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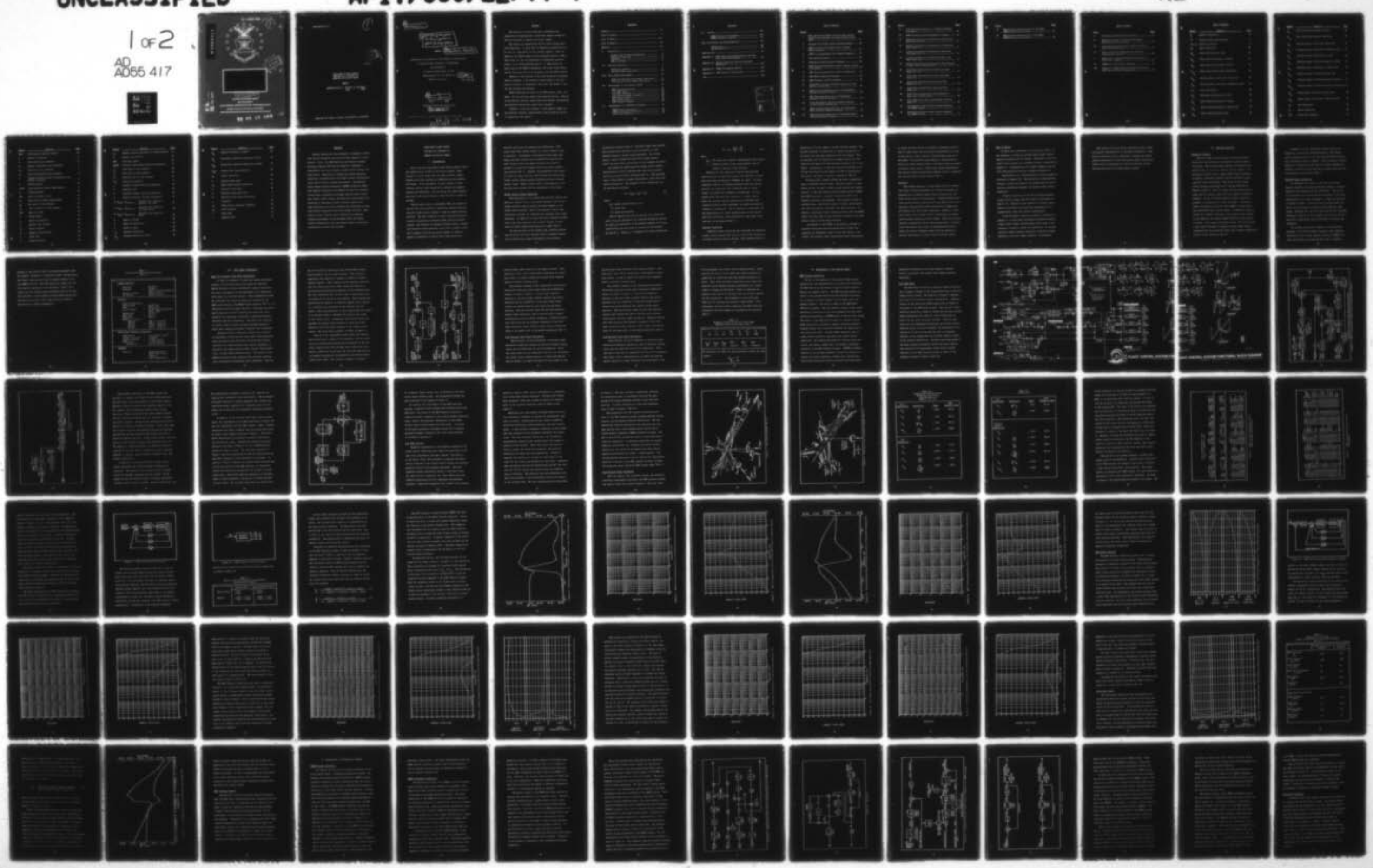

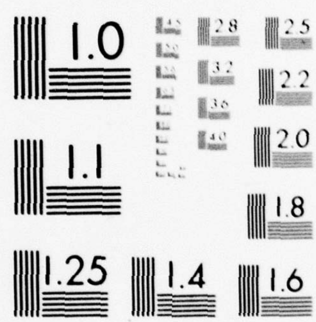

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PITCH RATE FLIGHT CONTROL FOR THE F-16 AIRCRAFT TO IMPROVE AIR-TO-AIR COMBAT

THESIS

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(14) AFIT/GGC/EE/77-7

(6) PITCH RATE FLIGHT CONTROL FOR THE F-16 AIRCRAFT TO IMPROVE AIR-TO-AIR COMBAT.

THESIS (9) 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 (12) 79p.

Master of Science

by

(10) Michael A. Marchand

Capt USAF

Graduate Electrical Engineering

(11) December 1977

Preface

The objective of this study was to determine the feasibility of implementing a pitch rate control system for the F-16 aircraft to improve air-to-air combat.

The thesis was sponsored by the Air Force Flight Dynamics Laboratory. I would like to express my appreciation to Lt. Col. E. Frank Moore for his overall support. Also, my thanks to Dr. Robert Huber for his technical advice, to Maj. Percy Gros, Jr. for his assistance in developing realistic models, to Lt. Rick Holdridge and Mr. J. Edgar Houtz for their help in the TAWDS programming, and to Mr. Frank George and Mr. Brian Van Vliet for assistance with the EASY program.

Because of the interest of Mr. Dick Quinlivan of General Electric Company, I was invited to participate in the F-16 manned simulation in Binghamton, New York. My thanks to him for his personal contribution.

Much credit must be given to my AFIT advisor, Capt. Jim Negro, for his untiring support and technical advice. Because of his genuine interest, many points were further investigated and analyzed, making this report more complete.

Finally, to my wife, Annette, a very special thanks for her personal interest, understanding, and secretarial skills in completing this thesis.

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List of Tables

List of Symbols

Symbol	Meaning	Page
A_n	Normal acceleration	3
C*	Flight control design method	3
c.g.,cg	Center of gravity	3
C_D	Drag coefficient	29
C_{D_o}	Drag coefficient for trim	31
C_{D_α}	Drag coefficient/angle of attack	31
C_{D_u}	Drag coefficient/forward velocity	31
$C_{D_{\delta_e}}$	Drag coefficient/elevator deflection	31
C_{l_B}	Rolling moment coefficient (body axis)	29
C_{l_S}	Rolling moment coefficient (stability axis)	29
C_L	Lift coefficient	29
C_{L_o}	Lift bias coefficient for trim	31
C_{L_α}	Lift coefficient/angle of attack	31
$C_{L_{\dot\alpha}}$	Lift coefficient/angle of attack rate	31
C_{L_q}	Lift coefficient/pitch rate	31

Symbol	Meaning	Page
C_{L_u}	Lift coefficient/forward velocity	32
$C_{L_{\delta_e}}$	Lift coefficient/elevator deflection	32
C_{m_B}	Pitching moment coefficient (body axis)	29
C_{m_S}	Pitching moment coefficient (stability axis)	29
C_{m_o}	Pitching moment coefficient for trim	32
C_{m_α}	Pitching moment coefficient/angle of attack	32
$C_{m_{\dot{\alpha}}}$	Pitching moment coef/angle of attack rate	32
C_{m_q}	Pitching moment coefficient/pitch rate	32
C_{m_u}	Pitching moment coefficient/forward velocity	32
$C_{m_{\delta_e}}$	Pitching moment coefficient/elevator deflection	32
C_{n_B}	Yawing moment coefficient (body axis)	29
C_{n_S}	Yawing moment coefficient (stability axis)	29
C_N	Yaw coefficient	29
C_Y	Pitch coefficient	29
DB	Pilot model deadband	17

Symbol	Meaning	Page
EASY	Environmental Analysis System	18
g	Gravity coefficient	3
K	Pilot model gain parameter	17
k_1	Normal acceleration gain parameter	3
k_2	Pitch rate gain parameter	3
k_3	Pitch acceleration gain parameter	3
L	Distance between linear accelerometer and center of gravity	4
L	Rolling moment	30
LCOSS	Lead Computing Optical Sight System	5
M	Pitching moment	30
MAC	Mean aerodynamic chord	12
mr	Milliradian (angular measurement)	17
M_m	Max peak of time response	49
M_o	Peak overshoot of time response	63
MSL	Mean sea level	10
N	Yawing moment	30
n_z	Normal acceleration	30
P	Angular roll velocity	30
P_s	Static pressure	21
Q	Angular pitch velocity	30
q	Pitch rate	21
q	Dynamic pressure	21

Symbol	Meaning	Page
q_c	Dynamic pressure adjusted for compressibility	21
R	Angular yaw velocity	30
RMS	Root mean square	81
TAWDS	Terminal Aerial Weapon Delivery Simulation	67
T_p	Peak time of time response	63
T_r	Rise time of time response	63
T_s	Settling time of time response	63
U_{co}	Cross-over velocity	4
u	Aircraft forward velocity pertubation	29
V	Relative wind	29
v	Aircraft lateral velocity pertubation	29
w	Aircraft vertical velocity pertubation	29
X, X_{Body}, $X_{Stability}$	Aircraft axis (positive-opposite air flow)	29
Y, Y_{Body}, $Y_{Stability}$	Aircraft axis (positive-out right wing)	29
Z, Z_{Body}, $Z_{Stability}$	Aircraft axis (positive-down)	29
α	Angle of attack	39
$\dot{\alpha}$	Angle of attack rate	39
β	Sideslip angle	29
δ_e	Elevator deflection	39
δ_{F_L}	Flaperon deflection (left)	30

Symbol	Meaning	Page
δ_{F_R}	Flaperon deflection (right)	30
δ_{H_L}	Horizontal stabilator deflection (left)	30
δ_{H_R}	Horizontal stabilator deflection (right)	30
δ_{LEF}	Leading edge flap deflection	30
δ_R	Rudder deflection	30
ϕ	Aircraft bank angle	17
ϕ_c	Phase margin angle (crossover)	63
θ	Aircraft pitch angle	49
$\dot{\theta}$	Aircraft pitch angle rate	3
$\ddot{\theta}$	Aircraft pitch angle acceleration	3
ω	Frequency	17
ω_c	Phase margin crossover frequency	63
ω_m	Peak frequency	63
τ	Time delay	17
ζ	Damping ratio	17

Abstract

Digital simulations were developed to implement a pitch rate control system for the F-16 aircraft engaged in aerial gunnery. First, the EASY Modelling and Analysis Program by Boeing Computer Services was adapted to implement a longitudinal axis F-16 aircraft, flight control system, and pilot model. Comparison of closed loop system responses indicated a proposed pitch rate flight control configuration would improve target tracking performance. The Terminal Aerial Weapon Delivery Simulation (TAWDS) program by McDonnell Douglas Corporation was adapted for the F-16 aircraft. A non-linear, six-degree-of-freedom aircraft model, multi-axis flight control system, and multi-axis pilot model were developed to demonstrate target tracking capabilities. Eight different air-to-air scenarios were developed to simulate evasive encounters with an F-4 target aircraft. Time history target tracking errors indicated the improved tracking performance of the proposed pitch rate flight control configuration over the present normal acceleration configuration of the F-16 aircraft.

PITCH RATE FLIGHT CONTROL

FOR THE F-16 AIRCRAFT TO

IMPROVE AIR-TO-AIR COMBAT

I. Introduction

One of the most challenging tasks facing today's tactical fighter pilot is that of air-to-air gunnery. When engaged in aerial combat with an enemy aircraft, today's fighter pilot must maintain an offensive role by tracking his target. To be successful, he must achieve a target tracking solution that allows him to deliver his weapons quickly and accurately. All too often, this task requires more skill and control precision than the pilot is able to provide.

During recent years, considerable USAF and industrial efforts have been directed to developing advanced tactical aircraft flight control systems to improve weapon delivery accuracy. The most promising of these engineering efforts involves integration of aircraft flight and fire control systems. The benefits of automatic flight control, coupled with automatic weapon delivery, will allow a fighter pilot, while engaged in air-to-air aerial combat, to select a degree of automation to assist him in both flying his aircraft and firing his weapons more effectively. This could range from a manual system to a fully automatic mode of operation. Preliminary investigations have shown that weapon delivery accuracy can be improved by coupling aircraft flight control and weapon delivery fire control systems to relieve the fighter pilot of his ever increasing workload (Ref 1). However, the possibility also exists of improving weapon delivery effectiveness by conditioning flight control systems without removing the pilot from his primary tasks. Manual flight control investigations of improving aerial gunnery will be considered in this study.

Flight Control System Background

The performance of air superiority aircraft such as the McDonnell Douglas F-15 or the General Dynamics F-16 in air combat maneuvers places unusual and heavy demands on the flight control system. This is true because today's high performance aircraft are operated over extremely wide flight envelopes. In addition to using the total altitude and Mach range, the pilot exercises the aircraft through its full angle of attack capabilities during air combat (Ref 2).

To aid the pilot in his primary task, handling quality specifications have been designed using a weighted combination of pitch rate, normal acceleration, and pitching acceleration criteria (Ref 3). Aircraft flight test performance ratings have indicated a pilot preference of this blended system for normal cruise maneuvers. As a consequence, several systems have been built which combine pitch rate and normal acceleration as the feedback variables.

One method for mechanizing the flight control system feel/response is the C* approach that was first proposed by Boeing aircraft design engineers (Ref 3). This approach uses a linear blend of normal acceleration, pitch rate, and pitch acceleration. The weighted control combination can be described as follows:

$$C^* = k_1 A_n + k_2 \dot{\theta} + k_3 \ddot{\theta} \qquad (1)$$

where

A_n = normal acceleration at c.g.

$\dot{\theta}$ = pitch rate

$\ddot{\theta}$ = pitch acceleration

The C* equation can also be defined in g's where the units of k_2 are equivalent to a velocity divided by gravity (g) and k_3 is equivalent to the distance between the linear accelerometer and the center of gravity of the aircraft divided by g. Using $k_1 = 1$, Equation (1) can be written as:

$$C^* = A_n + \frac{U_{co}\dot{\theta}}{g} + \frac{L\ddot{\theta}}{g} \qquad (2)$$

where

U_{co} = the cross-over velocity (approximately 400 ft/sec)

L = distance between linear accelerometer and the center of gravity of the aircraft.

Selection of the cross-over velocity specifies the operating point at which the control contributions of pitch rate and normal acceleration feedback are equal. At lower airspeeds, such as in landing approaches where the control surfaces are relatively less responsive than at cruise flight, the pitch rate feedback is predominant. At airspeeds above the cross-over velocity, in flight regions where the aircraft control surfaces are relatively more responsive than at lower airspeeds, the normal acceleration feedback is predominant. The C* approach is convenient for the mechanization of a feel system because of the ease by which the pitch rate, pitch acceleration, and normal accelerations can be measured (Ref 3).

Gunsight Technology

Although present technology has developed very advanced flight control systems that could be used in the integration of flight and fire control systems, a key limiting factor in advancing air-to-air combat is target tracking systems. The aircraft gunsight is mechanized to compute and display to the pilot the lead angle required to hit the target. This is generally done by displacing an aiming reticle for the required lead angle from some gunsight reference line to the target. Essentially, if the pilot flies his aircraft so as to keep the reticle on the target, he then is maintaining the proper lead angle to achieve a target hit (Ref 2).

For many years, target tracking has been accomplished using a disturbed reticle sight. The most popular of these sights and the one that is used on most present day fighter aircraft is the Lead Computing Optical Sight System (LCOSS). The LCOSS generates a gunsight lead angle based on the attacker aircraft's own dynamics. The attacker aircraft's own body rates, load factor, angle of attack, and airspeed are used to determine a gunsight lead angle solution. To achieve a continuous target tracking solution with the LCOSS sight, the pilot must fly his aircraft to remain in the same plane of motion as the target aircraft.

In contrast to the LCOSS, a new director gunsight is presently being developed and demonstration flight test programs are scheduled to begin in the near future. Generally, the director sight incorporates actual measurements of target aircraft motion to determine a gunsight solution. Line of sight angle rate and position measurements are used in the director sight instead of own-ship body rates as in the LCOSS. The director system employs a tracking device such as an angle tracking radar or an electro-optical tracker to measure target motion. With actual target measurements, the director system incorporates a Kalman filter to determine the expected future target position (Ref 4).

Objective

The primary objective of this study will be to compare the target tracking performance of a director gunsight implementation for manual flight control involving two aircraft flight control configurations. Present handling qualities specifications, supported by Cooper-Harper pilot ratings have indicated that normal acceleration feedback may be effective for most flight conditions. However, a pitch rate flight control scheme will be investigated to improve aerial gunnery during air-to-air combat. Since the director gunsight incorporates actual target measurements of angular error and angular error rate, it seems appropriate that a pitch rate control feedback scheme could be employed to provide improvements in manual target tracking systems.

Plan of Attack

To begin the investigation of pitch rate control, it was necessary to select an aircraft whose flight control system incorporates the C* concept. Selection of the F-16 flight control system as a candidate system is discussed in Chapter II. Considerations of a flight condition and aircraft characteristics are also included in Chapter II.

Implementation of a representative F-16 pilot model is discussed in Chapter III. This analytical representation allowed a closed loop system to be established for man-in-the-loop simulations necessary for manual flight control evaluation.

A digital simulation of the F-16 aircraft dynamics, flight control system, and pilot model is developed in Chapter IV. Analysis of the present F-16 flight control system is described along with the investigation of a predominately pitch rate control configuration.

A second digital simulation program is discussed in Chapter V. A non-linear six-degree-of-freedom aircraft, flight control model, and multi-axis pilot model is developed to provide a closed loop simulation. To provide realistic target tracking encounters, a series of eight different air-to-air combat scenarios is developed.

The results of the air-to-air encounters using a director gunsight implementation is included in Chapter V. Time history simulation data is generated to measure the target tracking performance of both the present normal acceleration flight control configuration of the F-16 aircraft and the new proposed pitch rate flight control system.

II. Aircraft Selection

Selection Criteria

The F-16 fighter aircraft built by General Dynamics Corporation was selected as the baseline aircraft simulation model. The F-16 was chosen because it represents the present state of the art in fighter aircraft design. Its fly-by-wire flight control system enabled design engineers to harness a basically unstable aircraft and obtain unprecedented flight performance. The design of this flight control system incorporates the C* concept discussed in Chapter I (Ref 3). The F-16 flight control system incorporates angle of attack, pitch rate, and normal acceleration feedback. As the C* concept implies, normal acceleration feedback is predominant at cruise airspeeds. A blending of normal acceleration and pitch rate feedback is employed in the longitudinal axis control system. In addition, angle of attack (i.e. alpha) is fed back to the flight control system to aid stability and achieve alpha limiting at high angles of attack. This unique configuration makes the F-16 aircraft a very likely candidate to examine various flight control configurations and incorporate these into a manual flight/fire control system evaluation (Ref 5).

In addition to this interesting flight control configuration, the F-16 was selected because of the ongoing joint programs between the Air Force Flight Dynamics Laboratory and General Electric Company. Their continuing investigations of integrating flight and fire control systems has recently included a manned simulation program using the F-16 as a baseline aircraft model (Ref 1).

Aircraft Model Description

To complement the efforts of the Air Force Flight Dynamics Laboratory and General Electric Company, realistic scenarios were developed for the simulation. The air-to-air encounters were set with the F-16 aircraft in its clean configuration at a cruise airspeed of .8 Mach and altitude of 20,000 feet MSL. It was from this cruising flight condition that the attacker aircraft would engage the enemy target. Assuming that the pilot had fired his two available Sidewinder missiles, he was equipped with only his 20-millimeter M-61 conventional cannon with which to continue the engagement.

To validate the aircraft dynamics of the modelling programs, F-16 aircraft dynamic simulation data obtained from the Air Force Flight Dynamics Laboratory LAMARS facility was selected as the desired test case. A digital program by John Griffin (Ref 6) provided aerodynamic data for computer validation of selected aircraft configurations and flight conditions for the F-16 manned simulations in the LAMARS facility. This data serves as a basis for the F-16 digital simulations to be developed. Table I describes the F-16 aircraft model characteristics of the test case selected. A more complete aircraft model description and detailed listing of the flight condition stability derivatives are shown in Appendix B.

Table I
F-16 Aircraft Model Characteristics
(Ref 6)

Flight Condition		
Altitude	-	20,000 ft
Airspeed	-	.8 Mach
		(829.5 ft/sec @ 20,000 ft)
Dynamic pressure	-	436.06 lbs/ft^2
Air Density	-	.001267 $slug\text{-}ft^3$
Aircraft		
Clean configuration		
Gross weight	-	19,000 lbs
Mass	-	590.5 slugs
c.g. location	-	33.92% mean aerodynamic chord (MAC)
Chordlength	-	11.32 ft
Wing span	-	30 ft
Wing area	-	300 ft^2
Moments of Inertia		
XX-axis	-	9007.5 $slugs\text{-}ft^2$
YY-axis	-	49956. $slugs\text{-}ft^2$
ZZ-axis	-	56770. $slugs\text{-}ft^2$
XZ-axis	-	198.0 $slugs\text{-}ft^2$
Trim Flight Condition Parameters		
Load factor	-	1 g (32.174 ft/sec^2)
Flight path angle	-	0 degrees
Angle of attack	-	2.1039 degrees
Stabilator (elevator)	-	-1.9123 degrees (up deflection)
Armament		
M-61 gun	-	20 mm ammunition
	-	3400 ft/sec muzzle velocity
	-	6000 rounds/minute

III. Pilot Model Development

Basic F-4 Aircraft Pilot Model Description

In order to implement a closed loop system performance analysis, an F-16 multi-axis pilot model was required. Manned simulation efforts by McDonnell Douglas Corporation have been instrumental in the development of an analytical pilot model for the F-4E aircraft. Their mathematical model was developed from target tracking data produced by two USAF pilots flying in the MCAIR flight simulator (Ref 7). In simulating air-to-air weapon delivery, a data base was provided by measuring aircraft tracking time histories, pilot tracking task responses, statistical tracking performance and weapon delivery performance. The pilots were required to track a target aircraft through programmed maneuvers while their tracking performance responses were documented.

Although efforts of McDonnell Douglas were directed to developing an F-4E aircraft pilot model, they determined from time history data that pilot elevation and traverse tracking error characteristics were similar regardless of the pilot, the weapon delivery task, aircraft flying qualities, or sight system characteristics. The results of the McDonnell Douglas study indicated that elevation tracking error contained two predominant modal components. This was due to the pilot's interaction with the aircraft's short period dynamics and the sight dynamics. Both frequency components were observed to exhibit a limited or lightly damped response. Their study of pilot responses indicates that the longitudinal pilot model treats the pilot as a proportional-plus-derivative observer of the tracking error. The pilot threshold limit of error rate is indicated by use of a dead zone in the error rate channel. This proportional-plus-derivative observer of elevation angular error results in a tracking error projected a time interval into the future. This projected error is then coupled with the output of a low pass filter to determine the pilot's rate input to the control stick. Integrating this control stick rate provides the control stick position or stick force that determines the pilot model response to the flight control system. The pilot model schematic is shown in Figure 1.

Just as in the longitudinal pilot model, the lateral-directional model is based on the assumption that the pilot acts as a proportional-plus-derivative observer of the traverse tracking error with the dead zone on the error rate. However, additional visual ques that the pilot may perceive in traverse tracking are incorporated in the lateral-directional pilot model. This includes feedback of attacker

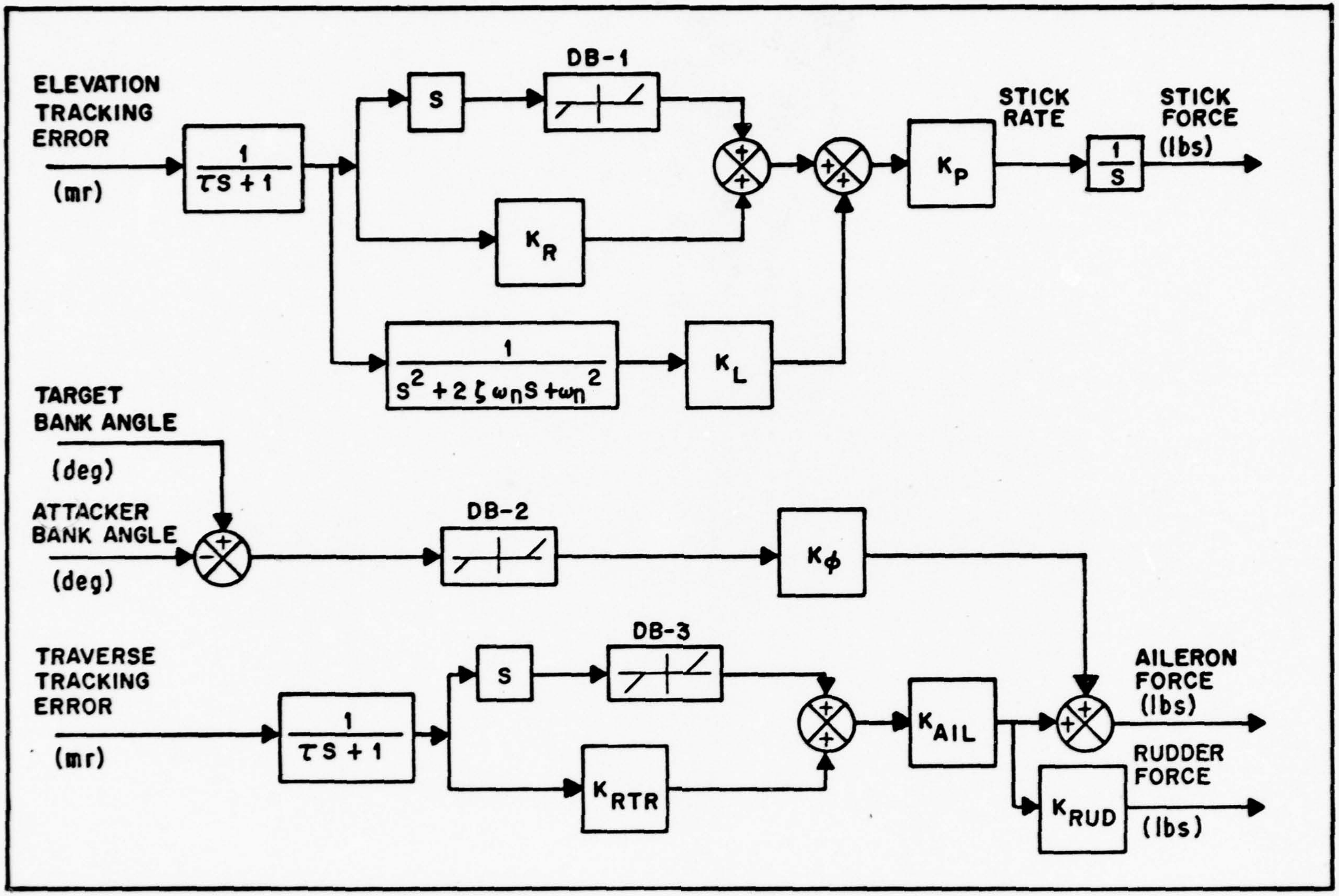

Figure 1. Multi-Axis Pilot Model for Air-to-Air Aerial Gunnery (Longitudinal and Lateral-Directional Axes) (Ref 7)

aircraft bank angle relative to the target aircraft. This additional input, which incorporates a dead band for threshold limits, is used to modify the lateral stick commands based on traverse tracking error.

The schematic diagram of the longitudinal and lateral-directional multi-axis pilot model developed by McDonnell Douglas is shown in Figure 1. A root locus stability analysis of the pilot model transfer function was used to determine how the parameters of the pilot model affect closed loop system stability and control during weapon delivery. Both the director sight and the lead computing optical sight system were used in the air-to-air gunnery investigation and pilot model validation. Tracking performance time histories and frequency responses of the pilot model performing weapon delivery tasks closely represented those of the human pilot in the manned simulations (Ref 7).

F-16 Aircraft Pilot Model Description

Unfortunately, the gain parameters of the pilot model developed by McDonnell Douglas for the F-4 aircraft configuration was not sufficient for an F-16 simulation. Since this basic model was not compatible with the F-16 aerodynamic and flight control characteristics, an effort was made by General Dynamics to adapt this basic F-4 pilot model to the aircraft bank angle relative to the target aircraft. This additional input, which incorporates a dead band for threshold limits, is used to modify the lateral stick commands based on traverse tracking error.

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F-16 Aircraft Pilot Model Description

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F-16 aerodynamic and flight control characteristics. Their approach was first a pilot model gain study followed by a comparison of flight test data with manned simulation results. Their study provided a multi-axis pilot model that produced fairly adequate tracking performance for a stabilized 5 g target aircraft model. Table II indicates the parameter gain values of the multi-axis pilot model adapted for this simulation. The parameters of the pilot model shown are for employing the director sight system. Pilot performance variations while employing the LCOS system are included by the gain changes as indicated by the asterisk (Ref 8).

Table II
Parameter Values of the F-16 Pilot Model
Implementing Director Sight (Ref 8)

τ	ω	ζ	K_R	K_L	K_p*	K_ϕ
.05	1.0	0.6	.125	.125	.25	.0573

K_{AIL}*	K_{RTR}	K_{RUD}	DB-1	DB-2	DB-3
.10	1.5	0.0	1mr/sec	5 deg	2.5mr/sec

*To implement the LCOS, the above parameters remain the same except:

$$K_{AIL} = .17$$
$$K_p = .20$$

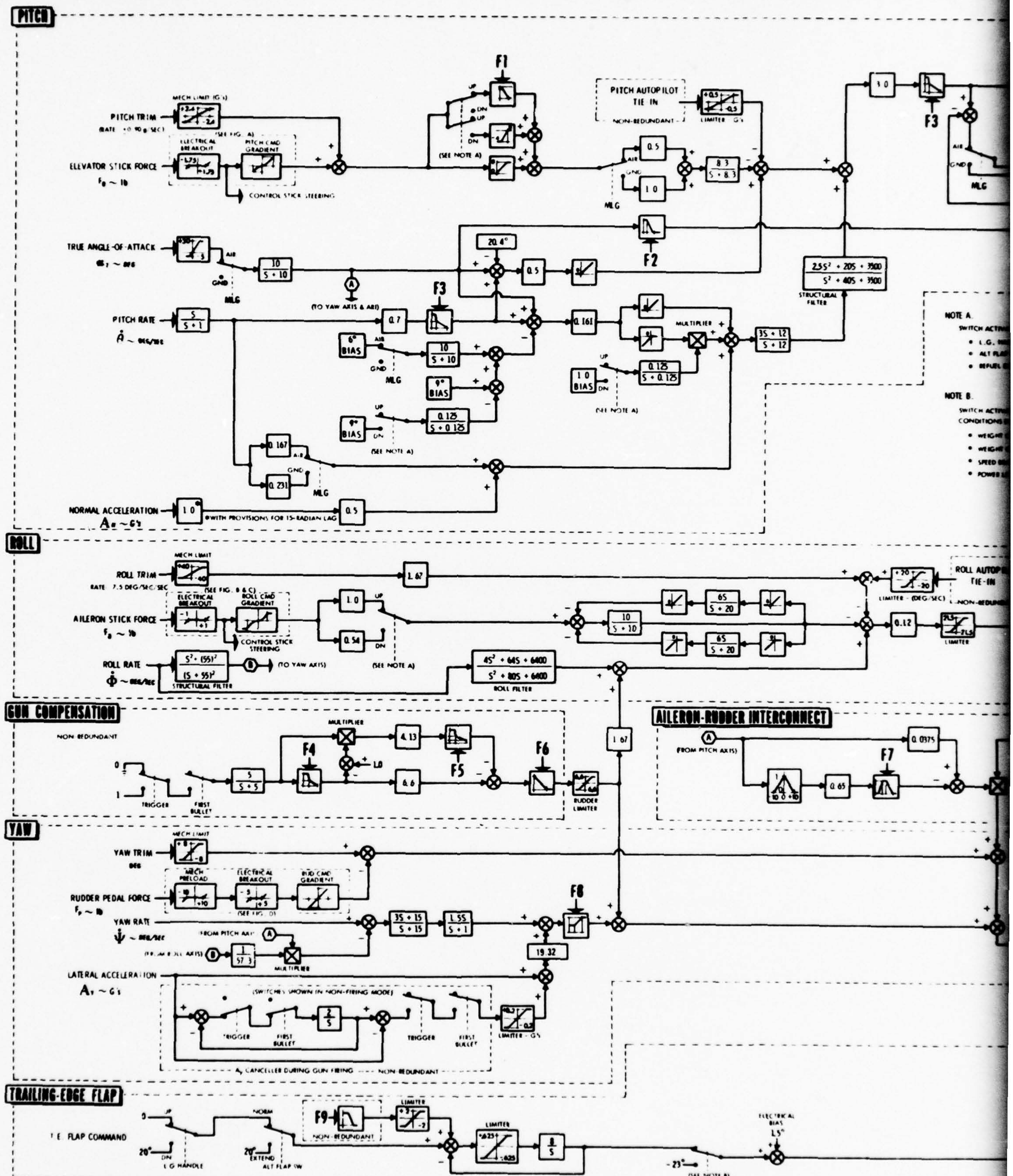
IV. Development of the Analysis Model

EASY Program Discussion

To aid in the analysis of the present flight control configuration and implementation of a pitch rate controller, the EASY Modelling and Analysis Program by Boeing Computer Service was adapted (Ref 9). The EASY program package consists of two programs which allow the modelling and analysis of dynamic aircraft systems in both steady state and dynamic behavior. The first of these is the EASY Model Generation program. This pre-compiler program accepts model description instructions from the programmer and from these instructions generates a FORTRAN model of the aircraft system. The output of the EASY model program is a complete system model description including a computer generated schematic diagram showing inter-connections between the components of the constructed model. Standard EASY components used include aircraft modelling components and control system components. The computerized model was analyzed using the linear, non-linear, steady state, and dynamic techniques available in the EASY Analysis program. FORTRAN statements, referred to as "program commands", allowed the analysis to include non-linear simulation, steady state calculations, linear model generation from the original non-linear model, eigenvalue calculation, root locus analysis, transfer function calculation and several other dynamic analysis techniques.

F-16 EASY Model

The EASY Model Generation program was begun by developing a schematic diagram of the longitudinal axis of the F-16 flight control system. The fold-out of Figure 2 indicates the present F-16 aircraft control configuration. Simplifications of the pitch axis system (upper left of Figure 2) were made for the EASY model program. The aircraft flight condition chosen was .8 Mach at 20,000 feet and the aircraft model configuration was that for cruise flight with no pitch trim nor pitch autopilot included. Trailing edge flaps were not implemented and, because very little control blending occurs at cruise airspeeds, the differential tail deflection of the F-16 aircraft was also not modelled. Instead, it was assumed that the aircraft exhibits conventional elevator deflections. Assuming rigid body dynamics, the high frequency structural filters were also omitted. The resulting F-16 longitudinal flight control system modelled for the EASY analysis program is shown in the schematic diagram of Figure 3 (Ref 10).


PITCH
PITCH TRIM
RATE ±0.90 g/SEC
MECH LIMIT (G's)
ELEVATOR STICK FORCE
ELECTRICAL BREAKOUT
PITCH CMD GRADIENT
CONTROL STICK STEERING
PITCH AUTOPILOT TIE IN
NON-REDUNDANT
LIMITER G's
(SEE NOTE A)
MLG
TRUE ANGLE-OF-ATTACK
AIR
GND
(TO YAW AXIS & ARI)
PITCH RATE
BIAS
MULTIPLIER
STRUCTURAL FILTER
NORMAL ACCELERATION
WITH PROVISIONS FOR 15-RADIAN LAG
NOTE A.
NOTE B.
ROLL
ROLL TRIM
RATE 7.5 DEG/SEC/SEC
(SEE FIG. B & C)
AILERON STICK FORCE
ROLL CMD GRADIENT
ROLL RATE
(TO YAW AXIS)
ROLL FILTER
LIMITER - (DEG/SEC)
ROLL AUTOPILOT TIE-IN
GUN COMPENSATION
NON REDUNDANT
TRIGGER
FIRST BULLET
RUDDER LIMITER
AILERON-RUDDER INTERCONNECT
(FROM PITCH AXIS)
YAW
YAW TRIM
RUDDER PEDAL FORCE
MECH PRELOAD
RUD CMD GRADIENT
YAW RATE
LATERAL ACCELERATION
(SWITCHES SHOWN IN NON-FIRING MODE)
LIMITER - G'S
A_y CANCELLER DURING GUN FIRING - NON-REDUNDANT
TRAILING-EDGE FLAP
T.E. FLAP COMMAND
L.G HANDLE
EXTEND
ALT FLAP SW
NON-REDUNDANT
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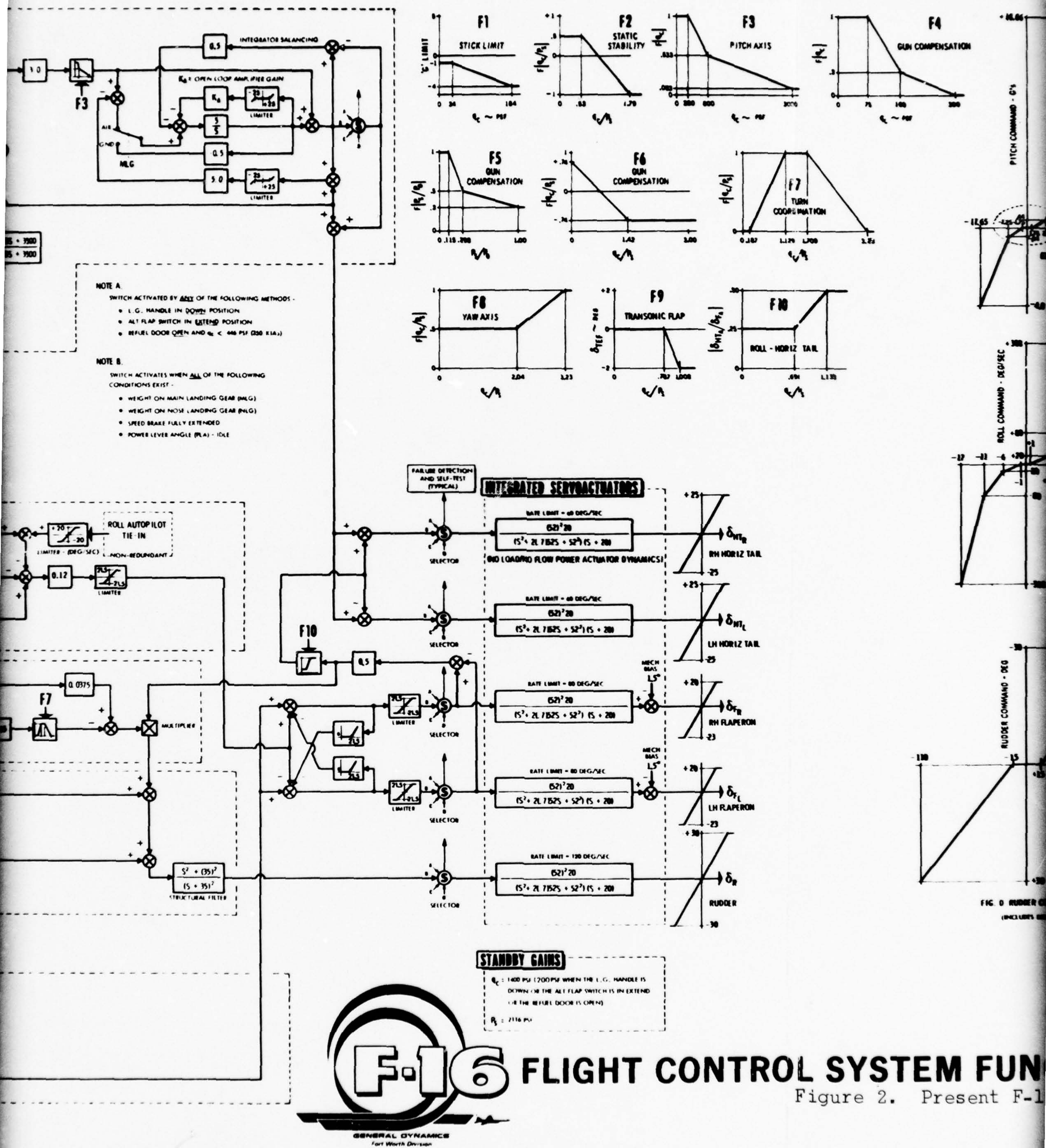
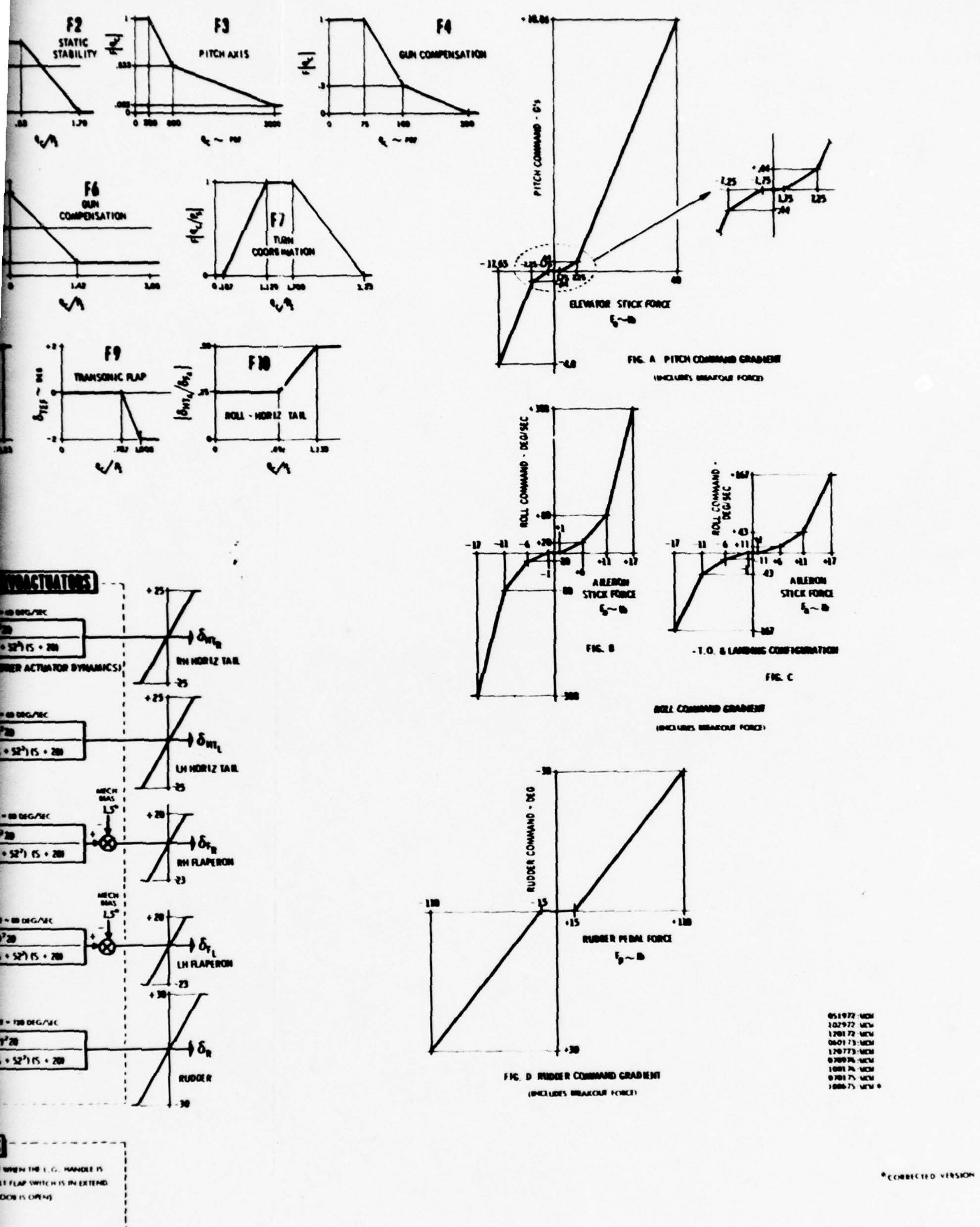


Figure 2. Present F-1



LIGHT CONTROL SYSTEM FUNCTIONAL BLOCK DIAGRAM

Figure 2. Present F-16 Flight Control System Diagram (Ref 11)

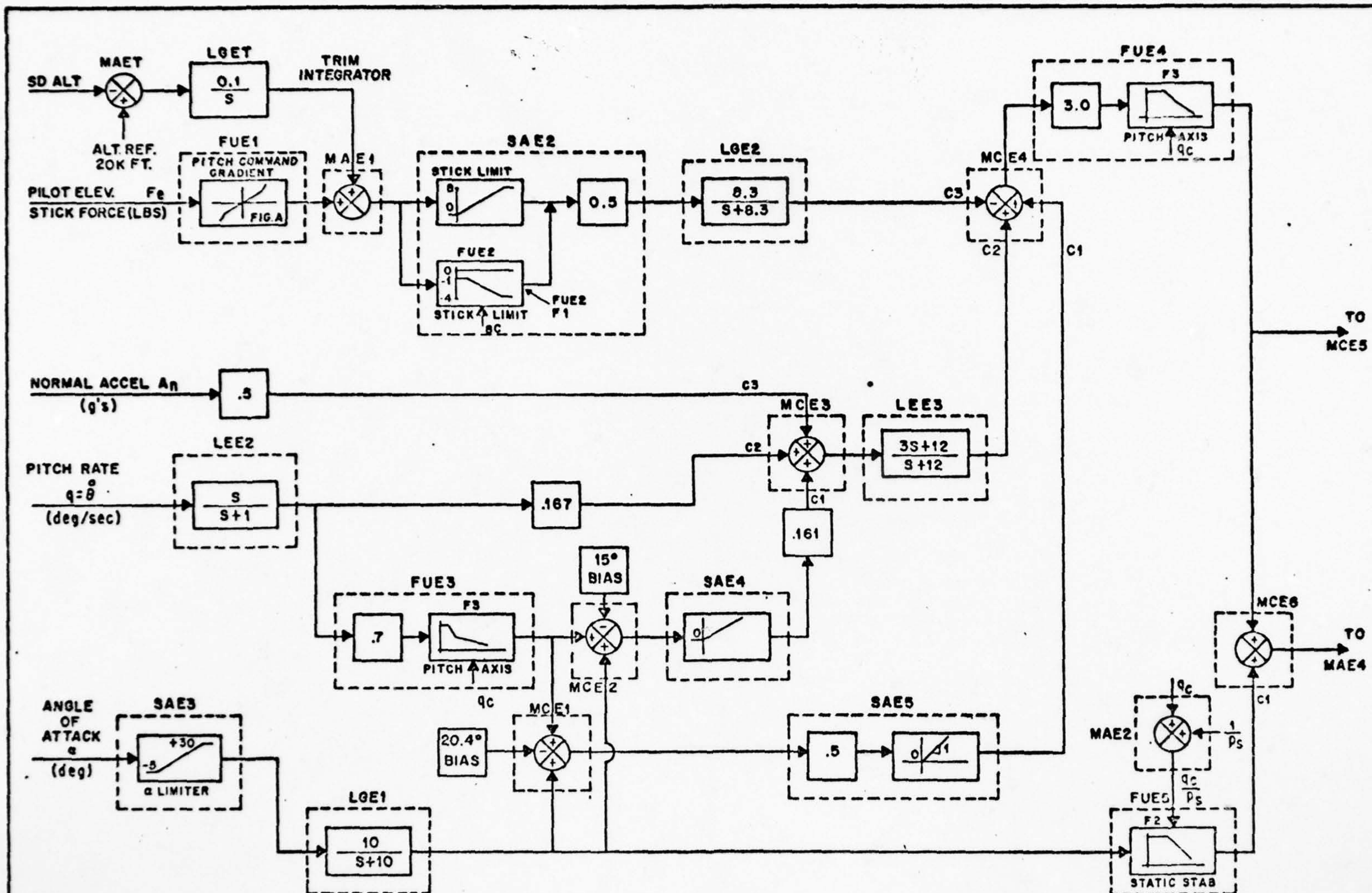


FIGURE 3—EASY F-16 AIRCRAFT FLIGHT CONTROL SYSTEM MODEL SCHEMATIC

Figure 3. EASY F-16 Aircraft Flight Control System Model Schematic

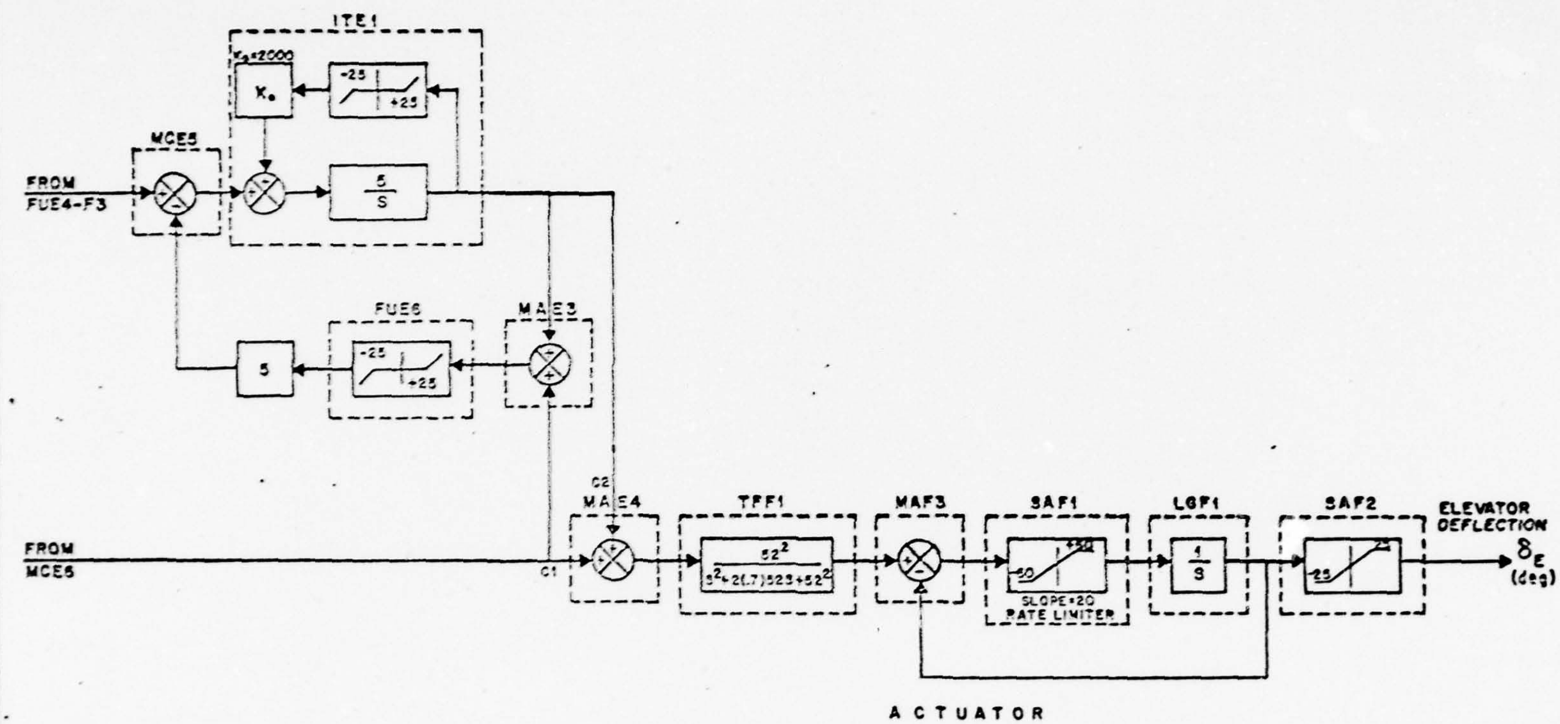


FIGURE 3-CONTINUED

Figure 3. Continued

Only standard components of the EASY program were necessary to complete the flight control system modelling. The dash boxes around the elements in the control system diagram of Figure 3 indicate each standard component used. For example, the FU components indicate table look-up functions. These include both the pitch command gradient and gain scheduled variables that are functions of dynamic and static pressure. The LA and LG components were used to model first order lag transfer functions. First order lead-lag transfer functions were modelled with the LE component. The multiply and add components, MA and MC, were used to model the summing junctions. Second order transfer functions such as in the elevator actuator were modelled using the TF component. Limiting functions or saturation function components, SA, were used to regulate the pilot commanded maximum g forces, angle of attack, actuator rates, and elevator deflection.

