	,	GLT16530
*8.589520	,10.55994	,5.019590	,4.473460	,3.731350	,3.511110	,	GLT16540
*3.849170	,4.677770	,6.049830	,8.020250	,3.898720	,3.250380	,	GLT16550
*1.250710	,0.903470	,1.158810	,1.987410	,3.359470	,5.329890	/	GLT16560
DATA (STG(I),I=649,684)/							GLT16570
*0.000000	,0.000000	,20.00000	,40.00000	,60.00000	,80.00000	,	GLT16580
*100.0000	,120.0000	,140.0000	,1500.00	,0.000000	,1500.000	,	GLT16590
*1102.055	,1076.035	,1023.741	,1012.939	,1055.591	,1128.295	,	GLT16600
*1270.255	,1531.148	,921.6850	,854.1230	,763.3410	,732.3630	,	GLT16610
*755.1900	,827.8940	,969.8540	,1230.747	,791.8486	,711.3020	,	GLT16620
*500.6865	,470.2615	,495.9614	,568.6654	,710.6254	,971.5184	/	GLT16630
END							GLT16640
\$IBFTC DA42 LIST,DECK							GLT16650
BLOCK DATA							GLT16660
COMMON/BBLOC4/STG(1296)							GLT16670
DATA (STG(I),I=685,756)/							GLT16680
*0.000000	,0.000000	,20.00000	,40.00000	,60.00000	,80.00000	,	GLT16690
*100.0000	,120.0000	,140.0000	,1500.00	,0.000000	,1500.000	,	GLT16700
*-0.020605	, -0.08482	, -0.10455	, -0.12256	, -0.14842	, -0.14842	,	GLT16710
*-0.14842	, -0.14842	, -0.026638	, -0.05408	, -0.07986	, -0.11823	,	GLT16720
*-0.15121	, -0.18040	, -0.19766	, -0.23442	, -0.08635	, -0.04068	,	GLT16730
*-0.11126	, -0.15170	, -0.18262	, -0.18262	, -0.18262	, -0.18262	,	GLT16740
*0.000000	,0.000000	,20.00000	,40.00000	,60.00000	,80.00000	,	GLT16750
*100.0000	,120.0000	,140.0000	,1500.00	,0.000000	,1500.000	,	GLT16760
*-0.40249	, -0.48197	, -0.63817	, -0.68143	, -0.63180	, -0.63180	,	GLT16770
*-0.63180	, -0.63180	, -0.76514	, -0.95618	, -1.15981	, -1.24824	,	GLT16780
*-1.23341	, -1.02295	, -0.76619	, -0.29372	, -1.10440	, -1.30270	,	GLT16790
*-1.78540	, -1.86230	, -1.73270	, -1.73270	, -1.73270	, -1.73270	/	GLT16800

02/13/70		80/80 LIST		PAGE NO. 000031	
DATA (STG(I),I=757,864)/				GLT16810	
*0.000000	,0.000000	,20.000000	,40.000000	,60.000000	,80.000000 ,
*100.0000	,120.0000	,140.0000	,1500.00	,0.000000	,1500.000 ,
*-0.04204	,0.040520	,0.06921	,0.04086	,0.015140	,0.015140 ,
*0.015140	,0.015140	,0.12517	,0.18179	,0.20082	,0.12813 ,
*-0.05819	,0.133800	,0.125140	,0.221250	,0.18435	,0.10798 ,
*-0.30137	,0.22815	,0.19244	,0.19244	,0.19244	,0.19244 ,
*0.000000	,0.000000	,20.000000	,40.000000	,60.000000	,80.000000 ,
*100.0000	,120.0000	,140.0000	,1500.00	,0.000000	,1500.000 ,
*1.039500	,1.042280	,1.040660	,1.042660	,1.062870	,1.062870 ,
*1.062870	,1.062870	,0.997940	,0.997000	,0.976730	,0.964260 ,
*0.969550	,0.971230	,1.016130	,1.102250	,0.980540	,0.970470 ,
*0.925610	,0.896870	,0.876750	,0.876750	,0.876750	,0.876750 ,
*0.000000	,0.000000	,20.000000	,40.000000	,60.000000	,80.000000 ,
*100.0000	,120.0000	,140.0000	,1500.00	,0.000000	,1500.000 ,
*0.149820	,0.148020	,0.128940	,0.118750	,0.129380	,0.129380 ,
*0.129380	,0.129380	,0.146520	,0.136340	,0.116520	,0.105830 ,
*0.098490	,0.116410	,0.138830	,0.152620	,0.142500	,0.112170 ,
*0.097510	,0.073010	,0.070080	,0.070080	,0.070080	,0.070080 /
DATA (STG(I),I=865,972)/				GLT17000	
*0.000000	,0.000000	,20.000000	,40.000000	,60.000000	,80.000000 ,
*100.0000	,120.0000	,140.0000	,1500.00	,0.000000	,1500.000 ,
*-0.02127	,0.01846	,0.01978	,0.02294	,0.02866	,0.02866 ,
*-0.02866	,0.02866	,0.00778	,0.01305	,0.01338	,0.01720 ,
*-0.02442	,0.03188	,0.04724	,0.05080	,0.00996	,0.00799 ,
*-0.00448	,0.00371	,0.00289	,0.00289	,0.00289	,0.00289 ,
*0.000000	,0.000000	,20.000000	,40.000000	,60.000000	,80.000000 ,
*100.0000	,120.0000	,140.0000	,1500.00	,0.000000	,1500.000 ,
*-0.37496	,0.40345	,0.45470	,0.46318	,0.42905	,0.42905 ,
*-0.42905	,0.42905	,0.50730	,0.57483	,0.64045	,0.65271 ,
*-0.62549	,0.52243	,0.41134	,0.23476	,0.63036	,0.71659 ,
*-0.86876	,0.87455	,0.79734	,0.79734	,0.79734	,0.79734 ,
*0.000000	,0.000000	,20.000000	,40.000000	,60.000000	,80.000000 ,
*100.0000	,120.0000	,140.0000	,1500.00	,0.000000	,1500.000 ,
*0.029070	,0.067980	,0.021130	,0.037400	,0.070880	,0.070880 ,
*0.070880	,0.070880	,0.02297	,0.04571	,0.05943	,0.02270 ,
*0.011720	,0.095310	,0.116590	,0.199550	,0.05234	,0.02797 ,
*-0.10977	,0.07677	,0.05688	,0.05688	,0.05688	,0.05688 /
DATA (STG(I),I=973,1080)/				GLT17190	
*0.000000	,0.000000	,20.000000	,40.000000	,60.000000	,80.000000 ,
*100.0000	,120.0000	,140.0000	,1500.00	,0.000000	,1500.000 ,
*0.481130	,0.482280	,0.482710	,0.484170	,0.491240	,0.491240 ,
*0.491240	,0.491240	,0.465360	,0.465580	,0.459540	,0.455750 ,
*0.458050	,0.458200	,0.473540	,0.505280	,0.459030	,0.457050 ,
*0.441700	,0.432300	,0.426300	,0.426300	,0.426300	,0.426300 ,
*0.000000	,0.000000	,20.000000	,40.000000	,60.000000	,80.000000 ,
*100.0000	,120.0000	,140.0000	,1500.00	,0.000000	,1500.000 ,
*-0.13312	,0.13406	,0.14131	,0.14556	,0.14455	,0.14455 ,
*-0.14455	,0.14455	,0.12638	,0.13036	,0.13422	,0.13544 ,
*-0.13910	,0.13256	,0.13248	,0.14433	,0.12454	,0.13516 ,
*-0.13158	,0.13554	,0.13256	,0.13256	,0.13256	,0.13256 ,
*0.000000	,0.000000	,20.000000	,40.000000	,60.000000	,80.000000 ,
*100.0000	,120.0000	,140.0000	,1500.00	,0.000000	,1500.000 ,
*0.001080	,0.000980	,0.000440	,0.000520	,0.000410	,0.000410 ,
*0.000410	,0.000410	,0.000130	,0.000370	,0.00123	,0.00290 ,
*-0.00415	,0.00536	,0.00377	,0.00060	,0.001220	,0.00016 ,

02/13/70										30/80 LIST										PAGE NO. 000032									
*-0.00236 , -0.00456 , -0.00706 , -0.00706 , -0.00706 , -0.00706 /																				GLT17370									
DATA (STG(I), I=1081, 1188) /																				GLT17380									
*0.000000 , 0.000000 , 20.00000 , 40.00000 , 60.00000 , 80.00000 ,																				GLT17390									
*100.0000 , 120.0000 , 140.0000 , -1500.00 , 0.000000 , 1500.000 ,																				GLT17400									
*-0.02133 , -0.02122 , -0.02478 , -0.02754 , -0.03693 , -0.03693 ,																				GLT17410									
*-0.03693 , -0.03693 , -0.01831 , -0.02076 , -0.02598 , -0.03947 ,																				GLT17420									
*-0.05344 , -0.06864 , -0.07797 , -0.07471 , -0.02085 , -0.01101 ,																				GLT17430									
*-0.02424 , -0.04001 , -0.05921 , -0.05921 , -0.05921 , -0.05921 ,																				GLT17440									
*0.000000 , 0.000000 , 20.00000 , 40.00000 , 60.00000 , 80.00000 ,																				GLT17450									
*100.0000 , 120.0000 , 140.0000 , -1500.00 , 0.000000 , 1500.000 ,																				GLT17460									
*-0.07653 , -0.06348 , -0.07218 , -0.07450 , -0.08262 , -0.08262 ,																				GLT17470									
*-0.08262 , -0.08262 , -0.05847 , -0.05450 , -0.04597 , -0.05020 ,																				GLT17480									
*-0.05438 , -0.05078 , -0.08642 , -0.12617 , -0.04986 , -0.02575 ,																				GLT17490									
*-0.03287 , -0.03310 , -0.03704 , -0.03704 , -0.03704 , -0.03704 ,																				GLT17500									
*0.000000 , 0.000000 , 20.00000 , 40.00000 , 60.00000 , 80.00000 ,																				GLT17510									
*100.0000 , 120.0000 , 140.0000 , -1500.00 , 0.000000 , 1500.000 ,																				GLT17520									
*0.030760 , 0.030530 , 0.029240 , 0.028560 , 0.029180 , 0.029180 ,																				GLT17530									
*0.029180 , 0.029180 , 0.030010 , 0.029230 , 0.027640 , 0.026630 ,																				GLT17540									
*0.026330 , 0.026960 , 0.028570 , 0.021700 , 0.029250 , 0.027440 ,																				GLT17550									
*0.025800 , 0.023850 , 0.023130 , 0.023130 , 0.023130 , 0.023130 /																				GLT17560									
DATA (STG(I), I=1189, 1296) /																				GLT17570									
*0.000000 , 0.000000 , 20.00000 , 40.00000 , 60.00000 , 80.00000 ,																				GLT17580									
*100.0000 , 120.0000 , 140.0000 , -1500.00 , 0.000000 , 1500.000 ,																				GLT17590									
*0.183380 , 0.183550 , 0.183660 , 0.184250 , 0.187300 , 0.187300 ,																				GLT17600									
*0.187300 , 0.187300 , 0.175840 , 0.175780 , 0.172610 , 0.170320 ,																				GLT17610									
*0.171410 , 0.171460 , 0.179330 , 0.195360 , 0.172850 , 0.171490 ,																				GLT17620									
*0.163730 , 0.159060 , 0.155400 , 0.155400 , 0.155400 , 0.155400 ,																				GLT17630									
*0.000000 , 0.000000 , 20.00000 , 40.00000 , 60.00000 , 80.00000 ,																				GLT17640									
*100.0000 , 120.0000 , 140.0000 , -1500.00 , 0.000000 , 1500.000 ,																				GLT17650									
*0.165670 , 0.150810 , 0.141810 , 0.155350 , 0.200650 , 0.200650 ,																				GLT17660									
*0.200650 , 0.200650 , 0.129830 , 0.084620 , 0.091910 , 0.134660 ,																				GLT17670									
*0.179310 , 0.297540 , 0.441540 , 0.497850 , 0.092550 , 0.044450 ,																				GLT17680									
*0.014040 , 0.051770 , 0.098820 , 0.098820 , 0.098820 , 0.098820 ,																				GLT17690									
*0.000000 , 0.000000 , 20.00000 , 40.00000 , 60.00000 , 80.00000 ,																				GLT17700									
*100.0000 , 120.0000 , 140.0000 , -1500.00 , 0.000000 , 1500.000 ,																				GLT17710									
*-0.23383 , -0.21772 , -0.28008 , -0.42589 , -0.61869 , -0.61869 ,																				GLT17720									
*-0.61869 , -0.61869 , -0.17764 , -0.04701 , -0.08508 , -0.33705 ,																				GLT17730									
*-0.61293 , -0.75397 , -1.04713 , -1.14123 , -0.07915 , 0.329280 ,																				GLT17740									
*0.069180 , -0.19696 , -0.43185 , -0.43185 , -0.43185 , -0.43185 /																				GLT17750									
END																				GLT17760									
IGIN PLACE																				GLT17770									
FTC PLOTR LIST, DECK																				GLT17780									
SUBROUTINE PLOTR (NTAPE)																													

