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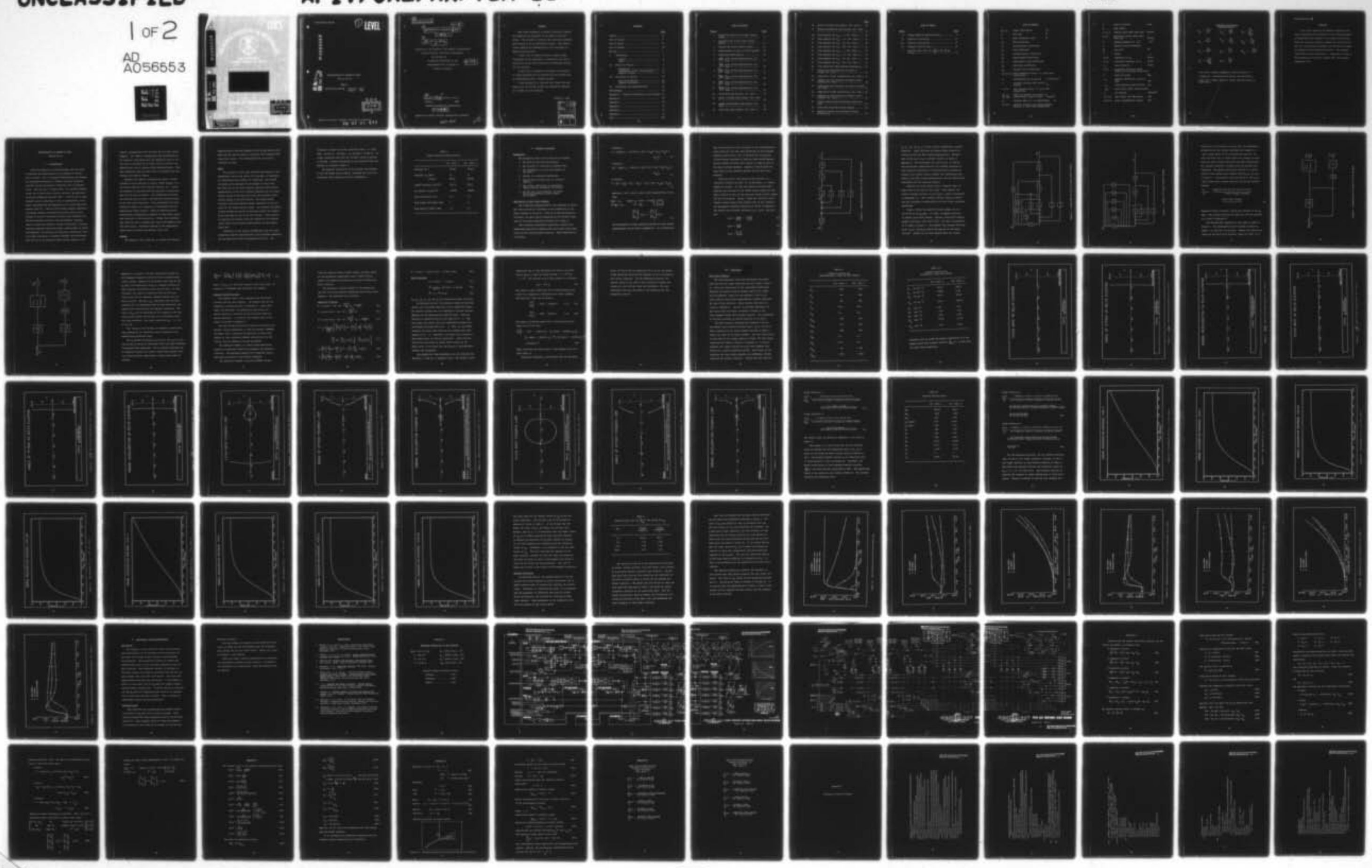

AFIT/GAE/AA/78M-16

(1) LEVEL II

MECHANIZATION OF BLENDED A_N MODE

FOR CCV YF-16

THESIS

AFIT/GAE/AA/78M-16 Kenneth R. Race
Captain USAF

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AFIT/GAE/AA/78M-16

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MECHANIZATION OF BLENDED A_N MODE 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

10

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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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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)

$$C_{D_\alpha} = \frac{\partial C_D}{\partial \alpha} \qquad C_{L_{\delta_e}} = \frac{\partial C_L}{\partial \delta_e} \qquad C_{M_q} = \frac{\partial C_M}{\partial \frac{q\bar{c}}{2V_R}}$$

$$C_{L_\alpha} = \frac{\partial C_L}{\partial \alpha} \qquad C_{L_{\delta_f}} = \frac{\partial C_L}{\partial \delta_f} \qquad C_{M_{\delta_e}} = \frac{\partial C_M}{\partial \delta_e}$$

$$C_{L_{\dot\alpha}} = \frac{\partial C_L}{\partial \dot\alpha} \qquad C_{M_\alpha} = \frac{\partial C_M}{\partial \alpha} \qquad C_{M_{\delta_f}} = \frac{\partial C_M}{\partial \delta_f}$$

$$C_{L_q} = \frac{\partial C_L}{\partial \frac{q\bar{c}}{2V_R}} \qquad C_{M_{\dot\alpha}} = \frac{\partial C_M}{\partial \dot\alpha}$$

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 -

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

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

$$\begin{bmatrix} V_R S - Z_\alpha & -(V_R \cos \alpha_1 + Zq)S - g \sin\Theta_1 \\ -(M_{\dot{\alpha}} S + M_\alpha) & S^2 - MqS \end{bmatrix} \begin{bmatrix} \alpha(S) \\ \theta(S) \end{bmatrix} =$$

$$\begin{bmatrix} Z_{\delta_e} \\ M_{\delta_e} \end{bmatrix} \delta_e(s) + \begin{bmatrix} Z_{\delta_f} \\ M_{\delta_f} \end{bmatrix} \delta_f(s) \quad (4)$$

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:

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

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

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

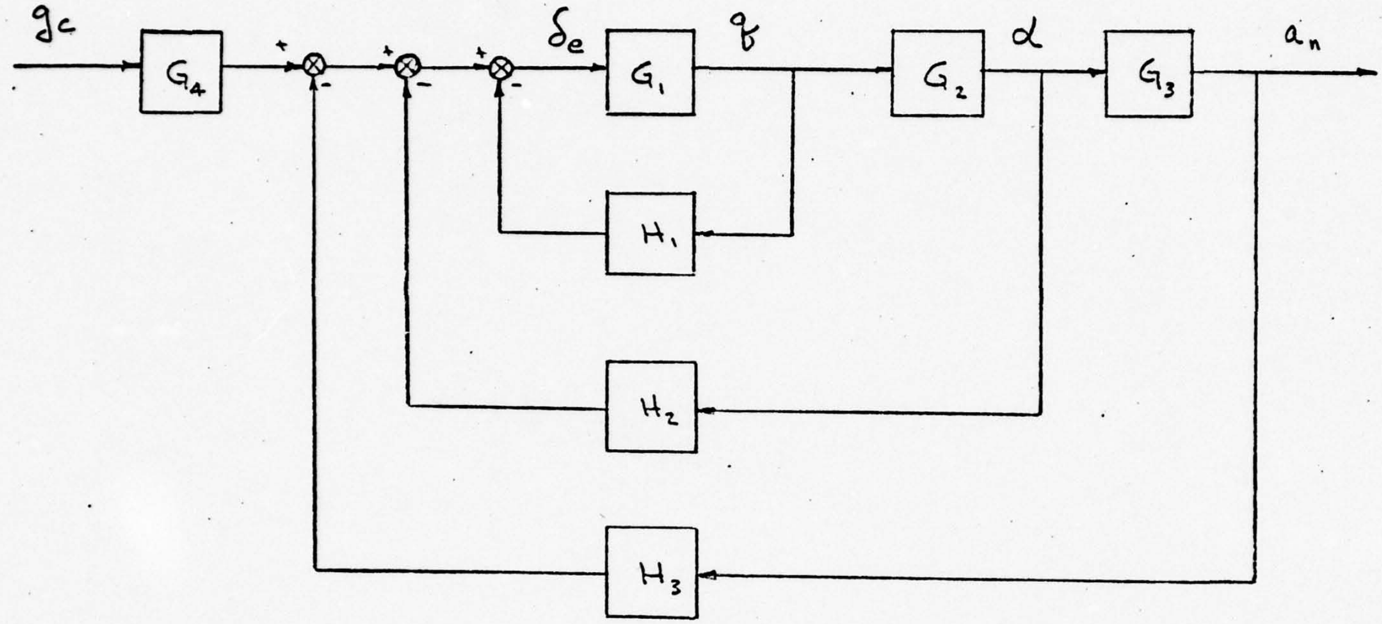


Figure 1. Simplified Basic YF-16 Flight Control System

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,

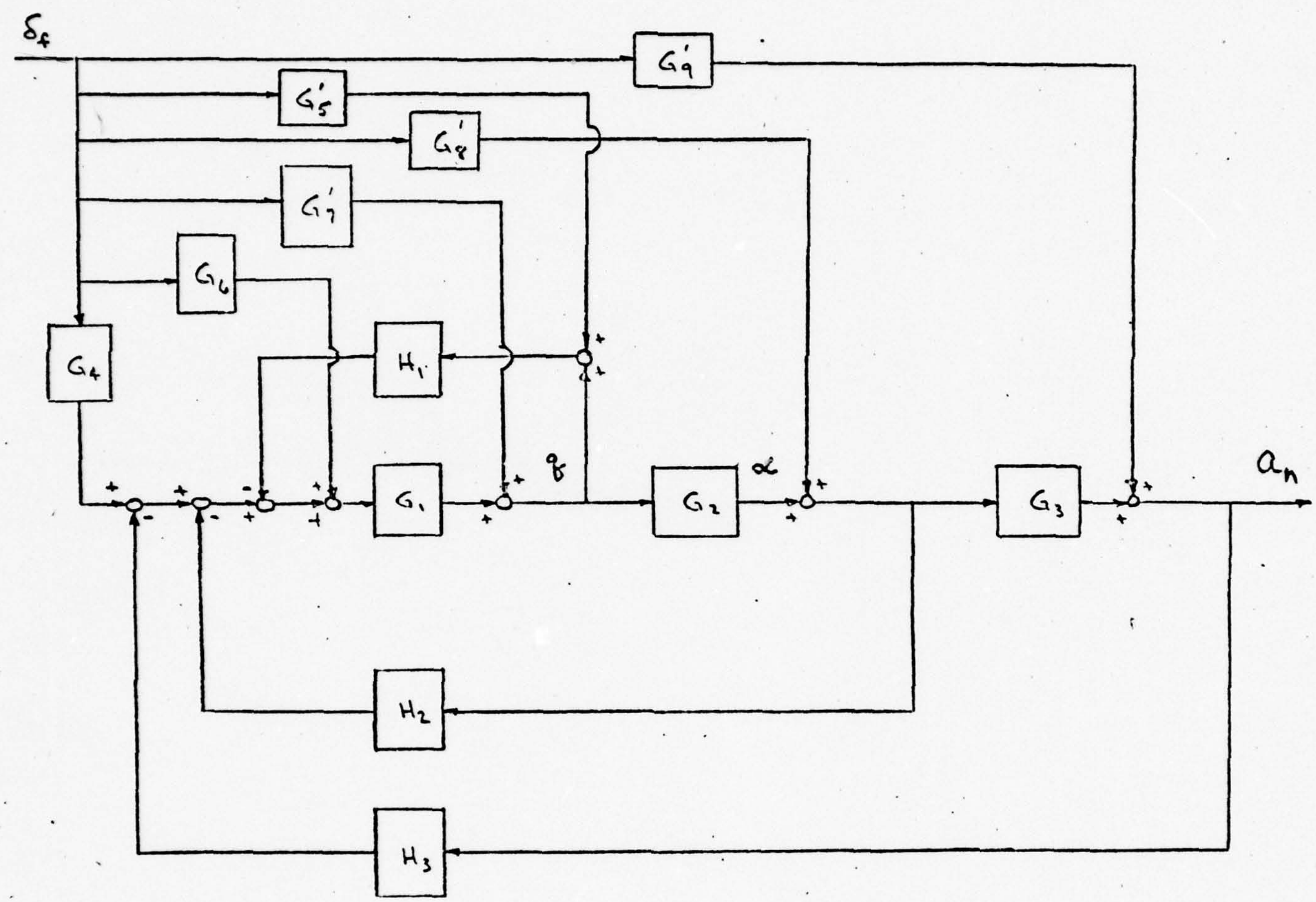


Figure 2. Simplified CCV YF-16 Flight Control System

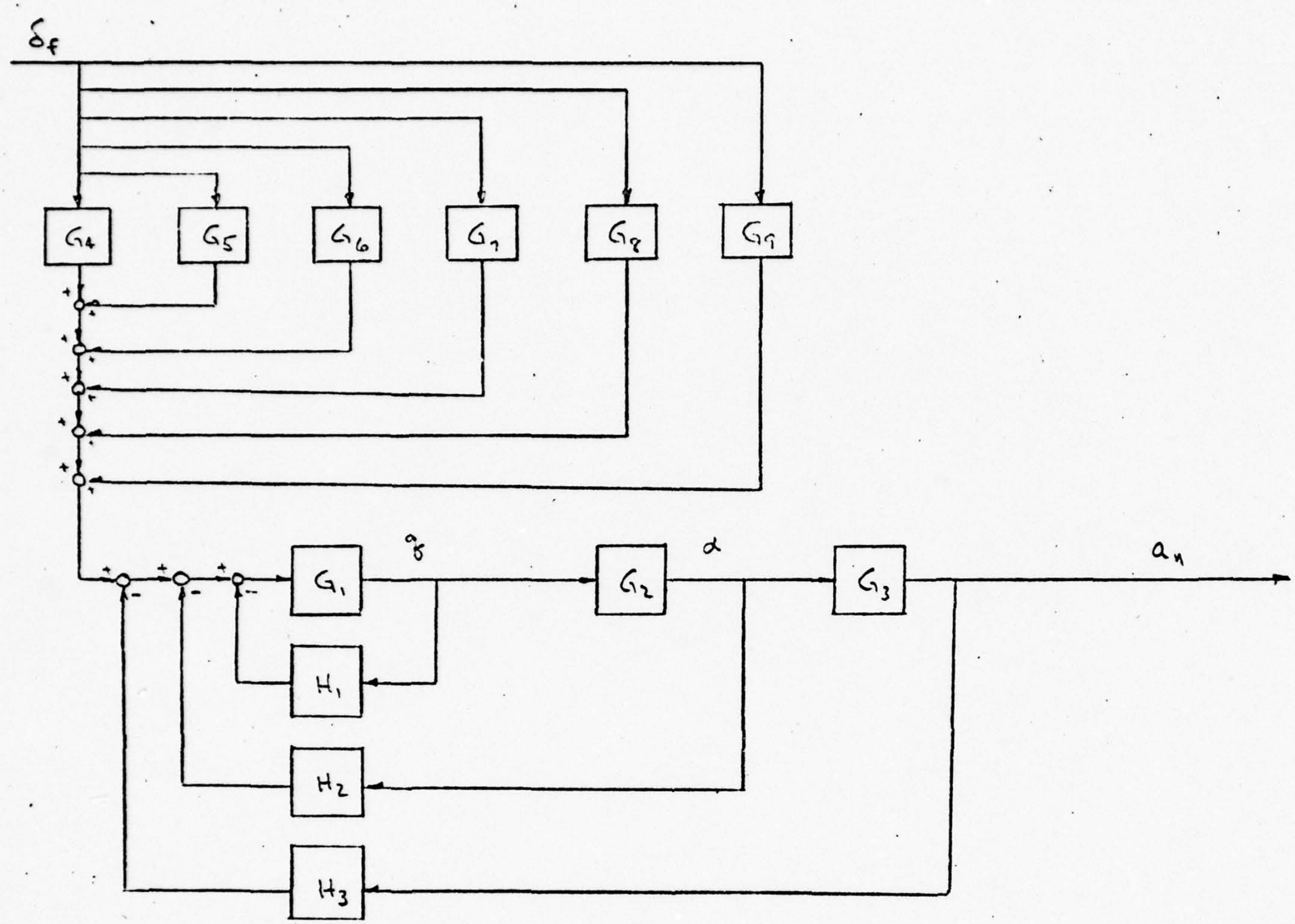


Figure 3. Redrawn CCV Flight Control System

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:

$$\frac{a_n}{\delta_f}(s) = \frac{G_1G_2G_3(G_4 + G_5 + G_6 + G_7) + G_3G_8\ (1 + G_1H_1)}{1 + G_1H_1 + G_1G_2H_2 + G_1G_2G_3H_3 + G_9(1 + G_1H_1 + G_1G_2H_2)} \tag{8}$$

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

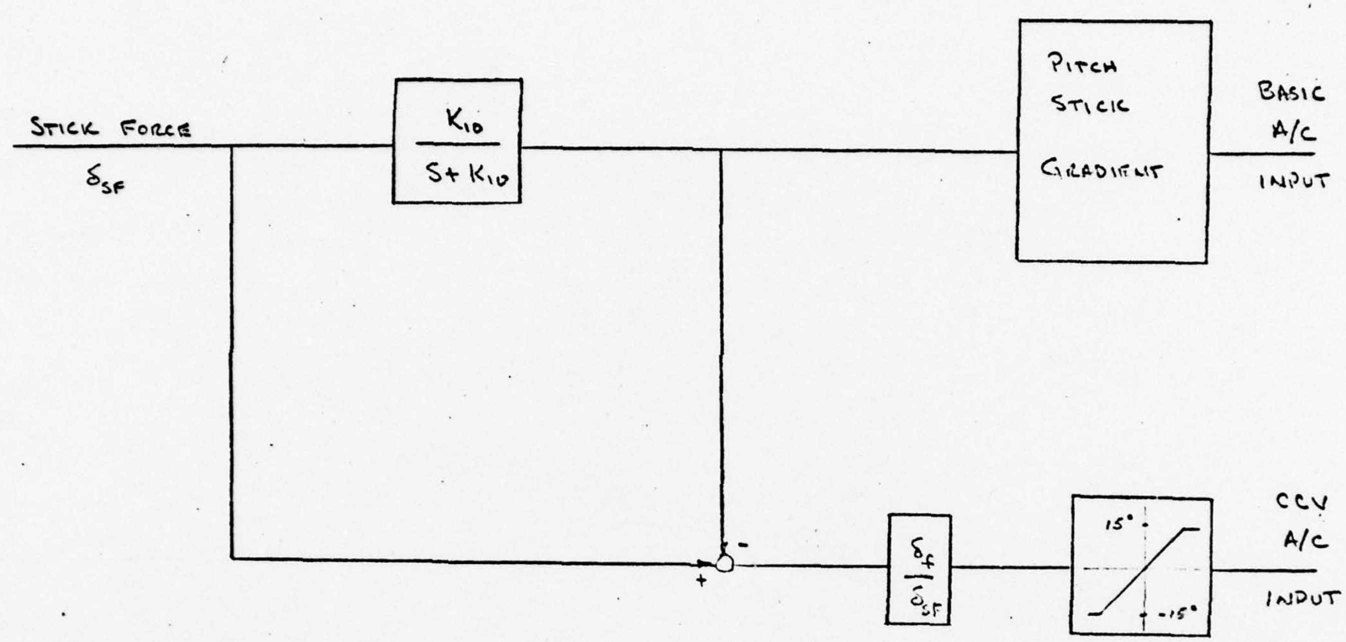


Figure 4. Mechanization of Basic A/C with A_N Mode

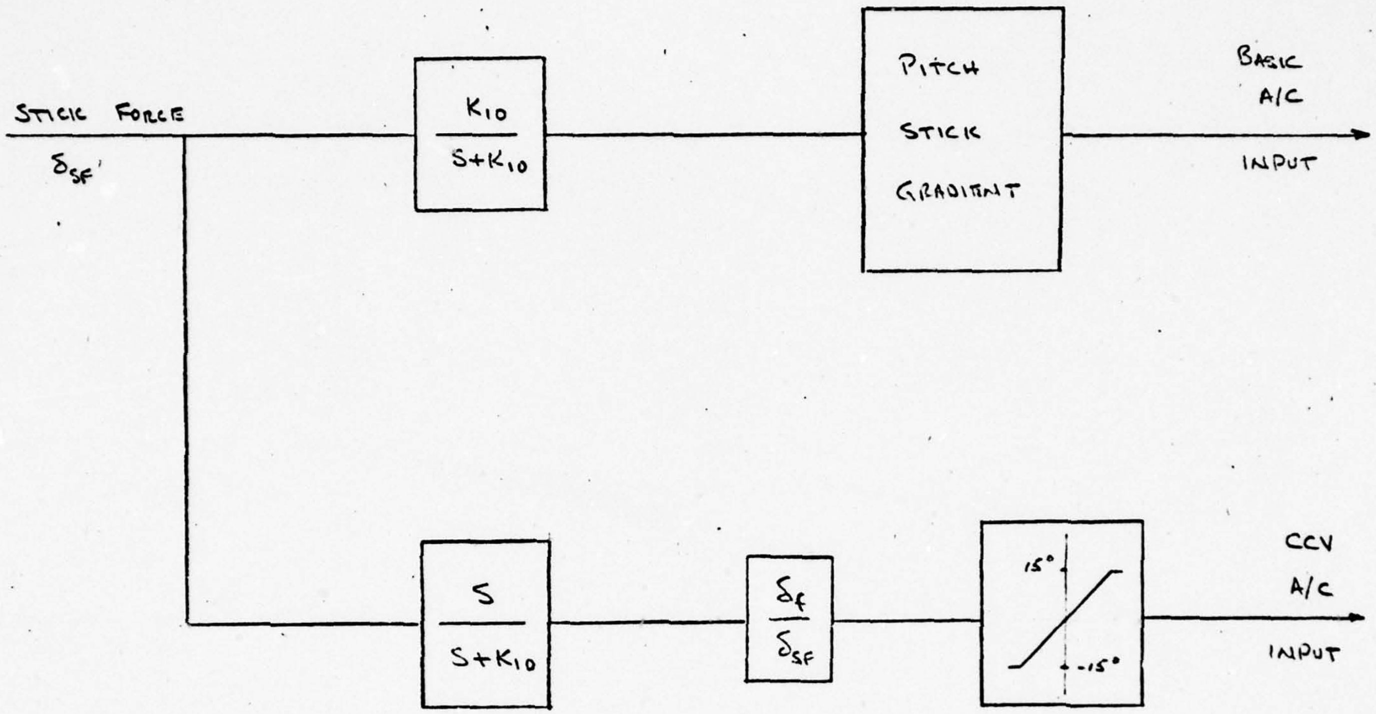


Figure 5. Simplified Mechanization

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:

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

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 provides 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

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

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

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

$$\dot{P} = \frac{1}{1 - \frac{(I_{xz})^2}{I_x I_z}} \left\{ \left[\frac{I_y - I_z}{I_x}\right] QR + \frac{I_{xz}}{I_x} \left[PQ\left(1 + \frac{I_x - I_y}{I_z}\right) - \right.\right.$$

$$\left.\left. - \frac{I_{xz}}{I_z} QR + \frac{Sb}{2\, I_z} \rho V_R^2 C_n \right] + \frac{Sb}{2\, I_x} \rho V_R^2 C_1 \right\} \tag{13}$$

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

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

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

Euler Relations

$$\dot{\Theta} = Q \cos\Phi - R \sin\Phi \quad (17)$$

$$\dot{\Psi} = \frac{1}{\cos\Theta}\left[Q \sin\Phi + R \cos\Phi\right] \quad (18)$$

$$\dot{\Phi} = P + \dot{\Phi} \sin\Theta \quad (19)$$

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:

$$\Delta C_L = .016\ \delta_f \tag{20}$$

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:

$$\frac{\Delta C_D}{\Delta \delta_f} = .0002 + .0001958\ \alpha \qquad \alpha \geq 0 \tag{21}$$

$$\frac{\Delta C_D}{\Delta \delta_f} = .0002 - .000325\ \alpha \qquad \alpha < 0 \tag{22}$$

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

$$\frac{\Delta C_m}{\Delta \delta_f} = (.0027 - .000659\ \delta_f) + \left[(-.00748 + .0000042\ \delta_f)\ \alpha\right]$$
$$\left[(-.000051 + .0000277\ \delta_f)\ \alpha^2\right] + \left[(.000011 - .0000015\ \delta_f)\ \alpha^3\right]$$
$$-.000000403\ \alpha^4 \tag{23}$$

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)

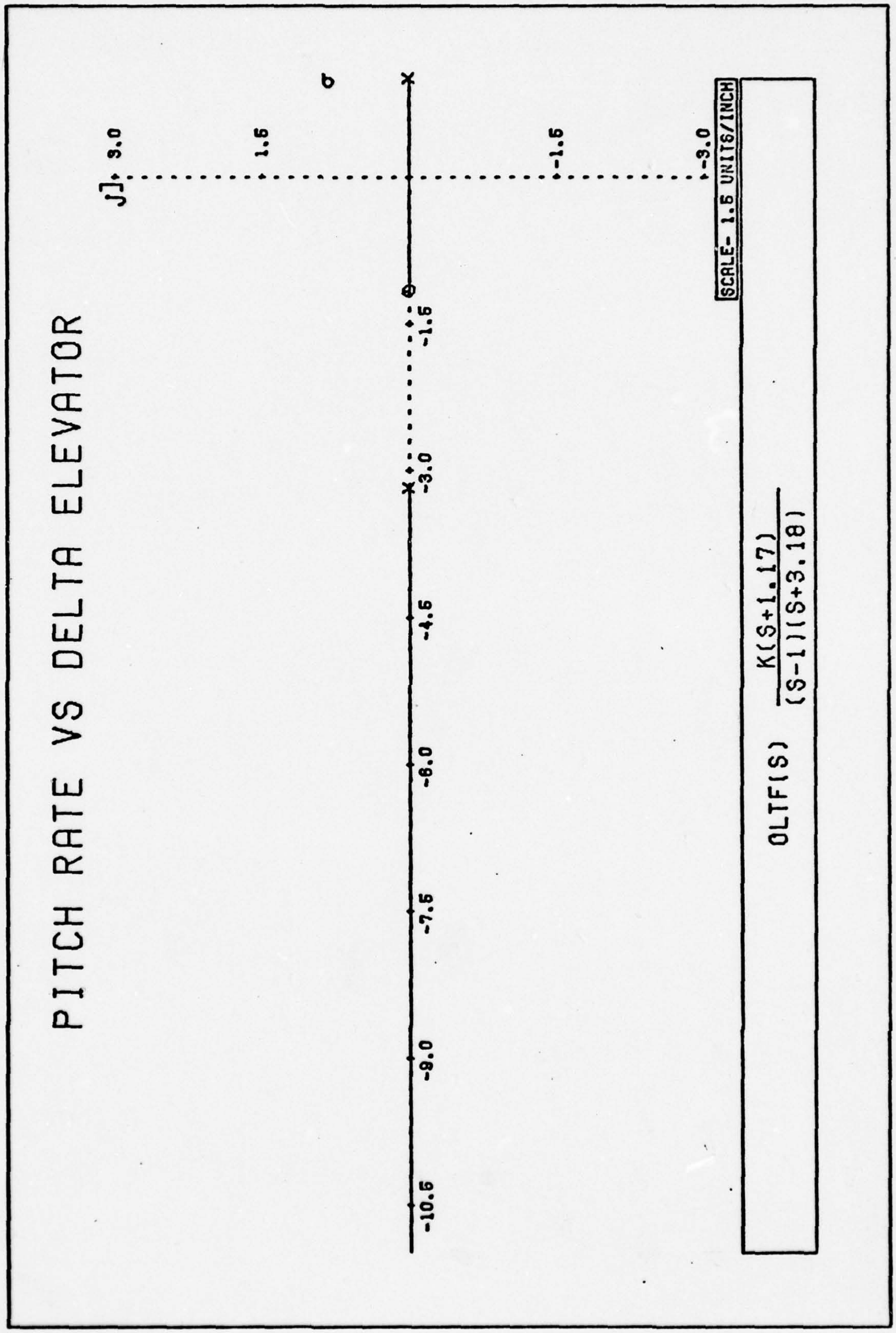
	Flt. Cond. 1	Flt. Cond. 2
C_{D_1}	.005	.020
C_{D_α}	.195	.280
C_{L_1}	.187	.246
C_{L_α}	4.18	4.56
C_{L_q}	1.3	3.8
$C_{L_{\delta_e}}$	.602	.516
$C_{L_{\delta_f}}$	.727	.802
C_{M_α}	.166	.092
$C_{M_{\dot{\alpha}}}$	-1.6	-1.5
C_{M_q}	-3.63	-4.1
$C_{M_{\delta_e}}$	- .59	- .602
$C_{M_{\delta_f}}$	- .056	- .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
J
3.0
1.5
σ
-1.5
-3.0
-1.5
-3.0
-4.5
-6.0
-7.5
-9.0
-10.5
SCALE- 1.5 UNITS/INCH
OLTF(S)
K(S+1.17)
(S-1)(S+3.18)