In addition to specifying the F-16 flight control system components, the aircraft dynamic modelling was necessary. Description of the aircraft motion centered around the standard components AV, LO, and SD. The AV component uses the aircraft states to compute aerodynamic variables such as angle of attack, airspeed, body rates, etc.

The longitudinal aerodynamic component, LO, computes the longitudinal aerodynamic forces and moments. The six-degree-of-freedom equations of motion component, SD, contains the rigid body dynamic equations for integrating the aircraft states and is driven by the aerodynamic variables generated in LO.

In addition to the aircraft and flight control system model, the longitudinal pilot model described in Chapter III was also implemented into the EASY program. Again, standard components were used to complete the pilot model description as shown in the schematic diagram of Figure 4. This pilot model implementation incorporates parameter requirements for the director sight. Although the description appears different from that of Figure 1, p. 16, a mathematically equivalent model is shown. The time delay component of Figure 1 has been incorporated in both the proportional and derivative channels of the longitudinal pilot model. In addition, Figure 4 indicates the pseudo target tracking task of the pilot model for the EASY analysis. A closed loop system was achieved by feeding back the attacker aircraft pitch angle. This pitch angle was compared to a reference angle to allow performance evaluations of system response to step inputs. The aircraft pitch angle was chosen since

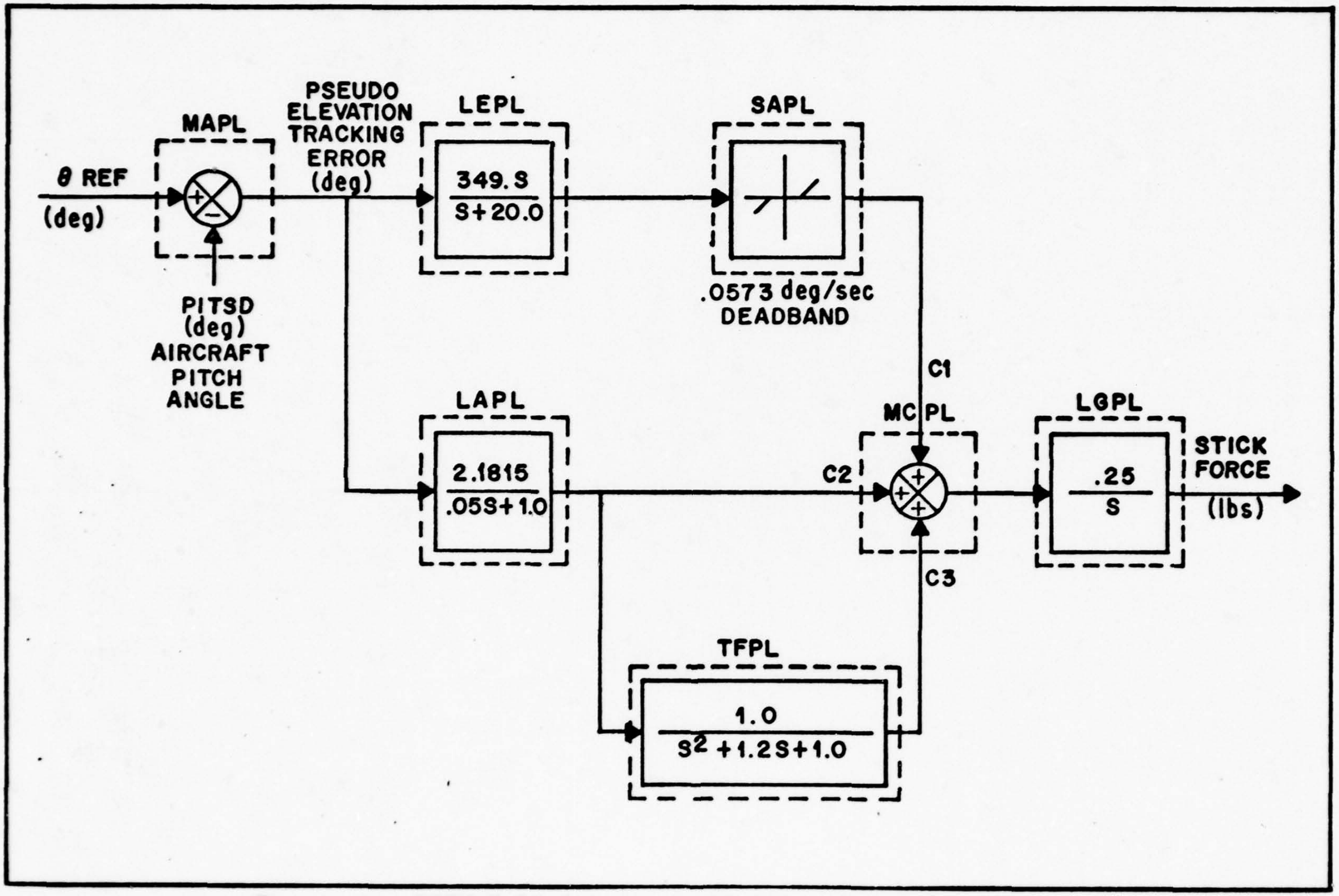


Figure 4. EASY F-16 Longitudinal Pilot Model Schematic

it is angular target measure that is observed by the pilot in his target tracking task. Unit measurement changes are also reflected in the diagram of Figure 4.

To complete the requirements of the EASY modelling program, a component block diagram with interconnections was specified. The output of the EASY Modelling Generation program provided a schematic of the overall system indicating input, output, and parameter requirements of the flight control system aircraft model and pilot model. A listing of the model description statements along with a computer generated schematic diagram of the total system modelled is included in Appendix A.

F-16 EASY Analysis

Parameter requirements of the analysis program for the flight control system and pilot model were specified by the input list generated by the model program. This data is in two parts; first, data necessary to generate the table look-up functions of the flight control system; and secondly, parameter values of the standard components. The gain scheduling blocks indicated in Figure 2 were built using the table function components, FU. This tabular data was loaded by describing both the independent and dependent variables. Additional parameters were loaded in the analysis program to specify either linear interpolation or extrapolation of the table look-up functions. Following the tabular data, parameter values were loaded to specify all requirements of the standard components shown in Figure 3 and Figure 4.

Additional data requirements included stability derivative information necessary to satisfy the longitudinal equations of motion. Inconsistencies were found in stability derivative definitions, sign conventions, and unit measurements. It was therefore necessary to develop an axis system and sign convention to be consistent throughout the simulations. The most convenient system was a set of mutually perpendicular reference axes intersecting at the center of gravity of the aircraft. About this point, the aircraft motion, moments and forces were measured. The positive directions for these axes were selected as: forward or opposite the direction of airflow for the X axis; to the right for the Y axis; and downward for the Z axis. Reference data provided by the aircraft manufacturer and the test case from the Griffin program was selected using the stability axes as reference. The stability axes are established with the X axis parallel to the undisturbed airflow with respect to the aircraft body. The axis system selected is described in Figure 5. The sign convention established, although not universally used, is consistent with both the data presented by General Dynamics and that of the test case selected. A graphic description of the sign convention used is shown in Figure 6 (Ref 11).

Data preparation for the constant coefficient aero model of the EASY analysis program included external forces, torques, and aerodynamic stability derivatives. The non-dimensional stability derivatives were obtained from test data derived from a test program used by the Air Force Flight Dynamics Laboratory LAMARS simulation program. Run #43 of this Griffin program was used as a data base and is listed in Appendix B. It should be noted that the dynamic stability derivatives (e.g. functions of control surface deflections) are listed in per degree units while static stability derivatives are listed in radian measure. The non-dimensional derivatives used to satisfy the longitudinal equations of motion of the EASY program are shown in Table III along with their respective EASY program names (Ref 6).

F-16 Aircraft Model Validation

With the tabular data, parameter values, and stability derivative requirements satisfied, the EASY analysis program was used to verify the aircraft dynamics. The first check

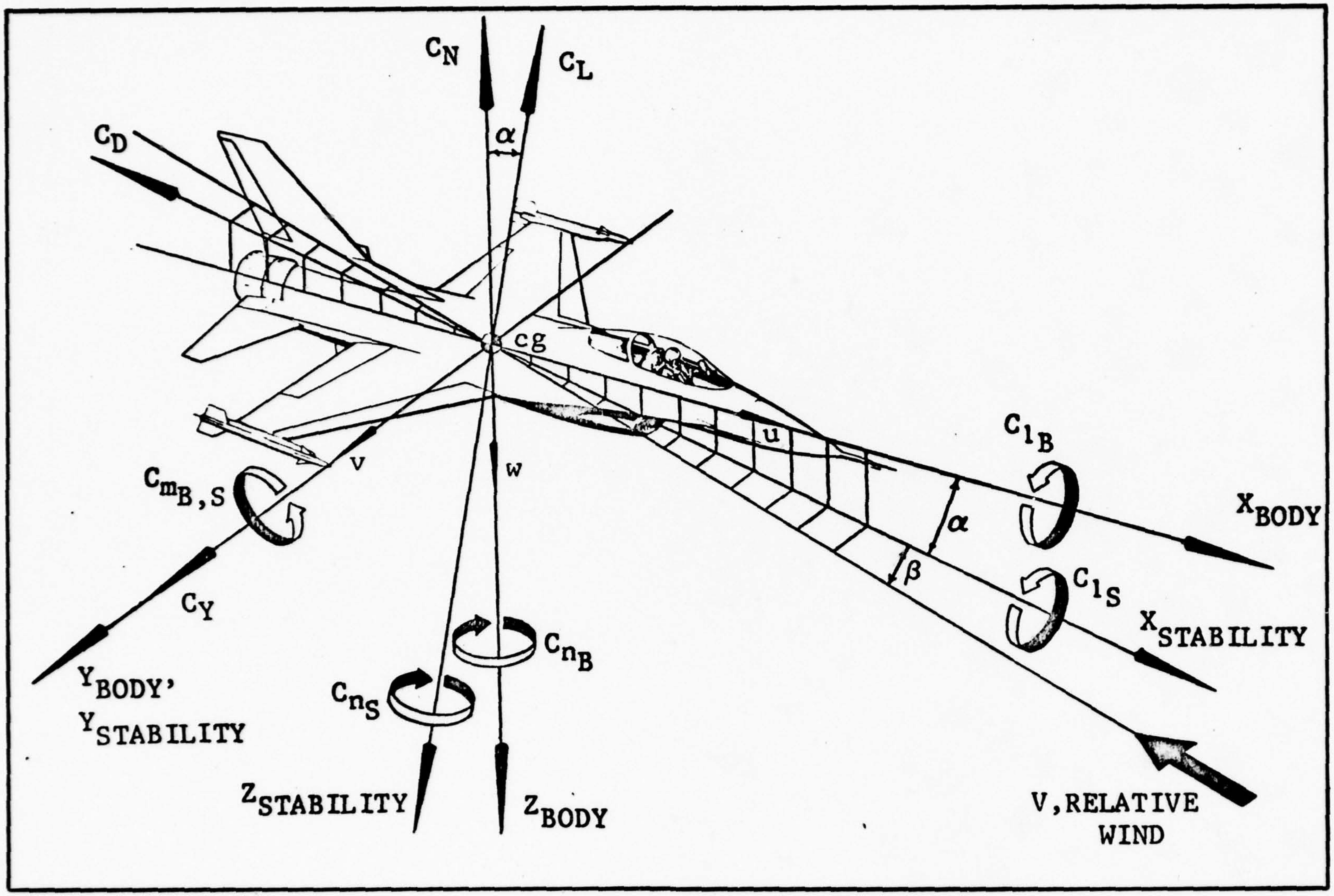


Figure 5. Axes System Diagram (Ref 11)

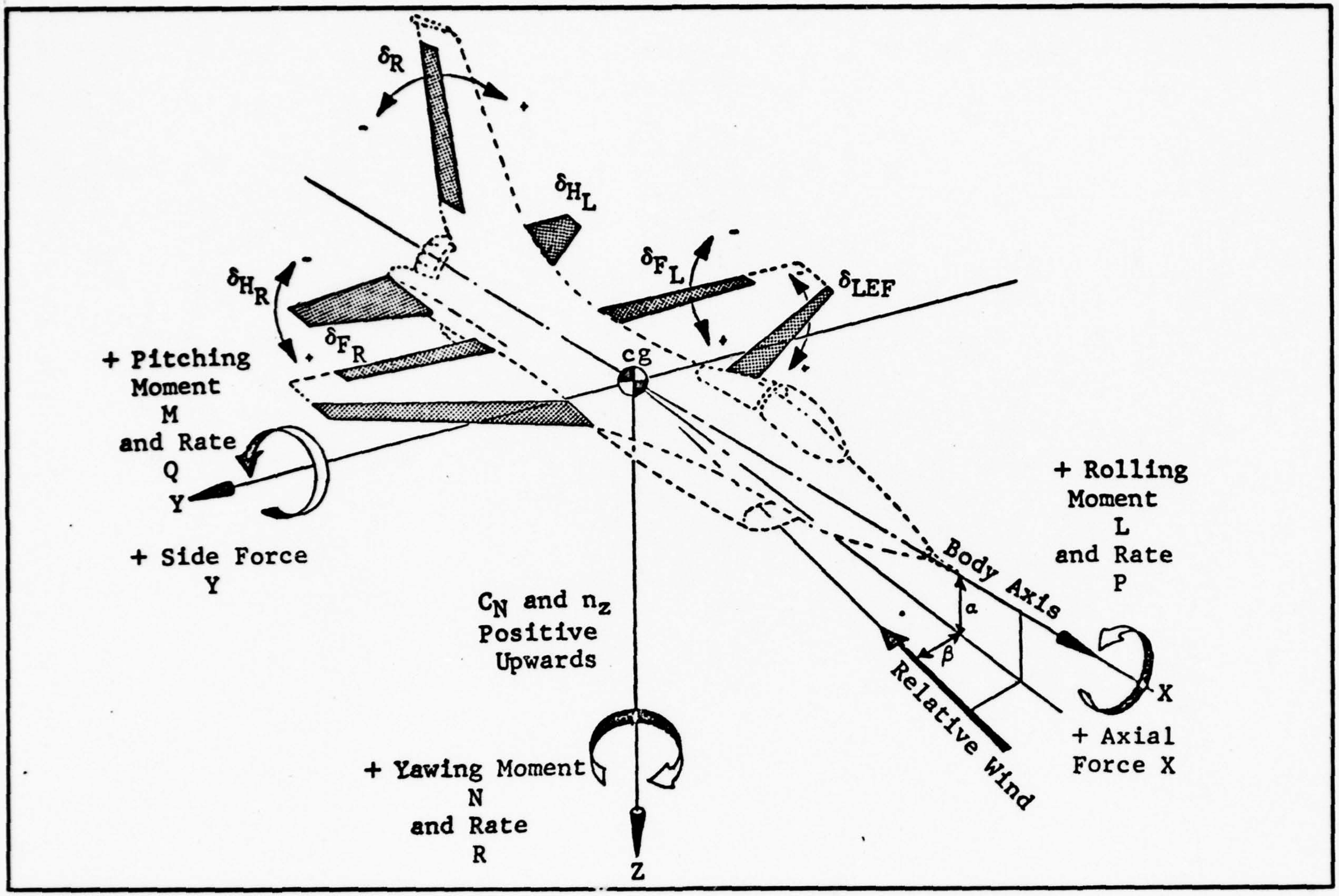


Figure 6. Simulation Sign Convention Diagram (Ref 11)

Table III
Longitudinal Stability Axis
Stability Derivatives
(Non-Dimensional)
(Refs 6, 12, 13)

Drag Coefficient	Definition	Value	EASY Parameter Name
$-C_{D_o}$	$\frac{-D}{qS}$	- .0250	XO LO
$-C_{D_\alpha}$	$\frac{-\partial C_D}{\partial \alpha}$	- .1644	XA LO
$-C_{D_u}$	$\frac{-M}{2} C_{D_M}$	- .0746	XU LO
$-C_{D_{\delta_e}}$	$\frac{-\partial C_D}{\partial \delta_e}$	+ .0525	XDELO
Lift Coefficient			
$-C_{L_o}$	$\frac{-L}{qS}$	- .1443	ZO LO
$-C_{L_\alpha}$	$\frac{-\partial C_L}{\partial \alpha}$	-4.8159	ZA LO
$-C_{L_{\dot{\alpha}}}$	$\frac{-\partial C_L}{\partial \dot{\alpha}}$	+ .6600	ZADLO
$-C_{L_q}$	$\frac{-\partial C_L}{\partial (\frac{q\bar{c}}{2U_o})}$	-2.5965	ZQ LO

Table III
(Continued)

Lift Coefficient	Definition	Value	EASY Parameter Name
$-C_{L_u}$	$\frac{-M}{2} C_{L_M}$	- .0607	ZU LO
$-C_{L_{\delta_e}}$	$\frac{-\partial C_L}{\partial \delta_e}$	- .4986	ZDELO
Pitching Moment Coefficient			
C_{m_o}	-	- .0182	MO LO
C_{m_α}	$\frac{\partial C_m}{\partial \alpha}$	+ .0943	MALLO
$C_{m_{\dot{\alpha}}}$	$\frac{\partial C_m}{\partial \dot{\alpha}}$	- .9550	MADLO
C_{m_q}	$\frac{\partial C_m}{\partial (\frac{q\bar{c}}{2U_o})}$	-2.3187	MQ LO
C_{m_u}	$\frac{M}{2} C_{m_M}$	- .0145	MU LO
$C_{m_{\delta_e}}$	$\frac{\partial C_m}{\partial \delta_e}$	- .6669	MDELO

of the system was to trim the aircraft in straight and level flight at an altitude of 20,000 feet and airspeed of .8 Mach, or an equivalent 829.5 feet per second. In order to trim the aircraft, two additional integrators were added to the system model. The input of the first trim integrator was the difference in reference altitude of 20,000 feet and the actual calculated altitude of the SD component during the trim iterations. This difference error was then integrated and the output fed into the system as a stick input to help achieve a steady state at 20,000 feet. This trim integrator is shown in the upper left hand corner of Figure 3. Likewise, a second trim integrator was used to compare actual velocity calculated in the SD component to the reference velocity of 829.5 feet per second. This velocity difference was integrated and the error was used to help achieve the desired trim condition.

Through the use of program commands, a steady state system solution was determined. Following trim iterations of the EASY program, the computer output shown in Figures 7 and 8 verify the aircraft trim condition. The system states, as defined by the EASY program, are those quantities described by first order differential equations. As shown in Figure 7, the system modelled consists of 25 states. The

```
/*/*/*/   STEADY STATE ANALYSIS   /*/*/*/

A MAXIMUM OF   30 ITERATIONS CAN BE USED

        TIME =  0.                                         STATES
  1 U  SD   =  823.50         2 V  SD   =  0.            3 W  SD   =  32.722         4 P  SD   =  0.             5 Q  SD   = -.39914E-18
  6 R  SD   =  0.             7 ROLSD   =  0.            8 PITSD   =  2.2590         9 YAWSD   =  0.            10 ALTSD   =  20000.
 11 X2 LGEN =  3529.4        12 XI LEPL = -1131.2       13 X2 LAPL =  7.0702        14 XI TFPL =  8.4842       15 X2 TFPL =  7.0702
 16 X2 LGPL =  0.            17 X2 LGET = -.20662E-03   18 X2 LGE2 = -.10331E-03    19 X2 LGE1 =  2.2590       20 XI LEF2 =  .27237E-18
 21 XI LEE3 =  .17034E-03    22 X2 ITE1 = -2.6722       23 XI TFF1 = -112.31        24 X2 TFF1 = -1.5427       25 X2 LGF1 = -1.5427

                                                           RATES
  1 R1      =  .13299E-08     2 R2      =  0.            3 R3      = -.95185E-08    4 R4      =  0.             5 R5      = -.78564E-07
  6 R6      =  0.             7 R7      =  0.            8 R8      = -.30914E-18    9 R9      =  0.            10 R10     =  .12287E-08
 11 R11     =  0.            12 R12     =  0.           13 R13     =  0.            14 R14     =  0.            15 R15     =  .56343E-13
 16 R16     =  479.93        17 R17     =  0.           18 R18     =  0.            19 R19     =  .49022E-09    20 R20     =  .36911E-19
 21 R21     = -.23372E-08    22 R22     = -.93098E-08   23 R23     = -.50341E-05    24 R24     =  0.            25 R25     =  0.

                                                          VARIABLES
  1 UO AV   =  823.50         2 VO AV   =  0.            3 WO AV   =  32.722         4 PO AV   =  0.             5 QO AV   = -.30914E-18
  5 PO AV   =  0.             7 IO2AV   =  3.0000        8 OA2AV   =  0.             9 RH2AV   =  0.            10 CALAV   =  .99933
 11 SALAV   =  .35712E-31    12 AL AV   =  2.2590       13 ALPAV   =  .15513        14 VT AV   =  830.15        15 PF AV   =  0.
 16 WP AV   =  2.2475        17 UP AV   =  .77410E-03   18 FJ AV   = -1.2692        19 EV AV   =  0.            20 FW AV   =  32.149
 21 SIGAV   =  .57333        22 QC AV   =  511.30       23 QS AV   =  .13103E+06    24 MACAV   =  .90059        25 X2 SAF2 = -1.5427
 26 FX2LO   =  748.39        27 FZ2LO   = -16934.       28 TY2LO   = -.68597E-04    29 UD LO   =  .13299E-08    30 WD LO   = -.95185E-08
 31 MA2LO   =  591.50        32 XP2LO   =  0.           33 XD SD   =  830.15        34 YD SD   =  0.            35 PD SD   =  0.
 35 QD SD   = -.79654E-07    37 RD SD   =  0.           38 X2 MAEN =  0.            39 X4 MC71 = -.16624E-03   40 X2 MAPL =  3.2410
 41 X2 LFPL =  0.            42 X2 SAPL =  0.           43 X4 MCPL =  14.140        44 X2 MAET =  0.            45 X2 FUE1 =  0.
 46 X2 MAE1 = -.20662E-03    47 X2 FUE2 = -4.0000       48 X2 SAE2 = -.10331E-03    49 X2 SAE3 =  2.2590       50 X2 LEF2 = -.36911E-19
 51 X2 FJE3 =  .55473        52 X4 MCE1 = -18.141       53 X4 MCE2 = -12.741        54 X2 SAE4 = -.12741E-04   55 X4 MCE3 = -.85170E-04
 56 X2 TIE5 = -.131-1E-04    57 X2 LEF3 = -.85170E-04   58 X4 MCE4 = -.78330E-09    59 X2 FUE4 =  2.3768       60 X2 MAF2 =  .52572
 61 X2 FJE5 =  .50000        62 X4 MCE6 =  1.1295       63 X2 MAE3 = -1.5427        64 X2 FUE6 =  0.           65 X4 MCES = -.18519E-09
 66 X2 MAE4 = -1.5427        67 X2 MAF3 =  0.           68 X2 SAF1 =  0.
```

Figure 7. EASY Program Steady State Output
(States, Rates, & Variables)

PARAMETERS

1 IP1AV =	3.0000	2 VS AV =	829.50	3 ALSAV =	2.1039	4 S AV =	301.00	5 UW AV =	0.
6 VW AV =	0.	7 WW AV =	0.	8 PA AV =	0.	9 QW1AV =	0.	10 RW1AV =	0.
11 C1 SAF2 =	1.0000	12 C2 SAF2 =	.10000E-05	13 C3 SAF2 =	25.000	14 C4 SAF2 =	1.0000	15 C5 SAF2 =	.10000E-05
16 C6 SAF2 =	-25.000	17 XQ LO =	-.25000E-01	18 XA LO =	-.20100E-01	19 XU LO =	-.74600E-01	20 XQFLO =	.52500E-01
21 ZQ LO =	-.14430	22 ZA LO =	-4.8159	23 ZADLO =	.66000	24 ZQ LO =	-2.5965	25 ZU LO =	-.12150
26 ZQFLO =	-.43950	27 MQ LO =	-.18200E-01	28 MALLO =	.94300E-01	29 MADLO =	-.35500	30 MU LO =	-2.3187
31 MW LO =	-.14500E-01	32 MQFLO =	-.66690	33 MA1LO =	590.50	34 C LO =	11.320	35 XP1LO =	0.
36 EZ1LO =	0.	37 TY1LO =	0.	38 VO SO =	0.	39 TX SO =	0.	40 TZ SO =	0.
41 IXXSO =	9007.5	42 IYYSO =	49956.	43 IZZSO =	56770.	44 IXZSO =	199.00	45 C1 MAEN =	-1.0000
46 C2 MAEN =	829.50	47 ZC LGEN =	10.000	48 PO LGEN =	0.	49 X3 MCZ1 =	0.	50 C1 MCZ1 =	.31100E-01
51 C2 MCZ1 =	-.31100E-01	52 C3 MCZ1 =	0.	53 C4 MCZ1 =	-1.0000	54 C1 MAPL =	-1.0000	55 C2 MAPL =	5.5000
56 GAILFPL =	349.04	57 ZO LFPL =	0.	58 PO LFPL =	20.000	59 GAILAPL =	2.1815	60 TC LAPL =	.50000E-01
61 C1 SAPL =	.10000E-05	62 C2 SAPL =	1.0000	63 C3 SAPL =	0.	64 C4 SAPL =	.10000E-05	65 C5 SAPL =	1.0000
66 C6 SAPL =	0.	67 ZO TFPL =	1.0000	68 Z1 TFPL =	0.	69 PO TFPL =	1.0000	70 P1 TFPL =	1.0000
71 C1 MCPL =	1.0000	72 C2 MCPL =	1.0000	73 C3 MCPL =	1.0000	74 C4 MCPL =	0.	75 ZO LGPL =	.25000
76 PO LGPL =	0.	77 C1 MAET =	-1.0000	78 C2 MAET =	20000.	79 ZO LGET =	.10000	80 PO LGET =	0.
81 AN FUE1 =	-1.0000	82 C1 MAE1 =	1.0000	83 AN FUE2 =	-1.0000	84 C1 SAE2 =	.50000	85 C2 SAE2 =	.10000E-05
86 C3 SAE2 =	6.0000	87 C4 SAE2 =	.50000	88 C5 SAE2 =	.10000E-05	89 ZO LGE2 =	8.3000	90 PO LGE2 =	8.3000
91 C1 SAE3 =	1.0000	92 C2 SAE3 =	.10000E-05	93 C3 SAE3 =	30.000	94 C4 SAE3 =	1.0000	95 C5 SAE3 =	.10000E-05
96 C6 SAE3 =	-5.0000	97 ZO LGE1 =	10.000	98 PO LGE1 =	10.000	99 GAILFE2 =	1.0000	100 ZO LFE2 =	0.
101 PO LFE2 =	1.0000	102 AN FUE3 =	-1.0000	103 X3 MCE1 =	-20.400	104 C2 MCE1 =	1.0000	105 C3 MCE1 =	1.0000
106 C4 MCE1 =	0.	107 X3 MCE2 =	-15.000	108 C2 MCE2 =	1.0000	109 C3 MCE2 =	1.0000	110 C4 MCE2 =	0.
111 C1 SAE4 =	1.0000	112 C2 SAE4 =	.10000E-05	113 C3 SAE4 =	.10000E+37	114 C4 SAE4 =	1.0000	115 C5 SAE4 =	.10000E-05
116 C6 SAE4 =	0.	117 C1 MCE3 =	.16100	118 C2 MCE3 =	.16000	119 C3 MCE3 =	.50000	120 C4 MCE3 =	0.
121 C1 SAE5 =	.50000	122 C2 SAE5 =	.10000E-05	123 C3 SAE5 =	.10000E+37	124 C4 SAE5 =	1.0000	125 C5 SAE5 =	.10000E-05
126 C6 SAE5 =	0.	127 GAILFE3 =	3.0000	128 ZO LFE3 =	4.0000	129 PO LFE3 =	12.000	130 C1 MCE4 =	1.0000
131 C2 MCE4 =	1.0000	132 C3 MCE4 =	-1.0000	133 C4 MCE4 =	0.	134 AN FUE4 =	-1.0000	135 C1 MAE2 =	.10282E-02
136 C2 MAE2 =	0.	137 AN FUE5 =	-1.0000	138 X3 MCE6 =	0.	139 C3 MCE6 =	0.	140 C4 MCE6 =	0.
141 C1 MAE3 =	1.0000	142 AN FUE6 =	1.0000	143 X3 MCE5 =	0.	144 C2 MCE5 =	-5.0000	145 C3 MCE5 =	0.
146 C4 MCE5 =	0.	147 GKIITE1 =	5.0000	148 GKLITE1 =	2000.0	149 AMAITE1 =	25.000	150 AMIITE1 =	-25.000
151 C1 MAE4 =	1.0000	152 ZO TFE1 =	2704.0	153 Z1 TFE1 =	0.	154 PO TFE1 =	2704.0	155 P1 TFE1 =	72.900
156 C1 MAE5 =	-1.0000	157 C1 SAF1 =	20.000	158 C2 SAF1 =	.10000E-05	159 C3 SAF1 =	3.0000	160 C4 SAF1 =	20.000
161 C5 SAF1 =	.10000E-05	162 C6 SAF1 =	-3.0000	163 ZO LGF1 =	1.0000	164 PO LGF1 =	0.		

Figure 8. EASY Program Steady State Output (Parameters)

value of each state is given for the trim condition. Output variables are shown that correspond to the component outputs of Figure 3, p. 21. The parameter values for each standard component are listed in Figure 8. To achieve the desired trim condition, the pilot model was isolated from the aircraft and flight control models. Program commands were then used to generate steady state iterations. In doing this, the dynamic equations of motion were perturbed after each iteration step until the trim condition specified by altitude and airspeed initial conditions was achieved. The state variables indicate the quantities that result from integrating the set of first order differential equations that comprise the dynamic system model.

Once that an operating point was established, all initial conditions of integrator states were transferred to the system through a program command. With the two additional trim integrators for altitude and airspeed turned off (i.e. integrator states "frozen") verification of the F-16 aircraft characteristics continued.

The model developed by the EASY program which includes the F-16 aircraft characteristics, longitudinal flight control system, and longitudinal pilot model, is described by the simplified block diagram of Figure 9.

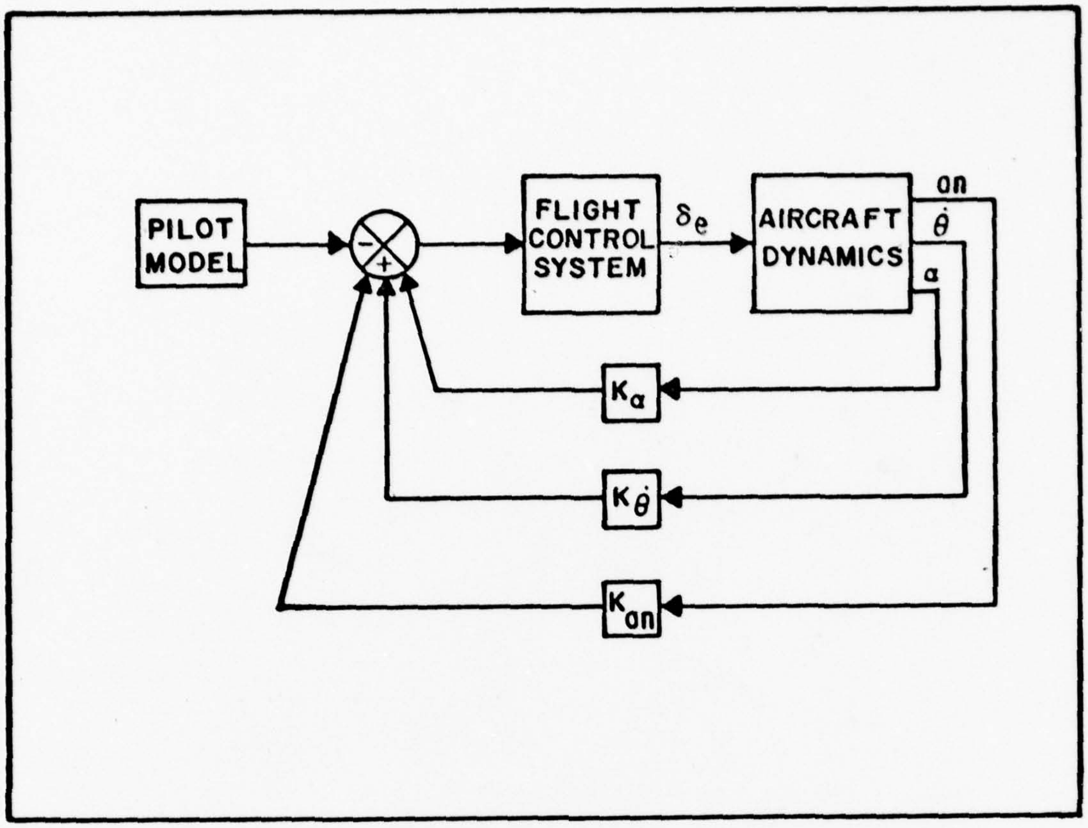


Figure 9. EASY Model Simplified Diagram

By selecting summing junction parameters to open all flight control system feedback loops and freezing integrators in the pilot model and flight control system, transfer functions of the aerodynamic variables for elevator deflection could be obtained. With the above provisions completed through program commands, the total system was effectively reduced to the aircraft dynamic model shown in the simplified diagram of Figure 10. The basic aircraft dynamics of the Griffin program were compared with EASY Analysis program calculations. A comparison of the computer generated

Figure 10. EASY Transfer Function Diagram

characteristic equation roots with the Griffin program data is listed in Table IV.

Table IV
Roots of the F-16 Characteristic Equation
(Longitudinal Dynamics)

	Griffin Data	Easy Analysis Data
Short Period	+.8282 -2.745	+.8168 -2.746
Phugoid	-.0262 + j.1528 -.0262 - j.1528	-.0288 + j.1245 -.0288 - j.1245

At the flight condition selected for this simulation, flight data indicates that the basic F-16 airframe is unstable. The relaxed static stability is demonstrated by the real positive eigenvalue. As shown above, the short period mode of the F-16 aircraft has two real roots. One of these in the right half plane brings about the airframe instability. The phugoid mode is indicated by the pair of dominant complex poles near the origin.

Although the numerator characteristics were calculated in the EASY Analysis program, it was not possible to have these printed to enable a comparison with the numerator dynamics of the Griffin program. However, transfer functions were calculated using the EASY program commands and the computer generated Bode diagrams were used to validate the numerator dynamics. From the Griffin program data, the following analytical transfer functions of angle of attack per elevator deflection and pitch rate per elevator deflection were derived:

$$\frac{\alpha}{\delta_e} = \frac{-.1329(s + 148.5)(s^2 + .0177s + .0040)}{(s - .8282)(s + 2.745)(s^2 + .0524s + .0240)} \quad (3)$$

$$\frac{\dot{\theta}}{\delta_e} = \frac{-19.72s(s + .01741)(s + 1.312)}{(s - .8282)(s + 2.745)(s^2 + .0524s + .0240)} \quad (4)$$

The AFIT frequency response program (FREQR) was used to generate plots of the above transfer functions. Figure 11 shows the angle of attack per elevator deflection transfer function of the Griffin program data. This compares very favorably with the computer generated EASY magnitude and phase plots of alpha per delta elevator shown in Figures 12 and 13, respectively. A similar comparison of the pitch rate per delta elevator transfer functions was made and the results are shown in Figures 14-16. The above comparisons clearly serve to substantiate the validation of the F-16 aircraft model developed.

As mentioned earlier, the F-16 basic aircraft is unstable at the flight condition selected for this simulation. This instability is evidence of a positive static margin which is defined as the ratio of C_{m_α} to C_{L_α}. The instability of the basic F-16 airframe was demonstrated by using the simulation program commands of the EASY Analysis program. With all integrator states in the flight control system frozen and also insuring that all feedback channels of the flight control system were opened, a time simulation was run to show the dynamics of the aircraft alone with no flight control system. An initial condition equivalent to a

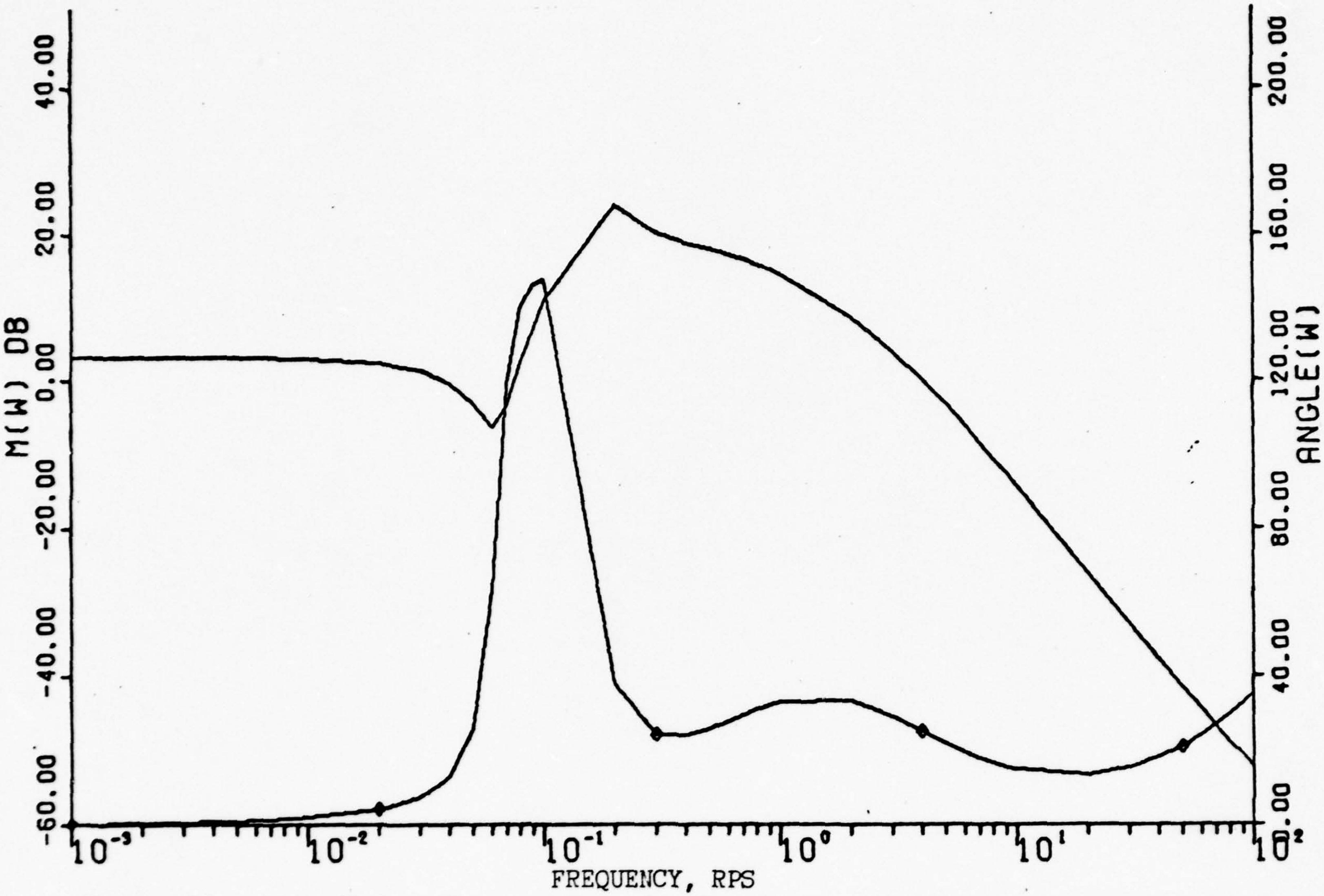


Figure 11. Alpha/Delta Elevator Transfer Function of the Griffin Program Data

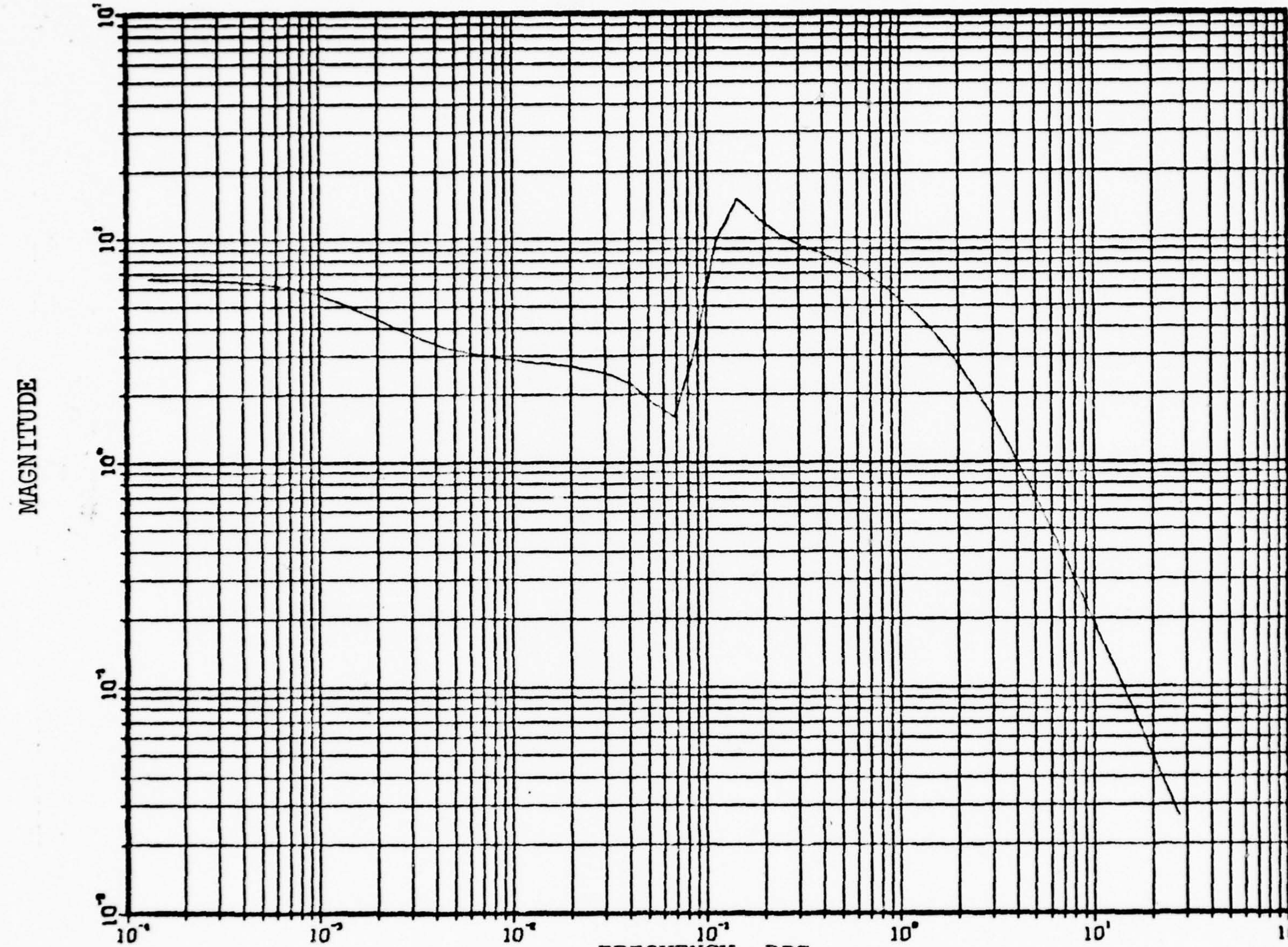


Figure 12. EASY Generated Magnitude Plot of Alpha/Delta Elevator Transfer Function

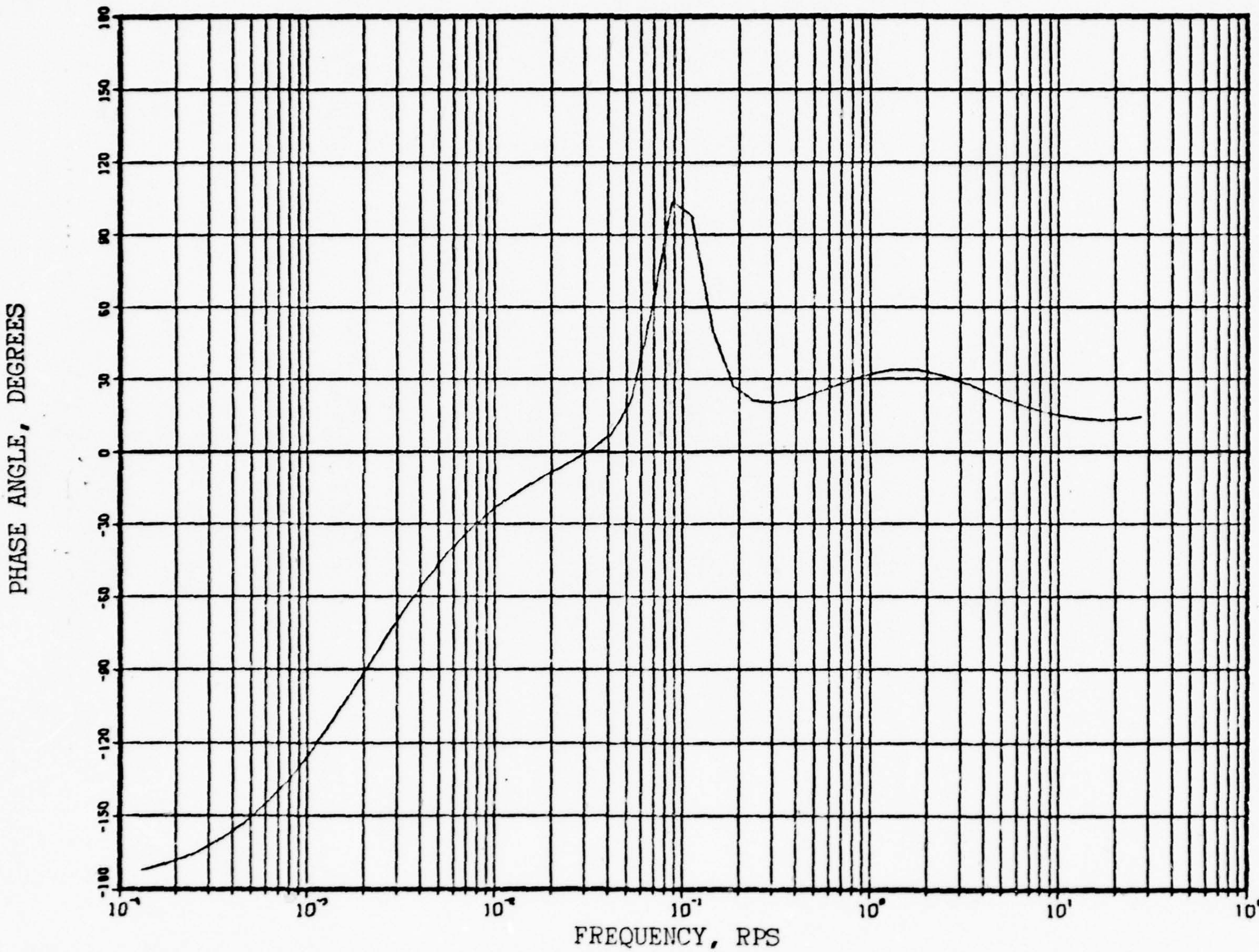


Figure 13. EASY Generated Phase Plot of Alpha/Delta Elevator Transfer Function

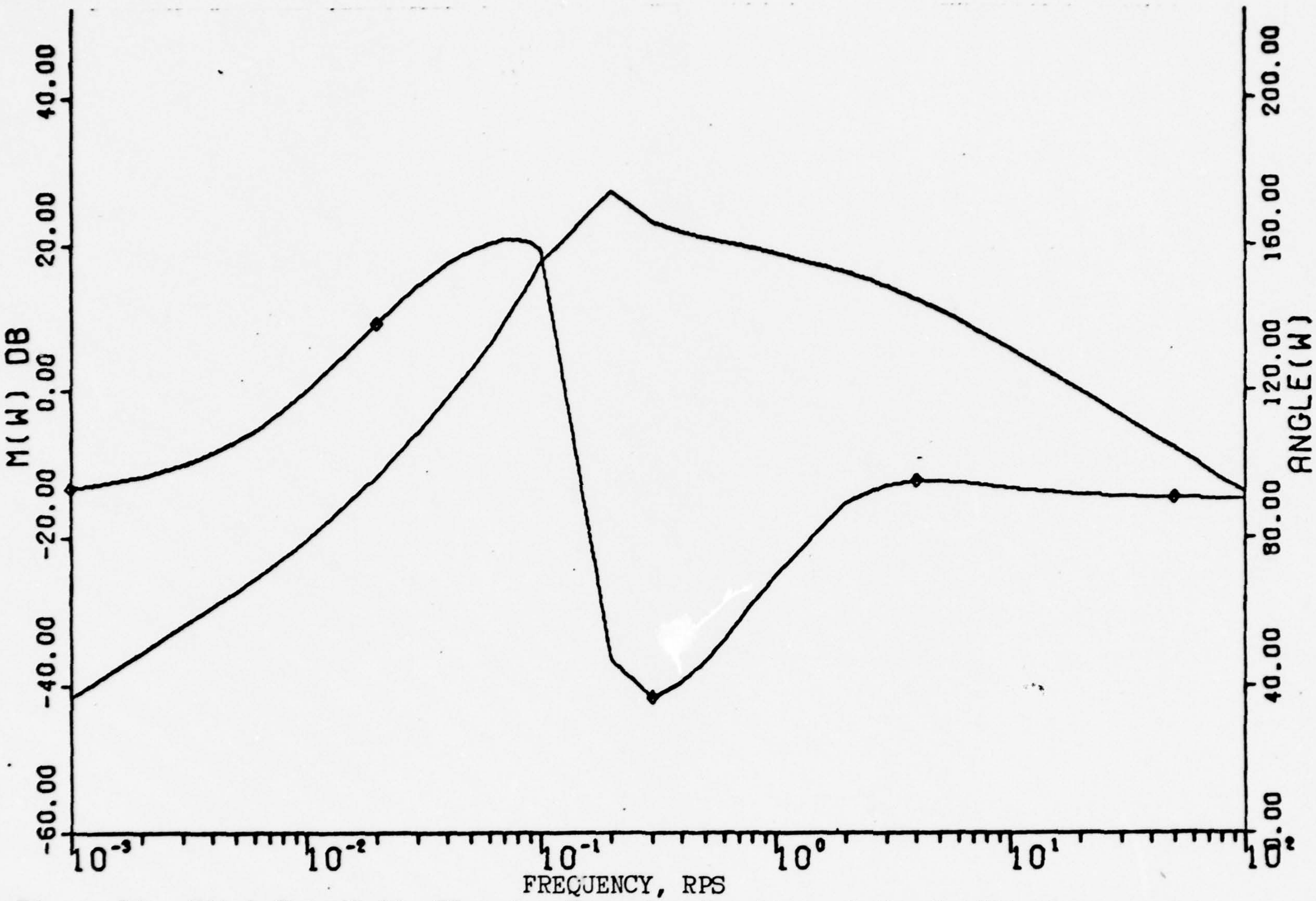


Figure 14. Pitch Rate/Delta Elevator Transfer Function of the Griffin Program Data