	02/13/70	80/80 LIST	PAGE NO. 000033
	1	PHI(500),ALPHA(500),BETA(500),VX(500),VY(500),VZ(500),AZ(500),GLT17930	
	2	YN(500),ZN(500), THETAC(500),	GLT17940
	3	PHIC(500),VXC(500),VYC(500),VZC(500),DDA(500),DDC(500),	GLT17950
	4	DDE(500),DDR(500)	GLT17960
		COMMON/BTAP/NIN,NOUT	GLT17970
		DIMENSION SAVE(500,24),YTIT(3),YTIT(3,15),NCHAR(15)	GLT17980
		DIMENSION IBUF(360),TEMP(1002),ORD1(502),ORD2(502)	GLT17990
		EQUIVALENCE (ORD1(1),TEMP(1))	GLT18000
		EQUIVALENCE (T(1),SAVE(1,1))	GLT18010
		DATA AXLEN,AYL1,AYL2,AYL3,AYL4 /6.0,4.5,4.0,2.5,1.99/,INTEQ/0/	GLT18020
		DATA (NCHAR(I),I=1,15)/16,17,3*10,2*9,11,4*12,8,10,11/	GLT18030
		DATA (YTIT(1,I),I=1,15) / 16HALTITUDE (-Z), M,	GLT18040
	1	17HCROSSRANGE (Y), M,	GLT18050
	2	10HVY - M/SEC,	GLT18060
	3	9HPSI - DEG,	GLT18070
	4	11HTHETA - DEG,	GLT18080
	5	12HDELTA-A - CM,	GLT18090
	6	12HDELTA-E - CM,	GLT18100
	7	10HBETA - DEG,	GLT18110
		10HVZ - M/SEC,	
		10HVX - M/SEC,	
		12HDELTA-R - CM,	
		12HDELTA-C - CM,	
		8HAZ - G'S,	
		11HALPHA - DEG /	
		CALL PLOTS (IBUF,360)	GLT18120
		CALL PLOT (0.0,+11.0,-3)	GLT18130
		CALL PLOT (0.0,-11.0,-2)	GLT18140
		CALL PLOT (1.4,1.4,-3)	GLT18150
		REWIND NTAPE	GLT18160
	10	NPTS=0	GLT18170
	20	READ (NTAPE) NNN,NRUN	GLT18180
		IF (NRUN.LT.0) GO TO 1000	GLT18190
		IF (NNN.LT.0) GO TO 40	GLT18200
		DO 30 I=1,NNN	GLT18210
		NPTS=NPTS+1	GLT18220
	30	READ (NTAPE) (SAVE(NPTS,J),J=1,24)	GLT18230
		GO TO 20	GLT18240
	35	WRITE (NOUT,36) NRUN,NPTS	GLT18250
	36	FORMAT (///19H *****RUN NO. I3,16H NOT PLOTTED -- ,	GLT18260
	1	24HNUMBER OF DATA POINTS (I5,26H) EXCEEDS MAXIMUM (498))	GLT18270
		GO TO 10	GLT18280
	40	FRUN=FLOAT(NRUN)	GLT18290
		IF (NPTS.GT.498) GO TO 35	GLT18300
		DO 50 I=1,NPTS	GLT18310
		Z(I)=-Z(I)	GLT18320
	50	ZN(I)=-ZN(I)	GLT18330
		NP1=NPTS+1	GLT18340
		NP2=NPTS+2	GLT18350
		N2=2*NPTS	GLT18360
		N2P1=N2+1	GLT18370
		N2P2=N2+2	GLT18380
		CALL SCALE (X,AXLEN,NPTS,+1)	GLT18390
		CALL AXIS (0.0,0.0,16HDOWNRANGE (X), M,-16,AXLEN,0.0,X(NP1),	GLT18400
	1	X(NP2))	GLT18410
		NPLT=1	GLT18420
		AYL=AYL1	GLT18430
		L1=4	GLT18440
		L2=15	GLT18450
		ASSIGN 130 TO NST	GLT18460
	100	DO 110 I=1,NPTS	GLT18470
		TEMP(I)=SAVE(I,L1)	GLT18480

	02/13/70	80/80 LIST	PAGE NO. 000034
	II=NPTS+I		GLT18490
	TEMP(II)=SAVE(I,L2)		GLT18500
110	ORD2(I)=SAVE(I,L2)		GLT18510
	DO 120 I=1,3		GLT18520
120	YTITLE(I)=YTIT(I,NPLT)		GLT18530
	NCH=NCHAQ(NPLT)		GLT18540
	CALL SCALE (TEMP,AYL,N2,+1)		GLT18550
	CALL AXIS (0.0,0.0,YTITLE,NCH,AYL,90.0,TEMP(N2P1),TEMP(N2P2))		GLT18560
	ORD2(NP1)=TEMP(N2P1)		GLT18570
	ORD2(NP2)=TEMP(N2P2)		GLT18580
	ORD1(NP1)=TEMP(N2P1)		GLT18590
	ORD1(NP2)=TEMP(N2P2)		GLT18600
	CALL LINE (X,ORD1,NPTS,1,+10,INTEQ)		GLT18610
	CALL LINE (X,ORD2,NPTS,1, 0,INTEQ)		GLT18620
	GO TO NST, (130,140,160,170,150,220 ,900)		GLT18630
130	AYL=AYL2		GLT18640
	L1=3		GLT18650
	L2=14		GLT18660
	NPLT=2		GLT18670
	ASSIGN 140 TO NST		GLT18680
	YNEW=AYL1+0.25		GLT18690
	CALL PLOT (0.0,YNEW,-3)		GLT18700
	GO TO 100		GLT18710
140	CALL SCALE (T,AXLEN,NPTS,+1)		GLT18720
	DO 145 I=1,NP2		GLT18730
145	X(I)=T(I)		GLT18740
	CALL PLOT (0.0,-0.2,-3)		GLT18750
	CALL PLOT (0.85,0.07,3)		GLT18760
	CALL PLOT (1.15,0.07,2)		GLT18770
	CALL SYMBOL (1.5,0.0, 0.14,7HNOMINAL,0.0,7)		GLT18780
	CALL SYMBOL (4.0,0.07,0.07,INTEQ,0.0,-1)		GLT18790
	CALL PLOT (3.85,0.07,3)		GLT18800
	CALL PLOT (4.15,0.07,2)		GLT18810
	CALL SYMBOL (4.5,0.0,0.14,8HRUN NO. ,0.0,8)		GLT18820
	CALL NUMBER (999.0,999.0,0.14,FRUN,0.0,-1)		GLT18830
	ASSIGN 155 TO NST1		GLT18840
150	CALL PLOT (7.1,11.0,-3)		GLT18850
	CALL PLOT (0.0,-11.0,-2)		GLT18860
	CALL PLOT (1.4,1.4,-3)		GLT18870
	CALL AXIS (0.0,0.0,13HTIME (T), SEC,-13,AXLEN,0.0,T(NP1),T(NP2))		GLT18880
	GO TO NST1, (155,180,230,270)		GLT18890
155	NPLT=3		GLT18900
	AYL=AYL3		GLT18910
	L1=12		GLT18920
	L2=20		GLT18930
	ASSIGN 160 TO NST		GLT18940
	GO TO 100		GLT18950
160	ASSIGN 165 TO NST3		GLT18960
161	YNEW=AYL +0.05		GLT18970
	CALL PLOT (0.0,YNEW,-3)		GLT18980
	CALL PLOT (0.85,0.07,3)		GLT18990
	CALL PLOT (1.15,0.07,2)		GLT19000
	CALL SYMBOL (1.5,0.0,0.14,9HCOMMANDED,0.0,9)		GLT19010
	CALL SYMBOL (4.0,0.07,0.07,INTEQ,0.0,-1)		GLT19020
	CALL PLOT (3.85,0.07,3)		GLT19030
	CALL PLOT (4.15,0.07,2)		GLT19040

	02/13/70	80/80 LIST	PAGE NO. 000035
	CALL SYMBOL (4.5,0.0,0.14,6HACTUAL,0.0,6)		GLT19050
	CALL PLOT (0.0,0.20,-3)		GLT19060
	GO TO NST3,(165,215)		GLT19070
165	L1=11		GLT19080
	L2=19		GLT19090
	ASSIGN 170 TO NST		GLT19100
	NPLT=4		GLT19110
	GO TO 100		GLT19120
170	ASSIGN 175 TO NST4		GLT19130
171	YNEW=AYL +0.05		GLT19140
	CALL PLOT (0.0,YNEW,-3)		GLT19150
	CALL SYMBOL (2.5,0.0,0.14,8HRUN NO. ,0.0,8)		GLT19160
	CALL NUMBER (999.0,999.0,0.14,FRUN,0.0,-1)		GLT19170
	CALL PLOT (0.0,0.20,-3)		GLT19180
	GO TO NST4, (175,225,255,295)		GLT19190
175	L1=10		GLT19200
	L2=18		GLT19210
	ASSIGN 150 TO NST		GLT19220
	ASSIGN 180 TO NST1		GLT19230
	NPLT=5		GLT19240
	GO TO 100		GLT19250
180	NPLT=6		GLT19260
	L1=5		GLT19270
	ASSIGN 210 TO NST2		GLT19280
190	DO 195 I=1,3		GLT19290
195	YTITLE(I)=YTIT(I,NPLT)		GLT19300
	NCH=NCHAR(NPLT)		GLT19310
	DO 200 I=1,NPTS		GLT19320
200	TEMP(I)=SAVE(I,L1)		GLT19330
	CALL SCALE (TEMP,AYL,NPTS,+1)		GLT19340
	CALL AXIS (0.0,0.0,YTITLE,NCH,AYL,90.0,TEMP(NP1),TEMP(NP2))		GLT19350
	CALL LINE (T,TEMP,NPTS,1,+10,INTEQ)		GLT19360
	GO TO NST2, (150,210,240,250,260,280,290,900)		GLT19370
210	ASSIGN 215 TO NST3		GLT19380
	GO TO 161		GLT19390
215	NPLT=7		GLT19400
	L1=7		GLT19410
	L2=17		GLT19420
	ASSIGN 220 TO NST		GLT19430
	GO TO 100		GLT19440
220	ASSIGN 225 TO NST4		GLT19450
	GO TO 171		GLT19460
225	NPLT=8		GLT19470
	L1=6		GLT19480
	L2=16		GLT19490
	ASSIGN 150 TO NST		GLT19500
	ASSIGN 230 TO NST1		GLT19510
	GO TO 100		GLT19520
230	NPLT=9		GLT19530
	AYL=AYL4		GLT19540
	L1=24		GLT19550
	ASSIGN 240 TO NST2		GLT19560
	GO TO 190		GLT19570
240	YNEW=AYL+0.25		GLT19580
	CALL PLOT (0.0,YNEW,-3)		GLT19590
	NPLT=10		GLT19600

