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MECHANIZATION OF BLENDED A SUB N MODE FOR CCV YF-16.(U)
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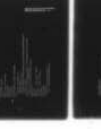
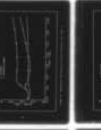
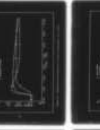
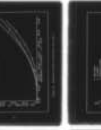
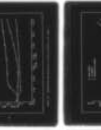
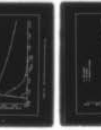
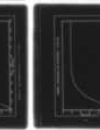
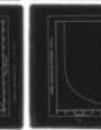
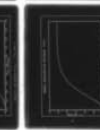
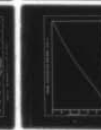
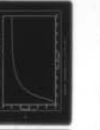
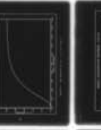
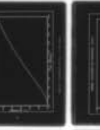
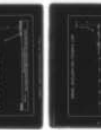
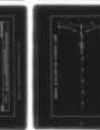
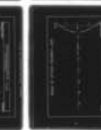
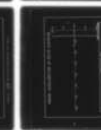
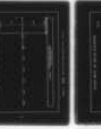
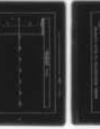
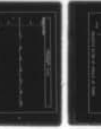
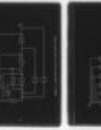
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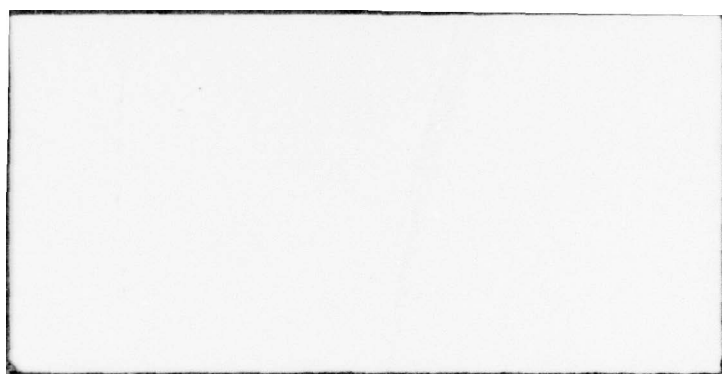
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MECHANIZATION OF BLENDED A_N MODE

FOR CCV YF-16

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Kenneth R. Race
Captain USAF

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FOR CCV YF-16 •

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Master's THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

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by

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Captain

USAF

Graduate Aeronautical Engineering

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Preface

This study represents my effort to provide a method for combining the responses of two modes of aircraft motion. The aircraft of interest was statically unstable which proved to be an interesting feature. The mechanization employed was demonstrated to have favorable response characteristics.

I would like to thank my advisor, Captain James Silverthorn of the Department of Aeronautics and Astronautics of the Air Force Institute of Technology faculty, for his guidance.

I would like to express my gratitude to my sponsor A. Finley Barfield for his patience and much needed help in understanding such a complex aircraft.

I wish especially to thank my wife, Sandy, who managed to put up with my ravings and condoned my absences as I fought with the computer.

Kenneth R. Race

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Contents

	<u>Page</u>
Preface	ii
List of Figures	iv
List of Tables	vi
List of Symbols	vii
Abstract	x
I. Introduction	1
Purpose	2
Scope	3
II. Method of Analysis	6
Assumptions	6
Description of Root Locus Analysis	6
Computer Program	17
III. Discussion of Results	22
Root Locus Analysis	22
Computer Simulation	48
IV. Conclusions and Recommendations	58
Bibliography	60
Appendix A: Physical Description of the Aircraft	61
Appendix B	64
Appendix C	69
Appendix D	71
Appendix E	73
Appendix F	75
Vita	118

List of Figures

<u>Figure</u>		<u>Page</u>
1	Simplified Basic YF-16 Flight Control System	9
2	Simplified CCV YF-16 Flight Control System	11
3	Redrawn CCV Flight Control System	12
4	Mechanization of Basic A/C with A_N Mode	14
5	Simplified Mechanization	15
6	$\frac{\alpha(s)}{\delta_e(s)}$, Short Period Approximation, Flt. Cond. 1	25
7	$\frac{\alpha(s)}{\delta_e(s)}$, Short Period Approximation, Flt. Cond. 1	26
8	$\frac{a_n(s)}{\delta_e(s)}$, Short Period Approximation, Flt. Cond. 1	27
9	$\frac{q(s)}{\delta_e(s)}$, Short Period Approximation, Flt. Cond. 2	28
10	$\frac{\alpha(s)}{\delta_e(s)}$, Short Period Approximation, Flt. Cond. 2	29
11	$\frac{a_n(s)}{\delta_e(s)}$, Short Period Approximation, Flt. Cond. 2	30
12	Pitch Rate Loop Closure, Flt. Cond. 1 .	31
13	Angle of Attack Loop Closure, Flt. Cond. 1	32
14	Normal Acceleration Loop Closure, Flt. Cond. 1	33
15	Pitch Rate Loop Closure, Flt. Cond. 2 .	34

	<u>Page</u>
16 Angle of Attack Loop Closure, Flt. Cond. 2	35
17 Normal Acceleration Loop Closure, Flt. Cond. 2	36
18 Step Response for $K_{10} = .1$, Flt. Cond. 1 ...	40
19 Step Response for $K_{10} = 1.0$, Flt. Cond. 1 ..	41
20 Step Response for $K_{10} = 10$, Flt. Cond. 1 ...	42
21 Step Response for $K_{10} = 100$, Flt. Cond. 1 ..	43
22 Step Response for $K_{10} = .1$, Flt. Cond. 2 ...	44
23 Step Response for $K_{10} = 1.0$, Flt. Cond. 2 ..	45
24 Step Response for $K_{10} = 10$, Flt. Cond. 2 ...	46
25 Step Response for $K_{10} = 100$, Flt. Cond. 2 ..	47
26 Flap Deflection Time Histories Varying K_{10} .	51
27 Comparative Time Histories of Angle of Attack, Flt. Cond. 1	52
28 Comparative Flight Trajectories, Flt. Cond. 1	53
29 Comparative Time Histories of Normal Accel- eration, Flt. Cond. 1	54
30 Comparative Time Histories of Angle of Attack Flt. Cond. 2	55
31 Comparative Flight Trajectories, Flt. Cond. 2	56
32 Comparative Time Histories of Normal Accel- eration, Flt. Cond. 2	57
33 Flight Control System Functional Block Dia- gram	62
34 Pitch Axis Functional Block Diagram	63
35 Reference System for Determining Normal Acceleration	71

List of Tables

<u>Table</u>		<u>Page</u>
I	Flight Condition Characteristics	5
II	Stability Derivatives	23
III	Stability Derivatives	24
IV	Transfer Function Gains	38
V	Settling Time (sec) for $\frac{a_n}{\delta f}(s)$ for Values of K_{10}	49

List of Symbols

A_N, a_n	normal acceleration	g's
b	wing span	ft
$\bar{c}$	mean aerodynamic chord	ft
C_D	drag coefficient	
C_l	rolling moment coefficient	
C_L	lift coefficient	
C_m	pitching moment coefficient	
C_n	yawing moment coefficient	
C_x	longitudinal force coefficient	
C_y	side force coefficient	
C_z	vertical force coefficient	
F_x, F_y, F_z	force components along X, Y, and Z axes respectively	
g	acceleration due to gravity	32.174ft/sec ²
h	aircraft altitude above earth's surface	ft
i, j, k	unit vectors along X, Y, and Z axes respectively	
I_x, I_y, I_z, I_{xz}	body axis moments and product of inertia about center of mass	slug-ft ²
l_z	distance from c.g. to accelerometer	ft
L, M, N	rolling, pitching, and yawing moments about X, Y, and Z axis respectively	

m	mass of aircraft	slugs
M	Mach number	
P, Q, R	angular rates about body axes	deg/sec
p, q, r	perturbed angular rates about body axes	deg/sec
$\bar{q}$	dynamic pressure $1/2 V_R^2$	/ft ²
s	laplace transform parameter	
S	wing area	ft ²
T	thrust	s
U, V, W	components of V_R	ft/sec
u, v, w	perturbed components of V_R	ft/sec
V_R	total velocity	ft/sec
X, Y, Z	orthogonal reference system fixed to the aircraft (body axes)	
α	angle of attack	deg
δ_e	elevator deflection, positive down	deg
δ_f	flap deflection positive down	deg
δ_{SF}	stick force input, positive when	
ρ	air density	slugs/ft ³
ψ, θ, ϕ	yaw, pitch, and bank angles	deg
Ψ, Θ, Φ	Euler transformation angles	deg

Stability Derivatives
(nondimensional)

$$C_{D_\alpha} = \frac{\partial C_D}{\partial \alpha}$$

$$C_{L_{\delta_e}} = \frac{\partial C_L}{\partial \delta_e}$$

$$C_{M_q} = \frac{\partial C_M}{\partial \frac{q \bar{c}}{2V_R}}$$

$$C_{L_\alpha} = \frac{\partial C_L}{\partial \alpha}$$

$$C_{L_{\delta_f}} = \frac{\partial C_L}{\partial \delta_f}$$

$$C_{M_{\delta_e}} = \frac{\partial C_M}{\partial \delta_e}$$

$$C_{L_{\dot{\alpha}}} = \frac{\partial C_L}{\partial \dot{\alpha}}$$

$$C_{M_\alpha} = \frac{\partial C_M}{\partial \alpha}$$

$$C_{M_{\delta_f}} = \frac{\partial C_M}{\partial \delta_f}$$

$$C_{L_q} = \frac{\partial C_L}{\partial \frac{q \bar{c}}{2V_R}}$$

$$C_{M_{\dot{\alpha}}} = \frac{\partial C_M}{\partial \dot{\alpha}}$$

A dot over a symbol represents a time derivative ($\dot{}$).

A subscript 1 represents equilibrium time conditions.

A bar over a symbol denotes a vector quantity except as noted above.

Abstract

A root locus analysis and computer simulation are used to determine the feasibility of one proposed method of mechanizing the blending of the normal acceleration mode with the basic aircraft response for the CCV YF-16. The root locus analysis predicts the stability and speed of response of the mechanized aircraft. The computer simulation confirms these results. Comparison is made of the responses of the basic, present CCV, and proposed mechanized YF-16.

MECHANIZATION OF BLENDED A_N MODE

FOR CCV YF-16

I. Introduction

Since the beginning of powered flight, man has sought to increase the effectiveness of his methods of control over his craft. Due to increased sophistication and demands for increased performance in fighter aircraft, improving aircraft control has become an important area of consideration. This has led, in recent years, to a greater emphasis on the use of more active controls and their implementation on Control Configured Vehicles (CCV). A CCV is one in which advanced control technology as well as aerodynamics, structures, and propulsion are employed in the initial definition process (Ref 5:1). The Air Force Flight Dynamics Laboratory and General Dynamics Corporation have been studying this concept on the YF-16 prototype airplane since December 1973. The CCV functions of direct lift and sideforce (constant angle of attack and sideslip, varying flight path), fuselage pointing (constant flight path angle, varying angle of attack and sideslip), and vertical and horizontal translation (varying flight path angle at constant attitude) can be achieved with the use of an auxiliary flight control computer in an

"add-on" configuration with the basic YF-16 flight control computer. The "add-on" configuration was necessitated by the program's requirement that the capability exist to revert back to the basic YF-16 flight control system at any desired point with no adverse flight characteristics. This also eliminated money and time costs in developing and certifying a new control system.

However, the "add-on" configuration caused a slight increase in pilot workload in certain flight regimes, e.g., air-to-air tracking, air-to-ground tracking, etc. Pilots are required to turn knobs and flip switches to transition from one CCV mode to another. The longitudinal CCV modes are available only through a two-axis force button mounted on the side stick controller. This non-optimum CCV button controller reduced the frequency of longitudinal CCV commands during flight testing. Years of conditioning plus neuromuscular considerations combined to make button inputs seem unnatural to the test pilots. Flight tests indicated that there was also a tendency for cross-talk between button and stick inputs. Alternate blending of CCV longitudinal inputs would alleviate this problem (Ref 9:19).

Purpose

The purpose of this study was to analyze one method of

mechanization to provide blending of the CCV A_N (Direct Lift) mode with the control system of the basic YF-16 through side-stick force inputs. The mechanization was to provide a "floating" A_N mode.

Scope

The analysis in this study involved the blending in the longitudinal axis of the direct lift, A_N mode, to determine its feasibility and to ensure its stability. Two methods of analysis were employed for the purpose of this study. The first was a root locus analysis using the short period approximation of the YF-16 airframe combined with the flight control system of the basic YF-16 and the auxiliary flight control system of the CCV aircraft. The second method utilized a modified computer program simulation of the aircraft and its flight control system. The aircraft considered in both methods was the YF-16 prototype without the canards which were added to the actual CCV aircraft. This was done to simplify the analysis since the canards did not substantially affect the aircraft characteristics in the longitudinal mode.

Evaluation of the results included both the root locus predictions and the time histories of the aircraft parameters for the basic YF-16 and the mechanized CCV YF-16. The

evaluation covered two flight conditions; Mach = .6, altitude = 10,000 ft., and Mach = .8, altitude = 30,000 ft. All flight conditions were with the aircraft center of gravity at 35% MAC. Further description of the selected flight conditions is outlined in Table I.

The physical description of the aircraft and diagrams of the CCV Flight Control System, including the Pitch Axis Functional Block Diagram are given in Appendix A.

Table I
Flight Condition Characteristics

	Flt. Cond. 1	Flt. Cond. 2
Altitude (ft.)	10,000	30,000
Airspeed, V_R (Mach)	.6	.8
(ft/sec)	646.8	795.88
Dynamic Pressure (lbs/ft ²)	361.31	281.9
Air Density (slugs/ft ³)	.001756	.00089
Trim Load Factor (g's)	1.0	1.0
Trim Flight Path Angle (deg)	0	0
Trim Angle of Attack (deg)	2.7	3.1

II. Method of Analysis

Assumptions

The assumptions made in this study are as follows:

1. The earth is flat and non-rotating.
2. The aircraft is rigid and of constant mass.
3. The atmosphere is at rest with respect to the earth.
4. Gravity is a constant acceleration.
5. The X-Z plane in body axes is a plane of symmetry.
6. Any control deflections at equilibrium remain constant throughout the motions.
7. For the root locus analysis, the short period approximation closely models the aircraft.

Description of Root Locus Analysis

The linearized representation of the equations of motion was used to obtain an indication of the instability of the basic airframe of the YF-16. From the linearized equations of motion, the short period approximation was formed in body axes in the manner described by Roskam (Ref 7:Chap 6).

The linearized longitudinal equations of motion with dimensional derivatives employed were the X and Z force equations and the pitching moment equation. These equations are as follows:

X equation -

$$\dot{u} = -V_R q \sin \alpha_1 - g \theta \sin \Theta_1 + X_U U + X_{T_U} U + X_\alpha \alpha + X_{\delta_e} \delta_e + X_{\delta_f} \delta_f \quad (1)$$

Z equation -

$$V_R \dot{\alpha} - V_R q \cos \alpha_1 = g \theta \sin \Theta_1 + Z_U U + Z_\alpha \alpha + Z_{\dot{\alpha}} \dot{\alpha} + Z_q q + Z_{\delta_e} \delta_e + Z_{\delta_f} \delta_f \quad (2)$$

M equation -

$$\dot{q} = M_U U + M_{T_U} U + M_\alpha \alpha + M_{T_\alpha} \alpha + M_{\dot{\alpha}} \dot{\alpha} + M_q q + M_{\delta_e} \delta_e + M_{\delta_f} \delta_f \quad (3)$$

Equations 2 and 3 yield a short period approximation of the form:

$$\begin{bmatrix} V_R S - Z_\alpha & -(V_R \cos \alpha_1 + Z_q) S - g \sin \Theta_1 \\ -(M_{\dot{\alpha}} S + M_q) & S^2 - M_q S \end{bmatrix} \begin{bmatrix} \alpha(S) \\ \theta(S) \end{bmatrix} = \begin{bmatrix} Z_{\delta_e} \\ M_{\delta_e} \end{bmatrix} \delta_e(s) + \begin{bmatrix} Z_{\delta_f} \\ M_{\delta_f} \end{bmatrix} \delta_f(s) \quad (4)$$

The development of these equations through the short period approximation can be found in Appendix B. It is noted here

that the necessity for the inclusion of the flap parameters arises from the fact that flap deflection is the principal method by which direct lift is achieved for the A_N mode. It then becomes necessary to form the short period approximation transfer functions with respect to flaps as part of the basic airframe dynamics. Equation 4 thus becomes the basic model of the aircraft dynamics for the root locus analysis.

Since the YF-16, from which the CCV evolved, is a statically unstable aircraft, it, by necessity, is a highly augmented aircraft. To form the complete aircraft model requires the inclusion of the flight control system for the basic aircraft as well as the auxiliary flight control system for the CCV aircraft. Figure 1 shows the simplified longitudinal control system block diagram used in this analysis. The appropriate transfer functions are listed in Appendix C. The forward loop transfer functions $G_1(s)$, $G_2(s)$, and $G_3(s)$ are:

$$G_1(s) = \frac{q(s)}{\delta_e(s)} = \frac{s \theta(s)}{\delta_e(s)} \quad (5)$$

$$G_2(s) = \frac{\alpha(s)}{q(s)} \quad (6)$$

$$G_3(s) = \frac{a_n(s)}{\alpha(s)} \quad (7)$$

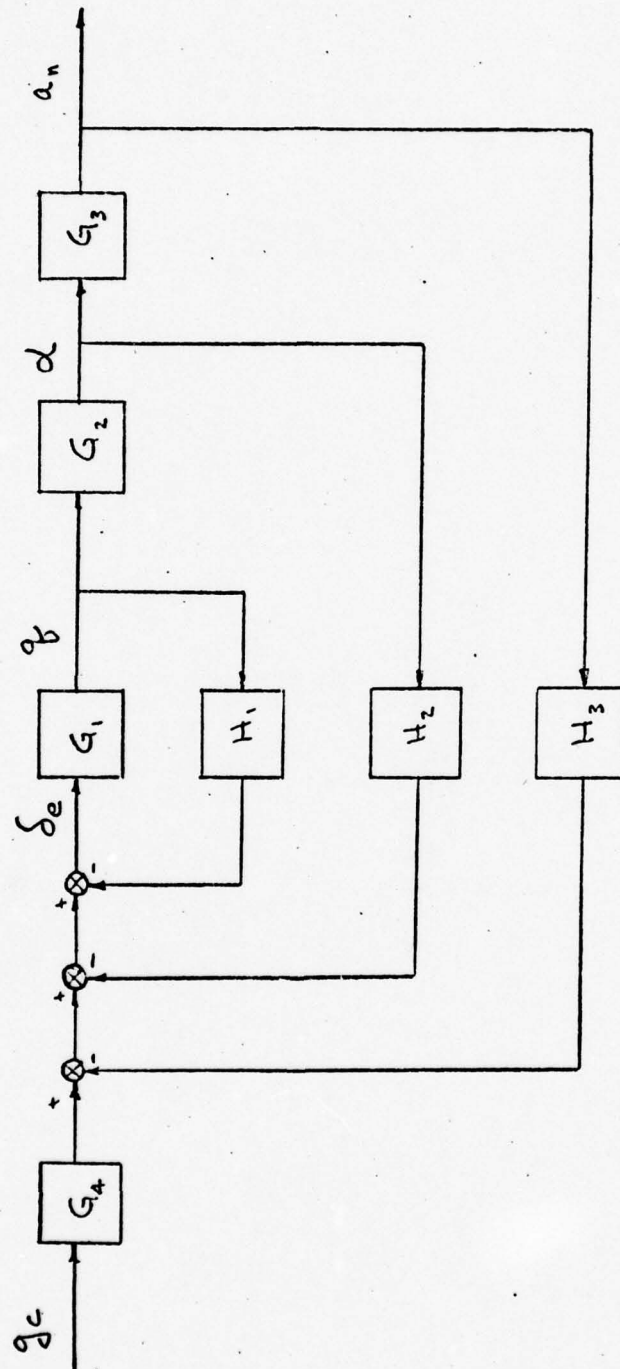


Figure 1. Simplified Basic YF-16 Flight Control System

G_4 , H_1 , H_2 , and H_3 are flight control augmentation transfer functions. These functions are formed either directly or indirectly from the short period approximation. Development of the $a_n(s)/\delta_e(s)$ transfer function is shown in Appendix D. The development for $a_n(s)/\delta_f(s)$ is similar. The coefficients associated with all transfer functions in this study are combinations of scheduled gains already employed in the flight control systems, the coefficients computed in the short period approximation, and the coefficients associated with the actuator dynamics.

Reduction of block diagram gives a complete model of basic YF-16 to be used in this study. Once reduced, the overall transfer function is $a_n(s)/g_c(s)$, normal acceleration to commanded g's. This transfer function should be stable and have acceptable characteristics at both flight conditions considered.

Figure 2 shows the simplified block diagram for the CCV YF-16 in the A_N mode. At first, it appears difficult to analyze this block diagram. However, using block diagram algebra and Mason's Rule (Ref 2:151), the task is simplified as is shown in Figure 3. The forward loop transfer functions $G_1(s)$, $G_2(s)$, and $G_3(s)$ remain the same as for the basic aircraft. However as the feed forward paths are closed,

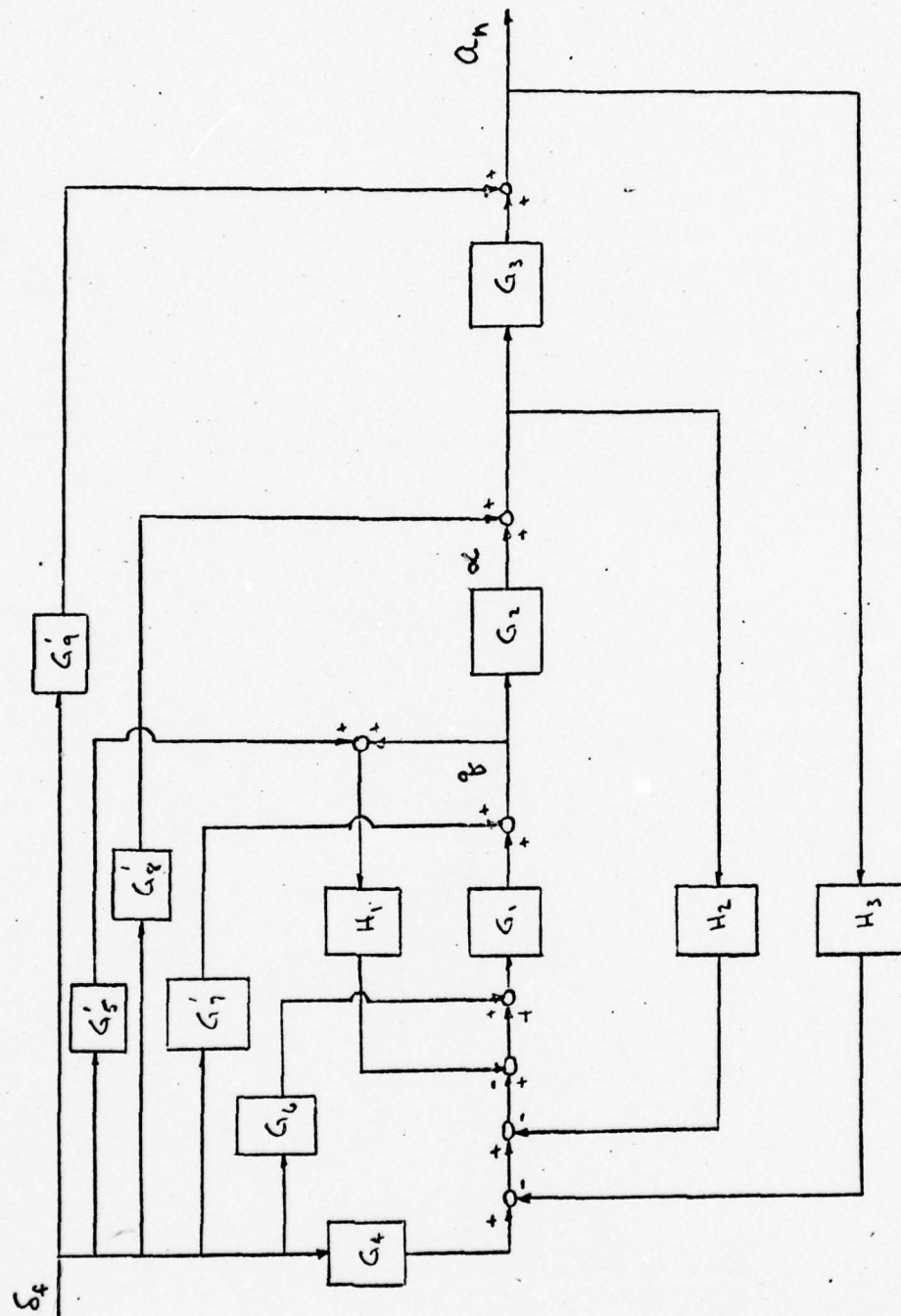


Figure 2. Simplified CCV VF-16 Flight Control System

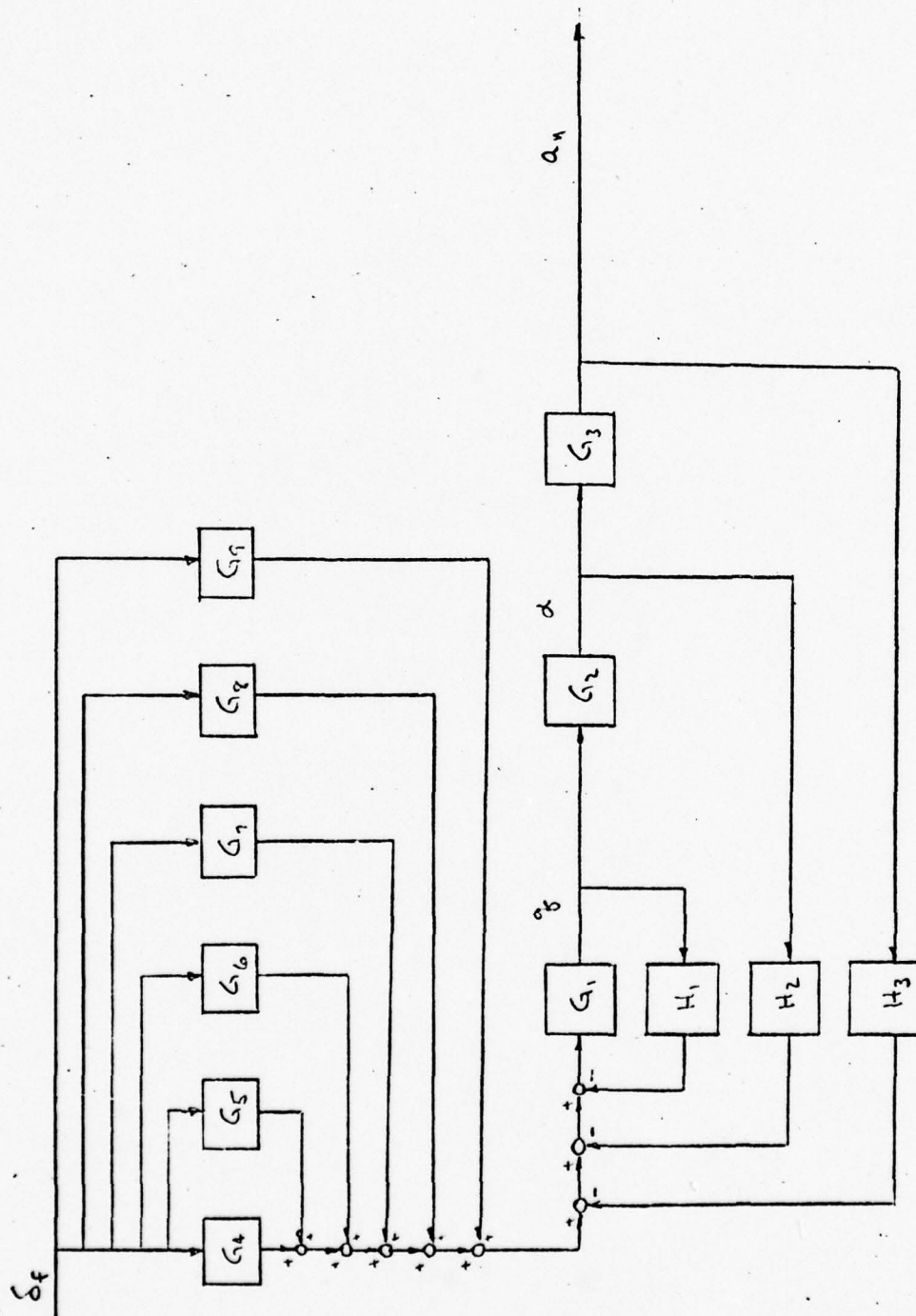


Figure 3. Redrawn CCV Flight Control System

caution must be exercised to ensure that the denominator polynomials of the transfer functions with respect to $\delta_f(s)$ become those of the now augmented aircraft. As each feed back loop is closed behind the summing junction where the feed forward loop enters the main forward path, the aircraft essentially changes roots and becomes more augmented. The problem essentially reduces to a modification of the forward loop transfer function G_4 , as seen in Figure 3. Using Mason's Rule and Figure 3, the $a_n(s)/\delta_f(s)$ closed loop transfer function for the CCV aircraft becomes:

$$\frac{a_n}{\delta_f}(s) = \frac{G_1 G_2 G_3 (G_4 + G_5 + G_6 + G_7) + G_3 G_8 (1 + G_1 H_1)}{1 + G_1 H_1 + G_1 G_2 H_2 + G_1 G_2 G_3 H_3 + G_9 (1 + G_1 H_1 + G_1 G_2 H_2)} \quad (8)$$

Equation 8 should indicate a stable CCV aircraft in the A_N mode. The transfer function and gains for the CCV aircraft are listed in Appendix E.

The mechanization employed in this study is shown in Figure 4. The mechanization can be redrawn as shown in Figure 5 to show how it functions. Between the stick force input and the Pitch Stick Gradient (shown in Figure 33 in

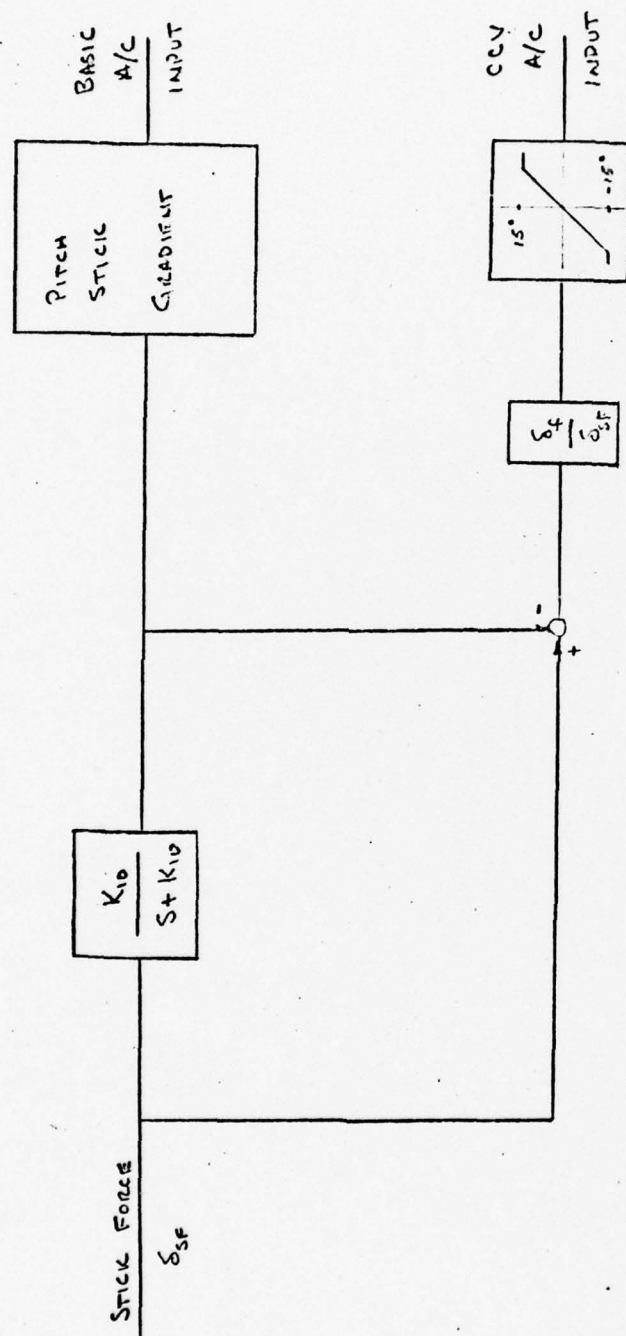


Figure 4. Mechanization of Basic A/C with A_N Mode

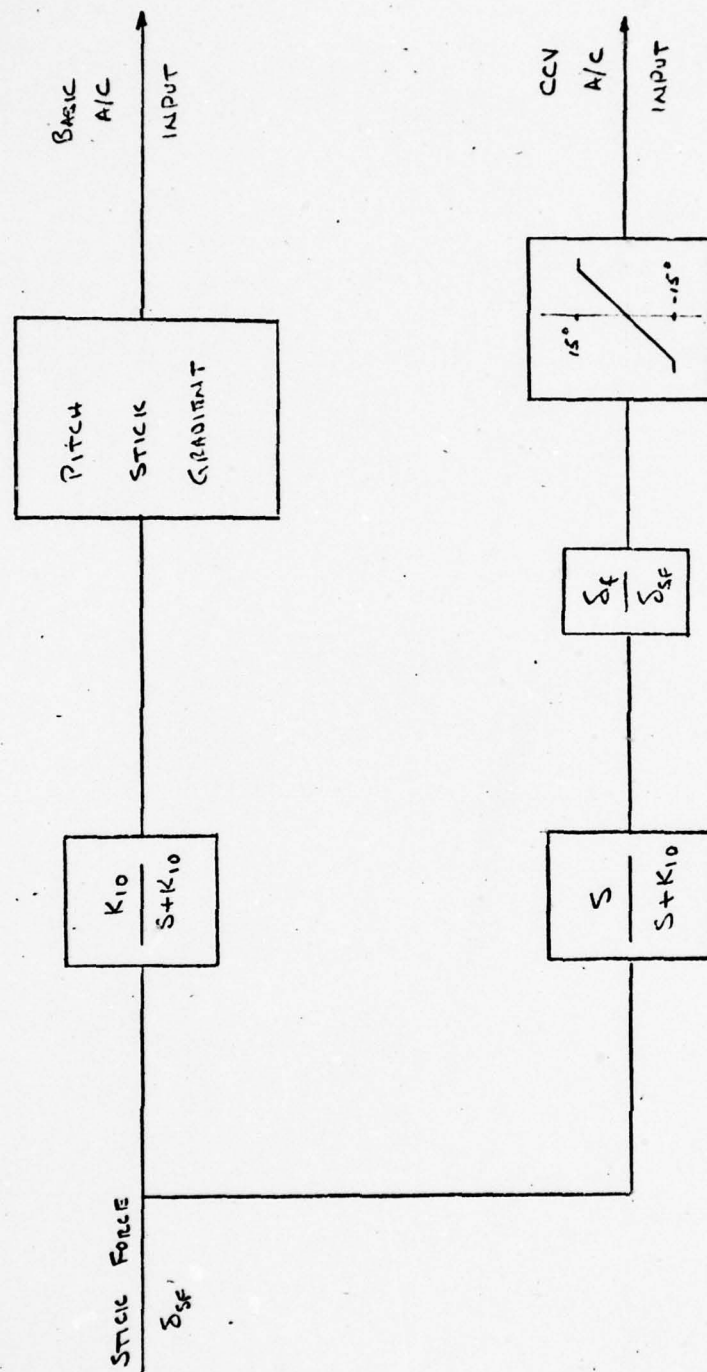


Figure 5. Simplified Mechanization

Appendix A) is placed a low pass filter which allows the low frequency commands to enter the basic aircraft flight control system. Between the stick force input and the CCV A_N mode, the mechanization acts as a washout allowing the high frequency transients to enter the CCV path. As time increases, the signal is washed out from the CCV path leaving only the low frequency commands flowing into the basic aircraft. The gain, K_{10} , associated with the mechanization will be determined from the flap deflection time history plots obtained from the computer simulation. The value of K_{10} will be determined by the response of the aircraft and the length of time that it is desirable to have the flaps deflected. The values tested are $K_{10} = .1, 1.0, 10$ and 100 .