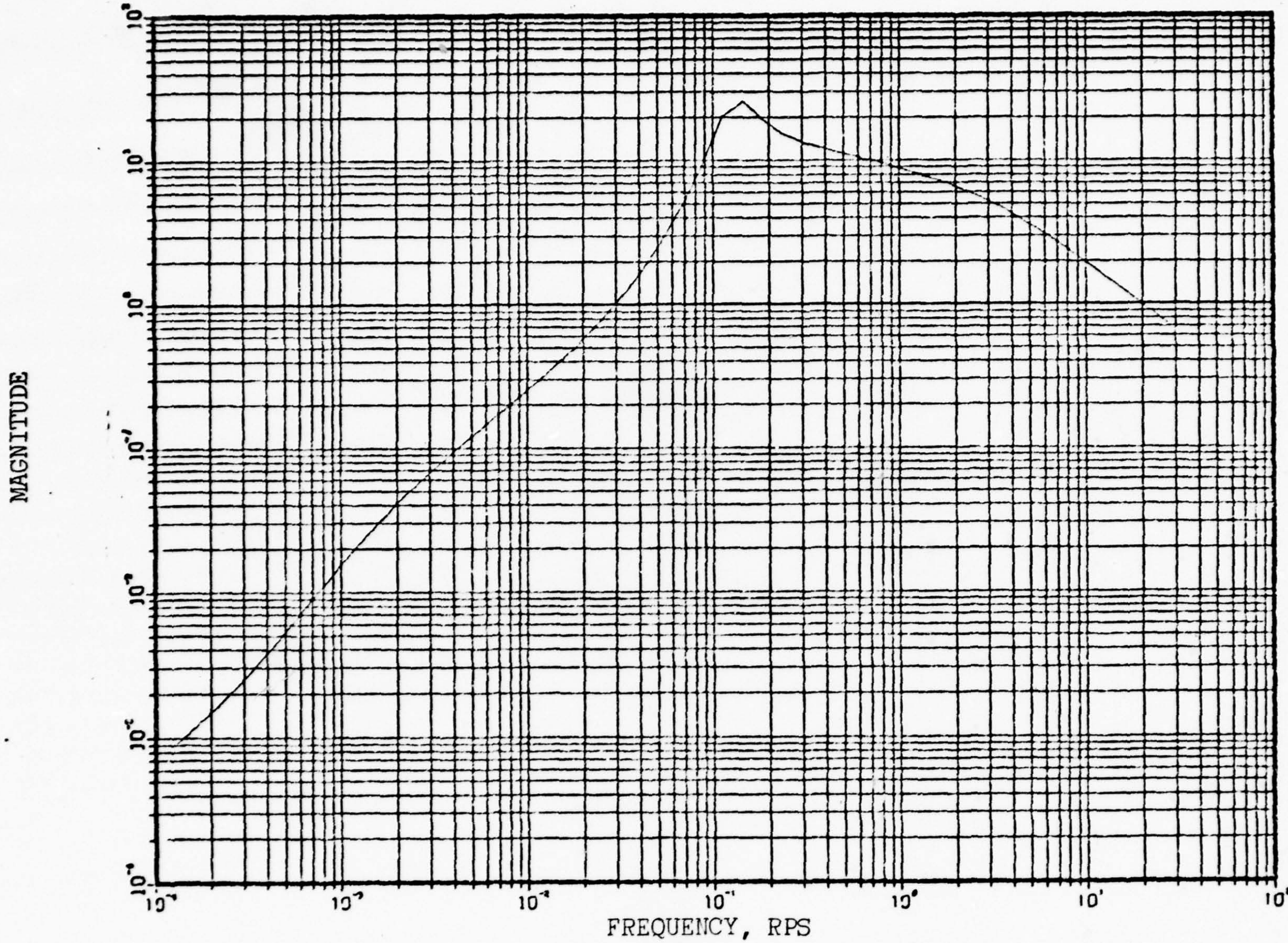


Figure 15. EASY Generated Magnitude Plot of Pitch Rate/Delta Elevator Transfer Function

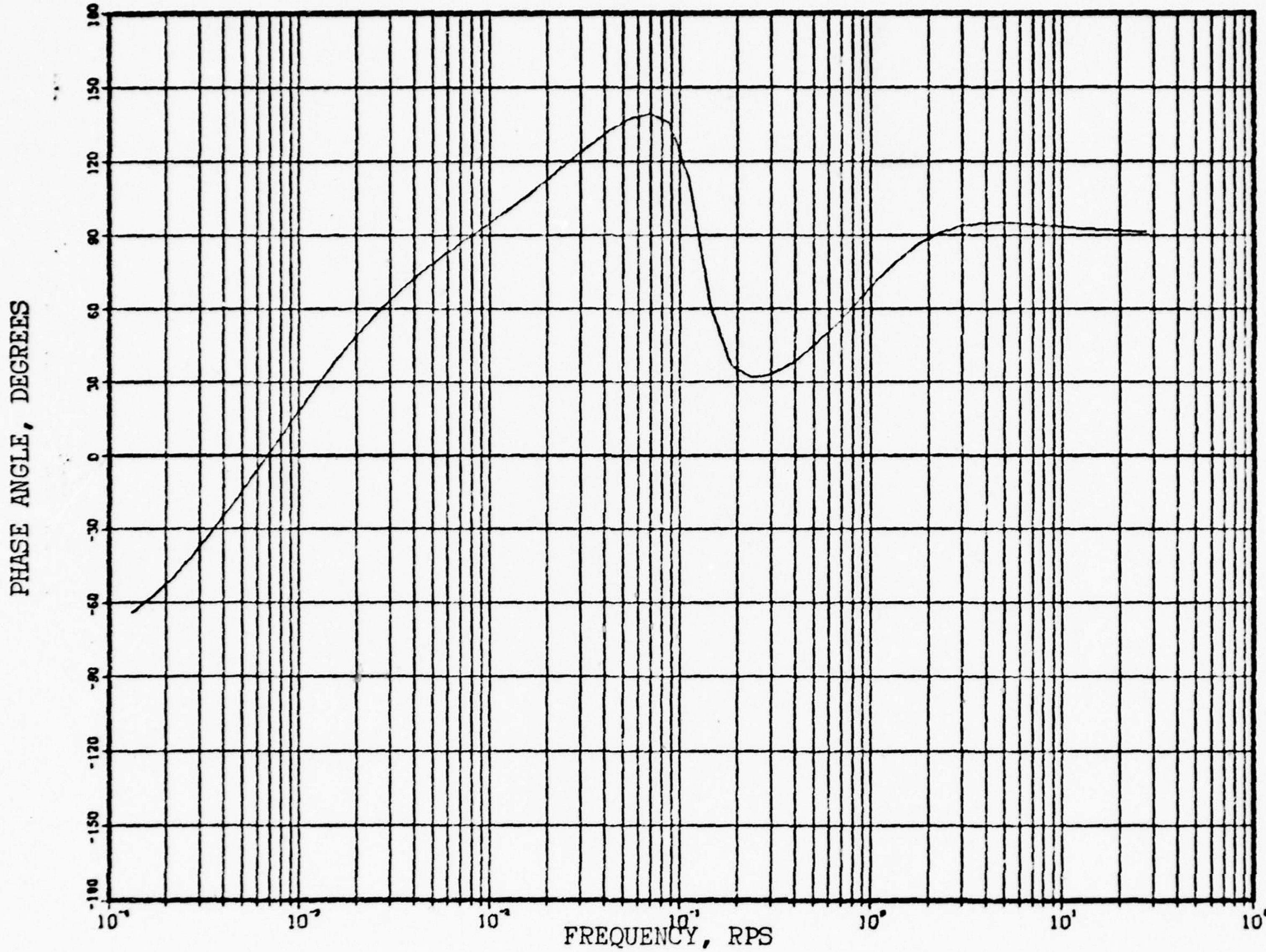


Figure 16. EASY Generated Phase Plot of Pitch Rate/Delta Elevator Transfer Function

one degree angle of attack pertubation was input into the aircraft system and the resulting dynamic response is shown in Figure 17. It can be seen that the aircraft does not return to its equilibrium trim condition with even a slight angle of attack pertubation. The display shows the angle of attack, pitch angle, and altitude increasing while the aircraft airspeed decreases. This demonstrates the necessity of maintaining the flight control system to harness the inherent aerodynamic instability.

EASY System Analysis

The EASY Analysis program was further used to examine the present F-16 flight control system. Investigations continued to establish a measure of the system effectiveness. The present F-16 flight control system, which is predominantly normal acceleration feedback, was evaluated in terms of tracking performance. As shown in Figure 18, a closed loop system was established by having the pilot model respond to an angular error input. The command angle was the difference between the aircraft pitch angle and a prescribed reference angle. By establishing this pseudo tracking task, a first order approximation of the director sight implementation was achieved. The pilot model parameters were selected to be consistent with the director sight characteristics.

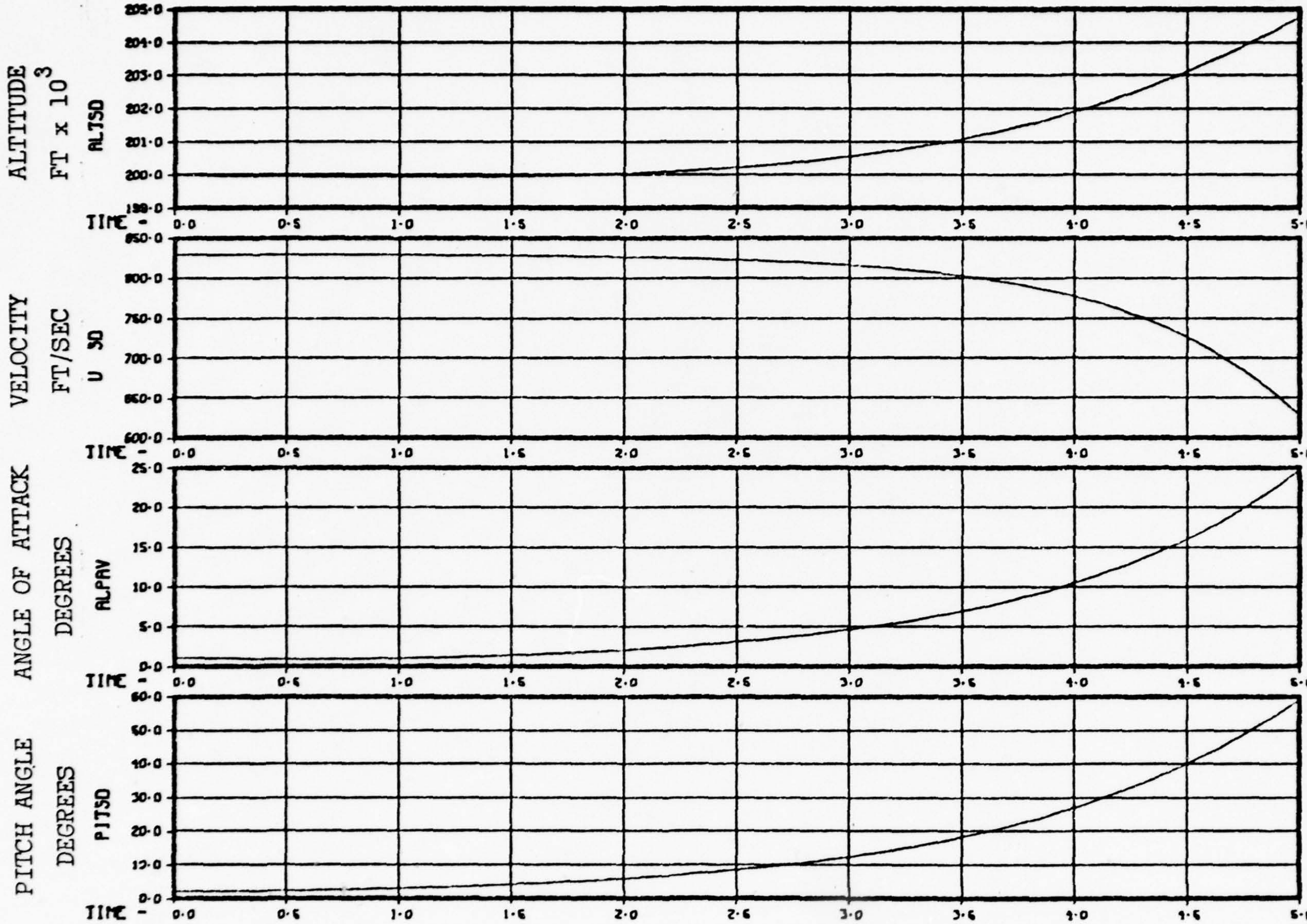


Figure 17. F-16 Aircraft Response to 1° Angle-of-Attack Pertubation

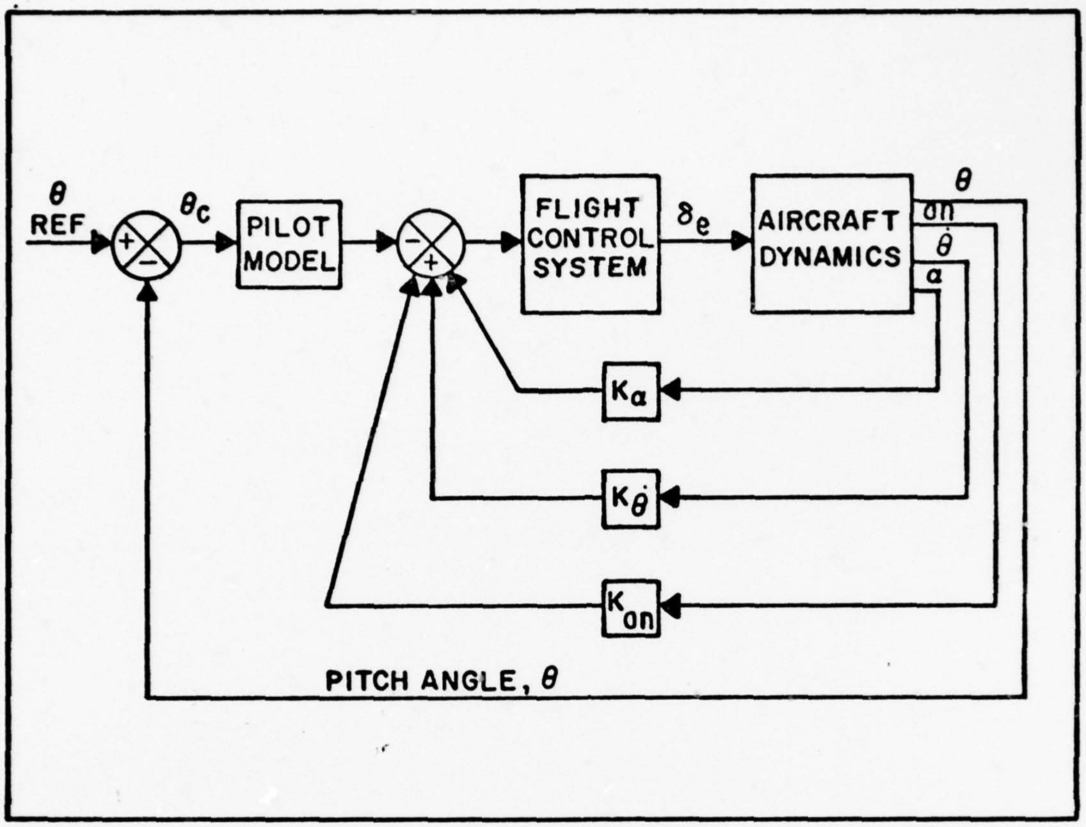


Figure 18. EASY Closed Loop System Schematic Diagram

Control of the pitch feedback summing junction of Figure 18 was gained through EASY program commands and by selecting the appropriate parameter, the θ/θ_{REF} transfer function was established for either closed or open loop analysis.

The magnitude and phase Bode plots of the normal acceleration configuration for the closed loop are shown in Figures 19 and 20, respectively. The magnitude plot indicates the transfer function is well behaved and the maximum peak, M_m, of 1.43 occurs at a frequency of .356 radians per second. As seen in Figure 19, the system bandwidth is

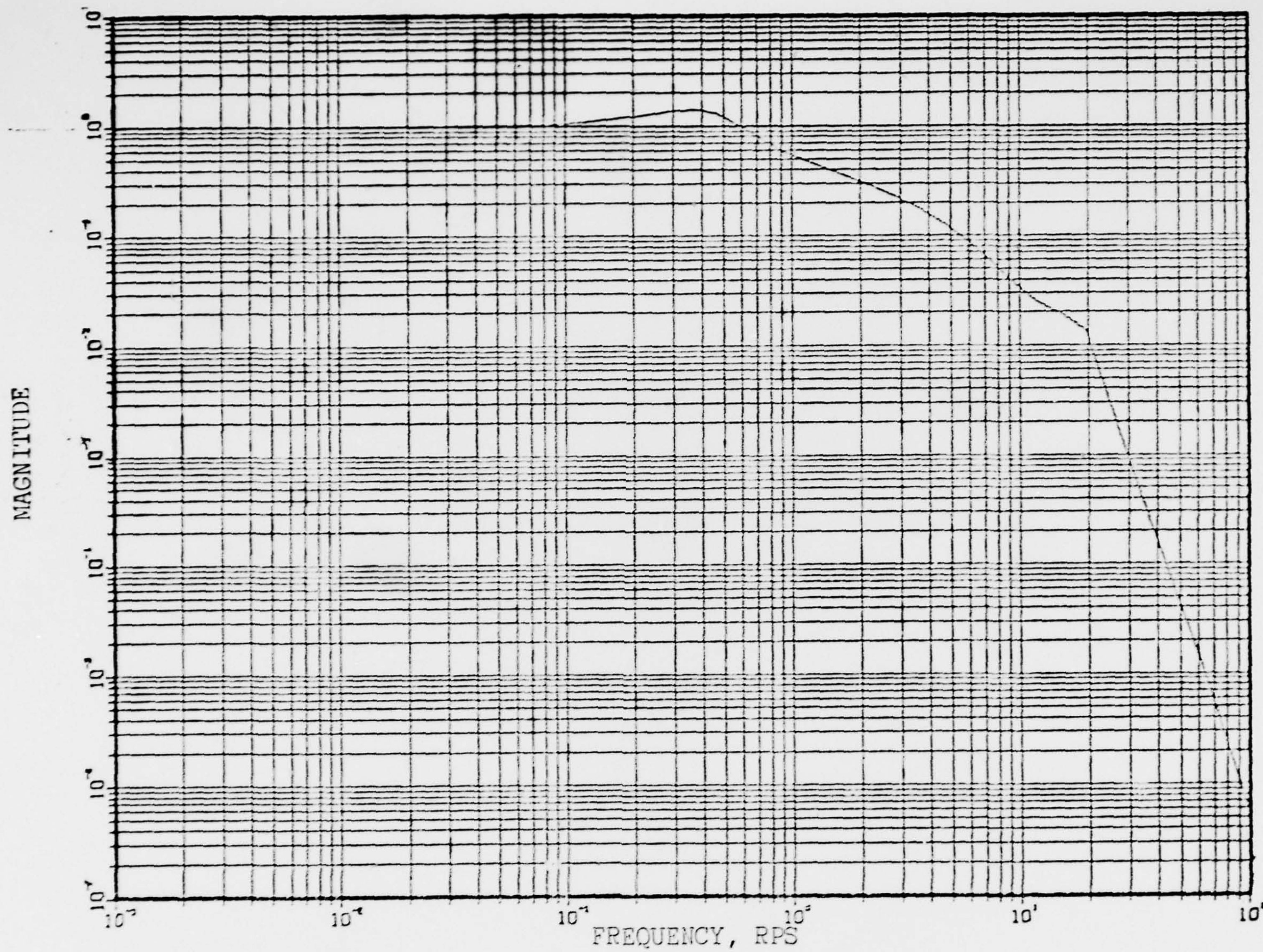


Figure 19. Normal Acceleration Configuration Closed Loop Bode Magnitude Plot

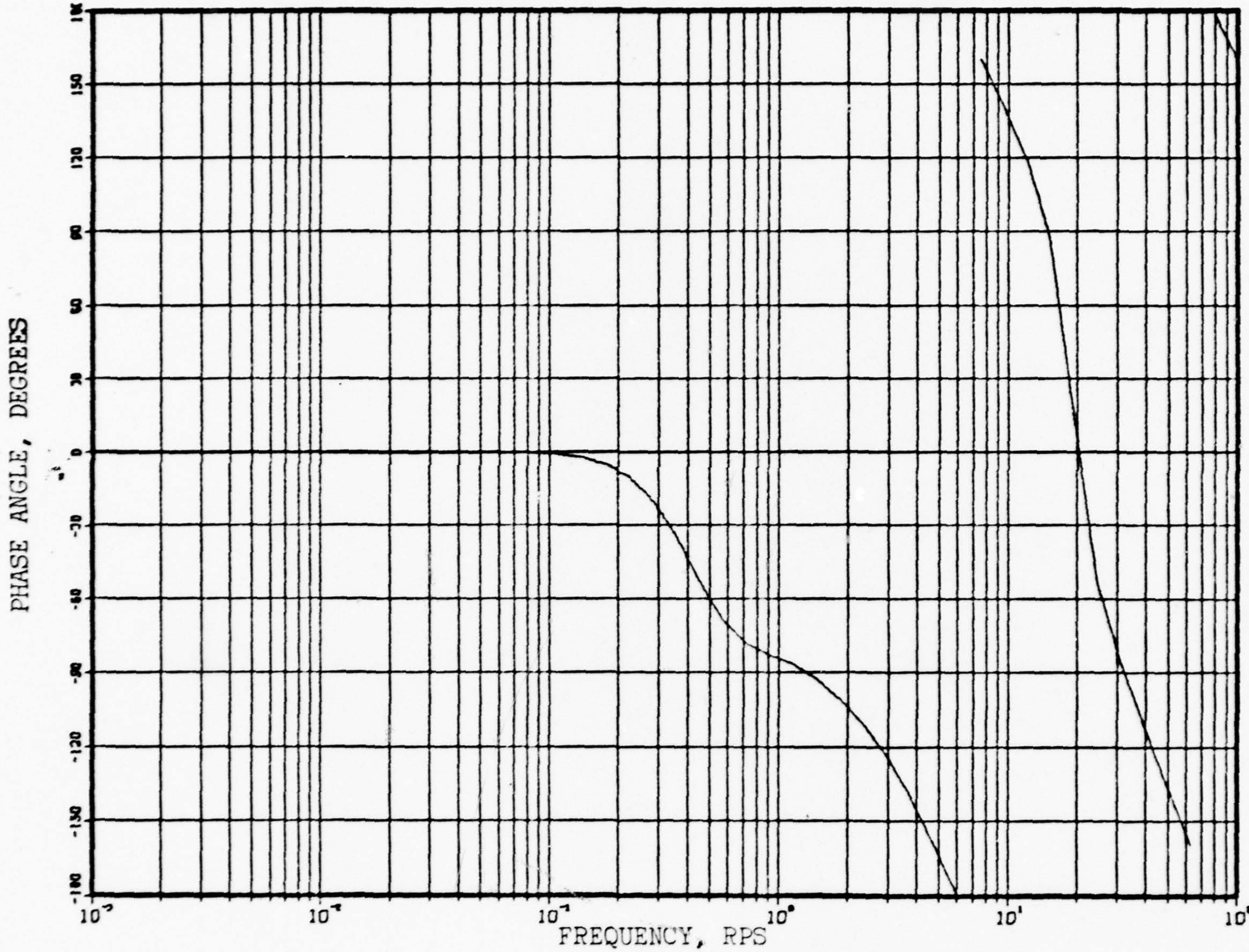


Figure 20. Normal Acceleration Configuration Closed Loop Bode Phase Plot

approximately .7 radians per second. Next the open loop transfer function was investigated by opening the feedback loop at the summing junction. The Bode plots of the open loop normal acceleration transfer function are shown in Figures 21 and 22. As seen in Figure 21, the gain crossover occurs at approximately .5 radians per second and the phase margin (Figure 22) is 52 degrees. To evaluate the effectiveness of the pseudo tracking task of the pilot model, a time simulation was run to show the system response to a step input of 5.5 degrees pitch. The time response to this step input is shown in Figure 23.

The EASY Analysis program was also used to investigate the merits of a pitch rate command system. As discussed in Chapter I, the C* design concept for the F-16 flight control system employs a predominantly normal acceleration command system at cruise airspeeds. This is evidenced by the larger weighting of normal acceleration to pitch rate in the feedback channels of the longitudinal control system. For air combat tracking tasks, pitch rate feedback could be made predominant by adjusting this weighting relationship. One possible implementation would be the total weighting of pitch rate as the command signal with the elimination of normal acceleration feedback.

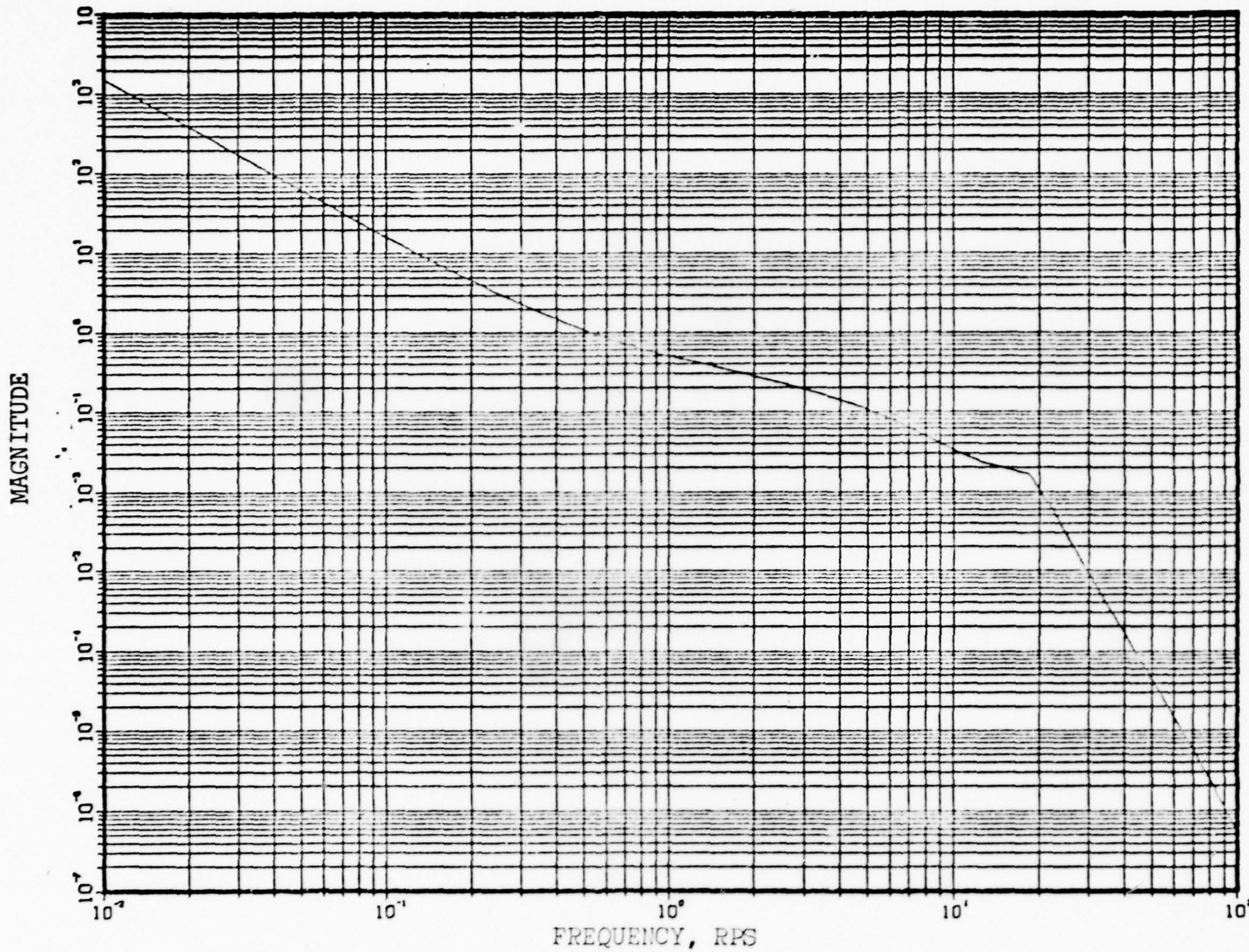


Figure 21. Normal Acceleration Configuration Open Loop Bode Magnitude Plot

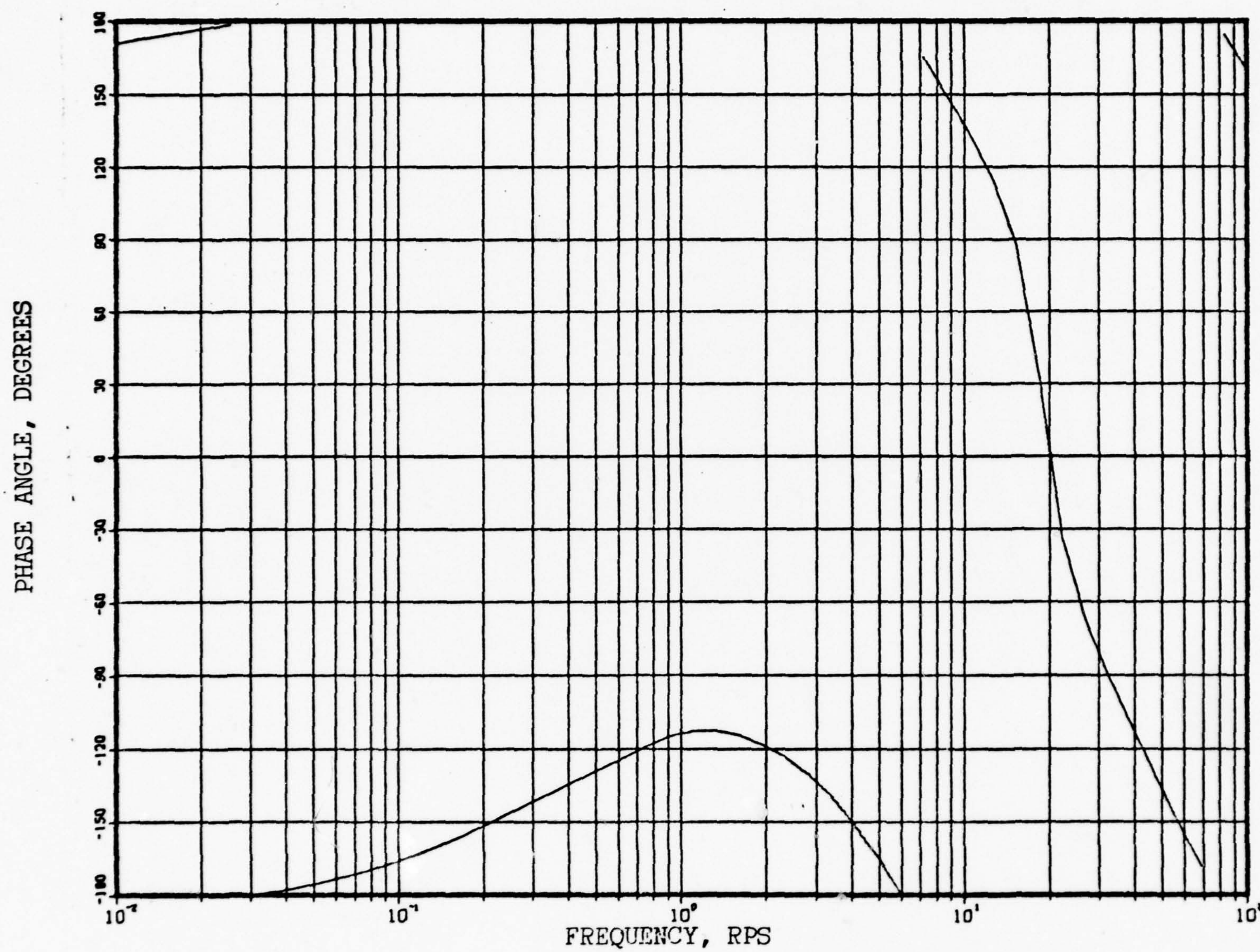


Figure 22. Normal Acceleration Configuration Open Loop Bode Phase Plot

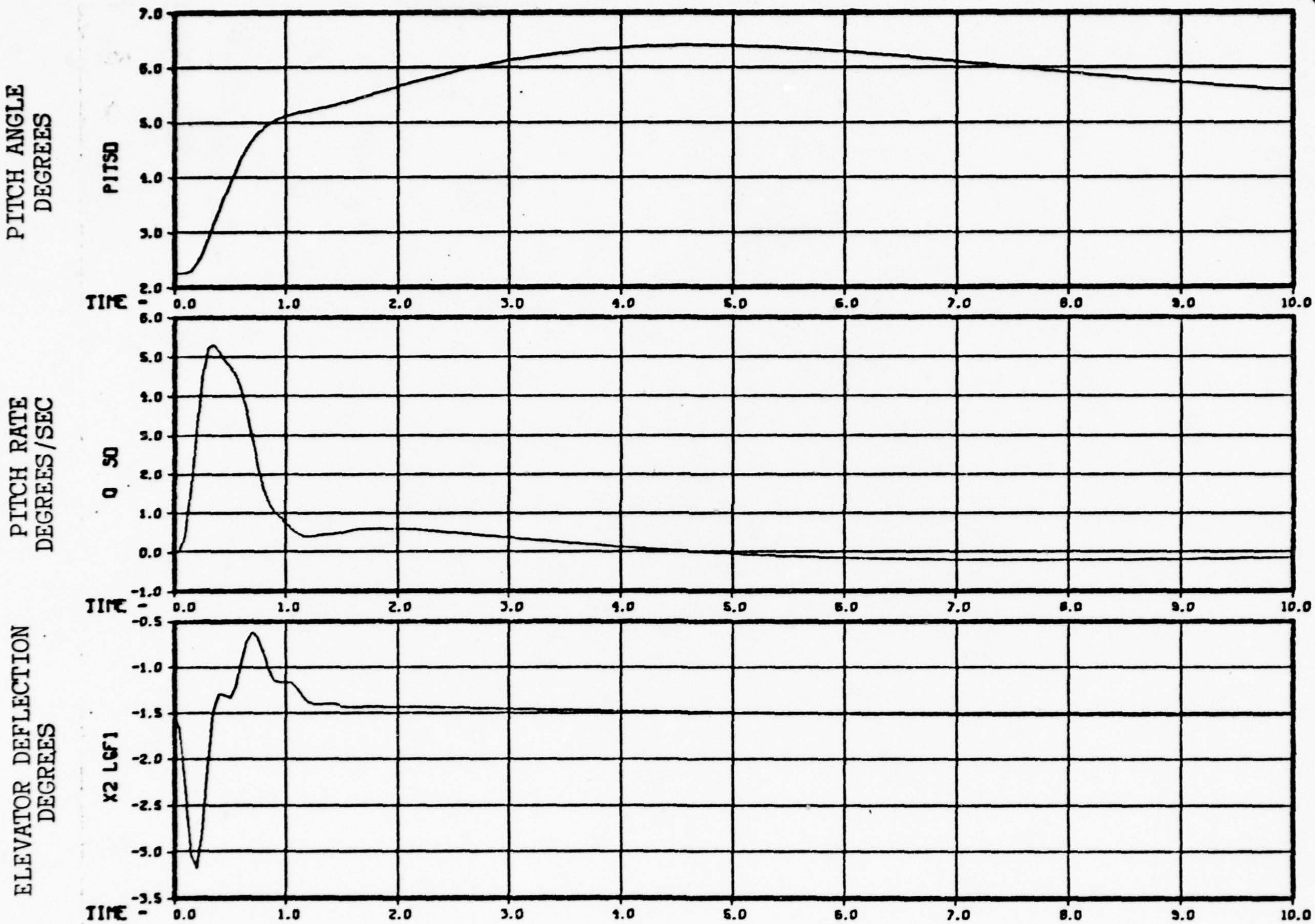


Figure 23. Normal Acceleration Configuration Time Response to Step Input Tracking Error

This method was attempted and the EASY program was modified to incorporate a pitch rate control system. As shown in the model diagram of Figure 3, p. 21, the normal acceleration channel was eliminated as a feedback signal by setting the gain parameter equal to zero. The angle of attack feedback channel was maintained to aid stability. Because the primary feedback variable was to be pitch rate, the washout filter in the pitch rate channel was removed. The lead-lag transfer function 2(s + 15)/(s + 30) was implemented as the new LEE3 component to increase the system bandwidth. Additionally, a root locus analysis was used to determine that a pitch rate feedback system gain of .3 would provide an overall system damping factor of approximately .7. An improved system performance was indicated by evaluating the open and closed loop transfer functions. The system response with the pitch rate feedback system is indicated in Figures 24, 25, 26, and 27. The response of the pitch rate system is similar to that of the normal acceleration, however, certain points are noteworthy. For example, the maximum peak of the closed loop transfer function, shown in Figure 24, occurs at the same frequency as in the normal acceleration system, but reduced to 1.28. As noted also in Figure 24, the effective

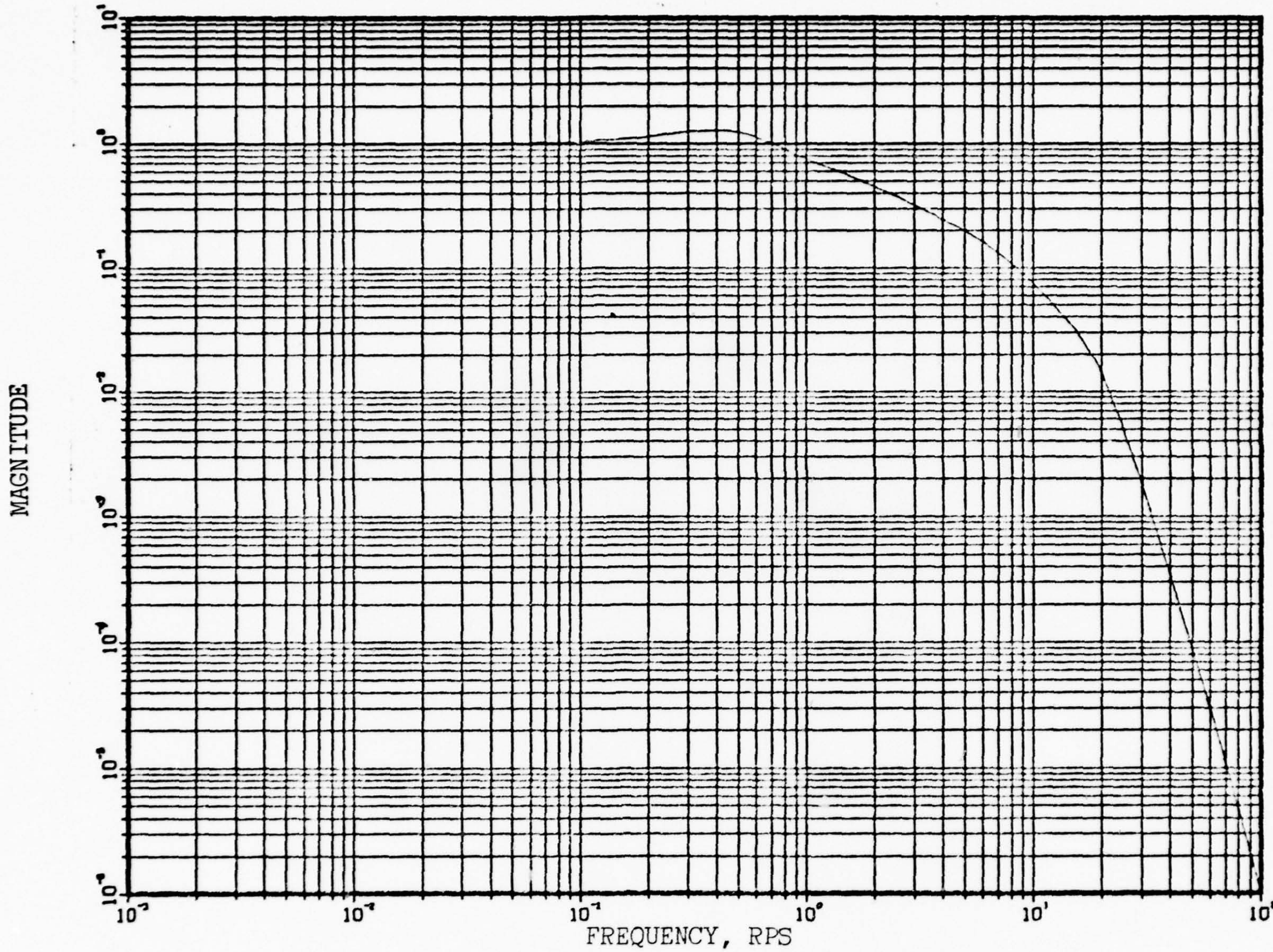


Figure 24. Pitch Rate Configuration Closed Loop Bode Magnitude Plot

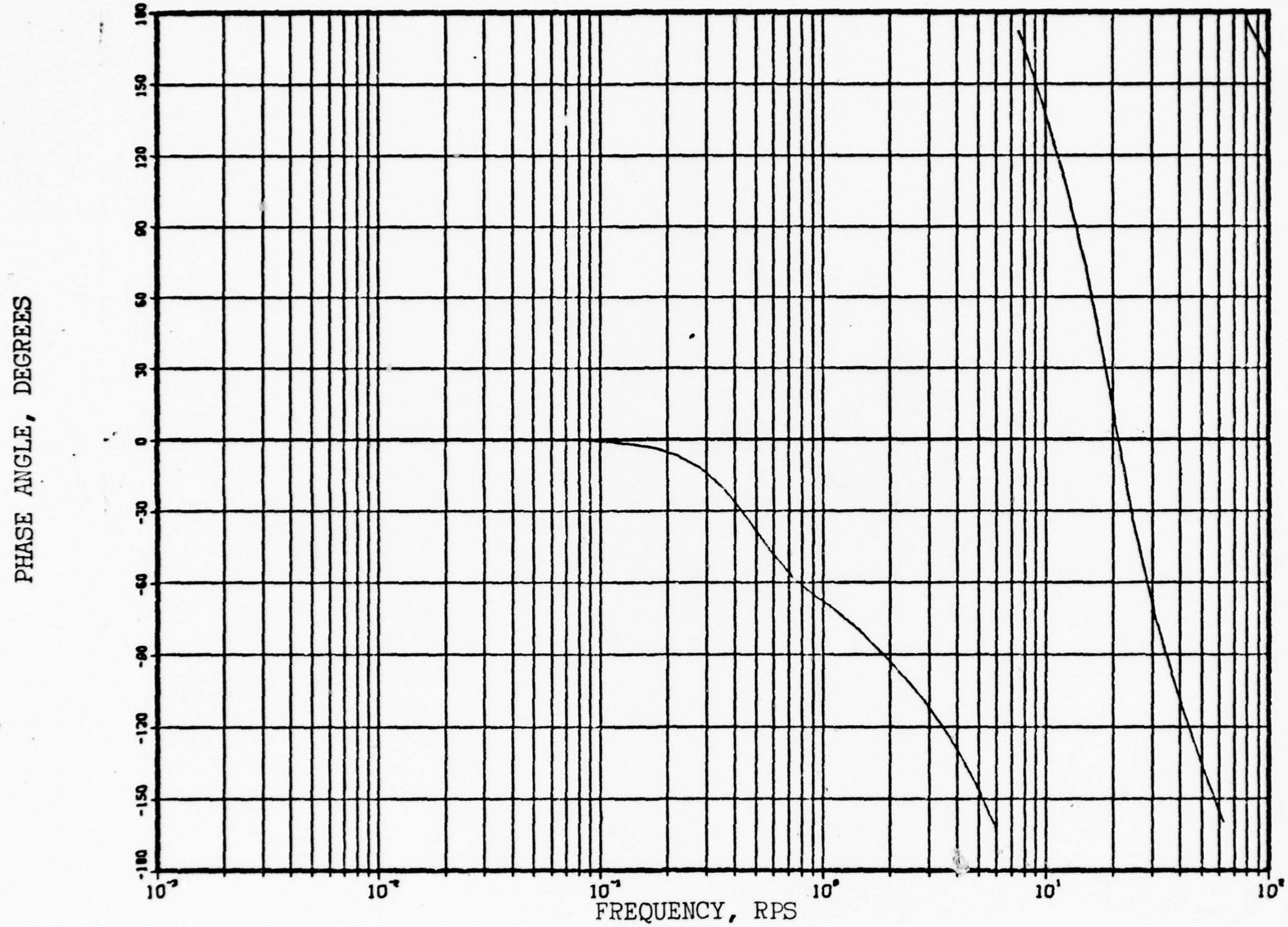


Figure 25. Pitch Rate Configuration Closed Loop Bode Phase Plot

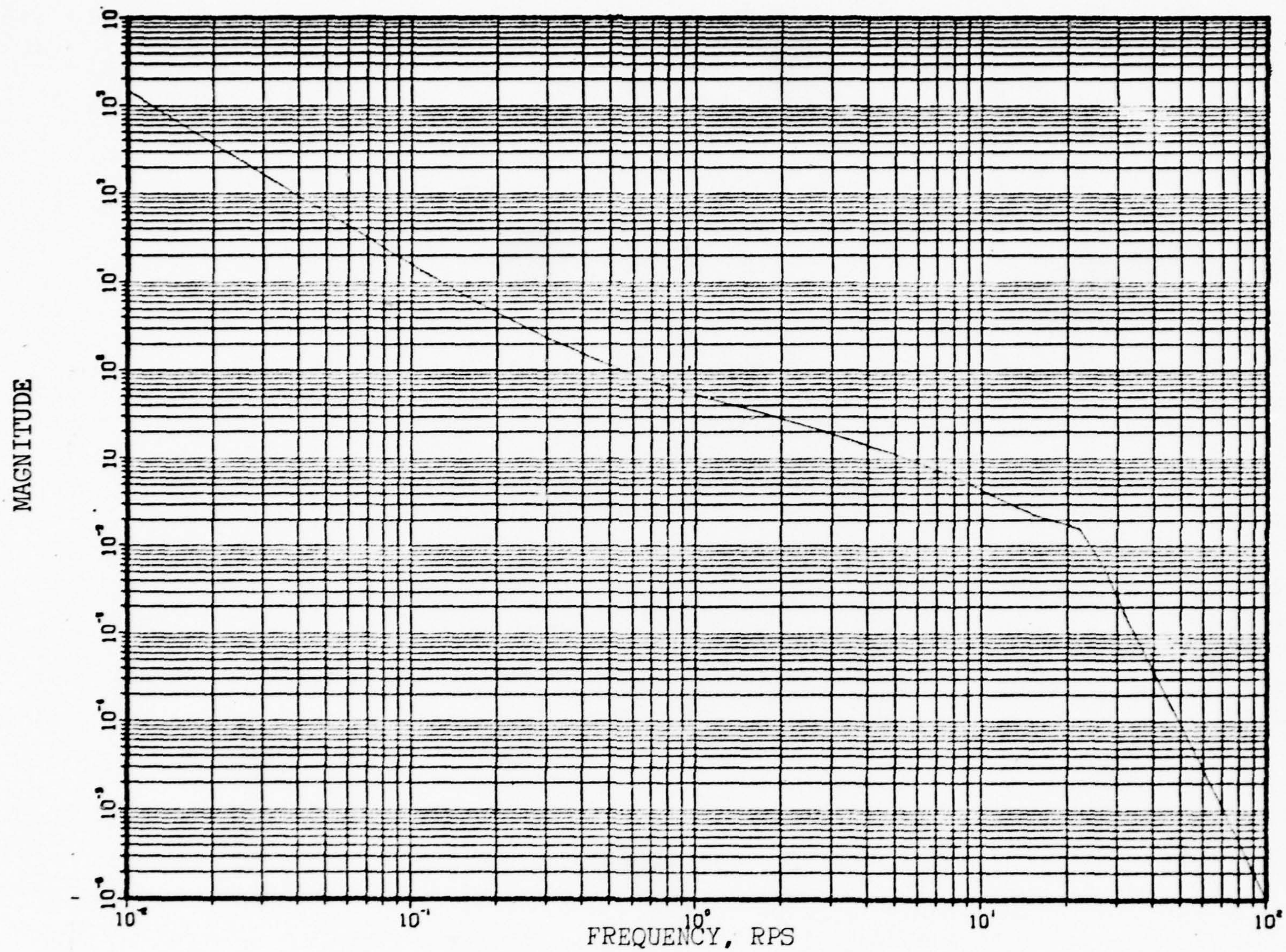


Figure 26. Pitch Rate Configuration Open Loop Bode Magnitude Plot

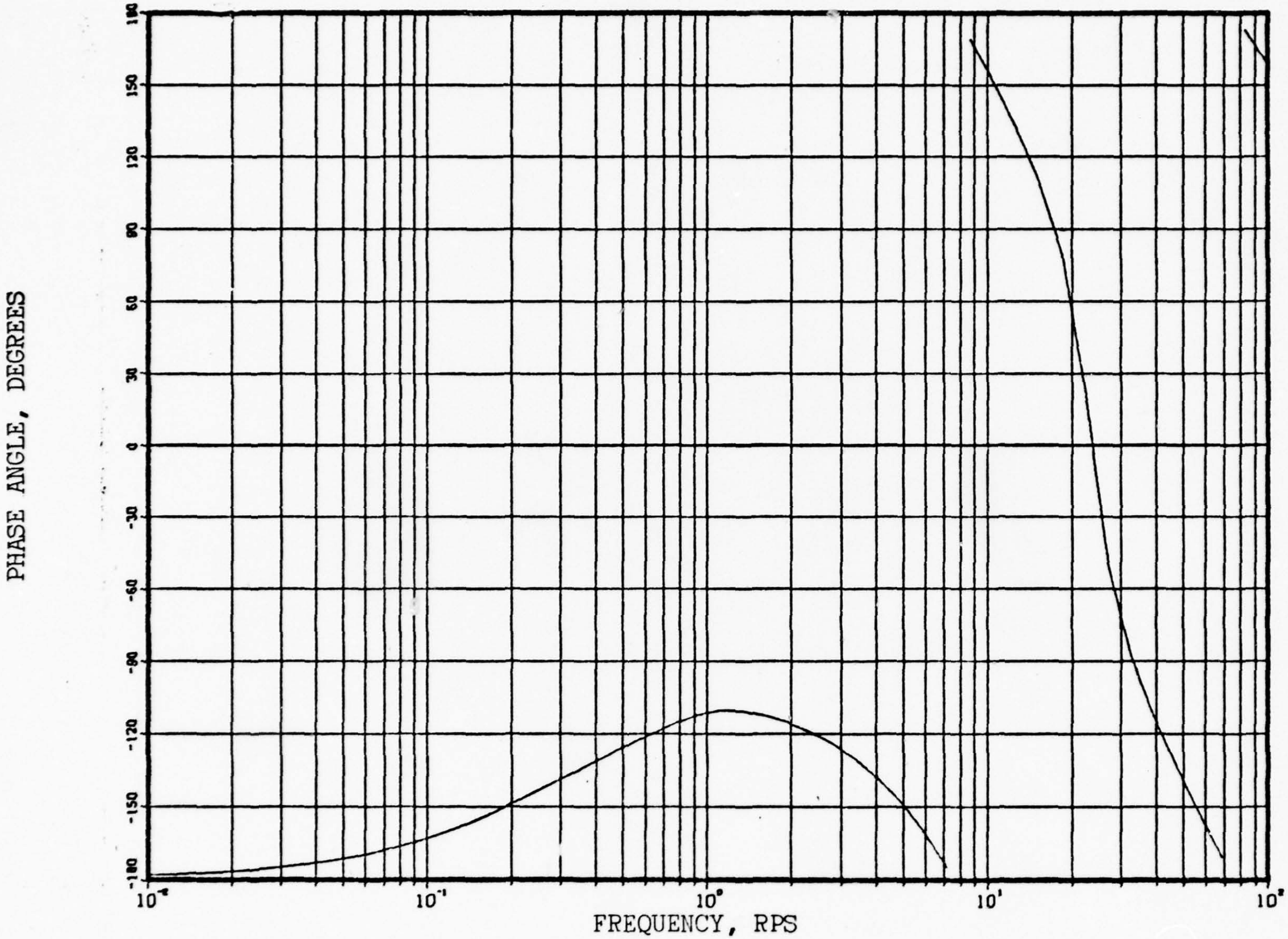


Figure 27. Pitch Rate Configuration Open Loop Bode Phase Plot

bandwidth of the system has been increased from .7 to 1.0 radians per second. Figure 26 indicates the gain crossover of the open loop pitch rate transfer function occurs at approximately .75 radians per second.