02/13/70	80/80 LIST	PAGE NO. 000036
L1=21		GLT19610
ASSIGN 250 TO NST2		GLT19620
GO TO 190		GLT19630
250 ASSIGN 255 TO NST4		GLT19640
GO TO 171		GLT19650
255 NPLT=11		GLT19660
L1=22		GLT19670
ASSIGN 260 TO NST2		GLT19680
GO TO 190		GLT19690
260 YNEW=AYL+0.25		GLT19700
CALL PLOT (0.0,YNEW,-3)		GLT19710
NPLT=12		GLT19720
L1=23		GLT19730
ASSIGN 150 TO NST2		GLT19740
ASSIGN 270 TO NST1		GLT19750
GO TO 190		GLT19760
270 NPLT=13		GLT19770
L1=13		GLT19780
AYL=AYL3		GLT19790
ASSIGN 280 TO NST2		GLT19800
GO TO 190		GLT19810
280 YNEW=AYL+0.25		GLT19820
CALL PLOT (0.0,YNEW,-3)		GLT19830
NPLT=14		GLT19840
L1=9		GLT19850
ASSIGN 290 TO NST2		GLT19860
GO TO 190		GLT19870
290 ASSIGN 295 TO NST4		GLT19880
GO TO 171		GLT19890
295 NPLT=15		GLT19900
L1=8		GLT19910
ASSIGN 900 TO NST2		GLT19920
GO TO 190		GLT19930
900 CALL PLOT (7.1,11.0,-3)		GLT19940
CALL PLOT (0.0,-11.0,-2)		GLT19950
CALL PLOT (1.4,1.4,-3)		GLT19960
INTEQ=INTEQ+1		GLT19970
GO TO 10		GLT19980
1000 CALL PLOT (0.0,0.0,999.0)		GLT19990
RETURN		GLT20000
END		GLT20010

Appendix B

THREE-DIMENSIONAL ANALYTICAL MODEL FOR THE MASS CENTER MOTIONS OF A HELICOPTER

For purposes of guidance and performance analysis, it is usually adequate to predict the motion of the mass center of an aircraft while neglecting its angular motions with respect to the mass center. The latter motions are assumed to take place on a much shorter time scale than motions of the mass center.

B.1 MASS CENTER EQUATIONS OF MOTION

The forces acting on the helicopter are lumped into four components as shown in Fig. B-1.

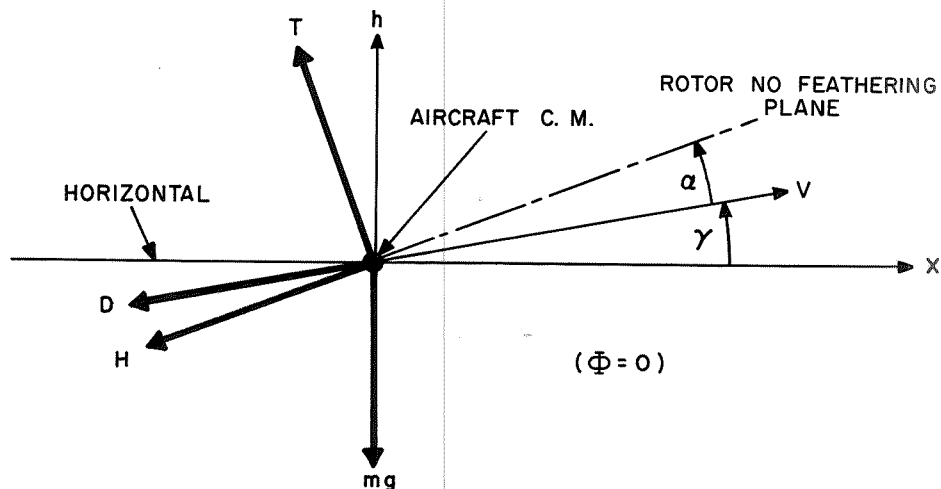


Fig. B-1. Forces Acting on a Helicopter
in the Vertical Plane

The equations of motion for a coordinated turn (i.e., no sideslip) are:

$$m\dot{V} = -D - H \cos \alpha - T \sin \alpha - mg \sin \gamma \quad (B-1)$$

$$mV\dot{\gamma} = (T \cos \alpha - H \sin \alpha) \cos \Phi - mg \cos \gamma \quad (B-2)$$

$$(mV \cos \gamma)\dot{\Psi} = (T \cos \alpha - H \sin \alpha) \sin \Phi \quad (B-3)$$

$$\dot{h} = V \sin \gamma \quad (B-4)$$

$$\dot{x} = V \cos \gamma \cos \Psi \quad (B-5)$$

$$\dot{y} = V \cos \gamma \sin \Psi \quad (B-6)$$

where the state variables are

V = velocity

γ = flight path angle

Ψ = azimuth angle

h = altitude

x = downrange

y = lateral range

m = mass of vehicle

The forces acting on the aircraft are functions of V , h and the three control variables:

α = angle of attack of NFP

Φ = bank angle (angle between the vertical and the plane containing T and V)

θ_r = collective pitch at $3/4$ rotor radius.

In place of θ_r , one may use δ_c = collective pitch stick deflection since it is uniquely related to θ_r .

It is convenient to use one additional variable:

λ = rotor inflow ratio

$$\underline{\lambda} \triangleq \frac{\text{average downward velocity thru rotor disk}}{\text{rotor tip speed}}$$

which is determined by V , α and θ_r through the implicit relation

$$0 = \lambda + \mu \tan \alpha - \frac{C_T}{2\sqrt{\mu^2 + \lambda^2}} \quad (\text{B-7})$$

where C_T , and hence T (rotor thrust $\perp$ to the NFP), is given by (Ref. 8)

$$C_T = \frac{T}{\rho S_r (\Omega R_r)^2} \cong \frac{\sigma a}{2} \left[\frac{\theta_r}{3} (1 + \frac{3}{2} \mu^2) - \frac{\lambda}{2} \right] \quad (\text{B-8})$$

and

$\rho = \rho(h)$ = air density

σ = rotor solidity ratio

a = lift coefficient slope of rotor blade section ($< 2\pi$)

$\mu = \frac{V \cos \alpha}{\Omega R_r}$ = rotor advance ratio

Ω = rotor angular velocity (assumed constant)

R_r = rotor radius

S_r = rotor disk area = πR_r^2

The in-plane rotor force, H (parallel to the NFP), is given by:

$$H = H_o + H_i \quad (\text{B-9})$$

where (Ref. 8)

$$C_{H_o} \triangleq \frac{H_o}{\rho S_r (\Omega R_r)^2} \cong 0.45 \sigma \mu C_{D_o} \quad (\text{B-10})$$

$$C_{H_i} \triangleq \frac{H_i}{\rho S_r (\Omega R_r)^2} \cong \frac{\sigma a_u}{2} \left[\left(\frac{\theta_r}{3} - \frac{3}{4} \lambda + \frac{1}{4} \mu^2 a_1 \right) a_1 + \left(\frac{1}{4} a_o - \frac{1}{6} b_1 \right) a_o + \frac{1}{2} \lambda \theta_r \right] \quad (B-11)$$

and

C_{D_o} = zero-lift drag coefficient of the rotor blade section

$$a_o = \frac{\gamma_r}{2} \left[\frac{\theta_r}{4} (1 + \mu^2) - \frac{\lambda}{3} \right]$$

$$a_1 = \frac{\frac{8}{3} (\theta_r - \frac{3}{4} \lambda)}{1 - \frac{1}{2} \mu^2}$$

$$b_1 = \frac{\frac{4}{3} a_o}{1 + \frac{1}{2} \mu^2}$$

γ_r = blade mass constant

Finally, the fuselage drag, D , is given approximately by

$$D \cong f_D \frac{\rho V^2}{2} \quad (B-12)$$

where

f_D = equivalent flat plate area (constant).

B.2 QUASI-STEADY ANALYSIS

For $\dot{V} \approx 0$, $V \dot{\gamma} \approx 0$, $\dot{\phi} = 0$, $\dot{\psi} = 0$, with given h , V and γ (or equivalently h , $\dot{x}$, $\dot{h}$), Eqs. (B-1), (B-2), and (B-7) become three

simultaneous algebraic equations for the trim values of α , θ_r and λ using the force equations, Eqs. (B-8) through (B-12).

B.2.1 Hover

This is a special case of the quasi-steady analysis with $V = 0$. However, for $V = 0$, neither α nor γ is defined. But since H and D vanish identically for $V = 0$, it is clear that T must be vertical and equal to mg . Thus, using Eq. (B-7), we have:

$$mg = \rho S_r (\Omega R_r)^2 \frac{\sigma a}{2} \left(\frac{\theta_r}{3} - \frac{\lambda}{2} \right) \quad (B-13)$$

$$\lambda^2 = \frac{\sigma a}{4} \left(\frac{\theta_r}{3} - \frac{\lambda}{2} \right) \quad (B-14)$$

Solving Eqs. (B-13) and (B-14) for λ gives:

$$\lambda = \sqrt{\frac{mg}{2 \rho S_r (\Omega R_r)^2}} \quad (B-15)$$

$$\left. \begin{aligned} \theta_r &= \frac{3}{2} \lambda + \frac{4\lambda^2}{\sigma a} \end{aligned} \right\} \text{for hover} \quad (B-16)$$

B.2.2 Trim Calculations for YHC-1A Helicopter

The quasi-steady analysis was applied to the calculation of equilibrium flight values of δ_c and α for the LaRC YHC-1A helicopter, where (References 5 and 6):

$$\Omega R_r = 680 \text{ ft/sec}$$

$$\sigma = .0593$$

$$\begin{aligned}
 a &= 5.70 \text{ rad}^{-1} \\
 C_{D_o} &= .012 \\
 f_D &= 36.7 \text{ ft}^2 \\
 S_r &= 3670 \text{ ft}^2 \\
 \theta_r &= 1.25 \delta_c + 1 \text{ } (\theta_r \text{ in degrees, } \delta_c \text{ in inches}) \\
 \gamma_r &= 10.0 \\
 mg &= 13,400 \text{ lb}
 \end{aligned}$$

Results are compared with trim values calculated by the Vertol Division, Boeing Co. (Ref. 6), in Table B-1. It is apparent from the table that, for the cases compared, the present method agrees quite well with the more accurate calculations obtained by Vertol. The results indicate that the analytical force model would be adequate for performing preliminary guidance and performance analyses.

Table B-1. Comparison of Trim Calculations for δ_c and α
(G.W. 13400 lb., C.M. Normal, Sea Level)

V_H kts	V_V fpm	$\delta_c^{(1)}$ in	$\delta_c^{(2)}$ in	$\alpha^{(1)}$ deg	$\alpha^{(2)}$ deg
40	1500	5.94	6.12	-13.8	-14.5
40	0	3.73	3.47	6.55	6.35
40	-1500	1.25	0.92	27.2	27.1
80	1500	6.39	7.36	-8.8	-10.5
80	0	3.85	4.24	2.3	1.6
80	-1500	1.16	1.48	13.7	13.2
100	0	4.68	4.80	1.4	1.0

Note: (1) Calculated by Vertol Division, Boeing Co.
(2) Calculated by present method.