The limiter in the CCV path is required to ensure that flap commands do not exceed the travel allowance of the symmetrically deflected flaps.

The a_n transfer functions, $a_n(s)/g_c(s)$ and $a_n(s)/\delta_f(s)$, can be used to obtain an indication of the aircrafts stability and response when mechanized. The a_n transfer functions can be combined to obtain the overall closed loop transfer function relating normal acceleration to stick force input as follows:

$$\frac{a_n}{\delta_{SF}}(s) = \left[\frac{K_{10}}{s + K_{10}} \right] \left[\frac{a_n}{g_c} \right] + \left[\frac{\delta_f}{\delta_{SF}} \right] \left[\frac{s}{s + K_{10}} \right] \left[\frac{a_n}{\delta_f}(s) \right] \quad (9)$$

where δ_f / δ_{SF} is a gain that converts stick force input (in pounds) to a commanded flap deflection (in radians).

Computer Program Analysis

The computer used in this simulation was the Wright-Patterson AFB CDC 6600 computer. The program used for the simulation is basically that in Reference 1. Since that report was published, the program has been used in departure studies of the YF-16 by the Air Force Flight Dynamics Laboratory. A listing of the program used in this study is provided in Appendix F.

The main program provides for setting the initial conditions, calling subroutines to trim the aircraft (TRNTRIM and ANGLE) and to integrate the equations of motion with respect to time (subroutine RKGXYZ) and plotting the time history plots of important aircraft parameters.

The subroutine RKGXYZ is a fourth order Runge-Kutta numerical integration scheme that integrates the equations of motion. The procedure computes 200 integration increments per one second of time history displayed.

The subroutine GYRATES is called by RKGXYZ and pro-

vides the modelled flight control system, provides values of the aerodynamic coefficients using a table look-up scheme, and defines the equations of motion including the Euler relations.

The equations of motion defined in the program are the full non-linear equations employing table look-up aerodynamics. The equations are as follows:

Equations of Motion

$$\dot{U} = -g \sin \theta + VR - WQ + \frac{\rho V_R^2 S}{2m} C_x + \frac{T \cos \epsilon}{m} \quad (10)$$

$$\dot{V} = g \cos \theta \sin \phi + WP - UR + \frac{\rho V_R^2 S}{2m} C_y \quad (11)$$

$$\dot{W} = g \cos \theta \cos \phi + UQ - VP + \frac{\rho V_R^2 S}{2m} C_z + \frac{T \sin \epsilon}{m} \quad (12)$$

$$\dot{P} = \frac{1}{1 - \frac{(I_{xz})^2}{I_x I_z}} \left\{ \left[\frac{I_y - I_z}{I_x} \right] QR + \frac{I_{xz}}{I_x} \left[PQ \left(1 + \frac{I_x - I_y}{I_z} \right) - \frac{I_{xz}}{I_z} QR + \frac{Sb}{2 I_z} \rho V_R^2 C_n \right] + \frac{Sb}{2 I_x} \rho V_R^2 C_l \right\} \quad (13)$$

$$\dot{Q} = \left[\frac{I_z - I_x}{I_y} \right] PR + \frac{I_{xz}}{I_y} \left[R^2 - P^2 \right] + \frac{S\bar{c}}{2 I_y} \rho V_R^2 C_m \quad (14)$$

$$\dot{R} = \left[\frac{I_x - I_y}{I_z} \right] PQ + \frac{I_{xz}}{I_z} \left[\dot{P} - QR \right] + \frac{Sb}{2 I_z} \rho V_R^2 C_n \quad (15)$$

$$\dot{h} = U \sin \theta - V \cos \theta \sin \phi - W \cos \theta \cos \phi \quad (16)$$

Euler Relations

$$\dot{\theta} = Q \cos \phi - R \sin \phi \quad (17)$$

$$\dot{\psi} = \frac{1}{\cos \theta} \left[Q \sin \phi + R \cos \phi \right] \quad (18)$$

$$\dot{\phi} = P + \dot{\theta} \sin \theta \quad (19)$$

C_x , C_y , C_z , C_l , C_m , and C_n are functions of angle of attack.

As mentioned earlier, the principal method of obtaining direct lift is through deflection of the symmetrical flaps. The computer program had to be modified to include the aerodynamics of the symmetrically deflected flaps. Data was obtained in graphical form for the flaps at $M = .2$. This Mach number was chosen since the aerodynamics package with the program contained data at $M = .2$. That is, any flight condition for which time histories are computed uses aerodynamics at $M = .2$. Therefore, any errors due to change in Mach number would at least be consistent. Given time histories that were close to actual flight traces for the basic YF-16, it was found that the errors at increased Mach numbers were acceptable.

The symmetrical flap aerodynamic data was obtained from Reference 3, Page 18, in graphical form. The change in lift

coefficient due to flap deflection was found to be essentially linear in angle of attack between $\alpha = -4^\circ$ and $\alpha = 12^\circ$. The function form of this change is as follows:

$$\Delta C_L = .016 \delta_f \quad (20)$$

The change in drag coefficient due to flap deflection was found to be composed to essentially two linear segments. The functional forms are as follows:

$$\frac{\Delta C_D}{\Delta \delta_f} = .0002 + .0001958 \alpha \quad \alpha \geq 0 \quad (21)$$

$$\frac{\Delta C_D}{\Delta \delta_f} = .0002 - .000325 \alpha \quad \alpha < 0 \quad (22)$$

The change in pitching moment due to flap deflection was found to be of the form:

$$\begin{aligned} \frac{\Delta C_m}{\Delta \delta_f} = & (.0027 - .000659 \delta_f) + [(-.00748 + .0000042 \delta_f) \alpha] \\ & [(-.000051 + .0000277 \delta_f) \alpha^2] + [(.000011 - .0000015 \delta_f) \alpha^3] \\ & -.000000403 \alpha^4 \end{aligned} \quad (23)$$

These functions were found using a least squares curve fit (Ref 4:Chap 7).

During the simulation, time history data for the basic

YF-16, CCV YF-16 and the mechanized YF-16 at the two chosen flight conditions were plotted together to aid in evaluating the various responses. For the mechanized aircraft, the various values of K_{10} (Fig 4) were inserted to compare the lengths of time that the flaps were deflected. The most reasonable value was then used in the simulation for the mechanized aircraft.

III. Discussion of Results

Root Locus Analysis

The non-dimensional stability derivatives were determined for the two flight conditions and are listed in Table II. Using the definitions of the longitudinal dimensional stability derivatives found in Roskam (Ref 6:6-17), Table III was prepared. Table III and equation 4 lead to the basic airframe short period approximation transfer functions for each flight condition. These transfer functions are listed in Appendix E. For the δ_e transfer functions, the Root Locus plots are shown in Figures 6 through 11 for unity feedback around each transfer function. The instability of the basic airframe is clearly observed in all plots.

The above transfer functions were combined to obtain the forward loop transfer functions $G_1(s)$, $G_2(s)$, and $G_3(s)$. These coupled with the control system outlined in Figure 1 formed the model of the basic aircraft. The root locus plots, as each loop of the control system is closed, for both flight conditions are shown in Figures 12 through 17. It can be observed that simply closing the pitch rate feedback loop results in a stable augmented aircraft. The closure of the remaining two loops simply improves the performance without impairing the systems stability. Closing the last loop and

Table II
Stability Derivatives
(Nondimensional, stability axis system)

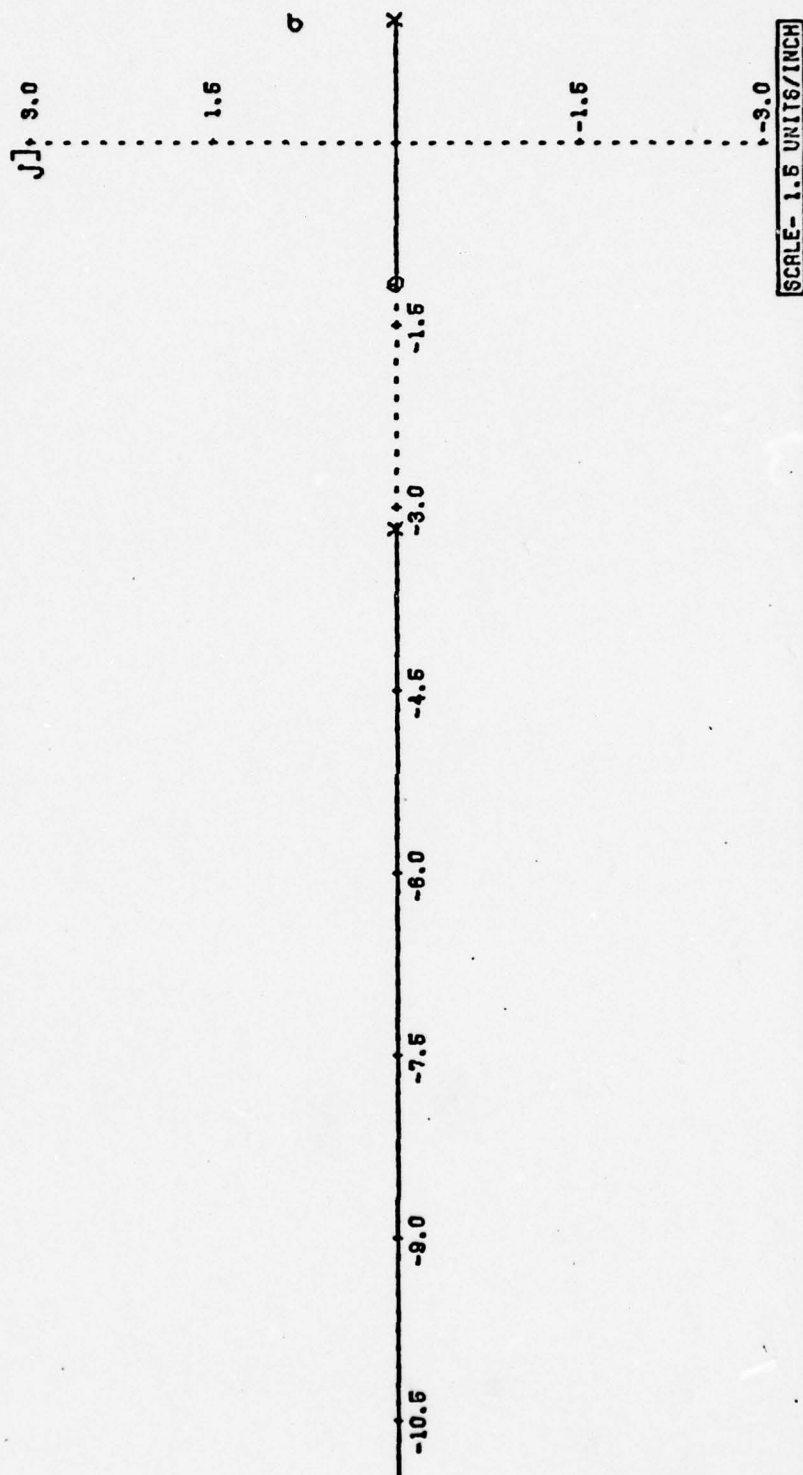
	Flt. Cond. 1	Flt. Cond. 2
C_{D_1}	.005	.020
C_{D_α}	.195	.280
C_{L_1}	.187	.246
C_{L_α}	4.18	4.56
C_{L_q}	1.3	3.8
$C_{L_{\delta_e}}$	.602	.516
$C_{L_{\delta_f}}$	.727	.802
C_{M_α}	.166	.092
$C_{M_{\dot{\alpha}}}$	-1.6	-1.5
C_{M_q}	-3.63	-4.1
$C_{M_{\delta_e}}$	- .59	- .602
$C_{M_{\delta_f}}$	- .056	- .1003

Table III
Stability Derivatives
(Dimensional, Body Axis System)

	Flt. Cond. 1	Flt. Cond. 2
Z_{α} (ft sec ⁻²)	-721.8	-600.5
Z_q (ft sec ⁻¹)	-1.895	-3.45
Z_{δ_e} (ft sec ⁻²)	-103.7	-68.22
Z_{δ_f} (ft sec ⁻²)	-125.3	-106.03
M_{α} (sec ⁻²)	4.02	1.70
$M_{\dot{\alpha}}$ (sec ⁻¹)	-.327	-.191
M_q (sec ⁻¹)	-.743	-.523
M_{δ_e} (sec ⁻²)	-14.23	-11.18
M_{δ_f} (sec ⁻²)	-1.35	-1.86

cascading with G_4 yields the Normal Acceleration to G commanded closed loop transfer function, $\frac{a_n}{g_{com}}$ (s), listed below for both flight conditions.

PITCH RATE VS DELTA ELEVATOR



$$OLTF(S) = \frac{K(S+1.17)}{(S-1)(S+3.18)}$$

SCALE- 1.5 UNITS/INCH

ANGLE OF ATTACK VS DELTA ELEVATOR

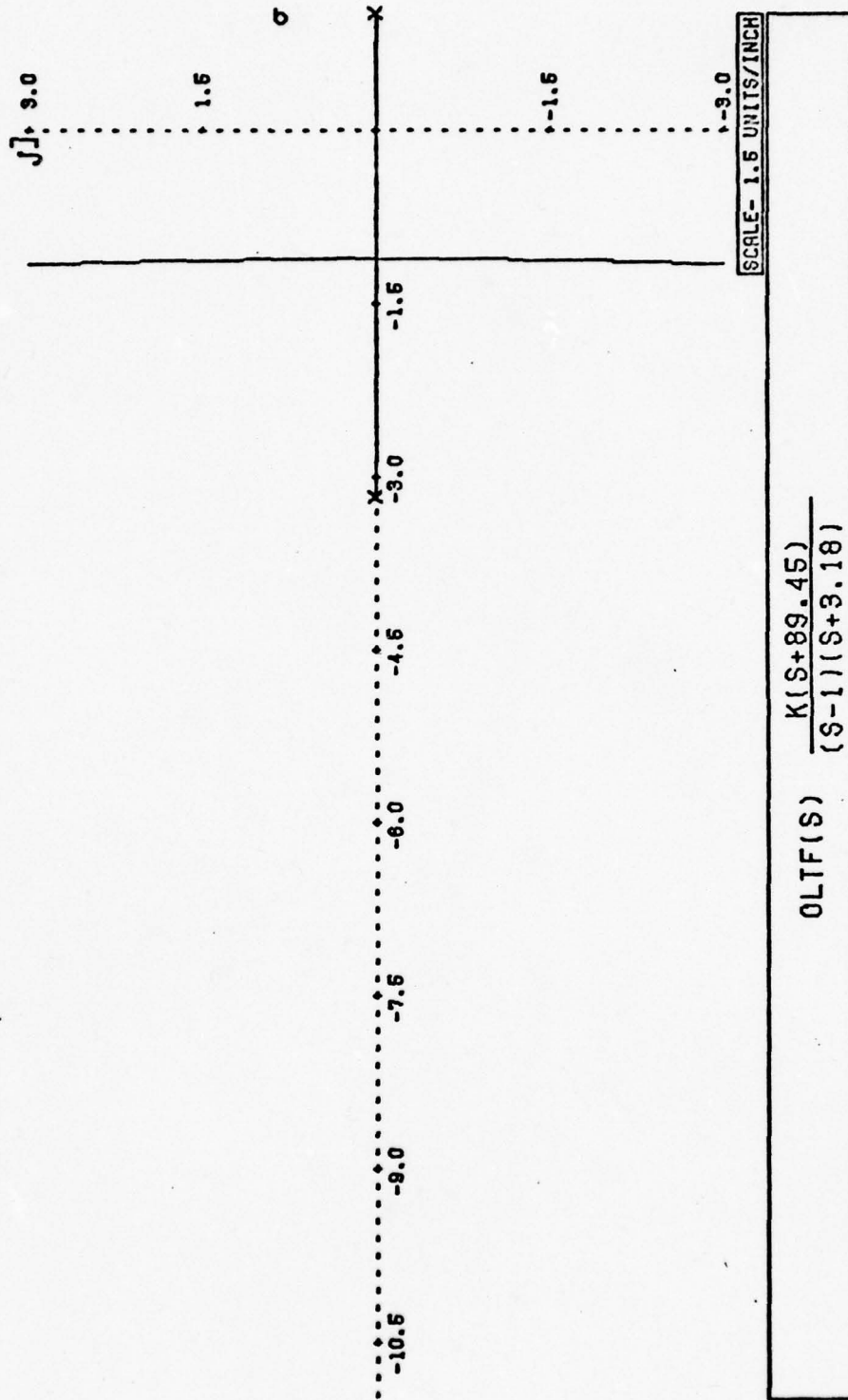


Figure 7. $\frac{\alpha_e(s)}{\delta_e(s)}$, Short Period Approximation, Flt. Cond. 1

NORMAL ACCELERATION VS DELTA ELEVATOR

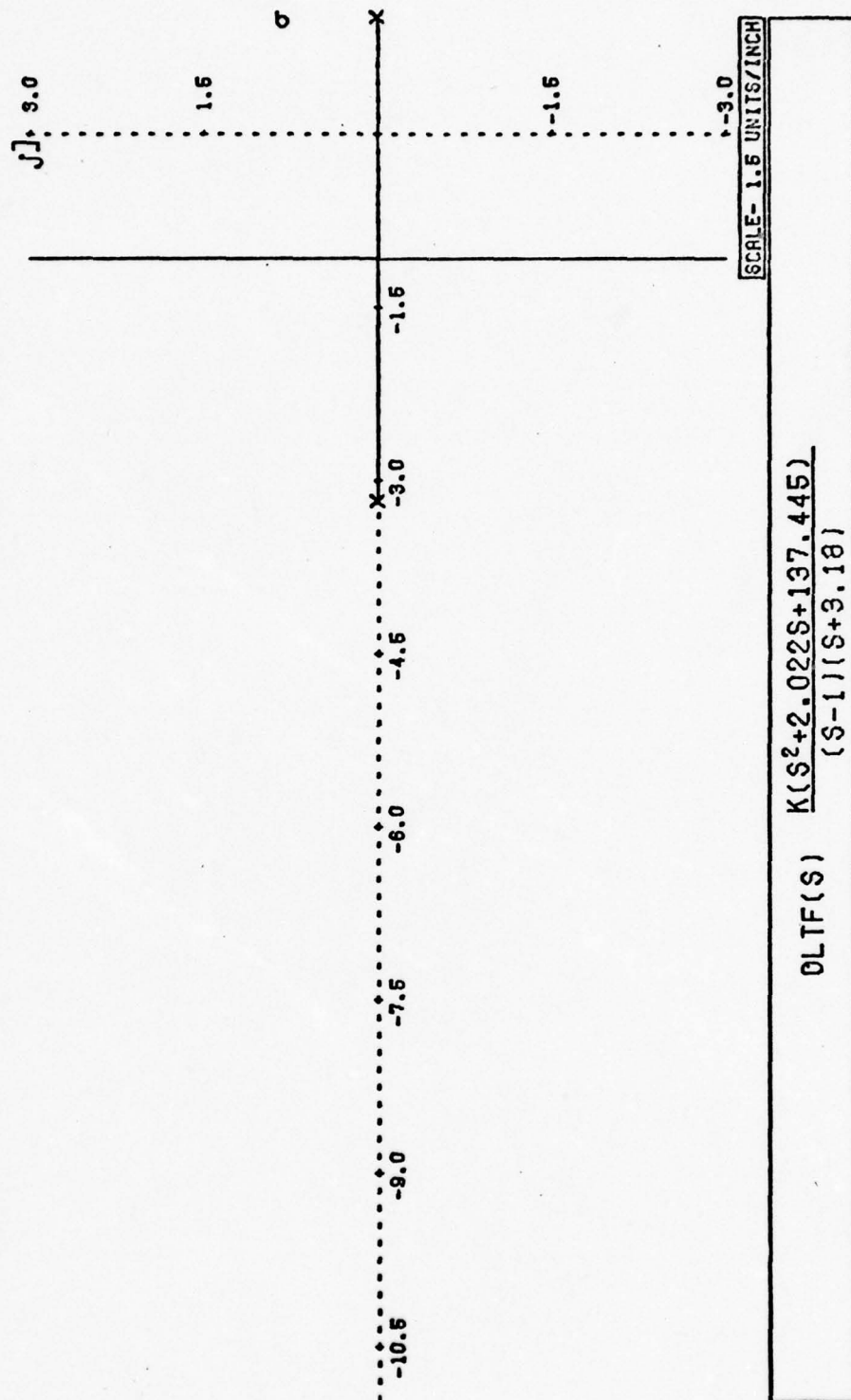


Figure 8. $\frac{a_n(s)}{\delta_e(s)}$, Short Period Approximation, Flt. Cond. 1

PITCH RATE VS DELTA ELEVATOR

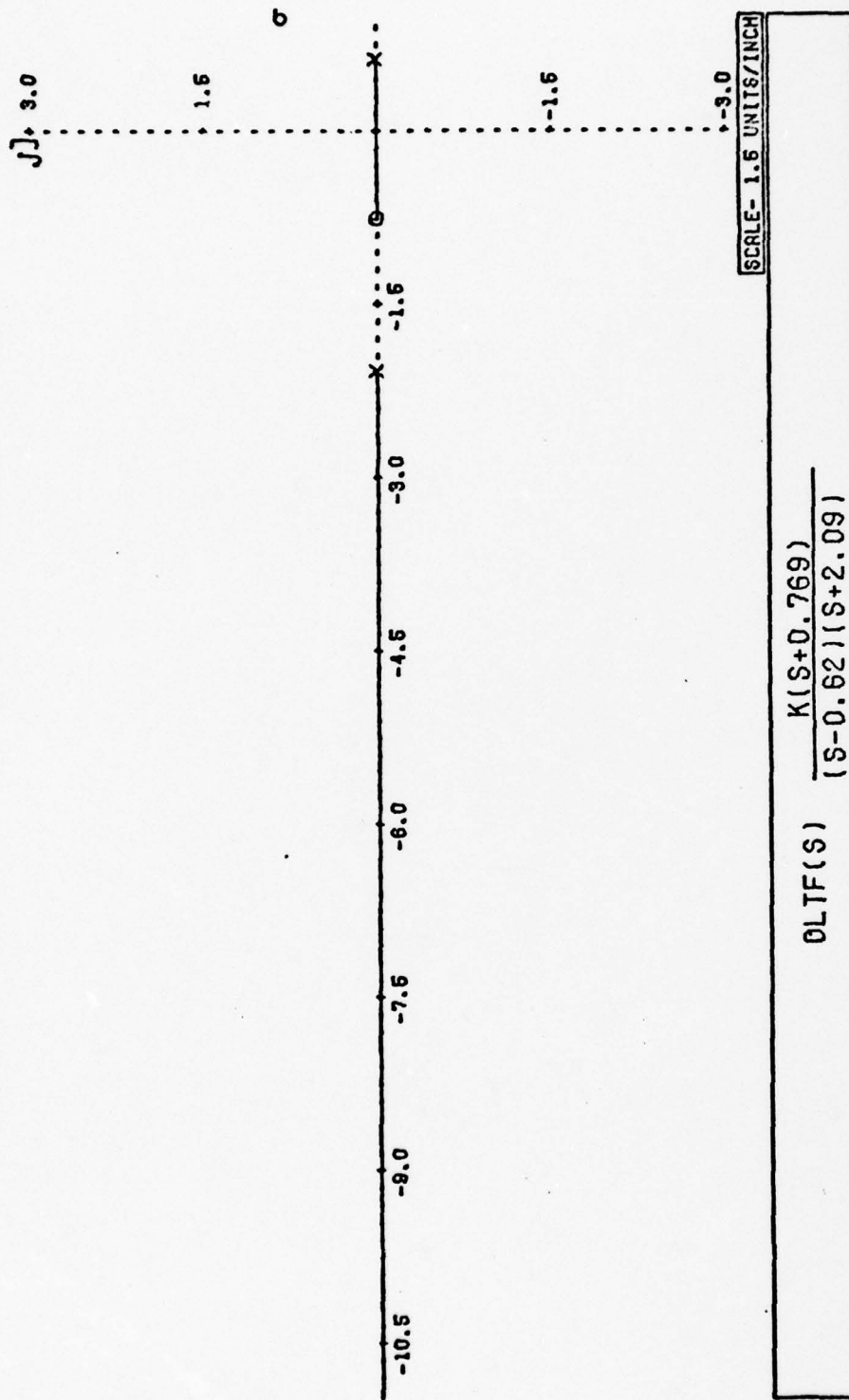


Figure 9. $-\frac{q(s)}{\delta_e(s)}$, Short Period Approximation, Flt. Cond. 2

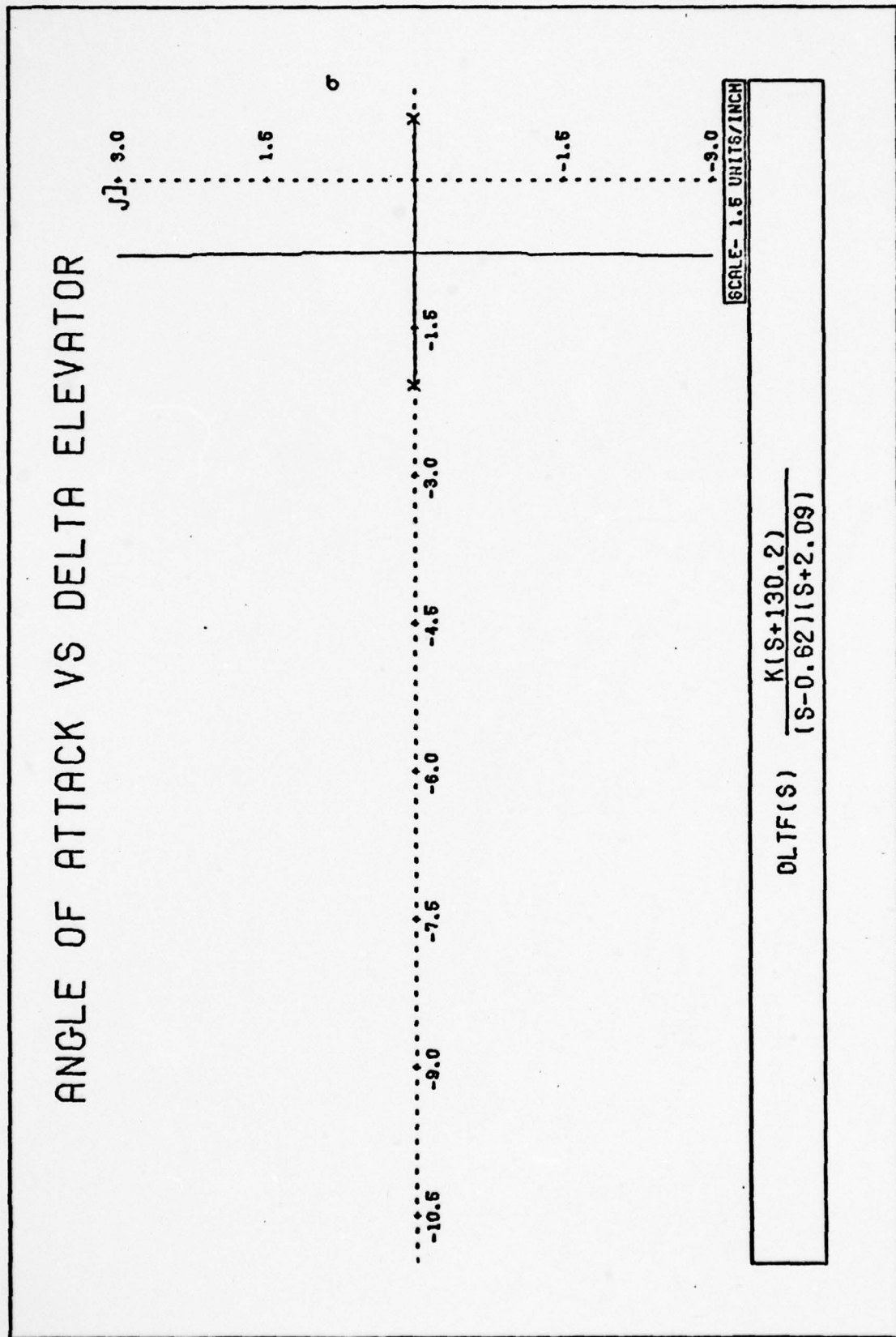


Figure 10. $\frac{\alpha(s)}{\delta_e(s)}$, Short Period Approximation, Flt. Cond. 2