The above observations imply that a pitch rate command system could be successfully implemented to achieve overall system performance improvement. To verify this, the time response of the pitch rate system to a step input tracking error is shown in Figure 28. The faster response with less overshoot is evidence of an improved system.

To summarize the results of the normal acceleration and pitch rate control system investigation, Table V lists a comparison of quantities of interest (Ref 14).

Pilot Model Study

The pilot model adapted for this investigation was developed by McDonnell Douglas Corporation with gain parameters adjusted by General Dynamics to meet the characteristics of the F-16 aircraft. It was beyond the scope of this thesis to extensively evaluate the pilot model and conduct an in-depth study to confirm that the pilot model used is adequate for the F-16 aircraft and gunsight characteristics. However, a brief examination of the pilot model loop was done to insure stability and adequate performance with

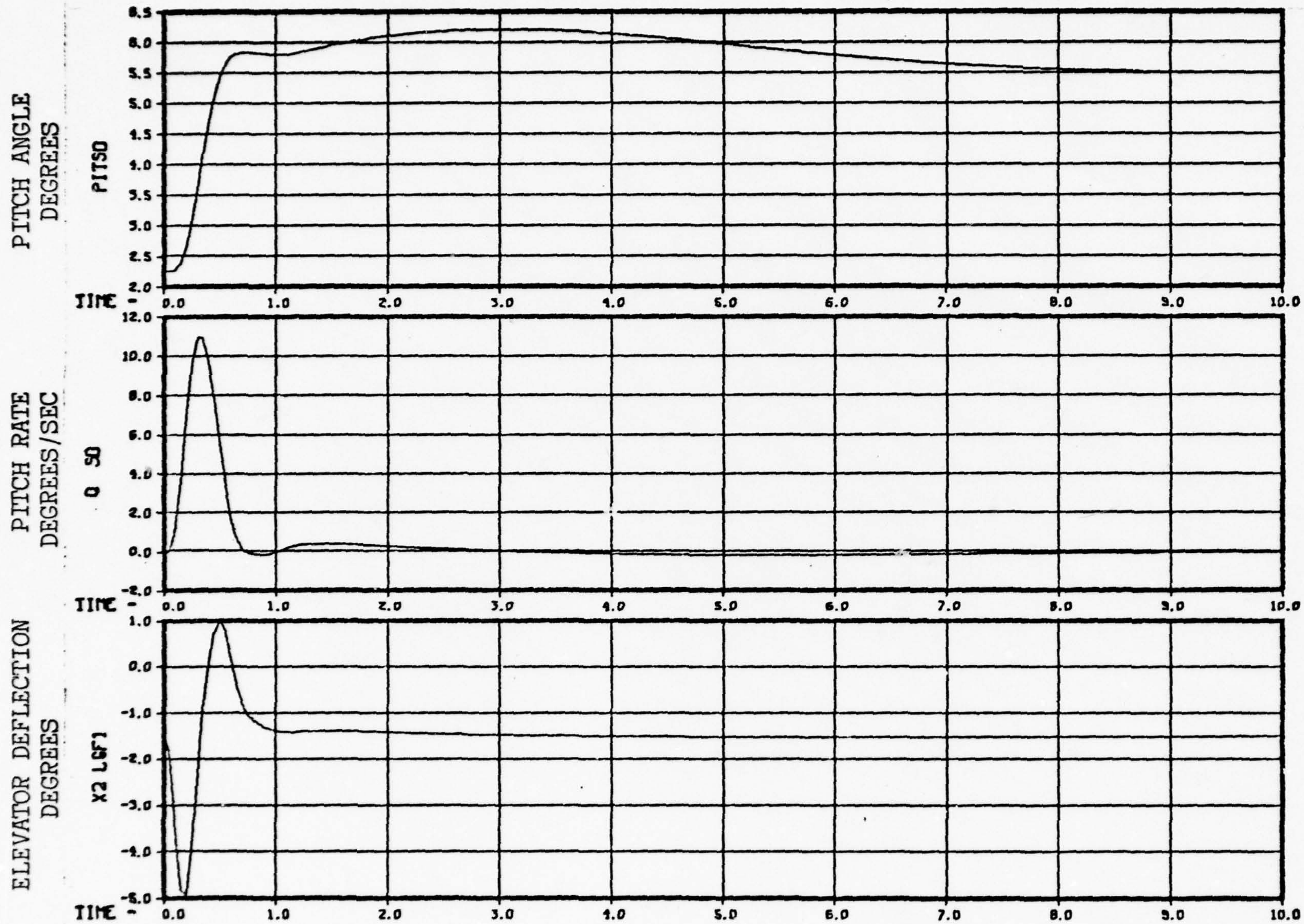


Figure 28. Pitch Rate Configuration Time Response to Step Input Tracking Error

Table V
Quantities of Interest
Normal Acceleration vs Pitch Rate Feedback
(Ref 14)

	Normal Acceleration Feedback	Pitch Rate Feedback
Max Peak Value M_m	1.43	1.28
Peak Frequency ω_m (rps)	.356	.356
Phase Margin ϕ_c (deg)	52	63
Gain Margin Frequency ω_c (rps)	.52	.75
Gain Margin (dB)	22.2	18.4
Bandwidth (rps)	.7	1.0
Time Simulation Results		
Peak Overshoot M_0 (%)	17.3	13.6
Peak Time T_p (sec)	4.7	3.25
Settling Time T_s (sec)	9.5	7.2
Rise Time T_r (sec)	.5	.4

the pitch rate control system. For the longitudinal axis, the pilot loop included the longitudinal pilot model as shown in Figure 1, p. 16, as well as the pitch command stick gradient and the stick conditioning lag filter. These three components represent the pilot loop and the open loop transfer function is as follows:

$$G(s) = \frac{159.1(s^3 + 1.325s^2 + 1.15s + 1.125)}{s(s + 8.3)(s + 20.)(s^2 + 1.2s + 1.)} \qquad (5)$$

where the pitch command stick gradient gain was selected as the upper slope value of .3182 as shown in the foldout diagram of Figure 2, p. 20.

Again, the AFIT FREQR program was used to produce the Bode magnitude and phase plot of Figure 29. The quadratic low pass filter of the pilot model causes an extensive phase shift near a frequency of 1 radian per second. An acceptable phase margin is maintained up to frequencies near 10 radians per second. The magnitude plot, although well behaved throughout the operational region of the pilot model, indicates a desirable -20 dB per decade slope at the lower frequencies for the crossover type model representation of an F-16 pilot. This brief study indicates that no adverse

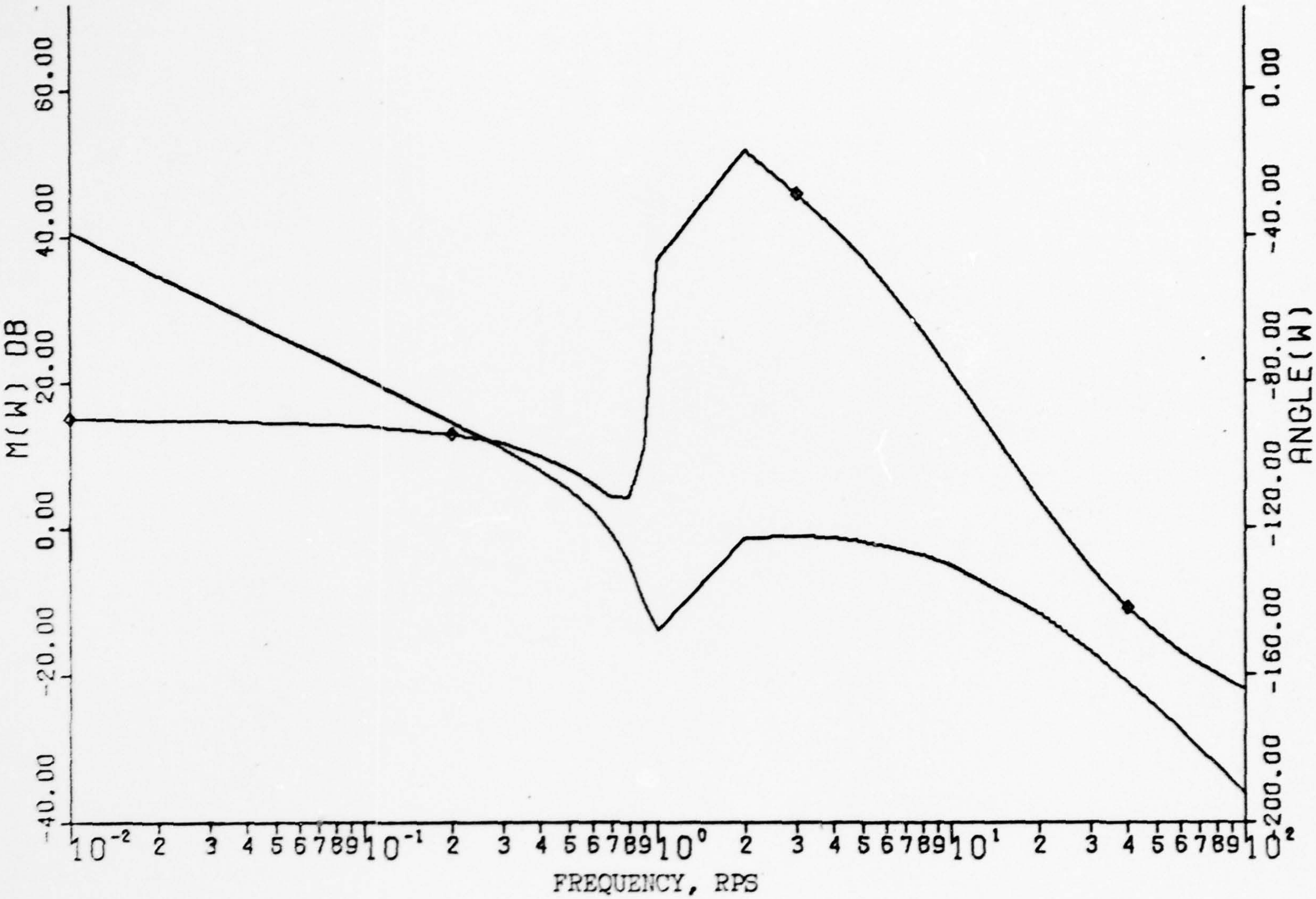


Figure 29. Pilot Model Loop Open Loop Transfer Function Bode Plot

effects should be expected with the same pilot model implemented in the pitch rate system since the effective bandwidth of the system has been increased from .7 to 1.0 radian per second. In fact, an improvement may be attained since larger magnitude outputs may be achieved through operation at the slightly higher frequencies possible with the pitch rate control system.

EASY Analysis Summary

Verification of the F-16 aircraft dynamics indicated that the EASY model characteristics were consistent with the simulation test data. By implementing an analytical pilot model, closed loop simulation analysis was made possible. A pseudo target tracking system was developed, and the performance of the present F-16 flight control configuration was examined. Investigation of a proposed pitch rate flight control configuration provided both frequency domain and time domain results that indicated target tracking improvements were possible by implementing a pitch rate control scheme. A listing of the EASY program statements used to generate the control system analysis is given in Appendix D.

V. Development of a Simulation Program

TAWDS Program Discussion

To evaluate the air-to-air tracking performance of the F-16 aircraft model, a simulation program was needed. The Terminal Aerial Weapon Delivery Simulation (TAWDS) program produced by McDonnell Douglas Corporation (Ref 15) was well suited to simulate the air-to-air encounters and provide an evaluation of the flight control systems employed. Although the program has provisions to simulate weapon delivery tasks for air-to-air gunnery, air-to-ground gunnery, and bombing, only the air-to-air, aerial gunnery programs were included in this study. The TAWDS digital simulation program was used to simulate both the present F-16 flight control configuration and the pitch rate configuration of Chapter IV. Implementing the pilot model discussed in Chapter II, a deterministic evaluation of the aircraft's tracking performance was completed. Provisions of the TAWDS program include many factors associated with aerial gunnery. For example, the program includes the modelling effects of aircraft dynamics, control system characteristics, gunsight characteristics, pilot control parameters, attacker to target geometry, target maneuvering, gun orientation, gun rate of fire and recoil forces, bullet trajectories, random windgusts, and stationary source errors. The above considerations make the TAWDS digital simulation program a well suited analytical tool to evaluate the non-linear six-degree-of-freedom air-to-air terminal tracking task.

TAWDS Programming Techniques

The deterministic mode of the TAWDS air-to-air program uses non-linear time varying equations to simulate a six-degree-of-freedom attacking aircraft tracking and firing at a five-degree-of-freedom maneuvering target. The major subroutines of the TAWDS air-to-air program are called by the Executive subroutine to describe the air-to-air terminal weapon delivery task. These subroutines include Data Input, Initial Encounter, Initial Condition, Measurement Error, Airframe, Augmentation, Pilot, Target Initialization, Target Aircraft, Relative Geometry, Bullet Time of Flight, LCOS Sight, Director Sight, Bullet Integration, Performance, Runge-Kutta Integration, and Output Subroutines (Ref 15).

In preparation for using the TAWDS program, it was necessary to develop tabular data for the six-degree-of-freedom non-linear F-16 aircraft model. Extensive stability derivative data supplied by the aircraft manufacturer (Ref 16) was input into the program to provide table look-up parameters necessary to satisfy the six-degree-of-freedom equations of motion. A flight condition of altitudes near 20,000 feet with airspeed varying from .8 to .9 Mach was considered. The aircraft model selected as the data base for the EASY programming was again used in the TAWDS program. Therefore, the aircraft characteristics of Table III, p. 31, were implemented. Additional simulation specifications were allowed and the reader is referred to Appendix C and Ref 15 if programming details are desired.

The generic design of the TAWDS Data Input subroutine allowed easy implementation of parameter values. Different aircraft characteristics, flight control or pilot model parameters, or gunsight selections could be made through data changes. Initially, use of the TAWDS program was to be limited to the longitudinal axis of the flight control system, however, since weapon system effectiveness was the overall objective of the study, it did not seem realistic to evaluate this system in only one plane of motion. It was hoped that air-to-air combat encounters could be developed to provide a tracking task that would realistically evaluate the candidate flight control systems. Therefore, it was decided to implement a full six-degree-of-freedom simulation.

After the aircraft data requirements were satisfied, the longitudinal flight control system was implemented. Since the F-16 has a very non-conventional flight control system, the generic flight control models of the TAWDS program were not adaptable for the F-16 aircraft. Therefore, FORTRAN statements were used instead to develop flight control signal processing. The same control system simplifications in the longitudinal axis as employed in the EASY programming were also considered in the TAWDS program. Since the primary objective was to evaluate longitudinal flight control tracking characteristics, the cross coupling of lateral and longitudinal control signalling was also eliminated. FORTRAN statements were used to generate the gain scheduling requirements of the flight control system. Functions such as dynamic pressure adjusted for compressibility, static pressure, and Mach number variables were developed within the logic of the flight control subroutine. The schematic diagram shown in Figure 30 shows the longitudinal flight control system implemented in the TAWDS program. The lateral-directional flight control system for the F-16 model is shown in Figure 31. The parameter names and transfer function names as indicated in the block diagram hold no significance except they were programmed parameters and transfer function

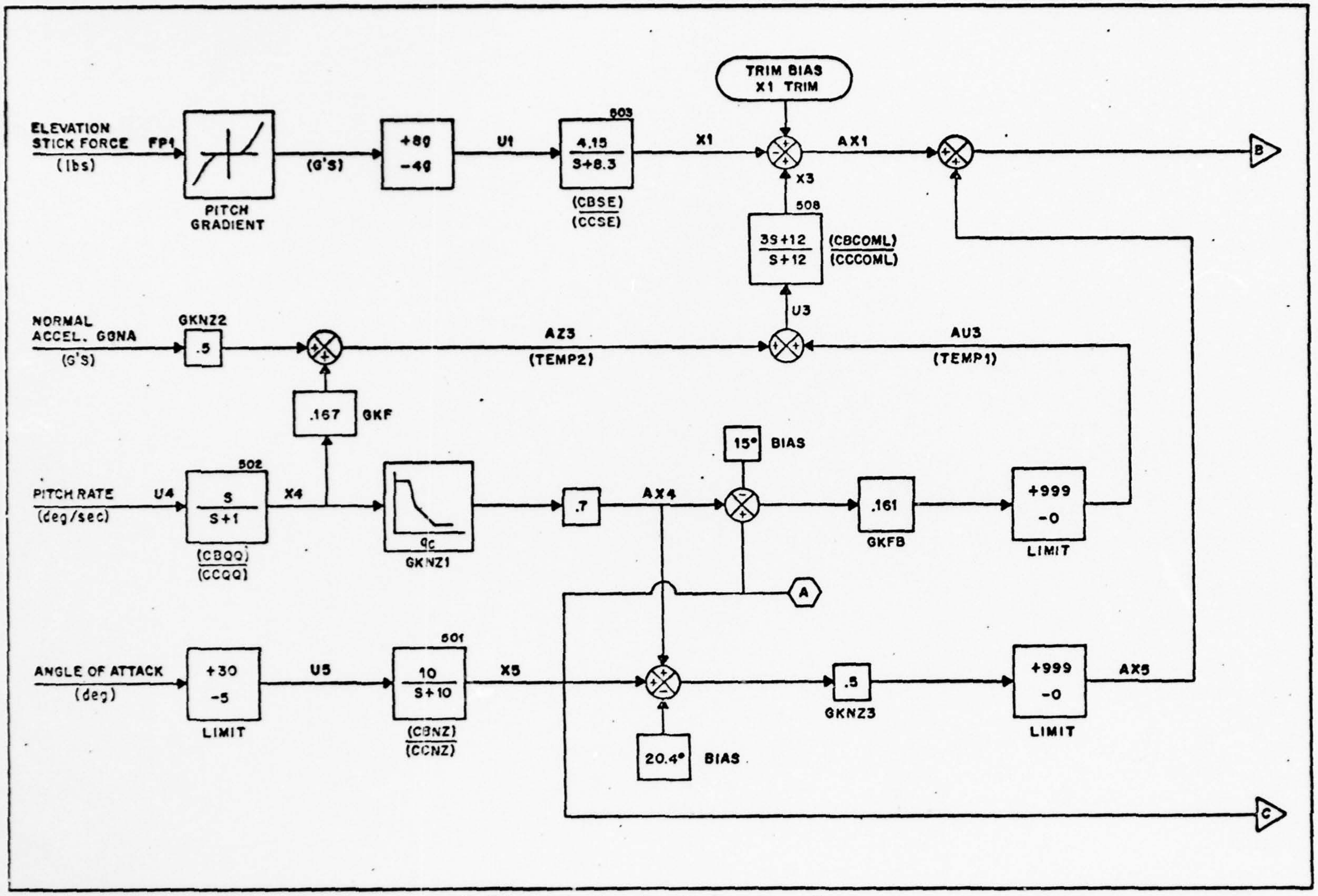


Figure 30. Longitudinal Flight Control System Schematic for TAWDS Program

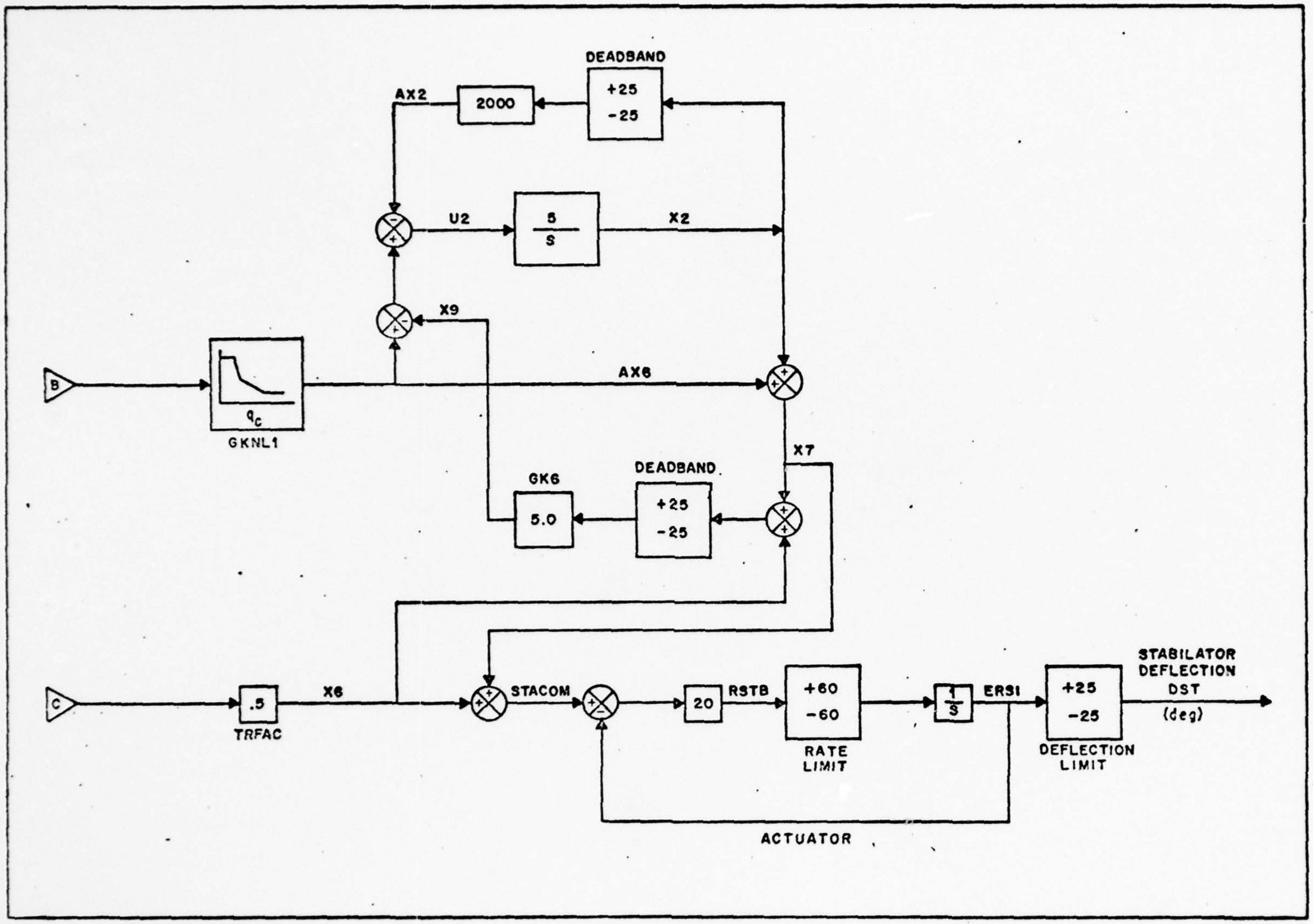


Figure 30. Continued

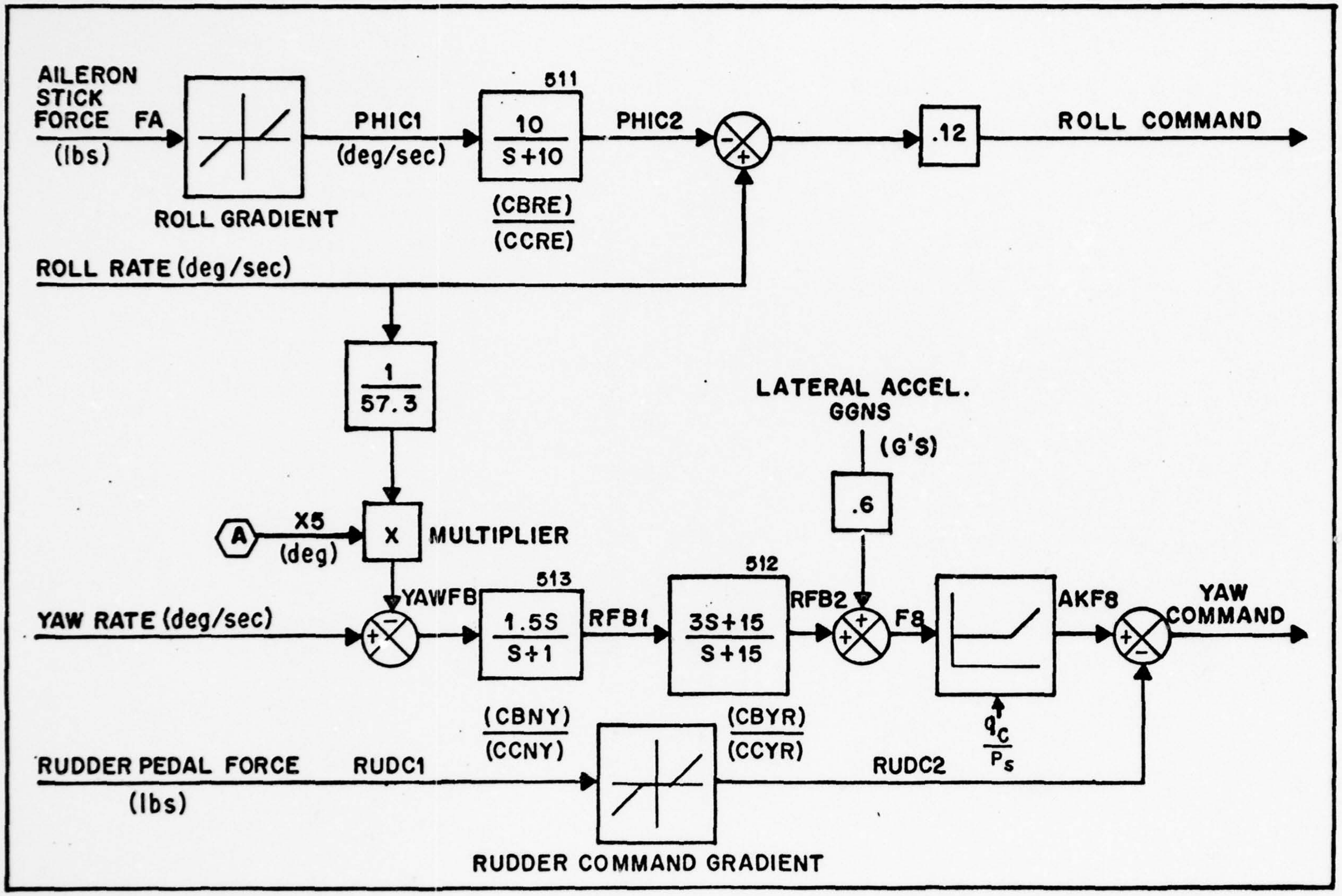


Figure 31. Lateral-Directional Flight Control Schematic for TAWDS Program

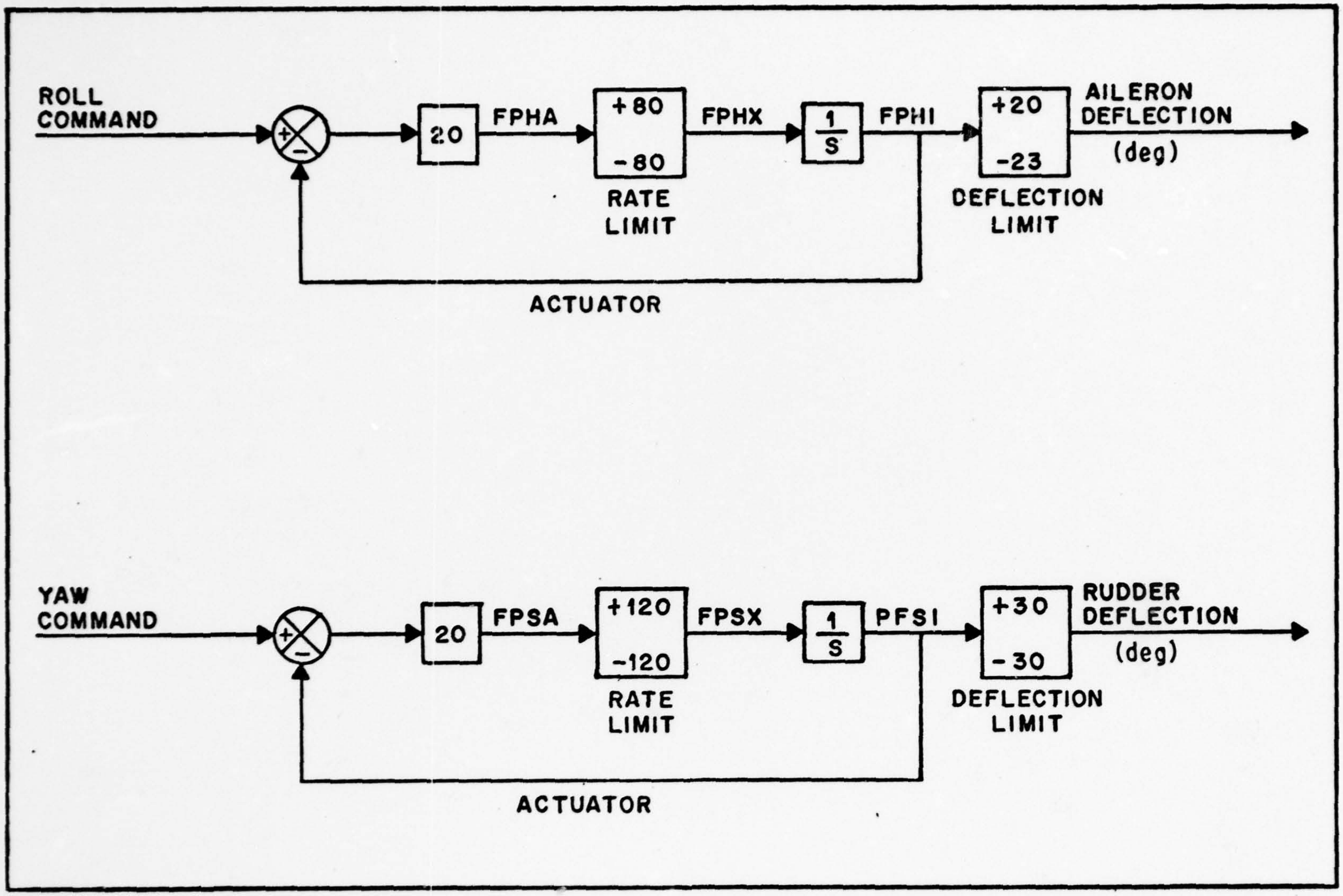


Figure 31. Continued

names already used in the generic TAWDS program. These were again used in the FORTRAN programming. Using these pre-programmed names simplified programming efforts, but these names bear no relation to the generic TAWDS program.

An additional trim subroutine was also used to replace the aircraft trimming techniques of the TAWDS program. This subroutine perturbed the six-degree-of-freedom equations by varying aircraft angle of attack, forces, and moments until a satisfactory trim solution was achieved about the desired flight condition. An added feature allows specification of the trim condition in terms of g's by reading in the parameter name GKMECH. For example, to achieve a trim condition of straight and level unaccelerated flight, GKMECH = 1.0. After selecting a 1 g flight condition, the TAWDS program output of stability derivatives and trim values indicated only minor numerical variances when compared to the trim condition values of the EASY program.

Next it was necessary to initialize the flight control system. The values of the aircraft feedback variables were used to initialize the transfer functions of the flight control system. The first pass through the flight control subprogram (AUTSI1) initialized the transfer functions and set control conditions to satisfy the trim condition. A stick trim bias as shown in the pilot channel of Figure 30 was calculated to provide the nominal stick forces necessary to balance the control surface deflection.

The pilot model and gain parameters as discussed in Chapter III were also included in the TAWDS programming model. Since a full six-degree-of-freedom simulation was to be developed, the multi-axis F-16 pilot model was adapted which included not only the longitudinal axis, but also the lateral-directional axis.

The generic quality of the TAWDS programming ability was very helpful in implementing the pitch rate control system of Chapter IV. It was not necessary to extensively change the flight control model as in the EASY program. Parameter value changes read in as data could effectively modify the normal acceleration system to incorporate the pitch rate control. For example, setting the parameter GKNZ2 shown in Figure 30 equal to zero eliminated normal acceleration feedback. The transfer function CBQQ/CCQQ was set to unity and the transfer function CBCOML/CCCOML was changed to the desired filter $2(s + 15)/(s + 30)$. By setting the parameter GKF = .3 as determined by the root locus analysis mentioned in Chapter IV, and adjusting the pilot loop gain to command degrees per second instead of g's, (e.g. CBSE = 10.00), the pitch rate system implementation for the TAWDS program was completed.

Data parameters would also allow the selection of either the LCOS or director sight to be implemented into the simulation program for each run. By implementing either of the above sights, the system developed to this point could be considered as a manual director system or a manual LCOS system. Variations of the multi-axis pilot parameters would be necessary to operate the different gunsight systems.

Air-to-Air Scenarios

A series of air-to-air gunnery encounters were developed to evaluate the flight control systems. The Initial Condition subroutine was programmed to set the attacker aircraft at the flight condition to begin eight air-to-air engagements. For each target scenario, the attacker aircraft was initialized near straight and level unaccelerated flight at 20,000 feet and airspeed of .8 Mach. A target range of 5,000 feet was selected for the first four target maneuvers and a range of 7,000 feet for the last four maneuvers. Varying range rates (i.e. attacker to target closure rate) from -50 to -200 feet per second were programmed also. This established the initial target aircraft airspeed for each scenario.

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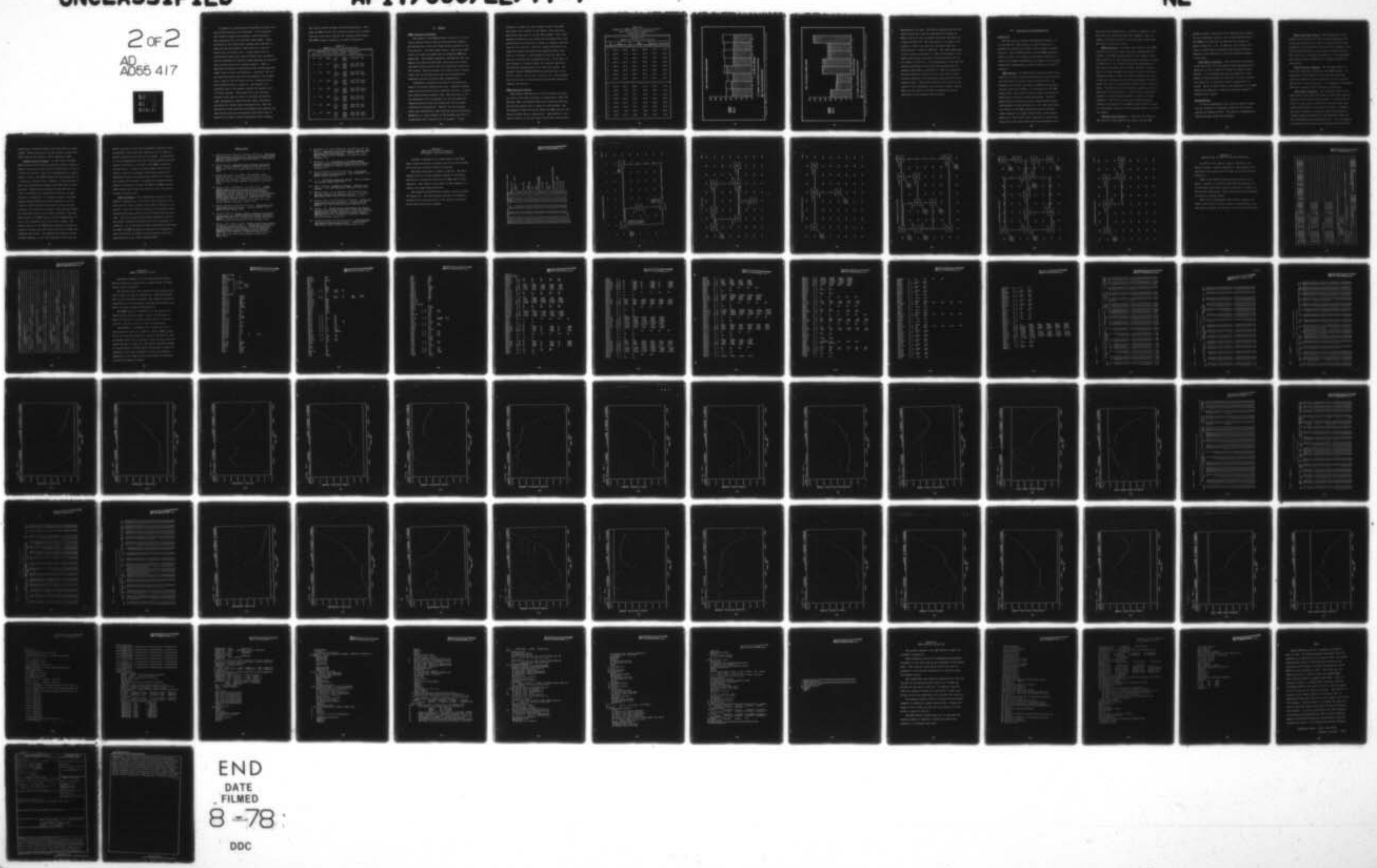

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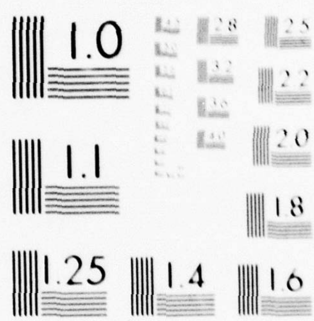

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

In addition to initializing the attacker aircraft, target aircraft maneuvers were developed. To be consistent with terminal tracking environments, evasive maneuvers were programmed for an F-4 aircraft target model. Specifications for the target model included time intervals to begin and end each maneuver, bank angle rate, angle-of-attack rate, and thrust rate. A three digit code of a selected bank angle rate, angle-of-attack rate, and thrust rate was developed for specific target maneuvers at selected time intervals during the tracking scenario. Table VI describes the maneuvers developed and the corresponding NIC number used to select each encounter. Generally, the target maneuvered during the first two seconds of the program into a right or left 90° bank turn for a specified g and then completed either a split S or jink maneuver at a specified time as the scenario reached the terminal time of fifteen seconds. These eight air-to-air encounter scenarios were used as a basis to evaluate the director sight implementation under both the normal acceleration and pitch rate flight control configurations. With the deterministic mode selected, the program would complete one pass through each case and generate time history data to measure the attacker aircraft performance while tracking the target aircraft through the selected maneuvers. Both mean and RMS elevation and traverse tracking error information was to be used to measure the tracking effectiveness. The TAWDS program information is shown in Appendix C.

Table VI
TAWDS Air-to-Air Target Maneuvers

NIC	Max g	Closure (ft/sec)	Time (sec)	Range (ft)	Maneuver Description
1	3.6	-100	0-2	5000	Roll 90° left
			15	1000	
2	4.2	-50	0-2	5000	Roll 90° left
			10-11	2600	Roll 30° left
			15	1200	
3	3.2	-150	0-2	5000	Roll 90° left
			12-13	1500	Roll 30° right
			15	800	
4	3.4	-150	0-2	5000	Roll 90° right
			8-10	2500	Roll 45° right
			15	800	
5	3.2	-150	0-2	7000	Roll 90° right
			8-10	4000	Roll 30° right
			15	1400	
6	3.5	-200	0-2	7000	Roll 90° left
			8-10	4000	Roll 45° left
			15	1400	
7	3.3	-150	0-2	7000	Roll 90° left
			6-8	5000	Roll 45° left
			15	1400	
8	4.3	-200	0-2	7000	Roll 90° right
			6-8	5000	Roll 90° right
			15	1500	

VI. Results

TAWDS Simulation Techniques

The results of the EASY Analysis of Chapter IV indicated an improved target tracking system could be achieved by implementing a pitch rate flight control system for the F-16 aircraft. To verify these results, each of the eight air-to-air target encounters was run using the TAWDS program model. This digital simulation included the full six-degree-of-freedom aircraft model, multi-axis pilot model, and lateral-directional as well as longitudinal flight control system. Both the present F-16 flight control configuration and the proposed pitch rate control system were evaluated using the director sight implementation.

Runge-Kutta integration was used for the simulation using a .05 second iteration step size. Although a smaller step size would provide better numerical accuracy, it would also require greater computer time. The step size of .05 was determined to be the maximum size for the simulation components and this step size worked well for the normal acceleration configuration. However, for the proposed pitch rate configuration, this step size was not sufficient. Modelling of a time constant of 1/30 seconds could not be accomplished with a step size of .05 seconds. It was necessary to reduce the step increment size to less than the largest time constant of the system. Test runs were made using step sizes of .01 and .001 seconds. Very little numerical differences were noted with the smaller step size and therefore the significant increase in computer operation time was not justified. Since the normal acceleration configuration system had already been completed with a step size of .05 second, it was desirable to use the same step size for the pitch rate configuration also. To do this, it was necessary to slightly modify the lead-lag compensator that had been implemented for the pitch rate system. The transfer function CBCOML/CCCOML was adjusted from a value of $2(s + 15)/(s + 30)$ to $2(s + 7.5)/(s + 15)$. This allowed the .05 step size to be maintained and provided significant computer cost savings.

TAWDS Simulation Results

The tracking performance of the F-16 attacker aircraft for each of the eight encounters is summarized in Table VII. The mean, RMS, and standard deviation of both the elevation and traverse aiming error is shown for both systems. The bar graphs of Figure 32 and 33 compare the RMS elevation and traverse aiming errors, respectively. Improvements in elevation tracking can be seen while the traverse errors remain

Table VII
Summary of TAWDS Simulation Tracking Aim Error
with Director Sight Implementation
(measured in mils)

Present F-16 Normal Acceleration Configuration						
	Mean		RMS		Standard Deviation	
NIC	Elevation	Traverse	Elevation	Traverse	Elevation	Traverse
1	-22.2	-17.8	24.1	19.8	9.4	8.7
2	-21.8	9.3	24.3	14.0	10.7	10.4
3	-21.2	7.7	23.3	13.7	9.6	11.4
4	-24.0	-24.8	26.2	27.9	10.4	12.8
5	-20.8	-16.7	25.7	25.1	15.0	18.8
6	-21.6	14.9	26.8	20.2	15.9	13.6
7	-20.6	11.1	26.3	20.1	16.3	16.8
8	-21.4	-28.1	27.5	35.4	17.3	21.5
Pitch Rate Configuration						
1	-15.8	-17.1	18.8	19.4	10.2	9.2
2	-15.8	8.9	19.1	14.5	10.8	11.5
3	-15.3	7.3	17.7	14.0	9.1	11.9
4	-19.0	-23.9	24.0	27.2	14.6	12.9
5	-13.2	-13.7	17.8	27.8	12.0	24.2
6	-13.2	13.4	17.1	22.4	10.8	18.0
7	-12.9	9.2	17.1	22.5	11.2	20.5
8	-13.0	-25.7	16.8	36.3	10.7	25.5

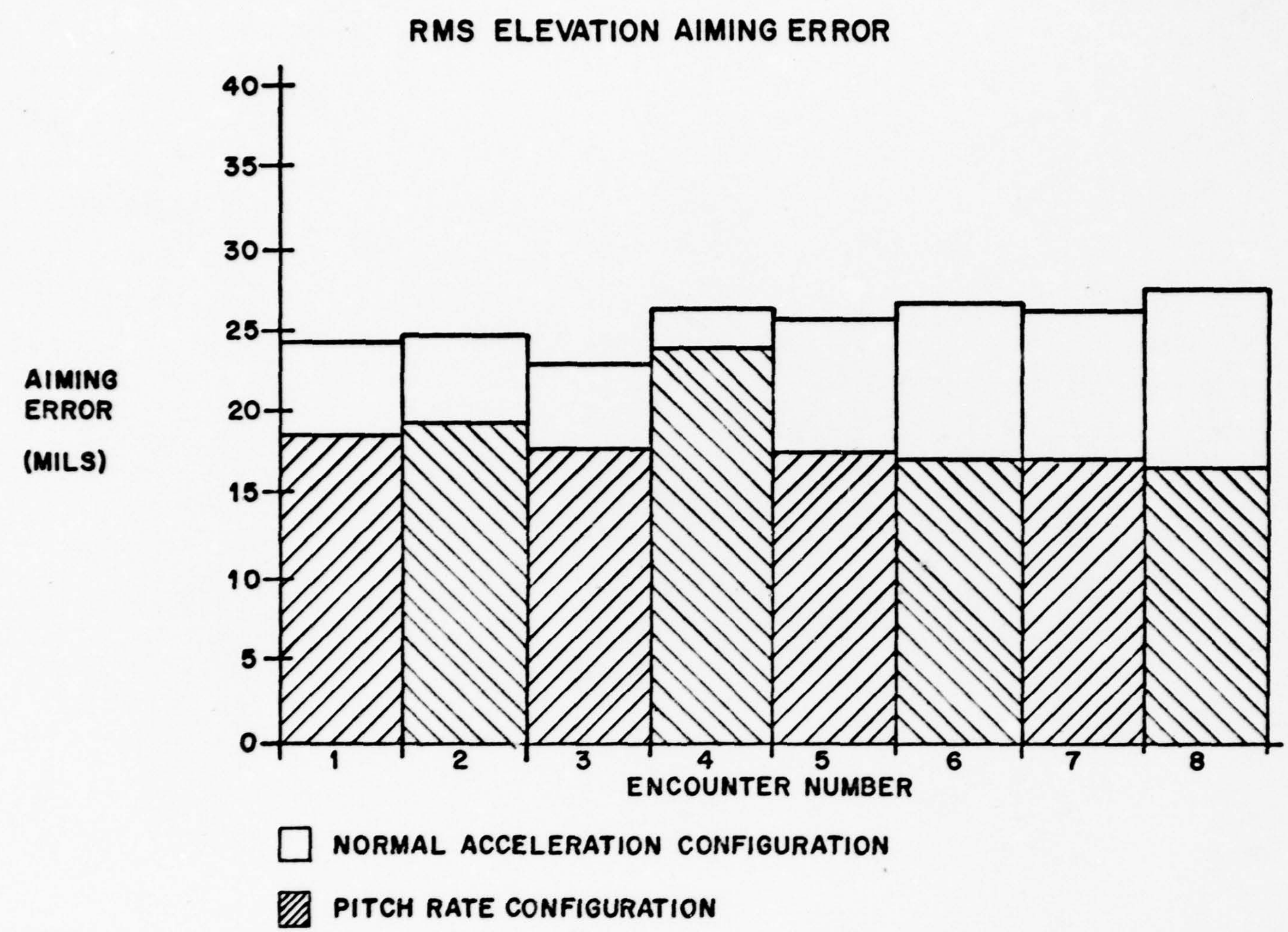

Figure 32. RMS Elevation Aiming Errors of the Eight TAWDS Simulation Encounters

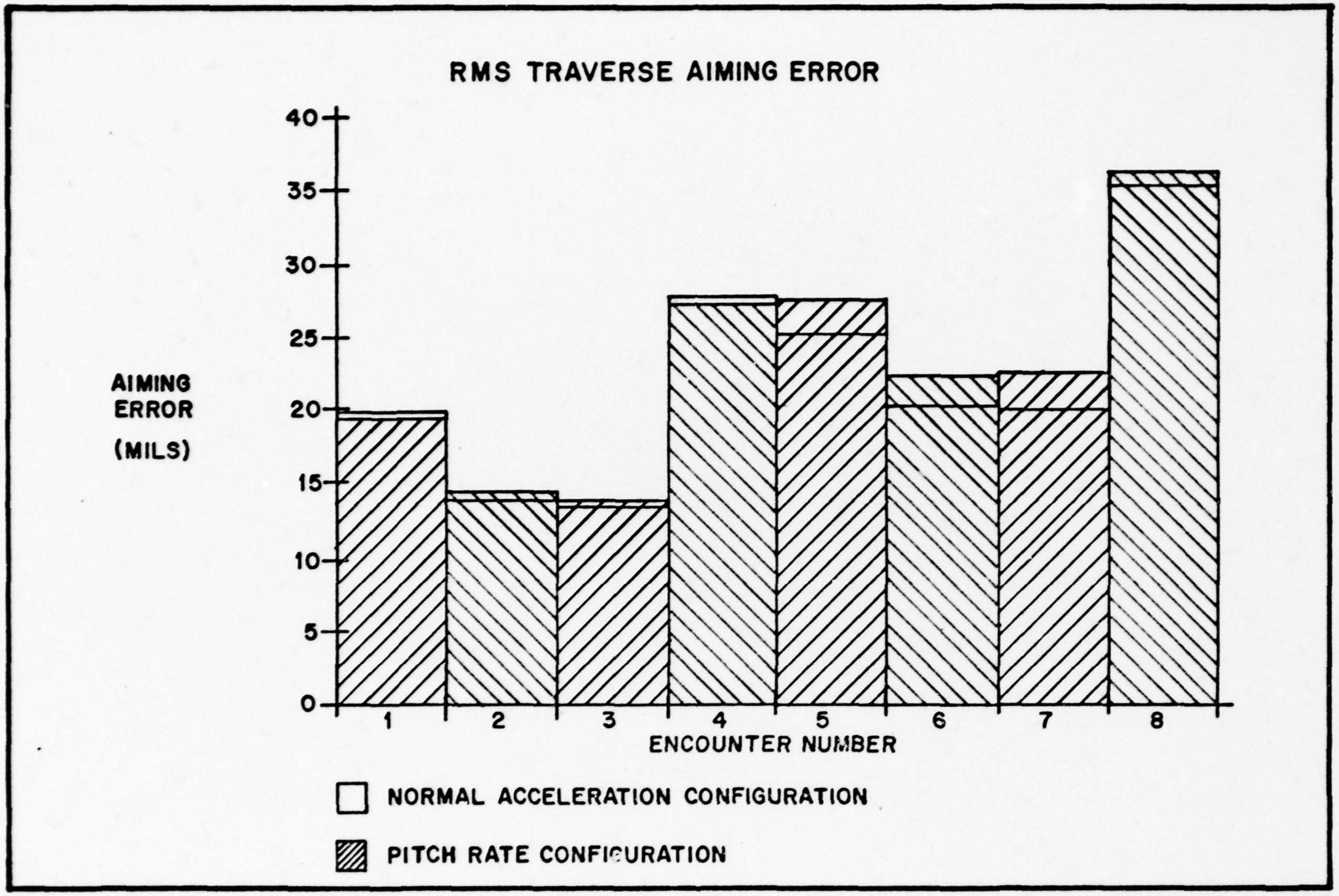

Figure 33. RMS Traverse Aiming Errors of the Eight TAWDS Simulation Encounters

approximately the same. The results indicate that the elevation aiming error has been improved by an average of 20% for the first four encounters that were initialized at a range of 5000 feet. The improvement is increased to an average of 35% for the last four encounters that were initialized at a range of 7000 feet. The least improvement of all is shown in encounter 4. This is attributed to the target maneuvering at the most critical range for air-to-air combat of 2500 feet. It is interesting to note that the tracking performance of the pitch rate system shows the greatest improvement in encounter 8. This was considered the most difficult encounter of all since the F-4 target aircraft completed a split-S maneuver during the 15 second terminal chase. This result indicates that the pitch rate system of the longitudinal axis provides a greater improvement over the normal acceleration configuration as the difficulty of the tracking task increases.