Appendix C

PHYSICAL AND AERODYNAMIC CHARACTERISTICS OF NASA/LaRC YHC-1A HELICOPTER

This appendix summarizes the data which has been used in Program LIFT to simulate the dynamics of the LaRC YHC-1A helicopter. All of the data presented here were obtained from References 5 and 6.

Table C-I summarizes the pertinent physical characteristics of the vehicle, including control displacement limits. Tables C-II through C-VII give the trim conditions, fuel flow and stability derivatives as functions of forward speed for three rates of descent. The data in Tables C-II through C-VII were calculated for a gross weight of 13,400 lbs, normal c.m. position and sea level flight. In Tables C-IV through C-VII (non-zero rate of descent), the data for forward speeds greater than 80 knots were extrapolated from 80-knot values by assuming constant offset from the corresponding zero rate of descent (Tables C-II and C-III) data. For the reader's convenience, the data in Tables C-II through C-VII are plotted in Figures C-1 to C-8.

Because of the different units in which the data was provided and used in Program LIFT, Table C-VIII contains a number of convenient conversion factors.

Table C-I. Physical Characteristics of
LaRC YHC-1A Helicopter

Operating mass, m	6078	kg	(13,400 lbs)
Rolling moment of inertia, I_{xx}	12,474	kg-m ²	(9203 slug-ft ²)
Pitching moment of inertia, I_{yy}	102,898	kg-m ²	(75,914 slug-ft ²)
Yawing moment of inertia, I_{zz}	97,238	kg-m ²	(71,738 slug-ft ²)
Cross-product of inertia, J_{xz}	-9638	kg-m ²	(7144 slug-ft ²)
Reference area, S_r	341	m ²	(3670 ft ²)
Reference chord, c	0.4572	m	(1.5 ft)
Rotor radius, R_r	7.367	m	(24.17 ft)
Control travel limits			
Collective stick, δ_c	0 - 32.512 cm (0 - 12.8 in)		
Longitudinal stick, δ_e	±13.97	cm	(±5.5 in)
Lateral stick, δ_a	±9.14	cm	(±3.6 in)
Pedal, δ_r	±5.85	cm	(±2.3 in)

Table C-II. YHC-1A Longitudinal Stability Derivatives (Rate of Descent = 0 ft/min)

FORWARD VELOCITY	KTS	0	20	40	60	80	100	120	140
θ_o	deg	9.30627	8.19834	6.62235	4.75227	2.32294	1.43387	-2.28871	-6.63310
δe_o	in	.66523	-.06503	-.23518	.28888	.77817	-.06119	.16392	.34298
δc_o	in	5.01959	4.47346	3.73135	3.51111	3.84917	4.67777	6.04983	8.02025
f	1b/hr	921.685	854.123	763.341	732.363	755.190	827.894	869.854	1230.747
X_u/m	$\frac{ft/sec^2}{ft/sec}$	-.02540	-.00181	-.02156	-.03604	-.04642	-.05579	-.06456	-.07206
X_w/m	$\frac{ft/sec^2}{ft/sec}$	.05449	.06818	.08255	.08944	.08548	.10343	.08523	.05666
X_q/m	$\frac{ft/sec^2}{rad/sec}$	.60185	.74915	.87508	.84957	.73079	1.24872	.77601	.25183
$X_{\delta e}/m$	$\frac{ft/sec^2}{in}$	.17696	.13988	.12312	.14237	.16406	-.05165	-.03776	-.01954
$X_{\delta c}/m$	$\frac{ft/sec^2}{in}$	1.20482	.97467	.87948	.80253	.68335	.88200	.72040	.48341
Z_u/m	$\frac{ft/sec^2}{ft/sec}$	.06009	-.12594	-.08296	-.02192	.01396	.06077	.06546	.04980
Z_w/m	$\frac{ft/sec^2}{ft/sec}$	-.36933	-.48399	-.63639	-.80152	-.92055	-1.00063	-1.04552	-1.10516
Z_q/m	$\frac{ft/sec^2}{rad/sec}$	-.71511	-1.16872	-1.77844	-1.81400	-1.81986	-2.22039	-2.25955	-2.47935
$Z_{\delta e}/m$	$\frac{ft/sec^2}{in}$	-.00407	.21188	.51943	.56820	.52527	.46341	.41480	.36743
$Z_{\delta c}/m$	$\frac{ft/sec^2}{in}$	-7.43006	-7.23138	-7.65410	-8.52446	-9.49008	-10.26600	-11.08740	-11.71110
M_u/I_{yy}	$\frac{rad/sec^2}{ft/sec}$	.00656	.00645	-.00587	-.00670	-.00582	-.00185	-.00120	-.00089
M_w/I_{yy}	$\frac{rad/sec^2}{ft/sec}$	-.00285	.00978	.01630	.01363	.01154	.00956	.00774	.00691
M_q/I_{yy}	$\frac{rad/sec^2}{rad/sec}$	-.73173	-.96002	-1.31158	-1.45996	-1.52219	-1.62003	-1.59067	-1.51570
$M_{\delta e}/I_{yy}$	$\frac{rad/sec^2}{in}$	.35447	.35364	.40144	.45022	.48135	.51572	.53335	.54565
$M_{\delta c}/I_{yy}$	$\frac{rad/sec^2}{in}$	-.04765	-.04252	.04556	.06776	.06725	.04707	.03948	.03505

Table C-III. YHC-1A Lateral Stability Derivatives (Rate of Descent = 0 ft/min)

FORWARD VELOCITY	KTS	0	20	40	60	80	100	120	140
δa_o	in	.12983	.08462	.09191	.13466	.17931	.29754	.44154	.49785
δr_o	in	-.17764	-.04701	-.08508	-.33705	-.61293	-.75397	-1.04713	-1.14123
Y_v/m	$\frac{ft/sec^2}{ft/sec}$	-.02663	-.05408	-.07986	-.11823	-.16121	-.18040	-.19766	-.23442
Y_p/m	$\frac{ft/sec^2}{rad/sec}$	-.76514	-.95618	-1.15981	-1.24824	-1.23341	-1.02295	-.76619	-.29372
Y_r/m	$\frac{ft/sec^2}{rad/sec}$	-.12517	-.18179	-.20082	-.12813	-.05819	.13380	.12514	.22125
$Y\delta_a/m$	$\frac{ft/sec^2}{in}$	.99794	.99700	.97673	.96426	.96955	.97123	1.01613	1.10225
$Y\delta_r/m$	$\frac{ft/sec^2}{in}$	.14652	.13634	.11652	.10583	.09849	.11641	.13883	.15262
L_v/I_{xx}	$\frac{rad/sec^2}{ft/sec}$	-.00778	-.01305	-.01338	-.01720	-.02442	-.03188	-.04724	-.05080
L_p/I_{xx}	$\frac{rad/sec^2}{rad/sec}$	-.50730	-.57483	-.64045	-.65271	-.62549	-.52243	-.41134	-.23476
L_r/I_{xx}	$\frac{rad/sec^2}{rad/sec}$	-.02297	-.04571	-.05943	-.02270	.01172	.09531	.11659	.19955
$L\delta_a/I_{xx}$	$\frac{rad/sec^2}{in}$	.46536	.46558	.45954	.45575	.45805	.45820	.47354	.50528
$L\delta_r/I_{xx}$	$\frac{rad/sec^2}{in}$	-.12638	-.13036	-.13422	-.13544	-.13910	-.13256	-.13248	-.14433
N_v/I_{zz}	$\frac{rad/sec^2}{ft/sec}$	.00013	.00037	-.00123	-.00290	-.00415	-.00536	-.00377	-.00060
N_p/I_{zz}	$\frac{rad/sec^2}{rad/sec}$	-.01831	-.02076	-.02598	-.03947	-.05344	-.06864	-.07747	-.07471
N_r/I_{zz}	$\frac{rad/sec^2}{rad/sec}$	-.05847	-.05450	-.04597	-.05020	-.05438	-.08078	-.08642	-.12617
$N\delta_a/I_{zz}$	$\frac{rad/sec^2}{in}$	.03001	.02923	.02764	.02663	.02633	.02696	.02857	.02970
$N\delta_r/I_{zz}$	$\frac{rad/sec^2}{in}$	.17534	.17578	.17261	.17032	.17141	.17146	.17933	.19536

Table C-IV. YHC-1A Longitudinal Stability Derivatives (Rate of Descent = 1500 ft/min)

FORWARD VELOCITY	KTS	0	20	40	60	80	100*	120*	140*
θ_o	deg	8.9881	8.13867	6.99471	5.34340	3.21352	2.32445	-1.37813	-5.74252
δe_o	in	.03060	-1.69234	-.56815	.11550	.60565	-.23371	-.00860	.17046
δc_o	in	3.89872	3.25038	1.25071	.90347	1.15881	1.98741	3.35947	5.32989
f	lb/hr	791.849	711.302	500.687	470.262	495.961	568.665	610.625	971.518
X_u/m	$\frac{ft/sec^2}{ft/sec}$	.01143	.02237	-.01281	-.03179	-.04306	-.05243	-.06120	-.06870
X_w/m	$\frac{ft/sec^2}{ft/sec}$	.04368	.05111	.10637	.10919	.10653	.12448	.10628	.07771
X_q/m	$\frac{ft/sec^2}{ft/sec}$	1.02536	.93903	1.55534	1.45965	1.37043	1.88836	1.41565	.89147
X_{δ_e}/m	$\frac{ft/sec^2}{in}$	.16625	.12347	.08223	.12593	.14599	-.06972	-.05583	-.03761
X_{δ_c}/m	$\frac{ft/sec^2}{in}$	1.13928	.94352	.82126	.88028	.82702	1.02567	.86407	.62708
Z_u/m	$\frac{ft/sec^2}{ft/sec}$	-.13435	-.23640	-.12619	-.02151	.01777	.06458	.06927	.05361
Z_w/m	$\frac{ft/sec^2}{ft/sec}$	-.28748	-.26321	-.82254	-.90575	-.98052	-1.06060	-1.10549	-1.16513
Z_q/m	$\frac{ft/sec^2}{ft/sec}$	-.79039	.30060	-2.45731	-2.40596	-2.42975	-2.83028	-2.86944	-3.08924
Z_{δ_e}/m	$\frac{ft/sec^2}{in}$	.00615	.19996	.94841	.77315	.71536	.65350	.60489	.55752
Z_{δ_c}/m	$\frac{ft/sec^2}{in}$	-7.45257	-7.38250	-6.35173	-8.00904	-9.05358	-9.82953	-10.65093	-11.27463
M_u/I_{yy}	$\frac{rad/sec^2}{ft/sec}$	.01308	.01863	-.00906	-.00696	-.00635	-.00238	-.00173	-.00142
M_w/I_{yy}	$\frac{rad/sec^2}{ft/sec}$	.00368	.03420	.00228	.00469	.00683	.00485	.00303	.00220
M_q/I_{yy}	$\frac{rad/sec^2}{ft/sec}$	-.58241	-.81810	-1.48310	-1.56553	-1.62309	-1.72093	-1.69157	-1.61660
M_{δ_e}/I_{yy}	$\frac{rad/sec^2}{in}$	.34363	.30612	.43861	.47166	.50338	.53775	.55538	.56768
M_{δ_c}/I_{yy}	$\frac{rad/sec^2}{in}$	-.05591	-.16472	.15368	.11620	.10884	.09602	.08843	.08400

* Data extrapolated from values at 80 knots.