NORMAL ACCELERATION VS DELTA ELEVATOR

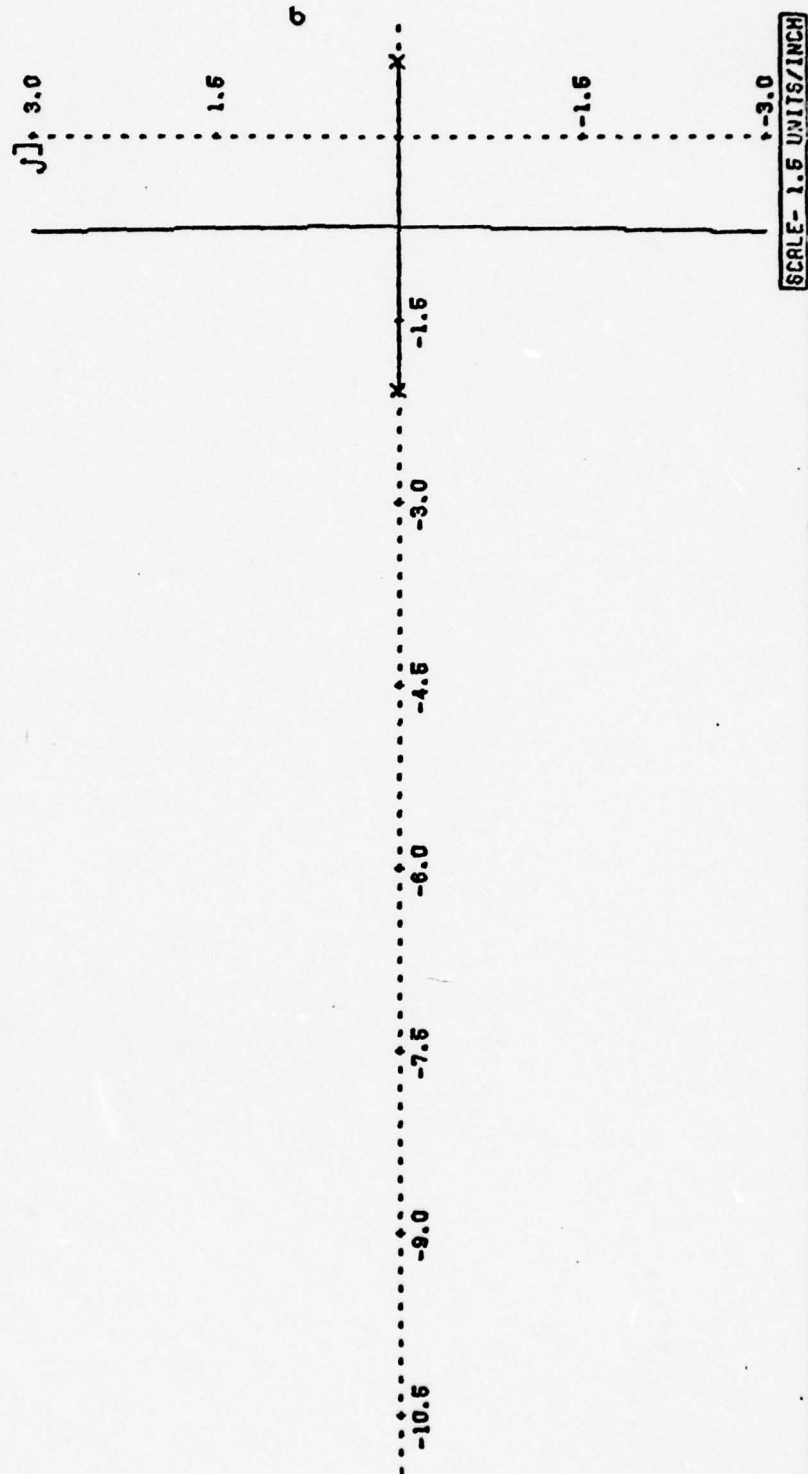


Figure 11. $\frac{a_n(s)}{1(s)}$, Short Period Approximation, Flt. Cond. 2

PITCH RATE FEEDBACK LOOP

σ

$j\omega$

(2)

-21 -18 -16 -12 -9 -8 -3

-3

-6

3

6

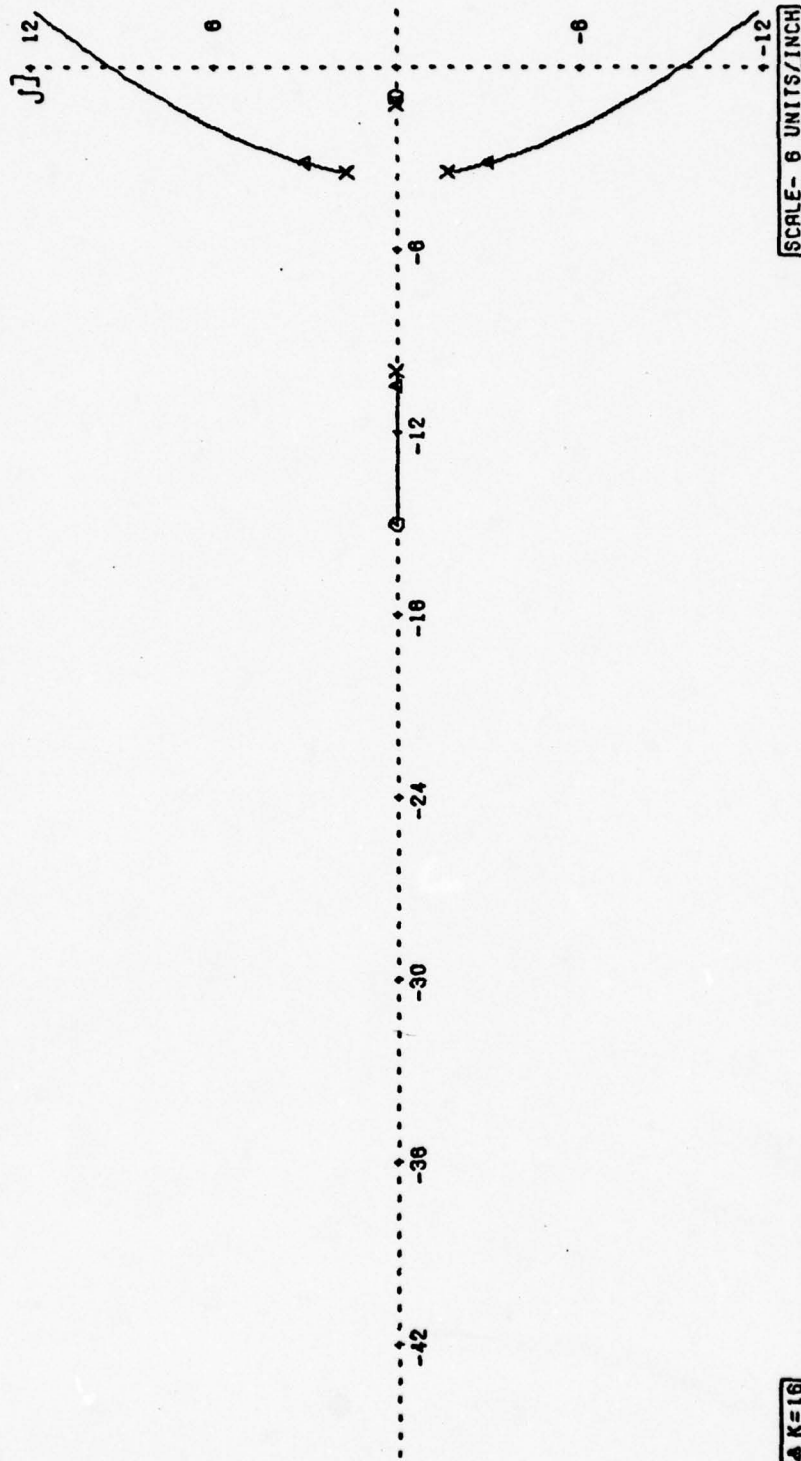
SCALE- 3 UNITS/INCH

$\Delta K = 307.07$

OLTF(S) $\frac{K(S+5)^2(S+1.17)}{(S-1)(S+1)(S+3.18)(S+15)(S+20)}$

31

ANGLE OF ATTACK FEEDBACK LOOP

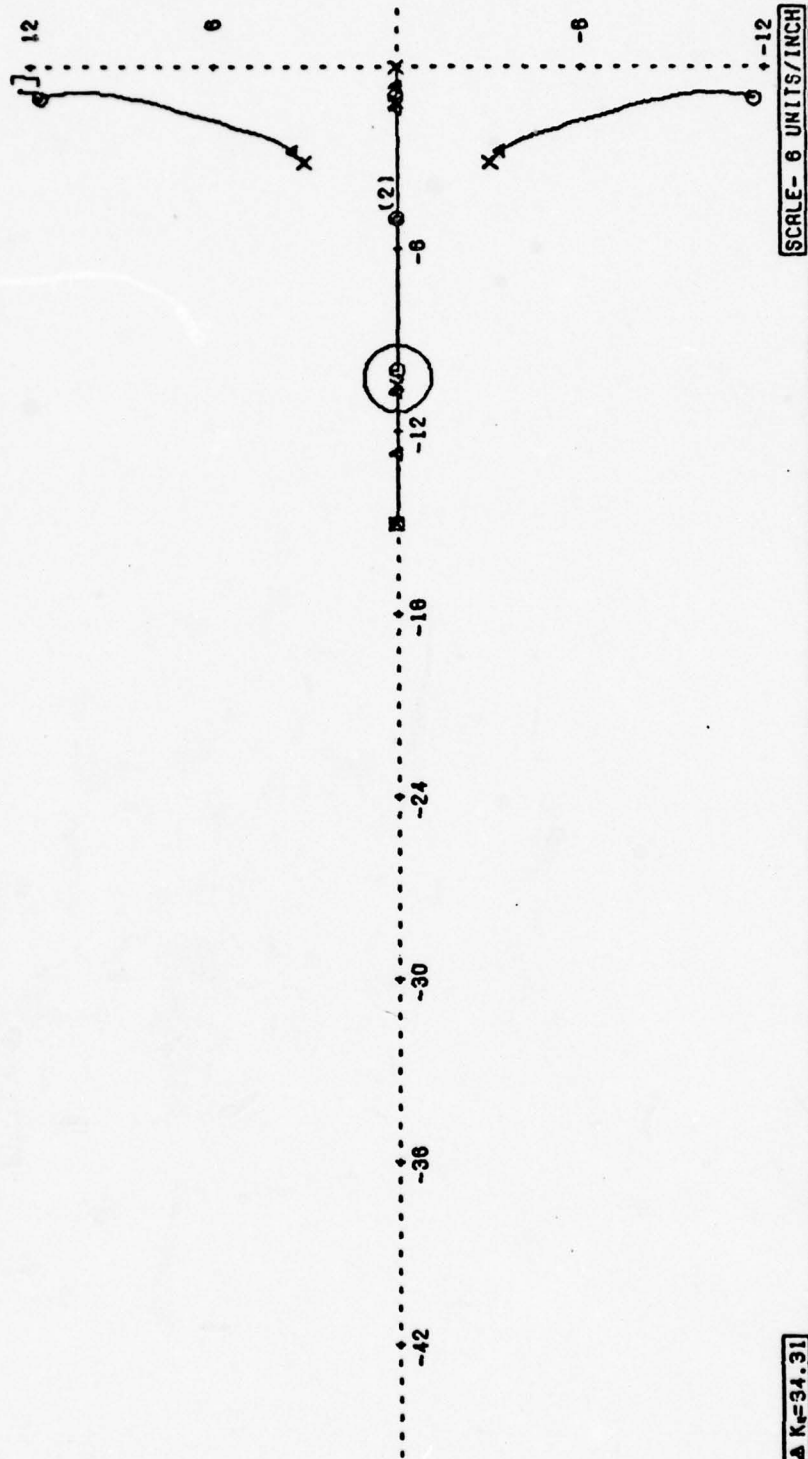


$\Delta K=16$ SCALE- 6 UNITS/INCH

$$OLTF(S) = \frac{K(S+1)(S+15)(S+89.45)}{(S+1.229)(S+10)(S^2+6.826S+14.454)(S^2+30.12S+451.804)}$$

Figure 13. Angle of Attack Loop Closure, Flt. Cond. 1

NORMAL ACCELERATION FEEDBACK LOOP



SCALE- 6 UNITS/INCH

$\Delta K=34.31$

$$OLTF(S) = \frac{K(S+5)^2(S+1)(S+10)(S+15)(S^2+2.022S+137.445)}{S(S+1.138)(S+15)^2(S+10.456)(S^2+6.250S+18.807)(S^2+30.331S+454.628)}$$

Figure 14. Normal Acceleration Loop Closure, Flt. Cond. 1

PITCH RATE FEEDBACK LOOP

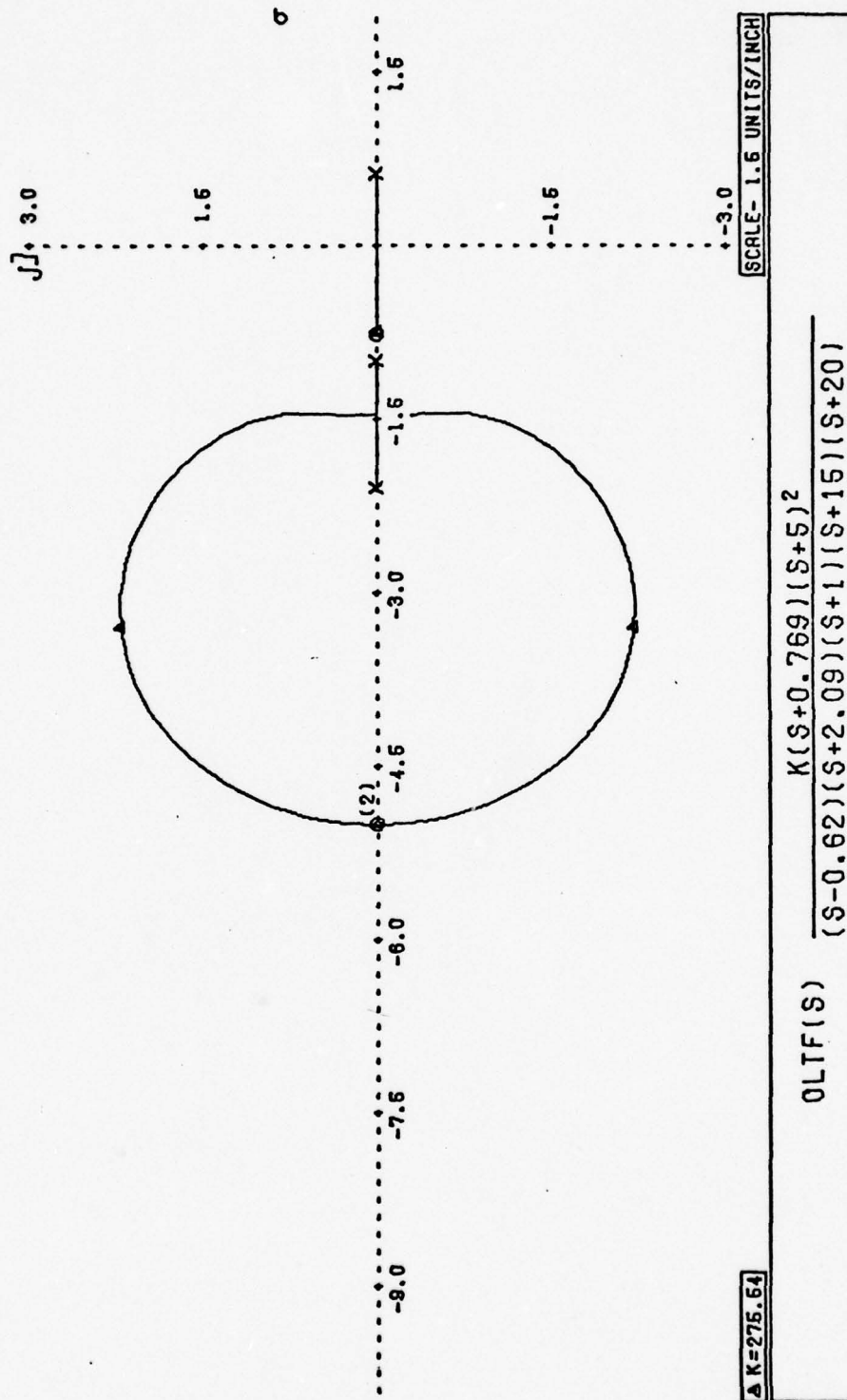
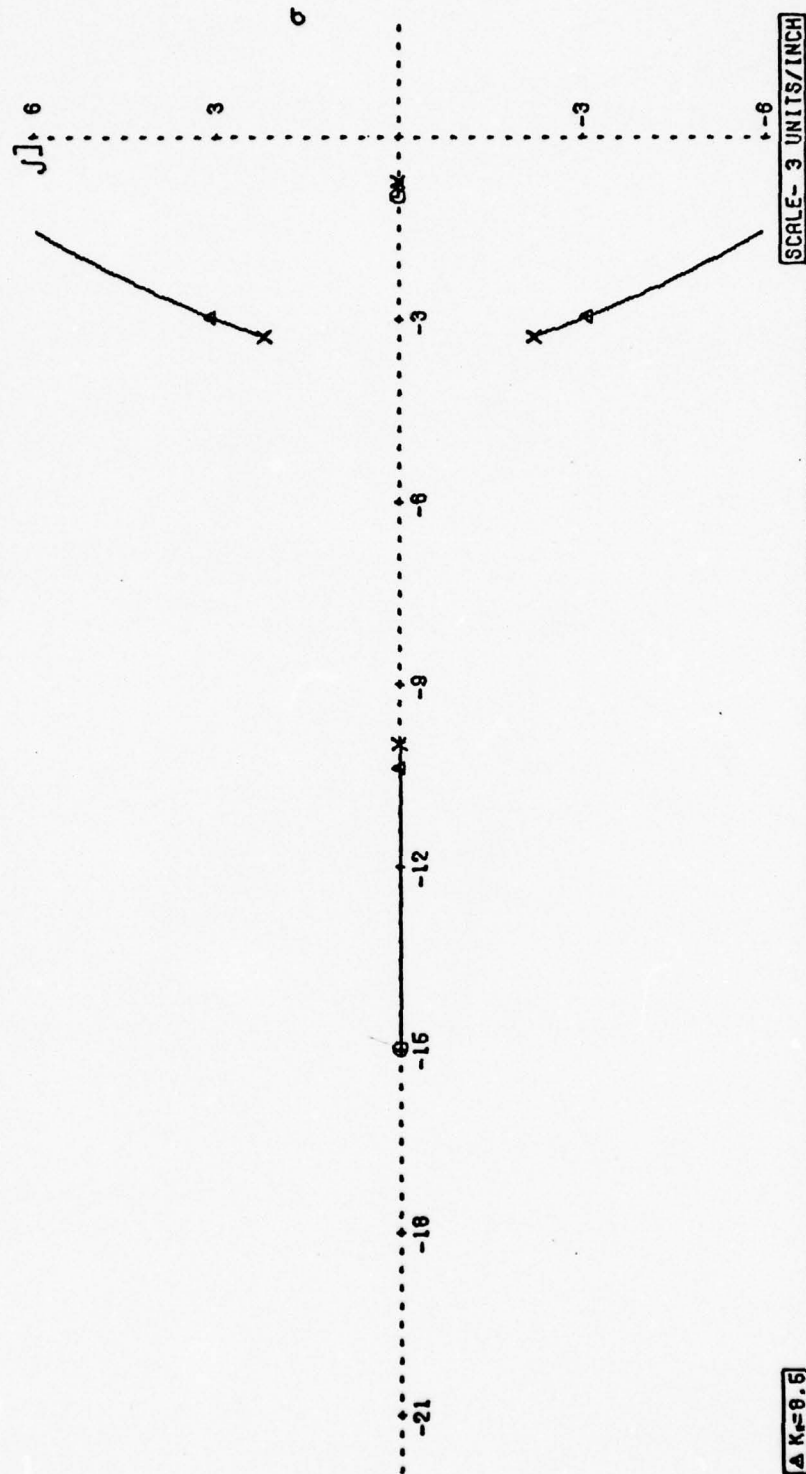


Figure 15. Pitch Rate Loop Closure, Flt. Cond. 2

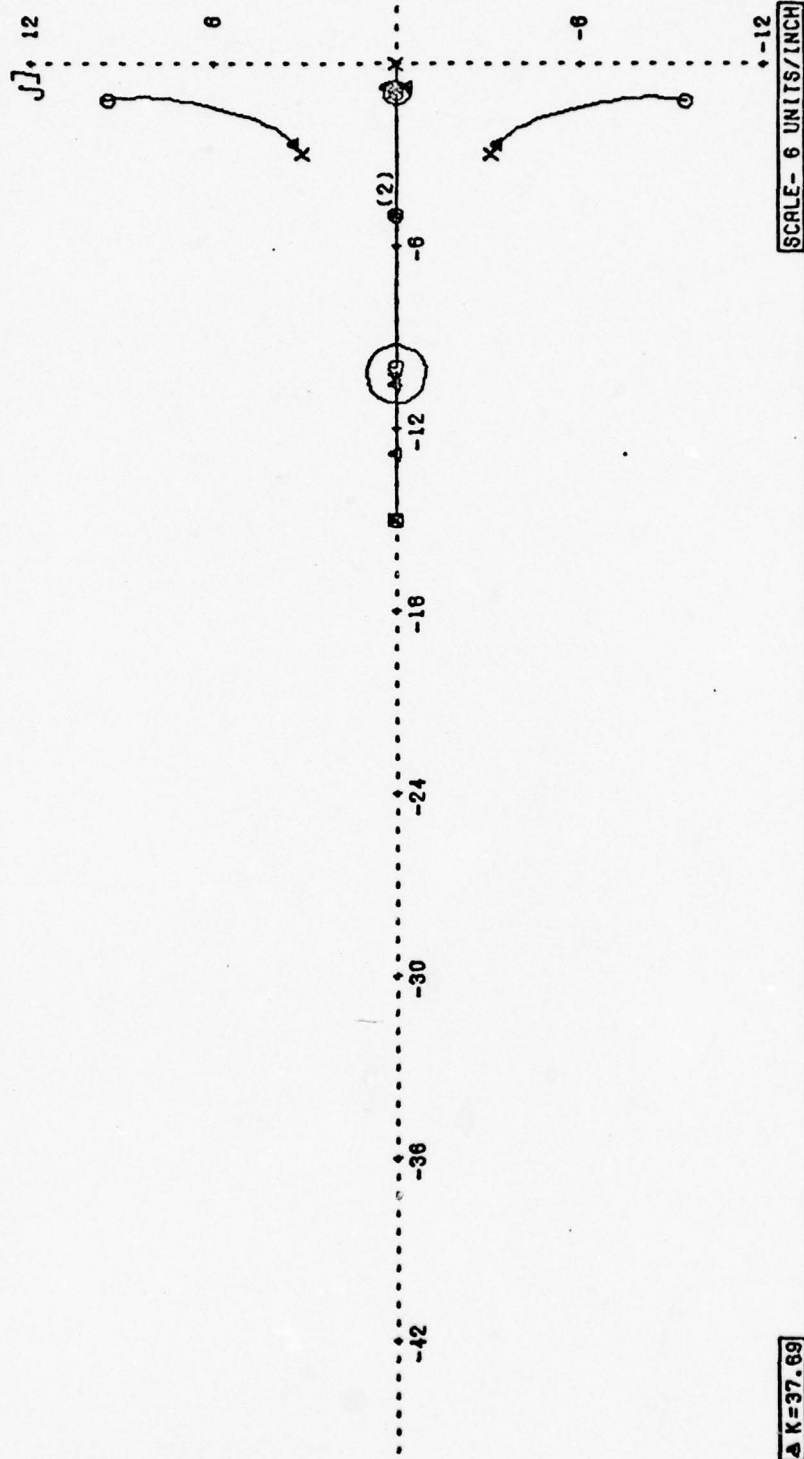
ANGLE OF ATTACK FEEDBACK LOOP



$$OLTF(S) = \frac{K(S+1)(S+15)(S+130.2)}{(S+0.743)(S+10)(S^2+6.566S+15.662)(S^2+30.161S+420.166)}$$

Figure 16. Angle of Attack Loop Closure, Flt. Cond. 2

NORMAL ACCELERATION FEEDBACK LOOP



$\Delta K = 37.69$

$$OLTF(S) = \frac{K(S+5)^2(S+1)(S+10)(S+16)(S^2+2.42S+91.031)}{S(S+0.816)(S+15.000)^2(S+10.386)(S^2+5.913S+18.272)(S^2+30.367S+423.399)}$$

SCALE- 6 UNITS/INCH

Figure 17. Normal Acceleration Loop Closure, Flt. Cond. 2

Flight Condition 1:

$$\frac{a_n(s)}{g_{com}} = \frac{(6.33)(s+5)(s+1)(s+10)(s+15)}{(s+8.3)(s+1.368)(s+.6434)(s+2.765 \pm 3.389j)} \cdot \frac{(s+1.011 \pm 11.68j)}{(s+10.7)(s+12.71)(s+16.11 \pm 15.89j)} \quad (24)$$

Flight Condition 2:

$$\frac{a_n(s)}{g_{com}} = \frac{(7.026)(s+5)(s+1)(s+10)(s+15)}{(s+8.3)(s+10.55)(s+12.83)(s+.7696 \pm .3564j)} \cdot \frac{(s+1.21 \pm 9.464j)}{(s+2.643 \pm 3.32j)(s+16.13 \pm 15.13j)} \quad (25)$$

The various gains (as defined in Appendix C) are listed in Table IV.

From Figure 3, it can be seen that the CCV aircraft would not present any new information from a root locus point of view since the basic aircraft portion remains intact. The forward transfer function G_4 is essentially what is being modified in this configuration. Therefore, the Normal Acceleration to Flap commanded transfer function, $\frac{a_n}{\delta_f}(s)$, was found directly using Mason's Rule. The appropriate values of the gains are also listed in Table IV. The transfer functions are presented below.

Table IV
Transfer Function Gains

	Flt. Cond. 1	Flt. Cond. 2
GK ₁	284.56	223.2
GK ₂	.0112	.0076
GK ₃	.265	.479
K ₄ (basic)	-7.46	-8.54
K ₄ (CCV)	-.525	-.473
K ₅	.758	.665
K ₆	-.426	-.701
K ₇	-.362	-.658
K ₈	-15.52	-10.64
K ₉	4.72	3.58
K ₁	1.079	1.235
K ₂	5	5
K ₃	40.46	46.29

Flight Condition 1:

$$\frac{a_n(s)}{\delta_f} = \frac{(.4706)(s + 3.18)(s + 1.231)(s + 9.978)(s + 15)}{(s + 3.229)(s + 1.367)(s + 3.987)(s + .642)(s + 12.72)}$$

$$\frac{(s + 15)(s + 7.557)(s + 24.17)(s + .8539 \pm .8628j)}{(s + 10.7)(s + 8.3)(s + 3.144 \pm .02483j)(s + 2.767 \pm 3.383j)}$$

$$\frac{(s + 1.004 \pm 11.68j)}{(s + 16.11 \pm 15.97j)} \quad (26)$$

Flight Condition 2:

$$\frac{a_n(s)}{\delta_f} = \frac{(.9499)(s + .7417)(s + 10.02)(s + 7.849)(s + 15)(s + 15)}{(s + 3.984)(s + .769)(s + 10.54)(s + 15.09)(s + 12.84)}$$

$$\frac{(s + 18.88)(s + .699 \pm .6017j)(s + 1.206 \pm 9.456j)}{(s + 8.3)(s + .767 \pm .355j)(s + 2.653 \pm 3.315j)(s + 16.12 \pm 16.16j)} \quad (27)$$

For the mechanized aircraft, the two transfer functions (Eqs. 24 and 26 for flight condition 1 and Eqs. 25 and 27 for flight condition 2) were blended according to Figure 5. The closed loop transfer function was formed for values of $K_{10} = 0.1, 1.0, 10.0$ and 100.0 . This transfer function represents the response of normal acceleration to stick force inputs. Figures 18 through 25 show the time response for a