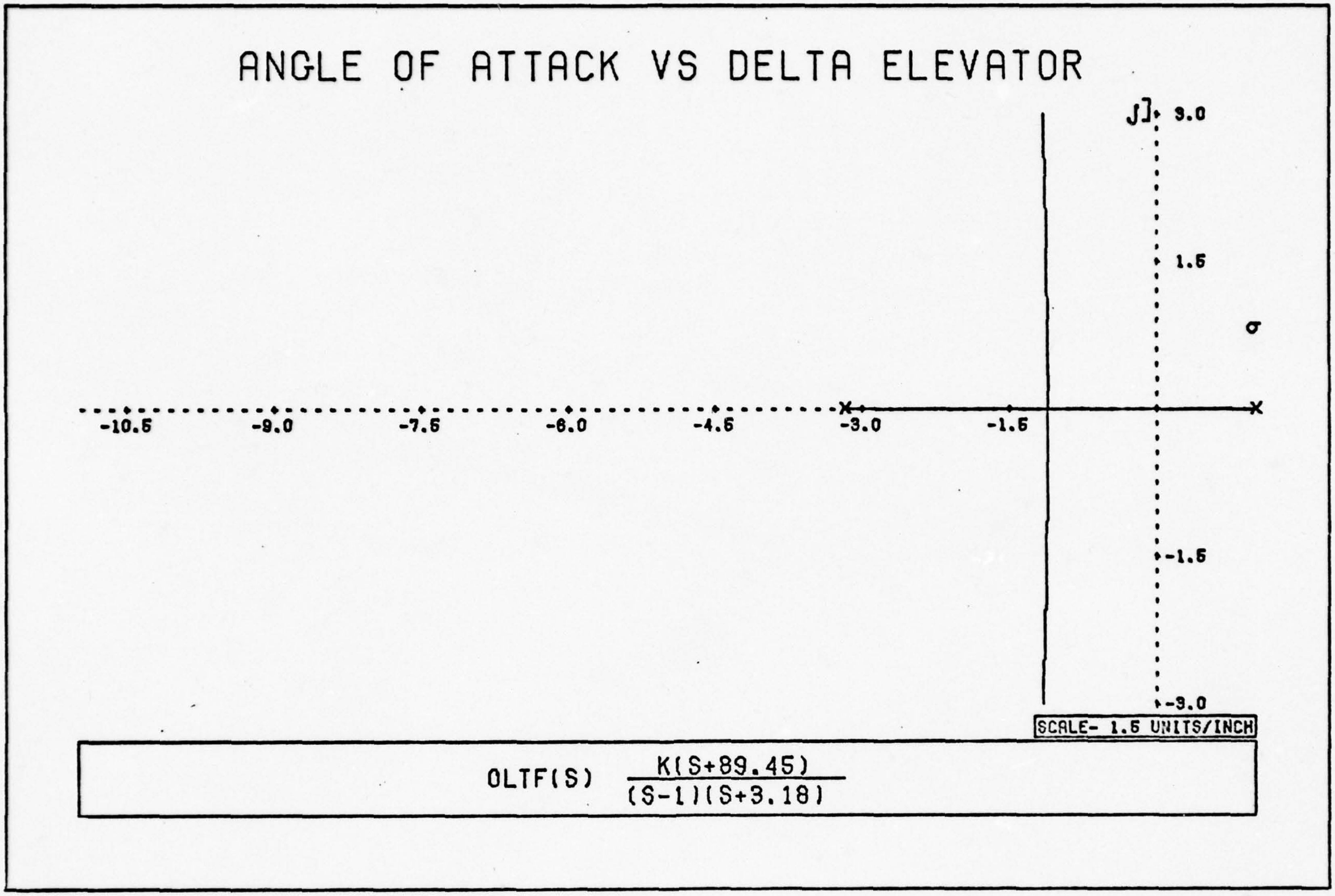


Figure 7. $\frac{\alpha(s)}{\delta_e(s)}$, Short Period Approximation, Flt. Cond. 1

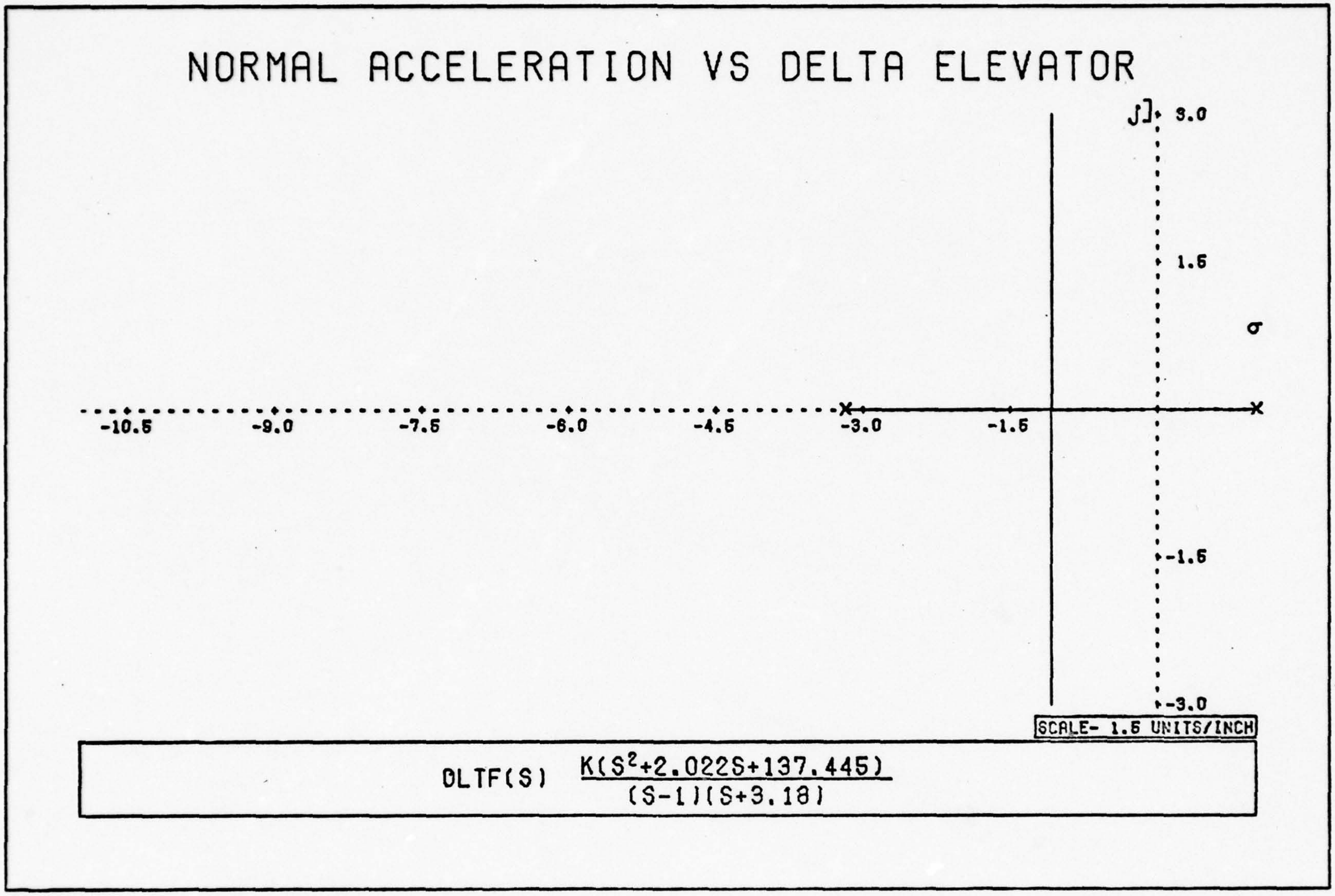


Figure 8. $\frac{a_n(s)}{\delta_e(s)}$, Short Period Approximation, Flt. Cond. 1

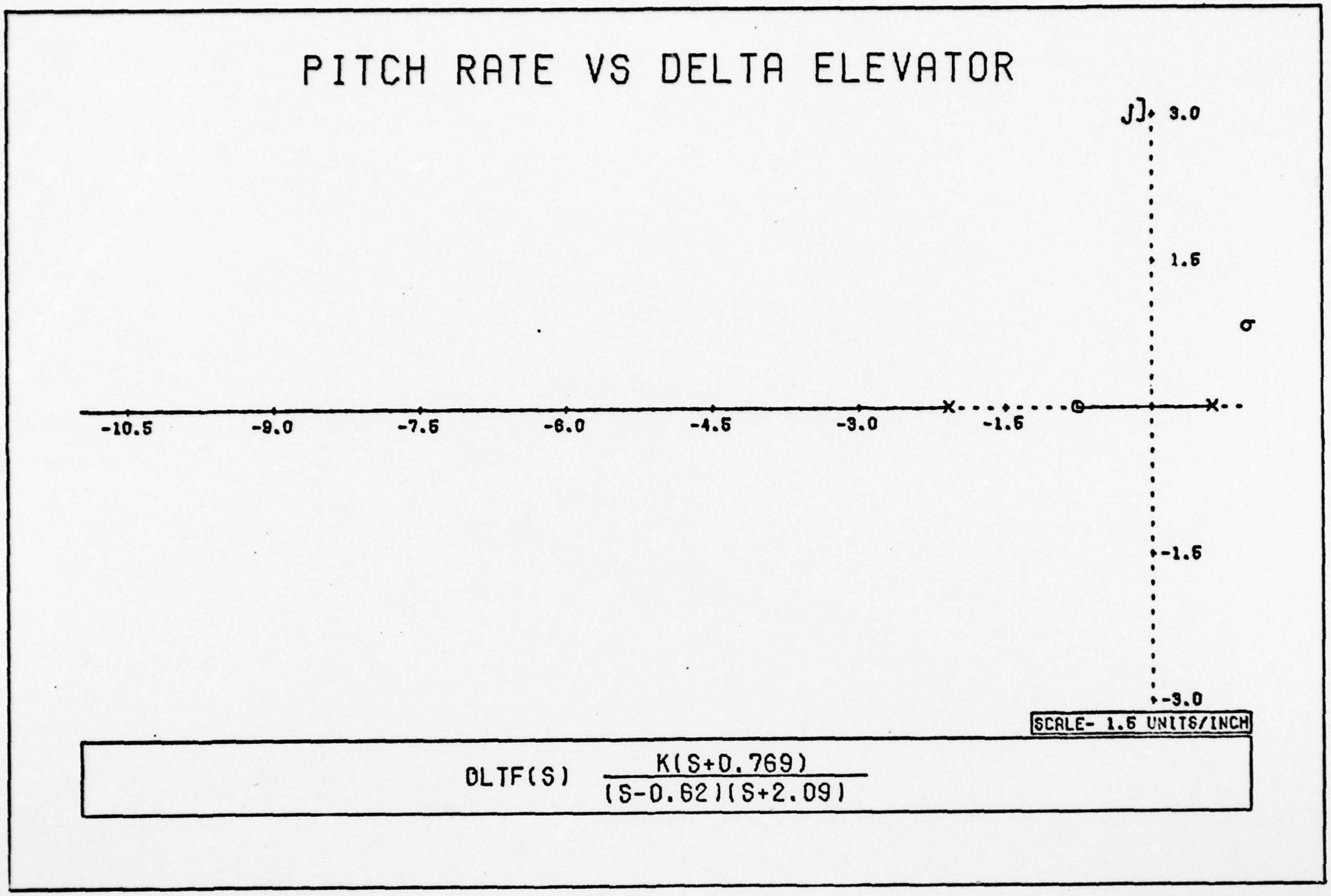


Figure 9. $\frac{q(s)}{\delta_e(s)}$, Short Period Approximation, Flt. Cond. 2

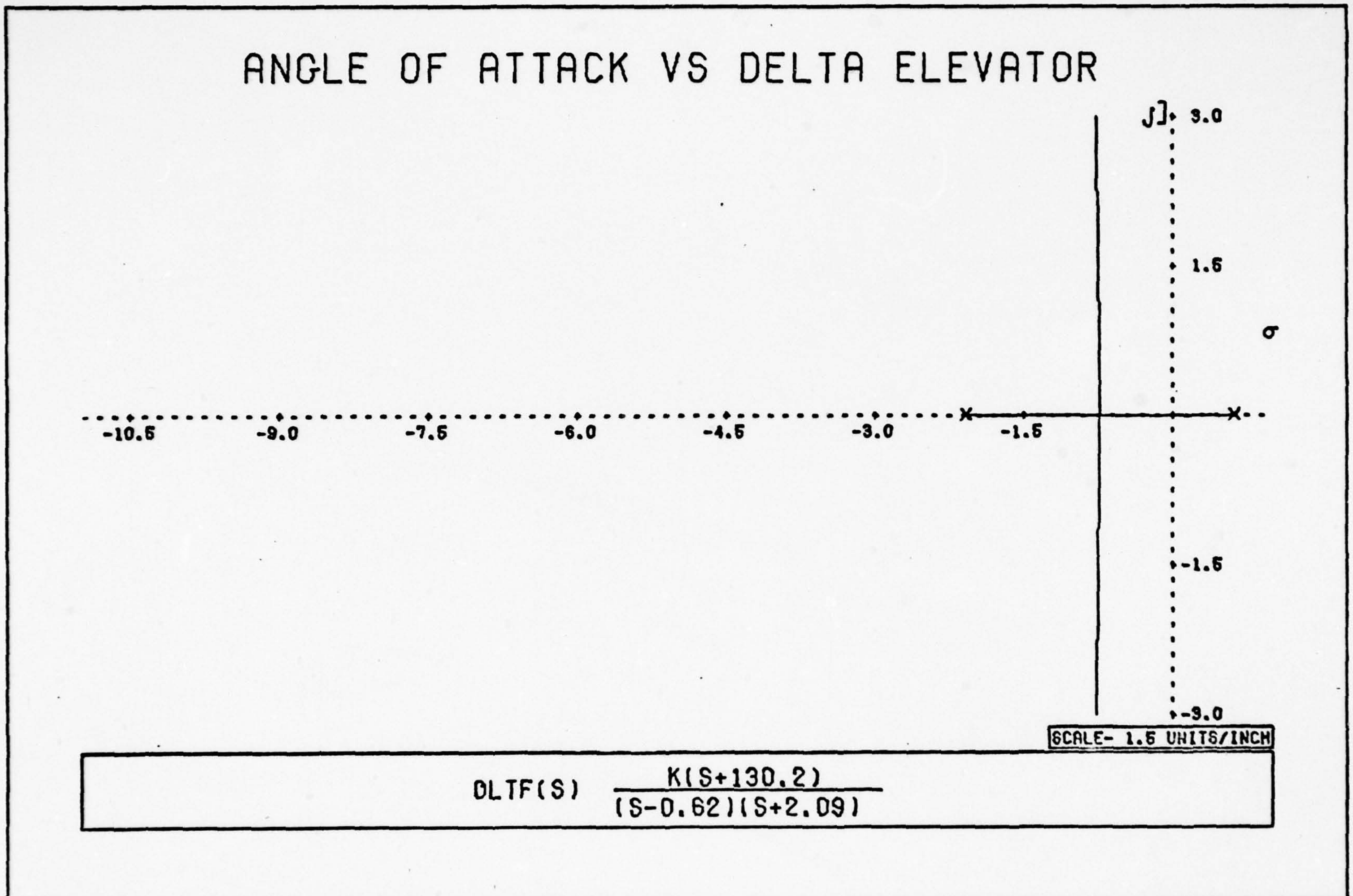


Figure 10. $\frac{\alpha(s)}{\delta_e(s)}$, Short Period Approximation, Flt. Cond. 2

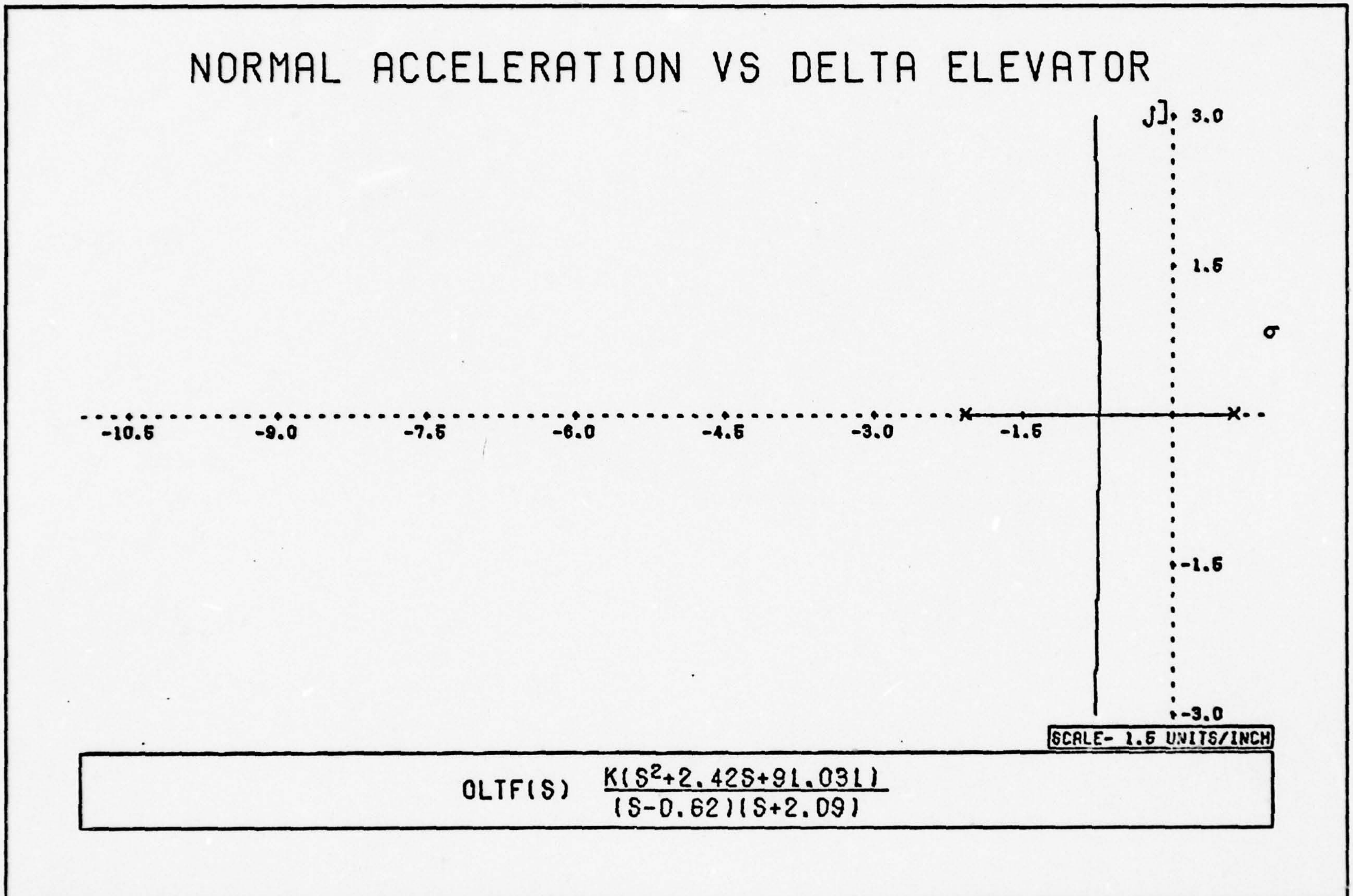


Figure 11. $\frac{a_n(s)}{\delta_e(s)}$, Short Period Approximation, Flt. Cond. 2

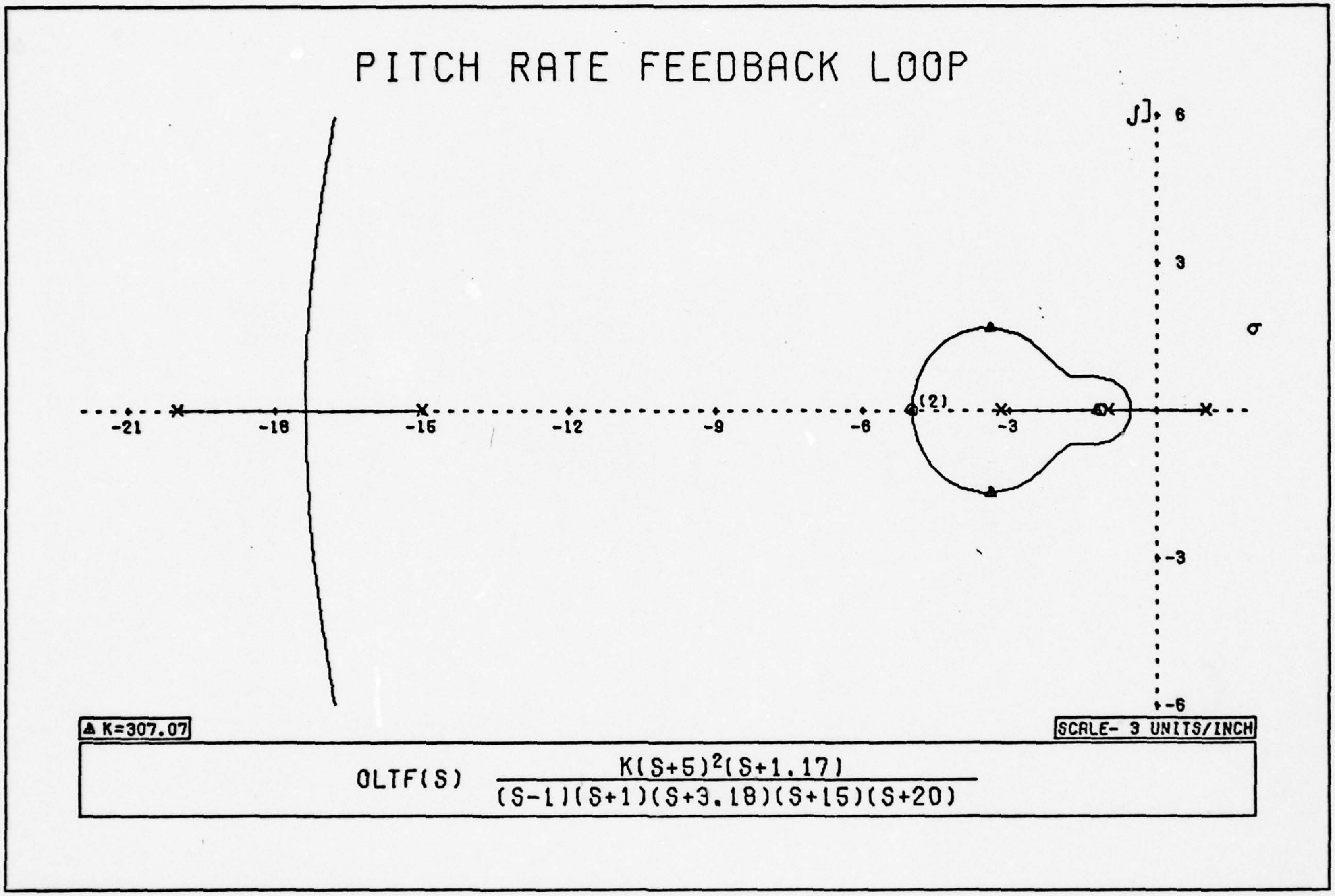


Figure 12. Pitch Rate Loop Closure, Flt. Cond. 1

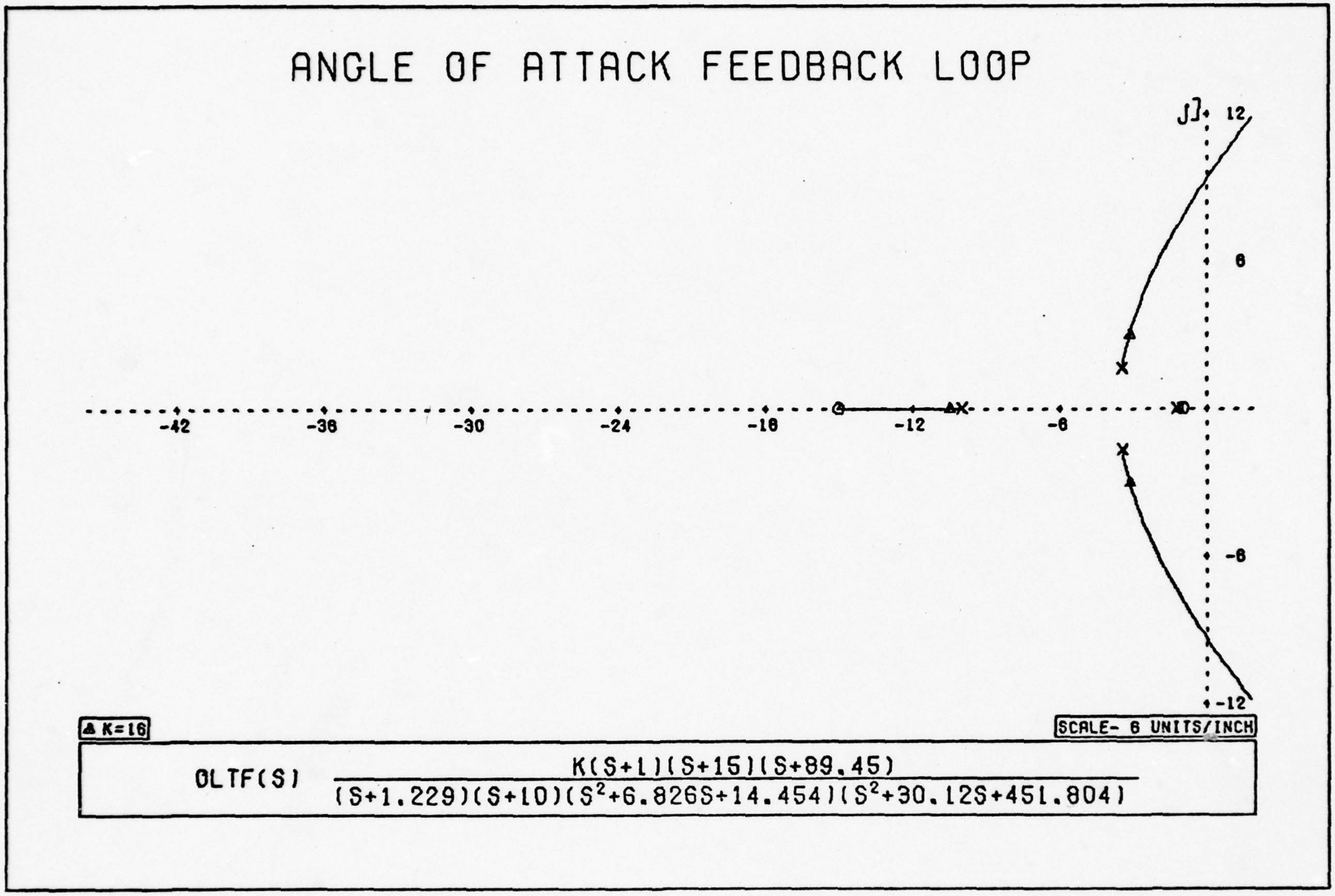
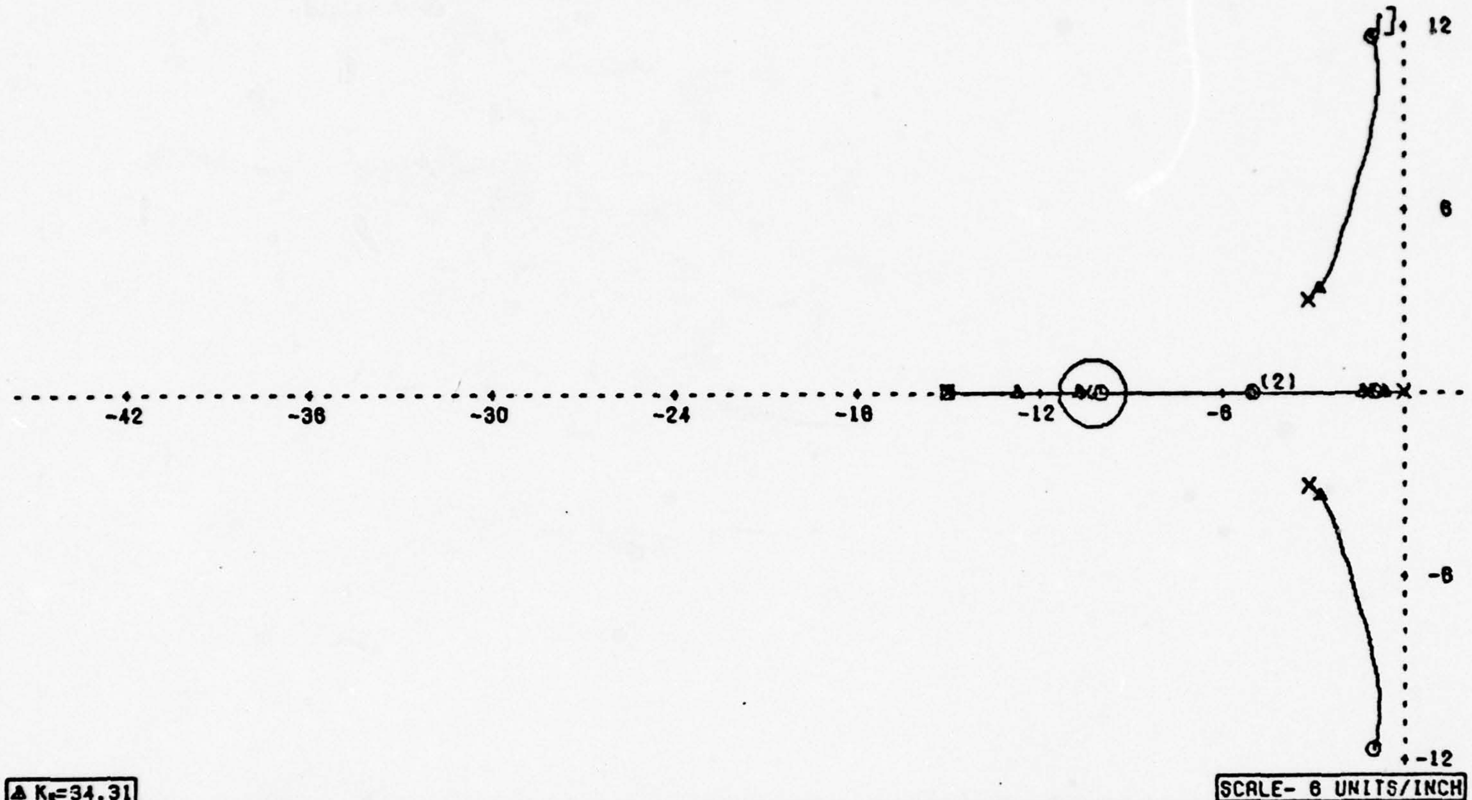