Table C-V. YHC-1A Lateral Stability Derivatives (Rate of Descent = 1500 ft/min)

FORWARD VELOCITY	KTS	0	20	40	60	80	100*	120*	140*
δa_o	in	.09255	.04445	.01404	.05177	.09882	.21705	.36105	.41736
δr_o	in	-.07915	.32928	.06918	-.19696	-.43185	-.57289	-.86605	-.96015
Y_v/m	$\frac{ft/sec^2}{ft/sec}$	-.08635	-.04068	-.11126	-.15170	-.18262	-.20181	-.21907	-.25583
Y_p/m	$\frac{ft/sec^2}{rad/sec}$	-1.10440	-1.30270	-1.78540	-1.86230	-1.73270	-1.52224	-1.26548	-.79301
Y_r/m	$\frac{ft/sec^2}{rad/sec}$	-.18435	-.10798	-.30137	-.22815	-.19244	-.00045	-.00911	.08700
$Y_{\delta a}/m$	$\frac{ft/sec^2}{in}$	.98054	.97047	.92561	.89687	.87675	.87843	.92333	1.00945
$Y_{\delta r}/m$	$\frac{ft/sec^2}{in}$	.14250	.11217	.09751	.07301	.07008	.08800	.11042	.12421
L_v/I_{xx}	$\frac{rad/sec^2}{ft/sec}$	-.00996	-.00799	-.00448	-.00371	-.00289	-.01035	-.02571	-.02927
L_p/I_{xx}	$\frac{rad/sec^2}{rad/sec}$	-.63036	-.71659	-.86876	-.87455	-.79734	-.69428	-.58319	-.40661
L_r/I_{xx}	$\frac{rad/sec^2}{rad/sec}$	-.05234	-.02797	-.10977	-.07677	-.05688	.02671	.04799	.13095
$L_{\delta a}/I_{xx}$	$\frac{rad/sec^2}{in}$	.45903	.45705	.44170	.43230	.42630	.42645	.44179	.47353
$L_{\delta r}/I_{xx}$	$\frac{rad/sec^2}{in}$	-.12454	-.13516	-.13185	-.13554	-.13256	-.12602	-.12594	-.13779
N_v/I_{zz}	$\frac{rad/sec^2}{ft/sec}$	.00122	-.00016	-.00236	-.00456	-.00706	-.00827	-.00668	-.00351
N_p/I_{zz}	$\frac{rad/sec^2}{rad/sec}$	-.02085	-.01101	-.02424	-.04001	-.05921	-.07441	-.08324	-.08048
N_r/I_{zz}	$\frac{rad/sec^2}{rad/sec}$	-.04986	-.02575	-.03287	-.03310	-.03704	-.06380	-.06944	-.10919
$N_{\delta a}/I_{zz}$	$\frac{rad/sec^2}{in}$	.02925	.02744	.02580	.02385	.02313	.02376	.02537	.02650
$N_{\delta r}/I_{zz}$	$\frac{rad/sec^2}{in}$	.17285	.17149	.16373	.15906	.15540	.15545	.16332	.17935

*Data extrapolated from values at 80 knots.

Table C-VI. YHC-1A Longitudinal Stability Derivatives (Rate of Descent = -1500 ft/min)

FORWARD VELOCITY	KTS	0	20	40	60	80	100*	120*	140*
θ_o	deg	9.09615	8.24561	6.51804	4.34680	1.74707	.85800	-2.84458	-7.20897
δ_{e_o}	in	.56611	.45244	.38166	.63183	1.02115	.18179	.40690	.58596
δ_{c_o}	in	6.51301	6.30131	5.94168	5.94845	6.38886	7.21746	8.58952	10.55994
f	lb/hr	1102.055	1076.035	1023.741	1012.939	1055.591	1128.295	1170.255	1531.148
X_u/m	$\frac{ft/sec^2}{ft/sec}$	-.02649	-.01935	-.03260	-.04491	-.05277	-.06214	-.07091	-.07841
X_w/m	$\frac{ft/sec^2}{ft/sec}$	.07505	.08122	.08209	.07521	.06568	.08363	.06543	.03686
X_q/m	$\frac{ft/sec^2}{rad/sec}$	.15633	.20875	.26690	.17058	.09717	.61510	.14239	-.38179
X_{δ_e}/m	$\frac{ft/sec^2}{in}$	.17842	.16228	.14484	.16227	.18105	-.03466	-.02077	-.00255
X_{δ_c}/m	$\frac{ft/sec^2}{in}$	1.16992	1.04008	.90570	.78861	.62563	.82428	.66268	.42569
Z_u/m	$\frac{ft/sec^2}{ft/sec}$	.04316	-.02454	-.00971	.00737	.02520	.07201	.07620	.06104
Z_w/m	$\frac{ft/sec^2}{ft/sec}$	-.52217	-.60121	-.72925	-.85332	-.94171	-1.02179	-1.06668	-1.12632
Z_q/m	$\frac{ft/sec^2}{rad/sec}$	-1.07268	-1.20010	-1.25010	-1.38662	-1.47426	-1.87479	-1.91395	-2.13375
Z_{δ_e}/m	$\frac{ft/sec^2}{in}$	.05444	.16010	.36218	.41296	.41472	.35286	.30425	.25688
Z_{δ_c}/m	$\frac{ft/sec^2}{in}$	-7.5865	-7.64041	-8.2477	-8.9541	-9.7090	-10.48495	-11.30635	-11.93005
M_u/I_{yy}	$\frac{rad/sec^2}{ft/sec}$	.00251	.00163	.00321	-.00458	-.00467	-.00070	-.00005	.00025
M_w/I_{yy}	$\frac{rad/sec^2}{ft/sec}$	-.00148	.00327	.00726	.00765	.00730	.00532	.00350	.00267
M_q/I_{yy}	$\frac{rad/sec^2}{rad/sec}$	-.93433	-1.03020	-1.24040	-1.37428	-1.4243	-1.52214	-1.49278	-1.41781
M_{δ_e}/I_{yy}	$\frac{rad/sec^2}{in}$	.37472	.37930	.40095	.43815	.46558	.49995	.51758	.52988
M_{δ_c}/I_{yy}	$\frac{rad/sec^2}{in}$	-.04570	-.03118	.01909	.03637	.04212	.02194	.01435	.00992

* Data extrapolated from values at 80 knots.

Table C-VII. YHC-1A Lateral Stability Derivatives (Rate of Descent = -1500 ft/min)

FORWARD VELOCITY	KTS	0	20	40	60	80	100*	120*	140*
δa_o	in	.16567	.15081	.14181	.15535	.20065	.31888	.46288	.51919
δr_o	in	-.23383	-.21772	-.28008	-.42584	-.61869	-.75973	-1.05289	-1.14699
Y_v/m	$\frac{ft/sec^2}{ft/sec}$	-.02060	-.08482	-.10455	-.12256	-.14842	-.16761	-.18487	-.22163
Y_p/m	$\frac{ft/sec^2}{rad/sec}$	-.40249	-.48197	-.63817	-.68143	-.63180	-.42134	-.16458	.30789
Y_r/m	$\frac{ft/sec^2}{rad/sec}$	-.04204	.04052	-.06921	-.04086	.01514	.20713	.19847	.29458
$Y_{\delta a}/m$	$\frac{ft/sec^2}{in}$	1.03950	1.04228	1.04066	1.04266	1.06287	1.06455	1.10945	1.19557
$Y_{\delta r}/m$	$\frac{ft/sec^2}{in}$	.14982	.14802	.12894	.11875	.12938	.14730	.16972	.18351
L_v/I_{xx}	$\frac{rad/sec^2}{ft/sec}$	-.02127	.01846	-.01978	.02294	-.02866	-.03612	-.05148	-.05504
L_p/I_{xx}	$\frac{rad/sec^2}{rad/sec}$	-.37496	-.40345	-.45470	-.46318	-.42905	-.32599	-.21490	-.03832
L_r/I_{xx}	$\frac{rad/sec^2}{rad/sec}$	.02907	.06798	.02113	.03740	.07088	.15447	.17575	.25871
$L_{\delta a}/I_{xx}$	$\frac{rad/sec^2}{in}$	.48113	.48228	.48271	.48417	.49124	.49139	.50673	.53847
$L_{\delta r}/I_{xx}$	$\frac{rad/sec^2}{in}$	-.13312	-.13406	-.14131	-.14556	-.14455	-.13801	-.13793	-.14978
N_v/I_{zz}	$\frac{rad/sec^2}{ft/sec}$	.00108	.00098	.00044	.00052	.00041	-.00080	.00079	.00396
N_p/I_{zz}	$\frac{rad/sec^2}{rad/sec}$	-.02133	-.02122	-.02478	-.02754	-.03643	-.05163	-.06046	-.05770
N_r/I_{zz}	$\frac{rad/sec^2}{rad/sec}$	-.07653	-.06348	-.07218	-.07450	-.08262	-.10902	-.11466	-.15441
$N_{\delta a}/I_{zz}$	$\frac{rad/sec^2}{in}$	.03076	.03053	.02424	.02856	.02918	.02981	.03142	.03255
$N_{\delta r}/I_{zz}$	$\frac{rad/sec^2}{in}$	.18338	.18355	.18366	.18425	.18730	.18735	.19522	.21125

*Data extrapolated from values at 80 knots.

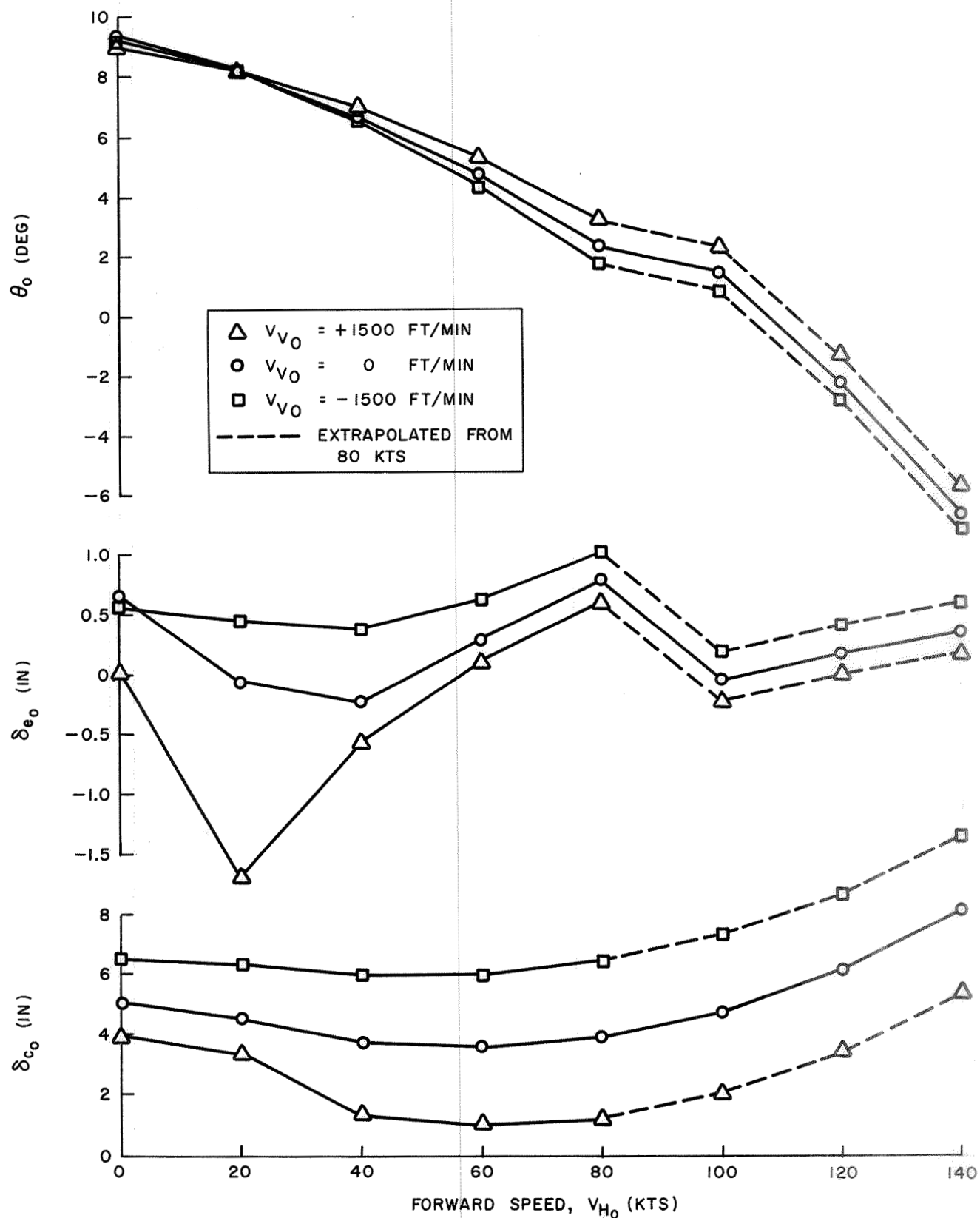


Fig. C-1. YHC-1A Trim Pitch Attitude and Longitudinal Control Displacements (13,400 lbs; sea level; normal c.m.)