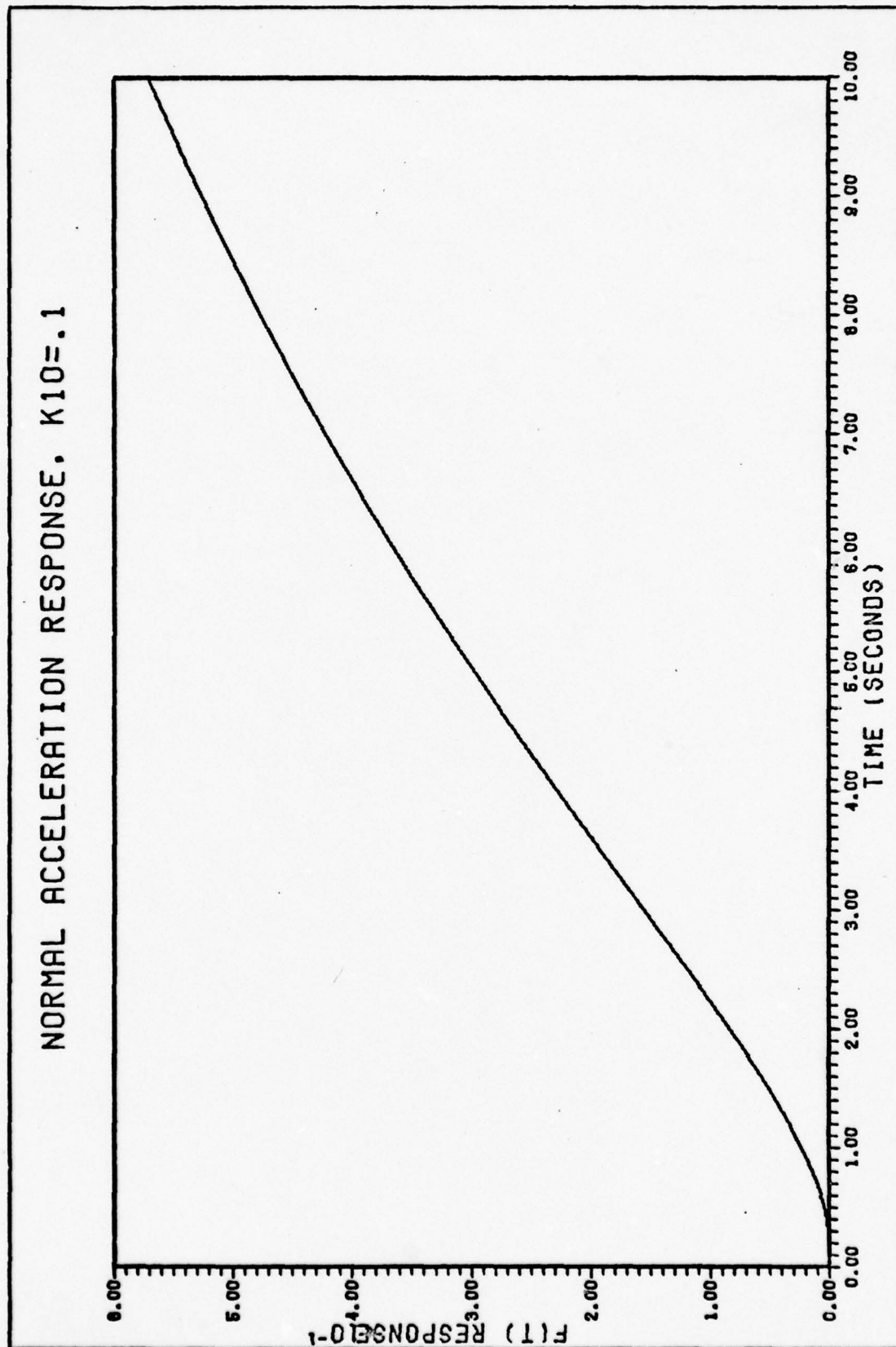


Figure 18. Step Response for $K_{10} = .1$, Flt. Cond.1

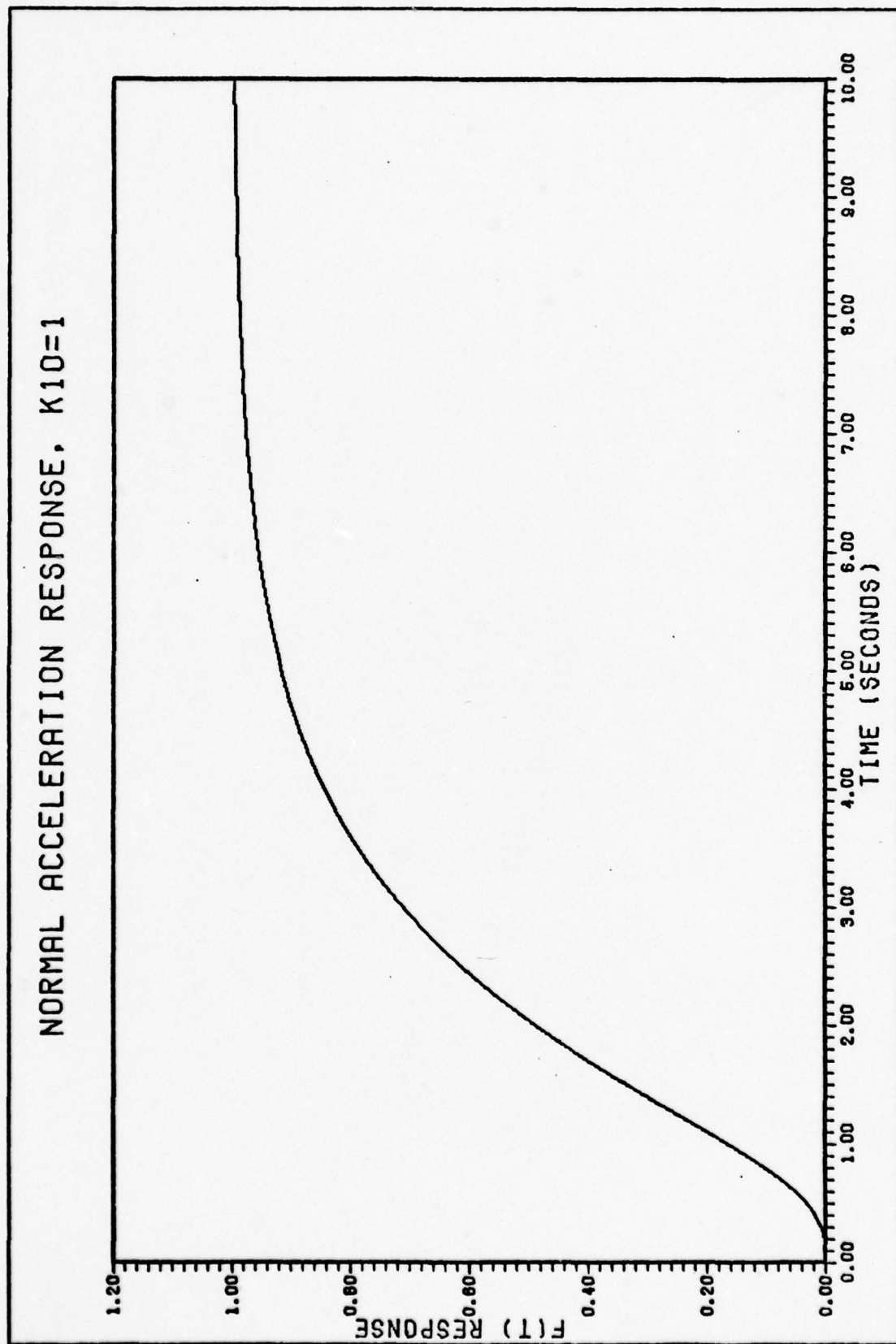


Figure 19. Step Response for $K_{10} = 1.0$, Flt. Cond. 1

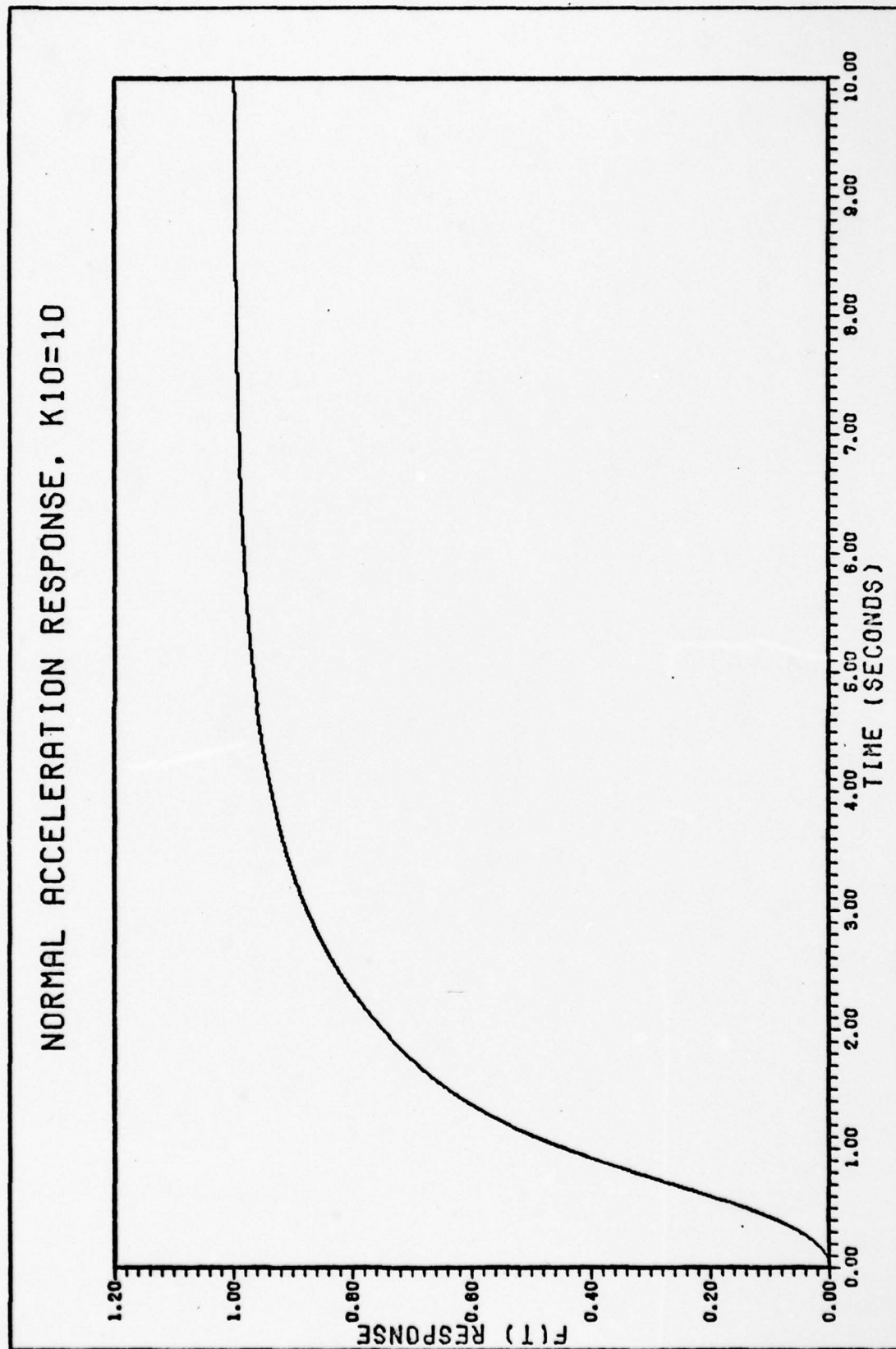


Figure 20. Step Response for $K_{10} = 10$, Flt. Cond. 1

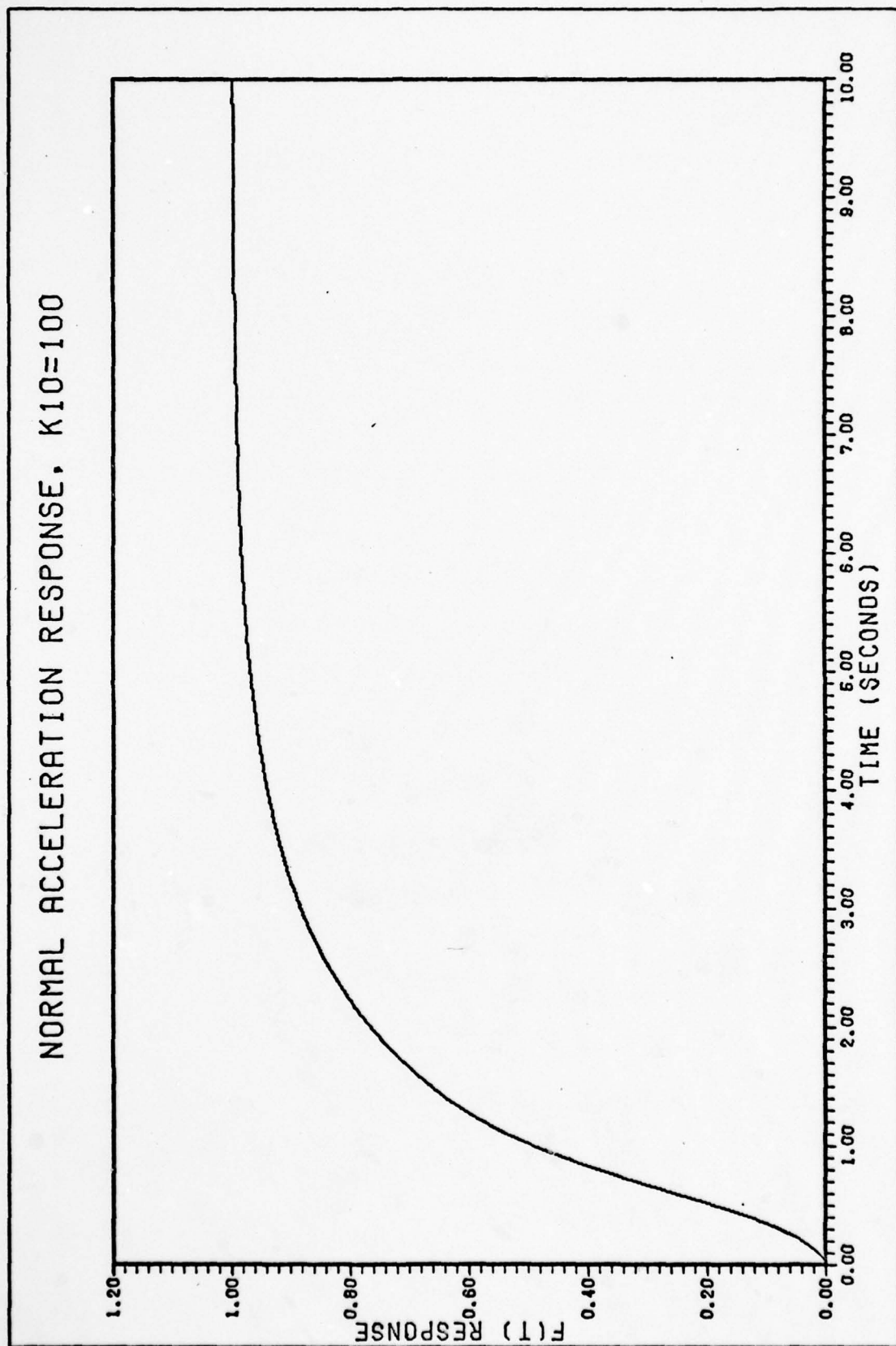


Figure 21. Step Response for $K_{10} = 100$, Flt. Cond. 1

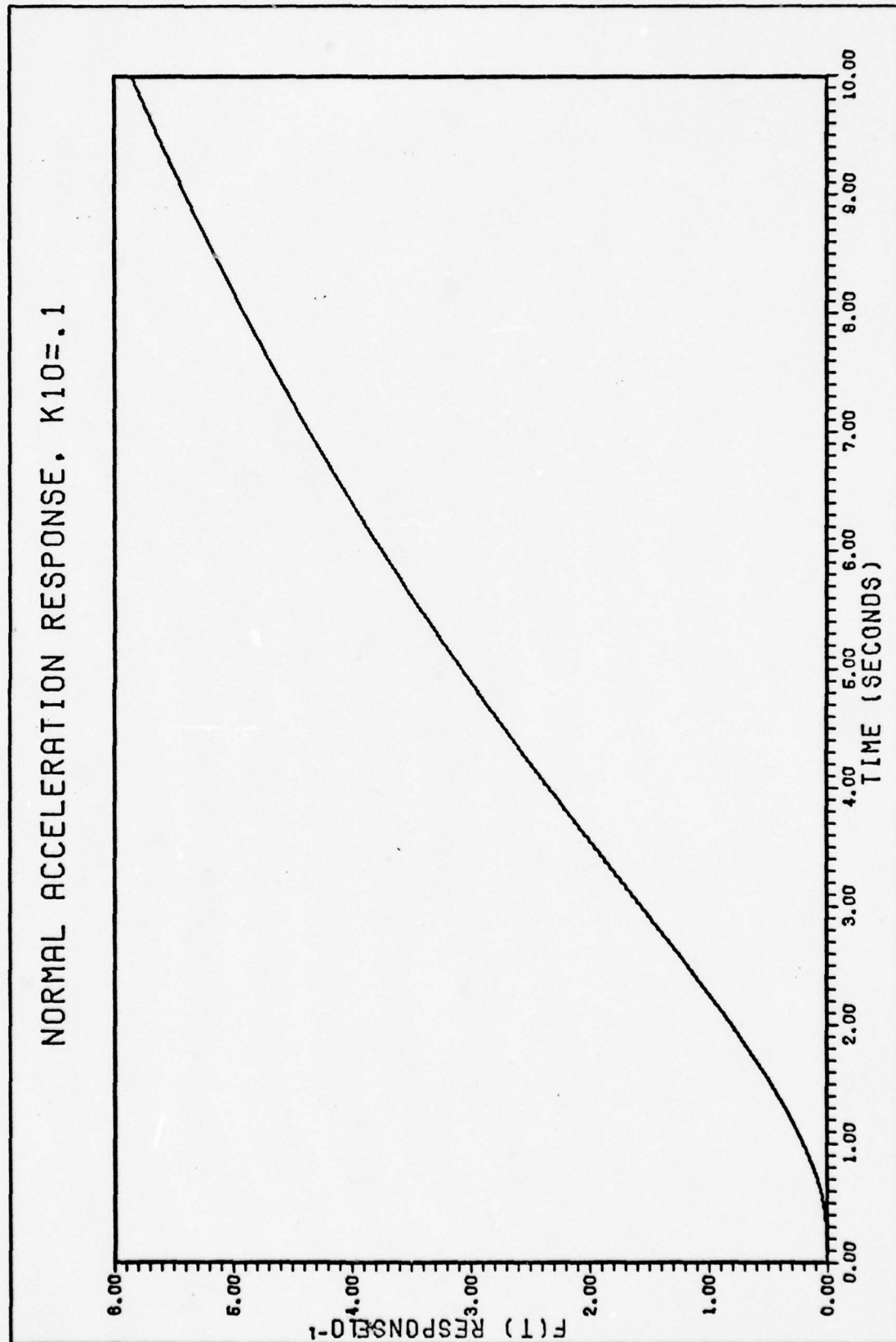


Figure 22. Step Response for $K_{10} = .1$, Flt. Cond. 2

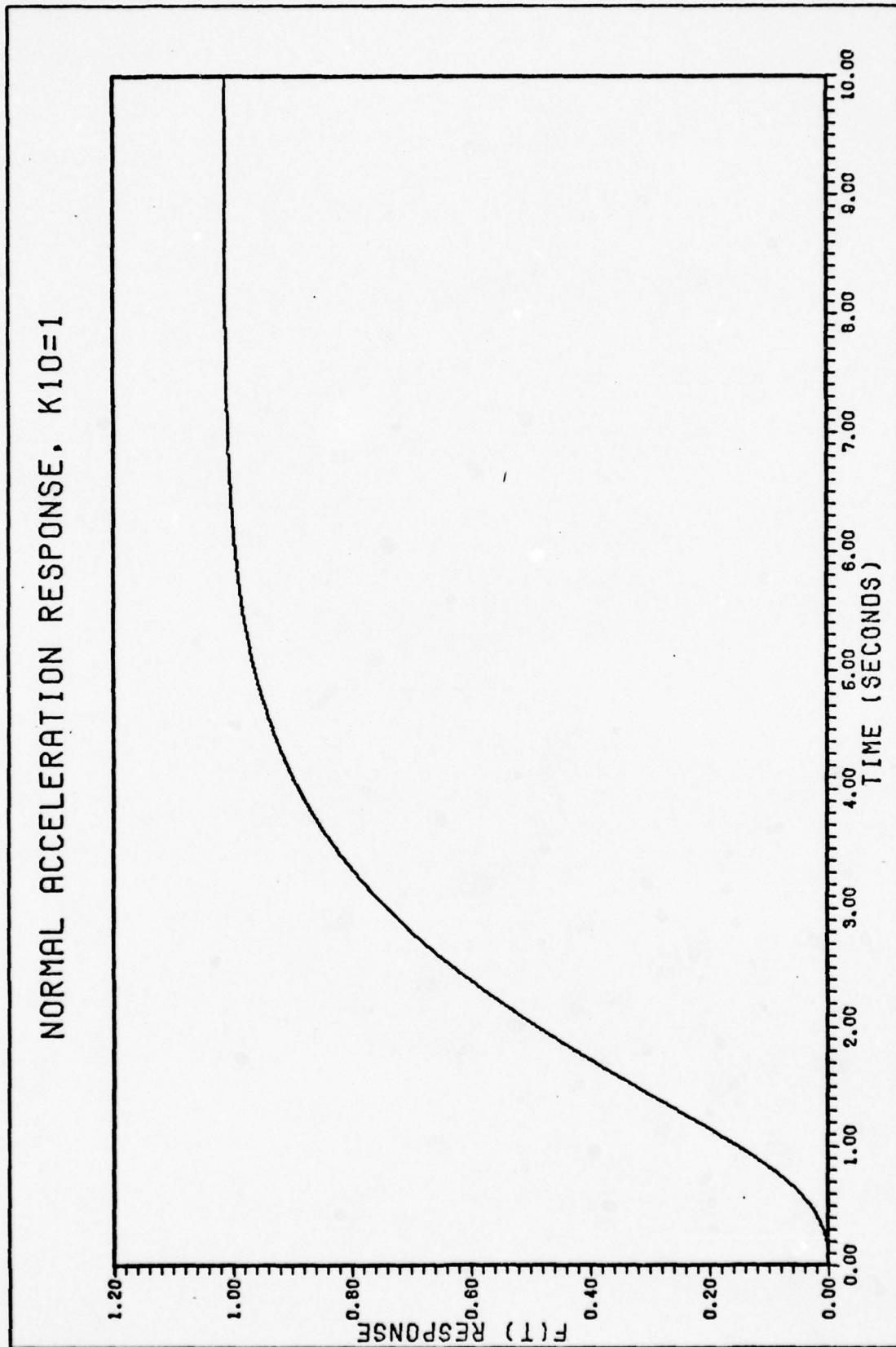


Figure 23. Step Response for $K_{10} = 1.0$, Flt. Cond. 2

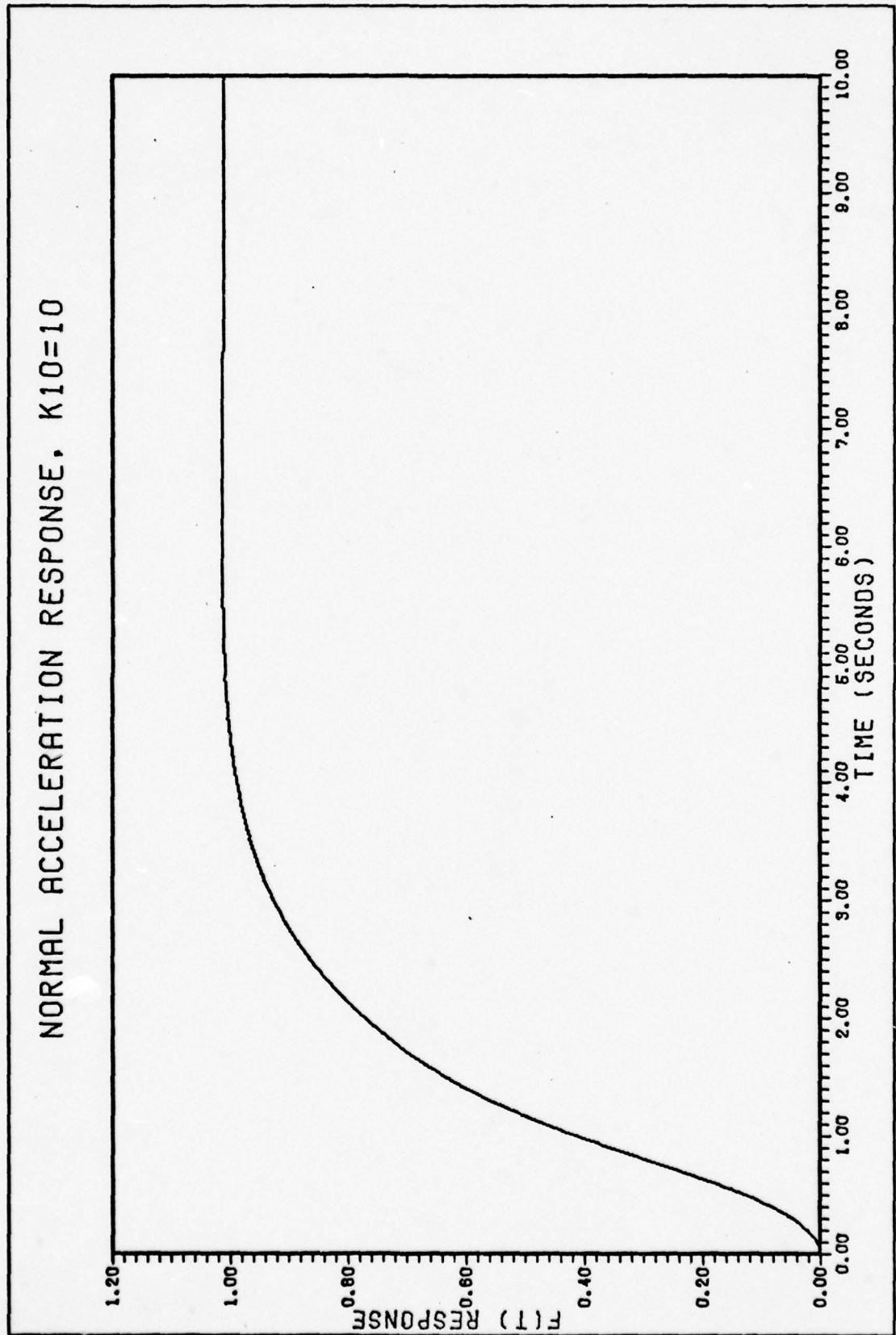


Figure 24. Step Response for $K_{10} = 10$, Flt. Cond. 2

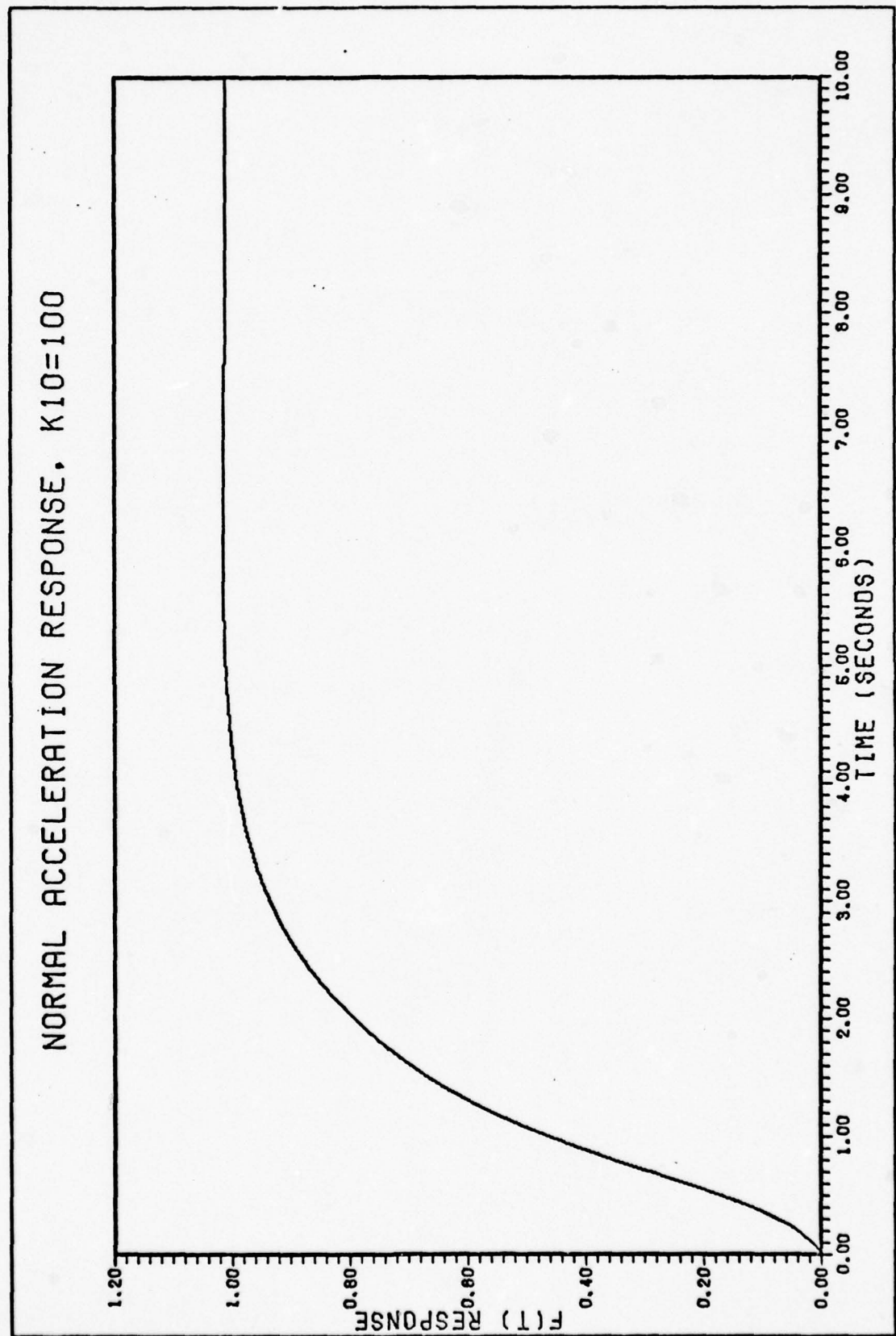


Figure 25. Step Response for $K_{10} = 100$, Flt. Cond. 2

unit step input for the various values of K_{10} at the two flight conditions. The settling time of the various responses are listed in Table V. It can be seen that the higher the value of K_{10} , the faster the settling time. However, from Eq. 9, it is determined that the higher values of K_{10} are in effect causing the basic aircraft response to dominate and penalizes the A_N mode response by washing out the flap command at an increasing rate for increasing values of K_{10} . Therefore, it is desirable to use the lower values of K_{10} . This will slow down the response of the basic aircraft, increase the time the flaps are deflected, and allow the flaps to reach a high maximum value which is closer to the actual CCV flap deflection. This will be shown more clearly in the results of the computer simulation.

Computer Simulation

As mentioned earlier, the characteristics of the CCV A_N mode were faster response in normal acceleration and an almost constant angle of attack while rotating the velocity vector. Therefore, in simulating this mode, it was apparent that the parameters of importance were angle of attack, normal acceleration, and altitude as a function of down range distance. These parameters can be compared to evaluate the response of the various modes.

Table V
Settling Time (sec) for $\frac{a_n}{\delta_{sf}}$ (s) for Values of K_{10}

K_{10}	Flight Condition 1	Flight Condition 2
0.1	40.66	40.47
1.0	7.24	5.80
10.0	5.76	4.04
100.0	5.67	3.94

The inputs for each run of the program were trim angle of attack, initial altitude, trim load factor, and a history of stick force inputs at discrete time intervals. The program would then give the trim conditions and initialize all the state variables before it worked its way through the flight trajectory. The scheme for each run was to input the trim conditions specified in Table I and after one second introduce a positive six (6) pound step input. Data for normal acceleration, angle of attack, and altitude was collected for plotting of the basic, CCV, and mechanized aircraft responses at each flight condition.

Once data was obtained for the basic and CCV aircrafts, the two modes were mechanized according to Figure 4. The value of K_{10} was allowed to vary in successive runs and the time history of the flap deflection was recorded. For a particular flight condition, the time histories of flap deflection for the various values of K_{10} were plotted together with the flap deflections during just the CCV mode. These plots are shown in Figure 26. It is clearly obvious that the lower value of K_{10} (0.1) yields the greatest deflection in flaps and, consequently, the more pronounced response of the A_N mode. The time over which some portion of the flaps remains deflected is increased for $K_{10} = 0.1$. This is in accordance with the prediction of the root locus analysis.

The important parameters listed at the beginning of this section were then plotted together for each flight condition. The value of K_{10} chosen for the mechanized aircraft was 0.1. The plots are shown in Figures 27 through 32. It is observed that the mechanization of Figure 4 allows a much quicker initial response and then evolves into the response of the basic aircraft.