Figure 13. Angle of Attack Loop Closure, Flt. Cond. 1

NORMAL ACCELERATION FEEDBACK LOOP



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

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

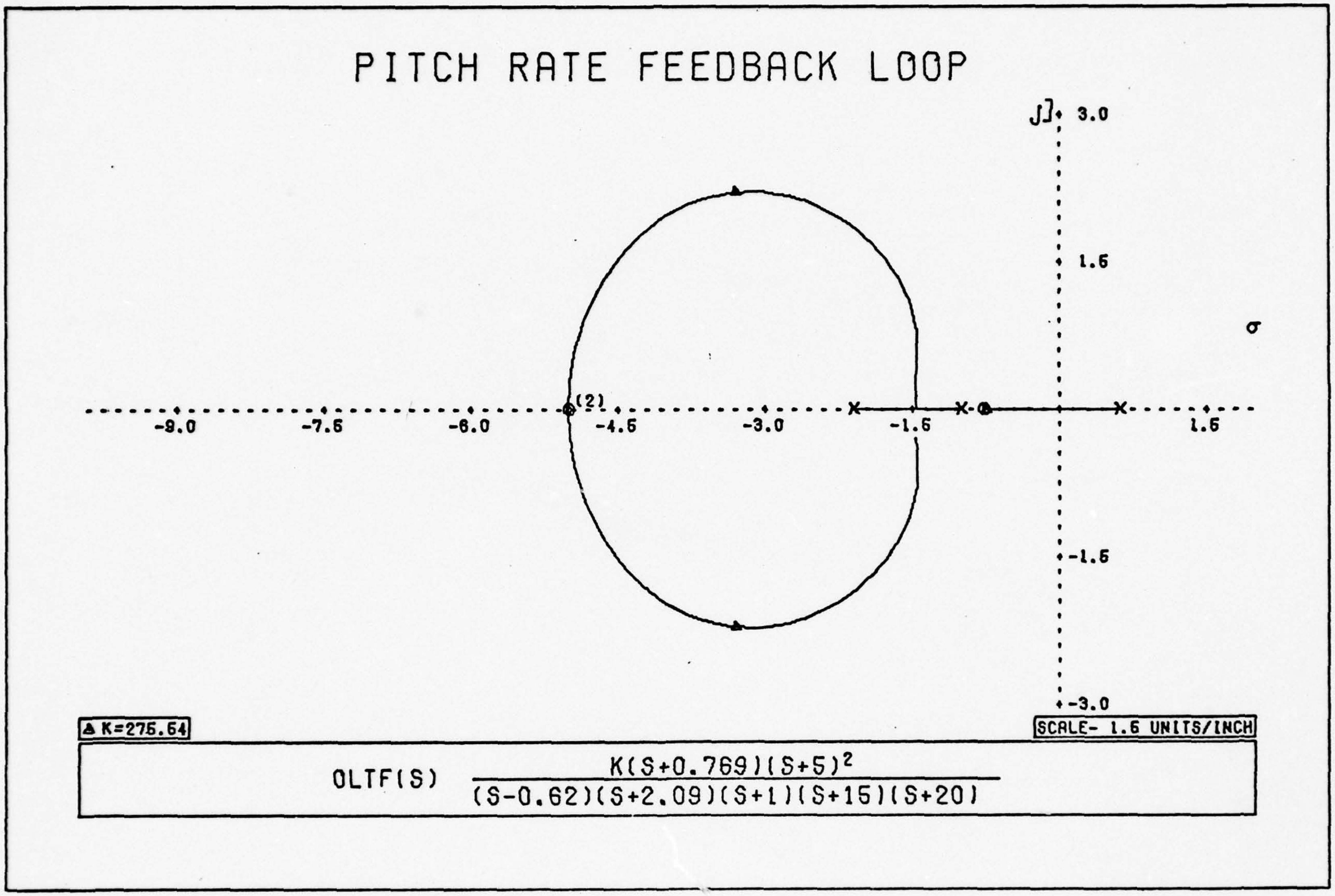


Figure 15. Pitch Rate Loop Closure, Flt. Cond. 2

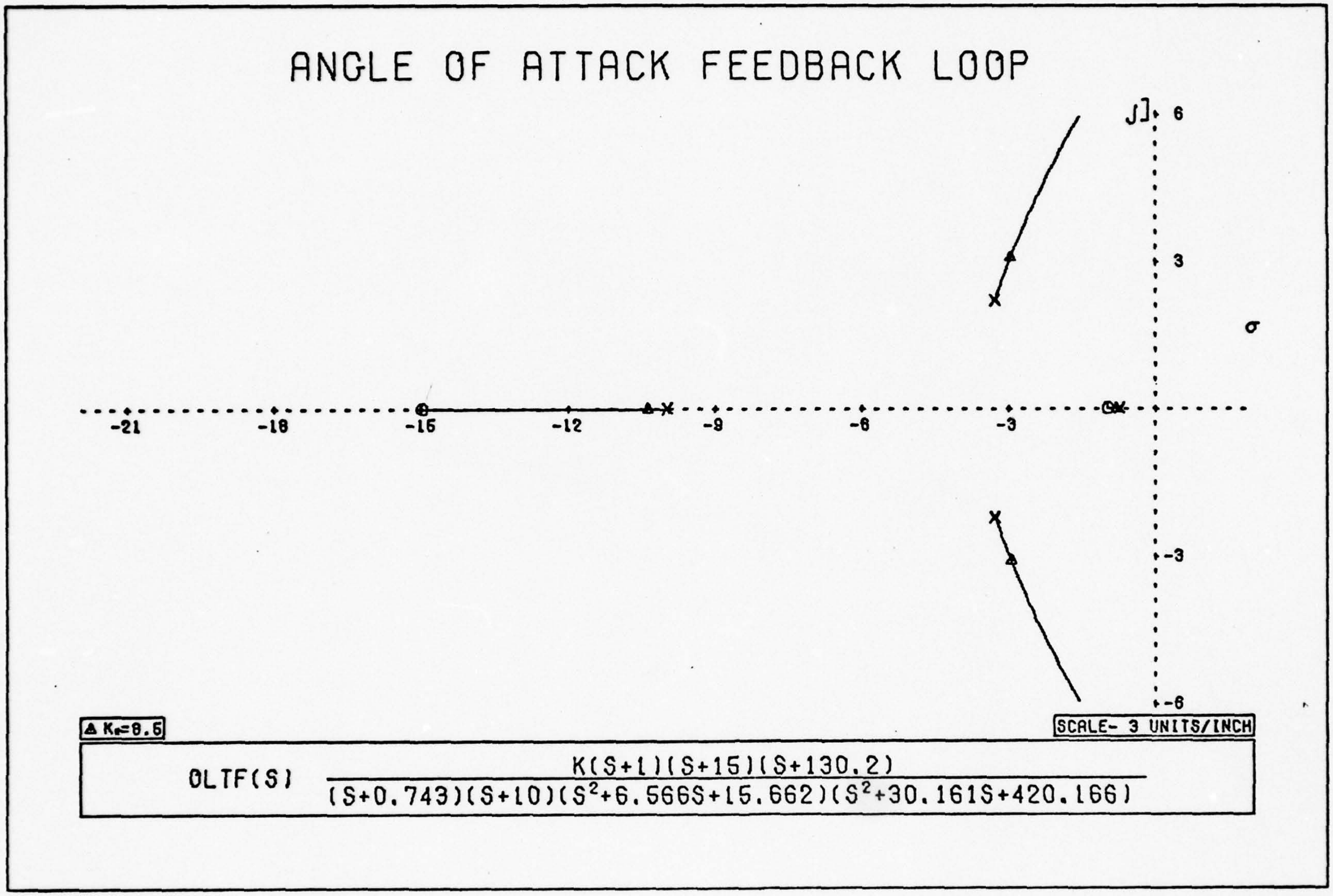


Figure 16. Angle of Attack Loop Closure, Flt. Cond. 2

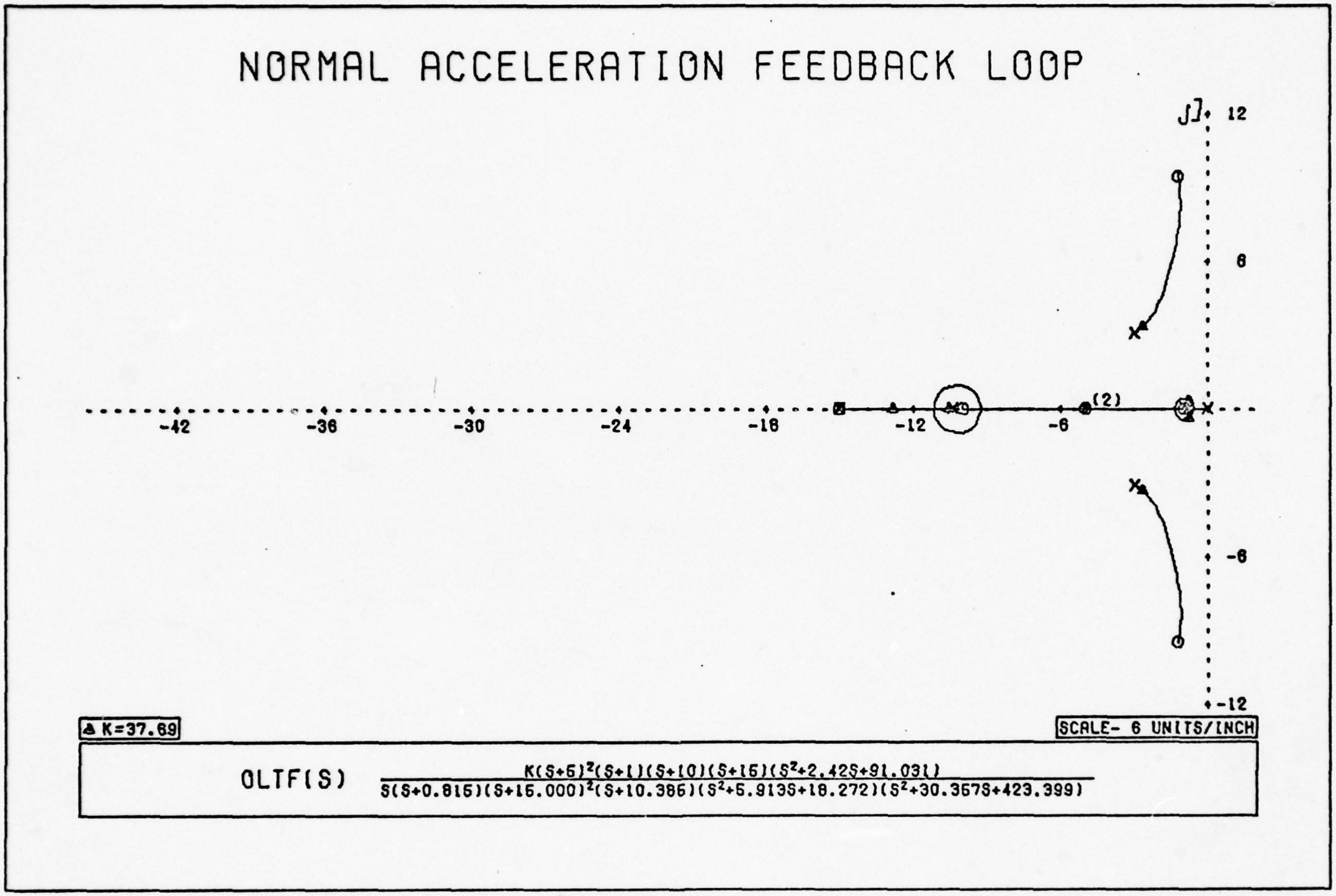


Figure 17. Normal Acceleration Loop Closure, Flt. Cond. 2

Flight Condition 1:

$$\frac{a_n(s)}{g_{com}} = \frac{(6.33)(s+5)(s+1)(s+10)(s+15)}{(s+8.3)(s+1.368)(s+.6434)(s+2.765 \pm 3.389j)}$$

$$\frac{(s \quad 1.011 \quad 11.68j)}{(s+10.7)(s+12.71)(S+16.11 \pm 15.89)} \tag{24}$$

Flight Condition 2:

$$\frac{a_n(s)}{g_{com}} = \frac{(7.026)(s+5)(s+1)(s+10)(s+15)}{(s+8.3)(s+10.55)(s+12.83)(s+.7696 \pm .3564j)}$$

$$\frac{(s+1.21 \pm 9.464j)}{(s+2.643 \pm 3.32j)(s+16.13 \pm 15.13j)} \tag{25}$$

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:

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

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

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

Flight Condition 2:

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

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

$$\frac{}{\pm 16.16j)} \tag{27}$$

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

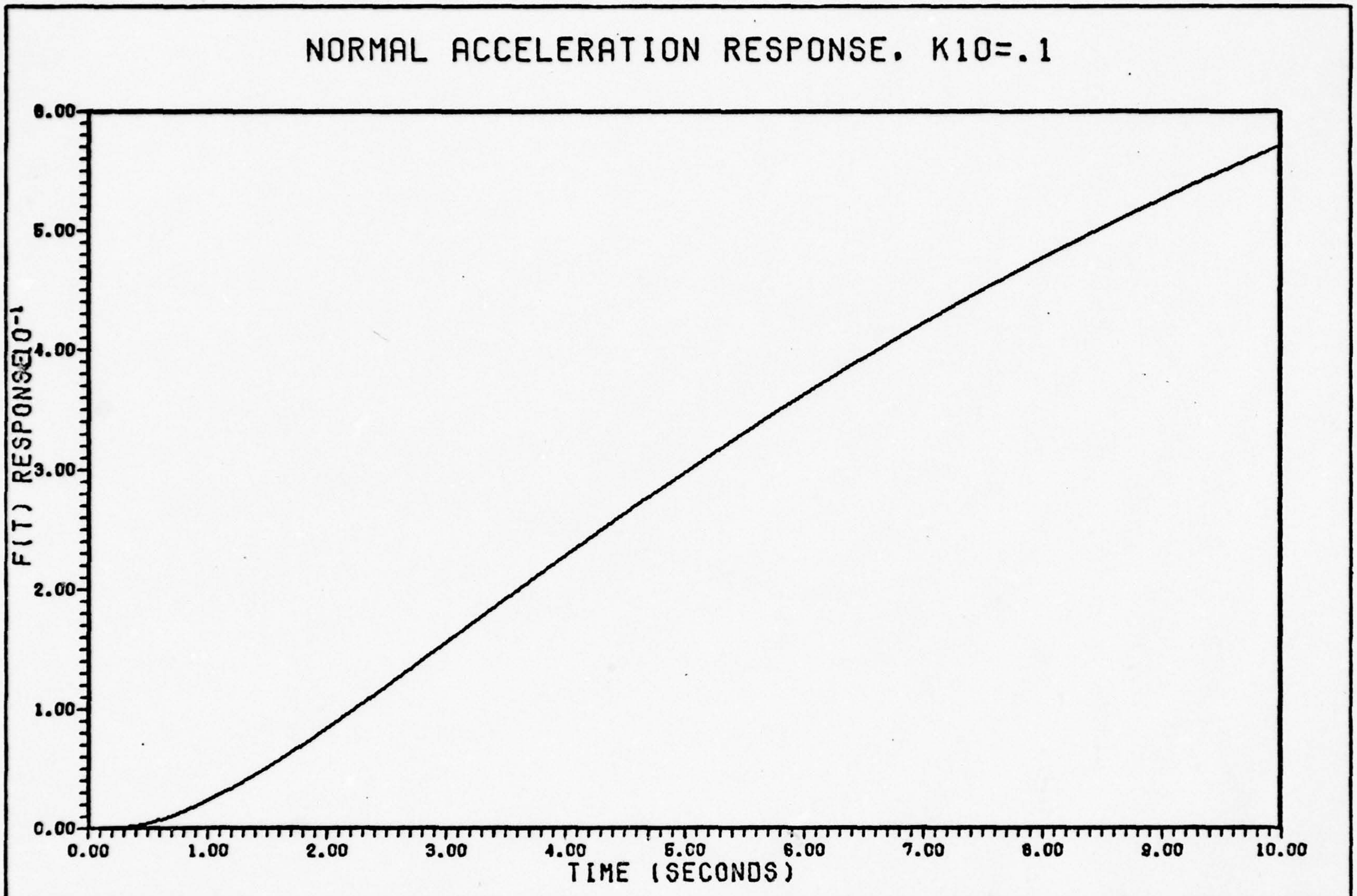


Figure 18. Step Response for K_{10} = .1, Flt. Cond.1

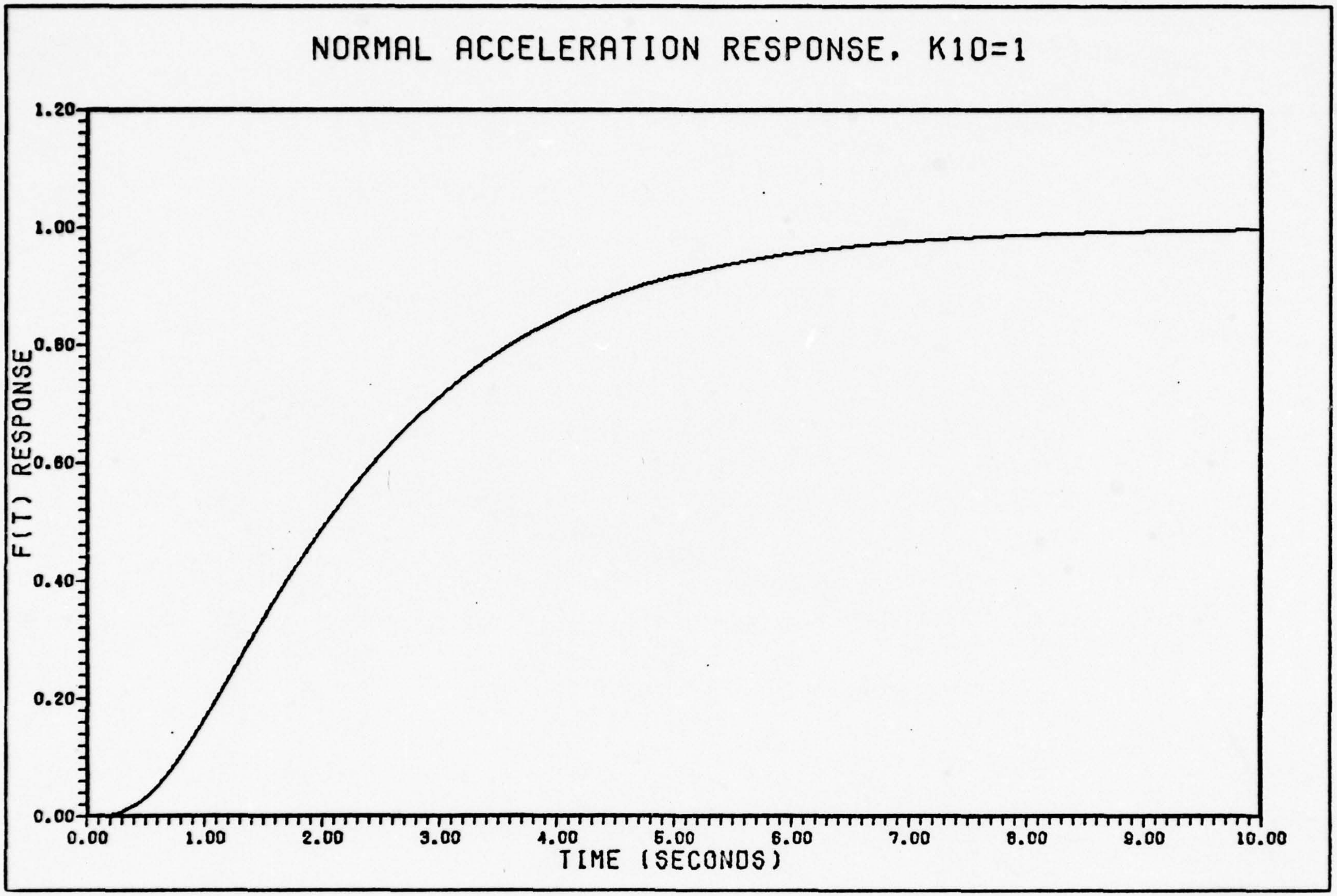


Figure 19. Step Response for K_{10} = 1.0, Flt. Cond. 1

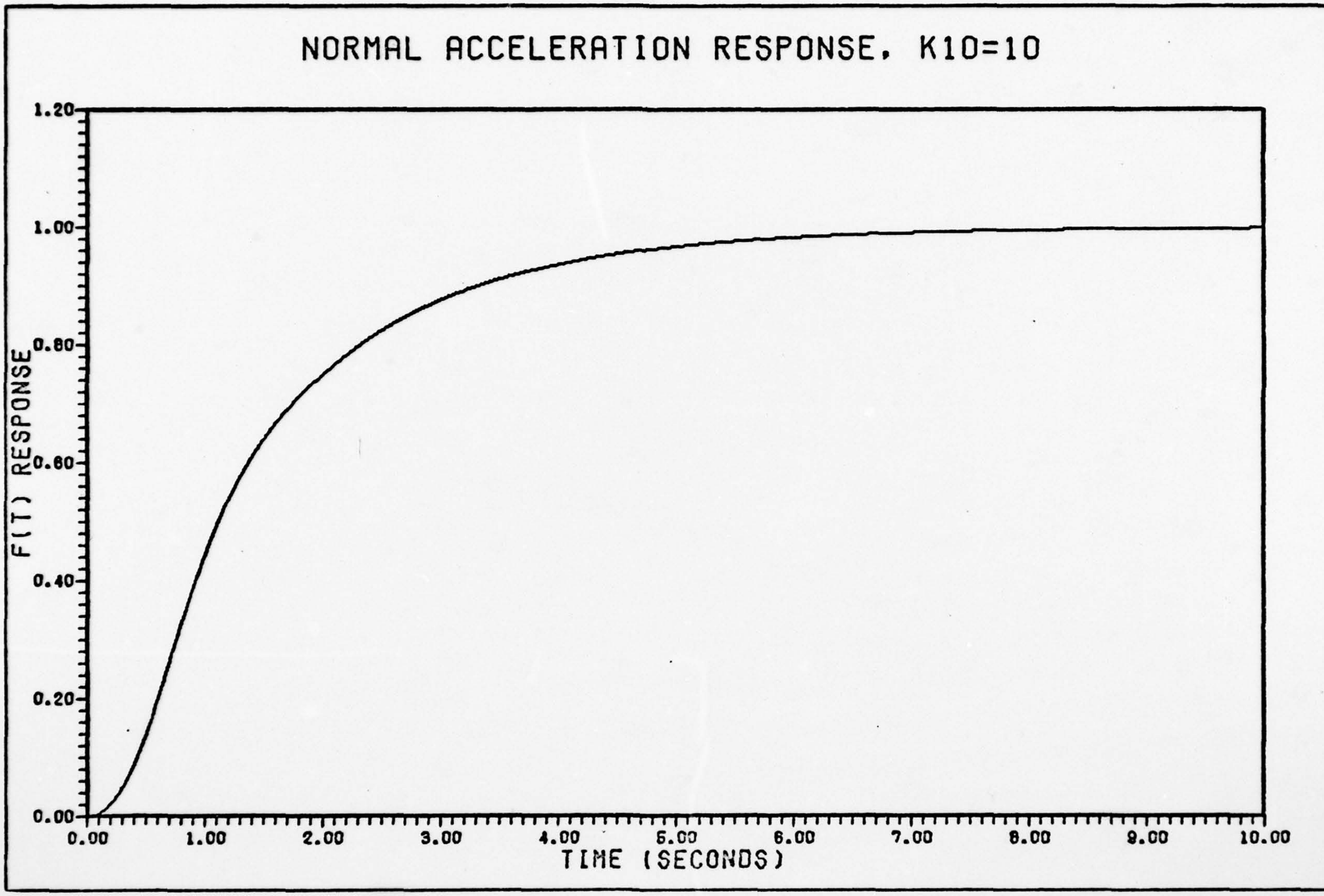


Figure 20. Step Response for $K_{10} = 10$, Flt. Cond. 1

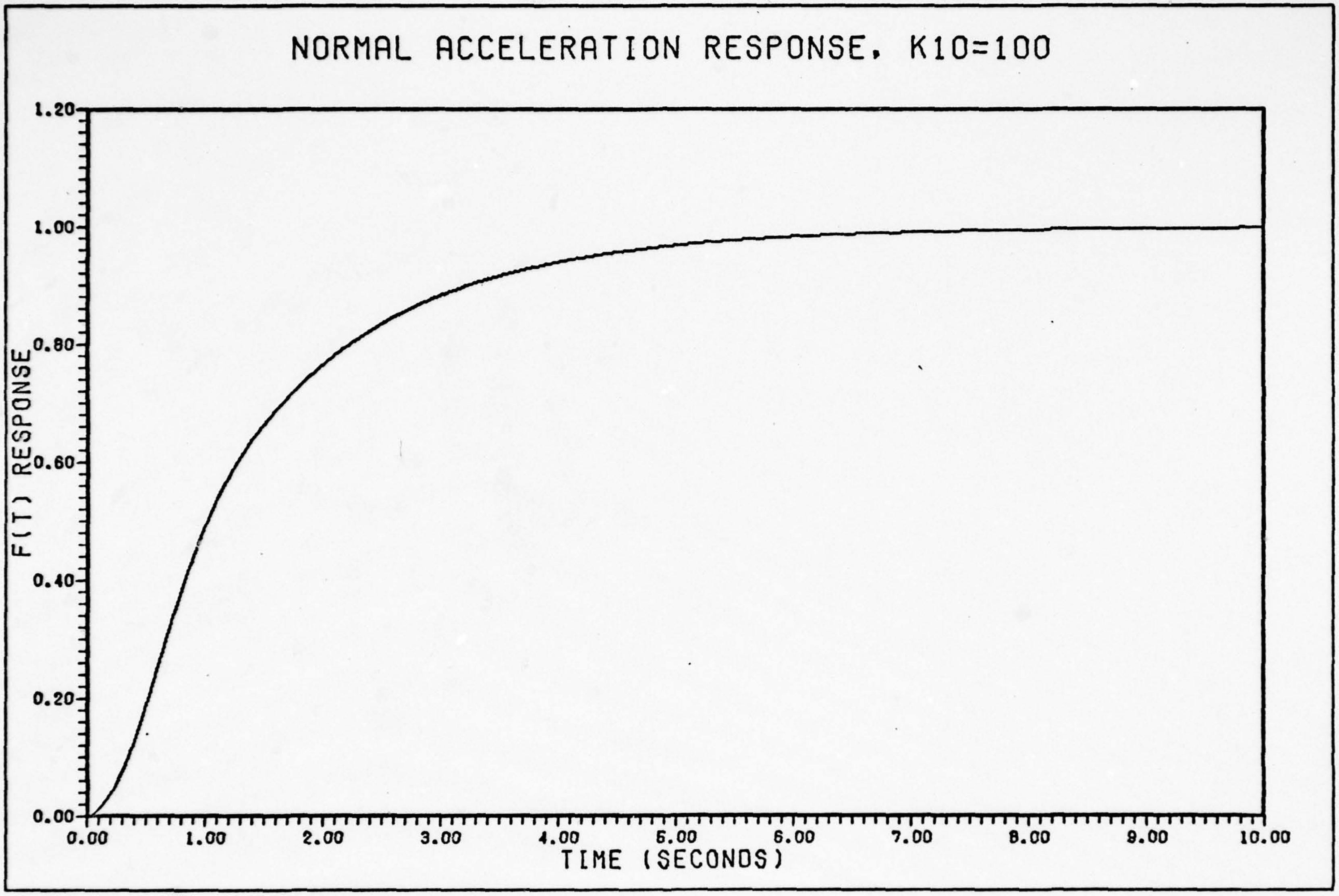


Figure 21. Step Response for $K_{10} = 100$, Flt. Cond. 1

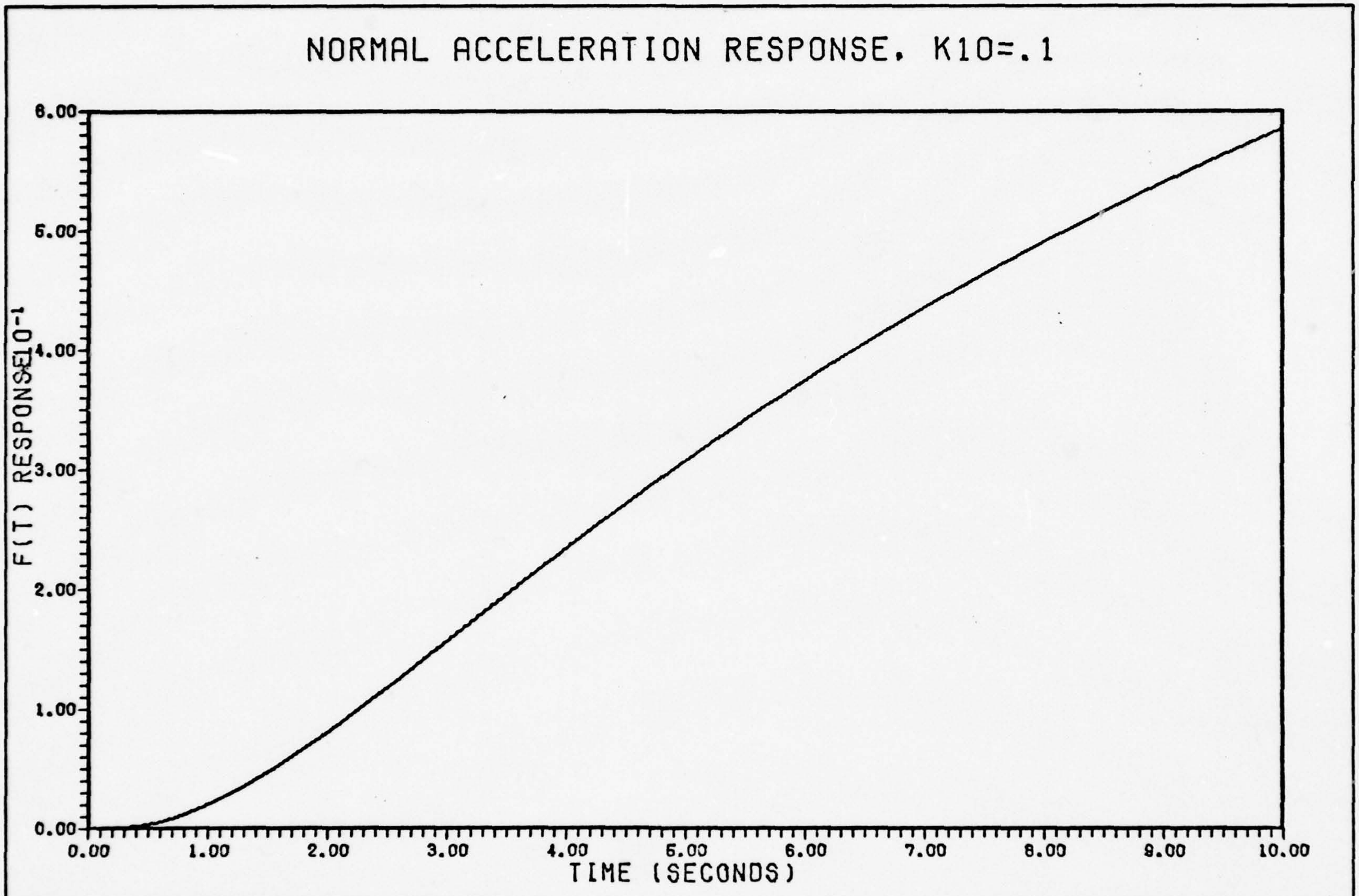


Figure 22. Step Response for K_{10} = .1, Flt. Cond. 2

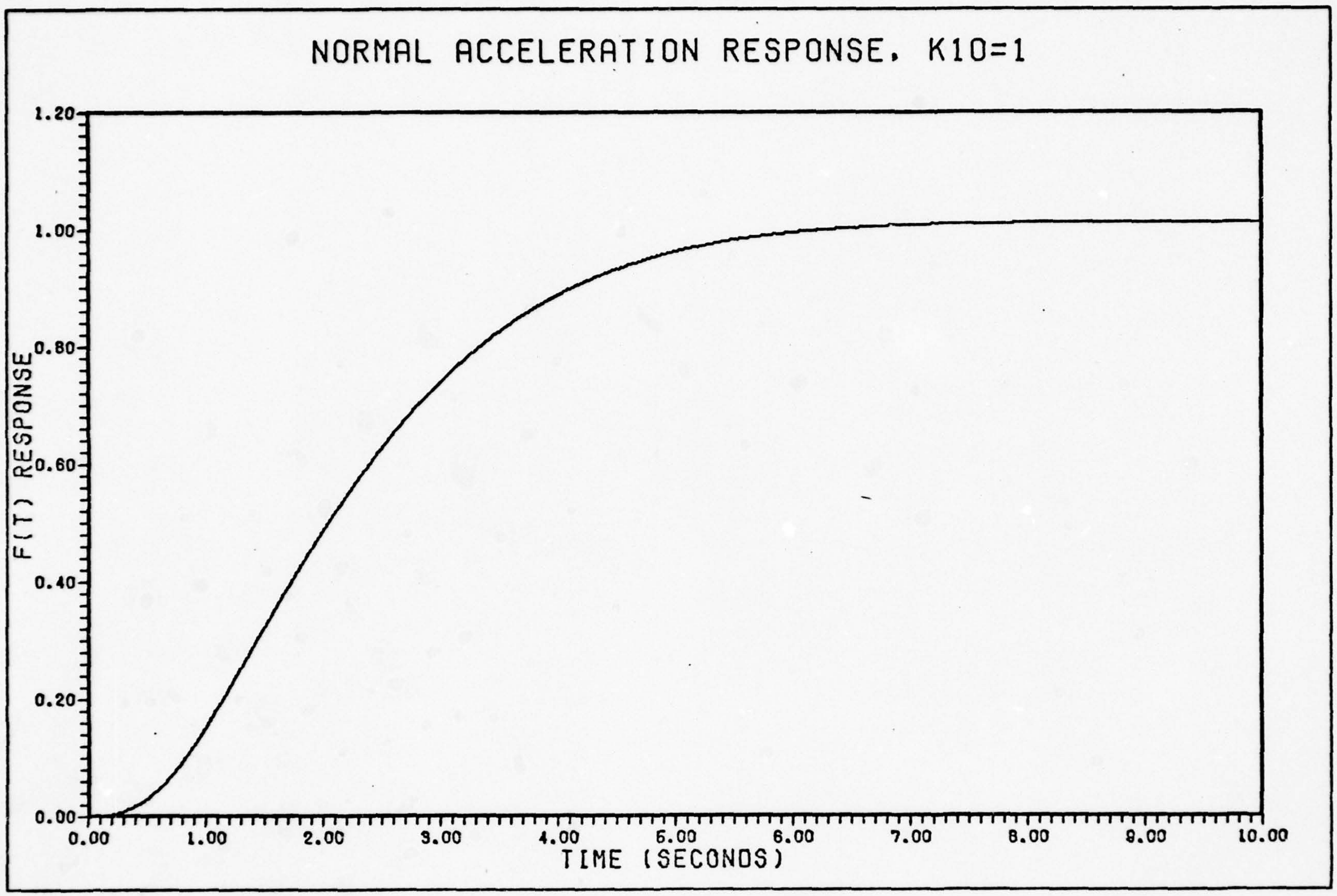


Figure 23. Step Response for K_{10} = 1.0, Flt. Cond. 2

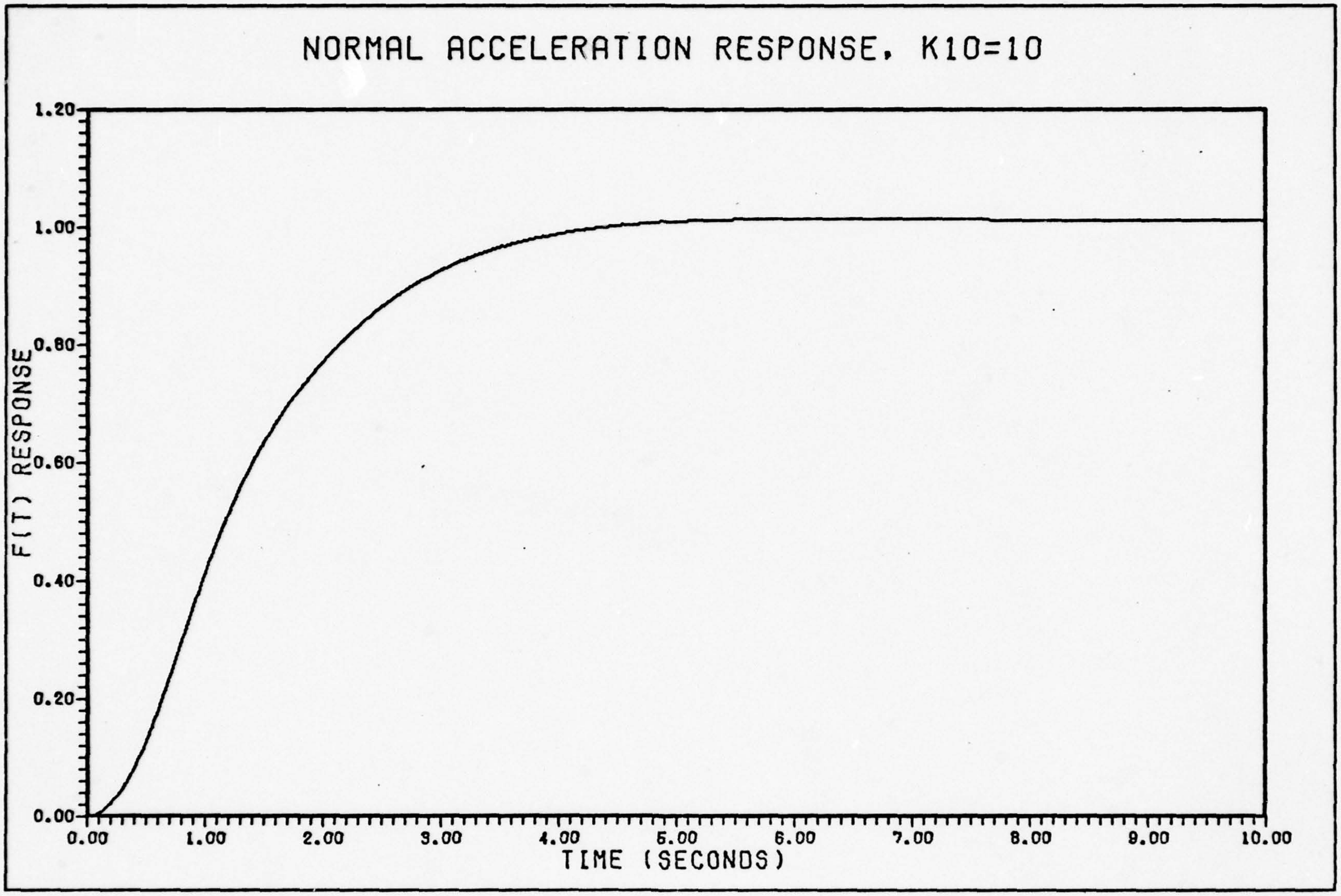


Figure 24. Step Response for K_{10} = 10, Flt. Cond. 2

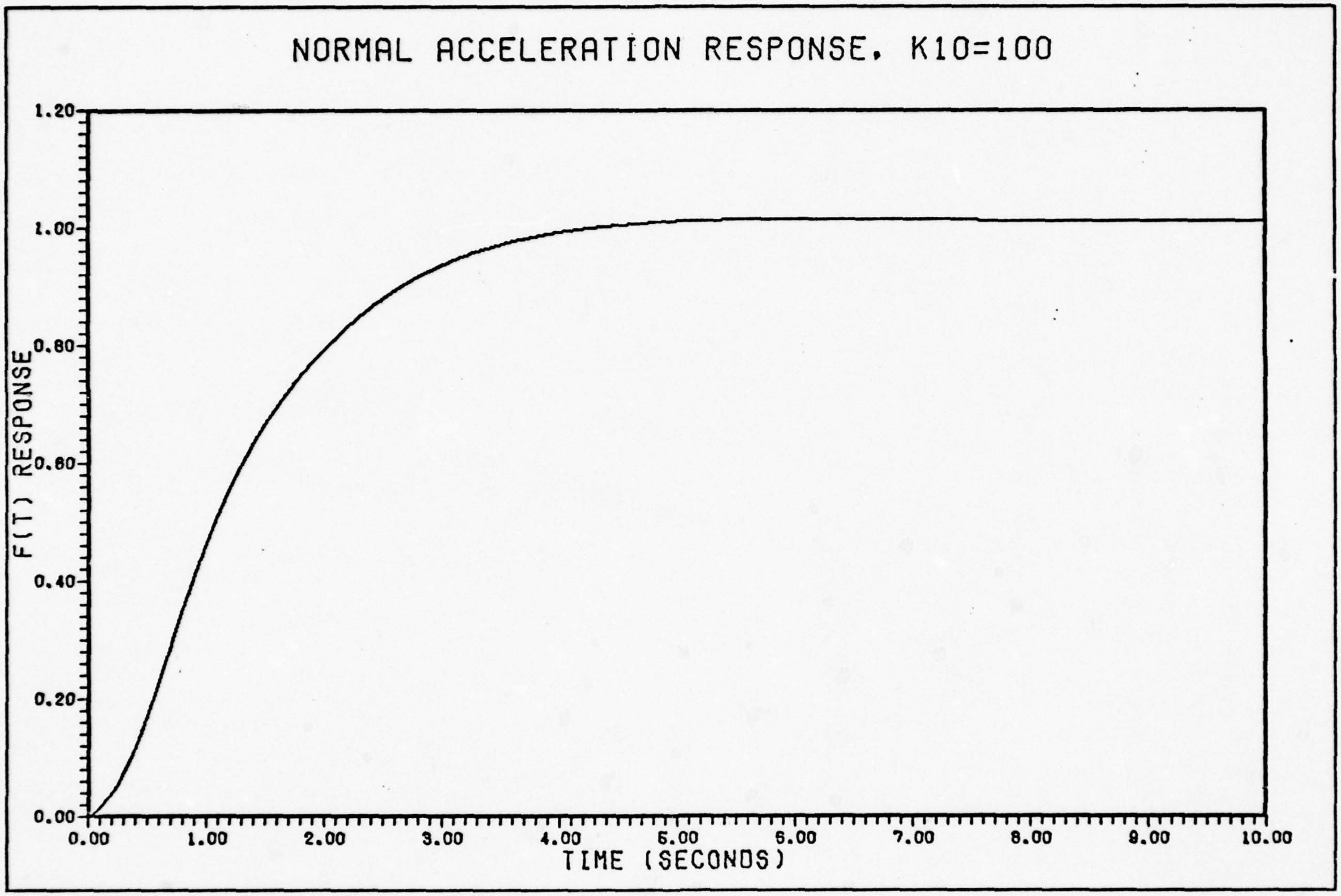


Figure 25. Step Response for K_{10} = 100, Flt. Cond. 2

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.