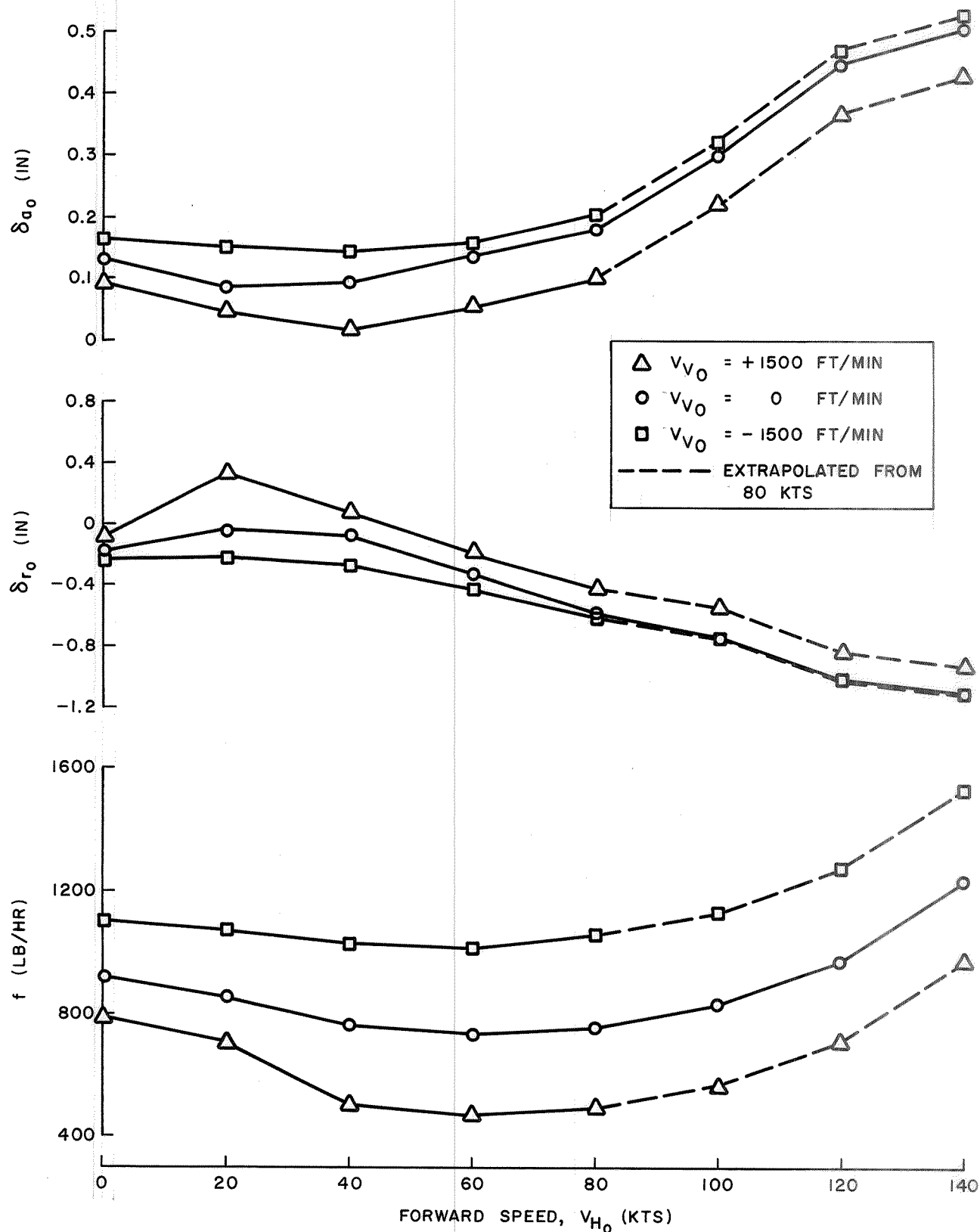


Fig. C-2. YHC-1A Trim Lateral Control Displacements and Fuel Flow (13,400 lbs; sea level; normal c.m.)

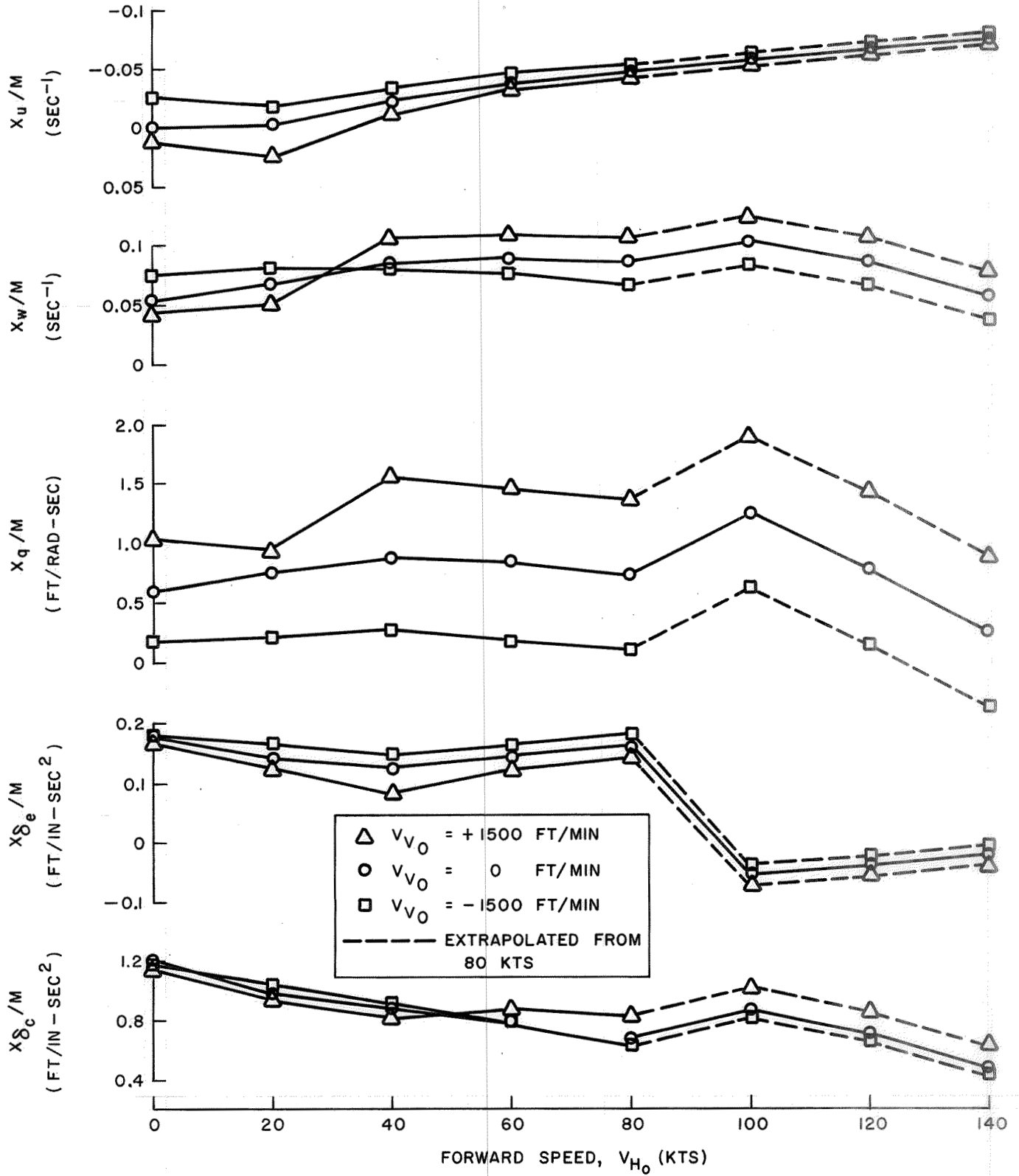


Fig. C-3. YHC-1A Trim Axial Force Derivatives (13,400 lbs; sea level; normal c.m.)

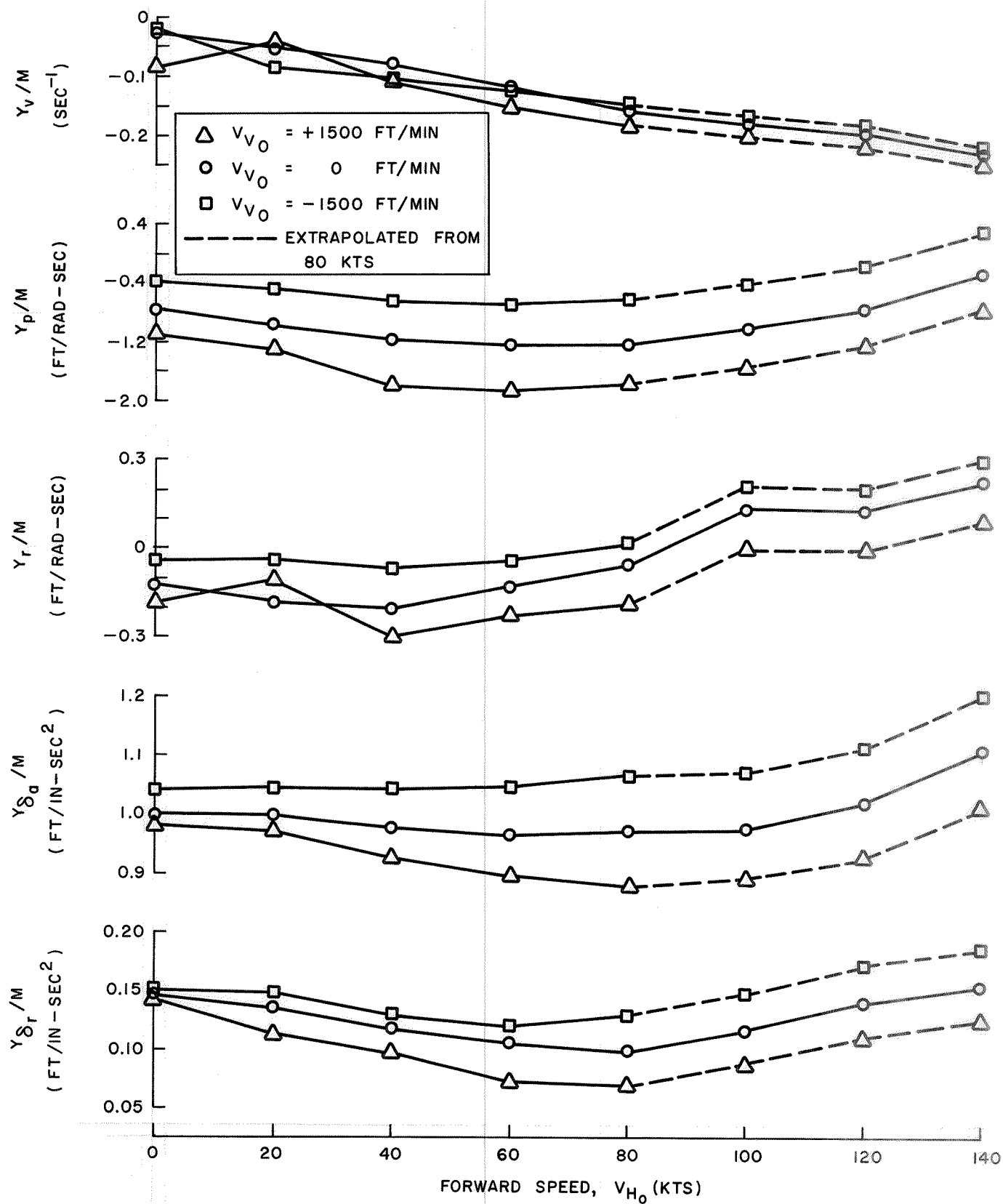


Fig. C-4. YHC-1A Trim Lateral Force Derivatives (13,400 lbs; sea level; normal c.m.)