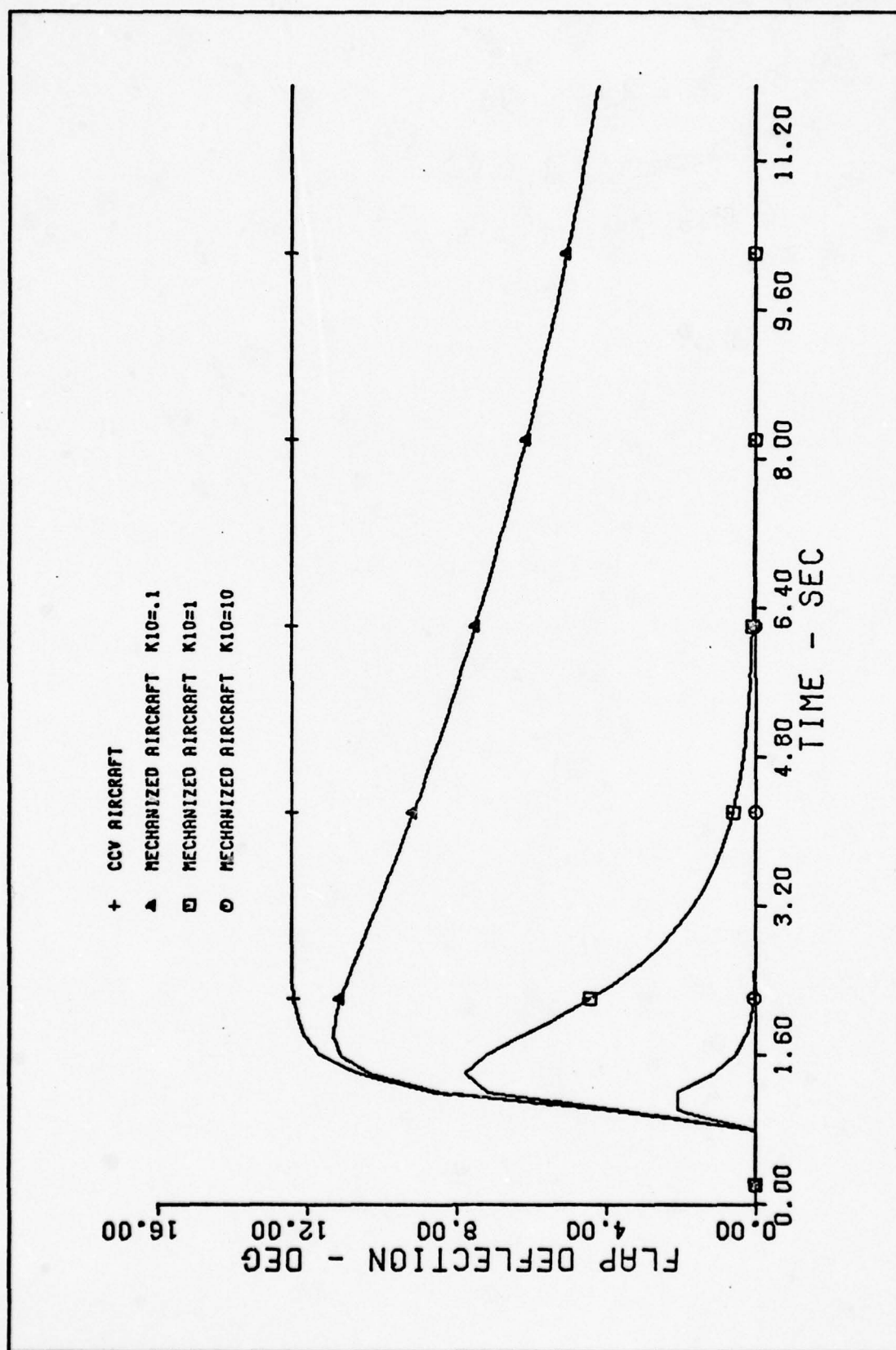


Figure 26. Flap Deflection Time Histories Varying K_{10}

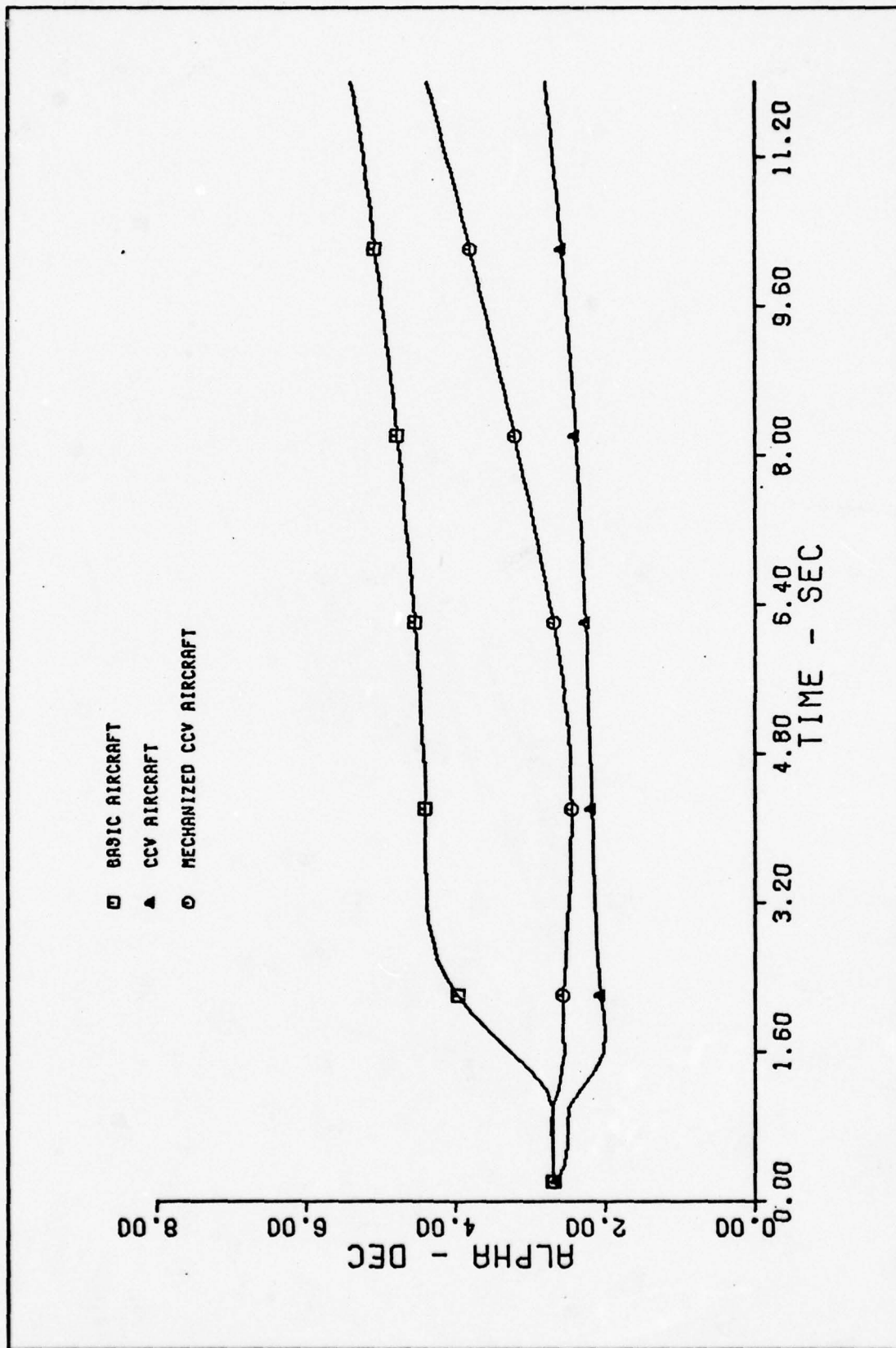


Figure 27. Comparative Time Histories of Angle of Attack, Flt. Cond. 1

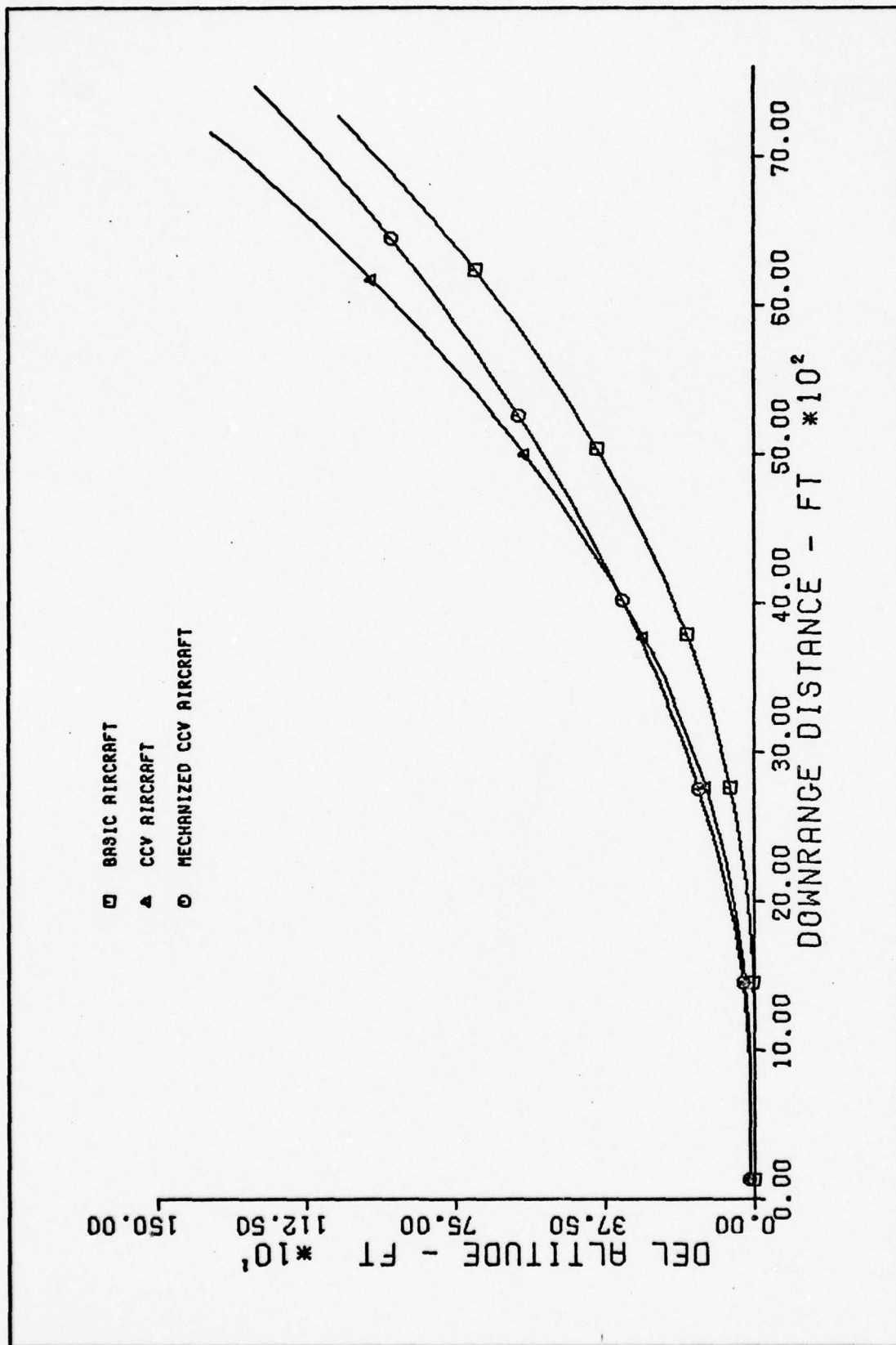


Figure 28. Comparative Flight Trajectories, Flt. Cond. 1

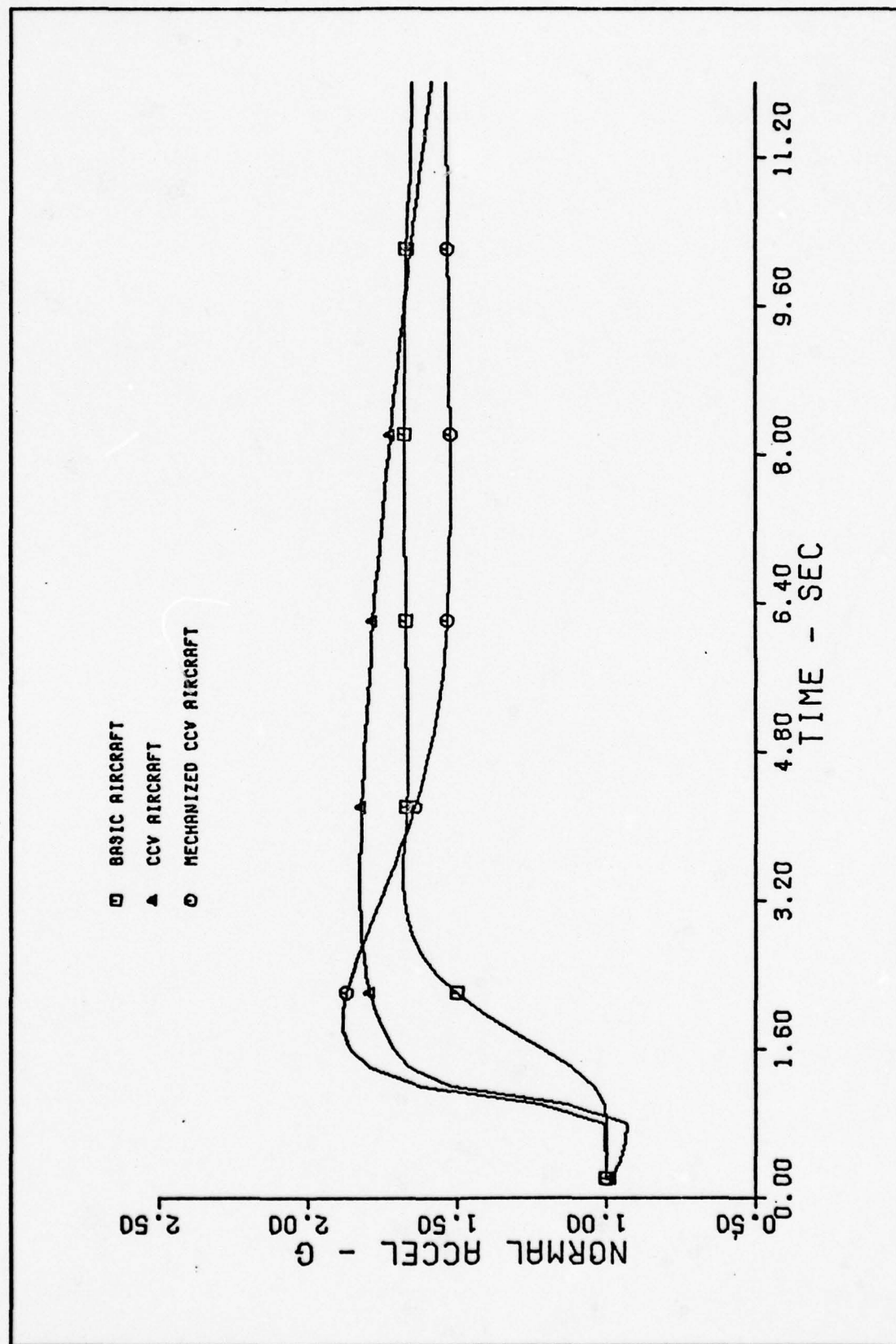


Figure 29. Comparative Time Histories of Normal Acceleration, Flt. Cond.1

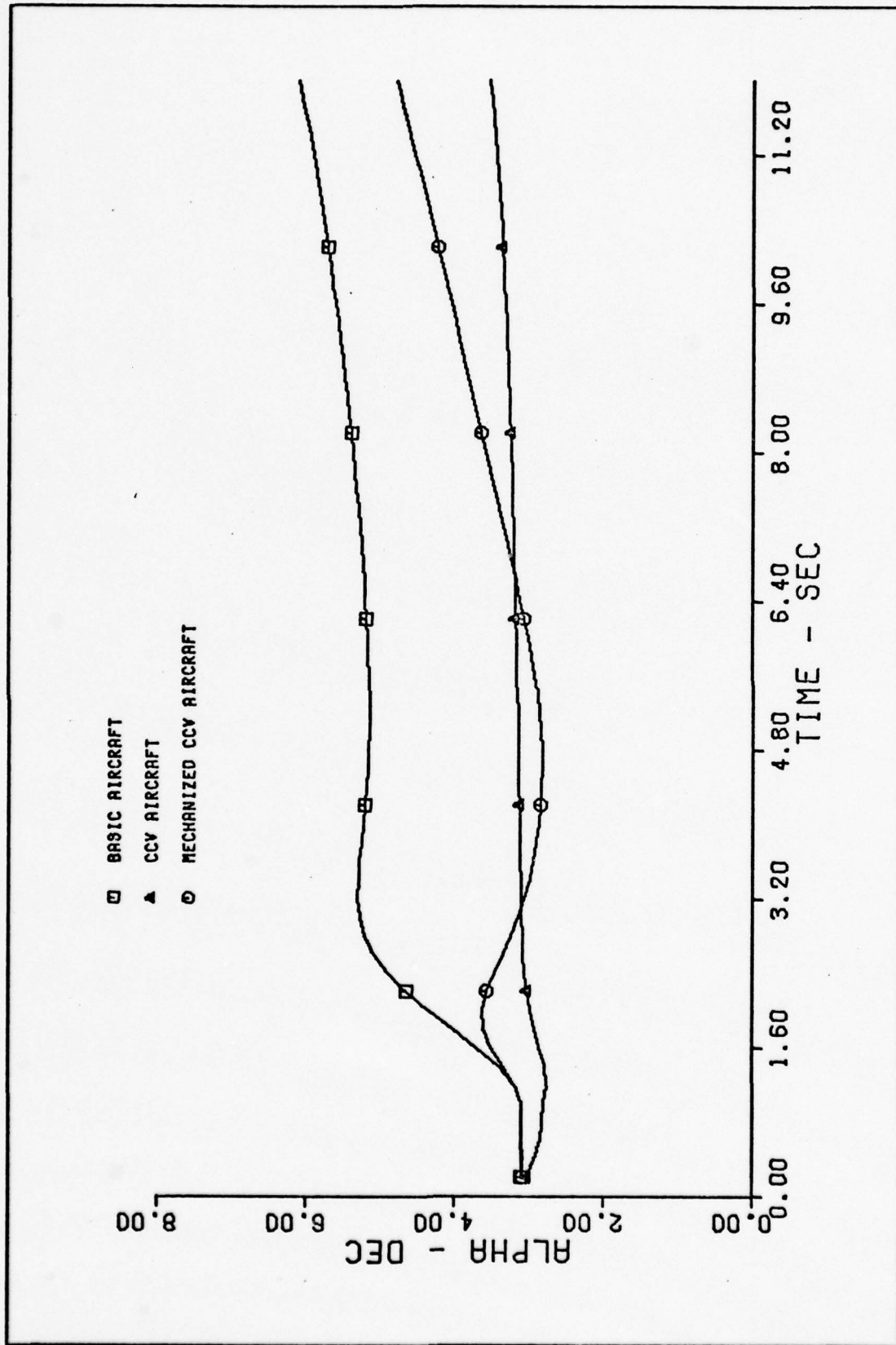


Figure 30. Comparative Time Histories of Angle of Attack, Flt. Cond. 2

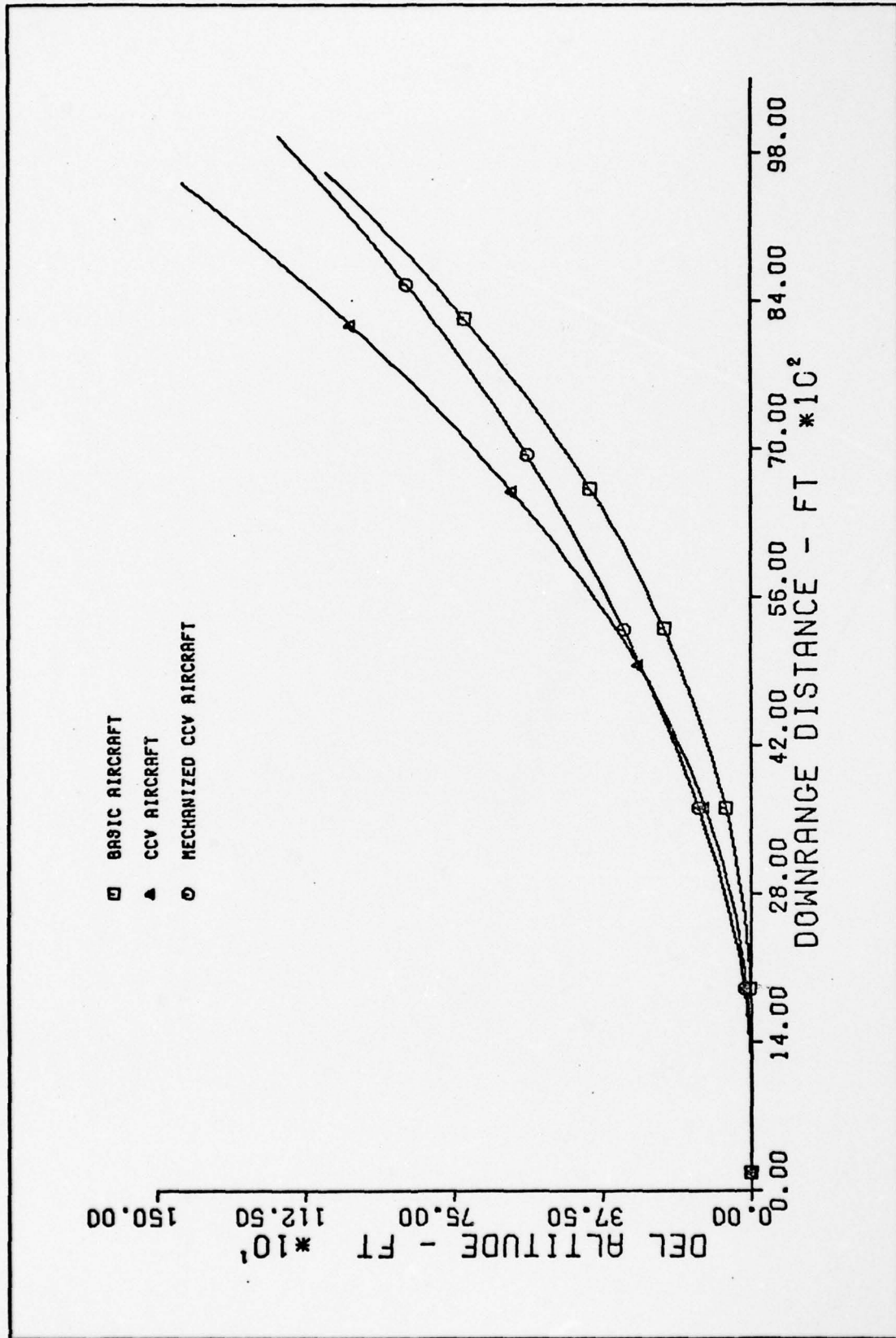


Figure 31. Comparative Flight Trajectories, Flt. Cond. 2

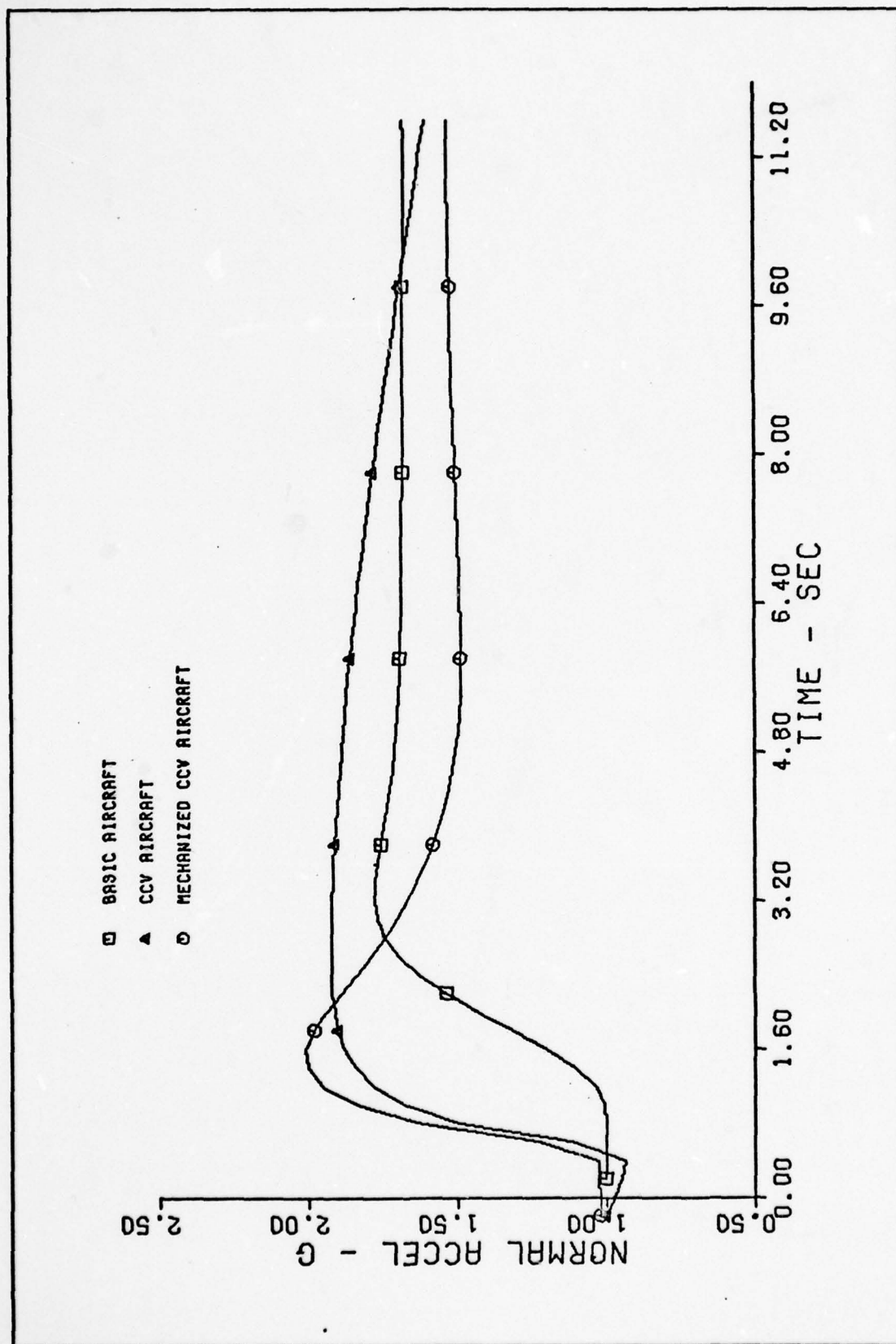


Figure 32. Comparative Time Histories of Normal Acceleration, Flt. Cond. 2

IV. Conclusions and Recommendations

Conclusions

The analyses of this study have led to the conclusion that mechanization of the blending of the CCV A_N mode and the basic YF-16 flight control systems is both feasible and worthwhile. The mechanized aircraft has effectively combined both modes to give increased performance over the basic aircraft. The mechanized function is available to the pilot through the sidestick controller and does not require inputs from a two axis force button. The cross talk between button and stick are eliminated. If the command is held as a step input, the CCV A_N mode will washout leaving only the basic aircraft mode. If faster inputs are required, the CCV A_N mode will predominate and little or no response will be seen from the basic aircraft. This is clearly an advantageous system for aerial maneuvers.

Recommendations

This study has only touched upon one possible method of blending the A_N mode with the basic aircraft. Other untested methods have been proposed by some of the aircraft industries. These methods should be tested and compared to the method of this study in an attempt to find the most

practical solution.

Five more modes are available on the present CCV aircraft, of which all the longitudinal modes are available only through the two axis force button. These, too, could be blended in some fashion.

There are almost limitless possibilities of improving the performance of modern fighter aircraft. To maintain the advantage of air superiority, these possibilities must be explored.

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9. Whitmoyer, R. A. and J. K. Ramage, "The Fighter Control Configured Vehicle (CCV) Program Development and Flight Test Summary", Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio.

Appendix A

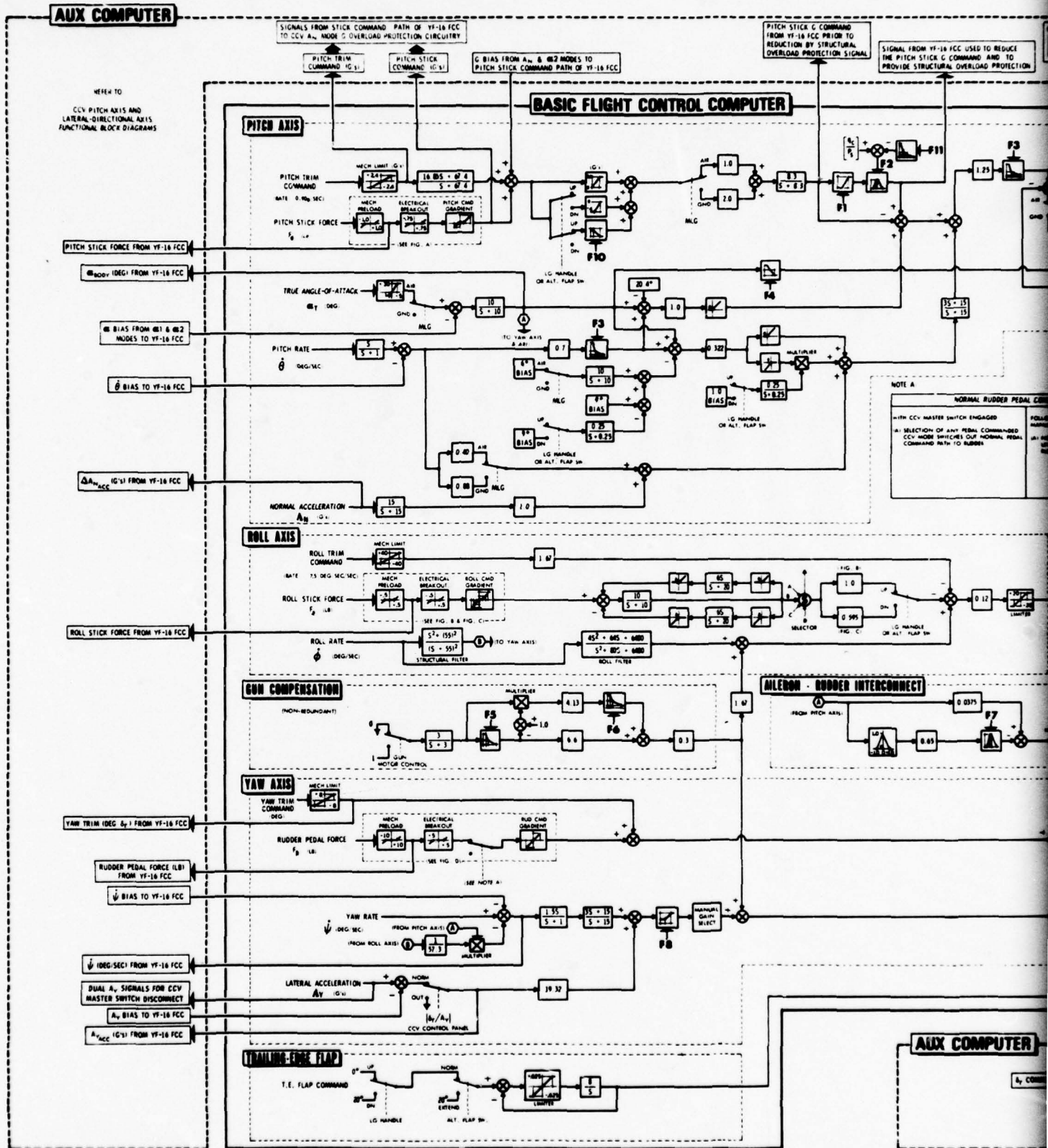
Physical Description of the Aircraft

Mass = 602.5 slugs	$I_x = 8400.9 \text{ slug} - \text{ft}^2$
$s = 280 \text{ ft}^2$	$I_y = 47000.0 \text{ slug} - \text{ft}^2$
$b = 29.0 \text{ ft}$	$I_z = 55000.0 \text{ slug} - \text{ft}^2$
$\bar{c} = 10.94 \text{ ft}$	$I_{xz} = 550.9 \text{ slug} - \text{ft}^2$

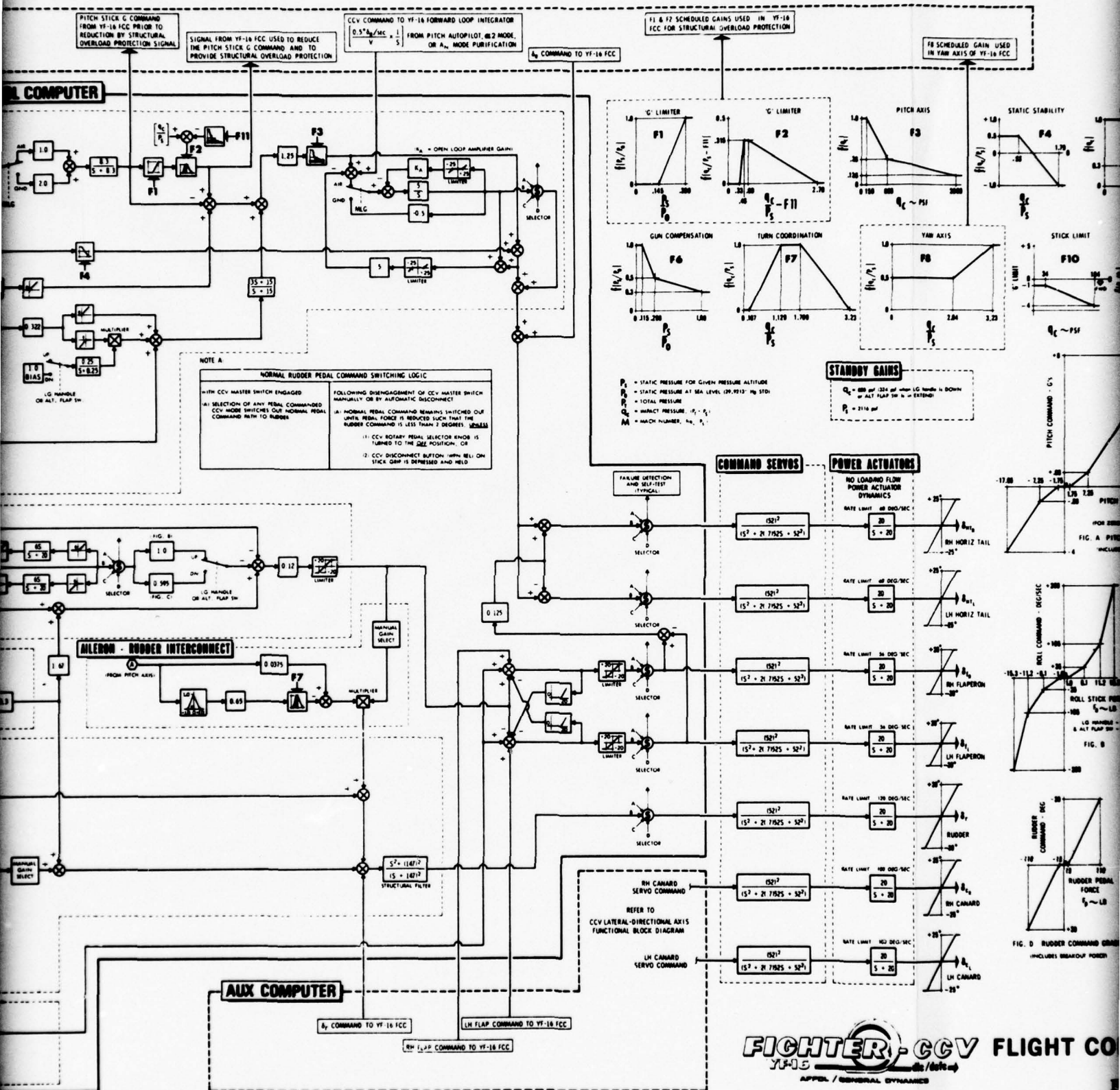
Control Surface Deflection Limits

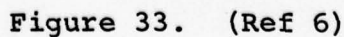
Elevator	$\pm 25^\circ$
Flaperons	$\pm 20^\circ$
Rudder	$\pm 30^\circ$

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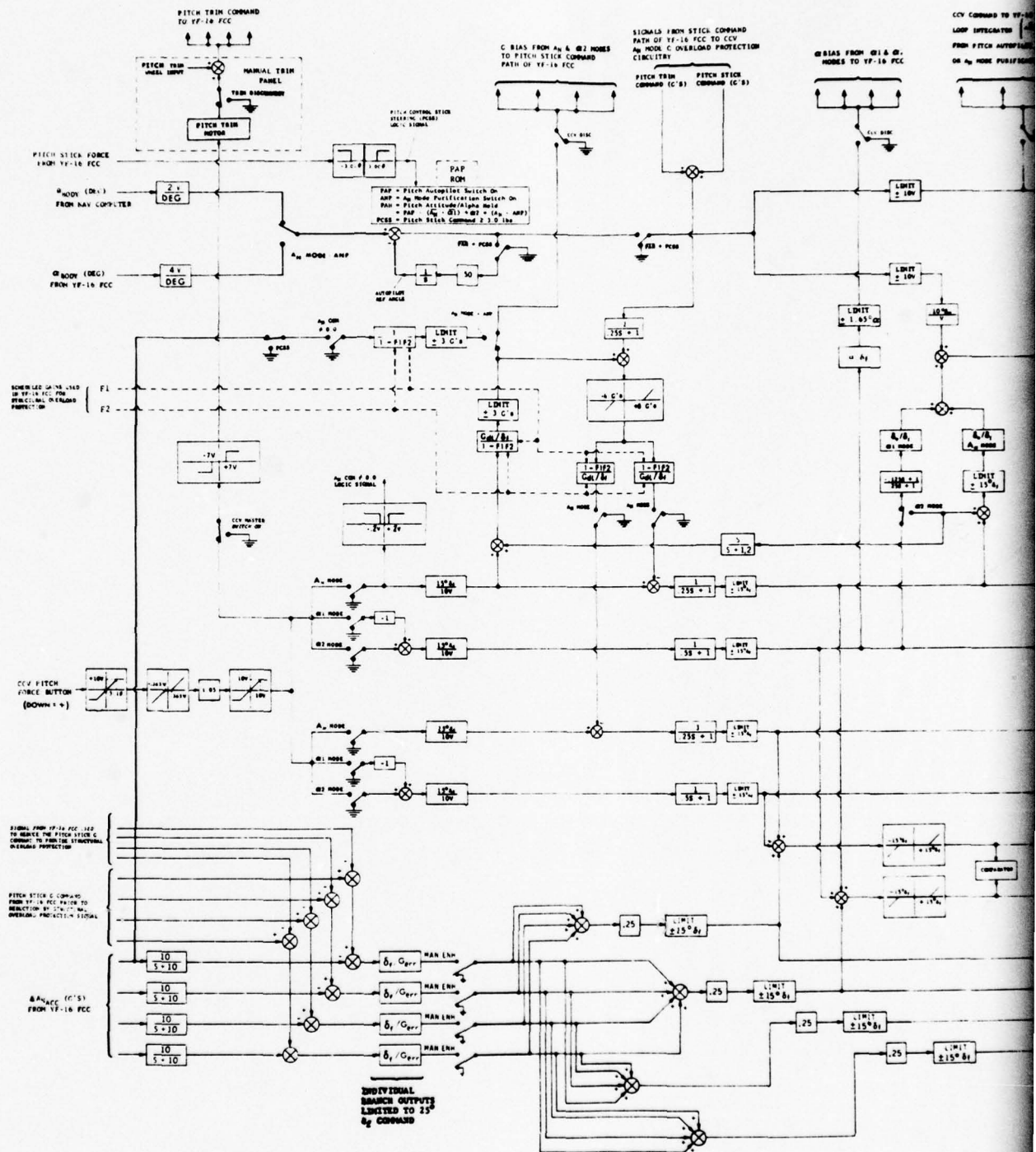