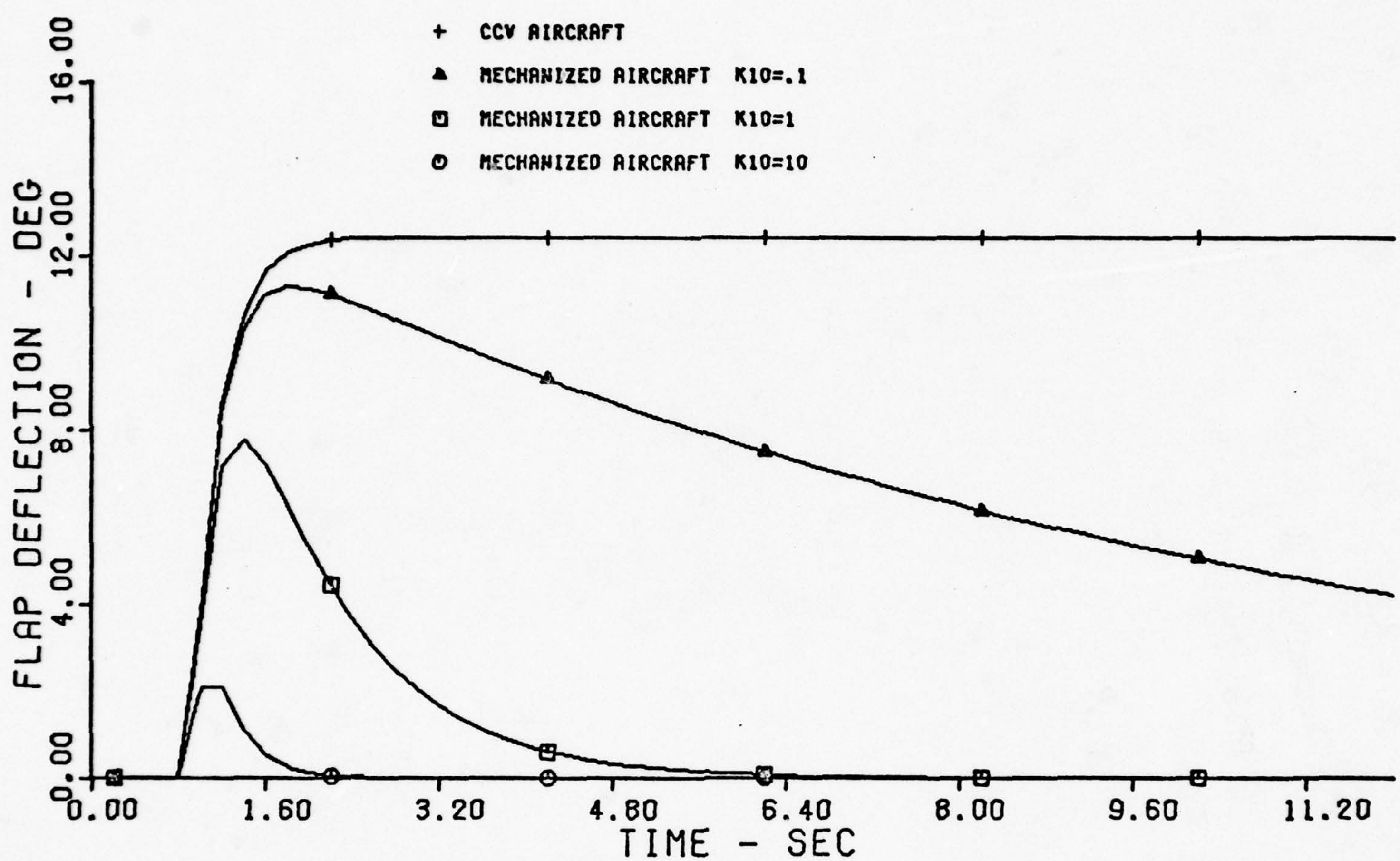


Figure 26. Flap Deflection Time Histories Varying K_{10}

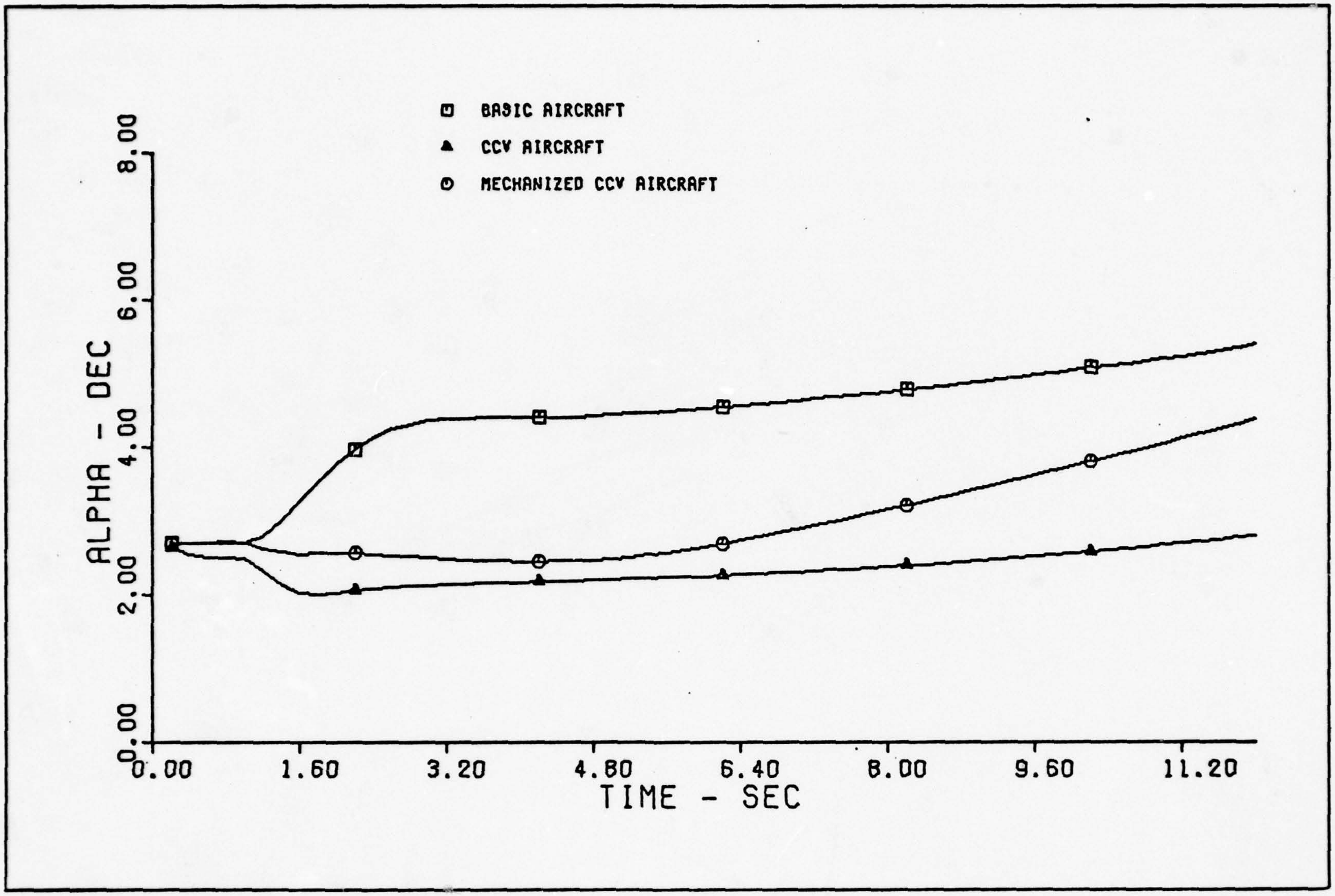


Figure 27. Comparative Time Histories of Angle of Attack, Flt. Cond. 1

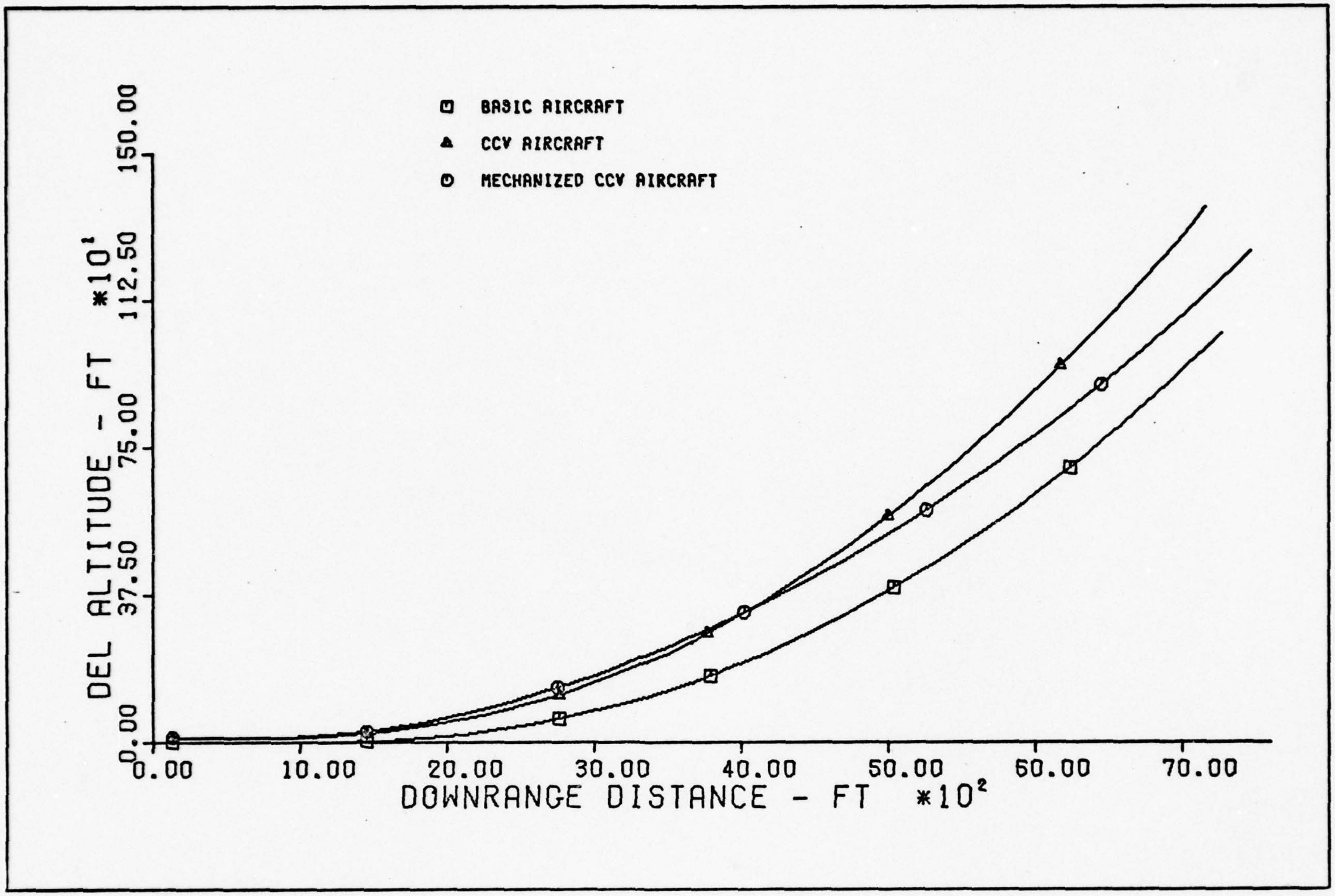


Figure 28. Comparative Flight Trajectories, Flt. Cond. 1

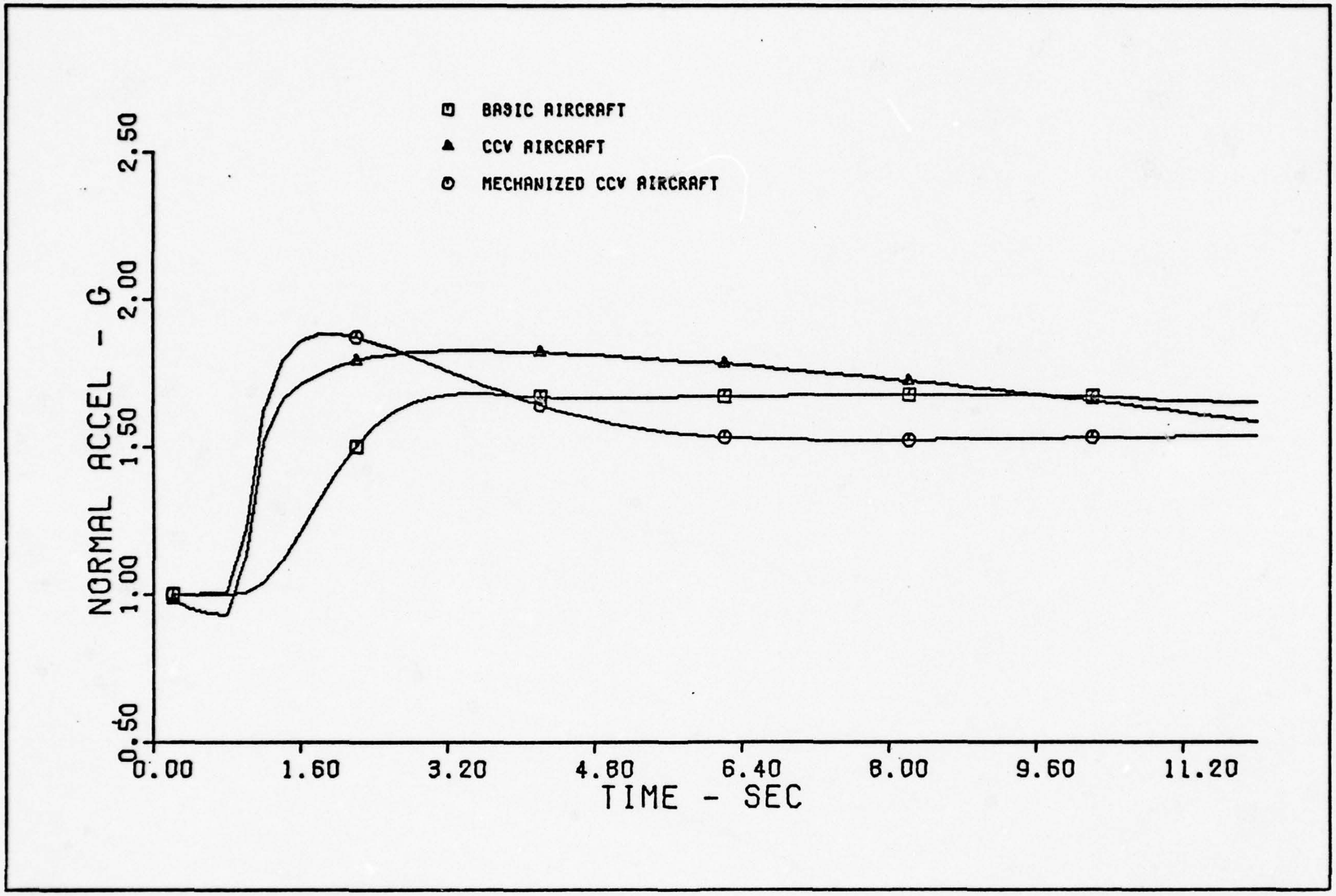


Figure 29. Comparative Time Histories of Normal Acceleration, Flt. Cond.1

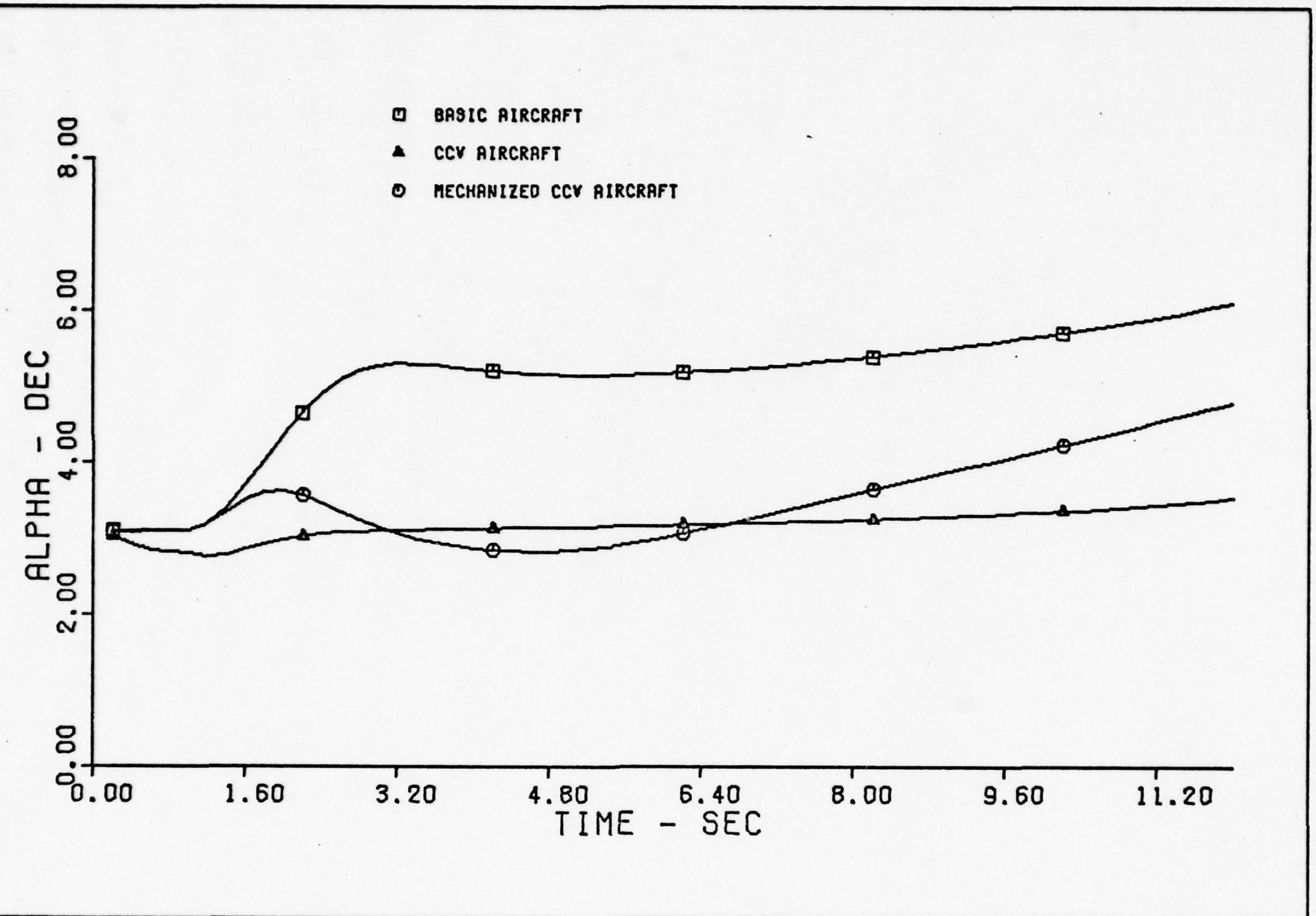


Figure 30. Comparative Time Histories of Angle of Attack, Flt. Cond. 2

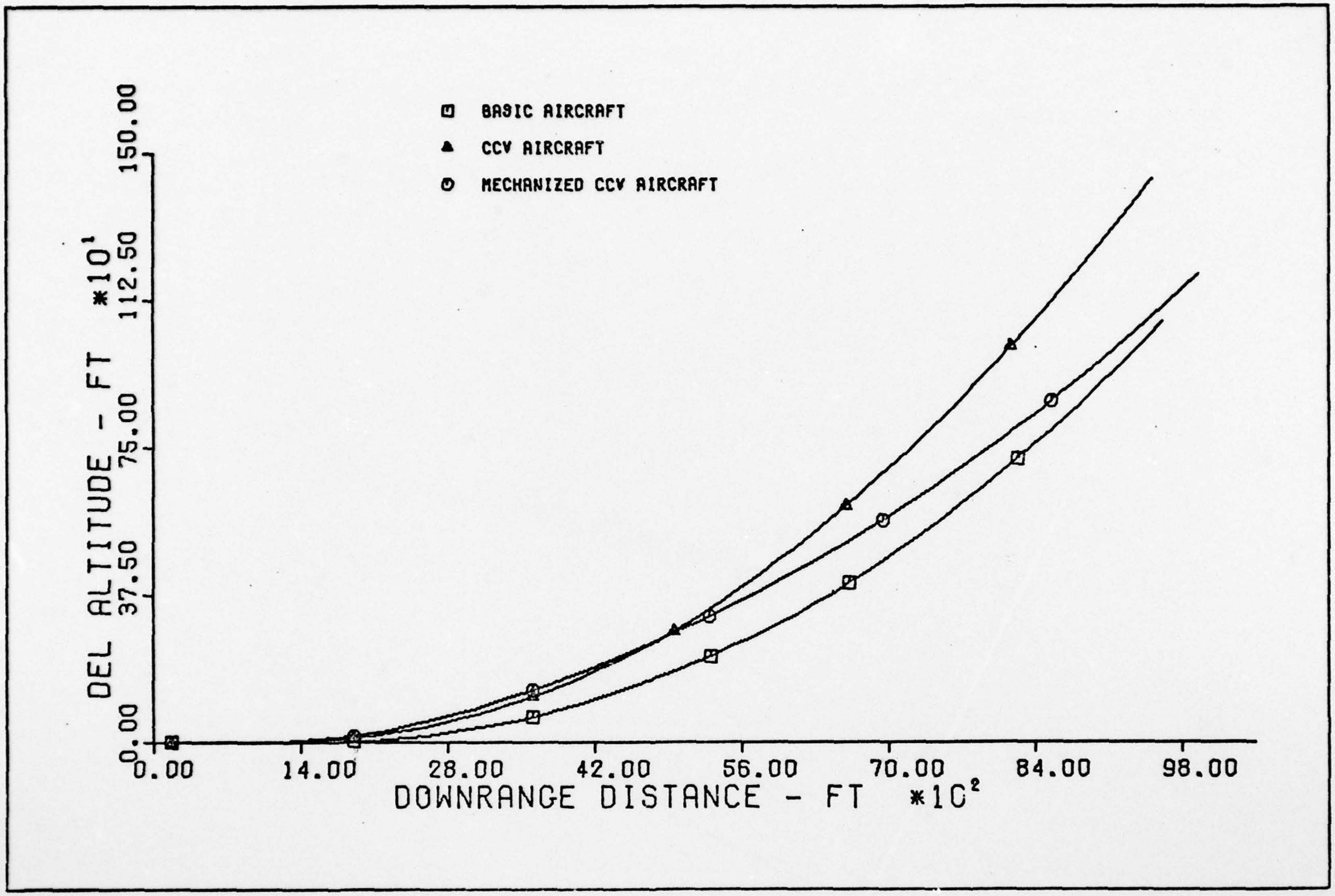


Figure 31. Comparative Flight Trajectories, Flt. Cond. 2

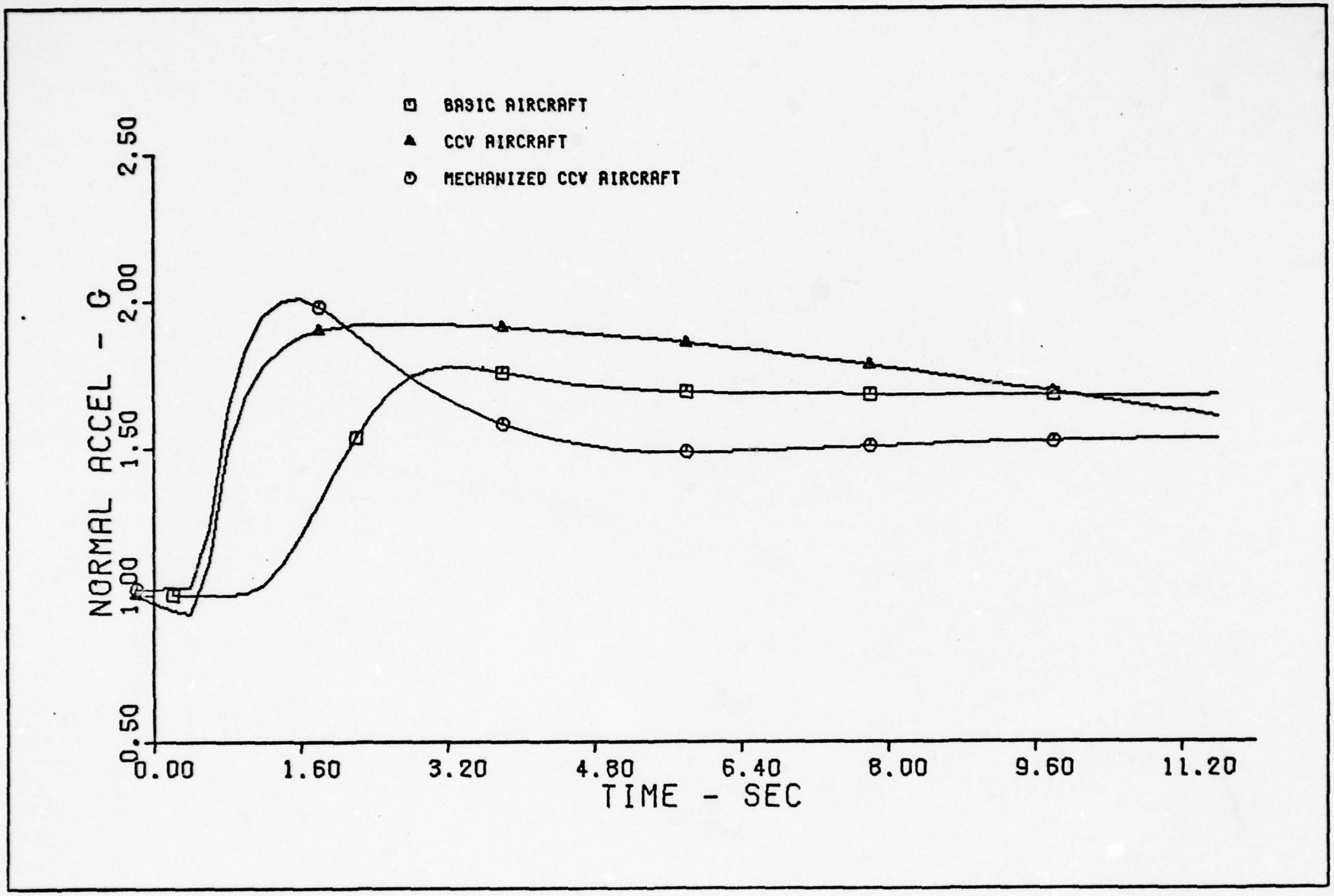


Figure 32. Comparative Time Histories of Normal Acceleration, Flt. Cond. 2

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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Appendix A

Physical Description of the Aircraft

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

Control Surface Deflection Limits

Elevator . . . . $\pm 25^{o}$

Flaperons . . . .$\pm 20^{o}$

Rudder . . . . $\pm 30^{o}$

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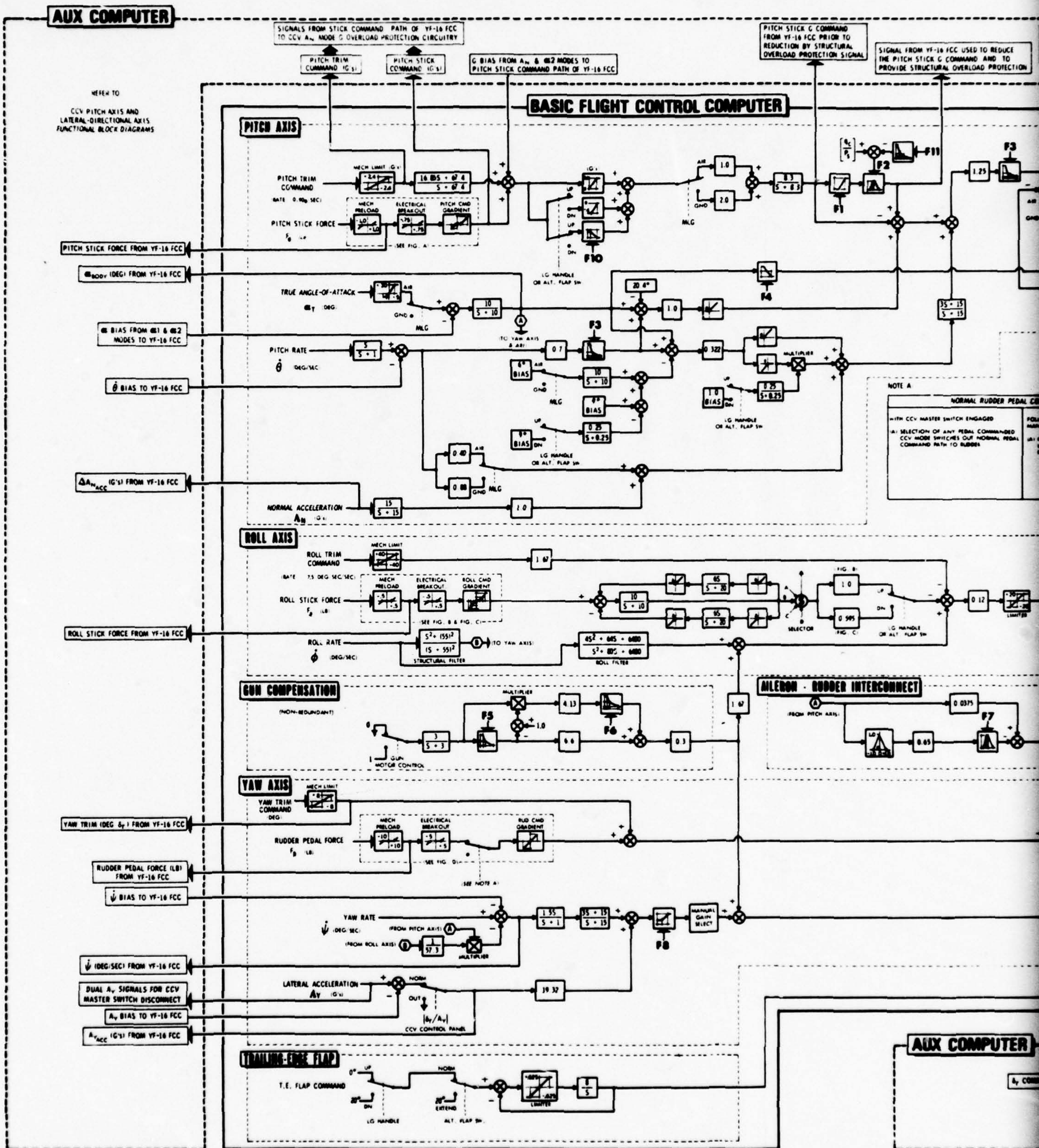
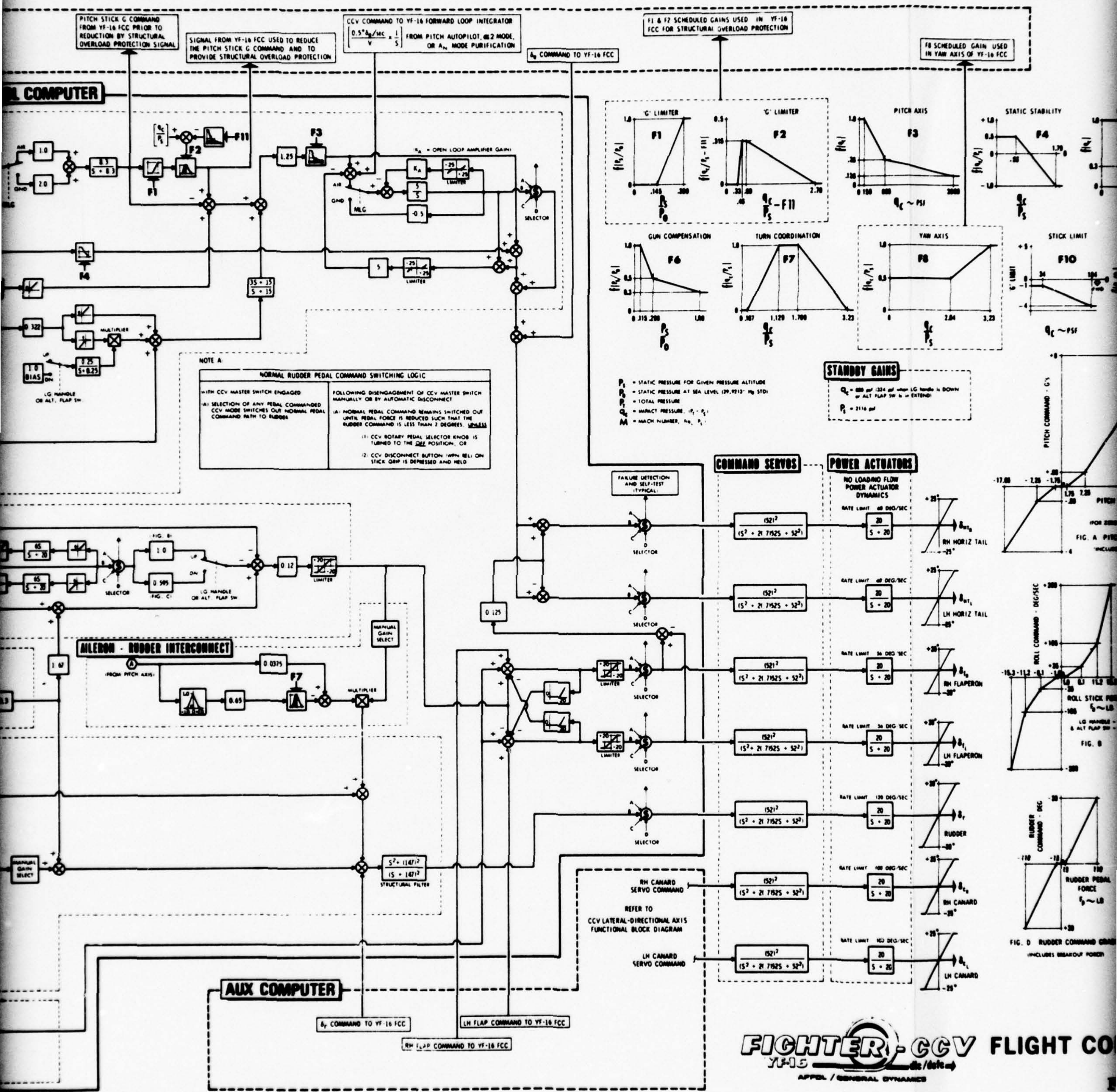
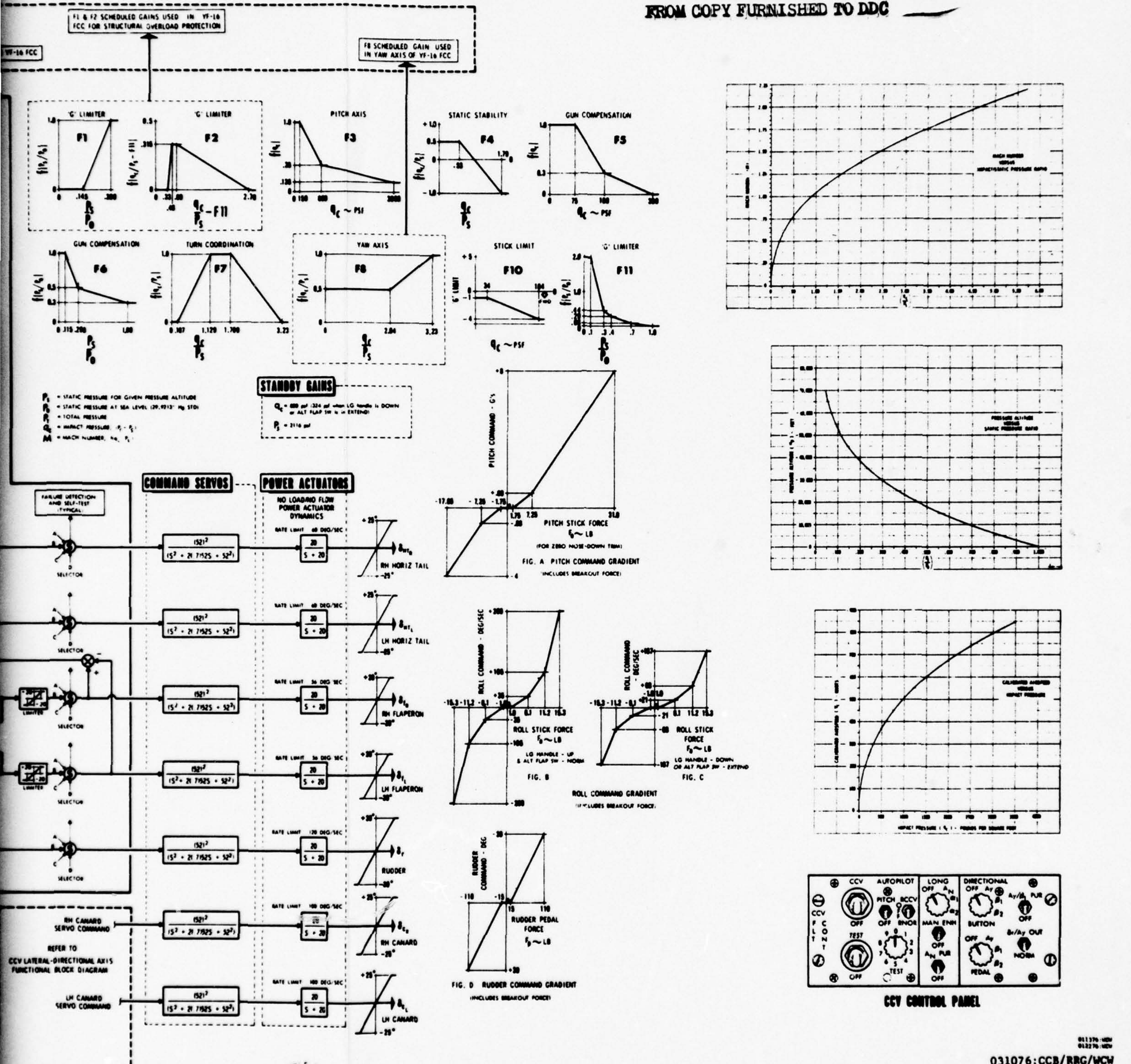