VII. Conclusions and Recommendations

Conclusions

From the previous analysis and simulation results, it is concluded that improvements in target tracking are possible by tailoring the flight control system of fighter aircraft. Both the EASY Analysis and the TAWDS simulation results indicate improvements in the system response of a pitch rate feedback implementation as compared to the normal acceleration implementation presently employed in the F-16 aircraft.

EASY Analysis. The EASY Analysis program allowed investigations of system responses with both the normal acceleration and pitch rate flight control configurations. By eliminating the normal acceleration feedback and compensating the pitch rate feedback, it was shown using the EASY program that a very similar overall closed loop system was maintained, with certain noted improvements. A better damped system was achieved with an increased phase margin and bandwidth as shown by Table V, p. 63. The time simulation results of the EASY program verified the improved system response to a pseudo tracking task in the longitudinal axis. The aircraft model response to a pitch angle step input to the pilot model indicated improvements with the pitch rate implementation. As shown in Table V, p. 63, the pitch rate system provides better damping, faster response, and quicker settling to the step input signal than the normal acceleration system.

TAWDS Simulation. Similarly, the results of the TAWDS simulation air-to-air combat encounters substantiated the results of the EASY program analysis. The tracking aiming error quantities of the eight air-to-air encounters as shown in Table VII, p. 82, clearly indicate the improvements of the pitch rate flight control system. Elevation tracking error, both mean and RMS, was reduced in each of the target tracking scenarios. These air-to-air encounters provided a realistic environment to test the performance of both the normal acceleration and pitch rate flight control configurations. The different target airspeeds, target load factors, and target rolling maneuvers of each scenario allowed the evaluation of each system throughout a variety of flight conditions. The full six-degree-of-freedom non-linear simulation developed for the TAWDS program enabled a realistic performance evaluation for the terminal phase of air-to-air combat.

Aircraft Model Validation. Techniques for verifying the aircraft flight dynamics were shown using the EASY

Analysis program. The roots of the characteristic equation for the longitudinal dynamics very closely matched those of the LAMARS test case used to model the F-16 aircraft as shown in Table IV, p. 38. In addition, the transfer functions of alpha/elevator deflection and theta dot/elevator deflection were completed to verify the numerator dynamics of the model.

Pilot Model Performance. The satisfactory performance of the analytical F-16 pilot model clearly demonstrated the usefulness of such a model for closed loop system investigations. It is concluded that the gain sensitivity parameters of the pilot model are sufficient to allow a qualitative comparison of the flight control configurations examined. The pilot model control stick responses of the TAWDS program (see Appendix C) indicated reasonable responses to tracking error signals.

Recommendations

It is my recommendation that extensive digital simulation be continued to investigate flight and fire control systems for fighter aircraft. The specific recommendations from this study include the following:

Refine Pitch Rate Control. The mechanization of the flight control system using the C* concept considered only one extreme implementation, that of eliminating the normal acceleration and conditioning the pitch rate feedback. Since the C* approach implies a linear blend of normal acceleration, pitch rate, and pitch acceleration, it is recommended that other possible combinations of feedback variables be investigated.

Flight Envelope Expansion. The end game problem of air-to-air combat was simulated in the TAWDS program. The excursions of the attacker aircraft did not effectively cover the operational flight envelope of the F-16 aircraft during the 15 second encounters. It is therefore recommended that more extensive flight envelopes be considered.

Pilot Model Validation. The analytical pursuit pilot model used in this thesis was based on actual pilot performance data during target tracking tasks. It was not the objective of this study to verify that the pilot model used closely matched that of the actual F-16 pilot. Instead, it was used to complete a closed loop study and provide consistent tracking performance for the different flight control configurations and target maneuvers. If it is required to closely match the actual pilot responses for future F-16 simulations, a detailed study of the pilot model is recommended. Radical departures from the present configuration would indicate the need for a pilot adaptation study.

Improve Software Programs. In this study, the EASY Model Generation and Analysis program was used to model and analyze the present flight control configuration of the F-16 aircraft and develop a pitch rate implementation to improve target tracking. The TAWDS program was used extensively as a simulation evaluation tool. However, it was necessary to master the programming techniques and terminology of both programs. Although both programs provided beneficial results, it would be very convenient for portions of each program to be combined in one compact program. The EASY program allowed extensive analysis techniques to be employed by simply manipulating parameter values and state conditions through program commands. Both frequency domain and time domain analysis was readily available. The many subroutines of the TAWDS program allowed implementation of many of the considerations for air-to-air combat. The generic quality of the TAWDS Input subroutine allowed configuration changes and system specifications by simply manipulating data values. By combining the benefits of each of these programs, a very large reduction in the time and effort required to learn both programming techniques could be achieved. This would also enable the user to develop a greater expertise by using only one program. In particular, it is my recommendation that the frequency response and time response techniques be included in the TAWDS programming. In this manner, a complete program package could be maintained so that the programmer could readily analyze his implemented system and complete time simulations to determine system effectiveness. A reduction in computer memory presently required to run both the EASY and TAWDS programs would significantly reduce the operating costs and improve program turnaround time.

Apply Techniques. The programming techniques of this thesis in implementing a pitch rate control system for the F-16 aircraft clearly indicate that digital simulations can provide a very cost effective approach for designing, developing, and optimizing advanced aircraft weapon delivery systems. Used in conjunction with manned simulation efforts, the digital simulation approach can provide invaluable information. It is therefore my final recommendation that both the EASY and TAWDS programming techniques be considered to aid in the design of fighter aircraft handling qualitites specifications as set forth by MIL-F-8785B.

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Appendix A
EASY Model Program Description
and Computer Generated Schematic

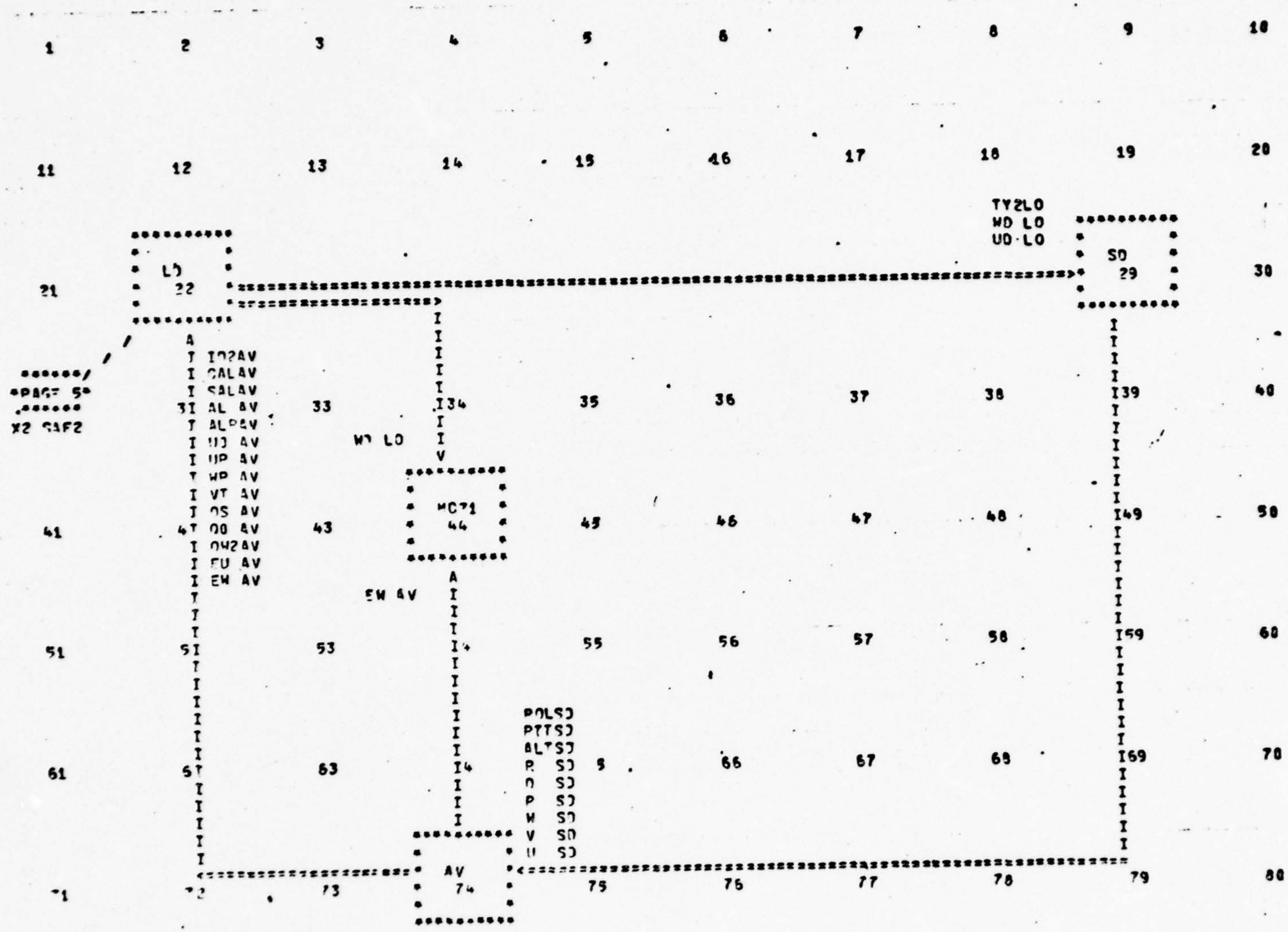
Included in Appendix A is a description of the EASY model program developed to simulate the F-16 control system, pilot model, and aircraft equations of motion.

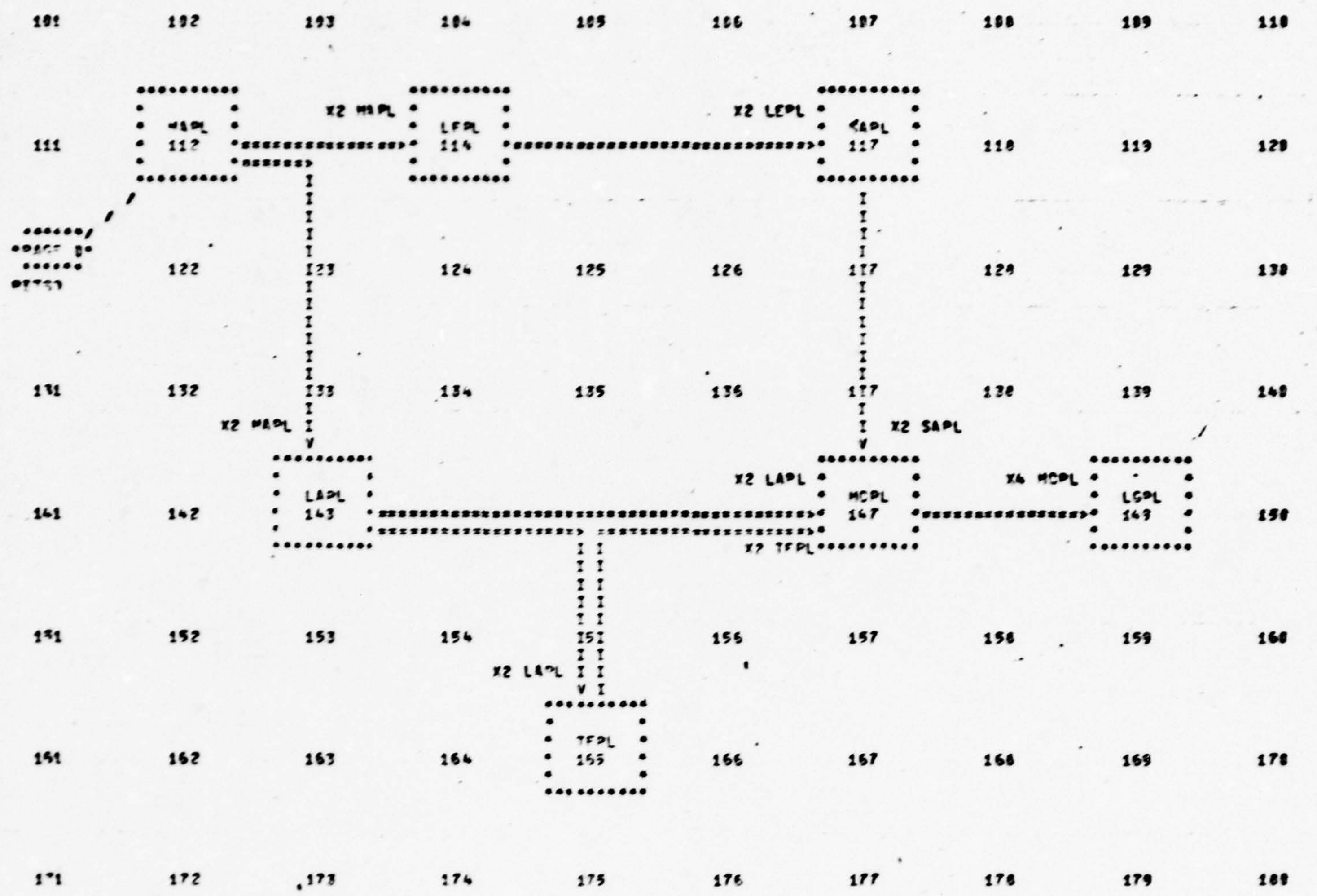
The model description is shown on page 95. The block diagram location of each standard component of the model description is specified along with the EASY name of each component. Also shown are the inputs of each component to specify the system interconnections.

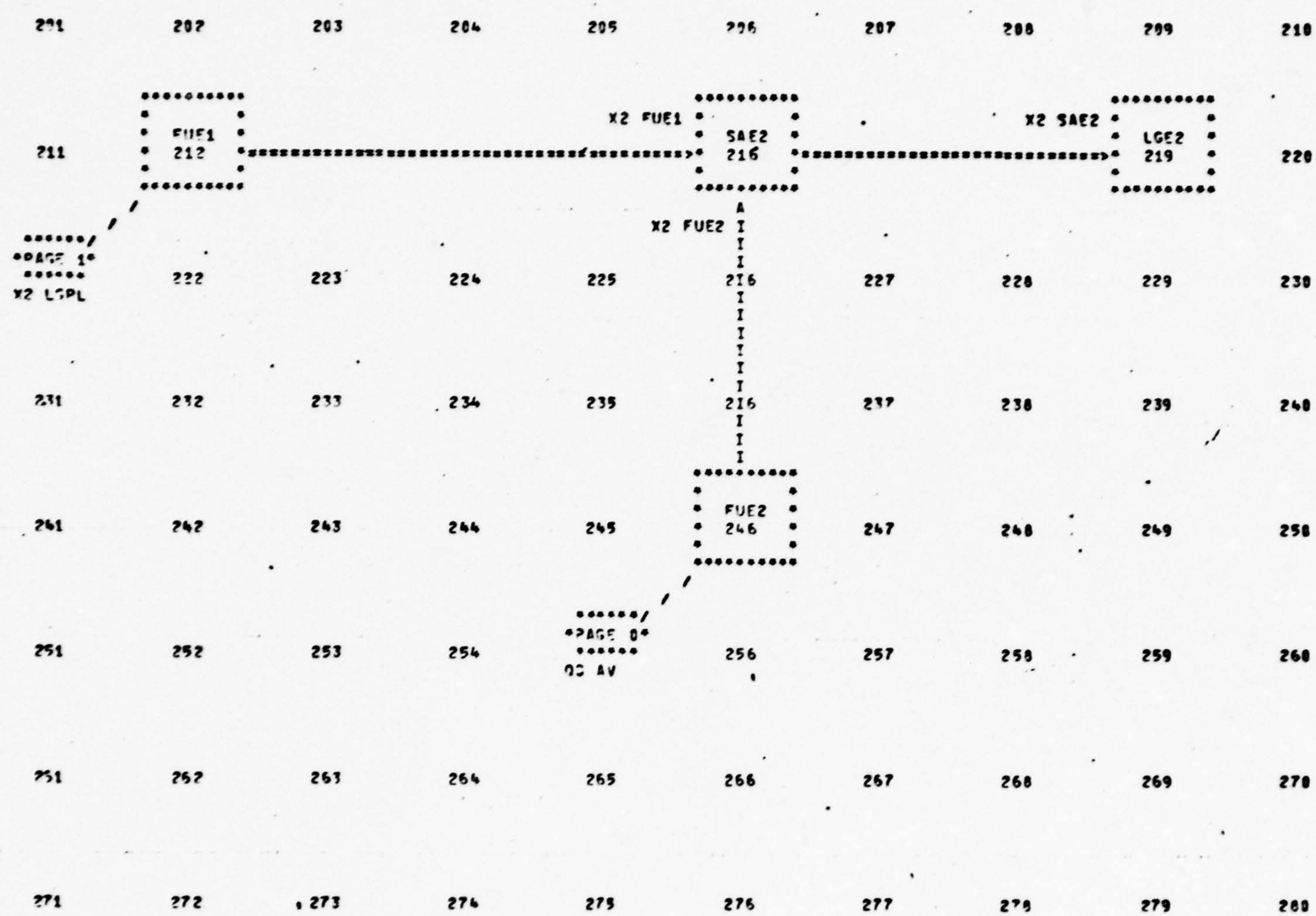
The computer generated block diagram is shown on pages 96 through 101. The block diagram verifies the component locations and interconnections of the system as specified by the model description commands.

```
MODEL DESCRIPTION    F-16 LONGITUDINAL FLT CONTROL SYSTEM
LOCATION   074   AV     INPUTS = SD
LOCATION   540   SAF2   INPUTS = LGF1
LOCATION   022   LO     INPUTS = AV,SAF2(X=ELE)
LOCATION   029   SD     INPUTS = LO
LOCATION   044   MCZ1   INPUTS = AV  (EW=X),LO  (WO=X)
LOCATION   112   MAPL   INPUTS = SD  (PIT=X)
LOCATION   114   LEPL   INPUTS = MAPL
LOCATION   143   LAPL   INPUTS = MAPL
LOCATION   117   SAPL   INPUTS = LEPL
LOCATION   155   TEPL   INPUTS = LAPL
LOCATION   147   MCPL   INPUTS = SAPL,LAPL,TEPL
LOCATION   149   LGPL   INPUTS = MCPL
LOCATION   212   FUE1   INPUTS = LGPL
LOCATION   246   FUE2   INPUTS = AV  (OC=X)
LOCATION   216   SAE2   INPUTS = FUE1,FUE2(X=C6)
LOCATION   213   LGE2   INPUTS = SAE2
LOCATION   470   SAE3   INPUTS = AV  (CL=X)
LOCATION   450   LGE1   INPUTS = SAE3
LOCATION   302   LEE2   INPUTS = SD  (O=X)
LOCATION   345   FUE3   INPUTS = AV  (OC=X)
LOCATION   322   MCE1   INPUTS = FUE3,LEE2(X=C1),LGE1
LOCATION   325   MCE2   INPUTS = FUE3,LEE2(X=C1),LGE1
LOCATION   328   SAE4   INPUTS = MCE2
LOCATION   303   MCE3   INPUTS = SAE4,LEE2,MCZ1
LOCATION   362   SAE5   INPUTS = MCE1
LOCATION   310   LEE3   INPUTS = MCE3
LOCATION   370   MCE4   INPUTS = SAE5,LEE3,LGE2
LOCATION   402   FUE4   INPUTS = AV  (OC=X)
LOCATION   410   MAE2   INPUTS = AV  (OC=X)
LOCATION   430   FUE5   INPUTS = MAE2
LOCATION   439   MCE6   INPUTS = FUE5,LGE1(X=C1),FUE4,MCE4(X=C2)
LOCATION   464   MAE3   INPUTS = ITE1,MCE5(X=C2)
LOCATION   472   FUE6   INPUTS = MAE3
LOCATION   432   MCE5   INPUTS = FUE4,MCE4(X=C1),FUE6
LOCATION   434   ITE1   INPUTS = MCE5
LOCATION   435   MAE4   INPUTS = ITE1,MCE5(X=C2)
LOCATION   512   TEF1   INPUTS = MAE4
LOCATION   515   MAF3   INPUTS = LGF1,TEF1(X=C2)
LOCATION   518   SAF1   INPUTS = MAF3
LOCATION   538   LGF1   INPUTS = SAF1
END OF MODEL
PRINT
```

F-16 LONGITUDINAL FLT CONTROL SYSTEM

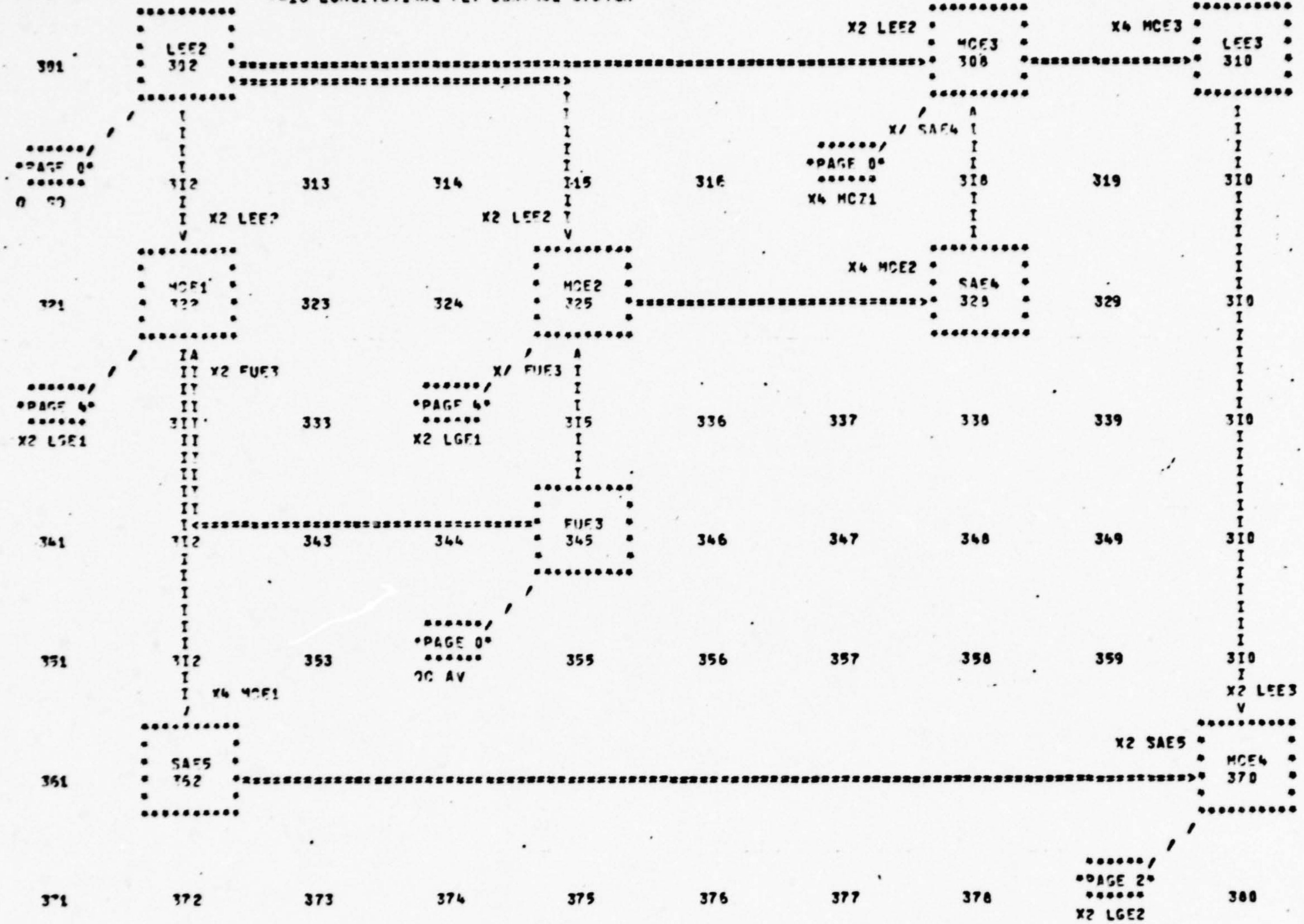



MAPL
112
X2 MAPL
LFPL
114
X2 LEPL
SAPL
117
X2 MAPL
X2 SAPL
LAPL
143
X2 LAPL
MCPL
147
X4 MCPL
LSPL
149
X2 TFPL
X2 LAPL
TFPL
165

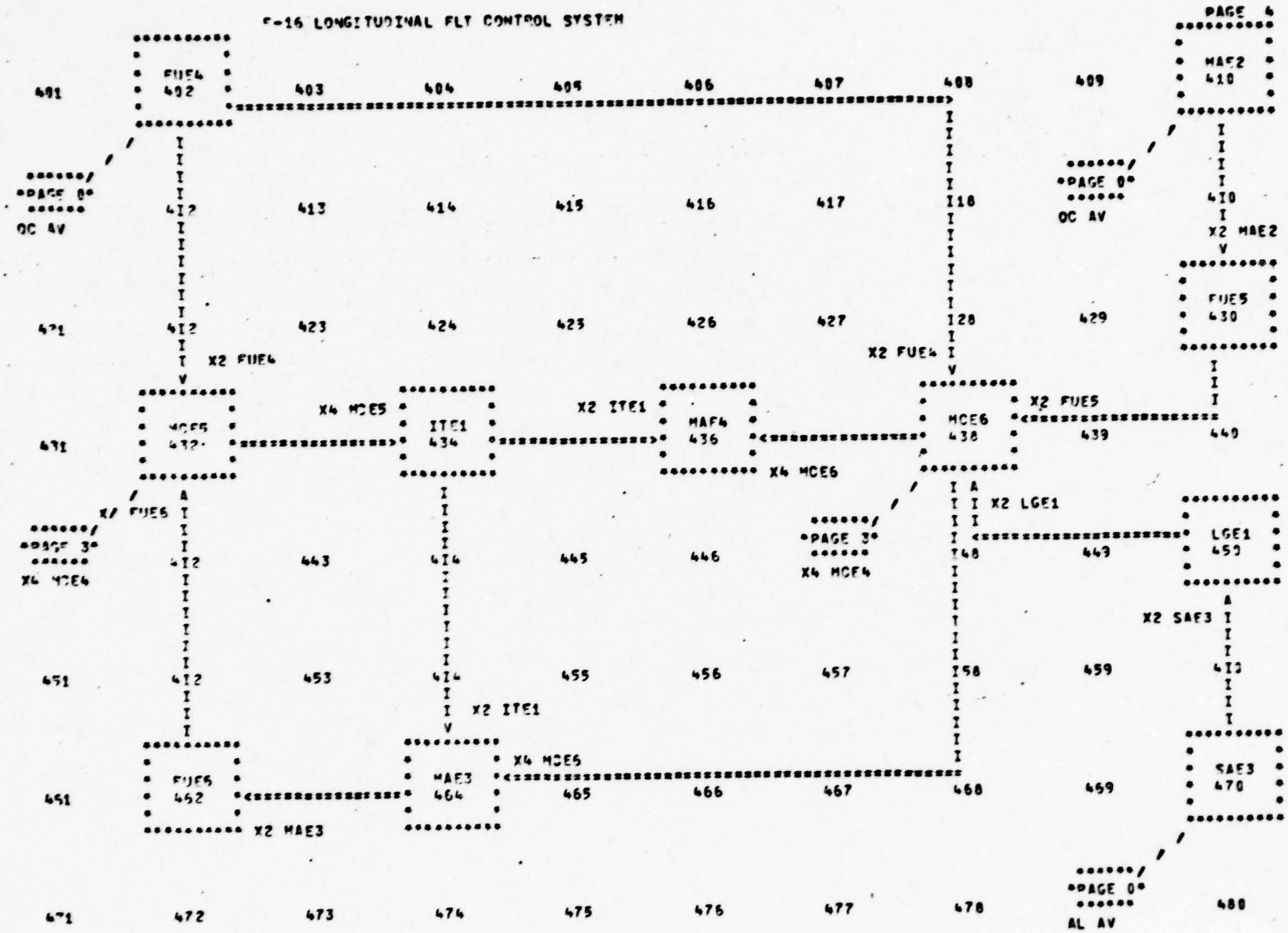

FUE1
212
X2 FUE1
SAE2
216
X2 SAE2
LGE2
219
PAGE 1
X2 LSPL
X2 FUE2
FUE2
246
PAGE 0
QC AV

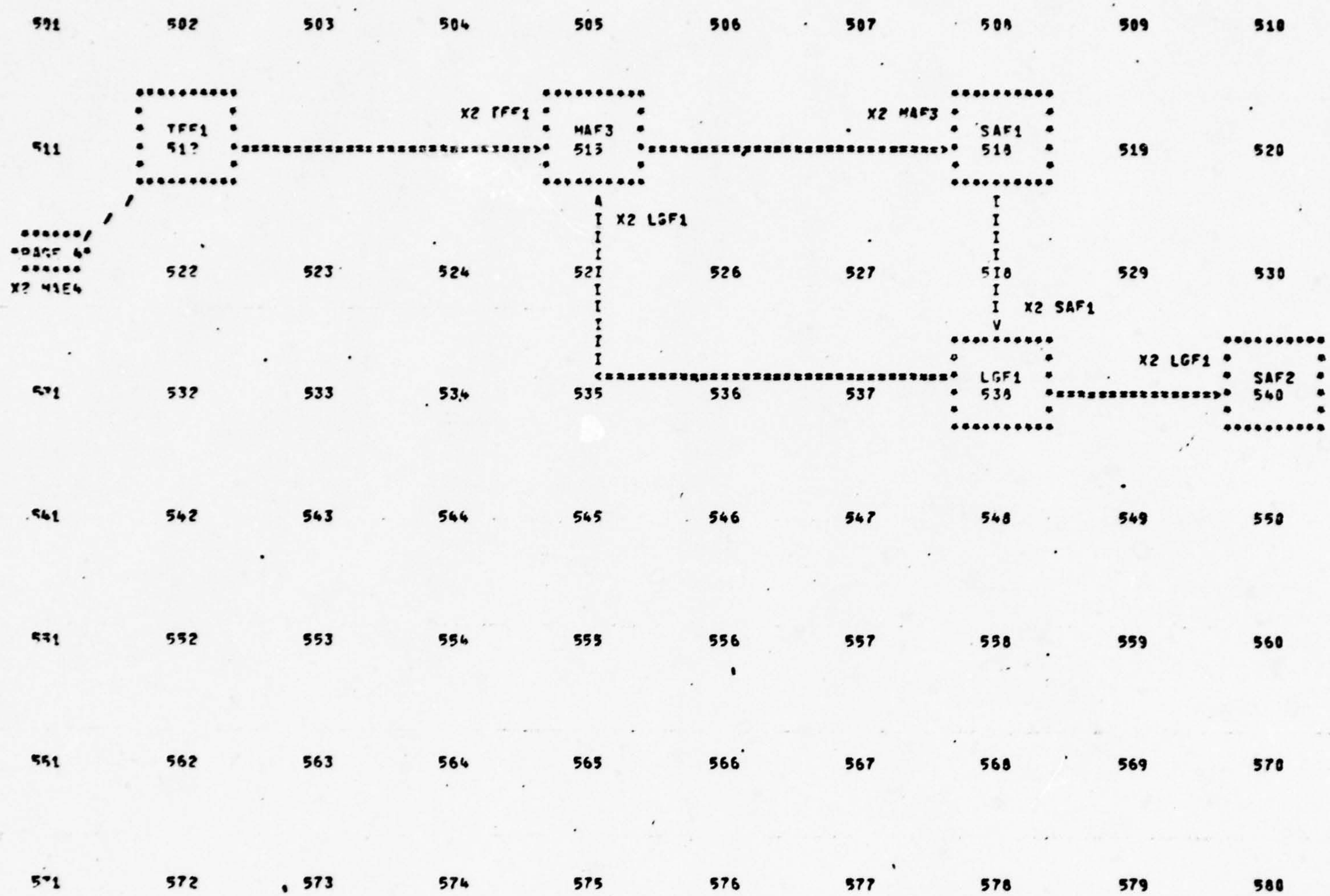
F-16 LONGITUDINAL FLT CONTROL SYSTEM

PAGE 3



F-16 LONGITUDINAL FLT CONTROL SYSTEM




501 502 503 504 505 506 507 508 509 510
TFF1
512
X2 TFF1
MAF3
513
X2 MAF3
SAF1
518
511 519 520
PAGE 4
X2 LGF1
522 523 524 521 526 527 518 529 530
X2 SAF1
LGF1
538
X2 LGF1
SAF2
540
531 532 533 534 535 536 537
541 542 543 544 545 546 547 548 549 550
551 552 553 554 555 556 557 558 559 560
561 562 563 564 565 566 567 568 569 570
571 572 573 574 575 576 577 578 579 580

Appendix B
Baseline Data for the F-16 Aircraft Simulation

A portion of the computer output of Run #43 of the Griffin program is shown as Appendix B. The stability axis derivatives were used as the test case for the F-16 aircraft simulation.

Units of the stability derivatives are given as per degree. However, it should be noted that this applies only to the dynamic derivatives that are functions of primary control surface deflections. Static derivatives were determined to be given in radian measure.

Roots of the longitudinal characteristic equation are shown along with the elevator numerator characteristics that were used to validate the dynamics of the F-16 aircraft model.

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```
INPUT DATA (STABILITY AXIS DERIVATIVES), PER DEG

    S =  3.0000E 02     MAC =  1.1320E 01    MACH =  8.0000E-01      U =  8.2956E 02     RHO =  1.2672E-03      G =  3.2108E 01
  WT =  1.9000E 04     IYY =  4.9956E 04      ZT =  0.0000E 00     LX =  0.0000E 00     TDT =  0.0000E 00     XI =  0.0000E 00
   CL =  1.4428E-01     CLA =  8.4047E-02    CLAD = -1.1518E-02    CLQ =  4.5314E-02    CLDE =  8.7012E-03    CLM =  1.5184E-01
   CD =  2.5024E-02     CDA =  2.8686E-03    CDAD =  0.0000E 00    CDQ =  0.0000E 00    CDDE = -9.1552E-04    CDM =  1.7547E-02
  CMT =  0.0000E 00     CMA =  1.6443E-03    CMAD = -1.6667E-02    CMQ = -4.0466E-02    CMDE = -1.1638E-02    CMM = -3.6183E-02
ALPHA =  2.1079E 00    GAMA =  0.0000E 00


      DIMENSIONAL STABILITY DERIVATIVES

   XU = -0.1727E-01     ZU = -0.1092E 00     MU = -0.1034E-02
   XA = -0.5366E-02     ZA = -0.1289E 01     MA =  0.3370E-02
  XAD =  0.0000E 00    ZAD =  0.1192E-02    MAD = -0.2320E-03
   XQ =  0.0000E 00     ZQ = -0.3915E 01     MQ = -0.4688E 00
   XD =  0.1159E 02     ZD = -0.1103E 03     MD = -0.1976E 02
    U =  0.8295E 03      G =  0.3210E 02   GAMA =  0.0000E 00
   XE =  0.8057E 03     LA =  0.1283E 01    NZA =  0.3315E 02
   KX =  0.9188E 01


      BODY AXIS DERIVATIVES

    U = -0.1458E-01     ZU = -0.6276E-01     MU = -0.1157E-02
    A =  0.4140E-01     ZA = -0.1292E 01     MA =  0.3330E-02
   AD = -0.4401E-04    ZAD =  0.1198E-02    MAD = -0.2326E-03
    Q =  0.1437E 00     ZQ = -0.3913E 01     MQ = -0.4688E 00
    D =  0.1587E 02     ZD = -0.1097E 03     MD = -0.1976E 02
    U =  0.8295E 03      G =  0.3210E 02   GAMA =  0.0000E 00
    E =  0.5057E 03     LA =  0.1283E 01    NZA =  0.3315E 02
   KX =  0.9188E 01


              THE CHACTERISTICS OF THE LONGITUDINAL DENOMINATOR ARE
      ROOTS (COMPLEX FORM)
         0.8282E 00           0.0000D 00
        -0.2652E-01           0.1528D 00
        -0.2652E-01          -0.1528D 00
        -0.2745D 01           0.8730D-24

 ZSP =  0.173982E 00     WSP =  0.155142E 00 RAD/SEC     1/TP1 =  0.828249E 00     1/TP2 = -0.274503E 01
                             =  0.246916E-01 CYCLES/SEC

S. RT PERIOD MODE,

        PERIOD =  0.41104E 02       TIME TO HALF AMP. =  0.26130E 02                    TIME TO ONE TENTH AMP. =  0.86802E 02
                                  CYCLES TO HALF AMP. =  0.63570E 00                  CYCLES TO ONE TENTH AMP. =  0.21117E 01
                        ONE OVER CYCLES TO HALF AMP. =  0.15730E 01     ONE OVER CYCLES TO ONE TENTH AMP. =  0.47354E 00
                                              2*Z*WN =  0.53053E-01                                      WSQ =  0.24069E-01
                                               WN/LA =  0.12020E 00                                    LA/WN =  0.82711E 01
```

```
 . = 0.999800E 00    B = 0.196742E 01    C = -0.214523E 01    D = -0.743957E-01    E = -0.546573E-01
 NO. 43          ELEVATOR NUMERATOR CHARACTERISTICS

            THETA PER DELTA ELEVATOR
         ROOTS (COMPLEX FORM)
         -0.17410-01        0.00000 00
         -0.13120 01        0.00000 00

 1/TT1 = -0.174129E-01     1/TT2 = -0.131219E 01

 AT = -0.197158E 02    BT = -0.262143E 02    CT = -0.450490E 00

            HORIZONTAL VELOCITY PER DELTA ELEVATOR  (u)
         ROOTS (COMPLEX FORM)
         -0.12130 01        0.00000 00
         -0.39510 00        0.74770 01
         -0.39510 00       -0.74770 01

 ZU = 0.514013E-01    WU = 0.744720E 01    1/TV = -0.121346E 01

 AU = 0.115816E 02    BU = 0.232062E 02    CU = 0.695503E 03    DU = 0.830504E 03

            ALTITUDE PER DELTA ELEVATOR
         ROOTS (COMPLEX FORM)
         -0.14350-01        0.00000 00
          0.13870 02        0.00000 00
         -0.14020 02        0.00000 00

 1/TH1 = -0.143564E-01      1/TH2 = 0.138773E 02      1/TH3 = -0.140298E 02

 AH = 0.110205E 03    BH = 0.183837E 02    CH = -0.214565E 05    DH = -0.308043E 03

            VERTICAL VELOCITY PER DELTA ELEVATOR  (w) = α/u
         ROOTS (COMPLEX FORM)
         -0.88440-02       -0.62710-01
         -0.88440-02        0.62710-01
         -0.14850 03       -0.24360-12

 ZW = 0.139456E 00     WW = 0.433330E-01     1/TW = -0.148559E 03

 AW = -0.110205E 03    BW = -0.163740E 05    CW = -0.290061E 03    DW = -0.656698E 02
```

Appendix C
TAWDS Programming Details

Included as Appendix C is the Terminal Aerial Weapon Delivery Simulation program data, program output, and additional program statements.

The extensive data list required for the program operation is shown on pages 106 through 114. Pages 106 through 108 lists the input data required. The stability derivative requirements for the non-linear, six-degree-of-freedom simulation are shown on pages 109 through 114.

The TAWDS output of encounter 8 for the present F-16 flight control system is shown on pages 115 through 129. Pages 130 through 145 show the program output of the same encounter with the pitch rate control configuration.

The Appendix is concluded with a listing of the program statements required to adapt the generic TAWDS program for an F-16 aircraft simulation, pages 146 through 154. The programmed target rates are shown on page 146 along with the target maneuvers of page 147. The control statements added to program the F-16 flight control system begin on page 147. Included are the logic statements for the gain scheduled parameters of the flight control system that are functions of static and dynamic pressure.

```
BEGIN***NCNTRL
MERGE                    0
ENDSET**
BEGIN***NAMINT
INITTIME      1   1   10.
FINTIME       1   1   115.1
CUTTOL        1   1   1          1.E-4
UPERROR       1   1   1          1.E-4
LOERROR       1   1   1          1.E-6
MAXSTEP       1   1   1.05
STEPVAR       1
STEPFACT      0
ENDSET
BEGIN***NAMCN1
ACCOFGVY                 32.174
MASS                     590.5
CORDLGTH                 11.32
MACHCNST                 829.
WINGAREA                 300.
XXDYADIC                 9007.5
XZDYADIC                 198.
YYDYADIC                 +9956.
ZZDYADIC                 56770.
NACCAXIS                 0.
WATERANG                 0.
THMOMARM                 .333
WINGSPAN                 31.
THANG                    0.
MAXTH                    25000.
XLATACRM                 12.58
YLATACRM                 0.
ZLATACRM                 .5
XGYROPOS                 18.24
YGYROPOS                 0.
ZGYROPOS                 -.95
XNOMACRM                 12.8
YNOMACRM                 0.
ZNOMACRM                 .42
SCNOFGVY                 .35
CENOFGVY                 .35
PILOTLOC                 15.          0.          -3.75
GYROANG                  0.
MANLOGON                 0.
IMSTAB                   1.
NIC                      3.
ATTERVEL                 829.5
ALTITUDE                 20000.
ATTPOSX                  0.0
ATTPOSY                  0.0
ATTPOSZ                  -20000.
RLSI                     5000.
RDOTI                    -100.
ELVERR                   10.0
```

```
TRAERR                  10.0
LOCOMIND                1.
BULCON                  .00614
SGHTFACT                .4
BWHT                    0.
DAMP                    0.
SWYAW                   0.
DHF                     2250.
MZLEVEL                 3400.
DGMABA      1   3       5.58       -2.21      0.
DGTABA      1   3       10.8       -2.21      0.
GN1ELANG                .5
GN1AZMTH                0.
FTGUN       1   5       0.         0.         0.        .05       1500.
FTGUN       5  10       .1         2800.      .3        2800.     .5
GUNFORI                 1500.
GUNFORSS                2800.
RTIMGUN                 .05
UPRNKLM                 100.
LORNKLM                 -100.
UPPERG                  500.
LOWERG                  -500.
DZEDOT                  .001
DZBANK                  0.0
GKPHI                   3.283
RCONV                   0.
CBEL1       1   2       0.         1.
CCEL1       1   2       1.         .05
CBEL2       1   2       .125       0.
CCEL2       1   2       1.         .05
CBEL3       1   3       1.         0.         0.
CCEL3       1   3       1.         1.2        1.
CBBNK       1   2       0.         1.
CCBNK       1   2       1.         .05
CBRAN       1   2       1.5        0.
CCRAN       1   2       1.         .05
GCONT       1   2       .250       .250
ARANGE      1   2       0.         1000000.
NPLS                    2.
BCONT       1   2       .1         .1
AELVERG     1   2       -100.      100.
NELV1                   2.
DZTDOTT     1   2       0.0        0.0
AELVERD     1   2       -100.      100.
NELV2                   2.
IPERF                   1.
INC                     0.
IPRESP                  0.
NRUN                    1.
DTF                     .05
IRANDNO1                11.
DMC                     6.
DTMC                    6.
LGST                    1750.
```

```
SDV                      4.7
SDALF                    .003
SDBET                    .004
SDH                      100.
SDPLS                    30.
SDRDOT                   0.
SDVM                     50.
SDIGL                    .0015
SDEGL                    .0015
SDTHD                    .001
SDEHD                    .001
SDLSPT                   .01
SDLSPE                   .01
ELVCPI                   100.
TRACPI                   100.
RADCPI                   100.
CASEIDES                 1.
PRINTIND                 7.
ENDSET**
BEGIN***NAMCN2
GKNL2                    30.1
GKNL1                    2.175
CKMECH                   1.0
CBSE          1   2      1.25        0.0
CCSE          1   2      1.0         0.12
GK6                      5.0
TRFACTOR                 0.5
CKF                      0.3
CBSDML        1   3      1.0         0.1333      0.0
CCSDML        1   3      1.0         0.0667      0.0
DSLU                     25.0
DSLL                     -25.0
CBSTAB        1   2      1.0         0.0
CCSTAB        1   2      1.0         0.05
GKNZ2                    0.0
GKNZ3                    0.5
GKNZ1                    0.5075
CBNZ          1   2      1.0         0.0
CCNZ          1   2      1.0         0.1
CBDD          1   2      1.0         0.0
CCDD          1   2      1.0         0.0
CKFB                     0.161
DSHI                     25.0
DSLO                     -25.0
CBRE          1   2      1.0         0.0
CCRE          1   2      1.0         0.1
DAHI                     20.0
DALO                     -20.0
CBNY          1   2      0.0         1.5
CCNY          1   2      1.0         1.0
CBYR          1   2      1.0         .20
CCYR          1   2      1.0         .0667
FUDHI                    30.0
FUDLO                    -30.0
```

```
ENDSET**
BEGIN***NAMTB1
NADRAGSC     10
ADRAGSC       1  5   0.0       4.        8.        10.       12.
ADRAGSC       6 10   14.       16.       20.       24.       28.
NMDRAGSC      2
MDRAGSC       1  2   .8        .9
DRAGSC        1  5   .0194     .0207     .0313     .0362     .0725
DRAGSC        6 10   .0918     .1077     .1286     .1517     .1677
DRAGSC       11 15   .2029     .2209     .2619     .2755     .4116
DRAGSC       13 16   .4309     .5852     .6054     .7849     .8150
NALFTSTB     10
ALFTSTB       1  5   0.        4.        8.        10.       12.
ALFTSTB       6 10   14.       16.       20.       24.       28.
NMLFTSTB      2
MLFTSTB       1  2   .8        .9
LFTSTBSC      1  5   -.02      -.0005    .3285     .3715     .6803
LFTSTBSC      6 10   .7471     .8223     .8638     .9458     .9845
LFTSTBSC     11 15   1.0721    1.0836    1.1632    1.1797    1.3822
LFTSTBSC     16 20   1.3939    1.5652    1.6103    1.7166    1.7644
NAPCHMOM     10
APCHMOM       1  5   0.        4.        8.        10.       12.
APCHMOM       6 10   14.       16.       20.       24.       28.
NMPCHMOM      2
MPCHMOM       1  2   .8        .9
PCHMOMC       1  5   -.0235    -.0302    -.0183    -.0244    -.0193
PCHMOMC       6 10   -.0425    -.0233    -.0454    -.03      -.0592
PCHMOMC      11 15   -.0407    -.0855    -.0537    -.0975    -.0865
PCHMOMC      16 20   -.1419    -.1132    -.1743    -.1152    -.1957
NADSSA        5
ADSSA         1  6   0.        4.        19.       25.       27.       30.
NMDSSA        2
MDSSA         1  2   .8        .9
NBDSSA        2
BDSSA         1  2   0.        4.
DSSLPANG      1  6   0.        -.072     0.        -.074     0.        -.068
DSSLPANG      7 12   0.        -.066     0.        -.064     0.        -.064
DSSLPANG     13 18   0.        -.05      0.        -.044     0.        -.05
DSSLPANG     19 24   0.        -.044     0.        -.058     0.        -.054
NADYSA        5
ADYSA         1  6   0.        10.       16.       20.       25.       30.
NMDYSA        2
MDYSA         1  2   .8        .9
NBDYSA        2
BDYSA         1  2   0.        4.
DYSLPANG      1  6   0.        .0108     0.        .011      0.        .0124
DYSLPANG      7 12   0.        .0112     0.        .0124     0.        .0096
DYSLPANG     13 18   0.        .0108     0.        .0108     0.        .0062
DYSLPANG     19 24   0.        .0044     0.        .0012     0.        .0016
NADRSA        8
ADRSA         1  4   0.        3.        6.        11.
ADRSA         5  8   15.       20.       26.       30.
NMDRSA        2
MDRSA         1  2   .8        .9
```

NADRSA	2							
ADRSA	1	2	0.	4.				
DRSLPANG	1	6	0.	-.0068	0.	-.0068	0.	-.0084
DRSLPANG	7	12	0.	-.009	0.	-.0072	0.	-.0098
DRSLPANG	13	18	0.	-.006	0.	-.0080	0.	-.0034
DRSLPANG	19	24	0.	-.0074	0.	-.0090	0.	-.0076
DRSLPANG	25	30	0.	-.005	0.	-.0136	0.	-.007
DRSLPANG	31	32	0.	-.014				
NADSRD	5							
ADSRD	1	6	0.	3.	5.	17.	24.	30.
NMDSRD	2							
MDSRD	1	2	.8	.9				
NBDSRD	2							
BDSRD	1	2	0.	1.				
DSRUDDEL	1	6	.0033	.0033	.0029	.0029	.0032	.0032
DSRUDDEL	7	12	.0029	.0029	.00285	.00285	.00295	.00295
DSRUDDEL	13	18	.0021	.0021	.0012	.0012	.0031	.0031
DSRUDDEL	19	24	.0022	.0022	.0026	.0026	.0024	.0024
NADYRD	5							
ADYRD	1	5	0.	6.	20.	25.	30.	
NRDYRD	2							
RDYRD	1	2	-30.	30.				
NMDYRD	2							
MDYRD	1	2	.8	.9				
NBDYRD	2							
BDYRD	1	2	-30.	30.				
DYRUDDEL	1	5	-.00165	-.00165	-.0015	-.0015	-.00165	
DYRUDDEL	6	10	-.00165	-.0015	-.0015	-.0016	-.0015	
DYRUDDEL	11	15	-.0015	-.0015	-.0016	-.0016	-.0015	
DYRUDDEL	16	20	-.0015	-.00155	-.00155	-.00125	-.00125	
DYRUDDEL	21	25	-.00155	-.00155	-.00125	-.00125	-.0016	
DYRUDDEL	26	30	-.0016	-.00115	-.00115	-.0016	-.0016	
DYRUDDEL	31	35	-.00115	-.00115	-.001	-.001	-.00095	
DYRUDDEL	36	40	-.00095	-.001	-.001	-.00095	-.00095	
NADRRD	5							
ADRRD	1	6	0.	4.	10.	20.	25.	30.
NRDRRD	2							
RDRRD	1	2	-30.	30.				
NMDRRD	2							
MDRRD	1	2	.8	.9				
NBDRRD	2							
BDRRD	1	2	-30.	30.				
DRRUDDEL	1	6	.0006	.0006	.0006	.0006	.0006	.0006
DRRUDDEL	7	12	.0006	.0006	.00035	.00035	.00035	.00035
DRRUDDEL	13	18	.00035	.00035	.00035	.00035	.0002	.0002
DRRUDDEL	19	24	0.	0.	.0002	.0002	0.	0.
DRRUDDEL	25	30	-.0001	-.0001	-.00005	-.00005	-.0001	-.0001
DRRUDDEL	31	36	-.00005	-.00005	-.0004	-.0004	-.00045	-.00045
DRRUDDEL	37	42	-.0004	-.0004	-.00045	-.00045	-.0003	-.0003
DRRUDDEL	43	48	-.00035	-.00035	-.0003	-.0003	-.00035	-.00035
NADSAD	4							
ADSAD	1	4	0.	5.	22.	30.		
NSDSAD	2							
SDSAD	1	2	-30.	30.				