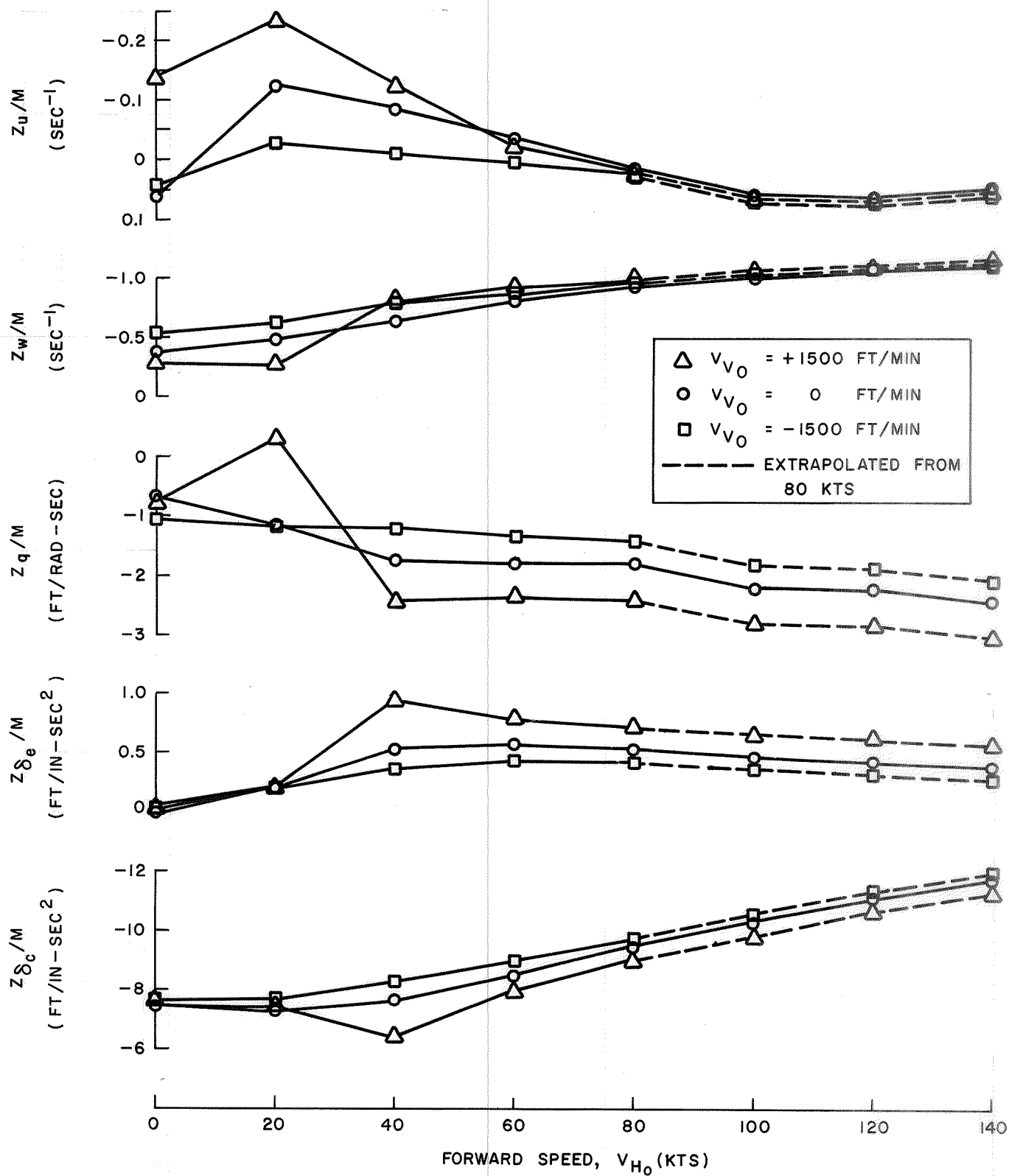


Fig. C-5. YHC-1A Trim Normal Force Derivatives (13,400 lbs; sea level; normal c.m.)

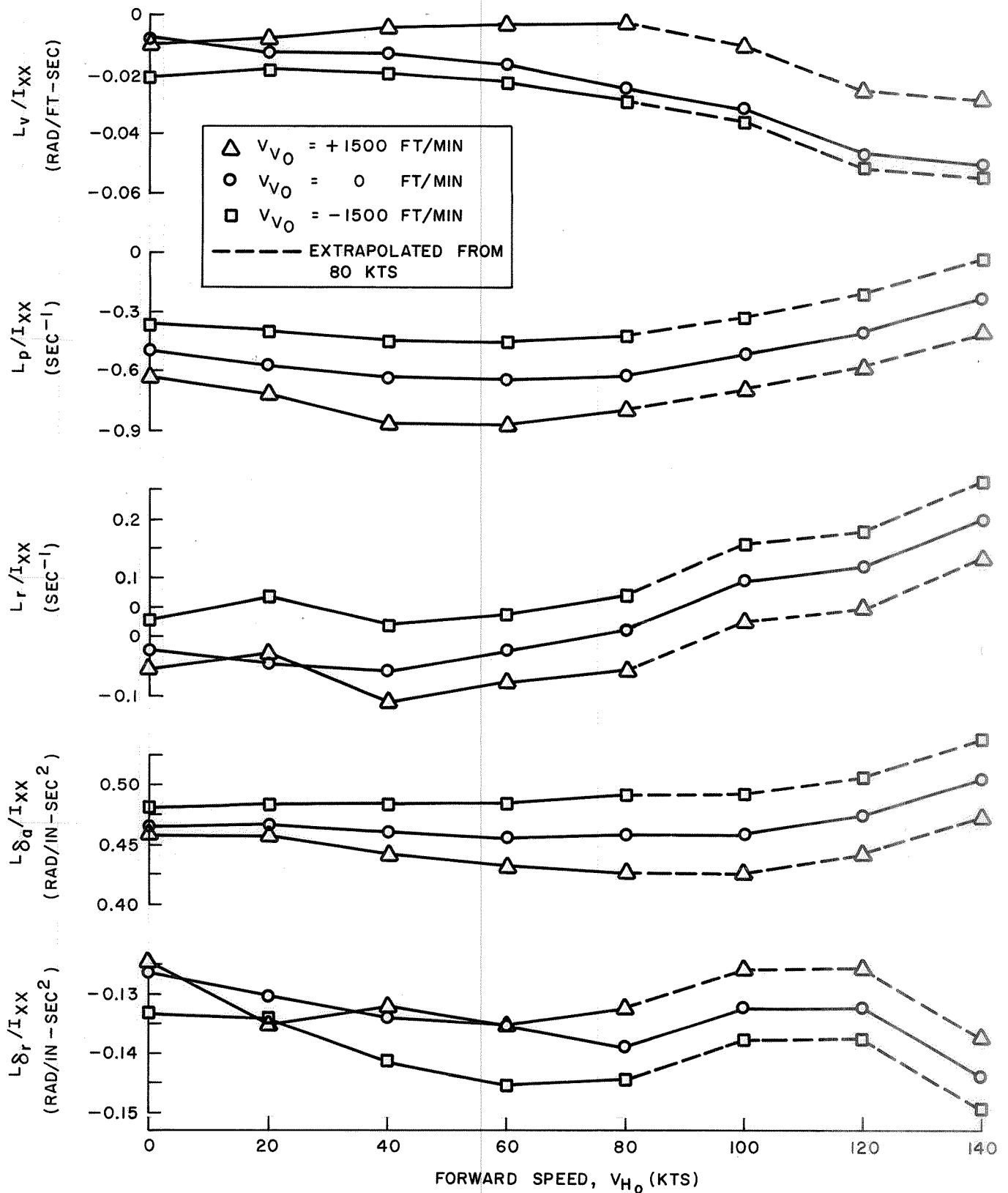


Fig. C-6. YHC-1A Trim Rolling Moment Derivatives (13,400 lbs; sea level; normal c.m.)

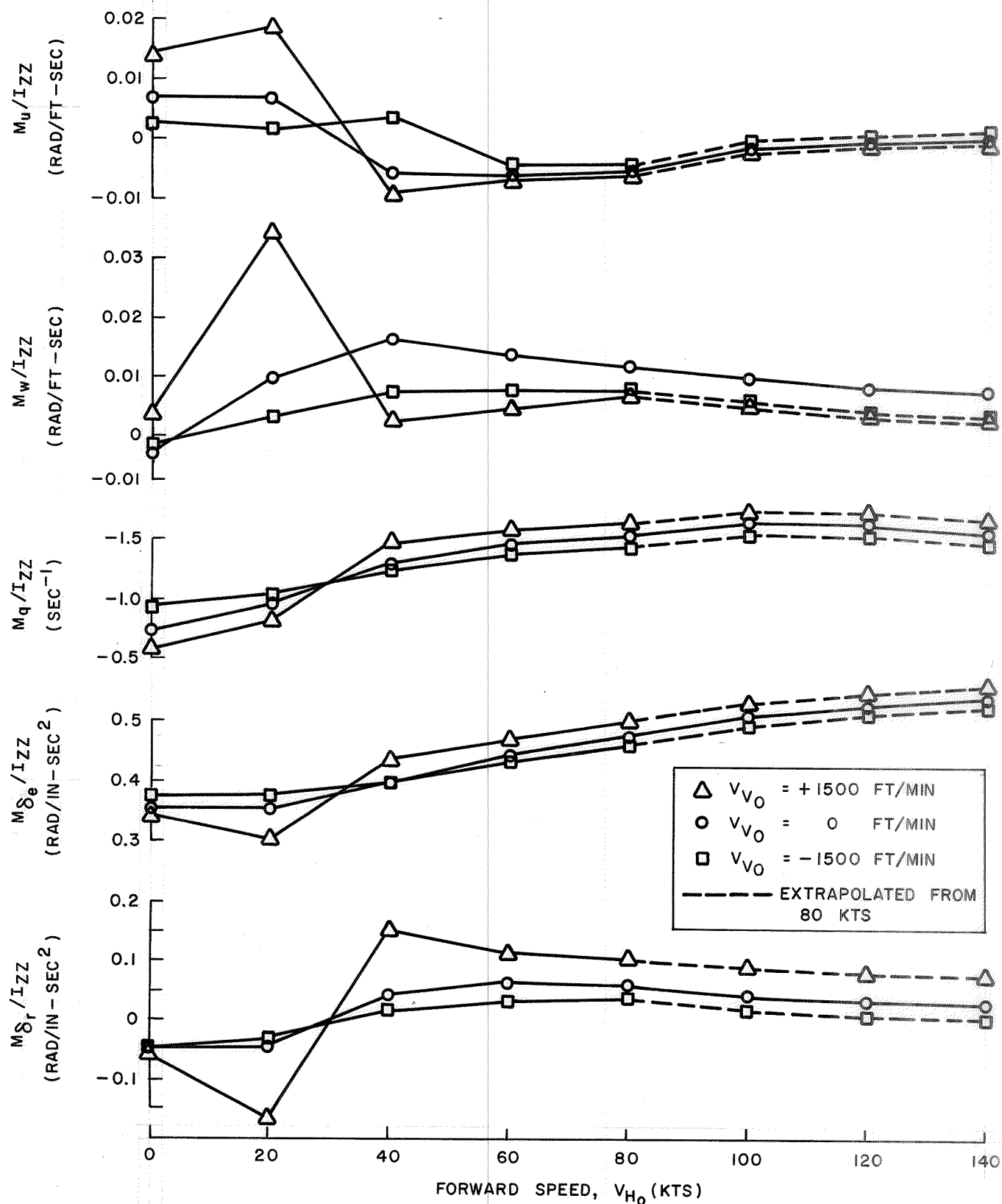


Fig. C-7. YHC-1A Trim Pitching Moment Derivatives (13,400 lbs; sea level; normal c.m.)