PITCH STICK G COMMAND FROM YF-16 FCC PRIOR TO REDUCTION BY STRUCTURAL OVERLOAD PROTECTION SIGNAL
SIGNAL FROM YF-16 FCC USED TO REDUCE THE PITCH STICK G COMMAND AND TO PROVIDE STRUCTURAL OVERLOAD PROTECTION
CCV COMMAND TO YF-16 FORWARD LOOP INTEGRATOR
FROM PITCH AUTOPILOT, MODE, OR A_n MODE PURIFICATION
δ_R COMMAND TO YF-16 FCC
F1 & F2 SCHEDULED GAINS USED IN YF-16 FCC FOR STRUCTURAL OVERLOAD PROTECTION
F8 SCHEDULED GAIN USED IN YAW AXIS OF YF-16 FCC
L COMPUTER
'G' LIMITER
PITCH AXIS
STATIC STABILITY
GUN COMPENSATION
TURN COORDINATION
YAW AXIS
STICK LIMIT
SELECTOR
LIMITER
MULTIPLIER
BIAS
LG HANDLE OR ALT. FLAP SW
NOTE A
NORMAL RUDDER PEDAL COMMAND SWITCHING LOGIC
WITH CCV MASTER SWITCH ENGAGED
(A) SELECTION OF ANY PEDAL COMMANDED CCV MODE SWITCHES OUT NORMAL PEDAL COMMAND PATH TO RUDDER
FOLLOWING DISENGAGEMENT OF CCV MASTER SWITCH MANUALLY OR BY AUTOMATIC DISCONNECT
(A) NORMAL PEDAL COMMAND REMAINS SWITCHED OUT UNTIL PEDAL FORCE IS REDUCED SUCH THAT THE RUDDER COMMAND IS LESS THAN 2 DEGREES, UNLESS
(1) CCV ROTARY PEDAL SELECTOR KNOB IS TURNED TO THE OFF POSITION, OR
(2) CCV DISCONNECT BUTTON (WPN REL) ON STICK GRIP IS DEPRESSED AND HELD
P_s = STATIC PRESSURE FOR GIVEN PRESSURE ALTITUDE
P_o = STATIC PRESSURE AT SEA LEVEL (29.9213" Hg STD)
P_T = TOTAL PRESSURE
Q_c = IMPACT PRESSURE
M = MACH NUMBER
STANDBY GAINS
COMMAND SERVOS
POWER ACTUATORS
NO LOAD/NO FLOW POWER ACTUATOR DYNAMICS
FAILURE DETECTION AND SELF-TEST (TYPICAL)
RH HORIZ TAIL
LH HORIZ TAIL
RH FLAPERON
LH FLAPERON
RUDDER
RH CANARD
LH CANARD
RH CANARD SERVO COMMAND
LH CANARD SERVO COMMAND
REFER TO CCV LATERAL-DIRECTIONAL AXIS FUNCTIONAL BLOCK DIAGRAM
AILERON - RUDDER INTERCONNECT
(FROM PITCH AXIS)
MANUAL GAIN SELECT
STRUCTURAL FILTER
AUX COMPUTER
δ_T COMMAND TO YF-16 FCC
LH FLAP COMMAND TO YF-16 FCC
RH FLAP COMMAND TO YF-16 FCC
FIG. A
FIG. B
ROLL STICK FORCE
FIG. D RUDDER COMMAND
RUDDER PEDAL FORCE
FIGHTER - CCV FLIGHT CO
YF-16
AFFDL / GENERAL DYNAMICS

2



FIGHTER-CCV FLIGHT CONTROL SYSTEM FUNCTIONAL BLOCK DIAGRAM

Figure 33. (Ref 6)

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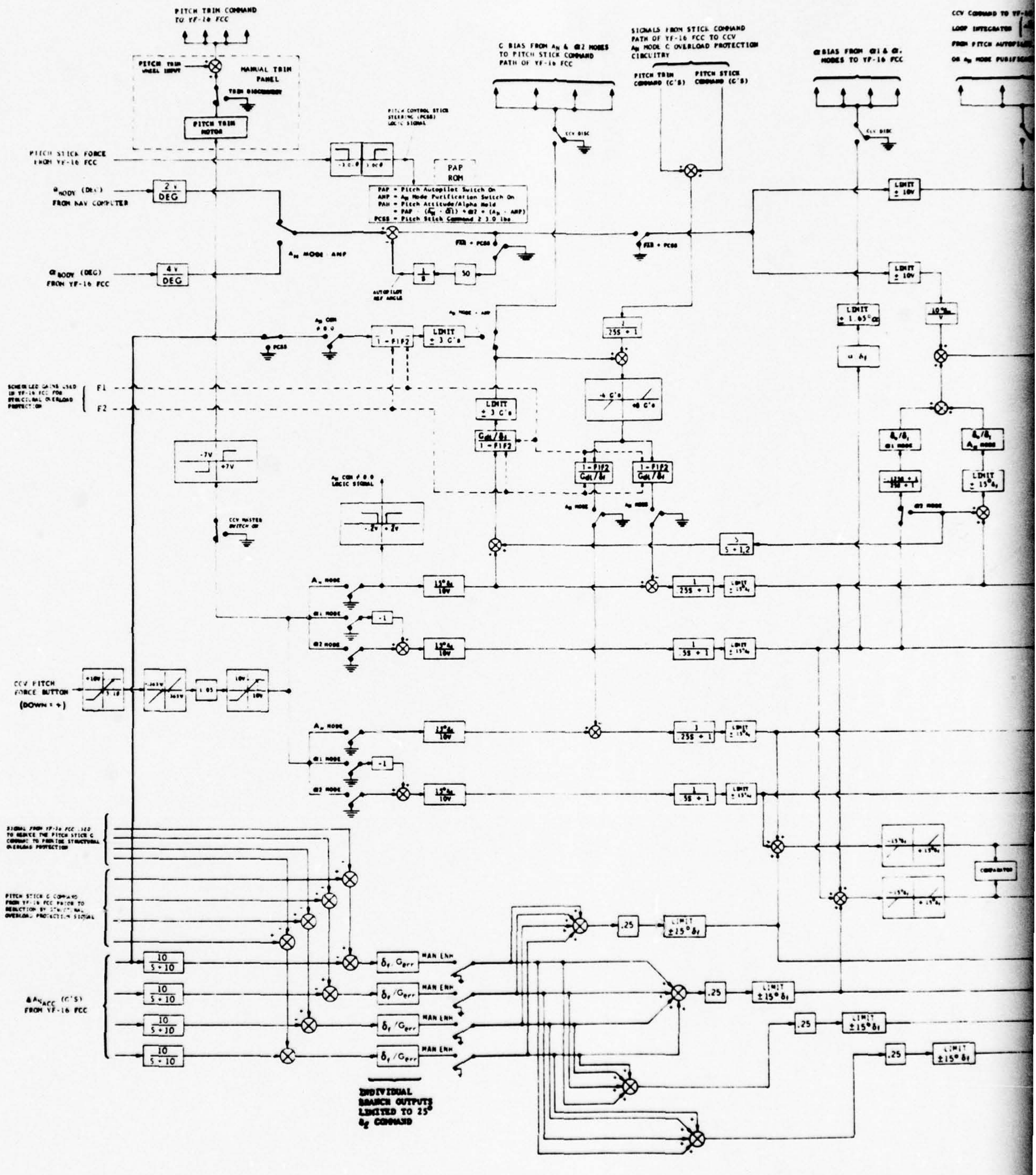
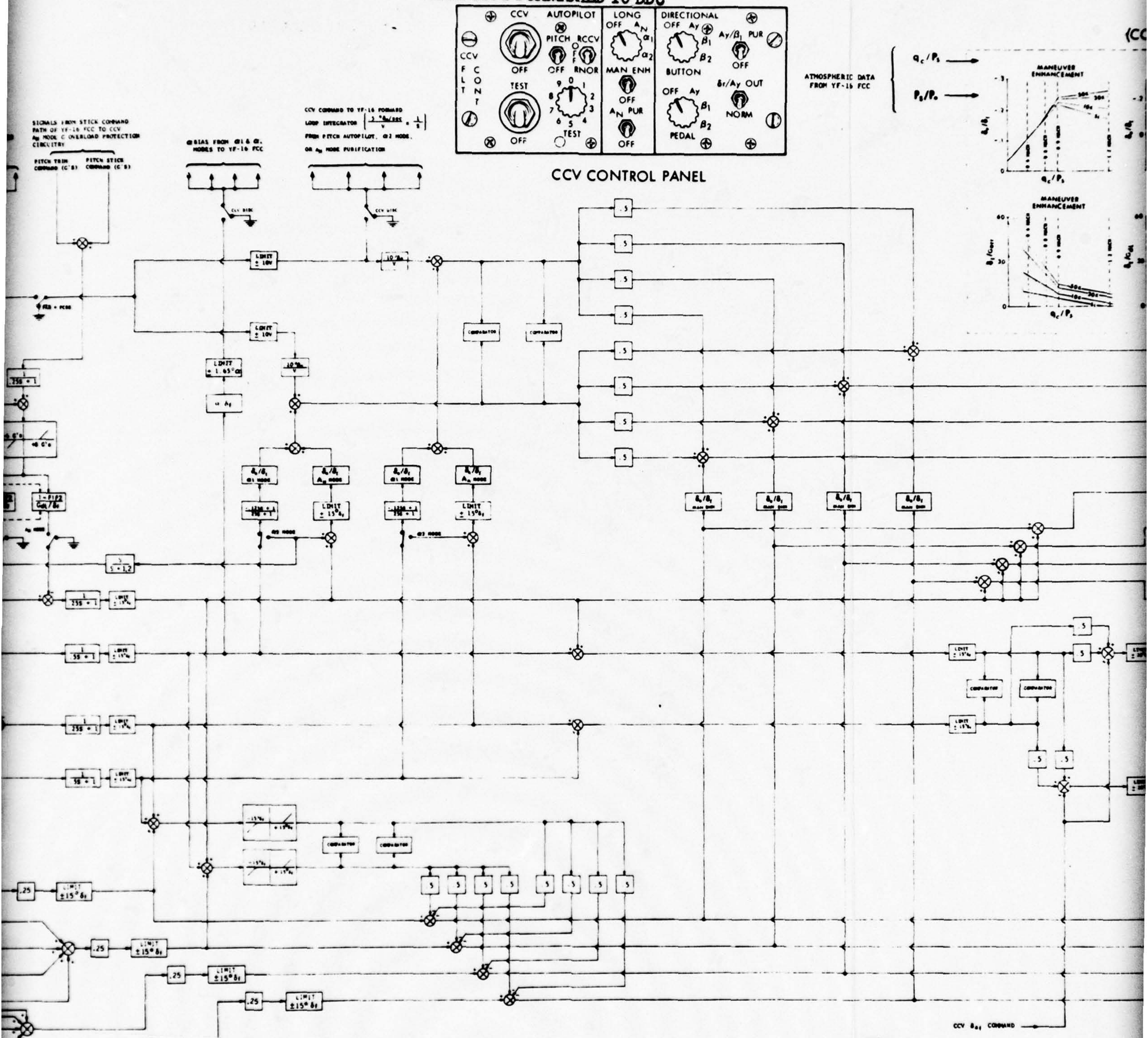




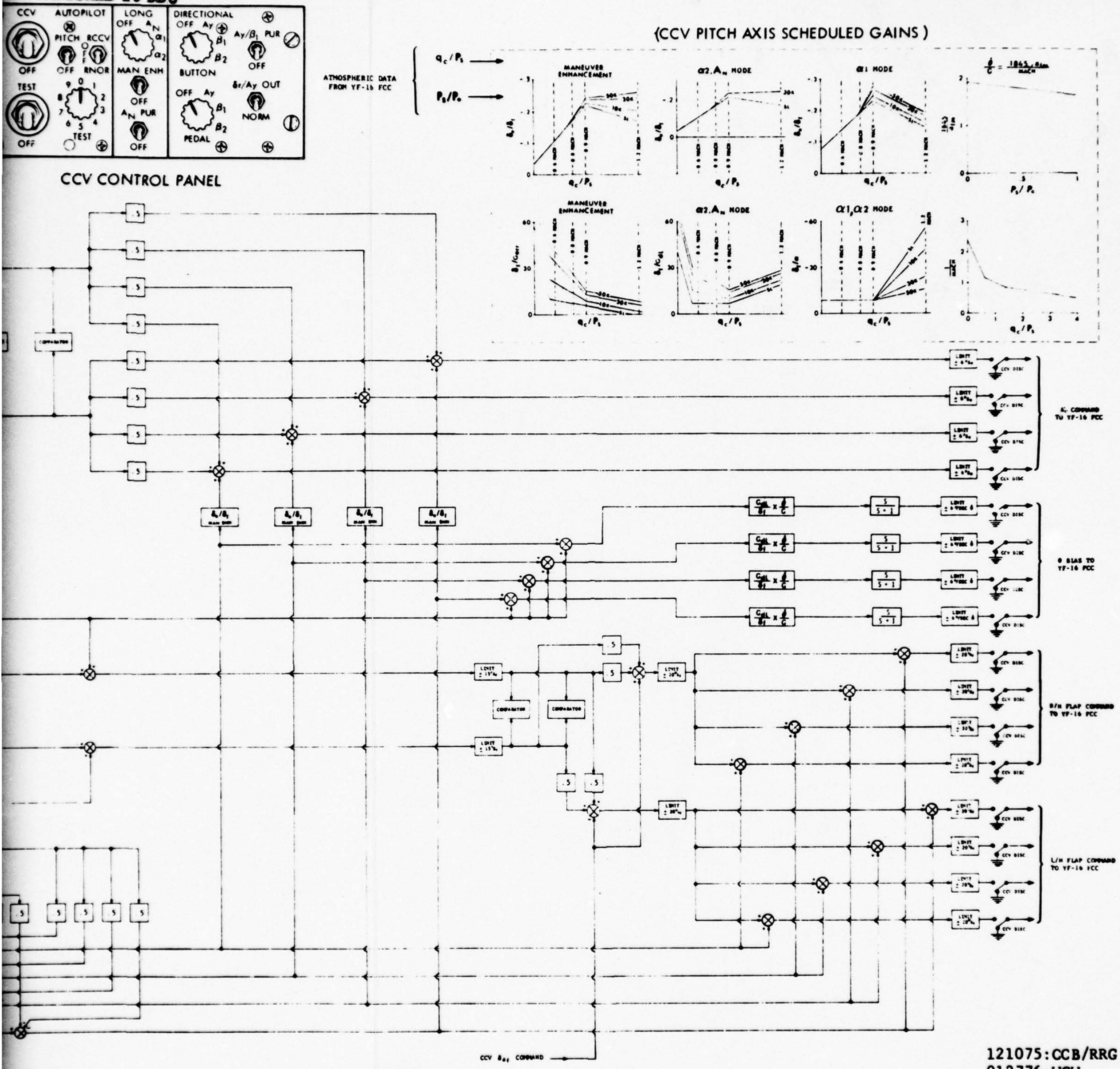
FIGHTER-CCV YF-16 dlc/dsfc

AFFDL / GENERAL DYNAMICS

PITC

Figur

J



121075:CCB/RRG
012776:WCW
031076:CCB/RRG/WCW

FIGHTER-CCV YF-16 dlc/dsfc.

AFFDL / GENERAL DYNAMICS

PITCH AXIS FUNCTIONAL BLOCK DIAGRAM

Figure 34. (Ref 6)

Appendix B

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

$\bar{i}$ component of force:

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

$\bar{j}$ component of force:

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

$\bar{k}$ component of force:

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

$\bar{i}$ component of moment:

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

$\bar{j}$ component of moment:

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

$\bar{k}$ component of moment:

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

The angular velocity vector is defined as:

$$\bar{\omega} = P\bar{i} + Q\bar{j} + R\bar{k} \tag{B7}$$

Using Euler angle Eq.(B7) becomes

$$\bar{\omega} = \bar{i}(-\dot{\Psi}\sin\Theta + \dot{\Phi}) + \bar{j}(\dot{\Psi}\cos\Theta\sin\Phi + \dot{\Theta}\cos\Phi) + \bar{k}(\dot{\Psi}\cos\Theta\cos\Phi - \dot{\Theta}\sin\Phi) \qquad \text{(B8)}$$

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

$$P = \dot{\Phi} - \dot{\Psi}\sin\Theta \qquad \text{(B9)}$$

$$Q = \dot{\Psi}\cos\Theta\sin\Phi + \dot{\Theta}\cos\Phi \qquad \text{(B10)}$$

$$R = \dot{\Psi}\cos\Theta\cos\Phi - \dot{\Theta}\sin\Phi \qquad \text{(B11)}$$

The gravity vector is defined as

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

Using Euler angles Eq.(B12) becomes

$$\bar{g} = \bar{i}(-g\sin\Theta) + \bar{j}(g\sin\Phi\cos\Theta) + \bar{k}(g\cos\Phi\cos\Theta) \qquad \text{(B13)}$$

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

$$g_x = -g\sin\Theta \qquad \text{(B14)}$$

$$g_y = g\sin\Phi\cos\Theta \qquad \text{(B15)}$$

$$g_z = g\cos\Phi\cos\Theta \qquad \text{(B16)}$$

Eqs(B14),(B15) and (B16) can now be substituted into Eqs(B1), (B2), and (B3)

$$m(\dot{U} - VR + QW) = -mg\sin\Theta + F_{A_x} + F_{T_z} \qquad \text{(B17)}$$

$$m(\dot{V} + UR - WP) = mg\sin\Phi\cos\Theta + F_{A_y} + F_{T_y} \qquad \text{(B18)}$$

$$m(\dot{W} - UQ + VP) = mg\cos\Phi\cos\Theta + F_{A_z} + F_{T_z} \qquad \text{(B19)}$$

Using the perturbed quantities

$$U = U_1 + u \qquad V = V_1 + v \qquad W = W_1 + w$$

$$P = P_1 + p \qquad Q = Q_1 + q \qquad R = R_1 + r$$

$$\Phi = \Phi_1 + \phi \qquad \Theta = \Theta_1 + \theta$$

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

$$U_1 = V_R \cos \alpha_1 \tag{B20}$$

and

$$W_1 = V_R \sin \alpha_1 \tag{B21}$$

The equations of motion for the longitudinal axis become

X force:

$$m \dot{u} + V_R q \sin \alpha_1 = -mg\,\theta \cos \Theta_1 + f_{A_x} + f_{A_x} \tag{B22}$$

Z force:

$$m V_R \dot{\alpha} - V_R q \cos \alpha_1 = -mg\,\theta \sin \Theta_1 + f_{A_z} + f_{T_z} \tag{B23}$$

M moment:

$$I_y \dot{q} = m_A + m_T \tag{B24}$$

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

X force:

$$\dot{u} = -V_R q \sin\alpha_1 - g\,\theta\cos\Theta_1 + X_u u + X_{T_u} u + X_\alpha \alpha$$

$$X_{\delta_e}\delta_e + X_{\delta_f}\delta_f \qquad \text{(B25)}$$

Z force:

$$V_R\alpha - V_R q\cos\alpha_1 = g\,\theta\sin\Theta_1 + Z_u u + Z_\alpha\alpha + Z_{\dot{\alpha}}\dot{\alpha}$$

$$+ Z_q q + Z_{\delta_e}\delta_e + Z_{\delta_f}\delta_f \qquad \text{(B26)}$$

M moment:

$$\dot{q} = M_u u + M_{T_u} u + M_\alpha \alpha + M_{T_\alpha}\alpha + M_{\dot{\alpha}}\dot{\alpha} + M_q q$$

$$+ M_{\delta_e}\delta_e + M_{\delta_f}\delta_f \qquad \text{(B27)}$$

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

$$\begin{bmatrix} (s - X_u - X_{T_u}) & -X_\alpha & (V_R\sin\alpha_1 S + g\cos\Theta_1) \\ -Z_u & V_R S - Z_\alpha & -(V_R\cos\alpha_1 + Z_q)s - g\sin\Theta_1 \\ (-M_u - M_{T_u}) & -(M_{\dot{\alpha}}S + M_\alpha) & S^2 - M_q S \end{bmatrix} \begin{bmatrix} u(s) \\ \alpha(s) \\ \theta(s) \end{bmatrix} =$$

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

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

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

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

Appendix C

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

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

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

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

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

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

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

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

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

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

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

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

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

The gains are defined as follows

$$GK_1 = 20 \ Cq_{/\delta_e} \tag{C13}$$

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

$$GK_3 = \frac{C_{an/\delta_e}}{C_{\alpha/\delta_e}} \qquad \text{(C15)}$$

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

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

$$K_5 = 6\ F3\ \frac{G_{DL}}{\delta f} \times \frac{q}{G} \qquad \text{(C18)}$$

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

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

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

$$K_9 = 80\ C_{an/\delta_f} \qquad \text{(C22)}$$

$$K_1 = (1.5)(F3) \qquad \text{(C23)}$$

$$K_2 = (10)(F4) \qquad \text{(C24)}$$

$$K_3 = (56.25)(F3) \qquad \text{(C25)}$$

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 $\Phi = 0$,

$$\theta = \alpha + \gamma \tag{D1}$$

where α = angle of attack

and γ = flight path angle

Therefore,

$$\gamma = \theta - \alpha \tag{D2}$$

Also,
$$\bar{V} = V\,\bar{e}_V \tag{D3}$$

and,
$$\dot{\bar{V}} = \dot{V}\,\bar{e}_V + V\,\dot{\bar{e}}_V \tag{D4}$$

Since
$$\bar{e}_V = \cos\gamma\ \bar{i} + \sin\gamma\ \bar{j} \tag{D5}$$

implies
$$\bar{e}_V = -\dot{\gamma}\sin\gamma\,\bar{i} + \dot{\gamma}\cos\gamma\,\bar{j} = \dot{\gamma}(-\sin\gamma\,\bar{i} + \cos\gamma\,\bar{j}) \tag{D6}$$

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

therefore,
$$\dot{\bar{e}}_V = \gamma\,\bar{e}_n \tag{D8}$$

Substituting Eq(D8) in Eq(D4) yields

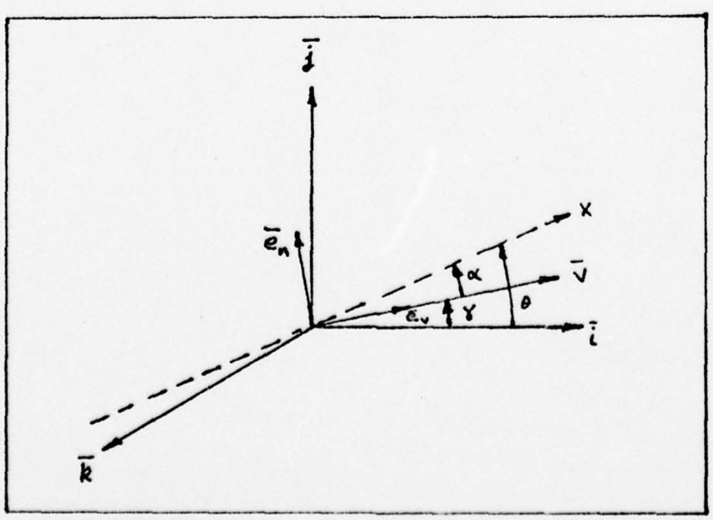


Figure 35. Reference System for Determining Normal Acceleration

$$\dot{\bar{v}} = \dot{V}\bar{e}_v + V\dot{\gamma}\bar{e}_n \tag{D9}$$

Linearizing Eq(D9) in the normal direction yields

$$V = (U_1 + u)(\dot{\gamma}_1 + \dot{\gamma}) \tag{D10}$$

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

leaving $V\dot{\gamma} = U_1\dot{\gamma} = A_N$ (D11)

normal acceleration about the center of gravity.

From Eq(D2),

$$\dot{\gamma} = \dot{\theta} - \dot{\alpha} \tag{D12}$$

Substituting Eq(D12) in Eq(D11) yields

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

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

$$A_{N_{P.S.}} = A_{N_{c.g.}} + l_z\dot{q} \tag{D14}$$

where $q = \dot{\theta}$.