```
NMDSAD       2
MDSAD        1  2   .8        .9
DSAILDEL     1  4   .0004     .0004     .0004     .0004
DSAILDEL     5  8   .0003     .0003     .0003     .0003
DSAILDEL     9 12   -.0004    -.0004    -.0004    -.0004
DSAILDEL    13 15   -.0012    -.0008    -.0012    -.0008
NADYAD       5
ADYAD        1  5   0.        11.       15.       25.       30.
NSDYAD       2
SDYAD        1  2   -30.      30.
NMDYAD       2
MDYAD        1  2   .8        .9
DYAILDEL     1  5   -.00025   -.00025   -.00025   -.00025   .000245
DYAILDEL     6 10   .00015    .000245   .00015    .0003     .00015
DYAILDEL    11 15   .0003     .00015    .0007     .0006     .0007
DYAILDEL    16 20   .0006     .0007     .00035    .0007     .00035
NADRAD       5
ADRAD        1  6   0.        7.        16.       21.       25.       30.
NSDRAD       2
SDRAD        1  2   -30.      30.
NMDRAD       2
MDRAD        1  2   .8        .9
DRAILDEL     1  6   -.00155   -.0014    -.00155   -.0014    -.0016    -.00145
DRAILDEL     7 12   -.0016    -.00145   -.00105   -.0009    -.00105   -.0009
DRAILDEL    13 18   -.0012    -.00085   -.0012    -.00085   -.001     -.00065
DRAILDEL    13 24   -.001     -.00065   -.0004    -.00015   -.0004    -.00015
NADSDET      5
ADSDET       1  6   0.        4.        8.        18.       24.       30.
NSDSDET      2
SDSDET       1  2   -30.      30.
NMDSDET      2
MDSDET       1  2   .8        .9
DSDIFFT      1  6   .0019     .00165    .0019     .00165    .0019     .0017
DSDIFFT      7 12   .0019     .0017     .0017     .0014     .0017     .0014
DSDIFFT     13 18   .0012     .0004     .0012     .0004     .0008     .0005
DSDIFFT     19 24   00008     .0005     .0007     .0002     .0007     .0002
NADYDET      4
ADYDET       1  4   0.        18.       24.       30.
NSDYDET      2
SDYDET       1  2   -30.      30.
NMDYDET      2
MDYDET       1  2   .8        .9
DYDIFFT      1  4   -.001     -.0009    -.001     -.0009
DYDIFFT      5  8   -.0001    .0001     -.0001    .0001
DYDIFFT      9 12   .0002     .0003     .0002     .0003
DYDIFFT     13 16   .0005     .00055    .0005     .00055
NADRDET      7
ADRDET       1  4   0.        5.        10.       18.
ADRDET       5  7   20.       23.       30.
NSDRDET      2
SDRDET       1  2   -30.      30.
NMDRDET      2
MDRDET       1  2   .8        .9
DRDIFFT      1  4   -.0015    -.0014    -.0015    -.0014
```

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```
DRDIFFT     5  8   -.0016      -.00145     -.0016      -.00145
DRDIFFT     9 12   -.00135     -.00155     -.00135     -.00155
DRDIFFT    13 16   -.00135     -.00105     -.00135     -.00105
DRDIFFT    17 20   -.00155     -.00105     -.00155     -.00105
DRDIFFT    21 24   -.0012      -.0009      -.0012      -.0009
DRDIFFT    25 28   .001        .0006       .001        .0006
NMDRCHP     2
MDRCHP      1  2   .8          .9
DPCHPCH     1  2   -2.25       -2.3
NMDRCHA     2
MDRCHA      1  2   .8          .9
DPCHANG     1  2   -.94        -1.3
NADRVL      5
ADRVL       1  5   0.          6.          13.         19.         30.
NMDRVL      2
MDRVL       1  2   .8          .9
DRROLVEL    1  5   -.29        -.35        -.295       -.345       -.225
DRROLVEL    5 10   -.225       -.245       -.315       -.15        -.215
NADRYV      5
ADRYV       1  5   0.          6.          14.         24.         30.
NMDRYV      2
MDRYV       1  2   .8          .9
DRYAWVEL    1  5   -.05        -.05        .1          .16         .175
DRYAWVEL    5 10   .27         .4          .4          .42         .51
NADYRL      5
ADYRL       1  6   0.          5.          8.          13.         22.         30.
NMDYRL      2
MDYRL       1  2   .8          .9
DYROLVEL    1  6   .004        .002        -.024       -.02        -.024       -.013
DYROLVEL    7 12   .004        .004        .06         .048        .055        .074
NADYYV      6
ADYYV       1  6   0.          6.          16.         20.         25.         30.
NMDYYV      2
MDYYV       1  2   .8          .9
DYYAWVEL    1  5   -.12        -.1         -.18        -.225       -.26        -.22
DYYAWVEL    7 12   -.255       -.26        -.275       -.26        -.15        -.185
NMDSSD      2
MDSSD       1  2   .8          .9
DSSTRDEL    1  2   -.43        -.43
NMDPCHS     2
MDPCHS      1  2   .8          .9
DPCHSTR     1  2   -.659       -.659
NADSRV      7
ADSRV       1  5   -100000.0 -6.0          6.0         12.0        16.0
ADSRV       5  7   28.0        100000.0
NMDSRV      2
MDSRV       1  2   .8          .9
DSROLVEL    1  6   -.18        -.15        -.18        -.15        .18         .15
DSROLVEL    7 12   .15         .12         .07         .1          .07         .02
DSROLVEL   13 14   .07         .02
NADSYV      2
ADSYV       1  2   -30.        30.0
NMDSYV      2
MDSYV       1  2   0.0         20.0
```

DSYAWVEL	1	4	0.0	0.0	0.0	0.0		
NMDRER	2							
MDRER	1	2	-30.0	30.0				
DREXPAT	1	2	0.0	0.0				
NMDYER	2							
MDYER	1	2	-30.0	30.0				
DYEXPAT	1	2	0.0	0.0				
NMDSER	2							
MDSER	1	2	-30.0	30.0				
DSEXPAT	1	2	0.0	0.0				
NMDRTE	2							
MDRTE	1	2	-30.0	30.0				
NSDRTE	2							
SDRTE	1	2	-30.0	30.0				
NADRTE	2							
ADRTE	1	2	-30.0	30.0				
DRTFLEX	1	6	0.0	0.0	0.0	0.0	0.0	0.0
DRTFLEX	7	8	0.0	0.0				
NMDYTE	2							
MDYTE	1	2	-30.0	30.0				
NSDYTE	2							
SDYTE	1	2	-30.0	30.0				
NADYTE	2							
ADYTE	1	2	-30.0	30.0				
DYTFLEX	1	6	0.0	0.0	0.0	0.0	0.0	0.0
DYTFLEX	7	8	0.0	0.0				
NMDSTE	2							
MDSTE	1	2	-30.0	30.0				
NSDSTE	2							
SDSTE	1	2	-30.0	30.0				
NADSTE	2							
ADSTE	1	2	-30.0	30.0				
DSTFLEX	1	6	0.0	0.0	0.0	0.0	0.0	0.0
DSTFLEX	7	8	0.0	0.0				
NMDLA	2		2					
MDLA	1	2	-30.0	30.0				
DLFTANG	1	2	0.0	0.0				
NCDRSA	2							
CDRSA	1	2	-30.0	30.0				
DRSACAN	1	2	0.0	0.0				
NCDYSA	2							
CDYSA	1	2	-30.0	30.0				
DYSACAN	1	2	0.0	0.0				
NCDSSA	2							
CDSSA	1	2	-30.0	30.0				
DSSACAN	1	2	0.0	0.0				
NCLFT	2							
CLFT	1	2	-30.0	30.0				
LFTCAN	1	2	0.0	0.0				
NCDRAG	2							
CDRAG	1	2	-30.0	30.0				
DRAGCAN	1	2	0.0	0.0				
NCPCHM	2							
CPCHM	1	2	-30.0	30.0				

```
DPCHMCAN    1  2   0.0        0.0
NCPCHP      2
CPCHP       1  2   -30.0      30.0
DPCHPCAN    1  2   0.0        0.0
NMDRRDF     2
MDRRDF      1  2   -30.0      30.0
DRRDFLEX    1  2   1.0        1.0
NMDYRDF     2
MDYRDF      1  2   -30.0      30.0
DYRDFLEX    1  2   1.0        1.0
NMDSRDF     2
MDSRDF      1  2   -30.0      30.0
DSRDFLEX    1  2   1.0        1.0
NMDLP       2
MDLP        1  2   -30.       30.0
DLETPCH     1  2   0.         0.
NMDYTF      2
MDYTF       1  2   -30.       30.
NSDYTF      2
SDYTF       1  2   -30.       30.
NADYTF      2
ADYTF       1  2   -30.       30.
DYTFLEX     1  7
DYTFLEX     7  8
NAIRALT    25
AIRALT      1  6   0.         2000.      4000.      6000.      8000.      10000.
AIRALT      7 12   12000.     14000.     16000.     18000.     20000.     22000.
AIRALT     13 18   24000.     26000.     28000.     30000.     32000.     34000.
AIRALT     19 24   36000.     38000.     40000.     42000.     44000.     46000.
AIRALT     25 26   48000.     50000.
AIRDNTY     1  6   .00238     .00224     .00211     .00199     .00187     .00176
AIRDNTY     7 12   .00165     .00155     .00145     .00135     .00127     .00118
AIRDNTY    13 18   .0011      .00103     .000957    .000889    .000826    .000766
AIRDNTY    19 24   .000704    .000640    .000582    .000529    .000481    .000437
AIRDNTY    25 26   .000397    .000361
NMTHMX      2
MTHMX       1  2   .1         1.2
THMX        1  2   12500.     12500.
NMTLGTH     2
MTLGTH      1  2   -30.       30.
TLGTH       1  2   15.87      15.87
ENDSET**
```

CASE = 1. ENCOUNTER = 8

TAWDS COMPUTER PROGRAM

TIME	ATTACKER: POSITION X	Y	Z	VELOCITY XDOT	YDOT	ZDOT	TARGET: POSITION EARTH COORD X	Y	Z	AIR-SPEED	BODY RATES P	Q	R	ALPHA	LOAD FACTOR
SEC	FEET	FEET	FEET	FEET/SEC	FEET/SEC	FEET/SEC	FEET	FEET	FEET	FT/SEC	DEGREES/SEC	DEGREES/SEC	DEGREES/SEC	DEG	G
0.00	0.0	0.0	-20000.0	827.6	0.0	0.0	7012.2	-75.2	-19788.9	627.63	19.91	5.60	1.33	3.83	1.00
.35	289.7	-.0	-19999.9	828.0	-.0	1.1	7231.8	-75.0	-19790.5	627.57	44.70	6.99	5.26	5.79	1.41
.70	579.5	-.0	[illegible]	828.5	-.2	5.3	7451.4	-72.6	-19794.5	626.31	44.79	8.30	7.52	7.75	1.78
1.05	869.7	-.1	-19996.0	829.1	-.1	11.5	7670.4	-68.7	-19799.5	625.29	44.00	9.79	9.67	9.71	2.11
1.40	1160.0	-.1	-19990.5	829.8	.2	17.7	7888.4	-58.1	-19805.3	622.45	42.63	11.29	11.46	11.67	2.40
1.75	1450.5	.2	-19983.9	830.4	1.6	21.2	8104.7	-39.5	-19812.7	618.41	36.26	12.74	11.77	13.63	2.63
2.10	1741.3	1.4	-19976.4	830.9	6.1	21.4	8318.3	-11.2	-19818.7	613.52	-.76	7.98	2.89	14.75	2.72
2.45	2032.2	4.9	-19969.0	831.3	14.6	21.0	8528.7	27.3	-19822.0	608.82	-.77	7.84	2.91	14.75	2.69
2.80	2323.2	12.0	-19961.6	831.5	26.2	21.3	8735.4	75.8	-19822.3	604.57	-.77	7.80	2.93	14.75	2.66
3.15	2614.2	23.5	-19954.0	831.3	40.1	22.1	8938.0	134.0	-19819.7	600.75	-.78	7.77	2.95	14.75	2.63
3.50	2905.1	40.2	-19946.1	830.8	55.3	23.4	9136.4	201.7	-19814.2	597.37	-.78	7.74	2.97	14.75	2.61
3.85	3195.7	62.2	-19937.5	830.0	70.6	25.6	9330.0	278.6	-19805.8	594.41	-.78	7.72	2.98	14.75	2.59
4.20	3485.9	88.6	-19928.0	828.9	85.5	28.9	9518.7	364.3	-19794.5	591.85	-.79	7.70	2.99	14.75	2.58
4.55	3775.3	122.1	-19917.3	827.7	100.3	32.7	9702.1	458.7	-19780.4	589.58	-.79	7.69	3.00	14.75	2.56
4.90	4065.3	158.8	-19905.1	826.1	115.3	35.9	9879.9	561.6	-19763.5	587.91	-.79	7.67	3.00	14.75	2.56
5.25	4354.2	202.8	-19891.5	824.3	130.6	41.0	10051.7	672.5	-19743.9	586.50	-.79	7.67	3.00	14.75	2.55
5.60	4642.3	251.2	-19876.4	822.2	145.8	45.3	10217.4	791.3	-19721.5	585.47	-.79	7.66	3.00	14.75	2.55
5.95	4929.7	304.9	-19859.7	818.8	161.1	49.7	10376.5	917.7	-19696.5	584.78	17.91	7.56	7.92	14.75	2.56
6.30	5216.2	[illegible]	-19841.6	[illegible]	176.6	54.0	10528.3	1051.4	-19668.6	584.45	32.65	8.28	11.81	14.75	2.56
6.65	5501.6	424.6	-19821.9	814.1	192.3	58.3	10673.9	1192.0	-19636.4	584.44	32.68	8.93	11.70	14.75	2.57
7.00	5785.0	499.8	-19800.8	810.7	208.5	62.3	10811.1	1338.8	-19597.8	585.15	32.74	9.54	11.45	14.75	2.58
7.35	6069.1	574.6	-19777.8	806.9	224.7	68.4	10940.7	1490.6	-19551.0	585.75	32.93	10.08	11.10	14.75	2.60
7.70	6350.7	656.0	-19752.7	802.7	240.6	75.5	11062.8	1645.9	-19494.4	588.25	32.95	10.53	10.66	14.75	2.63
8.05	6631.9	743.0	-19724.7	798.1	256.3	84.0	11177.9	1803.0	-19426.4	590.85	-.38	10.80	1.46	14.75	2.66
8.40	6909.3	835.5	-19693.0	792.8	272.1	97.1	11286.2	1960.6	-19346.4	594.05	-.38	10.76	1.44	14.75	2.69
8.75	7185.7	933.5	-19656.4	786.6	288.2	112.0	11387.9	2117.8	-19254.4	597.63	-.37	10.73	1.42	14.75	2.74
9.10	7459.9	1037.3	-19614.3	779.3	304.9	129.4	11481.9	2274.1	-19150.5	602.12	-.37	10.70	1.39	14.75	2.78
9.45	7731.1	1147.0	-19565.6	770.8	321.9	149.1	11568.3	2429.0	-19035.3	606.90	-.36	10.66	1.37	14.75	2.83
9.80	7999.2	1262.6	-19509.7	761.2	338.5	170.7	11646.5	2581.6	-18909.8	612.13	-.35	10.53	1.34	14.75	2.89
10.15	8263.3	1383.9	-19445.9	750.6	354.8	194.0	11718.1	2732.0	-18771.3	617.59	-.36	14.97	1.31	15.59	3.01
10.50	8524.5	1510.9	-19373.7	738.6	370.7	219.2	11776.4	2879.0	-18623.2	627.24	-.39	15.11	1.27	17.05	3.14
10.85	8781.7	1643.4	-19292.2	725.1	386.2	246.5	11826.3	3021.9	-18465.0	628.93	-.41	15.11	1.23	18.53	3.22
11.20	9031.8	1781.2	-19200.9	709.6	401.3	275.9	11867.2	3159.9	-18297.1	634.75	-.43	11.15	1.19	20.00	3.39
11.55	9277.2	1924.2	-19098.9	692.1	415.7	307.3	11896.5	3292.4	-18120.0	640.43	-.42	11.09	1.16	20.00	3.45
11.90	9516.0	2072.1	-18985.6	671.9	429.2	341.0	11914.9	3418.6	-17934.4	646.41	-.41	11.06	1.13	20.00	3.53
12.25	9747.2	2224.5	-18860.0	648.8	441.6	377.0	11921.7	3537.9	-17741.1	652.49	-.40	11.03	1.11	20.00	3.62
12.60	9969.7	2381.0	-18721.4	621.9	452.4	415.3	11916.9	3649.6	-17540.8	659.64	-.39	11.00	1.08	20.00	3.70
12.95	10182.0	2541.0	-18569.6	590.8	461.5	456.0	11900.2	3753.0	-17334.3	664.83	-.38	10.98	1.05	20.00	3.79
13.30	10382.6	2703.7	[illegible]	[illegible]	[illegible]	[illegible]	11871.5	3847.7	-17123.5	671.04	-.37	10.97	1.02	20.00	3.89
13.65	10567.7	2874.3	-18219.5	[illegible]	[illegible]	544.0	11830.9	3932.0	-16906.4	677.17	-.36	10.95	1.00	20.00	3.97
14.00	10741.0	3043.3	-18020.9	[illegible]	470.8	590.7	11778.0	4008.3	-16686.8	683.20	-.35	10.94	.97	20.00	4.07
14.35	10894.2	3187.2	-17815.9	409.5	465.0	638.4	11713.1	4073.2	-16464.9	689.66	-.34	10.93	.95	20.00	4.16
14.70	11026.8	3359.0	-17574.1	346.9	453.0	685.4	11636.2	4127.1	-16241.8	694.73	-.34	10.92	.92	20.00	4.25
15.05	11136.4	3513.5	-17326.4	278.6	434.1	729.3	11547.5	4169.6	-16018.4	700.14	-.33	10.91	.90	20.00	4.34

CASE = 1.   ENCOUNTER = 8

TAMOS COMPUTER PROGRAM

ATTACKER VARIABLES

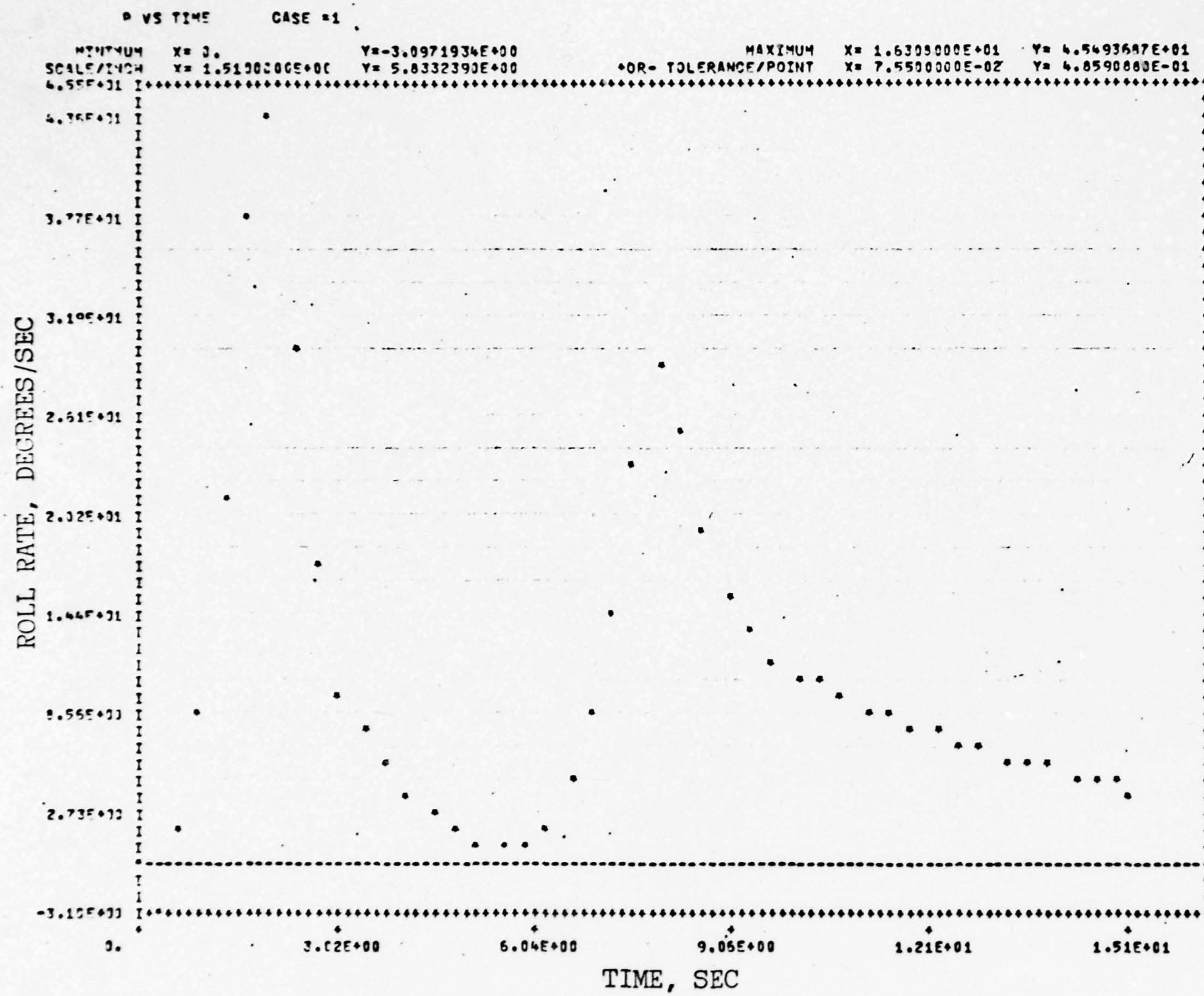
TIME SEC	// PILOT COMMANDS //// LONG //	LAT	DIR ////	STAB	SURFACE DEFLECTIONS CANARD	AIL DEGREES	DIF-TAIL	RUD ////.	//// ATTITUDE ANGLES PSI	THETA DEGREES	PHI	// GAMMA //	MACH	THRUST LBS
0.00	0.00	.00	0.00	-1.84	0.00	0.00	0.00	0.00	0.00	1.75	0.00	0.00	.80	3783.
.35	.53	-.87	0.00	-1.67	0.00	-.08	0.00	-.06	-.31	1.30	-.72	-.05	.80	3783.
.70	4.24	1.91	0.00	-1.91	0.00	-.79	0.00	-.07	.01	.54	-1.03	-.34	.80	3783.
1.05	8.11	3.37	0.00	-1.97	0.00	-1.42	0.00	-.09	.09	-.85	.77	-.76	.80	3783.
1.40	11.37	5.82	0.00	-2.18	0.00	-4.28	0.00	-.14	.23	-.31	5.77	-1.13	.80	3783.
1.75	11.85	7.69	0.00	-1.92	0.00	-5.04	0.00	-.11	.57	-.01	16.39	-1.43	.80	3783.
2.10	11.70	9.37	0.00	-1.67	0.00	-3.75	0.00	.26	1.29	.40	31.37	-1.49	.80	3783.
2.45	12.23	7.50	0.00	-1.74	0.00	-1.52	0.00	.77	2.24	.55	44.67	-1.45	.80	3783.
2.80	12.77	6.64	0.00	-1.77	0.00	-.67	0.00	.78	3.28	.57	52.89	-1.46	.80	3783.
3.15	11.45	5.64	0.00	-1.65	0.00	-.81	0.00	1.04	4.63	.51	57.36	-1.52	.80	3783.
3.50	10.56	4.94	0.00	-1.62	0.00	-.63	0.00	.95	5.85	.28	60.25	-1.60	.80	3783.
3.85	10.50	3.99	0.00	-1.72	0.00	-.38	0.00	.79	6.91	-.12	62.39	-1.75	.80	3783.
4.20	10.31	3.11	0.00	-1.80	0.00	-.21	0.00	.62	7.93	-.55	63.95	-1.97	.80	3783.
4.55	10.56	2.37	0.00	-1.78	0.00	-.11	0.00	.48	9.02	-.93	65.04	-2.23	.80	3783.
4.90	10.59	1.79	0.00	-1.75	0.00	-.08	0.00	.39	10.13	-1.28	65.75	-2.51	.81	3783.
5.25	10.52	1.35	0.00	-1.76	0.00	-.08	0.00	.34	11.20	-1.61	66.22	-2.79	.81	3783.
5.60	10.79	1.03	0.00	-1.80	0.00	-.09	0.00	.32	12.25	-1.93	66.48	-3.09	.81	3783.
5.95	11.01	.83	0.00	-1.81	0.00	-.13	0.00	.32	13.32	-2.22	66.60	-3.39	.81	3783.
6.30	11.09	1.50	0.00	-1.80	0.00	-.52	0.00	.33	14.45	-2.50	66.77	-3.68	.81	3783.
6.65	10.87	2.71	0.00	-1.76	0.00	-.32	0.00	.35	15.51	-2.79	67.75	-3.96	.81	3783.
7.00	10.51	4.12	0.00	-1.74	0.00	-1.29	0.00	.39	16.76	-3.18	69.99	-4.27	.81	3783.
7.35	10.57	5.61	0.00	-1.76	0.00	-2.90	0.00	.49	17.88	-3.70	73.80	-4.64	.81	3783.
7.70	10.32	6.81	0.00	-1.79	0.00	-3.41	0.00	.55	19.00	-4.44	8?.48	-5.11	.81	3783.
8.05	11.57	7.43	0.00	-1.84	0.00	-2.04	0.00	.58	20.16	-5.43	8?.?	-5.73	.81	3783.
8.40	12.74	7.02	0.00	-1.88	0.00	-1.73	0.00	.59	[illegible]	-6.54	93.33	-6.94	.81	3783.
8.75	13.03	6.61	0.00	-1.88	0.00	-1.45	0.00	.57	22.73	-8.01	106.76	-7.54	.81	3783.
9.10	13.09	5.28	0.00	-1.84	0.00	-1.29	0.00	.59	24.13	-9.53	112.66	-8.79	.82	3783.
9.45	13.20	5.01	0.00	-1.85	0.00	-1.20	0.00	.61	25.50	-11.15	117.48	-10.02	.82	3783.
9.80	13.53	5.80	0.00	-1.89	0.00	-1.13	0.00	.63	26.84	-12.86	121.54	-11.47	.82	3783.
10.15	14.15	5.60	0.00	-1.91	0.00	-1.09	0.00	.63	28.21	-14.69	125.15	-13.04	.82	3783.
10.50	14.75	5.35	0.00	-1.92	0.00	-1.09	0.00	.65	29.65	-16.65	128.47	-14.73	.82	3783.
10.85	15.42	5.08	0.00	-1.92	0.00	-1.08	0.00	.71	31.15	-18.77	131.51	-16.55	.83	3783.
11.20	16.21	4.77	0.00	-1.94	0.00	-1.07	0.00	.78	32.72	-21.05	134.23	-18.54	.83	3783.
11.55	17.15	4.58	0.00	-1.96	0.00	-1.11	0.00	.85	34.39	-23.49	136.60	-20.69	.83	3783.
11.90	18.31	4.41	0.00	-2.07	0.00	-1.14	0.00	.94	36.15	-26.12	138.67	-22.99	.83	3783.
12.25	19.53	4.27	0.00	-2.18	0.00	-1.18	0.00	1.04	38.07	-28.95	140.40	-25.47	.84	3783.
12.60	21.13	4.19	0.00	-2.31	0.00	-1.24	0.00	1.15	40.20	-32.04	141.77	-28.17	.84	3783.
12.95	22.84	4.19	0.00	-2.45	0.00	-1.32	0.00	1.29	42.59	-35.38	142.74	-31.03	.84	3783.
13.30	24.72	4.27	0.00	-2.62	0.00	-1.41	0.00	1.44	45.31	-39.00	143.27	-34.27	.84	3783.
13.65	26.93	4.43	0.00	-2.81	0.00	-1.50	0.00	1.61	48.47	-42.91	143.29	-37.73	.85	3783.
14.00	29.16	4.62	0.00	-3.02	0.00	-1.57	0.00	1.79	52.26	-47.13	142.64	-41.49	.85	3783.
14.35	31.54	4.87	0.00	-3.22	0.00	-1.68	0.00	1.98	56.94	-51.64	140.99	-45.55	.85	3783.
14.70	34.44	5.17	0.00	-3.24	0.00	-1.79	0.00	2.14	62.90	-55.31	137.94	-49.91	.85	3783.
15.05	38.84	5.43	0.00	-3.28	0.00	-1.84	0.00	2.27	70.36	-60.81	133.17	-54.41	.85	3783.

CASE = 1. ENCOUNTER = 8

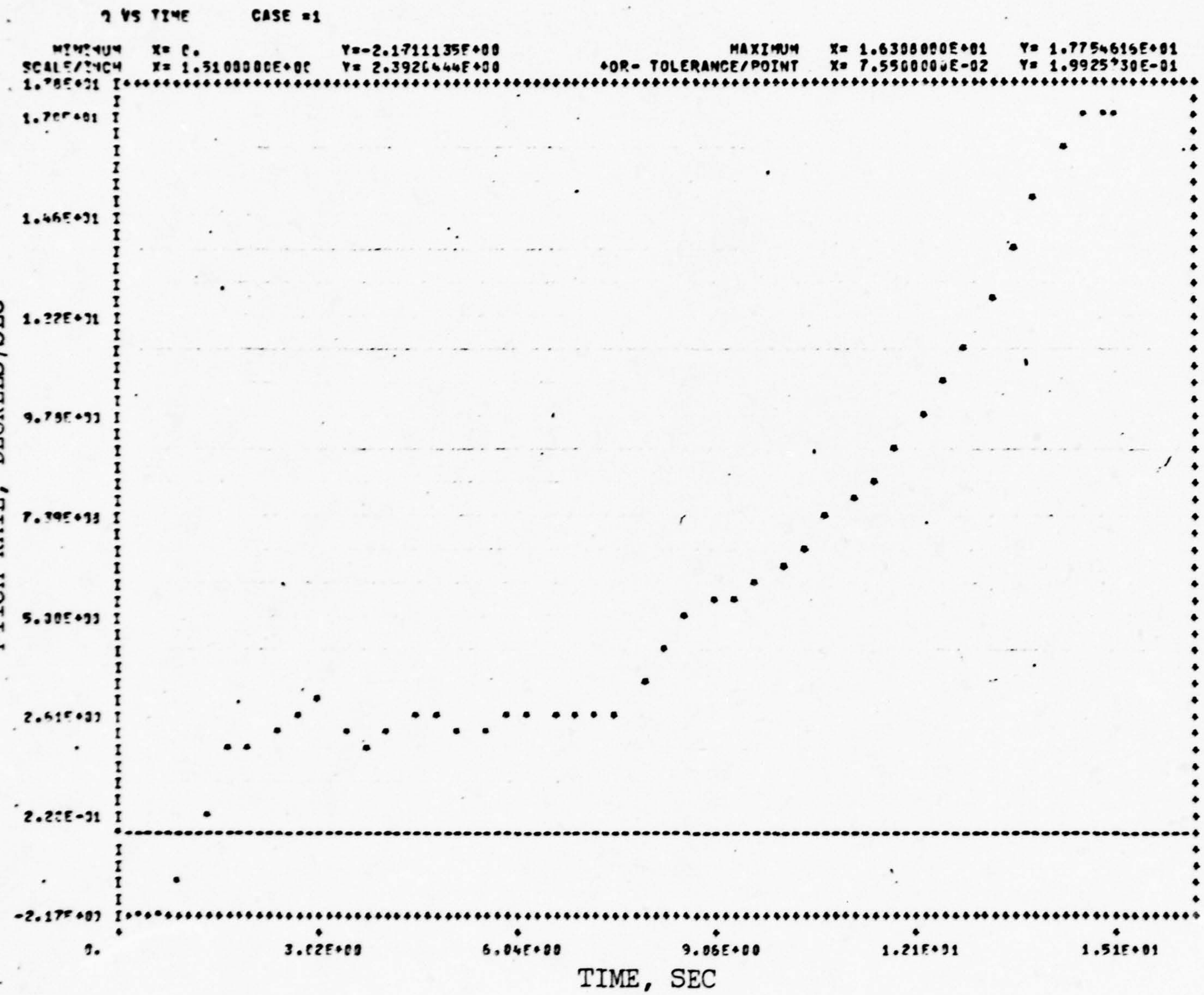
T A W D S C O M P U T E R P R O G R A M

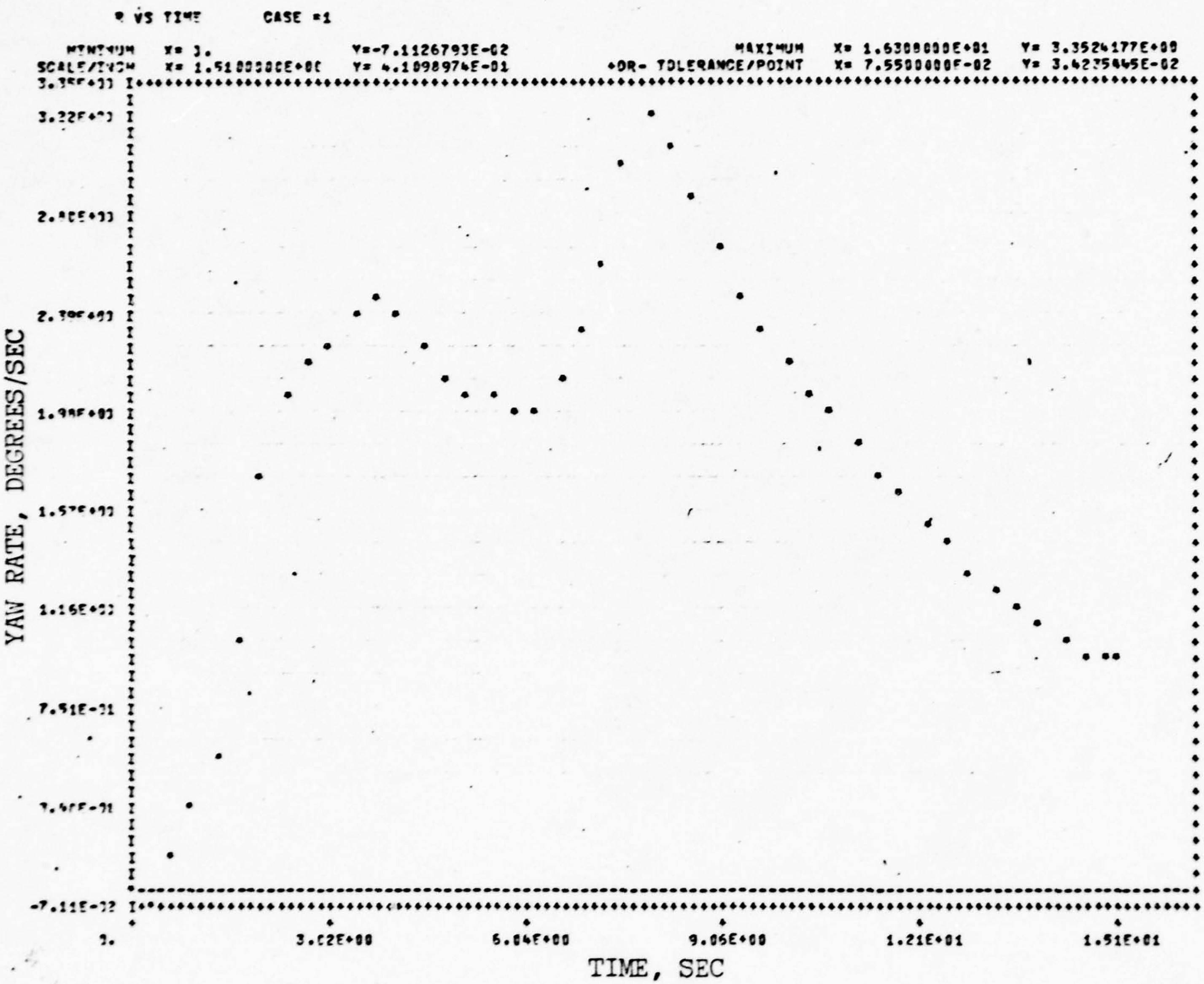
B U L L E T - S I G H T - G E O M E T R Y V A R I A B L E S .

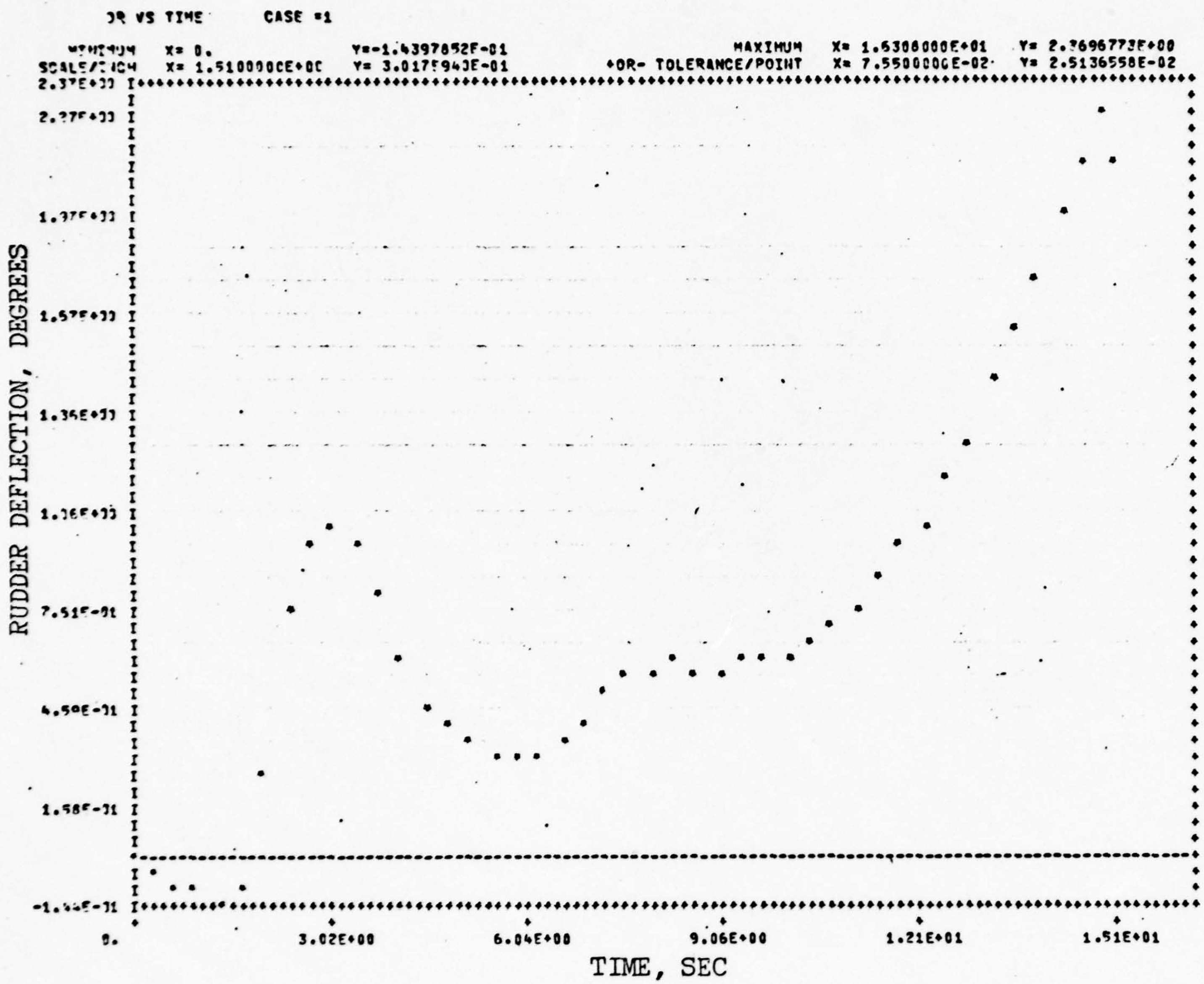
TIME SEC	TRACKING ERROR TR MR	TRACKING ERROR EL MR	DIRECTOR TF SEC	BULLET TF SEC	BULLET// RANGE FT	TR MR	BULLET EL MR	MISS TR FEET	EL FEET	/// LEAD ANGLE TR MR	LEAD ANGLE EL MR	//TARGET WRT GUN/ TR MR	TARGET WRT GUN EL MR	RANGE RATE FT/SEC	RANGE FEET
0.00	10.02	10.00	4.76	0.00	0.	0.00	0.00	0.	0.	-.7	-51.1	-10.9	-61.1	-200.0	7000.
.35	10.35	5.09	4.62	1.95	5385.****************			999.	999.	-.3	-48.2	-11.3	-53.3	-200.8	6931.
.70	5.94	-10.61	4.46	1.95	5385.****************			999.	999.	-4.6	-50.2	-11.5	-39.5	-202.2	6859.
1.05	-1.10	-24.96	4.30	1.95	5385.****************			999.	999.	-12.4	-53.9	-11.3	-28.8	-205.4	6789.
1.40	-11.92	-34.05	4.13	1.95	5385.****************			999.	999.	-22.2	-57.9	-10.4	-23.8	-210.3	6715.
1.75	-22.59	-37.91	3.97	1.95	5386.****************			999.	999.	-30.9	-63.4	-8.2	-29.4	-217.3	6641.
2.10	-30.34	-31.72	3.81	1.95	5386.****************			999.	999.	-35.5	-71.4	-4.6	-39.6	-226.0	6563.
2.45	-33.53	-32.01	3.65	1.95	5386.****************			999.	999.	-36.4	-80.7	-2.7	-48.7	-235.6	6482.
2.80	-32.81	-29.75	3.49	1.95	5386.****************			999.	999.	-37.2	-88.2	-4.3	-58.9	-245.6	6399.
3.15	-30.22	-22.95	3.35	1.95	5386.****************			999.	999.	-39.2	-93.5	-9.0	-70.6	-256.0	6311.
3.50	-26.20	-17.81	3.21	1.95	5386.****************			999.	999.	-41.6	-97.7	-15.4	-79.9	-266.7	6219.
3.85	-21.24	-15.69	3.08	1.95	5385.****************			999.	999.	-43.7	-101.5	-22.5	-85.4	-277.7	6124.
4.20	-16.13	-15.71	2.95	1.95	5385.****************			999.	999.	-45.8	-105.0	-29.7	-89.7	-289.0	6025.
4.55	-11.47	-13.39	2.82	1.95	5384.****************			999.	999.	-47.9	-108.2	-36.4	-94.8	-300.6	5922.
4.90	-7.57	-10.99	2.70	1.95	5384.****************			999.	999.	-50.1	-110.9	-42.5	-99.8	-312.3	5815.
5.25	-4.31	-3.55	2.59	1.95	5383.****************			999.	999.	-52.3	-113.0	-47.8	-103.5	-324.2	5703.
5.60	-2.34	-3.39	2.48	1.95	5383.****************			999.	999.	-54.6	-115.0	-52.4	-105.9	-336.1	5583.
5.95	-.73	-8.73	2.37	1.95	5382.****************			999.	999.	-57.0	-116.7	-56.3	-107.9	-348.1	5469.
6.30	-.83	-7.91	2.26	1.95	5381.****************			999.	999.	-60.1	-117.8	-59.2	-109.9	-360.4	5344.
6.65	-3.54	-6.11	2.16	1.95	5381.****************			999.	999.	-63.7	-118.5	-60.0	-112.4	-372.9	5215.
7.00	-9.59	-4.53	2.06	1.95	5380.****************			999.	999.	-66.8	-119.3	-58.2	-114.8	-385.1	5083.
7.35	-14.33	-4.13	1.96	1.90	5769.	-41.59	3.88	-240.	22.	-68.4	-120.9	-53.4	-116.7	-395.4	4947.
7.70	-21.37	-5.42	1.87	1.82	5583.	-45.47	1.01	-254.	6.	-65.4	-125.1	-44.1	-119.7	-406.1	4806.
8.05	-26.23	-3.38	1.78	1.73	5337.	-46.78	-4.96	-252.	-27.	-57.5	-131.5	-31.2	-123.5	-413.7	4663.
8.40	-29.72	-10.86	1.69	1.65	5210.	-45.52	-10.96	-237.	-57.	-47.5	-138.0	-18.7	-127.1	-420.6	4517.
8.75	-32.00	-11.66	1.61	1.57	5023.	-43.76	-13.92	-220.	-70.	-40.2	-142.7	-10.2	-131.0	-427.6	4369.
9.10	-33.33	-11.03	1.53	1.50	4834.	-42.22	-14.79	-204.	-72.	-35.2	-146.2	-4.2	-135.2	-434.5	4219.
9.45	-31.90	-10.90	1.45	1.42	4645.	-41.03	-15.53	-191.	-72.	-31.6	-149.1	.2	-138.2	-441.4	4065.
9.80	-32.31	-11.95	1.37	1.35	4455.	-40.27	-16.79	-179.	-75.	-29.1	-151.7	3.7	-139.9	-448.1	3909.
10.15	-34.24	-13.34	1.30	1.27	4264.	-39.89	-18.25	-170.	-78.	-26.9	-154.3	7.1	-141.0	-454.7	3752.
10.50	-35.57	-14.63	1.22	1.20	4073.	-39.80	-19.60	-162.	-80.	-24.9	-156.7	10.7	-142.1	-461.5	3592.
10.85	-37.34	-16.19	1.15	1.13	3881.	-39.98	-21.06	-155.	-82.	-22.9	-159.1	14.4	-142.9	-468.0	3429.
11.20	-39.33	-18.19	1.08	1.06	3688.	-40.45	-22.77	-149.	-84.	-21.1	-161.4	18.2	-143.2	-473.9	3264.
11.55	-41.59	-20.65	1.01	1.00	3497.	-41.25	-24.80	-144.	-87.	-19.7	-163.6	22.0	-142.9	-479.3	3098.
11.90	-44.23	-23.89	.94	.93	3305.	-42.35	-27.42	-140.	-91.	-18.3	-165.6	26.0	-141.7	-483.0	2930.
12.25	-47.15	-27.68	.88	.87	3116.	-43.74	-30.38	-136.	-95.	-17.0	-167.6	30.2	-139.9	-484.6	2760.
12.60	-50.32	-31.69	.81	.81	2928.	-45.45	-33.40	-133.	-98.	-15.8	-169.4	34.5	-137.8	-483.5	2591.
12.95	-53.80	-36.05	.75	.75	2743.	-47.47	-36.63	-130.	-100.	-14.8	-171.1	39.0	-135.1	-479.5	2423.
13.30	-57.49	-41.03	.70	.69	2563.	-49.71	-40.24	-127.	-103.	-13.7	-172.6	43.9	-131.6	-472.1	2257.
13.65	-61.25	-46.59	.64	.64	2387.	-52.05	-44.15	-124.	-105.	-12.5	-173.9	48.7	-127.3	-460.8	2094.
14.00	-64.31	-52.51	.59	.59	2218.	-54.26	-48.21	-120.	-107.	-11.2	-174.7	53.6	-122.1	-445.2	1935.
14.35	-69.23	-58.53	.54	.54	2057.	-56.27	-52.15	-116.	-107.	-9.8	-174.9	58.2	-116.4	-425.3	1783.
14.70	-70.32	-65.98	.50	.49	1904.	-58.01	-57.11	-110.	-109.	-8.5	-174.4	62.4	-108.4	-400.7	1639.
15.05	-72.75	-80.37	.46	.45	1762.	-59.14	-67.49	-104.	-119.	-7.3	-173.3	65.5	-92.9	-371.3	1504.