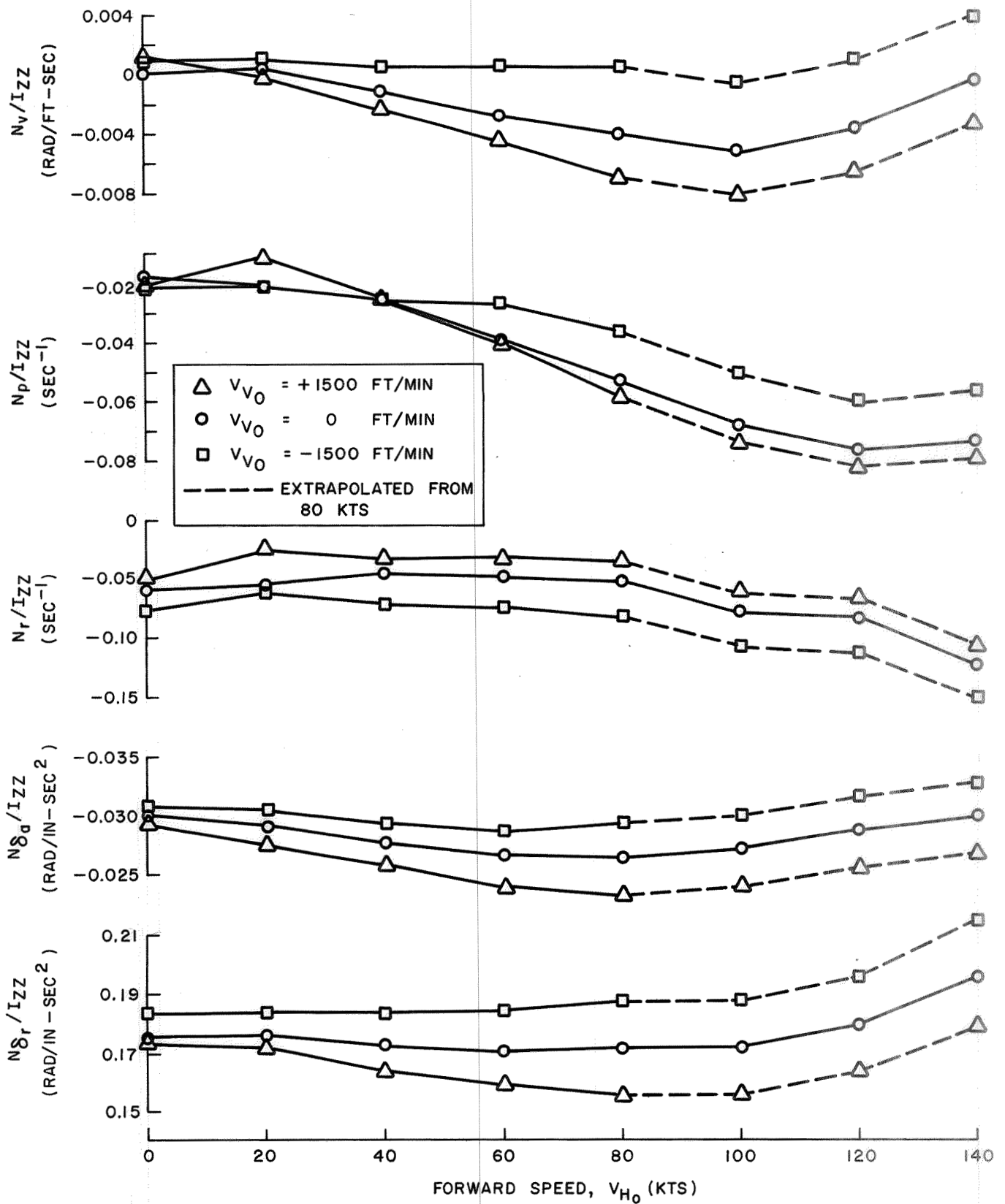


Fig. C-8. YHC-1A Trim Yawing Moment Derivatives (13,400 lbs; sea level; normal c.m.)

Table C-VIII. Conversion Factors

MULTIPLY	BY	TO OBTAIN
centimeters	0.39370	inches
meters	3.2808	feet
kilometers	0.53996	nautical miles
meters/second	3.2808	feet/second
meters/second	196.85	feet/minute
meters/second	1.9438	knots
kilograms	2.2046	pounds
kilograms/second	7936.6	pounds/hour
kilograms-meters ²	0.73756	slugs-feet ²
inches	2.540	centimeters
feet	0.30480	meters
nautical miles	1.8520	kilometers
feet/second	0.30480	meters/second
feet/minute	0.005080	meters/second
knots	0.51444	meters/second
pounds	0.45359	kilograms
pounds/hour	0.0001260	kilograms/second
slugs-feet ²	1.3558	kilograms-meters ²

NOMENCLATURE

- $A = 2 \times 2$ penalty matrix on enroute state variable deviations; see Eq. (17).
- $B = 3 \times 3$ penalty matrix on enroute control deviations; see Eq. (18).
- $C = 3 \times 2$ matrix of guidance feedback gains; see Eq. (20).
- C_{D_o} = zero-lift drag coefficient of the rotor blade section; see Eq. (B-10).
- C_{H_i}, C_{H_o} = coefficients of induced and profile rotor force in the NFP; see Eqs. (B-10) - (B-11).
- C_T = coefficient of rotor thrust $\perp$ to the NFP; see Eq. (B-8).
- $C_{V_{x,y}}$, etc. = feedback gains for V_x due to errors in y , etc.; see Eqs. (23) - (25); $1/\text{sec}$.
- D = aircraft fuselage drag; see Eq. (B-12); N.
- F = 2×2 homogeneous response matrix of linearized simplified model; see Eq. (12).
- F_ℓ, F_m, F_n = aerodynamic rolling, pitching and yawing moments; see Eqs. (32) - (33); N-m.
- F_x, F_y, F_z = aerodynamic axial, lateral and normal forces; see Eqs. (29) - (31); N.
- $G = 2 \times 3$ forced response matrix of linearized simplified model; see Eq. (13).
- H, H_i, H_o = total, induced and profile rotor force in the NFP; see Eq. (B-9); N.
- I_{xx}, I_{yy}, I_{zz} = moments of inertia about the roll, pitch and yaw axes; kg-m^2 .
- J = performance index for quadratic synthesis; see Eq. (15).
- J_{xz} = product of inertia; kg-m^2 .
- $K()$ = flight control system gains; see Figs. 5 and 6.

$L_{\ell}() = \partial F_{\ell} / \partial ()$ = trim rolling moment stability derivatives;
see Eq. (32).

$M_{\ell}() = \partial F_{\ell} / \partial ()$ = trim pitching moment stability derivatives;
see Eq. (33).

$N_{\ell}() = \partial F_{\ell} / \partial ()$ = trim yawing moment stability derivatives;
see Eq. (34).

NFP = "no feathering plane" of rotor; see Fig. B-1.

R = ground range to touchdown; see Eq. (4); m.

R_r = radius of rotor blade; m.

S = 2 x 2 Riccati matrix; see Eq. (21).

$S_r = \pi R_r^2$ = swept disk area of rotor; m^2 .

T = rotor thrust $\perp$ to the NFP; N.

$V = \sqrt{V_x^2 + V_y^2 + V_z^2}$ = magnitude of inertial velocity;
see Fig. 2; m/sec.

V_H, V_V = horizontal and vertical components of relative velocity;
see Eqs. (36) and (37); m/sec.

V_x, V_y, V_z = inertial components of aircraft velocity; see Fig. 2;
m/sec.

V_1 = true airspeed for mode switch of flight control system;
see Eq. (54); m/sec.

$X_{\ell}() = \partial F_x / \partial ()$ = axial force stability derivatives; see
Eq. (29).

$Y_{\ell}() = \partial F_y / \partial ()$ = lateral force stability derivatives;
see Eq. (30).

$Z_{\ell}() = \partial F_z / \partial ()$ = normal force stability derivatives;
see Eq. (31).

a = lift coefficient slope of rotor blade section
($< 2\pi$).

f = fuel flow rate; see Eq. (38); kg/sec.

f_D = equivalent flat plate area of fuselage; see Eq. (B-12); m^2 .
 g = acceleration of gravity; 9.80 m/sec^2 .
 h = $-z$ = altitude above touchdown; m .
 m = mass of aircraft; kg .
 p, q, r = roll, pitch and yaw rates; rad/sec .
 s = Laplace operator; $1/sec$.
 t = time; sec .
 $\underline{u}$ = 3×1 vector of control perturbations for simplified model; see Eq. (11).
 u, v, w = components of relative velocity in body axes; m/sec .
 w_x, w_y, w_z = inertial components of wind velocity, m/sec .
 $\underline{x}$ = 2×1 vector of state variable perturbations for simplified model; see Eq. (10).
 x, y, z = downrange, crossrange and vertical position coordinates; see Fig. 2; m .
 $\Delta()$ = $() - ()_0$ = deviation of indicated quantity from its trim value.
 Φ = bank angle = angle between vertical and plane containing T and V ; see Fig. B-1.
 $\Psi = \tan^{-1}(V_y/V_x)$ = heading angle; see Fig. 2.
 Ω = angular velocity of rotor; $1/sec$.
 α = angle of attack of the NFP; see Fig. B-1.
 $\beta = \tan^{-1}(v/u)$ = sideslip angle of fuselage.
 $\gamma = \sin^{-1}(-V_z/V)$ = flight path angle; see Fig. 2.
 γ_r = mass constant of rotor blade.
 $\delta()$ = $() - ()_N$ = deviation of indicated quantity from its nominal value.

δ_a = roll cyclic control deflection; cm.

δ_c = gang collective control deflection; cm.

δ_e = differential collective or longitudinal cyclic control deflection; cm.

δ_r = yaw cyclic control deflection; cm.

θ, ϕ, ψ = pitch, roll and yaw attitudes of fuselage; see Ref. 4.

θ_r = collective pitch of rotor blade at 3/4 radius.

λ = rotor inflow ratio; see Appendix B.

μ = rotor advance ratio; see Appendix B.

$\rho = \rho(h)$ = atmospheric density; kg/m^3 .

σ = rotor solidity ratio.

$\tau()$ = flight control system lag time constants; see Figs. 5 and 6.

Subscripts

E = error between commanded and existing values.

G = difference to be gained

I = integral of subscripted quantity

N = nominal value

c = commanded value

f = final value

i = initial value

m = maximum desirable value

o = trim value

Miscellaneous

$(\dot{})$ = derivative of indicated quantity.

$()^T$ = transpose of indicated matrix.

$()^{-1}$ = inverse of indicated matrix.

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