Substituting Eq(D13) in Eq(D14) yields

$$A_{N_{P.S.}} = U_1(q - \dot{\alpha}) + l_z\dot{q} \tag{D15}$$

Taking the Laplace Transform of Eq(D15) yields

$$a_n(s) = U_1(q(s) - s\,\alpha(s)) + l_z S\,q(s) \tag{D16}$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Appendix F

Listing of Computer Program

```
      PROGRAM TIMEH(INPUT,OUTPUT,TAPE1,TAPE5=INPUT,TAPE6=OUTPUT,PLOT
     C,TAPE2,PUNCH)
      DIMENSION X(7),Z(7),W(7),X3(7),Y3(7)
         DIMENSION DEFP(502),DAFP(502),DRFP(502)
      DIMENSION Y(35),YP(35),ALPHAD(502),BETAD(502),VEL(502),P(502),
     1Q(502),R(502),ALT(502),THETA(502),PHI(502),PSI(502),YO(7),
     2TIME(502),DIST(502),TRAV(502),AX(502),AY(502),AZ(502),DELE(502),
     3DELA(502),DELR(502),TGV(502),THRST(502),DELTF(502)
      DIMENSION TIME1M(102),ALPHA1M(102),DIST1M(102),ALT1M(102),
     *AN1M(102)
      DIMENSION FLAPD1(102),FLAPD2(102),FLAPD3(102),FLAPDC(102)
      COMMON/TIME/CYCLE
      COMMON/PARAM/ECMO(41),ECMA(41),ECMDE(41),ECMDLE(41),ECMQ(41),ECNQ
     1(41),ECCO(41),ECNDH(41),ECNBLE(41),ECLDR(41),ECLDH(41),ECLBLE(41),
     2ECYB(41),ECYDR(41),ECYDH(41),ECNDR(41,4),ECNP(41,2),ECNR(41,2),ECN
     3DF(41,2),ECLP(41,2),ECLR(41,2),ECLDF(41,2),ECYDF(41,2),ECNB(41,5),
     4ECLB(41,5),ECNO(41,7),ECND(41,7),ECCO(41,7),ECCD(41,7)
         COMMON/SFOM/MASS,C,B,THRUS,CG
      COMMON/OTHER/IX,IY,IZ,IXZ,S
         COMMON/REST/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,
     2ALPHA,BETA,DR,DE,DF,DH,DLEF,DEC,DRC,DFC,DHC,AMACH
         COMMON/CHECK/SUMCX,SUMCZ,SUMCM,CN,CNQ,CC,CCQ,CMO,CMA,CMDE,
     1CMDLE,CMQ
      COMMON/CHECK2/CNB,CNBLE,CNR,CNP,CNDP,CNDH,CNDF,CLDF,CLDH,CLP,CLR,
     CCLDR,CLBLE,CLB
      COMMON/TRIM/RED,GAMAD,AL,EN,   SUMCY,RLIFT,XCY,TCONST,GCONST
     C,THEO,SIGH),FEO
         COMMON/BIAS/AC,AA,AR,Q1,Q3,S7,S8,TH
         COMMON/STICK/DET,DAT,DRT,DEF,DAF,DRF,FB1,FB2
```

```
      COMMON/STICKF/DAFT(170),DRFT(170),DEFT(170)
         COMMON/THRUSTT/SOSFS(9),TMILT(9,11)
     C,TSAVE
      COMMON/CCC/DELFC,QBIAS,GBIAS,S10,DELF,XCD,DELF1,DELF2,S20
      EXTERNAL GRATES,TURNTRM,ANGLE
      REAL IX,IY,IZ,IXZ,MASS
      NAMELIST/FORCE/DAFT,DEFT,DRFT
      NAMELIST/AERO/ECMO,ECMA,ECMDE,ECMDLE,ECMQ,ECNO,ECCO,ECNDH,ECNBLE,
     1ECLDR,ECLDH,ECLBLE,ECYB,ECYDR,ECYDH,ECNDR,ECNP,ECNR,ECNDF,ECLP,ECL
     2R,ECLDF,ECYDF,ECNB,ECLB,ECNO,ECND,ECCO,ECCD
       NAMELIST/GEO/IX,IY,IZ,IXZ,MASS,S,C,B,THRUS,CG,YO,SIGHO,THEO,FEO,
     1EPS
         NAMELIST/ENGNTH/SOSFS,TMILT
      NAMELIST/PLOT1M/TIME1M,ALPHA1M,DIST1M,ALT1M,AN1M
      NAMELIST/FLPDAT1/FLAPD1
      NAMELIST/FLPDAT2/FLAPD2
      NAMELIST/FLPDAT3/FLAPD3
       READ(1,AERO)
       READ(5,GEO)
         READ(5,ENGNTH)
   43 CONTINUE
      READ(5,FORCE)
      WRITE(6,209)
      WRITE(6,210) (DAFT(I),I=1,20),(DEFT(J),J=1,20),(DRFT(K),K=1,20)
  209 FORMAT("1"/////,20X,"TIME HISTORIES OF AIRCRAFT PARAMETERS",
     *" FOR YF-16, BASIC AND CCV"///,2X," INPUTS ARE AS FOLLOWS:"//,
     *2X," STICK FORCES ARE DAFT, DEFT, AND DRFT, INPUT EVERY 1/2 SEC"/)
  210 FORMAT(" DAFT - ",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=1,11
       ECNB(I,1)=ECNB(I,3)
       ECNB(I,2)=ECNB(I,3)
       ECNB(I,4)=ECNB(I,3)
    66 ECNB(I,5)=ECNB(I,3)
         G=32.2
       AV=57.295779513
       A1=(IY-IZ)/IX
       A2=IXZ/IX
       A3=S*B/(2.*IX)
       A4=B/2.
       C4=A4
       B1=(IZ-IX)/IY
       B2=IXZ/IY
       B3=S*C/(2.*IY)
       B4=C/2.
       C1=(IX-IY)/IZ
       C2=IXZ/IZ
       C3=S*B/(2.*IZ)
       D1=S/(2.*MASS)
       SEPS=SIN(EPS)
       CEPS=COS(EPS)
       PI=3.1415927$TOPI=2.*PI
       DO 61 I=1,7
```

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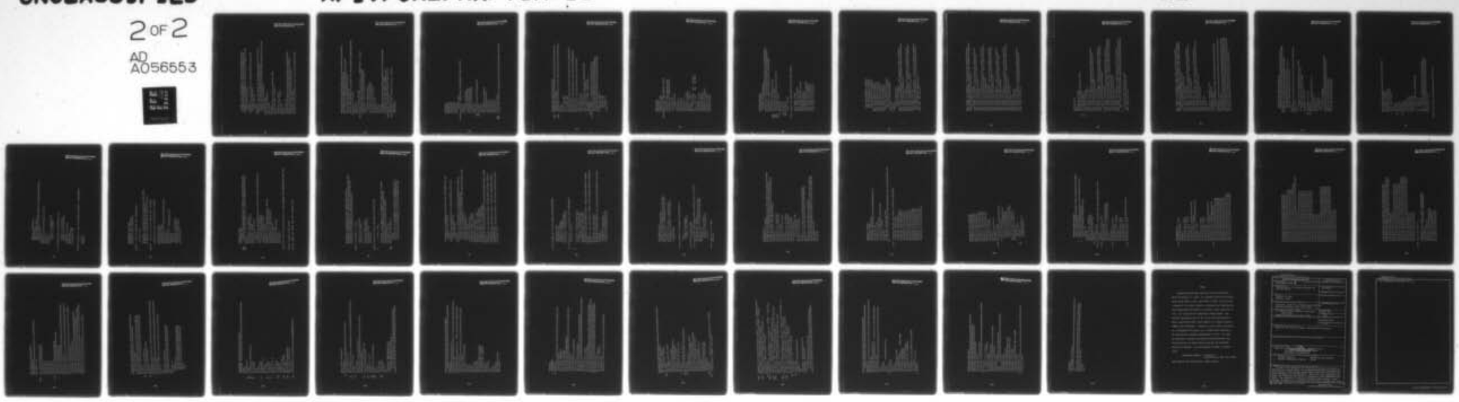
```
      YP(I)=0.$Y( I)=YO(I)
   61 CONTINUE
      AL=3.1/AV
      Y(7)=YO(7)=30000.
      EN=1.
      CALL TURNTIM(Y,YP,YO)
      TSAVE=THRUS
      DO60J=1,7
      YP(J)=0.0
   60 Y(J)=YO(J)
      IF(ABS(DE).LT..0001) DE=.0001
      T=0.
         RIALTF=' (7)/5000.+1.
         IALTF=RIALTF
         PERIALF=RIALTF-IALTF
         SOS=(SOSFS(IALTF+1)-SOSFS(IALTF))*PERIALF+SOSFS(IALTF)
         AMACH=V /SOS
      QBAR=RVF2/2.$PS=2116.33*((1.-.000006875*Y(7))**5.2561)
         PO=2116.2 $ PSOPO=PS/PO
      PTOT=PS*((1.+(AMACH**2.)/5.)**3.5)
      QC=PTOT-PS
      QCAR=QC
      PRINT*,"  MACH NO = ",AMACH
      PRINT*,"  QC = ",QC
      PRINT*,"  QBAR = ",QBAR
      QOP=QC/PS
      RKA=10000.
      Y(14)=AL*A/
        IF(Y(14).GT.30.)Y(14)=30.
          IF(   Y(14).LT.-5.)Y(14)=-5.
```

```
      CALL CONTROL(T)
      Y(15)=YP(5 *AV
      Y(16)=CTHE CFE-1.
      Y(15)=Y(15)+(Y(1)*Y(5)-Y(2)*Y(4))/G
      F3=1.
      IF(QCAR.GT.150.) F3=1.-(QCAR-150.)/650.*.64
      IF(QCAR.GT.800.) F3=.36-.224*(QCAR-800.)/2200.
      IF(QCAR.GT.3000.) F3=.136
      Q1=Y(15)*.'*F3
      S2=Y(14)-1 .+01$IF(S2.LT.0.) S2=0.
      Y(17)=Y(16)/2.+S2*.161
      Y(17)=Y(17)+.2*Y(15)
      S4=Y(14)-2 .4+01$IF(S4.LT.0.) S4=0.
      F4=.5
      IF(QOP.GT..53) F4=.5-(QOP-.53)/1.26*1.5
      IF(QOF.GT.1.79) F4=-1.
      F2=Y(14)*F
      Y(18)=DE-F
      IF(ABS(Y(18)).GT.25.) Y(18)=Y(18)/(1.+RKA*(1.-25./ABS(Y(18))))
      S6P=ABS(DE -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))
      Q3=S6+5.*S P*DE/ABS(DE)
      S5=Q3/2.5/F3
      PILOT=S5-Y(17)-S4/2.
      IF(ABS(DEF).LT.1.75) DEC=0.
      IF(ABS(DEF .GE.1.75) DEC=DEF/5.5*.88
      IF(ABS(DEF).GT.5.5) DEC=(.88+ABS(DEF-5.5)/22.5*7.12)*DEF/ABS(DEF)
        F11=2.
        IF(PSOP).GT..1.AND.PSOPO.LT..3)F11=-7.8*(PSOPO-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
AD
A056553



END
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```
   IF(PSOPO.GE..3.AND.PSOPO.LT..4)F11=-1.5*(PSOPO-.3)+.44
   IF(PSOPO.GE..4.AND.PSOPO.LT..7)F11=-.7*(PSOPO-.4)+.29
 IF(PSOPO.GE..7.AND.PSOPO.LT.1.)F11=-(.08/.3)*(PSOPO-.7)+.08
    IF(PSOPO.GE.1.)F11=0.
   GLF1=0.
 IF(PSOPO.GT..145.AND.PSOPO.LT..3)GLF1=(PSOPO-.145)/.155
   IF(PSOPO.GE..3)GLF1=1.
     GLF2I=QOP-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.
FUNC=GLF1*GLF2N
T2=2.*PILOT/(FUNC-1.)
Y(25)=T2/2.
FLMT=-1.
IF(QCAR.GE.34.) FLMT=-1.-(QCAR-34.)/50.
IF(QCAR.GE.184.) FLMT=-4.
T1=T2
IF(T1.GT.7.5) T1=7.5
IF(T1.LT.FLMT) T1=FLMT
DET=T1-DEC
DA=DF
Y(19)=Y(20)=0.
Y(25)=DR$Y(23)=DA$Y(24)=-DA$Y(21)=DE+DA/4.$Y(22)=DE-DA/4.
PEAK=1.-ABS(Y(14))/10.$IF(ABS(Y(14)).GT.10.)PEAK=0.
F7=0.$IF(QOP.GT..187) F7=(QOP-.187)/.942
IF(QOP.GT.1.129) F7=1.
IF(QOP.GT.1.709.AND.QOP.LT.3.23) F7=1.-(QOP-1.709)/1.521
```

```
      F8=.5$IF(QOP.GT.2.84)F8=(QOP-2.84)/.78+.5$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
      ADRF=0.$IF(ABS(DRF).GT.15.)ADRF=DRF-DRF/ABS(DRF)*15.$DRT=PILOTR+AD
     CRF$DAT=-PILOTA/1.67
      DAT=-DAT
      DAT=DRT=0.
      WRITE (6,206) DAT,DRT
206   FORMAT(* AILERON TRIM = *,F5.1,*    RUDDER TRIM = *,F5.1)
      IF(ABS(DAT).GT.40.) DAT=40.*DAT/ABS(DAT)
      IF(ABS(DRT).GT.8.) DRT=8.*DRT/ABS(DRT)
      Y(27)=0.
        FB1=FB2=Y(28)=Y(29)=0.
      Y(30)=1.6*(.5*Y(15)+Y(14)-2.)
      IF (Y(30).GT.25.) Y(30)=25.
      IF(Y(30).LT.0.) Y(30)=0.
      Y(31)=Y(32)=0.
      Y(33)=0.
      Y(34)=0.
      Y(35)=0.
      Y(23)=DA$Y(22)=DE-DA/4.$Y(24)=-DA$Y(21)=DE+DA/4.$Y(25)=DR
      IF(ABS(DET).GT.2.4) WRITE (6,205)
      IF(ABS(DET).GT.2.4) DET=2.4*DET/ABS(DET)
205   FORMAT (* DELTA TRIM GREATER THAN 2.4 *)
      WRITE(6,203) DET
203   FORMAT(* DELTA ELEVATOR TRIM IS = *,F5.1)
      U1=THEO/2.
      U2=SIGHO/2.
```

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      U3=FEO/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.)GOTO24
      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(8)=THEO$Y(9)=SIGHO$Y(10)=FEO
   25 CONTINUE
      Y(11)=0.
      Y(12)=0.
      Y(13)=U7*U4*U8-U6*U5*U9
      AL=ATAN2(Y(3),Y(1))
      ALPHA=AL*A/
      WRITE(6,19')
      WRITE(6,19')
      WRITE(6,19')
      WRITE(6,19')
196   FORMAT(10X,*W*//)
197   FORMAT("1",1X,*T*,7X,*VR*,8X,*P*,7X,*THETA*,5X,*ALPHA*,7X,*AX*,
```

```
      *8X,*DE*,7X,*QBIAS*,6X,*DELF1*)
198   FORMAT(10X,*U*,9X,*Q*,7X,*PSI*,7X,*BETA*,8X,*AY*,8X,*DR*,7X,
      **GBIAS*,6X,*DELF2*)
199   FORMAT(10X,*V*,9X,*R*,7X,*PHI*,19X,*AZ*,8X,*DA*,7X,*DELFC*,6X,
      **S20*)
       LOOP=60
       DO 77 J=1,LOOP
       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),DR,GBIAS,DELF2
       IF(T.LT..005)
      *WRITE(6,203) Y(2),Y(6),PHI(J),AZ(J),DF,DELFC,S20
       IF(T.LT..005)
      *WRITE(6,204) Y(3)
       CALL CONTROL(T)
       CALL RKGXYZ(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(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)=DE
```

```
      DELR(J)=DR
      DELA(J)=DF
      DELTF(J)=DELFC
      THRST(J)=THRUS
******TURNS ABOUT THE GRAVITY VECTOR
      TGV(J)=SIGH*AV
      IF(SIGH.LT.-PI)SIGH=SIGH+TOPI
      IF(SIGH.GT.PI) SIGH=SIGH-TOPI
      DIST(J)=Y( 1)
      TRAV(J)=Y( 2)
         BETAD(J)=BETA
      VEL(J)=VR
      P(J)=Y(4)*AV
      Q(J)=Y(5)*AV
      R(J)=Y(6)*AV
      ALT(J)=Y(7)
      THETA(J)= H *AV
      PSI(J)=SIGH*AV/360.
      PHI(J)=  FE*AV
      ALPHAD(J)=ALPHA
      IF(   FE.LT.-PI)    FE=   FE+TOPI
      IF(   FE.GT.PI)     FE=   FE-TOPI
      TIME(J)=T
      TIME1M(J)=TIME(J)
      ALPHA1M(J)=ALPHA
      DIST1M(J)=DIST(J)
      ALT1M(J)=ALT(J)-YO(7)
      AN1M(J)=-1.*A7(J)
      FLAPD1(J)=DELFC
      FLAPD2(J)=DELFC
```

```
      FLAPD3(J)=DELFC
      CALL SECOND(CPTM)
        IF(CPTM.GT.200.)GOTO618
      WRITE(6,200) T,VR,Y(4),THETA(J),ALPHA,AX(J),DE,QBIAS,DELF1
      WRITE(6,201) Y(1),Y(5),PSI(J),BETA,AY(J),DR,GBIAS,DELF2
      WRITE(6,202) Y(2),Y(6),PHI(J),AZ(J),DF,DELFC,S20
      WRITE(6,204) Y(3)
200   FORMAT(1X,F4.1,1X,8(F8.3,2X))
201   FORMAT(6X,8(F8.3,2X))
202   FORMAT(6X,3(F8.3,2X),10X,4(F8.3,2X))
204   FORMAT(6X,F8.3//)
   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(0.,-12.,-3)
      CALL PLOT(0.,1.,-3)
      CALL SCALE(TIME,12.,LOOP,1)
      ALPHAD(LOOP+1)=0.
      ALPHAD(LOOP+2)=1.5
      CALL SCALE(BETAD,4.,LOOP,1)
      CALL SCALE(VEL,4.,LOOP,1)
      CALL SCALE(P,4.0,LOOP,1)
      CALL SCALE(Q,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(DAEP,4.,LOOP,1)
      CALL SCALE(DREP,4.,LOOP,1)
   CALL SCALE(DELE,4.,LOOP,1)
   CALL SCALE(DELR,4.,LOOP,1)
   CALL SCALE(DELA,4.,LOOP,1)
   CALL SCALE(DELTF,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)=TGV(L)=-180.
       PHI(M)=TGV(M)=72.
   CALL AXIS(0.,0.,10HTIME - SEC,-10,12.,0.,TIME(L),TIME(M))
   CALL AXIS(0.,0.,17HVELOCITY - FT/SEC,17,4.,90.,VEL(L),VEL(M))
   CALL LINE(TIME,VEL,LOOP,1,0,75)
   CALL PLOT(0.,5.,-3)
   CALL AXIS(0.,0.,10HTIME - SEC,-10,12.,0.,TIME(L),TIME(M))
   CALL AXIS(0.,0.,12HTHRUST - LBS,12,4.,90.,THRST(L),THRST(M))
   CALL LINE(TIME,THRST,LOOP,1,0,75)
   CALL PLOT(0.,5.,-3)
    CALL AXIS(0.,0.,13HDISTANCE - FT,-13,12.,0.,DIST(L),DIST(M))
    CALL AXIS(0.,0.,13HALTITUDE - FT,13,4.,90.,ALT(L),ALT(M))
   CALL LINE(DIST,ALT ,LOOP,1,50,5)
   CALL PLOT (16.,-10.,-3)
```

```
CALL AXIS(0.,0.,10HTIME - SEC,-10,12.,0.,TIME(L),TIME(M))
CALL AXIS(0.,0.,11HALPHA - DEG,11,4.0,90.,ALPHAD(L),ALPHAD(M))
CALL LINE(TIME,ALPHAD,LOOP,1,0,75)
   CALL PLOT(0.,5.,-3)
CALL AXIS(0.,0.,10HTIME - SEC,-10,12.,0.,TIME(L),TIME(M))
CALL AXIS(0.,0.,11HQ - DEG/SEC,11,4.0,90.,Q(L),Q(M))
CALL LINE(TIME,Q,LOOP,1,0,75)
CALL PLOT(0., 5.,-3)
CALL AXIS(0.,0.,10HTIME - SEC,-10,12.,0.,TIME(L),TIME(M))
CALL AXIS(0.,0.,18HZ ACCELERATION - G,18,4.,90.,AZ(L),AZ(M))
CALL LINE(TIME,AZ,LOOP,1,0,75)
CALL PLOT (16.,-10.,-3)
CALL AXIS(0.,0.,10HTIME - SEC,-10,12.,0.,TIME(L),TIME(M))
CALL AXIS(0.,0.,10HBETA - DEG,10,4.,90.,BETAD(L),BETAD(M))
CALL LINE(TIME,BETAD,LOOP,1,0,75)
CALL PLOT(0.,5.,-3)
CALL AXIS(0.,0.,10HTIME - SEC,-10,12.,0.,TIME(L),TIME(M))
CALL AXIS(0.,0.,11HR - DEG/SEC,11,4.0,90.,R(L),R(M))
CALL LINE(TIME,R,LOOP,1,0,75)
CALL PLOT(0.,5.,-3)
CALL AXIS(0.,0.,10HTIME - SEC,-10,12.,0.,TIME(L),TIME(M))
CALL AXIS(0.,0.,18HY ACCELERATION - G,18,4.,90.,AY(L),AY(M))
CALL LINE(TIME,AY,LOOP,1,0,75)
CALL PLOT (16.,-10.,-3)
CALL DSP(21B8)
CALL PLOT(0.,-6.,-3)
CALL PLOT(0.,1.,-3)
CALL AXIS(0.,0.,10HTIME - SEC,-10,12.,0.,TIME(L),TIME(M))
CALL AXIS(0.,0.,9HPHI - DEG,9,4.0,90.,PHI(L),PHI(M))
CALL PLOT(0., 2.5,-3)
```

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```
      DO27J=1,LOOP
      NO=2
      IF(J.EQ.1)GO TO 26
      IF(ABS(PHI(J-1)-PHI(J)).GT.50.)NO=3
26    XX=TIME(J)/TIME(M)
      YY=PHI(J)/PHI(M)
27    CALL PLOT(XX,YY,NO)
      CALL PLOT(0.,-2.5,-3)
      CALL PLOT(0.,5.,-3)
      CALL AXIS(0.,0.,10HTIME - SEC,-10,12.,0.,TIME(L),TIME(M))
      CALL AXIS(0.,0.,11HP - DEG/SEC,11,4.0,90.,P(L),P(M))
      CALL LINE(TIME,P,LOOP,1,0,75)
      CALL PLOT(0.,5.,-3)
      CALL AXIS(0.,0.,10HTIME - SEC,-10,12.,0.,TIME(L),TIME(M))
      CALL AXIS(0.,0.,11HTHETA - DEG,11,4.,90.,THETA(L),THETA(M))
        CALL LINE(TIME,THETA,LOOP,1,0,75)
      CALL PLOT(16.,-10.,-3)
      CALL AXIS(0.,0.,10HTIME - SEC,-10,12.,0.,TIME(L),TIME(M))
      CALL AXIS(0.,0.,19HELEVATOR DISP - DEG,19,4.,90.,DELE(L),DELE(M))
      CALL AXIS(-.5,0.,18HELEVATOR 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(0.,5.,-3)
      CALL AXIS(0.,0.,10HTIME - SEC,-10,12.,0.,TIME(L),TIME(M))
      CALL AXIS(0.,0.,18HAILERON DISP - DEG,18,4.,90.,DELA(L),DELA(M))
        CALL AXES(-.5,0.,17HAILERON 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(0.,5.,-3)
```

```
      CALL AXIS(0.,0.,10HTIME - SEC,-10,12.,0.,TIME(L),TIME(M))
      CALL AXIS(0.,0.,17HRUDDER DISP - DEG,17,4.,90.,DELR(L),DELR(M))
      CALL AXIS(-.5,0.,16HRUDDER FORCE-LBS,16,4.,90.,DRFP(L),DRFP(M))
         CALL LINE(TIME,DRFP,LOOP,1,10,5)
      CALL LINE(TIME,DELR,LOOP,1,0,75)
      CALL PLOT (16.,-10.,-3)
      CALL AXIS(0.,0.,10HTIME - SEC,-10,12.,0.,TIME(L),TIME(M))
      CALL AXIS(0.,0.,18HX ACCELERATION - G,18,4.,90.,AX(L),AX(M))
      CALL LINE(TIME,AX,LOOP,1,0,75)
      CALL PLOT(0.,5.,-3)
      CALL AXIS(0.,0.,10HTIME - SEC,-10,12.,0.,TIME(L),TIME(M))
      CALL AXIS(0.,0.,16HFLAP DISP. - DEG,16,4.,90.,DELTF(L),DELTF(M))
      CALL LINE(TIME,DELTF,LOOP,1,0,75)
      CALL PLOT(16.,-20.,-3)
      CALL PLOTE
      CALL DSP(21BB)
      STOP 5555
      END
      SUBROUTINE GYRATES(T,Y,YP)
      DIMENSION Y(35),YP(35)
      COMMON/TIME/CYCLE
         COMMON/CHECK/SUMCX,SUMCZ,SUMCM,CN,CNO,CC,CCO,CMO,CMA,CMDE,
     1CMDLE,CMQ
      COMMON/CHECK2/CNB,CNBLE,CNR,CNP,CNDR,CNDH,CNDF,CLDF,CLDH,CLP,CLR,
     CCLDR,CLBLE,CLB
      COMMON/PARAM/ECMO(41),ECMA(41),ECMDE(41),ECMDLE(41),ECMQ(41),ECNQ
     1(41),ECCQ(41),ECNDH(41),ECNBLE(41),ECLDR(41),ECLDH(41),ECLBLE(41),
     2ECYB(41),ECYDR(41),ECYDH(41),ECNDR(41,4),ECNP(41,2),ECNR(41,2),ECN
     3DF(41,2),ECLP(41,2),ECLP(41,2),ECLDF(41,2),ECYDF(41,2),ECNB(41,5),
     4ECLB(41,5),ECNO(41,7),ECND(41,7),ECCO(41,7),ECCD(41,7)
```

```
      COMMON/GEOM/MASS,C,B,THRUS,CG
      COMMON/REST/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,
     2ALPHA,BETA,DP,DE,DF,DH,DLEF,DEC,DPC,DFC,DHC,AMACH
      COMMON/BIAS/AC,AA,AB,Q1.Q3,S7,S8,TH
      COMMON/STICK/DET,DAT,DPT,DEF,DAF,DRF,FB1,FB2
      COMMON/THRUSTT/SOSFS(3),TMILT(9,11)
     C,TSAVE
      COMMON/CCC/DELFC,QBIAS,GBIAS,S10,DELF,XCD,DELF1,DELF2,S20
      REAL MASS,K
      K=10.
        PS=2116.33*((1.-.00000687535*Y(7))**5.2561)
      ROH=.002378*((1.-.00000688*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=SQRT(Y(1)**2+Y(2)**2+Y(3)**2)
      RVR2=ROH*(VR**2)
      VOVR=Y(2)/VR
      BE=ASIN(VOVR)
        ALPHA=AL*AV
       BETA=BE*AV
        IF(T.LT.0.)GOTO52
      EP=1.-(Y(8)*Y(8)+Y(9)*Y(9)+Y(10)*Y(10)+Y(13)*Y(13))
      C11=Y(8)*Y(8)+Y(9)*Y(9)-Y(10)*Y(10)-Y(13)*Y(13)
      C12=2.*(Y(9)*Y(10)+Y(8)*Y(13))
      C13=2.*(Y(9)*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(THE)
      CTHE=COS(THE)
      SPST=SIN(SIGH)
      CPSI=COS(SIGH)
        IF(ABS(CTHE).LT..001)CTHE=.001
      PT   =Y(4)*1V
      QT   =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 *****
```

```
         RIALTF=Y(7)/5000.+1.
         IALTF=RIALTF
         PERIALF=RIALTF-IALTF
         SOS=(SOSFS(IALTF+1)-SOSFS(IALTF))*PERIALF+SOSFS(IALTF)
         AMACH=VP/SOS
      QBAR=RVP2/2.
      PTOT=PS*((1.+(AMACH**2.)/5.)**3.5)
      QC=PTOT-PS
      QCAR=QC
      QOP=QC/PS
         PO=2116.2 $ PSOPO=PS/PO
          IF(T.LT.0.)GOTO56

C *** LONGITUDINAL AUGMENTATION ***

         IF(DET.GT.2.4)DET=2.4
         IF(DET.LT.-2.4)DET=-2.4
         DEC=0.
      YP(35)=K4(DEF-Y(35))
      EASIN=Y(35)
      DEF1=ABS(EASIN)
      CCVIN=DEF-Y(35)

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

      DELFC=0.
      OBIAS=0.
```

```
      DELF=CCVIN 15./7.25
      IF(DELF.GT. 15.) DELF=15.
      IF(DELF.LT. -15.) DELF=-15.

C*****   FLAP DEFLECTION PER G SCHEDULING

C     - AT SEA LEVEL

      IF(QOP.GE.0..AND.QOP.LT..2) 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 (DELFOG)

      DELFOG=SLQUOT+(33.-(33.*QOP))*(1.-PSOPO)

      GODELF=1./DELFOG
      DELF1=DELF*GODELF
      ABDELF1=ABS(DELF1)
      IF(ABDELF1.GT.3.) DELF1=3.*DELF1/ABDELF1
      DAN=-AZT-1.0
      ADAN=ABS(DAN)
      IF(ADAN.GT.3.) DAN=SIGN(3.,DAN)
      GBIAS=DAN
       F0=ALPHA
       IF(ALPHA..LE.-5.)F0=-5.
      IF(ALPHA.GT.30.)F0=30.
       YP(14)=10.*(F0-Y(14))
      PUR1=4.*ALPHA
```

```
      S20=PUR1-Y(34)
      YP(34)=50.*S20
901      IF(DEF1.GT.1.75.AND.DEF1.LT.7.25)DEC=(.88/5.5)*(DEF1-1.75)
950   IF(DEF1.GT.7.25.AND.DEF1.LT.31.) DEC=((7.12/23.75)*(DEF1-7.25
     *))+.88
      IF(BASIN.LT.0.) DEC=-DEC
      IF(BASIN.LE.-17.65) DEC=-4.
      DEC=DEC+DET+GBIAS
      IF(DEC.GT.7.5) DEC=7.5
         DEC1=-1.
      IF(QCAR.GT.34..AND.QCAR.LT.184.) DEC1=((-3./150.)*(QCAR-34.))-1.
      IF(QCAR.GT.184.) DEC1=-4.
         IF(DEC.LT.DEC1)DEC=DEC1
      YP(31)=4.*(DEC+DET-Y(31))
      DELF1=DELFL+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*DELFOG
      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 GBIAS

C***** LOGIC FOR PITCH RATE PER G DIRECT LIFT
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```
      IF(QOP.GE.0..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-(.26/1.95)*(QOP-1.4)

C***** LET XMFACT = 1345/A

      XMFACT=1.91-(.26*PSOPO)
      QOGDL=XMFACT*XMINV

      YT=Y(32)*G0DELF*QOGDL
      DYT=YP(32)*G0DELF*QOGDL
      YP(33)=DYT-Y(33)
      QBIAS=Y(33)

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

C        - AT SEA LEVEL

      IF(QOP.GE.0..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.-PSOPO)
      DELF2=DELF*DEODF
      DELF2=DELF2+.1*S20
902   YP(26)=8.3*(DEC-Y(26))
         F11=2.
         IF(PSOPO.GT..1.AND.PSOPO.LT..3)F11=-7.8*(PSOPO-.1)+2.
         IF(PSOPO.GE..3.AND.PSOPO.LT..4)F11=-1.5*(PSOPO-.3)+.44
         IF(PSOPO.GE..4.AND.PSOPO.LT..7)F11=-.7*(PSOPO-.4)+.29
```

```
 IF(PSOPO.GE..7.AND.PSOPO.LT.1.)F11=-(.08/.3)*(PSOPO-.7)+.08
    IF(PSOPO.GE.1.)F11=0.
   GLF1=0.
 IF(PSOPO.GT..145.AND.PSOPO.LT..3)GLF1=(PSOPO-.145)/.155
   IF(PSOPO.GE..3)GLF1=1.
     GLF2I=OOP-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
   DEC=DEC1-Y(26)
 YP(15)=(YP(5)*AV)-Y(15)
 YP(16)=15.*(-AZT-1.-Y(16))
S1=Y(16)+.4*Y(15)-.4*OBIAS
DS1=YP(16)+.4*YP(15)
IF(QCAR.LE.150.) Q1=.7*Y(15)
IF(QCAR.LE.150.) DQ1=.7*YP(15)
IF(QCAR.GE.3000.) Q1=.0952*Y(15)
IF(QCAR.GE.3000.) DQ1=.0952*YP(15)
IF(QCAR.GT.150..AND.QCAR.LE.800.) Q1=Y(15)*(.7+(150.-QCAR)*(.448/
*650.))
IF(QCAR.GT.150..AND.QCAR.LE.800.) DQ1=YP(15)*(.7+(150.-QCAR)*(
*.448/650.))
IF(QCAR.GT.800..AND.QCAR.LT.3000.) Q1=Y(15)*(.252+(800.-QCAR)*
*(.1568/2200.))
IF(QCAR.GT.800..AND.QCAR.LT.3000.) DQ1=YP(15)*(.252+(800.-QCAR)*
*(.1568/2200.))
```