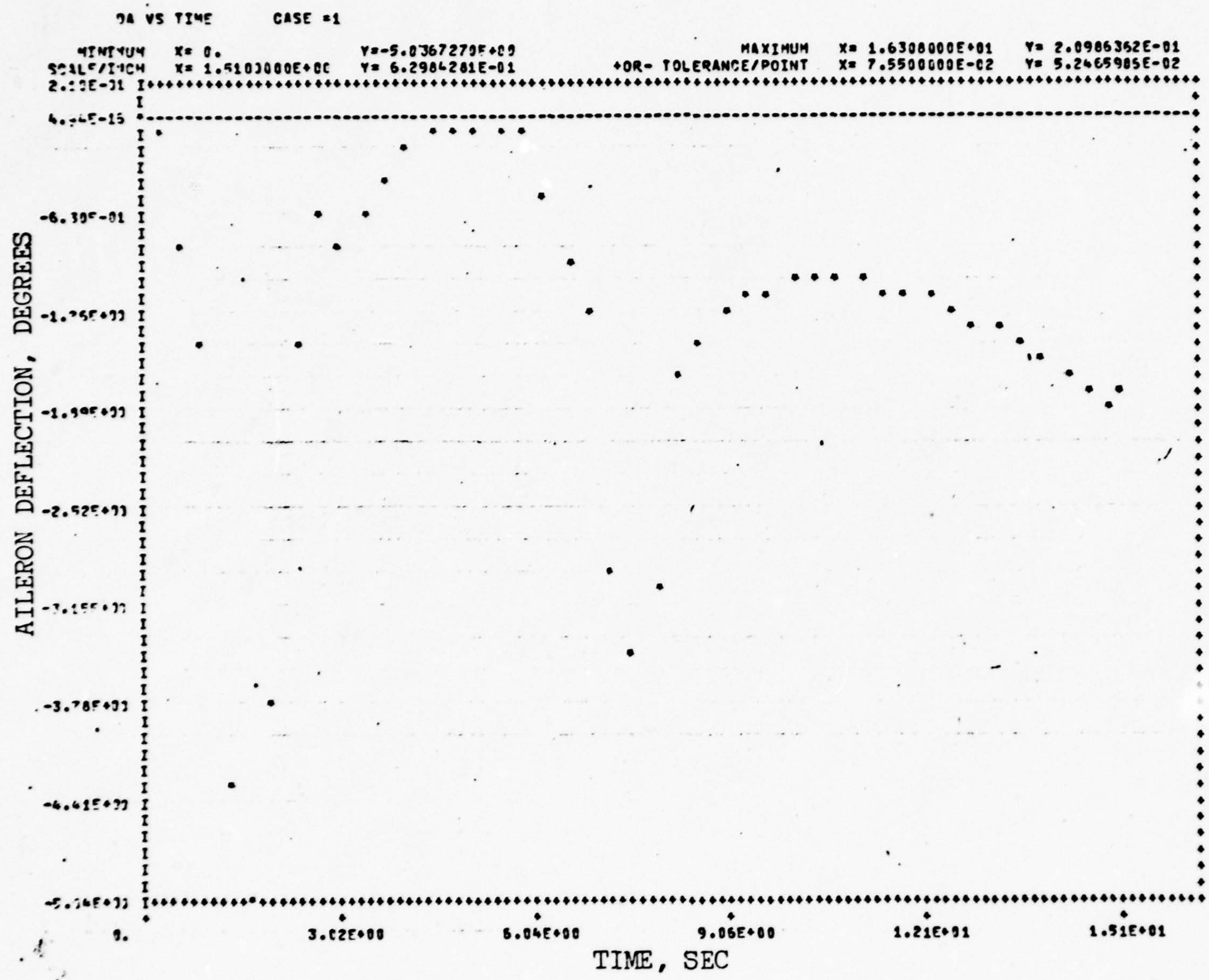


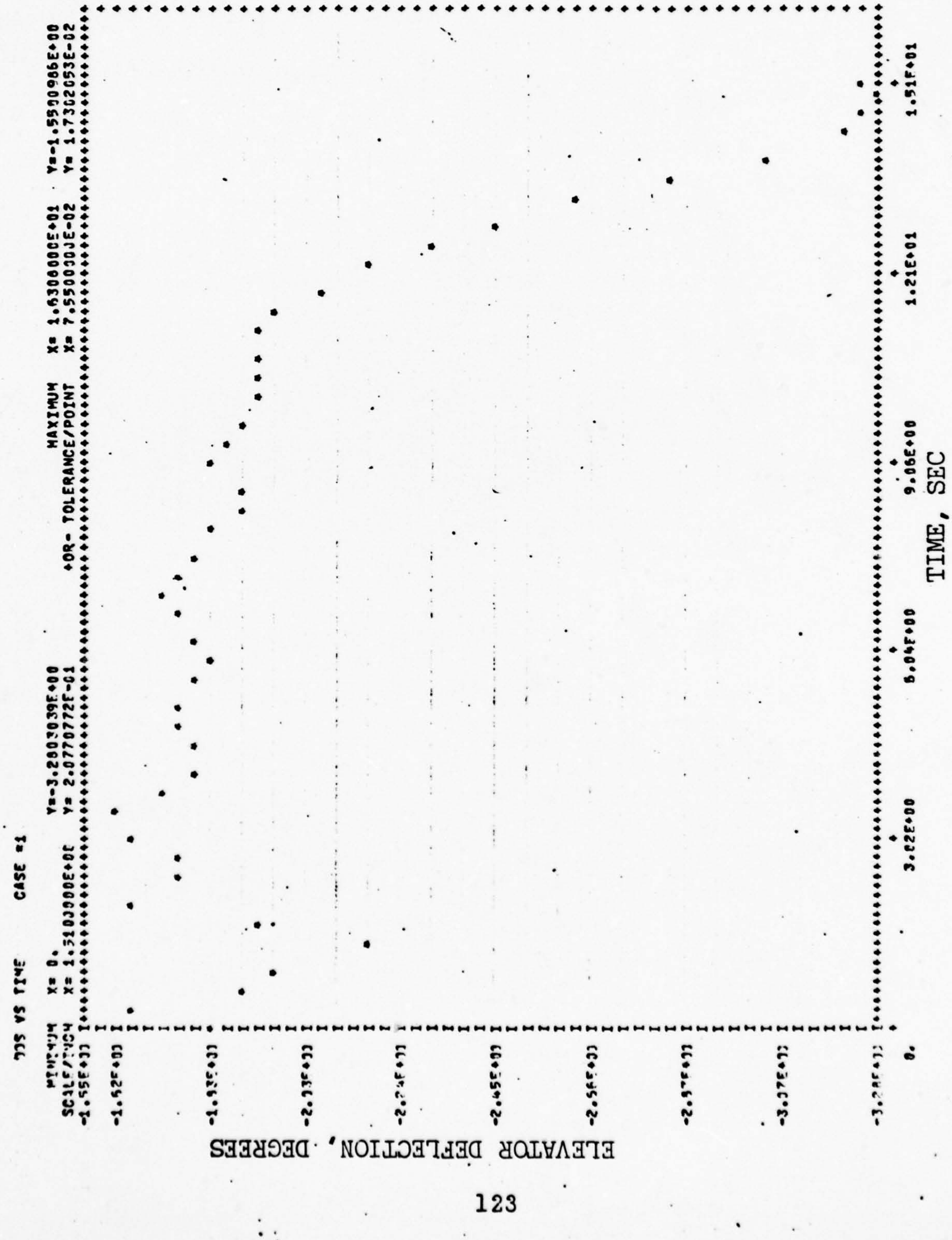
P VS TIME CASE =1
MINIMUM X= 0. Y=-3.0971934E+00
SCALE/INCH X= 1.5100000E+00 Y= 5.8332390E+00
MAXIMUM X= 1.6309000E+01 Y= 4.5493687E+01
-OR- TOLERANCE/POINT X= 7.5500000E-02 Y= 4.8590860E-01
4.55E+01
4.36E+01
3.77E+01
3.19E+01
2.61E+01
2.02E+01
1.44E+01
8.55E+00
2.73E+00
-3.10E+00
0.
3.02E+00
6.04E+00
9.06E+00
1.21E+01
1.51E+01
TIME, SEC
ROLL RATE, DEGREES/SEC

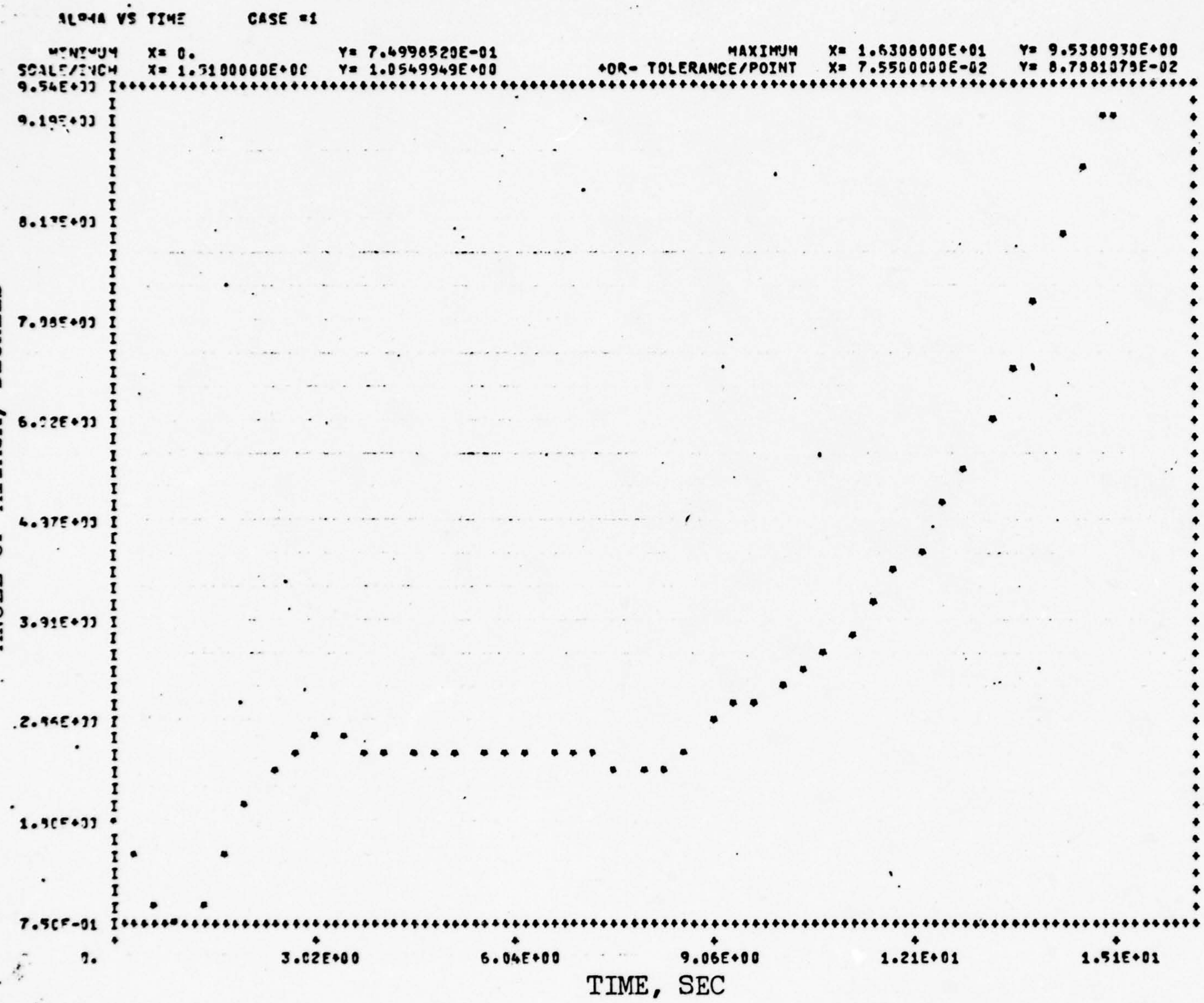

Q VS TIME CASE =1
MINIMUM X= 0. Y=-2.1711135E+00
SCALE/INCH X= 1.5100000E+00 Y= 2.3920444E+00
MAXIMUM X= 1.6308000E+01 Y= 1.7754616E+01
+OR- TOLERANCE/POINT X= 7.5500000E-02 Y= 1.9925730E-01
PITCH RATE, DEGREES/SEC
TIME, SEC
0.
3.02E+00
6.04E+00
9.06E+00
1.21E+01
1.51E+01

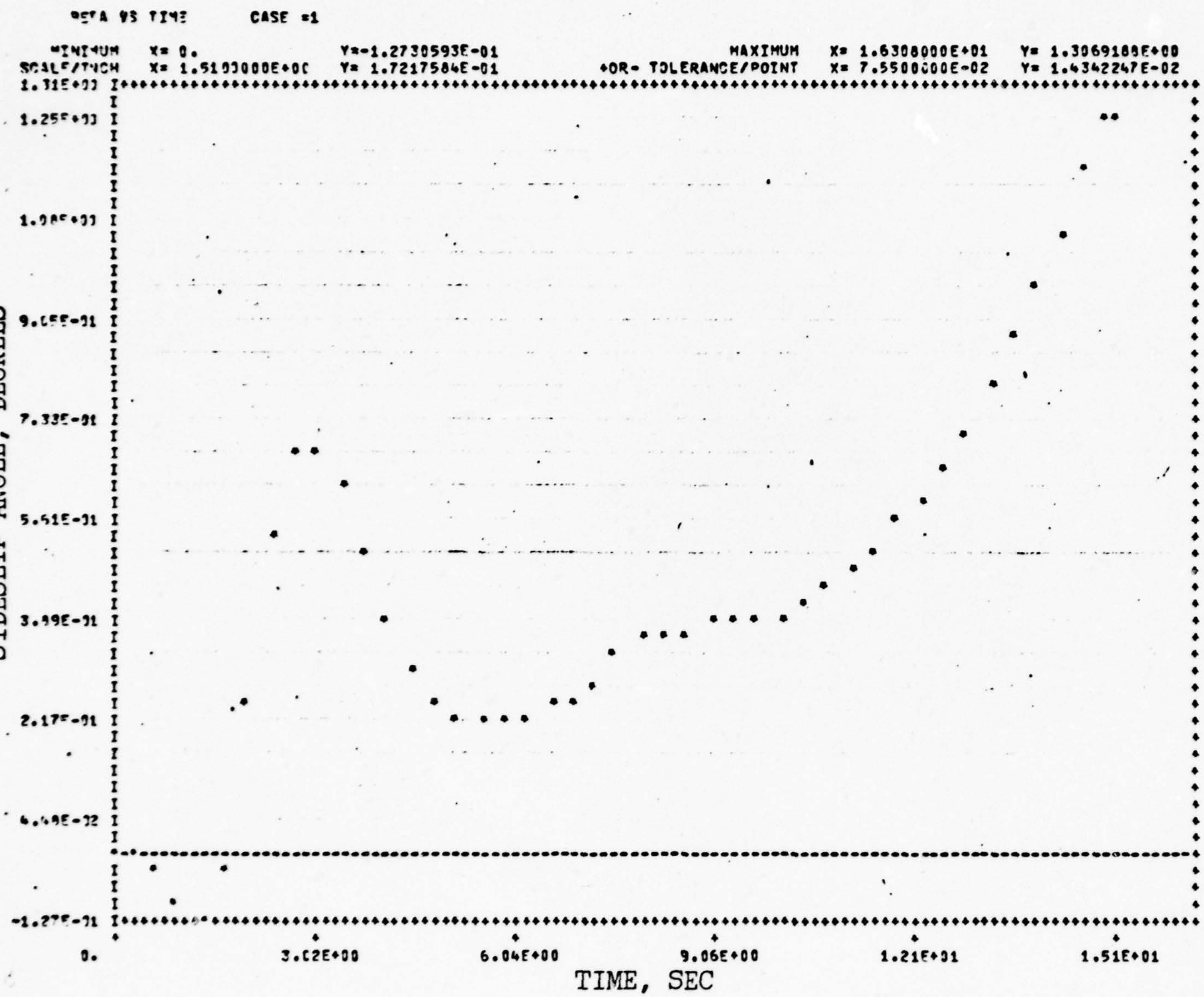

R VS TIME CASE =1
MINIMUM X= 0. Y=-7.1126793E-02
SCALE/INCH X= 1.5100000E+00 Y= 4.1098974E-01
MAXIMUM X= 1.6300000E+01 Y= 3.3524177E+00
+OR- TOLERANCE/POINT X= 7.5500000E-02 Y= 3.4275445E-02
3.22E+00
2.80E+00
2.39E+00
1.98E+00
1.57E+00
1.16E+00
7.51E-01
-7.11E-02
0.
3.02E+00
6.04E+00
9.06E+00
1.21E+01
1.51E+01
TIME, SEC
YAW RATE, DEGREES/SEC


DR VS TIME CASE =1
MINIMUM X= 0. Y=-1.4397852E-01 MAXIMUM X= 1.6308000E+01 Y= 2.3696773E+00
SCALE/INCH X= 1.5100000E+00 Y= 3.0175940E-01 +OR- TOLERANCE/POINT X= 7.5500000E-02 Y= 2.5136558E-02
2.37E+00
2.27E+00
1.97E+00
1.57E+00
1.36E+00
1.06E+00
7.51E-01
4.50E-01
1.58E-01
-1.44E-01
0.
3.02E+00
6.04E+00
9.06E+00
1.21E+01
1.51E+01
RUDDER DEFLECTION, DEGREES
TIME, SEC


DA VS TIME CASE =1
MINIMUM X= 0. Y=-5.0367270E+00
SCALE/INCH X= 1.5100000E+00 Y= 6.2984281E-01
MAXIMUM X= 1.6308000E+01 Y= 2.0986362E-01
+OR- TOLERANCE/POINT X= 7.5500000E-02 Y= 5.2465985E-02
-6.30E-01
-1.26E+00
-1.89E+00
-2.52E+00
-3.15E+00
-3.78E+00
-4.41E+00
0.
3.02E+00
6.04E+00
9.06E+00
1.21E+01
1.51E+01
AILERON DEFLECTION, DEGREES
TIME, SEC


DDE VS TIME
CASE =1
TIME, SEC
ELEVATOR DEFLECTION, DEGREES

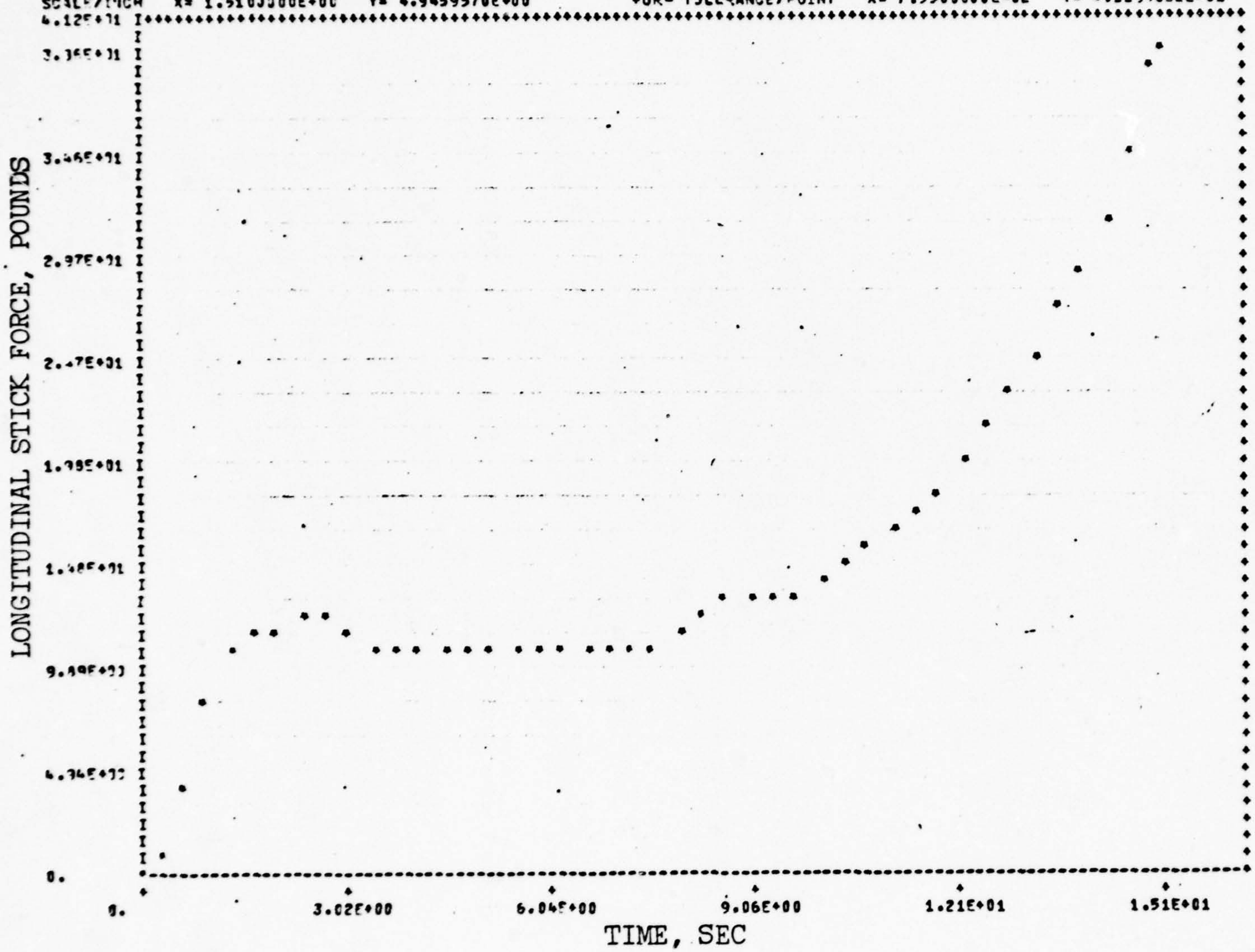

ALPHA VS TIME CASE =1
MINIMUM X= 0. Y= 7.4998520E-01
SCALE/INCH X= 1.5100000E+00 Y= 1.0549949E+00
MAXIMUM X= 1.6308000E+01 Y= 9.5380930E+00
+OR- TOLERANCE/POINT X= 7.5500000E-02 Y= 8.7881079E-02
9.54E+00
9.19E+00
8.17E+00
7.95E+00
6.22E+00
4.37E+00
3.91E+00
2.46E+00
1.90E+00
7.50E-01
0.
3.02E+00
6.04E+00
9.06E+00
1.21E+01
1.51E+01
ANGLE OF ATTACK, DEGREES
TIME, SEC

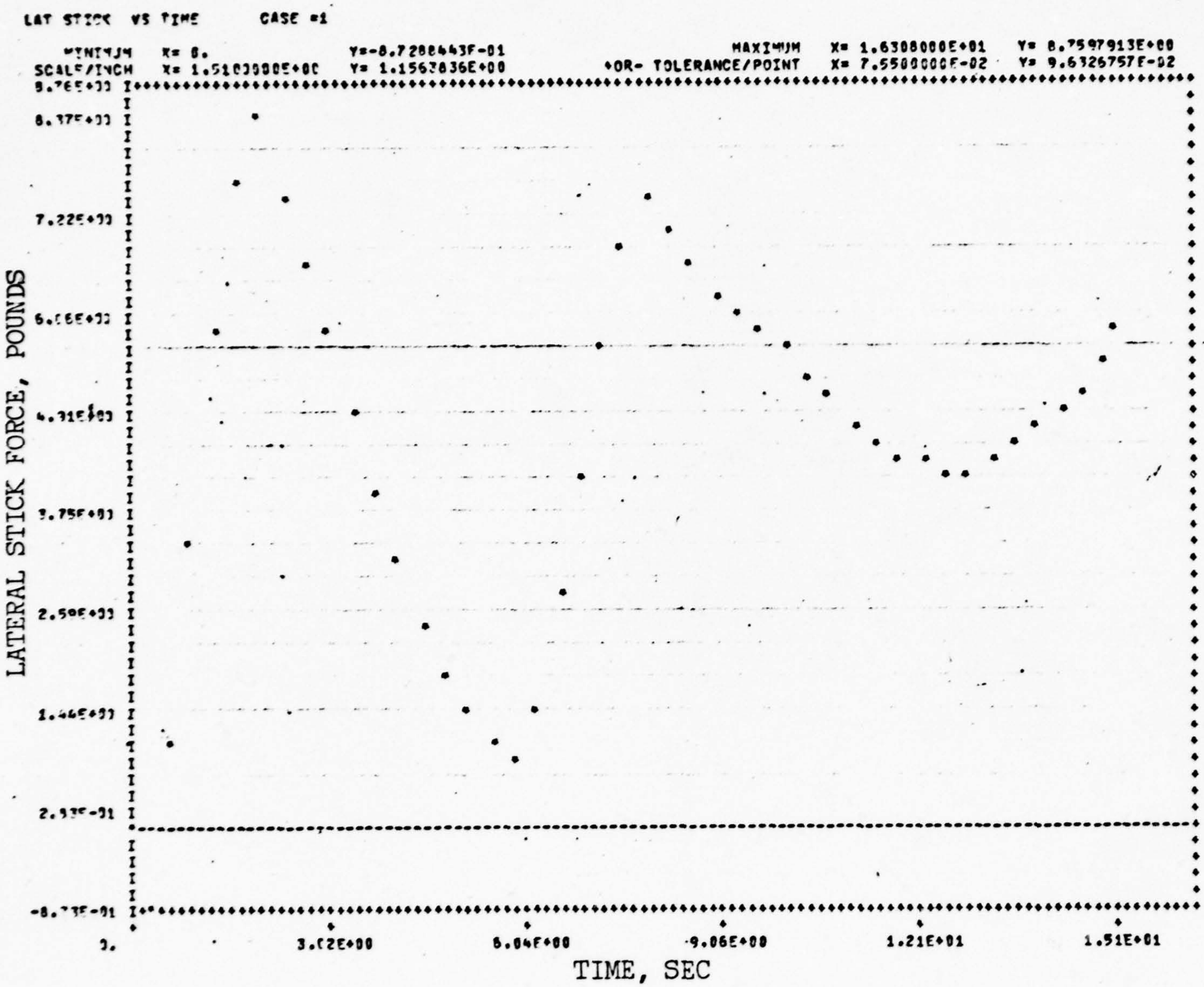

BETA VS TIME CASE =1
MINIMUM X= 0. Y=-1.2730593E-01
SCALE/INCH X= 1.5100000E+00 Y= 1.7217584E-01
MAXIMUM X= 1.6308000E+01 Y= 1.3069188E+00
+OR- TOLERANCE/POINT X= 7.5500000E-02 Y= 1.4342247E-02
1.31E+00
1.25E+00
1.08E+00
9.05E-01
7.33E-01
5.61E-01
3.89E-01
2.17E-01
4.49E-02
-1.27E-01
0.
3.02E+00
6.04E+00
9.06E+00
1.21E+01
1.51E+01
TIME, SEC
SIDESLIP ANGLE, DEGREES

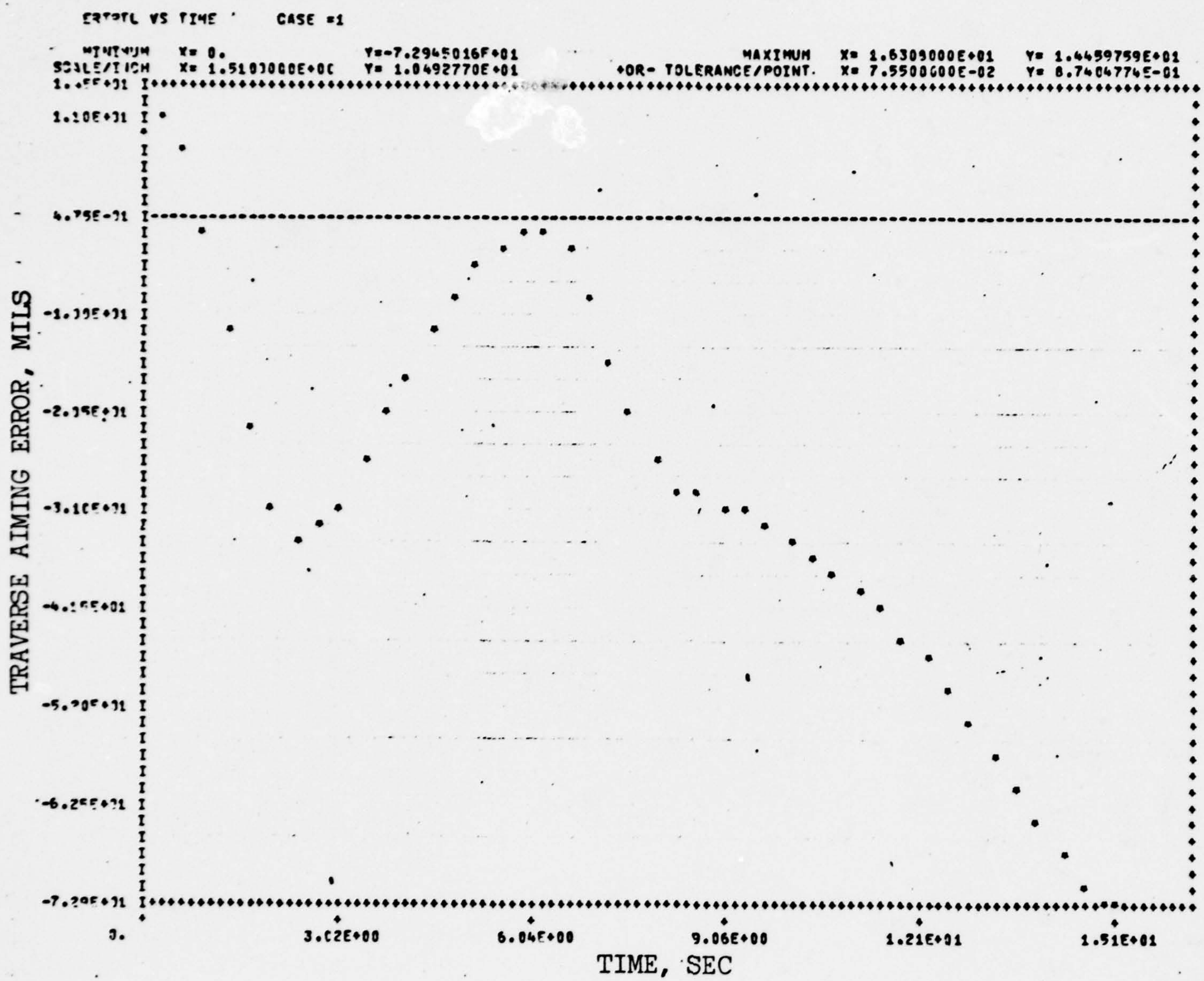
LONG STICK VS TIME CASE =1

MINIMUM X= 0. Y= 0. MAXIMUM X= 1.6308000E+01 Y= 4.1199822E+01

SCALE/INCH X= 1.5100000E+00 Y= 4.9459570E+00 +OR- TOLERANCE/POINT X= 7.5500000E-02 Y= 4.1199822E-01



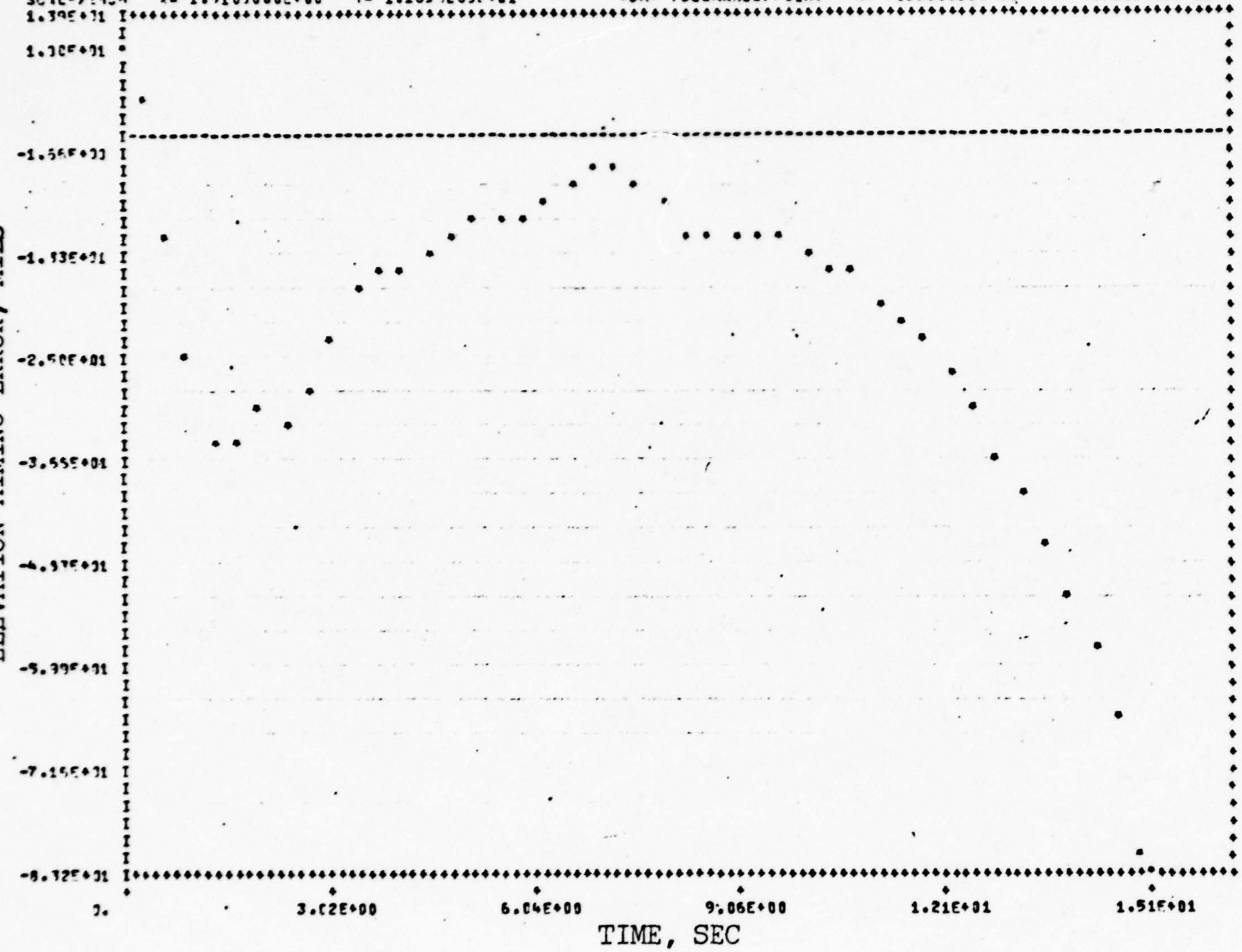

LAT STICK VS TIME CASE =1
MINIMUM X= 0. Y=-8.7288443F-01
SCALE/INCH X= 1.51000000E+00 Y= 1.1563836E+00
MAXIMUM X= 1.6308000E+01 Y= 8.7597913E+00
+OR- TOLERANCE/POINT X= 7.5500000E-02 Y= 9.6326757E-02
LATERAL STICK FORCE, POUNDS
TIME, SEC
3.02E+00
6.04E+00
9.06E+00
1.21E+01
1.51E+01



ERTRTL VS TIME CASE =1
MINIMUM X= 0. Y=-7.2945016E+01
SCALE/INCH X= 1.5100000E+00 Y= 1.0492770E+01
MAXIMUM X= 1.6309000E+01 Y= 1.4459759E+01
+OR- TOLERANCE/POINT. X= 7.5500000E-02 Y= 8.7404774E-01
1.10E+01
4.75E-01
-1.00E+01
-2.05E+01
-3.10E+01
-4.15E+01
-5.20E+01
-6.25E+01
-7.29E+01
0.
3.02E+00
6.04E+00
9.06E+00
1.21E+01
1.51E+01
TIME, SEC
TRAVERSE AIMING ERROR, MILS

EPELTL VS TIME CASE =1

MINIMUM X= 0. Y=-8.3239518E+01 MAXIMUM X= 1.6308000E+01 Y= 1.3982313E+01
SCALE/INCH X= 1.5100000E+00 Y= 1.1659283E+01 -OR- TOLERANCE/POINT X= 7.5500000E-02 Y= 9.7121830E-01



CASE = 1. ENCOUNTER = 8

TAWDS COMPUTER PROGRAM

TIME SEC	ATTACKER: POSITION X (FEET)	Y (FEET)	Z (FEET)	XDOT (FEET/SEC)	YDOT (FEET/SEC)	ZDOT (FEET/SEC)	TARGET: POSITION EARTH COORD X (FEET)	Y (FEET)	Z (FEET)	AIR-SPEED (FT/SEC)	BODY RATES P (DEGREES/SEC)	Q (DEGREES/SEC)	R (DEGREES/SEC)	ALPHA (DEG)	LOAD FACTOR (G)
0.00	0.0	0.0	-20000.0	827.6	0.0	0.0	7012.2	-75.2	-19789.9	627.69	19.91	5.60	1.33	3.83	1.00
.35	293.7	-.0	-20000.0	828.0	-.0	-.1	7231.3	-75.0	-19790.5	627.57	44.70	6.99	5.26	5.79	1.41
.70	579.5	-.0	-20000.0	828.3	-.2	.1	7451.4	-73.6	-19793.5	626.91	44.39	8.30	7.52	7.75	1.79
1.05	863.5	-.1	-19999.9	828.7	-.3	.5	7670.4	-68.7	-19798.5	625.29	44.00	9.78	9.67	9.71	2.11
1.40	1153.7	-.2	-19999.6	829.0	.3	1.1	7838.4	-58.1	-19805.3	622.45	42.63	11.29	11.46	11.67	2.40
1.75	1443.9	.3	-19999.2	829.4	2.9	1.9	8104.7	-39.5	-19812.7	618.41	38.26	12.74	11.77	13.63	2.63
2.10	1740.2	2.3	-19998.2	829.7	9.1	4.2	8318.3	-11.2	-19818.7	613.52	-.76	7.88	2.89	14.75	2.72
2.45	2033.7	7.0	-19995.9	830.0	18.2	9.1	8528.7	27.3	-19822.0	608.82	-.77	7.84	2.91	14.75	2.63
2.80	2321.2	15.5	-19991.9	829.9	31.2	13.6	8735.4	75.8	-19822.3	604.57	-.77	7.80	2.93	14.75	2.65
3.15	2611.6	28.2	-19986.4	829.3	47.5	17.9	8938.0	134.0	-19819.7	600.75	-.78	7.77	2.95	14.75	2.63
3.50	2901.7	48.5	-19979.3	828.6	62.5	23.1	9138.4	201.7	-19814.2	597.37	-.78	7.74	2.97	14.75	2.61
3.85	3191.6	72.8	-19970.1	827.9	76.1	29.3	9330.0	278.6	-19805.8	594.41	-.79	7.72	2.98	14.75	2.59
4.20	3481.2	101.7	-19958.8	827.0	89.2	35.6	9518.7	364.3	-19794.5	591.65	-.79	7.70	2.99	14.75	2.58
4.55	3770.4	135.4	-19945.2	825.8	103.1	41.6	9702.1	456.7	-19780.4	589.68	-.79	7.69	3.00	14.75	2.56
4.90	4059.2	174.0	-19929.7	824.3	117.7	47.1	9879.3	561.6	-19763.5	587.91	-.79	7.67	3.00	14.75	2.56
5.25	4347.4	217.7	-19912.3	822.6	132.2	52.1	10051.7	672.5	-19743.9	586.50	-.79	7.67	3.00	14.75	2.55
5.60	4635.0	266.6	-19893.3	820.7	147.0	56.5	10217.4	791.3	-19721.5	585.47	-.79	7.66	3.00	14.75	2.55
5.95	4921.9	321.7	-19872.9	818.4	162.4	60.1	10376.5	917.7	-19696.5	584.78	17.91	7.66	7.92	14.75	2.55
6.30	5207.9	383.2	-19851.2	815.9	177.9	63.7	10528.8	1051.4	-19668.6	584.45	32.65	8.29	11.81	14.75	2.56
6.65	5492.9	453.2	-19828.6	813.1	193.3	66.2	10673.9	1192.0	-19636.4	584.54	32.68	8.93	11.70	14.75	2.57
7.00	5775.9	515.5	-19804.8	809.9	208.0	69.4	10811.1	1338.8	-19597.8	585.15	32.74	9.54	11.46	14.75	2.59
7.35	6059.9	591.7	-19779.9	806.6	223.8	73.6	10940.7	1490.6	-19551.0	586.35	32.83	10.08	11.10	14.75	2.60
7.70	6341.5	672.2	-19753.2	803.0	238.4	79.4	11062.3	1645.9	-19494.4	588.27	32.95	10.53	10.66	14.75	2.63
8.05	6621.3	759.2	-19724.0	798.9	253.3	87.5	11177.3	1803.0	-19425.4	590.85	-.38	10.80	1.46	14.75	2.65
8.40	6900.7	849.5	-19691.6	794.0	268.5	98.5	11286.2	1960.5	-19346.4	594.05	-.38	10.76	1.44	14.75	2.69
8.75	7177.5	945.3	-19654.8	788.0	284.7	112.4	11387.3	2117.8	-19254.4	597.83	-.37	10.73	1.42	14.75	2.74
9.10	7452.1	1049.0	-19612.5	780.7	301.7	129.2	11481.9	2274.1	-19150.6	602.12	-.37	10.70	1.39	14.75	2.79
9.45	7724.0	1157.6	-19564.0	772.3	318.9	148.5	11568.3	2429.0	-19035.3	606.90	-.36	10.66	1.37	14.75	2.87
9.80	7992.6	1272.1	-19508.4	762.9	335.6	169.9	11646.5	2581.8	-18908.8	612.17	-.35	10.63	1.34	14.75	2.93
10.15	8257.8	1392.5	-19444.9	752.1	352.4	193.3	11715.1	2732.0	-18771.3	617.69	-.35	14.97	1.31	15.59	3.01
10.50	8518.9	1518.7	-19372.6	739.8	368.9	218.7	11776.4	2879.0	-18623.2	623.24	-.39	15.11	1.27	17.06	3.14
10.85	8775.5	1630.6	-19291.5	726.0	384.8	245.2	11826.9	3021.8	-18465.0	628.93	-.41	15.11	1.23	18.53	3.22
11.20	9025.9	1743.1	-19200.2	710.2	400.3	276.0	11867.2	3159.9	-18297.1	634.75	-.43	11.16	1.19	20.00	3.39
11.55	9272.4	1933.8	-19098.1	692.0	415.2	308.1	11898.5	3292.4	-18120.0	640.49	-.42	11.09	1.16	20.00	3.45
11.90	9511.0	2079.6	-18984.3	671.1	429.1	342.5	11914.9	3418.6	-17934.4	645.41	-.41	11.06	1.13	20.00	3.53
12.25	9741.7	2231.0	-18858.0	646.9	441.7	379.3	11921.7	3537.9	-17741.1	652.48	-.40	11.03	1.11	20.00	3.62
12.60	9963.4	2387.6	-18718.5	618.9	452.7	418.5	11916.3	3649.6	-17540.8	658.64	-.39	11.00	1.08	20.00	3.70
12.95	10174.5	2547.7	-18564.8	585.6	461.6	460.2	11900.2	3753.0	-17334.3	664.95	-.38	10.98	1.05	20.00	3.79
13.30	10373.4	2710.4	-18396.1	549.3	467.9	504.0	11871.5	3847.7	-17122.5	671.04	-.37	10.97	1.02	20.00	3.89
13.65	10559.3	2874.9	-18211.8	506.3	470.6	549.7	11830.5	3933.0	-16906.4	677.17	-.36	10.95	1.00	20.00	3.97
14.00	10727.1	3039.3	-18011.2	457.0	469.1	596.9	11778.0	4008.3	-16685.8	683.20	-.35	10.94	.97	20.00	4.07
14.35	10877.4	3202.5	-17793.9	400.6	462.2	644.7	11713.1	4073.2	-16464.9	689.05	-.34	10.93	.95	20.00	4.16
14.70	11005.9	3362.1	-17560.0	337.6	449.0	691.4	11635.2	4127.1	-16241.8	694.73	-.34	10.92	.92	20.00	4.25
15.05	11113.0	3515.9	-17310.2	268.4	428.5	735.1	11547.5	4169.6	-16018.4	700.14	-.33	10.91	.90	20.00	4.34

CASE = 1. ENCOUNTER = 8

TAMOS COMPUTER PROGRAM

ATTACKER VARIABLES

TIME SEC	VELOCITY FT/SEC	VEL DOT FT/SC2	ALPHA DEG	ALPHA DOT DEG/SEC	BETA DEG	BETA DOT DEG/SEC	ALTITUDE FEET	ALT DOT FT/SEC	// BODY RATES AND ACCELERATIONS P DEGREES/SEC	Q DEGREES/SEC	R DEGREES/SEC	PDOT DEGREES/SEC2	QDOT DEGREES/SEC2	RDOT DEGREES/SEC2 //	LOAD FACTOR G	LAT ACC FT/SC2
0.00	827.5	.979	1.747	-.012	0.000	0.000	20000.0	0.00	0.00	.00	0.00	0.00	1.45	0.00	1.01	0.00
.35	828.0	.969	1.747	-.108	-.002	-.013	20000.0	.06	-3.02	-.10	-.10	3.77	-.73	.03	1.00	.02
.70	828.3	1.053	1.692	-.158	-.009	-.018	20000.0	-.06	1.93	-.22	.04	5.85	-.05	.29	.97	.09
1.05	828.7	1.077	1.666	-.038	-.011	.029	19999.9	-.49	9.76	-.15	.29	-15.51	.23	-.09	.95	.07
1.40	829.0	1.048	1.660	.047	.016	.163	19999.6	-1.03	30.76	-.02	1.01	-12.01	.52	.78	.96	-.12
1.75	829.4	1.059	1.673	.102	.117	.435	19999.2	-1.73	62.70	.23	2.25	-39.32	1.47	.89	.96	-.41
2.10	829.8	1.152	1.647	-.047	.318	.643	19998.2	-3.92	64.85	.90	2.84	-168.44	1.90	-3.10	.93	-.19
2.45	830.2	1.215	1.808	1.707	.541	.572	19995.0	-8.76	17.04	3.19	1.88	-42.10	7.69	-.11	1.11	[illegible]
2.80	830.5	.777	2.066	1.712	.701	.268	19992.0	-13.34	9.56	4.43	2.36	-5.91	-3.95	1.71	1.50	[illegible]
3.15	830.9	.773	2.028	-.392	.715	-.177	19985.6	-17.47	5.42	1.70	2.37	4.47	-3.12	.73	1.51	-1.86
3.50	831.3	1.497	2.279	-.759	.609	-.401	19978.5	-22.68	2.01	1.50	2.46	9.59	-.75	.31	1.33	-1.71
3.85	831.9	1.751	2.109	-.241	.460	-.474	19970.5	-28.80	-.69	1.80	2.41	12.10	.50	-.00	1.25	-1.39
4.20	832.5	1.369	2.177	.435	.322	-.349	19959.2	-35.20	-2.61	2.50	2.29	12.32	1.71	-.23	1.29	-1.05
4.55	833.2	2.054	2.316	.391	.223	-.221	19945.7	-41.24	-3.78	2.57	2.09	11.07	-.32	-.38	1.38	-.79
4.90	834.0	2.226	2.361	-.069	.169	-.096	19930.3	-46.71	-4.32	2.21	1.93	8.73	-.46	-.28	1.41	-.62
5.25	834.8	2.396	2.365	.208	.150	-.022	19912.9	-51.77	-4.37	2.45	1.83	6.09	.98	-.11	1.43	-.52
5.60	835.6	2.454	2.404	.408	.149	.012	19894.0	-56.22	-4.09	2.80	1.78	3.89	.26	-.11	1.51	-.49
5.95	836.5	2.510	2.562	.058	.157	.036	19873.6	-59.91	-3.42	2.52	1.75	1.89	-.53	-.06	1.56	-.49
6.30	837.4	2.507	2.560	.023	.173	.060	19852.0	-57.09	-1.39	2.46	1.80	3.54	.72	.24	1.57	-.50
6.65	838.3	2.575	2.603	.019	.196	.081	19823.4	-55.01	2.83	2.53	1.96	-.02	-.21	.36	1.58	-.51
7.00	839.3	2.810	2.579	-.406	.224	.083	19805.7	-59.13	7.31	2.09	2.18	-3.92	-.78	.42	1.54	-.52
7.35	840.3	3.058	2.366	-.470	.251	.095	19780.8	-73.22	14.19	1.97	2.50	-37.13	.58	.01	1.45	-.30
7.70	841.4	3.319	2.266	-.144	.280	.109	19754.1	-78.91	24.47	2.46	2.93	-35.43	1.71	.09	1.39	-.31
8.05	842.7	3.589	2.261	.112	.320	.129	19725.1	-86.83	31.48	3.15	3.22	-37.01	2.12	-.24	1.39	-.35
8.40	844.0	3.895	2.360	.472	.358	.094	19692.9	-97.61	28.34	4.05	3.15	-44.01	2.52	-.97	1.47	-.44
8.75	845.4	4.203	2.572	.787	.388	.091	19655.1	-111.77	22.38	5.07	2.94	-28.51	1.70	-.63	1.62	-.64
9.10	846.9	4.611	2.814	.479	.408	.071	19614.1	-127.95	13.62	5.23	2.78	-20.05	.27	-.54	1.77	-.74
9.45	848.7	5.187	2.924	.319	.407	-.024	19565.8	-147.07	14.28	5.46	2.53	-14.24	.75	-.61	1.87	-.81
9.80	850.5	5.307	3.073	.556	.399	-.004	19510.4	-158.29	12.04	6.05	2.39	-10.84	1.19	-.55	1.99	-.85
10.15	852.7	6.445	3.277	.359	.405	.044	19447.3	-191.56	11.24	6.49	2.25	-9.29	.70	-.43	2.14	-.89
10.50	855.1	7.163	3.465	.504	.423	.066	19375.5	-216.90	10.59	6.82	2.12	-6.29	.91	-.36	2.29	-.93
10.85	857.8	7.314	3.651	.705	.449	.087	19294.5	-244.25	9.98	7.43	1.99	-6.10	1.40	-.34	2.46	-1.02
11.20	860.7	8.565	3.926	.833	.482	.110	19203.6	-273.65	9.14	8.07	1.85	-5.95	1.19	-.32	2.67	-1.12
11.55	863.8	9.037	4.217	.779	.523	.127	19101.8	-305.81	8.55	8.52	1.75	-7.23	.78	-.23	2.90	-1.23
11.90	867.0	9.266	4.509	.949	.568	.140	18988.5	-340.04	8.01	9.23	1.64	-8.03	1.12	-.19	3.15	-1.39
12.25	870.3	9.341	4.850	1.151	.619	.161	18862.7	-376.65	7.45	10.09	1.53	-8.69	.89	-.14	3.48	-1.55
12.60	873.6	9.311	5.269	1.189	.678	.181	18723.6	-415.77	6.95	10.83	1.43	-9.78	.60	-.04	3.83	-1.73
12.95	876.9	9.241	5.719	1.308	.743	.196	18570.4	-457.25	6.51	11.69	1.34	-10.00	.82	.06	4.21	-1.93
13.30	880.1	8.992	6.211	1.522	.814	.219	18402.3	-500.90	5.16	12.75	1.26	-10.23	.86	.19	4.65	-2.17
13.65	883.2	8.517	6.768	1.563	.894	.244	18219.5	-546.52	5.95	13.85	1.19	-10.41	.66	.34	5.15	-2.44
14.00	886.1	7.995	7.369	1.794	.982	.257	18018.4	-593.62	5.63	15.00	1.12	-10.61	.63	.41	5.70	-2.76
14.35	888.7	7.052	8.012	1.772	1.074	.268	17801.7	-641.46	5.19	16.06	1.04	-9.82	-2.87	.53	6.26	-3.11
14.70	890.9	5.103	8.657	2.011	1.165	.252	17558.4	-688.29	4.72	17.05	.99	-8.79	-5.97	.78	6.70	-3.47
15.05	892.2	2.321	9.449	2.553	1.250	.240	17313.2	-732.13	4.17	18.49	.92	-7.00	-10.77	.89	7.20	-3.85

CASE = 1. ENCOUNTER = 9

T A M D S C O M P U T E R P R O G R A M

A T T A C K E R V A R I A B L E S

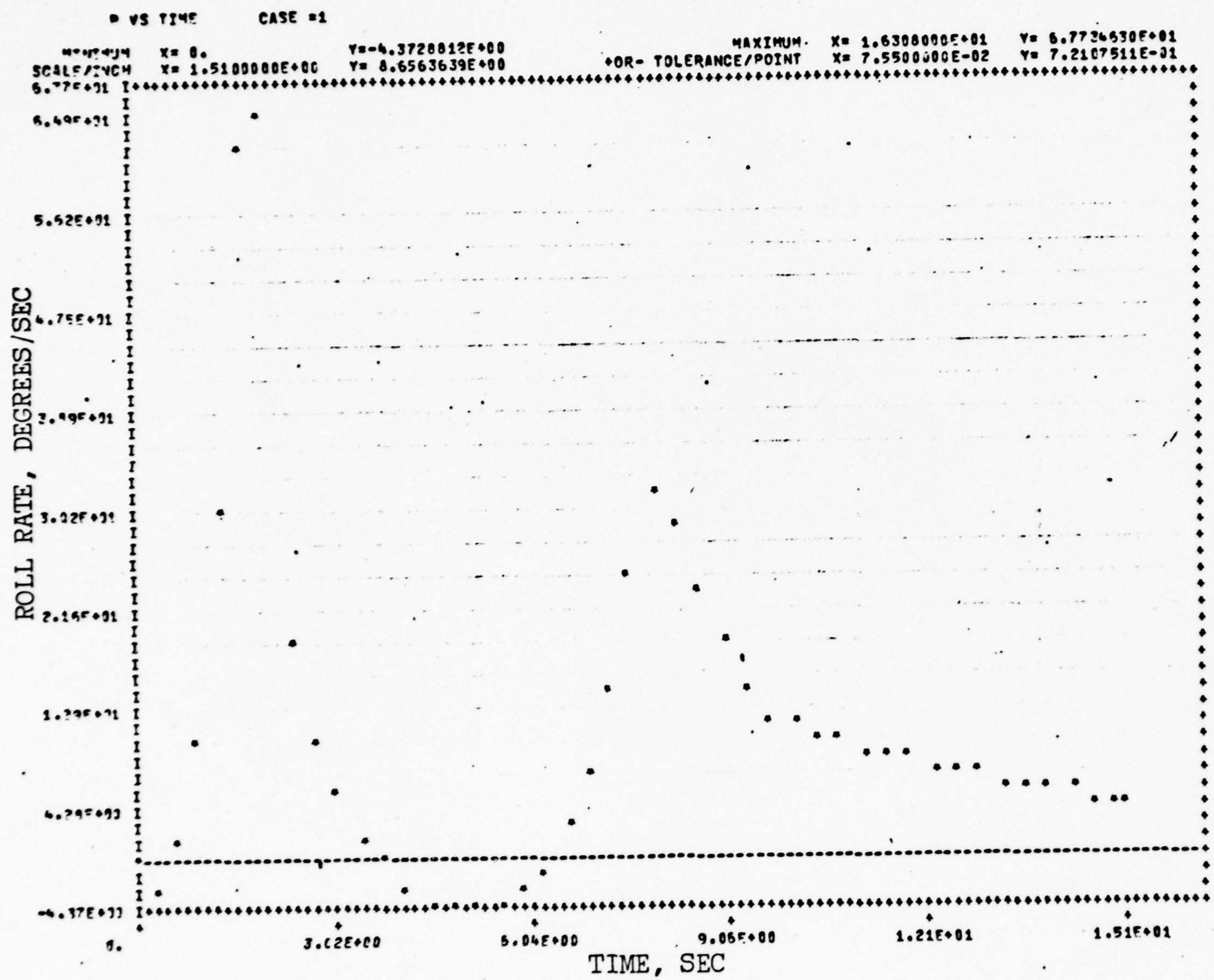
TIME SEC	// PILOT LONG //	COMMANDS //// LAT	DIP ////	STAB	SURFACE DEFLECTIONS CANARD (DEGREES)	AIL	DIF-TAIL	RUD ////	ATTITUDE ANGLES PSI (DEGREES)	THETA	PHI	GAMMA //	MACH	THRUST LBS
0.00	0.00	.00	0.00	-1.84	0.00	0.00	0.00	0.00	0.00	1.75	0.00	0.00	.80	3783.
.35	-.31	-.86	0.00	-1.70	0.00	-.08	0.00	-.02	-.02	1.75	-.71	.00	.80	3783.
.70	-.33	1.11	0.00	-1.77	0.00	-.86	0.00	-.01	-.04	1.69	-.93	-.00	.80	3783.
1.05	-.35	3.81	0.00	-1.80	0.00	-2.08	0.00	.02	.02	1.62	1.01	-.03	.80	3783.
1.40	.14	6.97	0.00	-1.77	0.00	-6.50	0.00	.13	.23	1.57	7.72	-.07	.80	3783.
1.75	1.30	9.47	0.00	-1.72	0.00	-8.75	0.00	.38	.79	1.45	24.47	-.12	.80	3783.
2.10	6.27	9.70	0.00	-1.81	0.00	-.20	0.00	.70	1.67	1.02	49.56	-.27	.80	3783.
2.45	9.37	6.79	0.00	-2.71	0.00	.32	0.00	.82	2.62	.68	62.84	-.60	.80	3783.
2.80	7.37	5.87	0.00	-1.11	0.00	-.68	0.00	.94	4.29	.71	67.43	-.92	.80	3783.
3.15	5.71	-.52	0.00	-1.56	0.00	-.35	0.00	1.07	5.50	.34	69.93	-1.20	.80	3783.
3.50	5.49	3.01	0.00	-1.87	0.00	.03	0.00	.93	6.28	-.28	71.23	-1.56	.80	3783.
3.85	7.44	1.61	0.00	-1.86	0.00	.29	0.00	.72	7.10	-.91	71.37	-1.93	.80	3783.
4.20	7.33	.45	0.00	-1.94	0.00	.42	0.00	.52	8.07	-1.44	70.70	-2.42	.80	3783.
4.55	7.55	-.79	0.00	-1.68	0.00	.44	0.00	.36	9.21	-1.85	69.40	-2.84	.80	3783.
4.90	7.55	-.92	0.00	-1.75	0.00	.38	0.00	.26	10.25	-2.20	67.98	-3.21	.80	3783.
5.25	7.35	-1.19	0.00	-1.92	0.00	.27	0.00	.23	11.24	-2.50	66.39	-3.56	.81	3783.
5.60	7.31	-1.24	0.00	-1.76	0.00	.15	0.00	.23	12.35	-2.68	64.43	-3.85	.81	3783.
5.95	7.37	-1.08	0.00	-1.70	0.00	.00	0.00	.24	13.47	-2.83	63.45	-4.11	.81	3783.
6.30	7.92	-.01	0.00	-1.82	0.00	-.49	0.00	.26	14.51	-2.99	62.47	-4.32	.81	3783.
6.65	7.31	1.60	0.00	-1.71	0.00	-.06	0.00	.29	15.60	-3.16	62.67	-4.52	.81	3783.
7.00	7.25	3.79	0.00	-1.65	0.00	-1.37	0.00	.34	16.65	-3.45	64.43	-4.72	.81	3783.
7.35	7.43	5.20	0.00	-1.82	0.00	-3.22	0.00	.46	17.62	-3.91	68.09	-5.00	.81	3783.
7.70	7.37	6.63	0.00	-1.87	0.00	-3.91	0.00	.53	18.65	-4.56	74.97	-5.33	.81	3783.
8.05	8.59	7.59	0.00	-1.89	0.00	-3.62	0.00	.55	19.82	-5.45	84.93	-5.91	.81	3783.
8.40	9.44	7.24	0.00	-2.01	0.00	-2.20	0.00	.59	21.07	-6.59	95.75	-6.64	.81	3783.
8.75	9.33	6.36	0.00	-1.93	0.00	-1.73	0.00	.59	22.43	-7.92	104.44	-7.57	.81	3783.
9.10	9.31	6.49	0.00	-1.82	0.00	-1.44	0.00	.63	23.92	-9.42	111.31	-8.63	.82	3783.
9.45	10.27	6.14	0.00	-1.94	0.00	-1.19	0.00	.65	25.27	-11.04	116.71	-9.98	.82	3783.
9.80	10.71	5.90	0.00	-1.87	0.00	-1.20	0.00	.65	26.65	-12.77	121.00	-11.41	.82	3783.
10.15	10.92	5.70	0.00	-1.90	0.00	-1.14	0.00	.65	28.11	-14.65	124.77	-12.93	.82	3783.
10.50	11.29	5.47	0.00	-1.94	0.00	-1.12	0.00	.68	29.58	-16.65	128.17	-14.63	.82	3783.
10.85	11.82	5.21	0.00	-2.00	0.00	-1.11	0.00	.73	31.11	-18.79	131.29	-16.54	.83	3783.
11.20	12.22	4.92	0.00	-1.95	0.00	-1.12	0.00	.79	32.75	-21.13	134.08	-18.55	.83	3783.
11.55	12.55	4.75	0.00	-2.03	0.00	-1.16	0.00	.88	34.48	-23.63	136.53	-20.73	.83	3783.
11.90	13.34	4.59	0.00	-2.19	0.00	-1.13	0.00	.97	36.30	-26.32	138.64	-23.09	.83	3783.
12.25	13.96	4.46	0.00	-2.29	0.00	-1.23	0.00	1.08	38.30	-29.26	140.47	-25.64	.84	3783.
12.60	14.55	4.39	0.00	-2.40	0.00	-1.28	0.00	1.20	40.51	-32.44	141.89	-28.42	.84	3783.
12.95	15.33	4.36	0.00	-2.59	0.00	-1.35	0.00	1.34	42.95	-35.86	142.90	-31.43	.84	3783.
13.30	16.13	4.43	0.00	-2.75	0.00	-1.44	0.00	1.49	45.73	-39.56	143.45	-34.69	.84	3783.
13.65	17.25	4.55	0.00	-2.95	0.00	-1.52	0.00	1.65	48.97	-43.56	143.45	-38.23	.85	3783.
14.00	18.31	4.73	0.00	-3.17	0.00	-1.59	0.00	1.84	52.84	-47.85	142.75	-42.05	.85	3783.
14.35	19.34	4.95	0.00	-3.41	0.00	-1.69	0.00	2.02	57.62	-52.40	141.01	-46.20	.85	3783.
14.70	20.55	5.21	0.00	-3.93	0.00	-1.73	0.00	2.20	63.66	-57.05	137.85	-50.59	.85	3783.
15.05	22.41	5.49	0.00	-4.46	0.00	-1.85	0.00	2.38	71.79	-61.74	132.43	-55.14	.85	3783.