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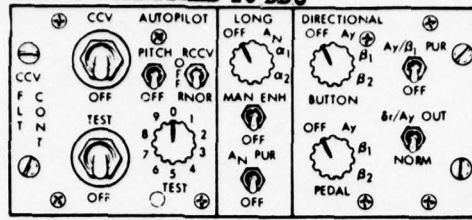




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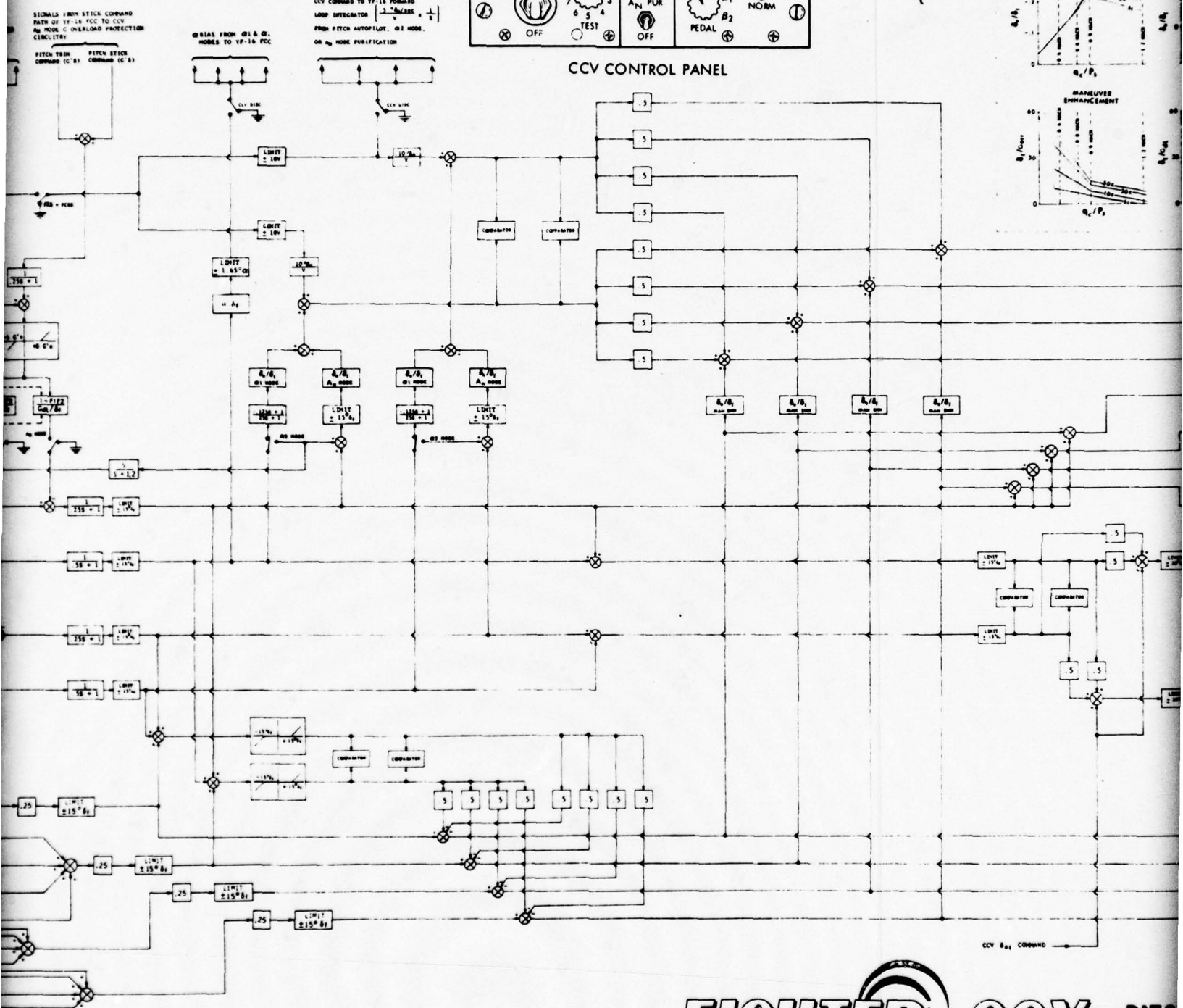
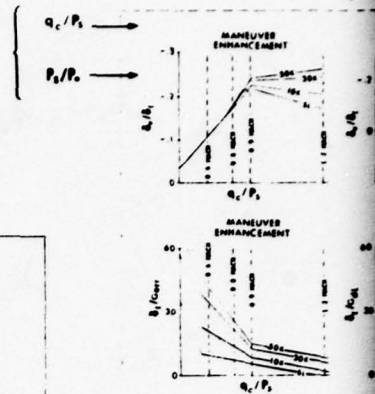


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CCV CONTROL PANEL

ATMOSPHERIC DATA
FROM YF-16 FCC



FIGHTER-CCV
YF-16 dlc/dsfc
AFFOL / GENERAL DYNAMICS

PITCH

Figure

Appendix B

Starting with the general non-linear equations for the
forces and moments in component form

$\bar{i}$ component of force:

$$m \left[\dot{U} + QW - VR \right] = mg_x + F_{A_x} + F_{T_x} \quad (B1)$$

$\bar{j}$ component of force:

$$m \left[\dot{V} + UR - PW \right] = mg_y + F_{A_y} + F_{T_y} \quad (B2)$$

$\bar{k}$ component of force:

$$m \left[\dot{W} + PV - QU \right] = mg_z + F_{A_z} + F_{T_z} \quad (B3)$$

$\bar{i}$ component of moment:

$$\dot{P}I_x - \dot{R}I_{xz} - I_{xz}PQ + RQ(I_z - I_y) = L_A + L_T \quad (B4)$$

$\bar{j}$ component of moment:

$$\dot{Q}I_y + (I_x - I_z)PR + I_{xz}(P^2 - R^2) = M_A + M_T \quad (B5)$$

$\bar{k}$ component of moment:

$$\dot{R}I_z - \dot{P}I_{xz} + (I_y - I_x)PQ + I_{xz}QR = N_A + N_T \quad (B6)$$

The angular velocity vector is defined as:

$$\bar{\omega} = P\bar{i} + Q\bar{j} + R\bar{k} \quad (B7)$$

Using Euler angle Eq. (B7) becomes

$$\begin{aligned}\bar{\omega} = \bar{i}(-\dot{\psi} \sin \theta + \dot{\phi}) + \bar{j}(\dot{\psi} \cos \theta \sin \phi + \dot{\theta} \cos \phi) \\ + \bar{k}(\dot{\psi} \cos \theta \cos \phi - \dot{\theta} \sin \phi)\end{aligned}\quad (B8)$$

Equating the components of Eqs. (B7) and (B8) yields

$$P = \dot{\phi} - \dot{\psi} \sin \theta \quad (B9)$$

$$Q = \dot{\psi} \cos \theta \sin \phi + \dot{\theta} \cos \phi \quad (B10)$$

$$R = \dot{\psi} \cos \theta \cos \phi - \dot{\theta} \sin \phi \quad (B11)$$

The gravity vector is defined as

$$\bar{g} = g_x \bar{i} + g_y \bar{j} + g_z \bar{k} \quad (B12)$$

Using Euler angles Eq. (B12) becomes

$$\bar{g} = \bar{i}(-g \sin \theta) + \bar{j}(g \sin \phi \cos \theta) + \bar{k}(g \cos \phi \cos \theta) \quad (B13)$$

Equating the components of Eqs (B12) and (B13) yields

$$g_x = -g \sin \theta \quad (B14)$$

$$g_y = g \sin \phi \cos \theta \quad (B15)$$

$$g_z = g \cos \phi \cos \theta \quad (B16)$$

Eqs (B14), (B15) and (B16) can now be substituted into

Eqs (B1), (B2), and (B3)

$$m(\dot{U} - VR + QW) = -mg \sin \theta + F_{Ax} + F_{Tz} \quad (B17)$$

$$m(\dot{V} + UR - WP) = mg \sin \phi \cos \theta + F_{Ay} + F_{Ty} \quad (B18)$$

$$m(\dot{W} - UQ + VP) = mg \cos \phi \cos \theta + F_{Az} + F_{Tz} \quad (B19)$$

Using the perturbed quantities

$$\begin{aligned} U &= U_1 + u & V &= V_1 + v & W &= W_1 + w \\ P &= P_1 + p & Q &= Q_1 + q & R &= R_1 + r \\ \Phi &= \Phi_1 + \phi & \Theta &= \Theta_1 + \theta \end{aligned}$$

assuming the perturbed quantities are small, assuming small angles, eliminating the steady state terms, and imposing the restrictions

$$V_1 = P_1 = Q_1 = R_1 = \Phi_1 = \dot{\Psi}_1 = \dot{\Theta}_1 = \dot{\Phi}_1 = 0$$

the linearized equations are formed. Using the relations in body axes for the following

$$U_1 = V_R \cos \alpha_1 \quad (B20)$$

and

$$W_1 = V_R \sin \alpha_1 \quad (B21)$$

The equations of motion for the longitudinal axis become

X force:

$$m \dot{u} + V_R q \sin \alpha_1 = -mg \theta \cos \theta_1 + f_{A_x} + f_{A_x} \quad (B22)$$

Z force:

$$m V_R \dot{\alpha} - V_R q \cos \alpha_1 = -mg \theta \sin \theta_1 + f_{A_z} + f_{T_z} \quad (B23)$$

M moment:

$$I_y \dot{q} = m_A + m_T \quad (B24)$$

Rewriting Eqs(B22), (B23), and (B24) with dimensional derivatives in the force terms yields

X force:

$$\begin{aligned} \ddot{u} = & -V_R q \sin \alpha_1 - g \theta \cos \theta_1 + X_u u + X_{T_u} u + X_\alpha \alpha \\ & + X_{\delta_e} \delta_e + X_{\delta_f} \delta_f \end{aligned} \quad (B25)$$

Z force:

$$\begin{aligned} V_R \alpha - V_R q \cos \alpha_1 = & g \theta \sin \theta_1 + Z_u u + Z_\alpha \alpha + Z_{\dot{\alpha}} \dot{\alpha} \\ & + Z_q q + Z_{\delta_e} \delta_e + Z_{\delta_f} \delta_f \end{aligned} \quad (B26)$$

M moment:

$$\begin{aligned} \ddot{q} = & M_u u + M_{T_u} u + M_\alpha \alpha + M_{T_\alpha} \alpha + M_{\dot{\alpha}} \dot{\alpha} + M_q q \\ & + M_{\delta_e} \delta_e + M_{\delta_f} \delta_f \end{aligned} \quad (B27)$$

Taking the Laplace Transforms of Eqs(B25), (B26), and (B27), collecting terms, and writing in matrix form yields

$$\begin{bmatrix} (s - X_u - X_{T_u}) & -X_\alpha & (V_R \sin \alpha_1 S + g \cos \theta_1) \\ -Z_u & V_R S - Z_\alpha & -(V_R \cos \alpha_1 + Z_q) s - g \sin \theta_1 \\ (-M_u - M_{T_u}) & -(M_{\dot{\alpha}} S + M_\alpha) & S^2 - M_q S \end{bmatrix} \begin{bmatrix} u(s) \\ \alpha(s) \\ \theta(s) \end{bmatrix} =$$

$$\begin{bmatrix} X_{\delta_e} \\ Z_{\delta_e} \\ M_{\delta_e} \end{bmatrix} \delta_e(s) + \begin{bmatrix} X_{\delta_f} \\ Z_{\delta_f} \\ M_{\delta_f} \end{bmatrix} \delta_f(s) \quad (B28)$$

Taking the short period approximation ($u(s) = 0$) yields the result

$$\begin{bmatrix} V_R s - Z_\alpha & -(V_R \cos \alpha_1 + Z_q) s - g \sin \theta_1 \\ -(M_\alpha \dot{s} + M_\alpha) & s^2 - M_q s \end{bmatrix} \begin{bmatrix} \alpha(s) \\ \theta(s) \end{bmatrix} =$$

$$\begin{bmatrix} Z_{\delta_e} \\ M_{\delta_e} \end{bmatrix} \delta(s) + \begin{bmatrix} Z_{\delta_f} \\ M_{\delta_f} \end{bmatrix} \delta_f(s) \quad (B29)$$

Appendix C

For figures 1 and 3, the transfer functions have the form

$$G_1(s) = \frac{GK_1}{s + 20} \frac{q(s)}{\delta_e(s)} \quad (C1)$$

$$G_2(s) = GK_2 \frac{\alpha(s)}{q(s)} \quad (C2)$$

$$G_3(s) = GK_3 \frac{a_n(s)}{\alpha(s)} \quad (C3)$$

$$G_4(s) = \frac{K_4 (s + 5)^2}{s (s + 8.3)} \quad (C4)$$

$$G_5(s) = \frac{K_5 (s + 5)^2}{(s + 1)(s + 4)(s + 15)} \quad (C5)$$

$$G_6(s) = \frac{K_6}{s + 4} \quad (C6)$$

$$G_7(s) = \frac{K_9}{s + 4} \frac{q(s)}{\delta_f(s)} \frac{\delta_e(s)}{q(s)} \quad (C7)$$

$$G_8(s) = \frac{K_8}{(s + 4)(s + 20)} \left[\frac{\alpha(s)}{\delta_f(s)} \right]_{Aug} \quad (C8)$$

$$G_9(s) = \frac{K_9}{(s + 4)(s + 20)} \left[\frac{a_n(s)}{\delta_f(s)} \right] \quad (C9)$$

$$H_1(s) = \frac{K_1 (s + 5)^2}{(s + 1)(s + 15)} \quad (C10)$$

$$H_2(s) = \frac{K_2}{s + 10} \quad (C11)$$

$$H_3(s) = \frac{K_3 (s + 5)^2}{s (s + 15)^2} \quad (C12)$$

The gains are defined as follows

$$GK_1 = 20 C_q / \delta_e \quad (C13)$$

$$GK_2 = \frac{C_{\alpha/\delta_e}}{C_{q/\delta_e}} \quad (C14)$$

$$GK_3 = \frac{C_{a_n/\delta_e}}{C_{\alpha/\delta_e}} \quad (C15)$$

$$K_4 = (F1F2 - 1) (8.3) (1.25) (F3) \quad \text{for Basic YF-16} \quad (C16)$$

$$= (F1F2 - 1) (8.3) (1.25) (F3) \left(\frac{G_{DL}}{f}\right) \quad \text{for CCV YF-16} \quad (C17)$$

$$K_5 = 6 F3 \frac{G_{DL}}{\delta_f} \times \frac{q}{G} \quad (C18)$$

$$K_6 = 4 \frac{\delta_e}{\delta_f} \quad (C19)$$

$$K_7 = 4 \frac{C_{q/\delta_f}}{C_{q/\delta_e}} \quad (20)$$

$$K_8 = 80 C_{\alpha/\delta_f} \quad (21)$$

$$K_9 = 80 C_{a_n/\delta_f} \quad (C22)$$

$$K_1 = (1.5) (F3) \quad (C23)$$

$$K_2 = (10) (F4) \quad (C24)$$

$$K_3 = (56.25) (F3) \quad (C25)$$

where F1, F2, F3, and F4 are scheduled gains that depend upon the flight condition.

A "C" indicates the coefficient associated with the transfer function specified by the subscript.

Appendix D

Referring to Figure 35, for $\Phi = 0$,

$$\theta = \alpha + \gamma \quad (D1)$$

where α = angle of attack

and γ = flight path angle

Therefore,

$$\gamma = \theta - \alpha \quad (D2)$$

Also,
$$\bar{V} = V \bar{e}_v \quad (D3)$$

and,
$$\dot{\bar{V}} = \dot{V} \bar{e}_v + V \dot{\bar{e}}_v \quad (D4)$$

Since
$$\bar{e}_v = \cos \gamma \bar{i} + \sin \gamma \bar{j} \quad (D5)$$

implies
$$\dot{\bar{e}}_v = -\dot{\gamma} \sin \gamma \bar{i} + \dot{\gamma} \cos \gamma \bar{j} = \dot{\gamma} (-\sin \gamma \bar{i} + \cos \gamma \bar{j}) \quad (D6)$$

However,
$$\bar{e}_n = -\sin \gamma \bar{i} + \cos \gamma \bar{j} \quad (D7)$$

therefore,
$$\dot{\bar{e}}_v = \dot{\gamma} \bar{e}_n \quad (D8)$$

Substituting Eq(D8) in Eq(D4) yields

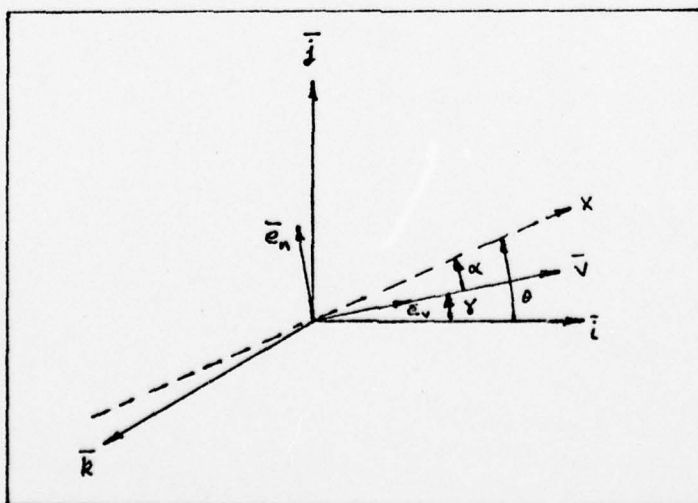


Figure 35. Reference System for Determining Normal Acceleration

$$\dot{\vec{v}} = \dot{v} \bar{e}_v + v \dot{\gamma} \bar{e}_n \quad (D9)$$

Linearizing Eq(D9) in the normal direction yields

$$v = (U_1 + u) (\dot{\gamma}_1 + \dot{\gamma}) \quad (D10)$$

However, $\dot{\gamma}_1 = 0$ and u is negligible

$$\text{leaving } v \dot{\gamma} = U_1 \dot{\gamma} = A_N \quad (D11)$$

normal acceleration about the center of gravity.

From Eq(D2),

$$\dot{\gamma} = \dot{\theta} - \dot{\alpha} \quad (D12)$$

Substituting Eq(D12) in Eq(D11) yields

$$A_{N_{c.g.}} = U_1 (\dot{\theta} - \dot{\alpha}) \quad (D13)$$

Normal acceleration at the pilot's station (location of the accelerometer) becomes

$$A_{N_{p.s.}} = A_{N_{c.g.}} + l_z \ddot{q} \quad (D14)$$

where $q = \theta$.

Substituting Eq(D13) in Eq(D14) yields

$$A_{N_{p.s.}} = U_1 (\dot{q} - \dot{\alpha}) + l_z \ddot{q} \quad (D15)$$

Taking the Laplace Transform of Eq(D15) yields

$$a_n(s) = U_1 (\dot{q}(s) - s \alpha(s)) + l_z s^2 q(s) \quad (D16)$$

Substituting the transfer functions $q/\delta_e(s)$ and $\alpha/\delta_e(s)$ and regrouping terms leads to the result

$$\frac{a_n}{\delta_e}(s) = (l_z s + U_1) q(s) - U_1 s \alpha(s) \quad (D17)$$

The accelerometer output equals the total acceleration minus gravity. However, the perturbation contributions due to gravity fall out at $\theta_1 = 0$, $\phi_1 = 0$.

Appendix E

Short Period Approximation Transfer Functions for Basic Airframe Flt. Cond. 1

$$\frac{\alpha}{\delta_e}(s) = \frac{-.160 (s + 89.48)}{(s - 1.0) (s + 3.18)}$$

$$\frac{q}{\delta_e}(s) = \frac{-14.228 (s + 1.17)}{(s - 1.0) (s + 3.18)}$$

$$\frac{a_n}{\delta_e}(s) = \frac{-.0424 (s^2 + 2.022 s + 137.53)}{(s - 1.0) (s + 2.09)}$$

$$\frac{\alpha}{\delta_f}(s) = \frac{-.194 (s + 7.68)}{(s - 1.0) (s + 3.18)}$$

$$\frac{q}{\delta_f}(s) = \frac{-1.287 (s + 1.78)}{(s - 1.0) (s + 3.18)}$$

$$\frac{a_n}{\delta_f}(s) = \frac{.059 (s^2 + .935s - 13.58)}{(s - 1.0) (s + 2.09)}$$

Short Period Approximation
Transfer Functions for
Basic Airframe
Flt. Cond. 2

$$\frac{\alpha}{\delta_e}(s) = \frac{-.085(s + 130.2)}{(s - .62)(s + 2.09)}$$

$$\frac{q}{\delta_e}(s) = \frac{-11.16(s + .769)}{(s - .62)(s + 2.09)}$$

$$\frac{a_n}{\delta_e}(s) = \frac{-.0407(s^2 + 2.42s + 91.03)}{(s - .62)(s + 2.09)}$$

$$\frac{\alpha}{\delta_f}(s) = \frac{-.133(s + 14.4)}{(s - .62)(s + 2.09)}$$

$$\frac{q}{\delta_f}(s) = \frac{-1.835(s + .888)}{(s - .62)(s + 2.09)}$$

$$\frac{a_n}{\delta_f}(s) = \frac{.0447(s^2 + .566s - 15.74)}{(s - .62)(s + 2.09)}$$

Appendix F

Listing of Computer Program

```

PROGRAM TIEH(INPUT,OUTPUT,TAPE1,TAPE5=INPUT,TAPE6=OUTPUT,PL0
C,TAPE2,PUNCH)
DIMENSION C(7),Z(7),W(7),X3(7),Y3(7)
DIMENSION QFFP(502),DAFP(502),DRFP(502)
DIMENSION Y(35),YP(35),ALPHA0(502),BETA0(502),VEL(502),P(502),
Q(502),R(502),ALT(502),THETA(502),PHI(502),PSI(502),YO(7),
ZTIME(502),ZIST(502),TRAV(502),AX(502),AY(502),A7(502),DELE(502)
ZDELA(502),ZELP(502),TGV(502),THPST(502),DELTF(502)
DIMENSION TIME1M(102),ALPHA1Y(102),DIST1M(102),ALT1M(102),
*AN1M(102)
DIMENSION FLAP01(102),FLAP02(102),FLAP03(102),FLAP0C(102)
COMMON/TIME/CYCLE
COMMON/PARIM/ECMO(41),ECMA(+1),ECMDE(+1),ECMLF(41),ECMO(41),E
1(41),ECCO(41),ECN0H(41),ECNBLE(41),ECLDP(41),ECLNH(41),ECLBLE(
2ECY3(41),EYDP(41),FCYDH(41),FONDR(41,4),ECNP(41,2),ECNR(41,2)
3OF(41,2),ELP(41,2),ECLR(41,2),ECLDF(41,2),ECYDF(41,2),ECNB(41
4ECL3(41,5),ECNO(41,7),ECNH(41,7),ECCO(41,7),ECCO(41,7)
COMMON/FOM/MASS,C,B,THRUS,C6
COMMON/OTHER/IX,IY,IZ,IX7,S
COMMON/REST/A1,A2,A3,A4,31,32,33,34,C1,C2,C3,C4,D1,AV,
1FUDGE,CEPS,SEPS,STHF,CTHE,SFE,CFE,RVR2,ROH,6,V2,THE,FE,SIGH,
2ALPHA,BETA,DR,DE,DF,DH,OLEF,DEC,DRC,DFC,DHC,AMACH
COMMON/HECK/SUMCY,SU437,SUMON,CN,CNO,CC,CCR,CMO,CMA,CMDE,
1CMLE,CMD
COMMON/CKE2/CNB,CNBLE,CNP,CNDP,CNDH,CNDF,CLOD,CLODH,CLP,C
CCLOR,CLALE,CLR
COMMON/TRI4/RED,GAMAD,AL,EN,SUMCY,RLIFT,XCY,TCONST,GCONST
C,THEO,SIGH,FEO
COMMON/IAS/AC,AA,AP,A1,A3,S7,S8,TH
COMMON/TICK/DET,DAT,DRT,DEF,DAF,DRF,F81,F82

```

```

COMMON/STICK/DAFT(170),DRFT(170),DEFT(170)
COMMON/HRUSTT/SOSFS(9),TMILT(9,11)
C,TSAVE
COMMON/CCCI/DELF1,DELF2,S20
EXTERNAL G/RATES,TURNTRM,ANGLE
REAL IX,IY,IZ,IXZ,MASS
NAMELIST/FORCE/DAFT,DEFT,DRFT
NAMELIST/AERO/ECMO,ECMA,ECMOE,ECMOLE,ECMQ,ECNQ,ECNO,ECCO,ECNDH,ECNBL,
1ECLOR,ECLON,ECLBLE,ECYB,ECYDR,ECYDH,ECNDR,ECNP,ECNR,ECNDF,ECLP,ECL
2R,ECLDF,ECYDF,ECNR,ECLB,ECN,ECND,ECCO,ECCD
NAMELIST/GEOM/IX,IY,IZ,IXZ,MASS,S,C,B,THRUS,CG,YO,SIGHO,THEO,FEO,
1EPS
NAMELIST/LENGTH/SOSFS,TMILT
NAMELIST/DOT1M/TIMF1M,ALPHA1M,DIST1M,ALT1M,AN1M
NAMELIST/F.PDAT1/FLAP01
NAMELIST/F.PDAT2/FLAP02
NAMELIST/F.PDAT3/FLAP03
READ(1,AE20)
READ(5,GF1)
READ(5,LENGTH)
43 CONTINUE
READ(5,FORCE)
WRITE(6,201)
WRITE(6,210) (DAFT(I),I=1,20), (DEFT(J),J=1,20), (DRFT(K),K=1,20)
FORMAT("1" //,20X,"TIME HISTORIES OF AIRCRAFT PARAMETERS",
** FOR YF-15, BASIC AND CCV"//,2X," INPUTS ARE AS FOLLOWS:"//,
*2X," STICK FORCES ARE DAFT, DEFT, AND DRFT, INPUT EVERY 1/2 SEC"/)
FCOMAT(" DEFT - ",20(F5.1,1X) //, " DEFT - ",20(F5.1,1X) //,
** DRFT - ",20(F5.1,1X) //)
WRITE(6,211) IX,IY,IZ,IXZ,MASS,S,C,B,THRUS,CG

```



```

211  FORMAT(" MOMENTS OF INERTIA:  IX = ",F8.1,"  IY = ",F8.1,
      *    "  IZ = ",F8.1,"  IXZ = ",F8.1/,"  MASS = ",F5.1,6X,
      *    "  WING AREA = ",F5.1,"  SQ FT ",6X,"  MAC = ",F7.3,6X,
      *    "  WING SPAN = ",F7.3/,"  THRUST = ",F7.1,6X,
      *    "  CENTER OF GRAVITY = ",F5.2,"  OF MAC"/)
      *
      * ***** PROGRAM CONSTANTS *****
      *
      * DO 66 I=1,1
      *   ECNR(I,1)=ECNR(I,3)
      *   ECNR(I,2)=ECNR(I,3)
      *   ECNR(I,4)=ECNR(I,3)
      *   ECNR(I,5)=ECNR(I,3)
      *   ECNR(I,5)=ECNR(I,3)
      *   G=32.2
      *   AV=57.2957*9513
      *   A1=(IY-I7)/IX
      *   A2=IX7/IX
      *   A3=S*R/(2.*IX)
      *   A4=R/2.
      *   C4=A4
      *   B1=(IZ-IX)/IY
      *   B2=IX7/IY
      *   B3=S*C/(2.*IY)
      *   P4=C/2.
      *   C1=(IX-IY)/IZ
      *   C2=IXZ/I7
      *   C3=S*R/(2.*I7)
      *   C4=S/(2.*MASS)
      *   SEPS=SIN(P/S)
      *   CEPS=COS(P/S)
      *   PI=3.1415927$STOP I=2.*PI
      *   DO 61 I=1,

```

```

        YP(I)=0.SY(I)=YO(I)
61 CONTINUE
        AL=3.1/AV
        Y(7)=YO(7)=30000.
        EN=1.
        CALL TURNTRM(Y,YP,YO)
        TSAVE=THRU
        COGOJ=1,7
        YP(J)=C.O
        Y(J)=YO(J)
60 IF(ABS(DE).LT..0001) DE=.0001
        T=0.
        RIALTF=(7)/5000.+1.
        IALTF=RIALTF
        PERIALF=RIALTF-IALTF
        SOS=(SOSFS(IALTF+1)-SOSFS(IALTF))*PERIALF+SOSFS(IALTF)
        AMACH=V2/SOS
        ORAR=RVF2/.SPS=2116.33*((1.-.000006875*Y(7))**5.2561)
        PO=2116.2 $ PSOP0=PS/PO
        PTOT=PS+((.+(AMACH**2.)/5.))**3.5)
        OC=PTOT-PS
        OCAR=OC
        PRINT*, " 1ACH NO = ",AMACH
        PRINT*, " 1C = ",OC
        PRINT*, " 1BAR = ",ORAR
        OOP=OC/PS
        PKA=10000.
        Y(14)=AL*A/
        IF(Y(14).GT.30.)Y(14)=30.
        IF(Y(14).LT.-5.)Y(14)=-5.

```

```

CALL CONTR(L(T)
Y(15)=YP(5)AV
Y(16)=CTHE'CEE-1.
Y(15)=Y(15)+(Y(1)*Y(5)-Y(2)*Y(4))/6
F3=1.
IF(OCAR.GT.150.) F3=1.-(OCAR-150.)/650.*.64
IF(OCAR.GT.800.) F3=.36-.224*(OCAR-800.)/2200.
IF(OCAR.GT.3000.) F3=.136
O1=Y(15)*.F3
S2=Y(14)-1.*O1$IF(S2.LT.0.) S2=0.
Y(17)=Y(16)/2.*S2*.161
Y(17)=Y(17)+.2*Y(15)
S4=Y(14)-2.*O1$IF(S4.LT.0.) S4=0.
F4=.5
IF(OOP.GT..53) F4=.5-(OOP-.53)/1.26*1.5
IF(OOF.GT.1.79) F4=-1.
F2=Y(14)*F4
Y(18)=OE-F2
IF(ABS(Y(18)).GT.25.) Y(18)=Y(18)/(1.*RKA*(1.-25./ABS(Y(18))))
S6P=ABS(OE)-25.$IF(S6P.LT.0.)S6P=0.
S7P=ABS(Y(18))-25.$IF(S7P.LT.0.)S7P=0.
S6=RKA*S7P*Y(18)/ABS(Y(18))
O3=S6+.5.*S6P*OE/ABS(OE)
S5=O3/2.5/.3
PILOT=S5-Y(17)-S4/2.
IF(ABS(OEF).LT.1.75) DEC=0.
IF(ABS(DEF).GE.1.75) DEC=DEF/5.*.89
IF(ABS(DEF).GT.5.5) DEC=(.89+ABS(DEF-5.5)/22.5*7.12)*DEF/ABS(DEF)
F11=2.
IF(PSOP).GT..1.AND.PSOP.LT..3)F11=-7.8*(PSOP-1.)*2.