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

      S2=Q1+Y(14)-15.
      DS2=DQ1+YP(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)+Q1-20.4

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(QCAR.LE.150.) Q3=1.25*S5
     IF(QCAR.GE.3000.) Q3=.17*S5
     IF(QCAR.GT.150..AND.QCAR.LE.800.) Q3=(1.25+(150.-QCAR)*(.8/650.
    *))*S5
     IF(QCAR.GT.800..AND.QCAR.LT.3000.) Q3=(.45+(800.-QCAR)*(.28/2200.
    *))*S5
     IF(QOP.LE..53) F4=.5*Y(14)
     IF(QOP.GE.1.79) F4=-Y(14)
     IF(QOP.GT..53.AND.QOP.LT.1.79) F4=Y(14)*(.5+(.53-QOP)*(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)
       S10=S10+DELF2

C *** LATERAL-DIRECTIONAL AUGMENTATION ***

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

C *** RUDDER PEDAL FORCE
            DTR=ABS(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.)
      DRC=DRF3-DRT
         IF(DAT.GT.40.)DAT=40.
         IF(DAT.LT.-40.)DAT=-40.
         DAC=0.

C *** AILERON STICK FORCE
      DAF1=0.
```

```
ADAF=ABS(DAF)
IF(ADAF.LE.1.) DAF1=0.
IF(ADAF.GT.1..AND.ADAF.LT.6.1) 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.) Y28=Y(28)
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(28)=6.*TU-20.*Y(28)
YP(29)=6.*TL-20.*Y(29)
DAC=Y(27)+DAT*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..AND.Y(14).LE.10.)P4=.65-.065*Y(14)
IF(Y(14).LT.0..AND.Y(14).GE.-10.)P4=.65+.065*Y(14)
P5=0.
IF(QOP.GE.1.129.AND.QOP.LE.1.709)P5=P4
IF(QOP.GT..187.AND.QOP.LT.1.129)P5=(1./.942)*(QOP-.187)*P4
IF(QOP.GT.1.709.AND.QOP.LT.3.23)P5=(1./1.521)*(3.23-QOP)*P4
S11=.0375*Y(14)-P5
P2=P1*S11
S17=2.*P1
```

```
      S18=S10-.125*S17
      S19=S10+.125*S17
      P3=Y(14)*AV*Y(4)/57.3
      DP3=(YP(14)*AV*Y(4)/57.3)+(Y(14)*AV*YP(4)/57.3)
      S12=AV*Y(6)-P3
      DS12=AV*YP(6)-DP3
      YP(19)=1.5*DS12-Y(19)
      YP(20)=3.*YP(19)+15.*(Y(19)-Y(20))
      S13=Y(20)+19.32*AYT
      S14=P2+S13
      IF(QOP.LE.2.04)S14=P2+.5*S13
      IF(QOP.GT.2.04.AND.QOP.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-DRC-Y(25))
      IF(YP(21).GT.60.)YP(21)=60.
      IF(YP(22).GT.60.)YP(22)=60.
      IF(YP(23).GT.56.)YP(23)=56.
      IF(YP(24).GT.56.)YP(24)=56.
      IF(YP(25).GT.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.
      DE=.5*(Y(21)+Y(22))
      DH=-.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.)
      DLEFT=DLEFT*1.6/2.1
         IF(DLEFT.GT.25.0)DLEFT=25.0
         IF(DLEFT.LT.0.)DLEFT=0.
         YP(30)=5.*(DLEFT-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 $ AB=F2
55       CONTINUE
         RIAMACH=AMACH/.1+1.
         IAMACH=RIAMACH
```

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```
      PERIAM=RIAMACH-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)
      TMIL=(TMILT2-TMILT1)*PERIALF+TMILT1
      THRUS=TMIL
   THRUT=TMIL
   IF(TMIL.LT.1.) THRUT=1.
   IF(T.LE..05) THRT=THRUT
   THRUS=THRUT/THRT*TSAVE
 56 CONTINUE
   TOM=THRUS/MASS
******* 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=ABS(BETA)
   IF(BETAI.LE.5.) BETAI=5.
   IB=BETAI/5.
   IF(BETAI.GT.15.) IB=3
   IF(BETAI.EQ.25.) IB=4
   PERB=BETAI/5.-IB
   IF(BETAI.GT.15.) PERB=BETAI/10.+1.5-IB
C *** INTERPOLATION ON DLEF
```

```
      PERD=DLEF/25.
C *** INTERPOLATION ON DELH
      RIH1=3.+DELH/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.+DELH/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 *** DETERMINATION OF AERO PARAMETERS
      CMO=(ECMO(IA+1)-ECMO(IA))*PERA+ECMO(IA)
      CMA=(ECMA(IA+1)-ECMA(IA))*PERA+ECMA(IA)
      CMQ=(ECMQ(IA+1)-ECMQ(IA))*PERA+ECMQ(IA)
      CNO=(ECNO(IA+1)-ECNO(IA))*PERA+ECNO(IA)
      CCO=(ECCO(IA+1)-ECCO(IA))*PERA+ECCO(IA)
      CYB=(ECYB(IA+1)-ECYB(IA))*PERA+ECYB(IA)
      CMDE=(ECMDE(IA+1)-ECMDE(IA))*PERA+ECMDE(IA)
      CNDH=(ECNDH(IA+1)-ECNDH(IA))*PERA+ECNDH(IA)
      CLDR=(ECLDR(IA+1)-ECLDR(IA))*PERA+ECLDR(IA)
```

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CLDH=(ECLDH(IA+1)-ECLDH(IA))*PERA+ECLDH(IA)
CYDR=(ECYDR(IA+1)-ECYDR(IA))*PERA+ECYDR(IA)
CYDH=(ECYDH(IA+1)-ECYDH(IA))*PERA+ECYDH(IA)
CMDLE=(ECMDLE(IA+1)-ECMDLE(IA))*PERA+ECMDLE(IA)
CNBLE=(ECNBLE(IA+1)-ECNBLE(IA))*PERA+ECNBLE(IA)
CLBLE=(ECLBLE(IA+1)-ECLBLE(IA))*PERA+ECLBLE(IA)
CNDR1=(ECNDR(IA+1,IB)-ECNDR(IA,IB))*PERA+ECNDR(IA,IB)
CNDR2=(ECNDR(IA+1,IB+1)-ECNDR(IA,IB+1))*PERA+ECNDR(IA,IB+1)
CNDR=(CNDR2-CNDR1)*PERB+CNDR1
CNP1=(ECNP(IA+1,1)-ECNP(IA,1))*PERA+ECNP(IA,1)
CNR1=(ECNR(IA+1,1)-ECNR(IA,1))*PERA+ECNR(IA,1)
CLP1=(ECLP(IA+1,1)-ECLP(IA,1))*PERA+ECLP(IA,1)
CLR1=(ECLR(IA+1,1)-ECLR(IA,1))*PERA+ECLR(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=(ECLR(IA+1,2)-ECLR(IA,2))*PERA+ECLR(IA,2)
CNP=(CNP2-CNP1)*PERD+CNP1
CNR=(CNR2-CNR1)*PERD+CNR1
CLP=(CLP2-CLP1)*PERD+CLP1
CLR=(CLR2-CLR1)*PERD+CLR1
CNDF1=(ECNDF(IA+1,1)-ECNDF(IA,1))*PERA+ECNDF(IA,1)
CLDF1=(ECLDF(IA+1,1)-ECLDF(IA,1))*PERA+ECLDF(IA,1)
CYDF1=(ECYDF(IA+1,1)-ECYDF(IA,1))*PERA+ECYDF(IA,1)
CNDF2=(ECNDF(IA+1,2)-ECNDF(IA,2))*PERA+ECNDF(IA,2)
CLDF2=(ECLDF(IA+1,2)-ECLDF(IA,2))*PERA+ECLDF(IA,2)
CYDF2=(ECYDF(IA+1,2)-ECYDF(IA,2))*PERA+ECYDF(IA,2)
CNDF=(CNDF2-CNDF1)*PERD+CNDF1
CLDF=(CLDF2-CLDF1)*PERD+CLDF1
CYDF=(CYDF2-CYDF1)*PERD+CYDF1
```

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      CNB1=(ECNB(IA+1,IH1)-ECNB(IA,IH1))*PERA+ECNB(IA,IH1)
      CLB1=(ECLB(IA+1,IH1)-ECLB(IA,IH1))*PERA+ECLB(IA,IH1)
      CNB2=(ECNB(IA+1,IH1+1)-ECNB(IA,IH1+1))*PERA+ECNB(IA,IH1+1)
      CLB2=(ECLB(IA+1,IH1+1)-ECLB(IA,IH1+1))*PERA+ECLB(IA,IH1+1)
      CNB=(CNB2-CNB1)*PERH1+CNB1
      CLB=(CLB2-CLB1)*PERH1+CLB1
      CNO1=(ECNO(IA+1,IH2)-ECNO(IA,IH2))*PERA+ECNO(IA,IH2)
      CCO1=(ECCO(IA+1,IH2)-ECCO(IA,IH2))*PERA+ECCO(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)
      CNO2=(ECNO(IA+1,IH2+1)-ECNO(IA,IH2+1))*PERA+ECNO(IA,IH2+1)
      CCO2=(ECCO(IA+1,IH2+1)-ECCO(IA,IH2+1))*PERA+ECCO(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)
      CNO=(CNO2-CNO1)*PERH2+CNO1
      CND=(CND2-CND1)*PERH2+CND1
      CCO=(CCO2-CCO1)*PERH2+CCO1
      CCD=(CCD2-CCD1)*PERH2+CCD1

C***** FLAP AERODYNAMICS

      IF(ALPHA.GE.0.) ECDDF=.0002+(.0001958*ALPHA)
      IF(ALPHA.LT.0.) ECDDF=.0002-(.000325*ALPHA)
      XCL=.015*DELF
      XCD=.0004+ECDDF*DELF
      DCCDF=-XCD*COS(AL)+XCL*SIN(AL)
      DCNDF=XCL*COS(AL)-XCD*SIN(AL)
      X0=.0027023 3-.00065931*DELF
      X1=-.00074 43+.00000419*DELF
      X2=-.0000 97+.00002774*DELF
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      X3=.0000102-.00000154*DELF
      X4=-.00000403
      DCMDF=X0+(X1*ALPHA)+(X2*ALPHA**2.)+(X3*ALPHA**3.)+
     *(X4*ALPHA**4.)

  903 CN=(CND-CNO)*PERD+CNO+DCNDF
      CC=(CCD-CCO)*PERD+CCO+DCCDF
      CLDH=2.*CLDH
      CLDF=2.*CLDF
      CYDH=2.*CYDH
      CYDF=2.*CYDF
      CNDH=2.*CNDH
      CNDF=2.*CNDF
C *** TOTAL AERODYNAMIC COEFFICIENTS
      SUMCY=CYB*BETA+CYDR*DR+CYDF*DF+CYDH*DH
      SUMCZ=-CN-(B4/VR)*CNQ*Y(5)
      SUMCX=-CC-(B4/VR)*CCQ*Y(5)
      SUMCN=CNB*BETA+CNDR*DR+CNDF*DF+CNDH*DH+CNBLE*BETA*DLEF+(C4/VR)*(
     *CNP*Y(4)+CNR*Y(6))
      SUMCL=CLB*BETA+CLDR*DR+CLDF*DF+CLDH*DH+CLBLE*BETA*DLEF+(A4/VR)*(
     *CLP*Y(4)+CLR*Y(6))
      SUMCM=CMO+CMA*ALPHA+CMDE*DE+CMDLE*DLEF+(B4/VR)*CMQ*Y(5)+DCMDF
      SUMCM=SUMCM-(CG-.35)*SUMCZ
      SUMCN=SUMCN+(CG-.35)*C*SUMCY/B
      YP(1)=-G*STHE+Y(2)*Y(6)-Y(3)*Y(5)+RVR2*D1*SUMCX+TOM*CEPS
       YP(2)=G*CTHE*SFE+Y(3)*Y(4)-Y(1)*Y(6)+RVR2*D1*SUMCY
      YP(3)=G*CTHE*CFE+Y(1)*Y(5)-Y(2)*Y(4)+RVR2*D1*SUMCZ+TOM*SEPS
      YP(4)=(A1*Y(5)*Y(6)+A2*(Y(4)*Y(5)*(1.+C1)-C2*Y(5)*Y(6)+C3*RVR2*
     1SUMCN)+A3*RVR2*SUMCL)/(1.-A2*C2)
      YP(5)=B1*Y(4)*Y(6)+B2*(Y(5)**2-Y(4)**2)+RVR2*B3*SUMCM
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      YP(6)=C1*Y(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.)GOTO49
      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(6)-Y(13)*Y(5))+2.*EP*Y(9)
      YP(10)=.5*(Y(8)*Y(5)-Y(9)*Y(6)+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
      SUBROUTINE CONTROL(T)
      COMMON/STICK/DET,DAT,DRT,DEF,DAF,DRF,FB1,FB2
      COMMON/STICKF/DAFT(170),DRFT(170),DEFT(170)
      BT=T
      RIC=BT*5.+1.
        IC=RIC
          PERIC=RIC-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))*PERIC+DEFT(IC)
          RETURN
           END
```

```
      SUBROUTINE RKGXYZ(X,Y,P3,N,DX,EMAX,F)
      DIMENSION Y(35),Y0(35),YT(35),YP(35),P0(35),P1(35),P2(35),P3(35)
      X0=X
      X=X+DX
1     H=0.5*(X-X0)
30    H=H+H
2     IF(ABS(X-X0)-ABS(H))1,3,3
3     DO 4 I=1,N
4     Y0(I)=Y(I)
      HT=H
      XT=X0
      DO 5 I=1,N
5     YT(I)=Y0(I)
      ASSIGN 6 TO K
      GO TO 20
6     DO 7 I=1,N
7     YP(I)=Y(I)
8     HT=0.5*H
      ASSIGN 9 TO K
      GO TO 20
9     DO 10 I=1,N
10    YT(I)=Y(I)
      XT=X0+HT
      ASSIGN 11 TO K
20    CALL F(XT,YT,P0)
      DO 21 I=1,N
21    Y(I)=YT(I)+0.5*HT*P0(I)
      CALL F(XT+0.5*HT,Y,P1)
      DO 22 I=1,N
22    Y(I)=YT(I)+HT*(.207106781*P0(I)+.292893219*P1(I))
```

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```
      CALL F(XT+0.5*HT,Y,P2)
      DO 23 I=1,J
   23 Y(I)=YT(I)+HT*(.707106781*(P2(I)-P1(I))+P2(I))
      CALL F(XT+HT,Y,P3)
      DO 24 I=1,J
24    Y(I)=YT(I)+HT*(P0(I)+.585786438*P1(I)+3.41421356*P2(I)+P3(I))/6.0
      GO TO K,(6,9,11)
11    RMAX=0
      DO 12 I=1,J
      R=ABS((0.03*(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-0.03*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/REST/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,
```

```
2ALPHA,BETA,DR,DE,DF,DH,DLEF,DEC,DRC,DFC,DHC,AMACH
     COMMON/CHECK/SUMCX,SUMCZ,SUMCM,CN,CNQ,CC,CCQ,CMO,CMA,CMDE,
1CMDLE,CMQ
 COMMON/OTHER/IX,IY,IZ,IXZ,S
 COMMON/CHECK2/CNB,CNBLE,CNR,CNP,CNDR,CNDH,CNDF,CLDF,CLDH,CLP,CLR,
CCLDR,CLBLE,CLB
 COMMON/TRIM/BED,GAMAO,AL,FN,   SUMCY,RLIFT,XCY,TCONST,GCONST
C,THEO,SIGHD,FEO
 COMMON/CCC/DELFC,QBIAS,GBIAS,S10,DELF,XCD,DELF1,DELF2,S20
 EXTERNAL GVRATES
 REAL IX,IY,IZ,IXZ,IR,MASS
 GAMMA=0.
 VR=100.
 GAMAO=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 =BE*AV
 T=0.
 T=-1.
 Y(2)=0.
 BE=BED/AV
 BET=BE*AVSBETA=BET
 EMG=MASS*G
```

```
      DF=DH=0.
      DA=DE=DR=0.
      CNTR=TT=0.
   50 CONTINUE
      Y(2)=VR*SIN(BE)$Y(1)=SQRT((VR**2-Y(2)**2)/(1.+TAN(AL)**2))
      Y(3)=Y(1)*TAN(AL)
      CALL GYRATES(T,Y,YP)
      FZZ=COS(AL)*EMG*EN
      FXX=-SIN(AL)*EMG*EN
      VR=SQRT(ABS(2.*FZZ/ROH/S/SUMCZ))
      Y(2)=VR*SIN(BE)$Y(1)=SQRT((VR**2-Y(2)**2)/(1.+TAN(AL)**2))
      Y(3)=Y(1)*TAN(AL)
      RVR2=ROH*VR*VR
      THRUS=-FXX-RVR2*D1*SUMCX*MASS
      DO 150 I=1,3
      CALL ANGLE(Y,YP,XB,YB,ZB)
      DSUMCM=-(B1*Y(4)*Y(6)+B2*(Y(5)**2-Y(4)**2))/RVR2/B3
      TSUM=DSUMCM-CMO-CMA*ALPHA-CMDLE*DLEF-B4/VR*CMQ*Y(5)+(CG-.35)*SUMCZ
      DE=TSUM/CMDE
      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/B+CNB*BETA+CNDR*DR+CNBLE*BETA*DLEF+C4/VR*(CNP*
     CY(4)+CNR*Y(6))))-A3*RVR2*(CLB*BETA+CLDR*DR+CLBLE*BETA*DLEF+
     CA4/VR*(CLP*Y(4)+CLR*Y(6))))/(C3*RVR2*(CNDF+.25*CNDH)+A3*RVR2*(
     CCLDF+.25*CLDH))
      IF (DA.GT.25.) DA=25.
      IF (DA.LT.-25.) DA=-25.
      DF=DA$DH=DA/4.
      DSUMCN=(-C1*Y(4)*Y(5)-C2*(YP(4)-Y(5)*Y(6)))/RVR2/C3
```

```
      DR=(DSUMCN-CNB*BETA-CNDF*DF-CNDH*DH-CNBLE*BETA*DLEF-C4/VR*(
     CCNP*Y(4)+CNR*Y(6)))/CNDR
      IF (DR.GT.20.) DR=20.
      IF (DR.LT.-20.) DR=-20.
  150 CONTINUE
      CALL ANGLE(Y,YP,XB,YB,ZB)
      CNTR=CNTR+1.
      IF(CNTR.GT.15.)GOTO20
      TSTG=XCY/MASS+G*SQRT(EN**2-1.)
      OUT1=ABS(LIFT-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)*57.3$Y2=Y(10)*57.3$Y3=Y(9)*57.3
   64 CONTINUE
      GAMMMA=GAMMA*57.3
      P1=Y(4)*AV$Q1=Y(5)*AV$R1=Y(6)*AV
      WRITE(6,881) VR,Y(7),AMACH
      WRITE(6,781)EN,BCONST,TCONST,GCONST
      WRITE(6,905)OUT1,TSTG,ALFA,BET
      WRITE(6,101)DA,DE,DR
      WRITE(6,102)GAMMMA,Y1,Y2,Y3
      WRITE(6,807)
      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 THRUST, THRUS = ",F8.3///)
```

```
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 AILERON = ",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,8(E12.5,3X)//,
     *3X," YP'S - ",7X,"9",14X,"10",14X,"11",14X,"12"/,14X,
     *4(E12.5,3X)/)
880   FORMAT(" TOTAL VELOCITY, VR = ",F7.1," FT/SEC ",8X," ALTITUDE = ",
     *F7.1," FEET ",8X," MACH NUMBER AT ALT. = ",F5.3/)
906   FORMAT(" XS LFT = ",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)
      DO 22 K=1,'
   22 YO(K)=Y(K)
      THEO=Y(8)$FEO=Y(10)$SIGHO=Y(9)
      RETURN
      END
      SUBROUTINE ANGLE(Y,YP,XB,YB,ZB)
      DIMENSION Y(35),YP(35)
      REAL MASS,IY
         COMMON/FOM/MASS,C,B,THRUS,CG
         COMMON/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,
```

```
2ALPHA,BETA,DR,DE,DF,DH,DLEF,DEC,DRC,DFC,DHC,AMACH
     COMMON/CHECK/SUMCX,SUMCZ,SUMCM,CN,CNQ,CC,CCQ,CMO,CMA,CMDE,
1CMDLE,CMQ
 COMMON/CHECK2/CNB,CNBLE,CNR,CNP,CNDR,CNDH,CNDF,CLDF,CLDH,CLP,CLR,
CCLDR,CLBLE,CLB
 COMMON/OTHER/IX,IY,IZ,IXZ,S
 COMMON/TRIM/BED,GAMAD,AL,EN,   SUMCY,RLIFT,XCY,TCONST,GCONST
C,THEO,SIGHO,FEO
 COMMON/CCC//DFLFC,QBIAS,GBIAS,S10,DELF,XCD,DELF1,DELF2,S20
 T=-1.
 GAMA=0.
 BE=BED/AV
 OMEGA=      G/VR*SQRT(EN**2-1.)
 CR=0.
1 EMG=MASS*G
 GAMMA=5./AV
 TGH=0.
 CR=CR+1.
 CALL GYRATES(T,Y,YP)
 TOM=THRUS/MASS
 XB=(RVR2*D1*(SUMCX      )+TOM)*MASS
 YB=RVR2*D1*MASS*SUMCY
 ZB=RVR2*D1*MASS*SUMCZ
 IF (TCONST.NE.0.) GAMMA=0.
 IF (GCONST.NE.0.) GAMMA=GAMA
 GETOUT=0.
 IF(TCONST.NE.0..OR.GCONST.NE.0.)GOTO6
 DO 4 I=1,2
 GAMMA=GAMMA-5./57.3
6 CONTINUE
```

```
      PSIP=ATAN(Y(2)/Y(1))
      THETP=ATAN(SORT(SIN(AL)**2/(COS(AL)**2+TAN(BE)**2)))
      SGAM=SIN(GAMMA)$SP=SIN(PSIP)$ST=SIN(THETP)
      CGAM=COS(GAMMA)$CT=COS(THETP)$CP=COS(PSIP)
      AAA=XB*ST*CP-YB*ST*SP-ZB*CT
      BBB=XB*SP+YB*CP
      CCC=XB*CT*CP-YB*CT*SP+ZB*ST
      TPHIP=(BBB*(-EMG+SGAM*CCC)/CGAM-AAA*EMG*SORT(EN*EN-1.))/(BBB*B
     CBB+AAA*AAA)
      IF (TPHIP.GT.1.) TPHIP=1.
      IF (TPHIP.LT.-1.) TPHIP=-1.
      PHIP=ASIN(TPHIP)
      SF=SIN(PHIP)$CF=COS(PHIP)
      TTHET=CP*CF*SGAM-SP*SF*CGAM+CP*ST*CF*CGAM
      PTHET=SORT(1.-TTHET**2)
      Y(8)=ACOS(TTHET)
      TPHI=     -(ST*SGAM-CT*CF*CGAM)/PTHET
      TPSI=      (CP*CT*CGAM+SP*SF*SGAM-CP*ST*CF*SGAM)/PTHET
      Y(9)=ACOS(TPSI)
      Y(10)=ACOS(TPHI)
      Y(4)=-OMEGA*SIN(Y(8))
      Y(5)=OMEGA*COS(Y(8))*SIN(Y(10))
      Y(5)=OMEGA*COS(Y(8))*COS(Y(10))
      CALL GYRATES(T,Y,YP)
      IF(GETOUT.EQ.1.)GOTO7
      IF(TCONST.NE.0..OR.GCONST.NE.0.)GOTO7
      IF(I.EQ.2)GOTO5
    4 TGH=YP(3)/YP(1)
    5 GAMMA=GAMMA-5.*(Y(3)/Y(1)-YP(3)/YP(1))/(TGH-YP(3)/YP(1))/AV
      GETOUT=1.$GOTO6
```

```
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
 1B
  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)))*ZB
  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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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

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20. proposed mechanized YF-16.

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