```

AD-A056 553

AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO SCH--ETC F/G 1/3
MECHANIZATION OF BLENDED A SUB N MODE FOR CCV YF-16.(U)
MAR 78 K R RACE

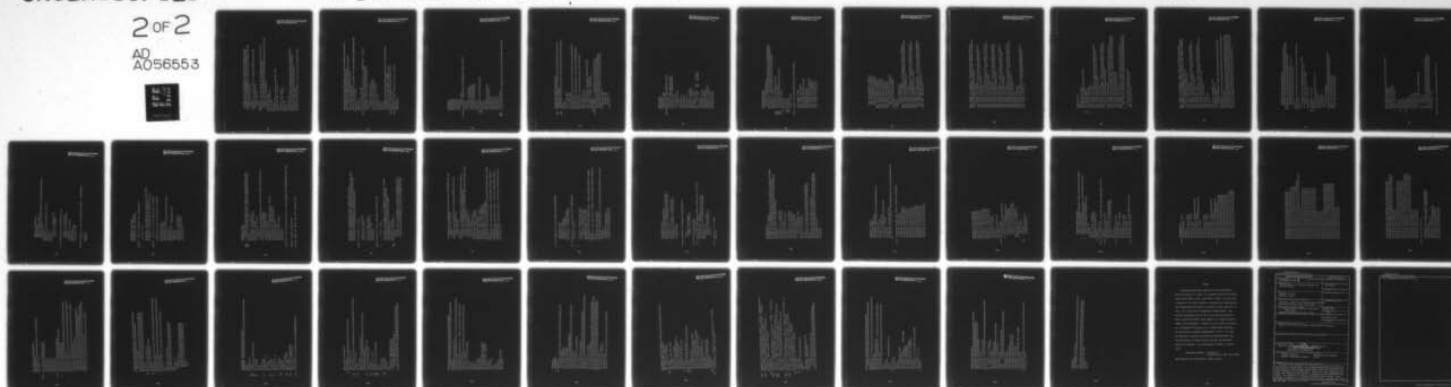
UNCLASSIFIED

AFIT/GAE/AA/78M-16

NL

2 OF 2

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END
DATE
FILMED
9-78

DDC


```

IF(PSOP).GE..3.AND.PSOP.LT..4)F11=-1.5*(PSOP-.3)+.44
IF(PSOP).GE..4.AND.PSOP.LT..7)F11=-.7*(PSOP-.4)+.29
IF(PSOP).GE..7.AND.PSOP.LT..1)F11=-(.08/.3)*(PSOP-.7)+.08
  IF(PSOP).GE..1)F11=0.
  GLF1=0.
IF(PSOP).GT..145.AND.PSOP.LT..3)GLF1=(PSOP-.145)/.155
  IF(PSOP).GE..3)GLF1=1.
    GLF2=COP-F11
    GLF2N=0.
  IF(GLF2I.GT..33.AND.GLF2I.LT..46)GLF2N=.315*(GLF2I-.33)/.13
  IF(GLF2I.GE..46.AND.GLF2I.LT..6)GLF2N=.315
  IF(GLF2I.GE..5.AND.GLF2I.LT..2.7)GLF2N=-.315*(GLF2I-.6)/2.1+.315
  IF(GLF2I.GE..2.7)GLF2N=0.
  FUNC=GLF1+.5*LF2N
  T2=2.*PILOT/(FUNC-1.)
  Y(25)=T2/2.
  FLMT=-1.
  IF(OCAR.GE.34.) FLMT=-1.-(OCAR-34.)/50.
  IF(OCAR.GE.184.) FLMT=-4.
  T1=T2
  IF(T1.GT.7.5) T1=7.5
  IF(T1.LT.FLMT) T1=FLMT
  CET=T1-DEC
  DA=DF
  Y(19)=Y(20)=0.
  Y(25)=ORV(23)=DASY(24)=-DASY(21)=DE+DA/4. $Y(22)=DE-DA/4.
  PEAK=1.-ABS(Y(14))/10.$IF(ABS(Y(14)).GT.10.)PEAK=0.
  F7=0.$IF(OP.GT..187) F7=(OOP-.187)/.942
  IF(OOP.GT..1.129) F7=1.
  IF(OOP.GT..1.709.AND.OOP.LT.3.23) F7=1.-(OOP-1.709)/1.521

```

```

F8=.5$IF(0)P.GT.2.84)F8=(70P-2.84)/.78+.5$IF(QOP.GT.3.23)F8=1.
S11=.0375*Y(14)-PEAK*.65*F7$P2=S11*DA
AYT =(YP(2)-Y(3)*Y(4)+Y(1)*Y(6))/32.2)-CTHE*SFE
S13=.6*AYT*G+0.$PILOTR=DR-P2-S13*F8
PILOTA=-DA*.12+Y(4)*AV
ACRF=0.$IF(ABS(DRF).GT.15.)ACRF=DRF-DRF/ABS(DRF)*15.$DRT=PILOTR+AN
CRF$DAT=-PI.OTA/1.67
DAT=-DAT
DAT=DRT=0.
WRITE (5,2)6) DAT,DRT
206 FORMAT(*,A1L,ON TRIM = *,F5.1,* RUDDER TRIM = *,F5.1)
IF(ABS(DAT).GT.40.) DAT=40.*DAT/ABS(DAT)
IF(ABS(DRT).GT.8.) DRT=8.*DRT/ABS(DRT)
Y(27)=0.
    F81=F82=Y(28)=Y(29)=0.
    Y(30)=1.6*(.5*Y(15)+Y(14)-2.)
    IF (Y(30).GT.25.) Y(30)=25.
    IF(Y(30).LT.0.) Y(30)=0.
    Y(31)=Y(32)=0.
    Y(33)=0.
    Y(74)=0.
    Y(35)=0.
    Y(23)=DASY(22)=DE-DA/4.$Y(24)=-DASY(21)=DE+DA/4.$Y(25)=DR
    IF(ABS(DE).GT.2.4) WRITE (6,205)
    IF(ABS(DE).GT.2.4) DET=2.4*DET/ABS(DE)
205 FORMAT (* )DELTA TRIM GREATER THAN 2.4 *)
    WRITE(6,207) DET
203 FORMAT(* DELTA ELEVATOR TRIM IS = *,F5.1)
    U1=THEO/2.
    U2=SIGHO/2.

```

```

U3=FE0/2.
U4=COS(U1)
U5=SIN(U1)
U6=COS(U2)
U7=SIN(U2)
U8=COS(U3)
U9=SIN(U3)
      FUDGE=9) ./AV
***** INITIAL CONDITIONS FOR AIRCRAFT STATES *****
YP(8)=0.
YP(10)=0.
      IF (T.LT.0.) GOT024
Y(8)=U6+U4- U8+U5+U7+U9
Y(9)=U6+U4- U9-U5+U7+U8
Y(10)=U6+U5 +U8+U7+U4+U9
Y(13)=0.
CO TO 25
24 Y(9)=THEOSY (9)=SIGHOSY(10)=FE0
25 CONTINUE
Y(11)=0.
Y(12)=0.
Y(13)=U7+U. +U8-U6+U5+U9
AL=ATAN2(Y(3),Y(1))
ALPHA=AL+A/
WRITE(6,10)
WRITE(6,10)
WRITE(6,10)
WRITE(6,10)
FORMAT(10X, *W*//)
196 FORMAT("1", 1X, *T*, 7X, *VR*, 8X, *P*, 7X, *THETA*, 5X, *ALPHA*, 7X, *AX*,
197

```



```

      *8X,*DE*,7X,*QBIA*,6X,*DRLF1*)
      FORMAT(10X,*U*,9X,*O*,7X,*PSI*,7X,*RETA*,8X,*AY*,8X,*OR*,7X,
      **QBIA*,6X,*DRLF2*)
      FORMAT(10X,*V*,9X,*P*,7X,*PHI*,19X,*AZ*,8X,*OA*,7X,*DELFC*,6X,
      **S2C*)
      LOOP=60
      DO 77 J=1,-00P
      DO 76 JFK=1,40
      IF (T.LT..005)
      *WRITE(6,201) T,VR,Y(4),THETA(J),ALPHA,AX(J),DE,QBIAS,DELF1
      IF(T.LT..005)
      *WRITE(6,201) Y(1),Y(5),PSI(J),BETA,AY(J),OR,GBIAS,DELF2
      IF(T.LT..005)
      *WRITE(6,201) Y(2),Y(6),PHI(J),A7(J),DF,DELF3,S20
      IF(T.LT..005)
      *WRITE(6,201) Y(3)
      CALL CONTRL(T)
      CALL PKGXY(T,Y,YP,35,.005,1.000005,GYRATES)
      IF(Y(18).GT.100.) Y(18)=100.
      IF(Y(18).LT.-100.) Y(18)=-100.
      76 CONTINUE
      ***** STORAGE OF PARAMETERS FOR PLOTTING *****
      AX(J)=((YP(1)-Y(2)*Y(2)+Y(6)*Y(3)*Y(5))/32.2)+STHE
      AY(J)=((YP(2)-Y(3)*Y(4)+Y(1)*Y(6))/32.2)-CTHE*SFE
      AZ(J)=((YP(3)-Y(1)*Y(5)+Y(2)*Y(4))/32.2)-CTHE*CFE-
      *YP(5)*12.7/32.2
      DEFP(J)=DEF
      DAFP(J)=DAF
      DRFP(J)=DRF
      DELE(J)=7F

```



```

DELR(J)=DR
DELA(J)=DF
DELTF(J)=DELFC
THRST(J)=TIRUS
*****TURNS ABOUT THE GRAVITY VECTOR
TGV(J)=SIGH*AV
IF(SIGH.LT.-PI)SIGH=SIGH+TOPI
IF(SIGH.GT.PI)SIGH=SIGH-TOPI
CIST(J)=Y(1)
TRAV(J)=Y(2)
      RETAD(J)=RETA
VEL(J)=VR
P(J)=Y(4)*V
Q(J)=Y(5)*V
R(J)=Y(6)*V
ALT(J)=Y(7)
THETA(J)=H*AV
PSI(J)=SIGH*AV/360.
PHI(J)=E*AV
ALPHAD(J)=ALPHA
IF( FE.LT.-PI)FE=FE+TOPI
IF( FE.GT.PI)FE=FE-TOPI
TIME(J)=T
TIME1M(J)=IME(J)
ALPHA1M(J)=ALPHA
DIST1M(J)=DIST(J)
ALT1M(J)=A.T(J)-Y0(7)
AN1M(J)=-1.*A7(J)
FLAP01(J)=ELFC
FLAP02(J)=ELFC

```

```

FLAPD3(J)=1ELFC
CALL SECON(CPTM)
IF(CPTM.GT.200.)GOTO618
WRITE(6,201) T,VR,Y(4),THETA(J),ALPHA,AX(J),DE,GBIAS,DELF1
WRITE(6,202) Y(1),Y(5),PSI(J),BETA,AY(J),DR,GBIAS,DELF2
WRITE(6,203) Y(2),Y(5),PHI(J),AZ(J),DF,DELFC,S20
WRITE(6,204) Y(3)
FORMAT(1X,F4.1,1X,8(F8.3,2X))
200  FORMAT(6X,8(F8.3,2X))
201  FORMAT(6X,8(F8.3,2X))
202  FORMAT(6X,8(F8.3,2X),10X,4(F8.3,2X))
204  FORMAT(6X,8.3//)
77  CONTINUE
GO TO 616
618 LOOP=J-1
616 CONTINUE
PUNCH FLPDAT2

C *** PLACE STOP CARD HERE TO STOP PLOT ROUTINE

CALL FACTOR(.65)
CALL PLOT(.,-12.,-3)
CALL PLOT(.,1.,-3)
CALL SCALE(TIME,12.,LOOP,1)
ALPHAD(LOOP+1)=0.
ALPHAD(LOOP+2)=1.5
CALL SCALE(RETAD,4.,LOOP,1)
CALL SCALE(VEL,4.,LOOP,1)
CALL SCALE(F,4.0,LOOP,1)
CALL SCALE(O,4.0,LOOP,1)
CALL SCALE(R,4.0,LOOP,1)

```

```

CALL SCALE(THETA,4.,LOOP,1)
CALL SCALE(DEEP,4.,LOOP,1)
CALL SCALE(DAFP,4.,LOOP,1)
CALL SCALE(DDEP,4.,LOOP,1)
CALL SCALE(DELE,4.,LOOP,1)
CALL SCALE(DELR,4.,LOOP,1)
CALL SCALE(DELA,4.,LOOP,1)
CALL SCALE(DELT,4.,LOOP,1)
CALL SCALE(AX,4.,LOOP,1)
CALL SCALE(AY,4.,LOOP,1)
CALL SCALE(AZ,4.,LOOP,1)
CALL SCALE(DIST,12.,LOOP,1)
CALL SCALE(ALT,4.,LOOP,1)
CALL SCALE(THRST,4.,LOOP,1)
L=LOOP+1
M=LOOP+2
PHI(L)=FGV(L)=-180.
PHI(M)=TGV(M)=72.
CALL AXIS(0.,0.,10*TIME - SEC,-10,12.,0.,TIME(L),TIME(M))
CALL AXIS(0.,0.,17*HVELOCITY - FT/SEC,17,4.,90.,VEL(L),VEL(M))
CALL LINE(IME,VEL,LOOP,1,0,75)
CALL PLOT(0.,5.,-3)
CALL AXIS(0.,0.,10*TIME - SEC,-10,12.,0.,TIME(L),TIME(M))
CALL AXIS(0.,0.,12*THRST - LRS,12,4.,90.,THRST(L),THRST(M))
CALL LINE(IME,THRST,LOOP,1,0,75)
CALL PLOT(0.,5.,-3)
CALL AXIS(0.,0.,13*DISTANCE - FT,-13,12.,0.,DIST(L),DIST(M))
CALL AXIS(0.,0.,13*ALTITUDE - FT,13,4.,90.,ALT(L),ALT(M))
CALL LINE(DIST,ALT,LOOP,1,50,5)
CALL PLOT(15.,-10.,-3)

```



```

CALL AXIS(0,0,10,TIME - SEC,-10,12,0,0,TIME(L),TIME(M))
CALL AXIS(0,0,11,HALPHA - DEG,11,4,0,90,0,ALPHAD(L),ALPHAD(M))
CALL LINE( TIME,ALPHAD,LOOP,1,0,75)
CALL PLOT(0,5,-3)
CALL AXIS(0,0,10,TIME - SEC,-10,12,0,0,TIME(L),TIME(M))
CALL AXIS(0,0,11,H - DEG/SEC,11,4,0,90,0(L),0(M))
CALL LINE( TIME,H,LOOP,1,0,75)
CALL PLOT(0,5,-3)
CALL AXIS(0,0,10,TIME - SEC,-10,12,0,0,TIME(L),TIME(M))
CALL AXIS(0,5,18,H ACCELERATION - G,18,4,90,0,0(L),0(M))
CALL LINE( TIME,AZ,LOOP,1,0,75)
CALL PLOT(16,-10,-3)
CALL AXIS(0,0,10,TIME - SEC,-10,12,0,0,TIME(L),TIME(M))
CALL AXIS(0,0,10,BETA - DEG,10,4,90,0,BETAD(L),BETAD(M))
CALL LINE( TIME,BETAD,LOOP,1,0,75)
CALL PLOT(0,5,-3)
CALL AXIS(0,0,10,TIME - SEC,-10,12,0,0,TIME(L),TIME(M))
CALL AXIS(0,0,11,H - DEG/SEC,11,4,0,90,0(L),0(M))
CALL LINE( TIME,R,LOOP,1,0,75)
CALL PLOT(0,5,-3)
CALL AXIS(0,0,10,TIME - SEC,-10,12,0,0,TIME(L),TIME(M))
CALL AXIS(0,0,18,H ACCELERATION - G,18,4,90,0,0(L),0(M))
CALL LINE( TIME,AY,LOOP,1,0,75)
CALL PLOT(15,-10,-3)
CALL DSP(2189)
CALL PLOT(0,-6,-3)
CALL PLOT(0,1,-3)
CALL AXIS(0,0,10,TIME - SEC,-10,12,0,0,TIME(L),TIME(M))
CALL AXIS(0,0,9,PHI - DEG,9,4,0,90,0,PHI(L),PHI(M))
CALL PLOT(0,2.5,-3)

```



```

D027J=1,LOOP
NO=2
IF(J.EQ.1) 0 TO 26
IF(ARS(PHI(J-1)-PHI(J)).GT.50.)NO=3
XX=TIME(J)/TIME(M)
YY=PHI(J)/PHI(M)
CALL PLOT(X,YY,NO)
CALL PLOT(.,-2.5,-3)
CALL PLOT(.,5.,-3)
CALL AXIS(.,0.,10,TIME - SEC,-10,12.,0.,TIME(L),TIME(M))
CALL AXIS(.,0.,11,HP - DEG/SEC,11,4.0,90.,P(L),P(M))
CALL LINE(TIME,P,LOOP,1,0,75)
CALL PLOT(.,5.,-3)
CALL AXIS(.,0.,10,TIME - SEC,-10,12.,0.,TIME(L),TIME(M))
CALL AXIS(.,0.,11,THETA - DEG,11,4.,90.,THETA(L),THETA(M))
CALL LINE(TIME,THETA,LOOP,1,0,75)
CALL PLOT(15.,-10.,-3)
CALL AXIS(.,0.,10,TIME - SEC,-10,12.,0.,TIME(L),TIME(M))
CALL AXIS(.,0.,19,HFLEVATOR DISP - DEG,19,4.,90.,DELE(L),DELE(M))
CALL AXIS(-.5,0.,18,HFLEVATOR FORCE-LBS,18,4.,90.,DEFP(L),DEFP(M))
CALL LINE(TIME,DEFP,LOOP,1,10,5)
CALL LINE(TIME,DELE,LOOP,1,0,75)
CALL PLOT(.,5.,-3)
CALL AXIS(.,0.,10,TIME - SEC,-10,12.,0.,TIME(L),TIME(M))
CALL AXIS(.,0.,18,HAILERON DISP - DEG,18,4.,90.,DELA(L),DELA(M))
CALL AXIS(-.5,0.,17,HAILERON FORCE-LBS,17,4.,90.,DAFP(L),DAFP(M))
1) CALL LINE(TIME,DAFP,LOOP,1,10,5)
CALL LINE(TIME,DELA,LOOP,1,0,75)
CALL PLOT(.,5.,-3)

```

26

27

```

CALL AXIS(0,0,0,10,TIME - SEC,-10,12,0,0,TIME(L),TIME(M))
CALL AXIS(0,0,0,17,PUDDER DISP - DEG,17,4,0,90,0,DELR(L),DELR(M))
CALL AXIS(0,0,0,16,PUDDER FORCE-LRS,16,4,0,90,0,DRFP(L),DRFP(M))
CALL LINE(TIME,DRFP,LOOP,1,10,5)
CALL LINE(TIME,DELR,LOOP,1,0,75)
CALL PLOT(16,0,-10,-3)
CALL AXIS(0,0,0,10,TIME - SEC,-10,12,0,0,TIME(L),TIME(M))
CALL AXIS(0,0,0,18,ACCELERATION - G,18,4,0,90,0,AX(L),AX(M))
CALL LINE(TIME,AX,LOOP,1,0,75)
CALL PLOT(16,0,-10,-3)
CALL AXIS(0,0,0,10,TIME - SEC,-10,12,0,0,TIME(L),TIME(M))
CALL AXIS(0,0,0,16,FLAP DISP. - DEG,16,4,0,90,0,DELTF(L),DELTF(M))
CALL LINE(TIME,DELTF,LOOP,1,0,75)
CALL PLOT(16,0,-10,-3)
CALL PLOT(16,0,-10,-3)
CALL DSP(21,BR)
STOP 5555
END
SUBROUTINE GYRATES(T,Y,YP)
DIMENSION Y(35),YP(35)
COMMON/TIME/CYCLE
COMMON/HECK/SUMCX,SUMCZ,SUMCM,ZN,CND,CC,CCO,CMA,CMDE,
1CMDE,CMO
COMMON/CHK/K2/CNB,CNRL,CNR,CNP,CNDR,CNDH,CNDF,CLOH,CLP,CLR,
CCLOH,CLRL,CLB
COMMON/PAP/M/ECMO(41),ECMA(41),ECMD(41),ECMDL(41),ECMQ(41),ECNQ
1(41),ECCQ(41),FCNDH(41),ECNBL(41),ECLOH(41),ECLE(41),
2ECYB(41),FYDR(41),FCYDH(41),ECNDR(41,4),ECNP(41,2),ECNR(41,2),ECN
3DF(41,2),FCLP(41,2),ECLP(41,2),ECLOF(41,2),ECYDF(41,2),ECNB(41,5),
4ECLB(41,5),ECNC(41,7),ECND(41,7),ECCO(41,7)

```

```

COMMON/GEOM/MASS,C,B,THRU,S,CG
COMMON/REST/A1,A2,A3,A4,B1,B2,B3,B4,C1,C2,C3,C4,D1,AV,
1FUDGE,CEPS,SEPS,STHE,CTHE,SFE,OFF,RVR2,ROH,G,VR,THE,FE,SIGH,
2ALPHA,BETA,DP,DE,DF,DH,DLEF,DEC,DEC,DFC,DHC,AMACH
COMMON/IAS/AC,A1,AB,A1.03,S7,S8,TH
COMMON/TICK/DET,DAT,OPT,DEF,DAF,DRF,FP1,FR2
COMMON/THRUST/SOSFS(3),TMILT(9,11)
C,TSAVE
COMMON/CCC/DELFC,ORIAS,GRIAS,S10,DELF,XCD,DELF1,DELF2,S20
REAL MASS,K
K=10.
PS=211.33*(1.-.00000687535*Y(7))*5.2561)
ROH=.002373*(1.-.00000638*Y(7))*4.256)
IF(ABS(Y(1)).LT.1.E-20)GOTO53
AL=ATAN2(Y(3),Y(1))
GO TO 54
53 AL=SIGN(FUDGE,Y(3))
54 CONTINUE
VR=SQR(Y(1)**2+Y(2)**2+Y(3)**2)
RVR2=ROH*(VR**2)
VOVR=Y(2)/VR
PE=ASIN(VOVR)
ALPHA=AL-AR
BETA=BETA-AT
IF(T.LT.C.)GOTO52
EP=1.-(Y(8)*Y(8)+Y(9)*Y(9)+Y(10)*Y(10)+Y(13)*Y(13))
C11=Y(3)*Y(8)+Y(9)*Y(9)-Y(10)*Y(10)+Y(13)*Y(13)
C12=2.*(Y(10)*Y(10)+Y(8)*Y(13))
C13=2.*(Y(13)*Y(13)-Y(8)*Y(10))
C23=2.*(Y(10)*Y(13)+Y(8)*Y(9))

```

```

C33=Y(8)*Y(8)+Y(13)*Y(13)-Y(9)*Y(9)-Y(10)*Y(10)
FE= ATAN2(C23,C33)
IF(C13.GT.1.)C13=1.
IF(C13.LT.-1.)C13=-1.
SIGH= ATAN2(C12,C11)
THE= ASIN(-C13)
TH=THE
GO TO 51
52 FE=Y(10)
SIGH=Y(9)
THE=Y(8)
51 CONTINUE
SFE=SIN(FE)
CFE=COS(FE)
STHE=SIN(TH)
CTHE=COS(TH)
SPST=STN(SIGH)
CPSI=COS(SIGH)
IF(ABS(CTHE).LT..001)CTHE=.001
PT =Y(4)*1V
OT =Y(5)*1V
RT =Y(6)*1V
AXT =((YP(1)-Y(2)*Y(6)+Y(3)*Y(5))/32.2)+STHE
AYT =((YP(2)-Y(3)*Y(4)+Y(1)*Y(6))/32.2)-CTHE*SFE
AZT =((YP(3)-Y(1)*Y(5)+Y(2)*Y(4))/32.2)-CTHE*CFE-
*YP(5)*12.7/32.2

```

***** YF-16 STABILITY AUGMENTATION SYSTEM *****


```

PIALTF=(7)/5000.+1.
IALTF=PIALTF
PERIALF=PIALTF-IALTF
SOS=(SOSFS(IALTF+1)-SOSFS(IALTF))*PERIALF+SOSFS(IALTF)
AMACH=V/SOS
QBAR=RVF2/2.
PTOT=PS*(1.+(AMACH**2.)/5.)*3.5)
QC=PTOT-PS
QCAR=QC
QCP=QC/PS
PO=2116.2 $ PSOP0=PS/PO
IF(T.L..0.)GOTO56

```

C *** LONGITUDINAL AUGMENTATION ***

```

IF(DET..T.2.4)DET=2.4
IF(DET..T.-2.4)DET=-2.4
DFC=0.
YP(35)=K*(DEF-Y(35))
EASIN=Y(35)
DEF1=ABS(P1 SIN)
CCVIN=DEF-Y(35)

```

C***** BLENDED AI MODE WITH BASIC AIRCRAFT (MECHANIZED)

```

DELFC=0.
OBIAS=0.

```

```

DOLF=CCVIN*15./7.25
IF(DOLF.GT.15.) DOLF=15.
IF(DOLF.LT.-15.) DOLF=-15.

C***** FLAP DEFLECTION PER G SCHEDULING
C - AT SEA LEVEL

IF(QOP.GE..2.AND.QOP.LT..7) SLQUOT=40.-(165.*QOP)
IF(QOP.GE..2.AND.QOP.LT..7) SLQUOT=7.
IF(QOP.GE..7) SLQUOT=7.+(37.2/2.1)*(QOP-.7)

C***** DELTA FLAP PER G DIRECT LIFT (DOLF0G)
DOLF0G=SLQUOT*(33.-(33.*QOP))*(1.-PSOP0)

G0DOLF=1./FLF0G
DOLF1=DOLF*G0DOLF
AR0DOLF1=ABS(DOLF1)
IF(AR0DOLF1.GT.3.) DOLF1=3.*DOLF1/AR0DOLF1
DAN=-A77-1.1
ADAN=ABS(DAN)
IF(ADAN.GT.3.) DAN=SIGN(3.,DAN)
GR1AS=DAN
F0=ALPHA
IF(ALPHA..E.-5.) F0=-5.
IF(ALPHA.GE..30.) F0=30.
YP(14)=10.*(F0-Y(14))
PUR1=4.*ALPHA

```

```

S20=PUR1-Y(34)
YP(34)=50.'S20
  IF(DEF1.GT.1.75.AND.DEF1.LT.7.25) DEC=(.88/5.5)*(DEF1-1.75)
  IF(DEF1.GT.7.25.AND.DEF1.LT.31.) DEC=((7.12/23.75)*(DEF1-7.25
*))+.38
  IF(BASIN.LT.0.) DEC=-DEC
  IF(BASIN.LE.-17.65) DEC=-4.
  DEC=DEC+DEF+GRIAS
  IF(DEC.GT.7.5) DEC=7.5
  DEC1=-1.
  IF(OCAR.GT.34..AND.OCAR.LT.184.) DEC1=(((-3./150.)*(OCAR-34.))-1.
  IF(OCAR.GT.184.) DEC1=-4.
  IF(DEC.LT.DEC1) DEC=DEC1
  YP(31)=4.+(DEC+DEF-Y(31))
  DELF1=DELF1+Y(31)
  IF(DELF1.GE.-4..AND.DELF1.LE.8.) DELF1=0.
  IF(DELF1.LT.-4.) DELF1=DELF1+4.
  IF(DELF1.GT.8.) DELF1=DELF1-8.
  DELF1=DELF1*DELF0
  DELF=DELF-DELF1
  YP(32)=4.+(DELF-Y(32))
  DELF=Y(32)
  DELFC=DELF

```

C***** AT THIS POINT DELFC IS DELTA FLAP COMMAND FOR SYMMETRICAL FLAP DEF.

C***** METHOD TO GET GRIAS

C***** LOGIC FOR PITCH RATE PER G DIRECT LIFT

```
IF(QOP.GE..1) ..AND.QOP.LT..165) XMINV=2.35-(2.*QOP)
IF(QOP.GE..165.AND.QOP.LT..6) XMINV=2.02-(.84/.435)*(QOP-.165)
IF(QOP.GE..6.AND.QOP.LT.1.4) XMINV=1.18-(.35/.8)*(QOP-.6)
IF(QOP.GE.1.4) XMINV=.83-(.25/1.95)*(QOP-1.4)
```

C***** LET XMFACI = 1345/A

```
XMFACI=1.91-(.26*PSOP0)
QOGOL=XMFACI*T*XMINV
```

```
YT=Y(32)*G) DELF*QOGOL
DYT=YP(32)*G) DELF*QOGOL
YP(33)=DYT-Y(33)
QRIAS=Y(33)
```

C***** LOGIC FOR DELTA ELEVATOR PER DELTA FLAP

C - AT SEA LEVFL

```
IF(QOP.GE..1) ..AND.QOP.LT..7) SLDEODF=-.035-(.180/.7)*QOP
IF(QOP.GE..7) SLDEODF=-.215+(.035/2.1)*(QOP-.7)
DEODF=SLDEODF*(.05-(.11*QOP))*(1.-PSOP0)
DELF2=DEODF*DEODF
DELF2=DELF2+.1*S20
YP(26)=8.31 (DEC-Y(25))
```

902

```
F11=2.
IF(PSOP0).GT..1.AND.PSOP0.LT..3) F11=-7.8*(PSOP0-.1)+2.
IF(PSOP0).GE..3.AND.PSOP0.LT..4) F11=-1.5*(PSOP0-.3)+.44
IF(PSOP0).GE..4.AND.PSOP0.LT..7) F11=-.7*(PSOP0-.4)+.29
```



```

IF(PSOP0;.E..7.AND.PSOP0.LT.1.)F11=-(.03/.3)*(PSOP0-.7)+.08
  IF(PSOP0.GE.1.)F11=0.
  GLF1=0.
IF(PSOP0;.T..145.AND.PSOP0.LT..3)GLF1=(PSOP0-.145)/.155
  IF(PSOP0.GE..3)GLF1=1.
  GLF2J=00P-F11
  GLF2N=0.
  IF(GLF2I.GT..33.AND.GLF2I.LT..46)GLF2N=.315*(GLF2I-.33)/.13
  IF(GLF2I.GE..46.AND.GLF2I.LT..6)GLF2N=.315
  IF(GLF2I.GE..6.AND.GLF2I.LT.2.7)GLF2N=-.315*(GLF2I-.6)/2.1+.315
  IF(GLF2I.GE.2.7)GLF2N=0.
  DEC1=Y(25)*GLF1*GLF2N
  NEC=DEC1-Y(26)
  YP(15)=(Y(5)*AV)-Y(15)
  YP(15)=15.*(-A7T-1.-Y(15))
  S1=Y(15)+.*Y(15)-.4*CR1AS
  NS1=Y(15)+.4*Y(15)
  IF(QCAR.LE.150.) Q1=.7*Y(15)
  IF(QCAR.LE.150.) Q1=.7*YP(15)
  IF(QCAR.GE.3000.) Q1=.0952*Y(15)
  IF(QCAR.GE.3000.) Q1=.0952*YP(15)
  IF(QCAR.GT.150..AND.QCAR.LE.800.) Q1=Y(15)*(.7+(150.-QCAR)*(.448/
    *50.))
  IF(QCAR.GT.150..AND.QCAR.LE.800.) Q1=YP(15)*(.7+(150.-QCAR)*(.
    *.448/50.))
  IF(QCAR.GT.800..AND.QCAR.LT.3000.) Q1=Y(15)*(.252+(900.-QCAR)*
    *(.1568/220.))
  IF(QCAR.GT.800..AND.QCAR.LT.3000.) Q1=YP(15)*(.252+(900.-QCAR)*
    *(.1568/220.))

```

C *** CHANGE S2 FOR 1ST LEVEL ALPHA COMPARATOR

S2=Q1+Y(1)-15.
DS2=Q1+Y(14)
IF(S2.LE.0.) S3=S1
IF(S2.LE.0.) DS3=DS1
IF(S2.GT.0.) S3=S1+.322*S2
IF(S2.GT.0.) DS3=DS1+.322*DS2

C *** CHANGE S4 FOR 2ND LEVEL ALPHA COMPARATOR

S4=Y(14)+1-20.4

C

YP(17)=3. DS3+15.*(S3-Y(17))
IF(S4.GT.0.) S5=Y(17)+S4+DEC
IF(S4.LE.0.) S5=Y(17)+DEC
IF(OCAR.LE.150.) Q3=1.25*S5
IF(OCAR.GE.3000.) Q3=.17*S5
IF(OCAR.GT.150..AND.OCAR.LE.3000.) Q3=(1.25+(150.-OCAR)*(.8/650.
*)) *S5
IF(OCAR.GT.800..AND.OCAR.LT.3000.) Q3=(.45+(800.-OCAR)*(.28/2200.
*)) *S5
IF(OCAR.LE.53) F4=.5*Y(14)
IF(OCAR.GE.1.79) F4=-Y(14)
IF(OCAR.GT.53..AND.OCAR.LT.1.79) F4=Y(14)*(.5+(.53-QCAR)*(1.5/1.26))
S9=F4+Q3
S8=S9+Y(1)
IF(ABS(S8).LE.25.) Q5=0.
IF(S8.GT.25.) Q5=(S8-25.)*5.
IF(S8.LT.-25.) Q5=(S8+25.)*5.

```

S6=Q3-Q5+.5*S20
IF(ABS(Y(18)).LE.25.)S7=S6
IF(Y(18).GT.25.) S7=S6-10000.*(Y(18)-25.)
IF(Y(18).LT.-25.) S7=S6-10000.*(Y(18)+25.)
YP(18)=5.*S7
IF(YP(18).GT.100000.) YP(18)=100000.
IF(YP(18).LT.-100000.) YP(18)=-100000.
S10=S9+Y(18)
S11=S10+Q1*LF2

```

C *** LATERAL-DIRECTIONAL AUGMENTATION ***

```

DRG=0.
IF(DRT.GT.8.)DRT=8.
IF(DRT.LT.-8.)DRT=-8.

```

```

C *** RUDDER PENAL FORCE
      DTR=D*S(DRF)
C *** RUDDER BREAKOUT FORCE UPDATED FROM 20 LB. TO 15 LB.
      IF(DTR.LE.15.) DRF3=0.
      IF(DRF.GT.15.) DRF3=(DRF-15.)*(30./95.)
      IF(DRF.LT.-15.) DRF3=(DRF+15.)*(30./95.)
      DRG=DRF3-DRT
      IF(DAT.GT.40.)DAT=40.
      IF(DAT.LT.-40.)DAT=-40.
      DAC=0.
C *** AILERON STICK FORCE
      DAF1=0.

```

```

ADAF=ARS(M F)
IF(ADAF.LE.1.) DAF1=0.
IF(ADAF.GT.1..AND.ADAF.LT.5.1) DAF1=((ADAF-1)/5.1*35.)*DAF/ADAF
IF(ADAF.GE.6.1) DAF1=(35.+(ADAF-6.1)/5.1*70.)*DAF/ADAF
IF(ADAF.GE.11.2) DAF1=(105.+(ADAF-11.2)/5.1*175.)*DAF/ADAF
IF(ADAF.GE.15.3) DAF1=280.*DAF/ADAF
Y28=Y29=0.
IF(Y(28).GT.0.) Y23=Y(23)
IF(Y(29).LT.0.) Y29=Y(29)
T21=DAF1-Y28-Y29
YP(27)=10.*T21-10.*Y(27)
TU=TL=0.
IF(Y(27).LT.0.) TL=YP(27)
IF(Y(27).GT.0.) TU=YP(27)
YP(23)=6.*TU-20.*Y(28)
YP(29)=6.*TL-20.*Y(29)
DAC=Y(27)+)AT*1.67
P1=.12*(AV*Y(4)-DAC)
IF(P1.GT.20.) P1=20.
IF(P1.LT.-20.) P1=-20.
P4=0.
IF(Y(14).GT.0.) AN7=Y(14).LE.10.) P4=.65-.065*Y(14)
IF(Y(14).LE.0..AND.Y(14).GE.-10.) P4=.65+.065*Y(14)
P5=0.
IF(OPP.GE.1.129..AND.OPP.LE.1.709) P5=P4
IF(OPP.GT.1.187..AND.OPP.LT.1.129) P5=(1./1.942)*(OPP-.187)*P4
IF(OPP.GT.1.709..AND.OPP.LT.3.23) P5=(1./1.521)*(3.23-OPP)*P4
S11=.0375*Y(14)-P5
P2=P1*S11
S17=2.*P1

```



```

S18=S10-.125*S17
S19=S10+.125*S17
P3=Y(14)*A/*Y(4)/57.3
DPR=(YP(14)*AV*Y(4)/57.3)+(Y(14)*AV*YP(4)/57.3)
S12=AV*Y(6)-P3
DS12=AV*Y(6)-DP3
YP(19)=1.5*DS12-Y(19)
YP(20)=3.*P(19)+15.*(Y(19)-Y(20))
S13=Y(20)+19.32*AYT
S14=P2+S13
IF(POP.LF.2.04)S14=P2+.5*S13
IF(POP.GT.2.04.AND.00P.LT.3.23)S14=P2+S13*(.5+ (.5/1.19)*(QOP-2.04)
1)

C *** ACTUATOR DYNAMICS AND CONTROL SURFACE POSITIONS
YP(21)=20.*(S19-Y(21))
YP(22)=20.*(S18-Y(22))
YP(23)=20.*(P1+DELFC-Y(23))
YP(24)=20.*(-P1+DELFC-Y(24))
YP(25)=20.*(S14-DPC-Y(25))
IF(YP(21).LT.60.)YP(21)=60.
IF(YP(22).LT.60.)YP(22)=60.
IF(YP(23).LT.56.)YP(23)=56.
IF(YP(24).LT.56.)YP(24)=56.
IF(YP(25).LT.120.)YP(25)=120.
IF(YP(21).LT.-60.)YP(21)=-60.
IF(YP(22).LT.-60.)YP(22)=-60.
IF(YP(23).LT.-56.)YP(23)=-56.
IF(YP(24).LT.-56.)YP(24)=-56.
IF(YP(25).LT.-120.)YP(25)=-120.

```

```

IF(Y(21).GT.25.)Y(21)=25.
IF(Y(22).GT.25.)Y(22)=25.
IF(Y(23).GT.20.)Y(23)=20.
IF(Y(24).GT.20.)Y(24)=20.
IF(Y(25).GT.30.)Y(25)=30.
IF(Y(21).LT.-25.)Y(21)=-25.
IF(Y(22).LT.-25.)Y(22)=-25.
IF(Y(23).LT.-20.)Y(23)=-20.
IF(Y(24).LT.-20.)Y(24)=-20.
IF(Y(25).LT.-30.)Y(25)=-30.
CF=.5*(Y(21)+Y(22))
CH=-.5*(Y(21)-Y(22))
DR=Y(25)
DELF=(Y(23)+Y(24))/2.
DF=Y(23)-DELF
C *** DLEF SCHEDULING
      DLEFT=2.1*(.5*Y(15)+Y(14)-2.)
      TLEFT=DLEFT*1.5/2.1
      IF(OLEFT.GT.25.0)DLEFT=25.0
      IF(OLEFT.LT.0.)DLEFT=0.
      YP(30)=3.*(OLEFT-Y(30))
      IF(YP(30).GT.30.)YP(30)=30.
      IF(YP(30).LT.-30.)YP(30)=-30.
      IF(Y(30).GT.25.)Y(30)=25.
      IF(Y(30).LT.0.)Y(30)=0.
      DLEF=Y(30)
      AA=F1 S AR=F2
      CONTINUE
      RIAMACH=AMACH/.1+1.
      IAYACH=RIAMACH
5F

```

```

PERIAM=2IAMACH-IAMACH
TMILT1=(TMILT(IAMACH+1,IALTF)-TMILT(IAMACH,IALTF))*PERIAM
1  +TMILT(IAMACH,IALTF)
TMILT2=(TMILT(IAMACH+1,IALTF+1)-TMILT(IAMACH,IALTF+1))
2  *PERIAM+TMILT(IAMACH,IALTF+1)
TMILT=(TMILT2-TMILT1)*PERIALF+TMILT1
THRUS=T4IL
THRUT=TMILT
IF(TMILT.LT.1.) THRUT=1.
IF(T.LE..05) THRUT=THRUT
THRUS=THRUT/THRUT*TSAVE
F6 CONTINUE
TOM=THRUS/ASS
***** AIRCRAFT STATE EQUATIONS AND EULER RELATIONS *****
DELH=DE
C *** INTERPOLATION ON ALPHA
RIA=21.+ALPHA/5.
IF(ALPHA.GT.80.) RIA=29.+ALPHA/10.
IF(ALPHA.LT.-80.) RIA=13.+ALPHA/10.
IA=RIA
PERA=RIA-IA
C *** INTERPOLATION ON BETA
BETAI=ARS(BETA)
IF(BETAI.LT.5.) BETAI=5.
IR=BETAI/5.1
IF(BETAI.GT.15.) IR=3
IF(BETAI.FT.25.) IR=4
PERB=BETAI/5.-IR
IF(BETAI.GT.15.) PERB=BETAI/10.+1.5-IR
C *** INTERPOLATION ON DLFF

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```

C ***
PERD=OLEF/5.
INTERPOLAT: ON ON DELH
RIH1=3.+DE. H/10.
IH1=RIH1
IF(DELH.GT.10.) IH1=4
IF(DELH.EQ.25.) IH1=5
IF(DELH.LT.-10.) IH1=1
PERH1=RIH1-IH1
IF(DELH.GT.10.) PERH1=(DELH-10.)/15.
IF(DELH.EQ.25.) PERH1=0.
IF(DELH.LT.-10.) PERH1=(DELH+25.)/15.
RIH2=4.+DE. H/10.
IH2=RIH2
IF(DELH.GT.20.) IH2=6
IF(DELH.EQ.25.) IH2=7
IF(DELH.LT.-20.) IH2=1
PERH2=RIH2-IH2
IF(DELH.GT.20.) PERH2=(DELH-20.)/5.
IF(DELH.EQ.25.) PERH2=0.
IF(DELH.LT.-20.) PERH2=(DELH+25.)/5.
C *** DETERMINAT: ON OF AERO PARAMETERS
CMO=(ECMO(A+1)-ECMO(IA))*PERA+ECMO(IA)
CMA=(ECMA(A+1)-ECMA(IA))*PERA+ECMA(IA)
CMQ=(ECMQ(A+1)-ECMQ(IA))*PERA+ECMQ(IA)
CNO=(ECNO(A+1)-ECNO(IA))*PERA+ECNO(IA)
CCO=(ECCO(A+1)-ECCO(IA))*PERA+ECCO(IA)
CVB=(ECVB(A+1)-ECVB(IA))*PERA+ECVB(IA)
CMDE=(ECMD(A+1)-ECMD(IA))*PERA+ECMD(IA)
CNDH=(ECNH(A+1)-ECNH(IA))*PERA+ECNH(IA)
CLDP=(ECLD(A+1)-ECLD(IA))*PERA+ECLD(IA)

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CLOH=(ECLD(IA+1)-ECLDH(IA))*PERA+ECLDH(IA)
 CYDR=(ECYD(IA+1)-ECYDR(IA))*PERA+ECYDR(IA)
 CYDH=(ECYD(IA+1)-ECYDH(IA))*PERA+ECYDH(IA)
 CMOLE=(ECMLE(IA+1)-ECMOLE(IA))*PERA+ECMOLE(IA)
 CNMLE=(ECNMLE(IA+1)-ECNMLE(IA))*PERA+ECNMLE(IA)
 CLBLE=(ECLBLE(IA+1)-ECLBLE(IA))*PERA+ECLBLE(IA)
 CNDR1=(ECNDR(IA+1,IR)-ECNDR(IA,IR))*PERA+ECNDR(IA,IR)
 CNDR2=(ECNDR(IA+1,IR+1)-ECNDR(IA,IR+1))*PERA+ECNDR(IA,IR+1)
 CNDR=(CNDR2-CNDR1)*PERA+CNDR1
 CNP1=(ECNP(IA+1,1)-ECNP(IA,1))*PERA+ECNP(IA,1)
 CNP2=(ECNP(IA+1,1)-ECNP(IA,1))*PERA+ECNP(IA,1)
 CLP1=(ECLP(IA+1,1)-ECLP(IA,1))*PERA+ECLP(IA,1)
 CLP2=(ECLP(IA+1,1)-ECLP(IA,1))*PERA+ECLP(IA,1)
 CNP2=(ECNP(IA+1,2)-ECNP(IA,2))*PERA+ECNP(IA,2)
 CNR2=(ECNR(IA+1,2)-ECNR(IA,2))*PERA+ECNR(IA,2)
 CLP2=(ECLP(IA+1,2)-ECLP(IA,2))*PERA+ECLP(IA,2)
 CLR2=(ECLP(IA+1,2)-ECLR(IA,2))*PERA+ECLP(IA,2)
 CNP=(CNP2-CNPI)*PERD+CNPI
 CNR=(CNR2-CNRI)*PERD+CNRI
 CLP=(CLP2-CLPI)*PERD+CLPI
 CLR=(CLR2-CLRI)*PERD+CLRI
 CHOF1=(ECHOF(IA+1,1)-ECHOF(IA,1))*PERA+ECHOF(IA,1)
 CLOF1=(ECLF(IA+1,1)-ECLOF(IA,1))*PERA+ECLOF(IA,1)
 CYOF1=(ECYF(IA+1,1)-ECYOF(IA,1))*PERA+ECYOF(IA,1)
 CNDF2=(ECNF(IA+1,2)-ECNDF(IA,2))*PERA+ECNDF(IA,2)
 CLDF2=(ECLF(IA+1,2)-ECLDF(IA,2))*PERA+ECLDF(IA,2)
 CYOF2=(ECYF(IA+1,2)-ECYOF(IA,2))*PERA+ECYOF(IA,2)
 CNDF=(CNDF2-CNDF1)*PERD+CNDF1
 CLDF=(CLDF2-CLDF1)*PERD+CLDF1
 CYOF=(CYOF2-CYOF1)*PERD+CYOF1

```

CNB1=(ECNR(IA+1,IH1)-ECN3(IA,IH1))*PERA+ECN3(IA,IH1)
CLB1=(ECLR(IA+1,IH1)-ECL3(IA,IH1))*PERA+ECL3(IA,IH1)
CNR2=(ECNR(IA+1,IH1+1)-ECN3(IA,IH1+1))*PERA+ECN3(IA,IH1+1)
CLR2=(ECLR(IA+1,IH1+1)-ECL3(IA,IH1+1))*PERA+ECL3(IA,IH1+1)
CNB=(CNB2-:NR1)*PERH1+CNB1
CLB=(CLB2-:LR1)*PERH1+CLB1
CN01=(ECN0(IA+1,IH2)-ECN0(IA,IH2))*PERA+ECN0(IA,IH2)
CC01=(ECC0(IA+1,IH2)-ECC0(IA,IH2))*PERA+ECC0(IA,IH2)
CND1=(ECND(IA+1,IH2)-ECND(IA,IH2))*PERA+ECND(IA,IH2)
CCD1=(ECCD(IA+1,IH2)-ECCD(IA,IH2))*PERA+ECCD(IA,IH2)
GN02=(ECN0(IA+1,IH2+1)-ECND(IA,IH2+1))*PERA+ECND(IA,IH2+1)
CC02=(ECC0(IA+1,IH2+1)-ECC0(IA,IH2+1))*PERA+ECC0(IA,IH2+1)
CND2=(ECND(IA+1,IH2+1)-ECND(IA,IH2+1))*PERA+ECND(IA,IH2+1)
CCD2=(ECCD(IA+1,IH2+1)-ECCD(IA,IH2+1))*PERA+ECCD(IA,IH2+1)
CN0=(CN02-:N01)*PERH2+CN01
CND=(CND2-:ND1)*PERH2+CND1
CC0=(CC02-:C01)*PERH2+CC01
CCD=(CCD2-:CD1)*PERH2+CCD1

```

C***** FLAP AERODYNAMICS.

```

IF(ALPHA.GT.0.) ECDPF=.0002+(:.0001958*ALPHA)
IF(ALPHA.LT.0.) ECDPF=.0002-(:.000325*ALPHA)
XCL=.015*DELFL
XCN=.0004+(:CDPF*DEFL
DCCDF=-XCN*CCS(AL)+XCL*SIN(AL)
DCNDF=XCL*CCS(AL)-XCN*SIN(AL)
XC=.0027027-:.00065031*DELFL
X1=-.00074143+.00000419*DELFL
X2=-.000005197+.000002774*DELFL

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X3=.000010;2-.00000154*DELF
X4=-.00000;403
DCMDF=X0+(Y1*ALPHA)+(X2*ALPHA**2.)+(X3*ALPHA**3.)*
*(X4*ALPHA**4.)

903 CN=(CND-CND)*PERD+CND+DCNDF
CC=(CCO-CCO)*PERD+CCO+DCCDF
CLOH=2.*CLOH
CLOF=2.*CLOF
CYOH=2.*CYOH
CYOF=2.*CYOF
CNDH=2.*CNDH
CNDF=2.*CNDF

C *** TOTAL AERO DYNAMIC COEFFICIENTS
SUMCY=CYR*ETA+CYDR*DR+CYDF*DF+CYOH*OH
SUMCZ=-CN-(R4/VR)*CND*Y(5)
SUMCX=-CC-(R4/VR)*CCO*Y(5)
SUMCN=CND*ETA+CND*DR+CND*DF+CND*OH+CND*RETA*DLEF+(C4/VR)*
*(CND*Y(4)+CNR*Y(4))
SUMCL=CLR*ETA+CLDR*DR+CLDF*DF+CLDH*DH+CLBLE*BETA*DLEF+(A4/VR)*
*(CLP*Y(4)+CNR*Y(4))
SUMCM=CND*MA*ALPHA+CMDF*DF+CMCL*DE+(R4/VR)*CMO*Y(5)+DCMDF
SUMCN=SUMCL-(CG-.35)*SUMCZ
SUMCN=SUMCL+(CG-.35)*C*SUMCY/R
YP(1)=-G*S*HE+Y(2)*Y(6)-Y(3)*Y(5)+RVR2*D1*SUMCX+TOM*CEPS
YP(2)=G*S*HE+SFE+Y(3)*Y(4)-Y(1)*Y(5)+RVR2*D1*SUMCY
YP(3)=G*CTHF+CFE+Y(1)*Y(5)-Y(2)*Y(4)+RVR2*D1*SUMCZ+TOM*SEPS
YP(4)=(A1*Y(5)+A2*Y(6)+A2*Y(4)*Y(5)*(1.+C1)-C2*Y(5)*Y(6)+C3*RVR2*
1SUMCN)+A3*VR2*SUMCL/(1.-A2*C2)
YP(5)=A1*Y(4)+Y(5)+A2*Y(5)*Y(4)*Y(5)+A2*Y(4)*Y(5)*Y(4)*Y(5)+SUMCY

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YP(6)=C1*(4)*Y(5)+C2*(YP(4)-Y(5)*Y(6))+RVR2*C3*SUMCN
YP(7)=Y(1)*STHE-Y(2)*CTHE*SFE-Y(3)*CTHE*CFE
IF(T.LT.0.)GO TO 49
YP(8)=.5*(-Y(9)*Y(4)-Y(10)*Y(5)-Y(13)*Y(6))+2.*EP*Y(8)
YP(9)=.5*(Y(8)*Y(4)+Y(10)*Y(5)-Y(13)*Y(6))+2.*EP*Y(9)
YP(10)=.5*(Y(8)*Y(5)-Y(9)*Y(5)+Y(13)*Y(4))+2.*EP*Y(10)
GO TO 50
49 YP(8)=Y(5)*CFE-Y(6)*SFE
   YP(9)=(Y(5)*SFE+Y(6)*CFE)/CTHE
   YP(10)=Y(4)+YP(9)*STHE
50 CONTINUE
   YP(11)=Y(1)*CTHE*CPSI+Y(2)*(SFE*STHE*CPSI-CFE*SPSI)+Y(3)*(CFE*STHE
1*CPSI+SFE*SPSI)
   YP(12)=Y(1)*CTHE*SPSI+Y(2)*(SFE*STHE*SPSI+CFE*CPSI)+Y(3)*(CFE*STHE
1*SPSI-SFE*CPSI)
   YP(13)=.5*(Y(8)*Y(6)+Y(9)*Y(5)-Y(10)*Y(4))+2.*EP*Y(13)
RETURN
END
SURROUTINE CONTROL(T)
COMMON/STICK/DET,DAT,ORT,DEF,DAF,DRF,F91,F92
COMMON/STICK/KF/DAFT(170),DRFT(170),DEFT(170)
BT=T
RIC=RT*5.*.
IC=RIC
PEPIC=RT*IC-IC
DAF=(DAFT(IC+1)-DAFT(IC))*PERIC+DAFT(IC)
DRF=(DRFT(IC+1)-DRFT(IC))*PERIC+DRFT(IC)
DEF=(DEFT(IC+1)-DEFT(IC))*PEPIC+DEFT(IC)
RETURN
END

```



```

SUBROUTINE RKGXYZ(X,Y,P3,N,DX,EMAX,F)
DIMENSION / (35),Y0(35),YT(35),YP(35),P0(35),P1(35),P2(35),P3(35)
XC=X
X=X+DX
H=0.5*(X-X1)
H=H+H
IF(ABS(X-X1))-ABS(H))1,3,3
DO 4 I=1,N
YC(I)=Y(I)
HT=H
XT=X0
DO 5 I=1,N
YT(I)=Y0(I)
ASSIGN 6 T) K
GO TO 20
DO 7 I=1,N
YP(I)=Y(I)
HT=0.5*H
ASSIGN 9 T) K
GO TO 20
DO 10 I=1,N
YT(I)=Y(I)
XT=X0+HT
ASSIGN 11 T) K
CALL F(XT,T,P0)
DO 21 I=1,N
Y(I)=YT(I)+0.5*HT*P0(I)
CALL F(XT+.5*HT,Y,P1)
DO 22 I=1,N
Y(I)=YT(I)+HT*(.207106761*P0(I)+.292893219*P1(I))

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CALL F(XT+).5*HT,Y,P2)
DO 23 I=1,J
23 Y(I)=YT(I)+HT*(.707106781*(P2(I)-P1(I))+P2(I))
CALL F(XT+T,Y,3)
DO 24 I=1,J
24 Y(I)=YT(I)+HT*(P0(I)+.535786438*P1(I)+3.41421356*P2(I)+P3(I))/6.0
GO TO K,(6,9,11)
11 RMAX=C
DO 12 I=1,J
R=ABS((0.67*(Y(I)-YP(I)))/Y(I))
IF(ABS(Y(I)).LT.EMAX)R=ABS((0.03*(Y(I)-YP(I)))/EMAX)
RMAX=AMAX1(R,RMAX)
12 Y(I)=Y(I)+(Y(I)-YP(I))/15.0
IF(RMAX-EMAX)13,13,17
13 X0=X0+H
IF(X0-X)15,14,15
14 RETURN
15 IF(RMAX-0.13*EMAX)30,30,2
17 H=HT
XT=X0
DO 19 I=1,J
18 YP(I)=YT(I)
19 YT(I)=Y0(I)
GO TO 8
END
SUBROUTINE TURNTRM(Y,YP,Y0)
DIMENSION Y(35),YP(35),Y0(7)
COMMON/ FOM/MASS,C,B,THRUS,CG
COMMON/PEST/A1,A2,A3,A4,31,82,B3,B4,C1,C2,C3,C4,D1,AV,
1FUDDGE,CEPS,SEPS,STHE,CTHE,SFE,CFE,RVR2,ROH,G,VR,THE,FE,SIGH,

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2ALPHA,BETA,DR,DE,DF,DH,DLEF,DEC,DRC,DFC,DHC,AMACH
COMMON/)/HECK/SUMCX,SUMCZ,SUMCM,CN,CN0,CC,CCQ,CMA,CMDE,
1CMDE,CM0
COMMON/OTHER/IX,IY,IZ,IX7,S
COMMON/CHEN K2/CNB,CNBL,CNR,CNP,CNDR,CNDH,CNDF,CLOH,CLP,CLR,
CCLR,CLBLF,CLR
COMMON/TRIA/REF,GAMAD,AL,FN, SUMCY,RLIFT,XCY,TCONST,SCONST
C,THFO,SIGH,FFO
COMMON/CCC/DELEFC,GBIAS,GRIAS,S10,DELF,XCD,DELF1,DELF2,S20
EXTERNAL C/RATES
REAL IX,IY,IZ,IX7,IR,MASS
GAMMA=C.
VR=130.
GAMAD=0.
BED=0.
BCONST=0.
ALFA=AL*AV
ALPHA=ALFA
DLEF=25.*(ALPHA-2.)/15.5
IF(DLEF.GT.25.) DLEF=25.
IF (DLEF.LT.0.) DLEF=0.
GCONST=1.
TCONST=1.
BET =RE*AV
T=0.
T=-1.
Y(2)=0.
BE=REO/AV
BET=RE*AVS1ETA=BET
EMG=MASS*G

```

```

DF=0H=0.
DA=DE=DR=0.
CNTR=TT=0.
50 CONTINUE
Y(2)=VR*SIN(AR)=SQRT((VR**2-Y(2)**2)/(1.+TAN(AL)**2))
Y(3)=Y(1)*AN(AL)
CALL GYRATE S(T,Y,YP)
FZZ=COS(AL)*EMG*EN
FXX=-SIN(AL)*FMG*EN
VR=SQRT(AR*(2.*FZZ/POH/S/SUMCZ))
Y(2)=VR*SIN(AR)=SQRT((VR**2-Y(2)**2)/(1.+TAN(AL)**2))
Y(3)=Y(1)*AN(AL)
RVR2=ROH*VR*VP
THOUS=-FXX-RVR2*01*SUMCX*MASS
DO 150 I=1,3
CALL ANGLE(Y,YP,XR,YR,ZR)
DSUMCN=- (R1*Y(4)*Y(5)+R2*(Y(5)**2-Y(4)**2))/RVR2/93
TSUM=DSUMCN-CMO-CMA*ALPHA-CMDLE*DLEF-B4/VR*CMQ*Y(5)+(CG-.35)*SUMCZ
DE=TSUM/CMF
IF (DE.GT.25.) DE=25.
IF (DE.LT.-25.) DE=-25.
DA=(-A1+Y(6)*Y(5)-A2*(Y(4)*Y(5)*(1.+C1)-C2*Y(5)*Y(6)+C3*RVR2
C*(CG-.35)*C*SUMCY/2+CMQ*BETA+CMNR*DR+CMRLE*BETA*DLEF+C4/VR*(CNP*
CY(4)+CNR*Y(6))) -A3*RVR2*(CLR*BETA+CLR*OP+CLBLE*BETA*DLEF+
CA4/VR*(CLP*Y(4)+CLR*Y(6)))/(C3*RVR2*(CNDP+.25*CNDR)+A3*RVR2*(
CCLDP+.25*CDH))
IF (DA.GT.25.) DA=25.
IF (DA.LT.-25.) DA=-25.
DF=DA$DH=01/4.
DSUMCN=(-C1*Y(4)*Y(5)-C2*(YP(4)-Y(5)*Y(5)))/RVR2/C3

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```

D0=(DSUMCN-CNR*BETA-CNDF*DF-CNDH*DH-CN3LE*BETA*DLEF-C4/VP*(
CCND*Y(4)+CNR*Y(6))/CNR
IF (DR.GT.20.) DR=20.
IF (DR.LT.-20.) DR=-20.
150 CONTINUE
CALL ANGLE(Y,YP,XB,YB,ZB)
CNTR=CNTR+.
IF(CNTR.GT.15.)GOTO20
TSTG=XCY/MASS+G*SQRT(EN**2-1.)
OUT1=ABS(C.1FT-EMG)/MASS
IF(EN.LT.1.1) GO TO 7
IF(ABS(TSTG).GT..2)GO TO 50
7 CONTINUE
IF(OUT1.GT..05) GO TO 50
20 Y1=Y(8)*57.3Y2=Y(10)*57.3Y3=Y(9)*57.3
F4 CONTINUE
GAMMA=GAMMA*57.3
P1=Y(4)+AVS01=Y(5)*AV3R1=Y(6)*AV
WRITE(6,281) VR,Y(7),AMACH
WRITE(6,781)EN,BCONST,TCONST,GCONST
WRITE(6,903)OUT1,TSTG,ALFA,BET
WRITE(6,101)DA,DE,DR
WRITE(6,102)GAMMA,Y1,Y2,Y3
WRITE(6,80')
WRITE(6,803)(YP(I),I=1,12)
WRITE(6,101)P1,Q1,R1,THRUS
WRITE(6,101)
21 CONTINUE
101 FORMAT(" P = ",F8.3,2X," Q = ",F8.3,2X," R = ",F8.3/,
+" " TRIM THUS, THRUS = ",F9.3///)

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102  FORMAT(" TRIM FLIGHT PATH ANGLE, GAMMA = ",F7.2/," EULER ANGLES:",
      *3X," THETA = ",F7.2/18X," PHI = ",F7.2/18X," PSI = ",F7.2/)
105  FORMAT(" TRIM SURFACE DEFLECTIONS: ",/27X,
      *" DELTA ALFRON = ",F8.3/27X," DELTA ELEVATOR = ",
      *F8.3/27X," DELTA RUDDER = ",F8.3/)
109  FORMAT(1X/)
783  FORMAT(" TRIM LOAD FACTOR, FN = ",F5.2,3X," RCONST = ",F5.2,3X,
      *"TCONST = ",F5.2,3X,"GCONST = ",F5.2/)
807  FORMAT(" TRIMMED RATES FOR VARIABLES, YP(1-12) ")
808  FORMAT(3X," YP'S - ",7X,"1",14X,"2",14X,"3",14X,"4",14X,"5",
      *14X,"6",14X,"7",14X,"8",14X,"9",14X,"10",14X,"11",14X,"12",14X,
      *3X," YP'S - ",7X,"9",14X,"10",14X,"11",14X,"12",14X,
      *4(E12.5,3X)/)
880  FORMAT(" TOTAL VELOCITY, VP = ",F7.1," FT/SEC ",8X," ALTITUDE = ",
      *F7.1," FEET ",8X," MACH NUMBER AT ALT. = ",F5.3/)
906  FORMAT(" XS LEFT = ",E12.4,3X," XS SIDE = ",E12.4//,
      *" TRIM ANGLE OF ATTACK, ALPHA = ",F5.2,3X,
      *" TRIM ANGLE OF SIDESLIP, BETA = ",F5.2/)
907  FORMAT(22H/R ABOVE 800 TRY AGAIN)
22  DO 22 K=1,
    YO(K)=Y(K)
    THEO=Y(8)$FEO=Y(10)$SIGHO=Y(9)
    RETURN
    END
SUBROUTINE ANGLE(Y,YP,X3,YR,ZR)
DIMENSION I(35),YP(35)
REAL MASS,:Y
COMMON/3 FOM/MASS,C,B,THRUS,CG
COMMON/3 EST/A1,A2,A3,A4,B1,B2,B3,B4,C1,C2,C3,C4,D1,AV,
1FUDGE,CEPS,SEPS,STHE,CTHE,SFE,CFE,RVR2,ROH,G,VR,THE,FE,SIGH,

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2 ALPHA, BETA, DR, DE, DF, DH, DLEF, DEC, DRC, DFC, DHC, AMACH
  COMMON/HECK/SUMCX, SUMCZ, SUMCM, CN, CNR, CC, CCQ, CMO, CMA, CMDE,
1 CMDE, CNO
  COMMON/CHCK2/CNB, CNBLE, CNR, CNP, CNDR, CNDH, CNDF, CLDH, CLP, CLR,
  CLDR, CLBLE, CLR
  COMMON/OTHER/IX, IY, IZ, IX7, S
  COMMON/TRI4/BED, GAMAD, AL, EN, SUMCY, RLIFT, XCY, TCONST, GCONST
  C, THEO, SIGH, FEO
  COMMON/CCCI/DFLFC, OPIAS, GRIAS, S10, DELF, XCD, DELF1, DELF2, S20
  T=-1.
  GAMMA=0.
  SE=SED/AV
  OMEGA= G/VR*SQRT(EN**2-1.)
  CR=0.
1  EMG=MASS*G
  GAMMA=5./AI
  TGH=3.
  CR=CR+1.
  CALL GYRATE(S(T,Y,YP))
  TOM=THRUS/MASS
  X3=(PVR2*OL*(SUMCX )+TOM)*MASS
  Y3=RVR2*O1*MASS*SUMCY
  Z3=RVR2*O1*MASS*SUMCZ
  IF (TCONST.NE.0.) GAMMA=0.
  IF (GCONST.NE.0.) GAMMA=GAMA
  GETOUT=3.
  IF (TCONST.IE.0..OR.GCONST.NE.0.) GO TO 6
  DO 4 I=1,2
  GAMMA=GAMMA-5./57.3
6  CONTINUE

```



```

PSIP=ATAN( (2)/Y(1))
THETP=ATAN( SORT(SIN(AL)**2/(COS(AL)**2+TAN(RE)**2)))
SGAM=SIN(CA/MMA)*SP=SIN(PSIP)*ST=SIN(THETP)
CGAM=COS(CA/MMA)*CT=COS(THETP)*CP=COS(PSIP)
AAA=X3*ST*:D-YB*ST*SP-79*CT
B93=XB*CP*:D*CP
CCC=XB*CT*:D-YB*CT*SP+ZR*ST
TPHIP=(B93*(-EMG+SGAM*CCC)/CGAM-AAA*EMG*SORT(EN*EN-1.))/(B93*3
CPR+AAA*AAA
IF (TPHIP.GT.1.) TPHIP=1.
IF (TPHIP.LT.-1.) TPHIP=-1.
PHIP=ASIN(TPHIP)
SF=SIN(PHIP)*CF=COS(PHIP)
TTHET=CP*CT*SGAM-SP*SF*CGAM+CP*ST*CF*CGAM
PTHET=SQRT(1.-TTHET**2)
Y(8)=ACOS(TTHET)
TPHI=- (3T*SGAM-CT*CF*CGAM)/PTHET
TPSI= (CP*CT*CGAM+SP*SF*SGAM-CP*ST*CF*SGAM)/PTHET
Y(9)=ACOS(TPSI)
Y(10)=ACOS(TPHI)
Y(4)=-OMEGA* SIN(Y(8))
Y(5)=OMEGA* COS(Y(8))*SIN(Y(10))
Y(6)=OMEGA* COS(Y(8))*COS(Y(10))
CALL GYRAT(S(T,Y,YP)
IF(GETOUT.EQ.1.)GOTO7
IF(TCONST.IE.C..OR.GCONST.NE.G.)GOTO7
IF(I.EQ.2):GOTO5
4 TGH=YP(3)/P(1)
5 GAMMA=GAMMA*-5.*(Y(3)/Y(1)-YP(3)/YP(1))/(TGH-YP(3)/YP(1))/AV
GETOUT=1.:GOTO6

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```

7 CONTINUE
IF (CR.EQ.1.) GO TO 1
RLIFT=-SIN(Y(8))*XB+SIN(Y(10))*COS(Y(8))*YB-COS(Y(10))*COS(Y(8))*Z
10
XCY=-COS(Y(8))*SIN(Y(9))*XB+(COS(Y(10))*COS(Y(9))-SIN(Y(10))*
1SIN(Y(3))*SIN(Y(9)))*YB+(SIN(Y(10))*COS(Y(9))+COS(Y(10))*SIN(
2Y(8))*SIN(Y(9)))*Z9
RETURN
END

```

Vita

Captain Kenneth Race was born in Dover-Foxcroft, Maine on August 17, 1950. He graduated from Peru Central Jr-Sr High School, Peru, New York in 1968. He received a Bachelor of Science degree in Aeronautical Engineering from Rensselaer Polytechnic Institute, Troy, New York in 1972. He received his commission through ROTC. His initial assignment was to the 321st Strategic Missile Wing, Grand Forks AFB, North Dakota as a Deputy Missile Combat Crew Commander. Before his tour ended, he served as a Standboard Evaluator and a Combat Crew Commander. He received his Regular appointment in 1975. In 1976, he received a Masters in Business Administration from the University of North Dakota through the Minuteman Education Program. He was assigned to AFIT in August 1976.

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20. proposed mechanized YF-16.

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