CASE = 1. ENCOUNTER = 8

TAMDS COMPUTER PROGRAM

BULLET - SIGHT - GEOMETRY VARIARLES

TIME SEC	TRACKING FRROR TR MR	FL MR	DIRECTOR TF SEC	BULLET TF SEC	BULLET// RANGE FT	TR MR	BULLET FL MR	MISS TR FEET	/// FL FEET	LEAD ANGLE TR MR	FL MR	//TARGET WRT GUN/ TR MR	FL MR	RANGE RATE FT/SEC	RANGE FEET
0.17	10.32	10.83	4.75	0.00	0.	0.00	0.00	0.	0.	-.7	-51.1	-10.8	-61.1	-200.0	7030.
.35	10.33	13.23	4.62	1.95	5836.	********	********	999.	999.	-.3	-47.9	-11.2	-61.2	-200.5	6930.
.79	5.54	11.68	4.46	1.95	5836.	********	********	999.	999.	-4.6	-48.2	-11.1	-59.8	-201.9	6863.
1.03	-7.11	9.26	4.30	1.95	5837.	********	********	999.	999.	-12.6	-43.3	-9.5	-58.5	-204.6	6793.
1.43	-17.74	6.40	4.14	1.95	5837.	********	********	999.	999.	-22.7	-51.7	-5.8	-58.1	-209.2	6716.
1.77	-34.33	-2.57	3.97	1.95	5837.	********	********	999.	999.	-30.3	-53.8	4.3	-57.2	-215.8	6642.
2.13	-41.57	-21.93	3.81	1.95	5837.	********	********	999.	999.	-27.6	-75.5	14.1	-53.6	-224.5	6555.
2.47	-38.72	-31.41	3.65	1.95	5837.	********	********	999.	999.	-23.8	-87.3	15.0	-55.9	-234.0	6495.
2.83	-34.47	-19.73	3.50	1.95	5836.	********	********	999.	999.	-24.2	-94.4	10.7	-76.1	-244.0	6401.
3.15	-24.47	-12.83	3.35	1.95	5836.	********	********	999.	999.	-25.2	-99.2	3.3	-86.4	-254.2	6314.
3.59	-20.17	-13.59	3.21	1.95	5835.	********	********	999.	999.	-27.0	-103.7	-6.9	-88.1	-264.9	6223.
3.95	-11.15	-17.92	3.08	1.95	5835.	********	********	999.	999.	-29.6	-107.8	-18.5	-89.9	-276.2	6128.
4.33	-2.75	-19.31	2.95	1.95	5834.	********	********	999.	999.	-33.1	-111.3	-30.3	-93.2	-287.7	6031.
4.67	4.39	-14.85	2.83	1.95	5833.	********	********	999.	999.	-37.4	-113.6	-41.5	-98.8	-299.5	5927.
4.93	9.11	-17.62	2.71	1.95	5833.	********	********	999.	999.	-42.3	-115.0	-51.4	-101.3	-311.4	5823.
5.25	12.31	-17.76	2.59	1.95	5832.	********	********	999.	999.	-47.4	-115.7	-59.3	-102.0	-323.5	5709.
5.63	13.37	-11.70	2.48	1.95	5832.	********	********	999.	999.	-52.7	-116.0	-66.6	-104.7	-335.6	5594.
5.93	14.15	-3.90	2.37	1.95	5831.	********	********	999.	999.	-57.9	-115.7	-71.3	-105.9	-347.8	5475.
6.31	11.39	-3.23	2.27	1.95	5831.	********	********	999.	999.	-63.7	-115.0	-75.3	-105.8	-360.3	5351.
6.65	5.97	-5.95	2.16	1.95	5830.	********	********	999.	999.	-68.9	-114.1	-75.3	-107.1	-373.1	5222.
7.19	-.25	-7.15	2.06	1.95	5829.	********	********	999.	999.	-73.5	-113.5	-73.3	-108.4	-385.7	5090.
7.37	-3.85	-3.59	1.96	1.90	5774.	-37.94	6.02	-213.	35.	-76.2	-114.4	-67.4	-108.8	-397.3	4953.
7.73	-17.27	-5.91	1.87	1.82	5598.	-47.43	2.69	-247.	15.	-74.0	-119.0	-56.3	-112.1	-407.3	4812.
8.35	-24.34	-3.83	1.78	1.73	5411.	-46.35	-3.47	-250.	-19.	-65.8	-126.3	-41.7	-118.0	-415.1	4663.
8.43	-29.15	-11.54	1.70	1.65	5214.	-46.18	-10.30	-241.	-54.	-54.3	-135.1	-26.2	-127.6	-422.1	4522.
8.75	-33.23	-11.95	1.61	1.57	5026.	-44.89	-13.54	-226.	-69.	-44.9	-141.2	-14.6	-130.2	-429.1	4373.
9.10	-31.53	-11.27	1.53	1.50	4877.	-43.33	-14.89	-210.	-72.	-38.0	-145.6	-6.3	-134.3	-436.0	4222.
9.45	-32.42	-12.17	1.45	1.42	4647.	-41.86	-16.64	-195.	-77.	-33.2	-148.9	-.3	-136.7	-442.8	4068.
9.81	-37.80	-12.82	1.37	1.35	4457.	-40.91	-17.69	-182.	-79.	-30.2	-151.7	3.1	-138.9	-449.5	3912.
10.17	-34.37	-12.67	1.30	1.27	4265.	-40.50	-17.89	-177.	-76.	-27.8	-154.3	6.3	-141.7	-455.9	3754.
10.51	-36.20	-13.74	1.22	1.20	4074.	-40.43	-18.68	-165.	-76.	-25.5	-156.7	10.7	-143.4	-462.6	3593.
10.87	-38.26	-14.35	1.15	1.13	3881.	-40.65	-19.67	-159.	-76.	-23.4	-159.1	14.7	-144.7	-469.0	3431.
11.23	-40.23	-14.69	1.08	1.05	3689.	-41.19	-20.04	-152.	-74.	-21.4	-161.2	18.9	-146.5	-474.8	3265.
11.57	-42.71	-15.47	1.01	1.00	3497.	-42.18	-20.68	-147.	-72.	-19.7	-163.1	23.0	-147.7	-480.1	3093.
11.93	-45.43	-15.91	.94	.93	3305.	-43.22	-21.89	-143.	-72.	-18.0	-164.9	27.4	-148.0	-483.7	2930.
12.29	-48.39	-17.69	.88	.87	3115.	-44.63	-22.61	-139.	-70.	-16.5	-166.5	31.9	-148.6	-485.2	2761.
12.65	-51.63	-18.90	.81	.81	2927.	-46.35	-23.27	-136.	-68.	-15.0	-167.9	36.5	-149.0	-484.3	2592.
12.99	-55.04	-20.60	.75	.75	2742.	-48.30	-24.41	-132.	-67.	-13.7	-169.1	41.3	-148.5	-480.6	2427.
13.33	-58.53	-22.35	.70	.69	2560.	-50.45	-25.53	-129.	-65.	-12.4	-170.0	46.2	-147.6	-473.7	2256.
13.69	-62.25	-24.05	.64	.63	2384.	-52.67	-26.47	-126.	-63.	-11.1	-170.5	51.2	-146.5	-463.2	2093.
14.03	-65.55	-25.55	.59	.59	2213.	-54.76	-27.53	-121.	-61.	-9.6	-170.5	56.1	-144.6	-449.8	1937.
14.37	-68.72	-28.21	.54	.54	2049.	-56.65	-28.58	-116.	-59.	-8.1	-170.1	60.5	-141.8	-430.3	1780.
14.73	-71.25	-32.50	.49	.49	1894.	-58.19	-31.27	-110.	-59.	-6.7	-168.9	64.5	-136.4	-407.5	1634.
15.05	-72.35	-37.33	.45	.45	1748.	-59.19	-34.31	-103.	-60.	-5.4	-167.1	67.5	-129.7	-380.0	1496.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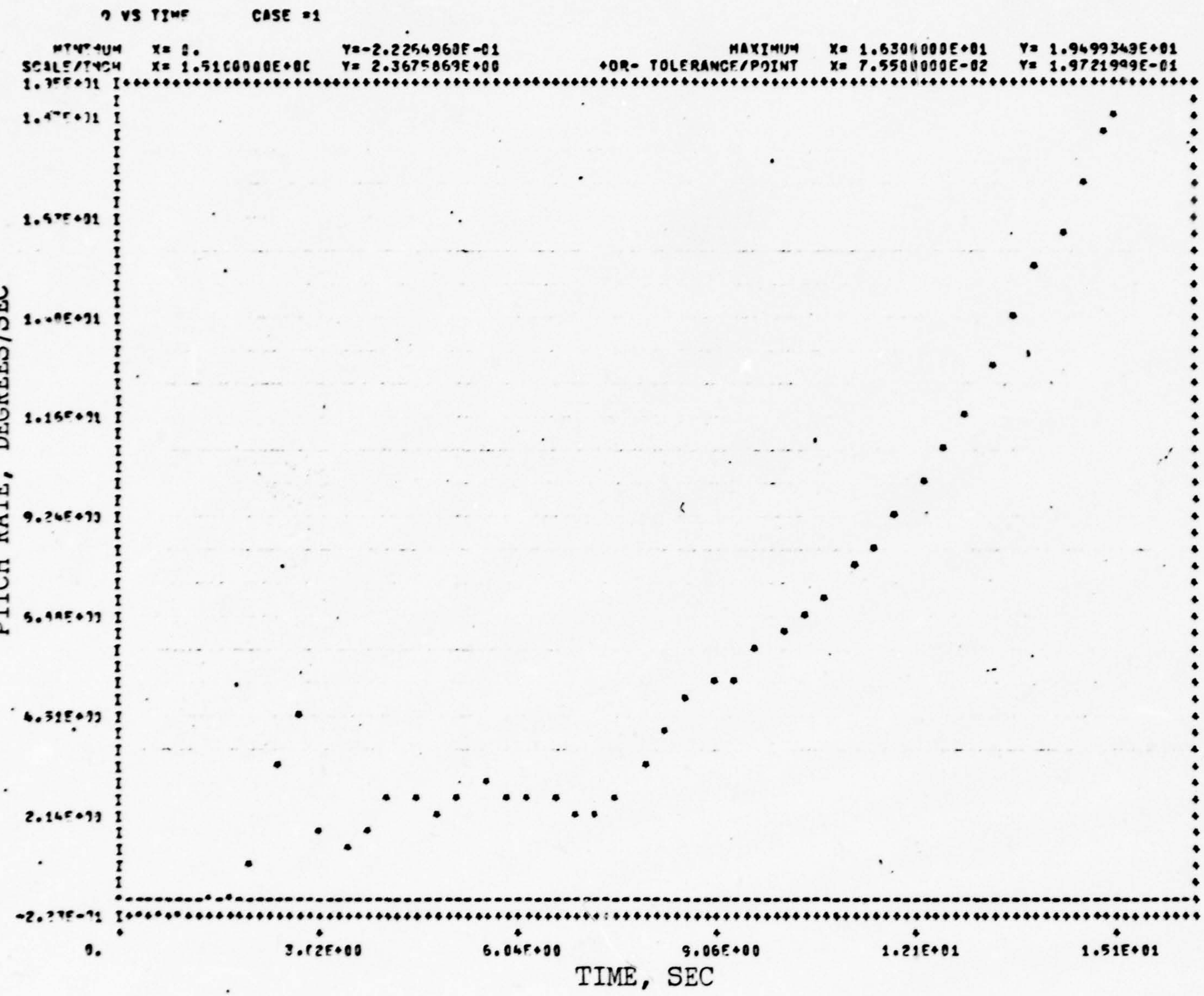
SCALE/INCH X= 1.5100000E+00 Y= 8.6563639E+00
MAXIMUM X= 1.6308000E+01 Y= 6.7724630E+01
+OR- TOLERANCE/POINT X= 7.5500000E-02 Y= 7.2107511E-01
ROLL RATE, DEGREES/SEC
5.62E+01
3.02E+01
2.16E+01
-4.37E+00
0.
3.02E+00
6.04E+00
9.06E+00
1.21E+01
1.51E+01
TIME, SEC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MAXIMUM X= 1.6300000E+01 Y= 1.9499349E+01
+OR- TOLERANCE/POINT X= 7.5500000E-02 Y= 1.9721999E-01
PITCH RATE, DEGREES/SEC
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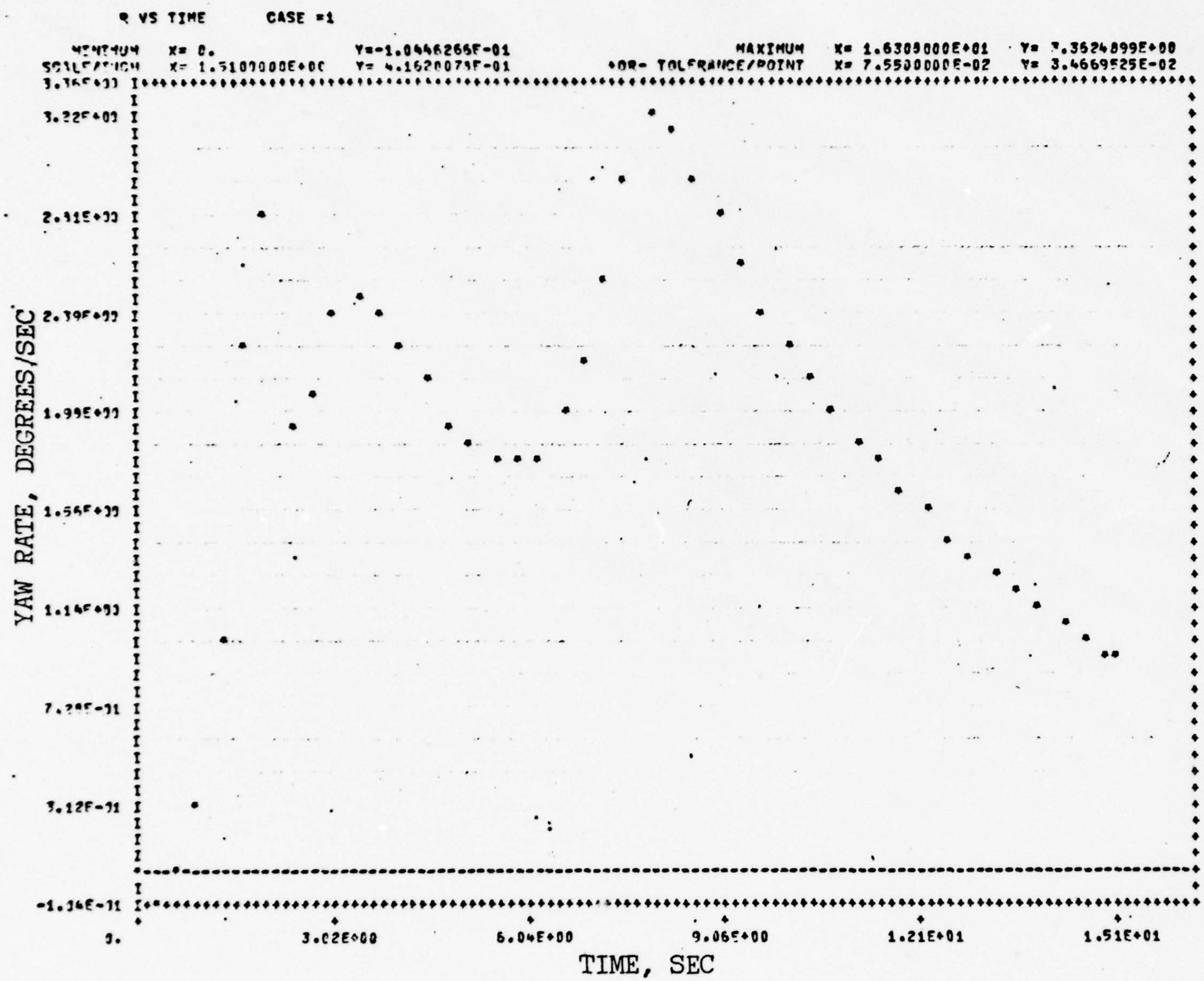
9.06E+00
1.21E+01
1.51E+01
TIME, SEC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X= 1.5107000E+00 Y= 4.1620078E-01
+OR- TOLERANCE/POINT X= 7.5500000E-02 Y= 3.4669525E-02
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2.39E+00
1.99E+00
1.56E+00
1.14E+00
7.29E-01
3.12E-01
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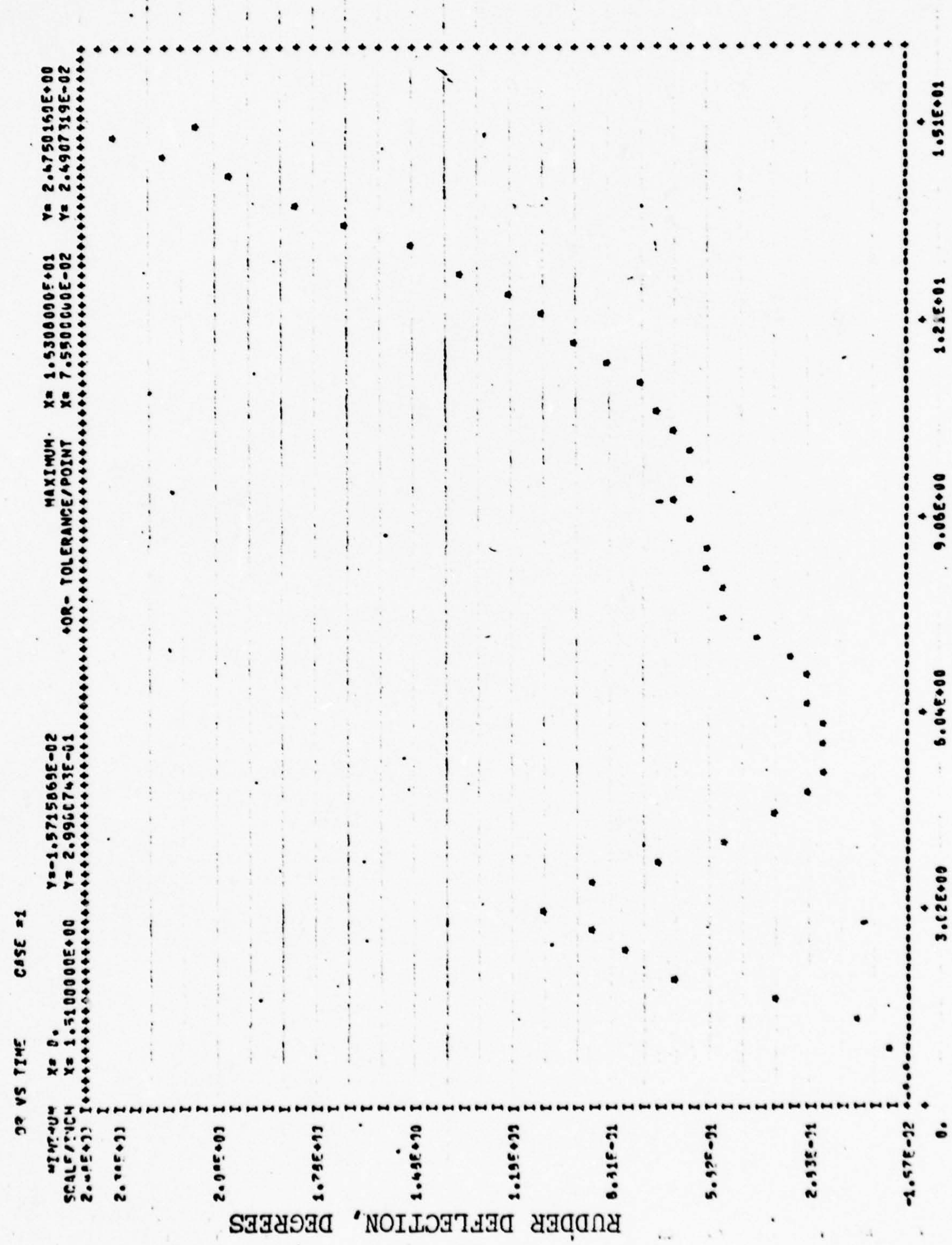
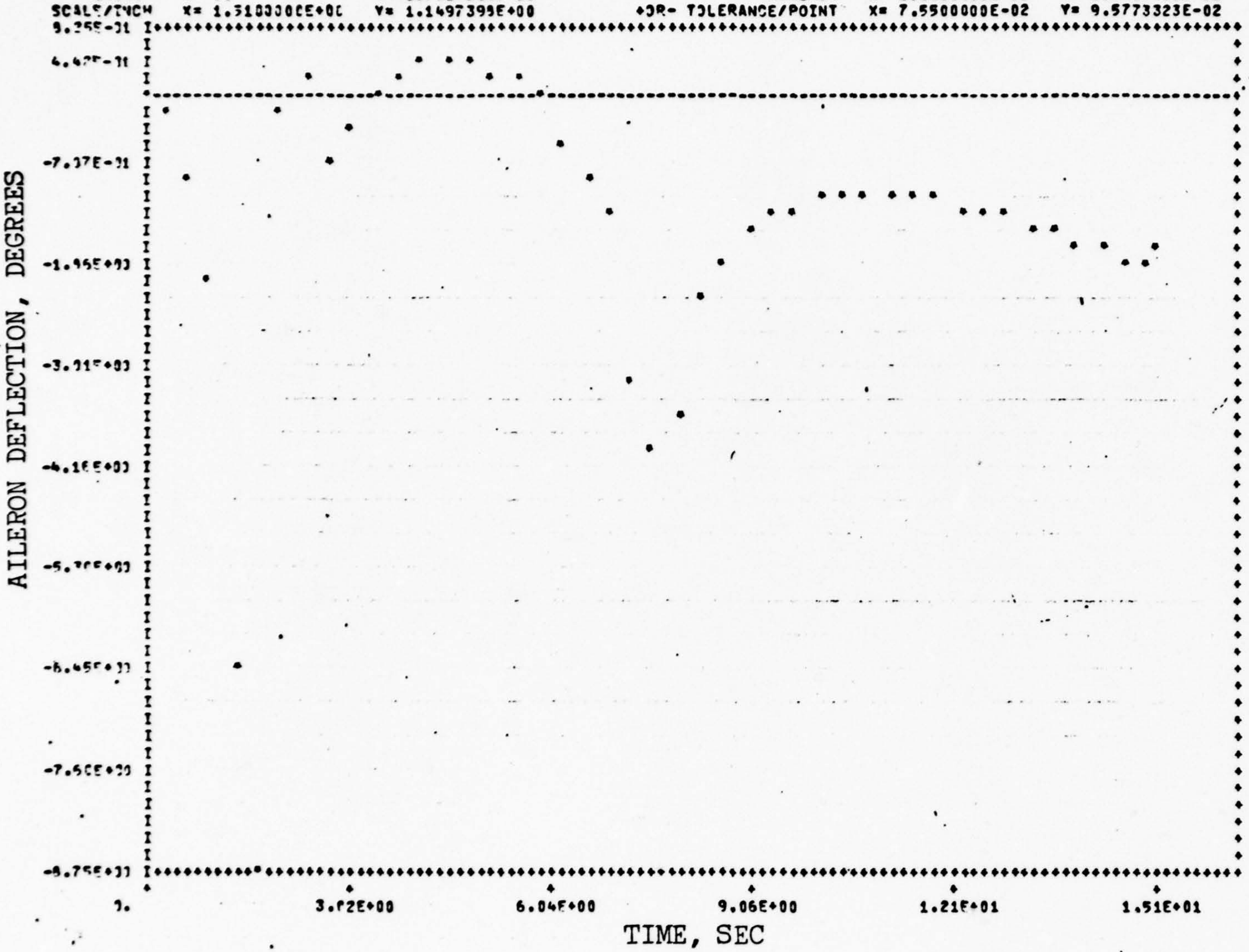
TIME, SEC
YAW RATE, DEGREES/SEC

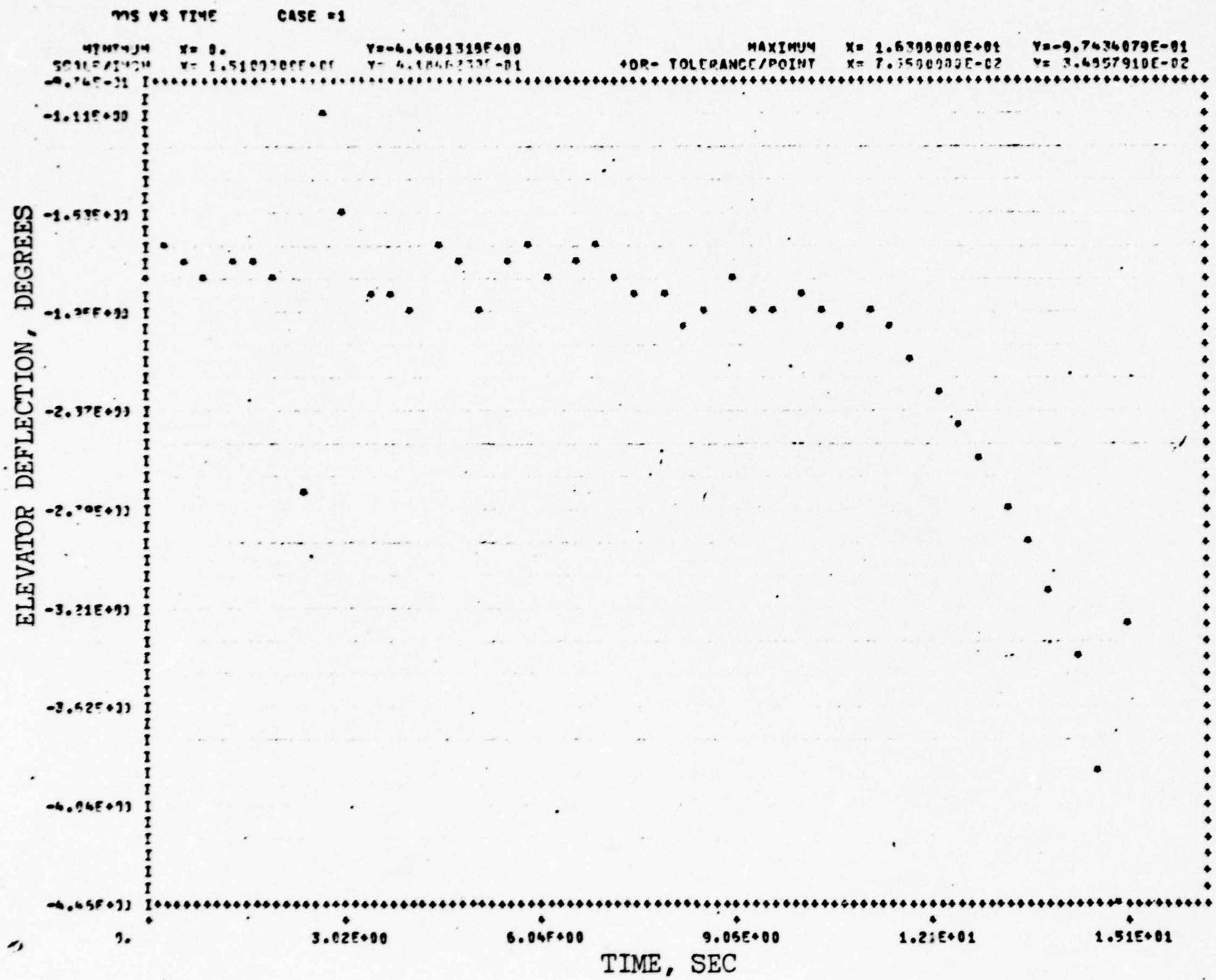


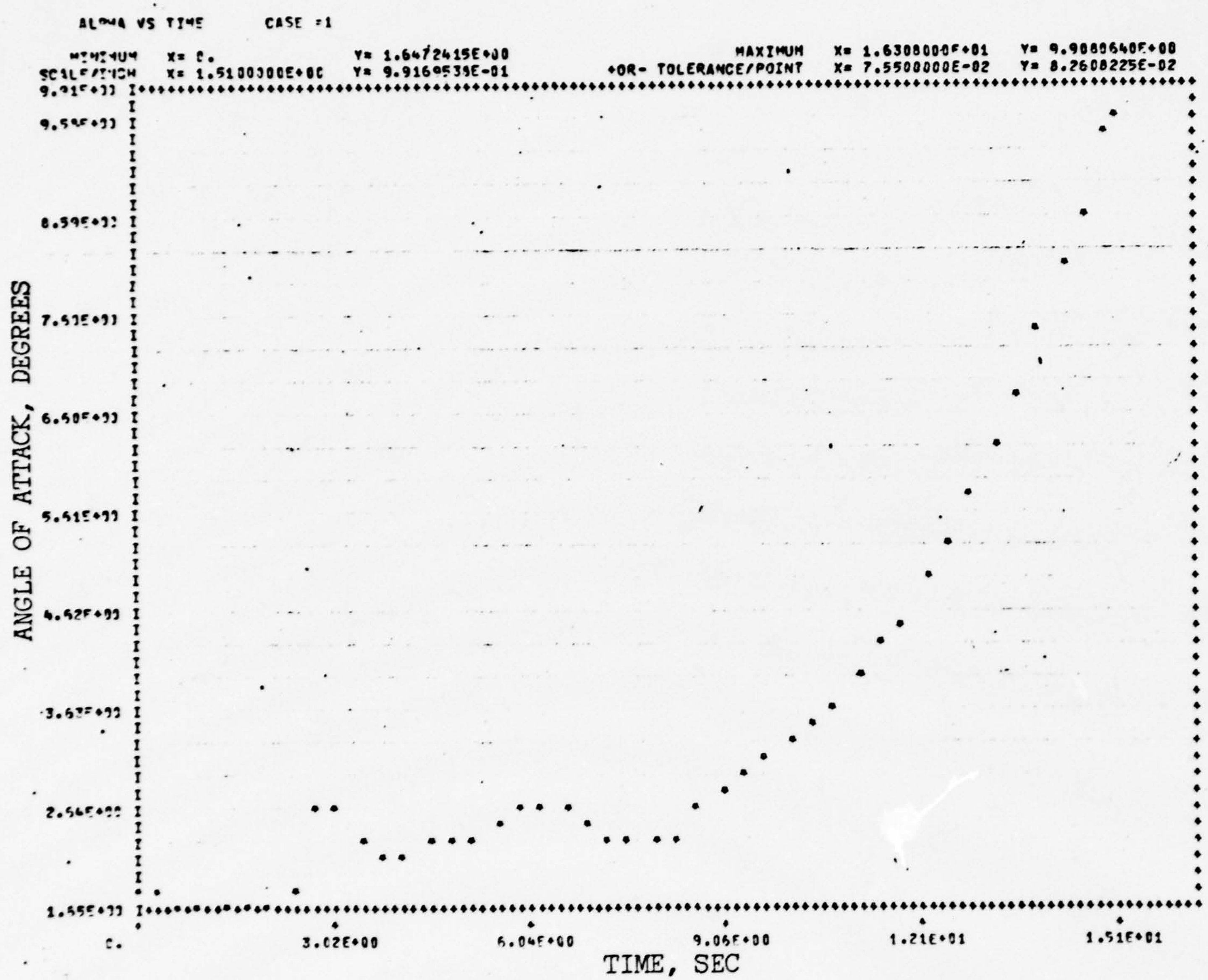
CASE =1
MAXIMUM
-OR- TOLERANCE/POINT
TIME, SEC
RUDDER DEFLECTION, DEGREES

DA VS TIME CASE =1

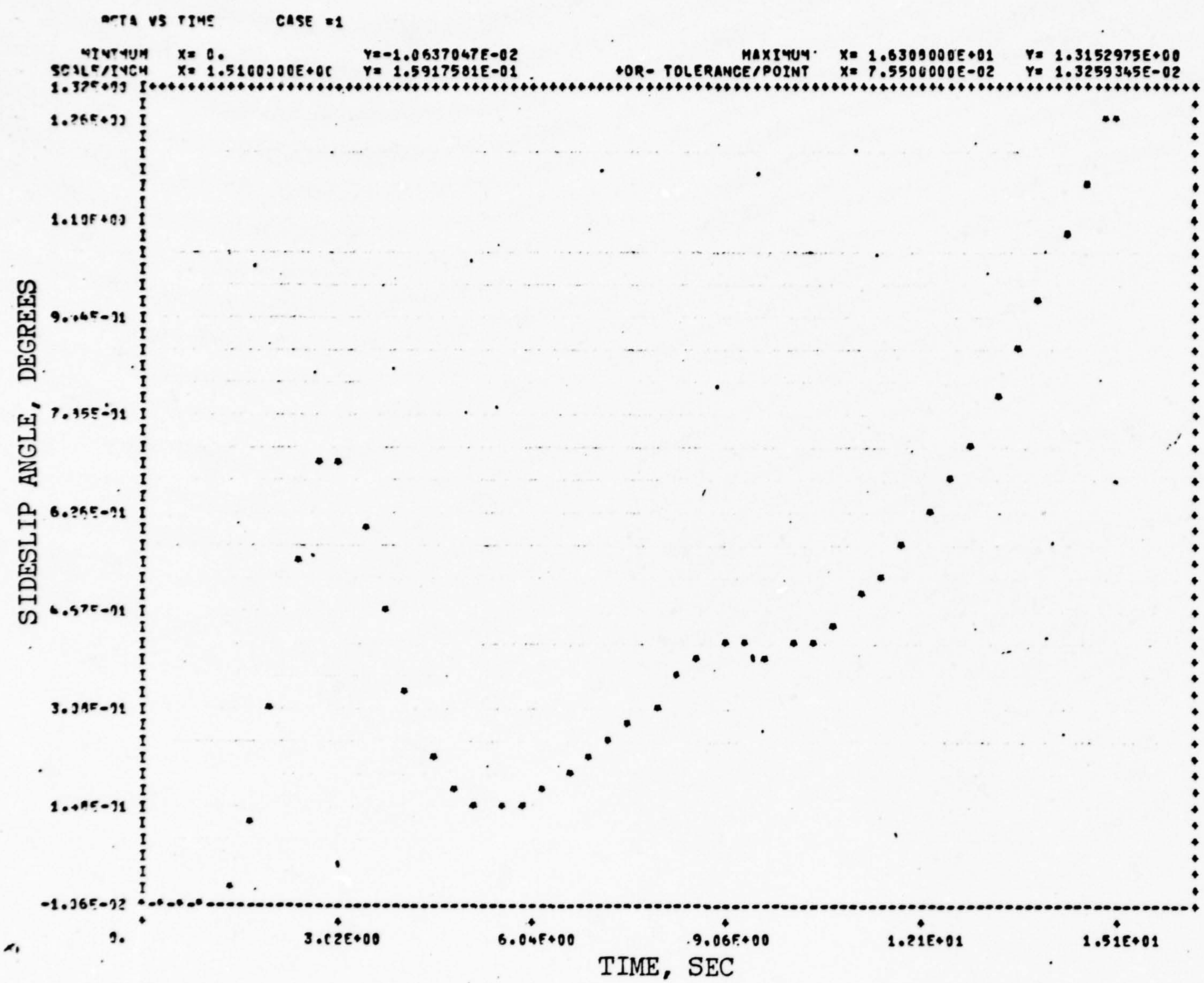
MINIMUM X= 0. Y=-8.7524583E+00 MAXIMUM X= 1.6308000E+01 Y= 8.2487400E-01
SCALE/INCH X= 1.5100000E+00 Y= 1.1497399E+00 -OR- TOLERANCE/POINT X= 7.5500000E-02 Y= 9.5773323E-02

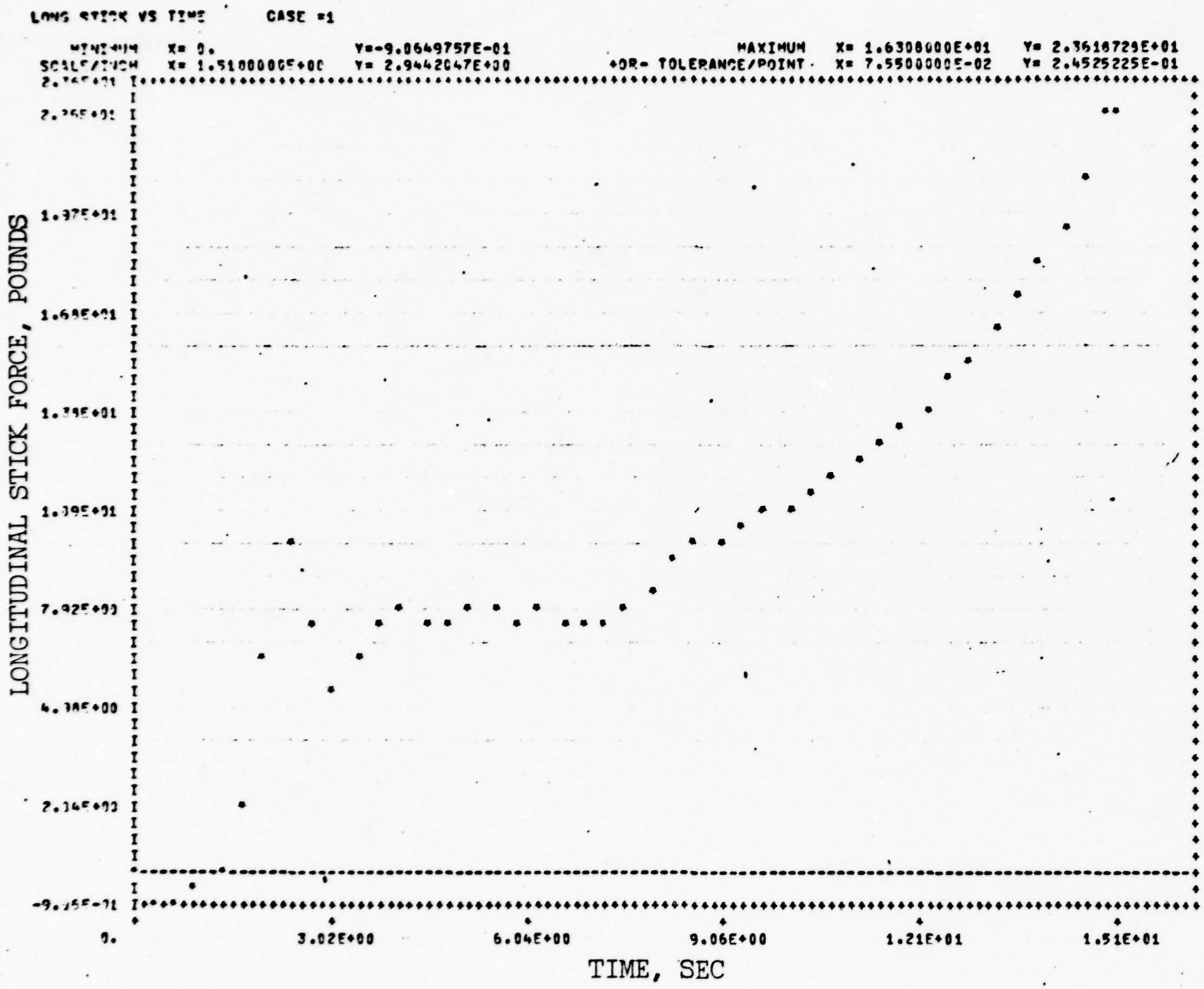



DDS VS TIME CASE =1
MINIMUM X= 0. Y=-4.4601319E+00
MAXIMUM X= 1.6300000E+01 Y=-9.7434079E-01
+OR- TOLERANCE/POINT
Y= 3.4557910E-02
-1.11E+00
-1.53E+00
-2.37E+00
-3.21E+00
-4.04E+00
0.
3.02E+00
6.04E+00
9.06E+00
1.51E+01
ELEVATOR DEFLECTION, DEGREES
TIME, SEC

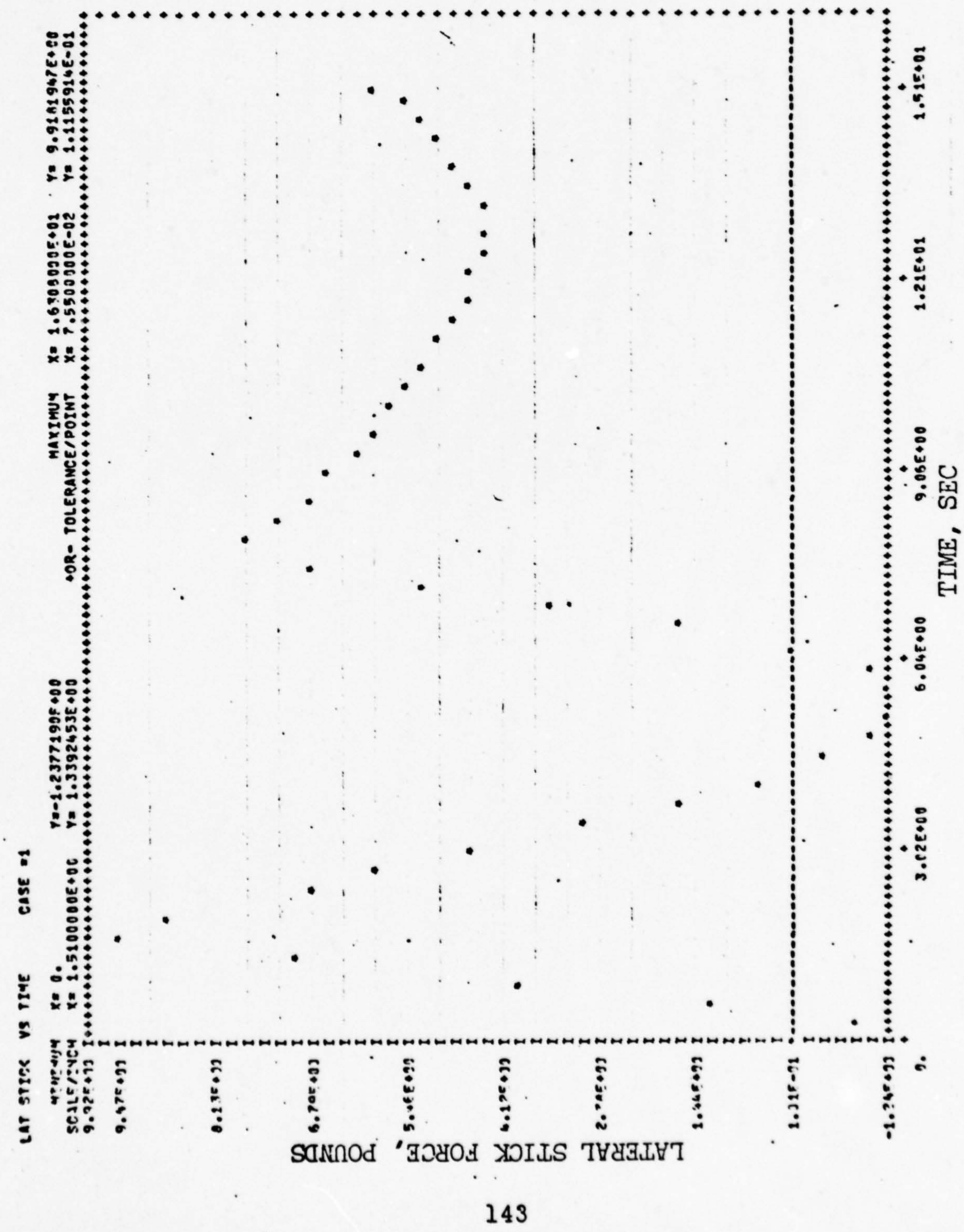


ALPHA VS TIME CASE =1
MINIMUM X= 0. Y= 1.6472415E+00
SCALE/INCH X= 1.5100000E+00 Y= 9.9169539E-01
MAXIMUM X= 1.6308000E+01 Y= 9.9080640E+00
+OR- TOLERANCE/POINT X= 7.5500000E-02 Y= 8.2608225E-02
9.91E+00
9.59E+00
8.59E+00
7.51E+00
6.50E+00
5.51E+00
4.62E+00
3.63E+00
2.56E+00
1.55E+00
0.
3.02E+00
6.04E+00
9.06E+00
1.21E+01
1.51E+01
ANGLE OF ATTACK, DEGREES
TIME, SEC

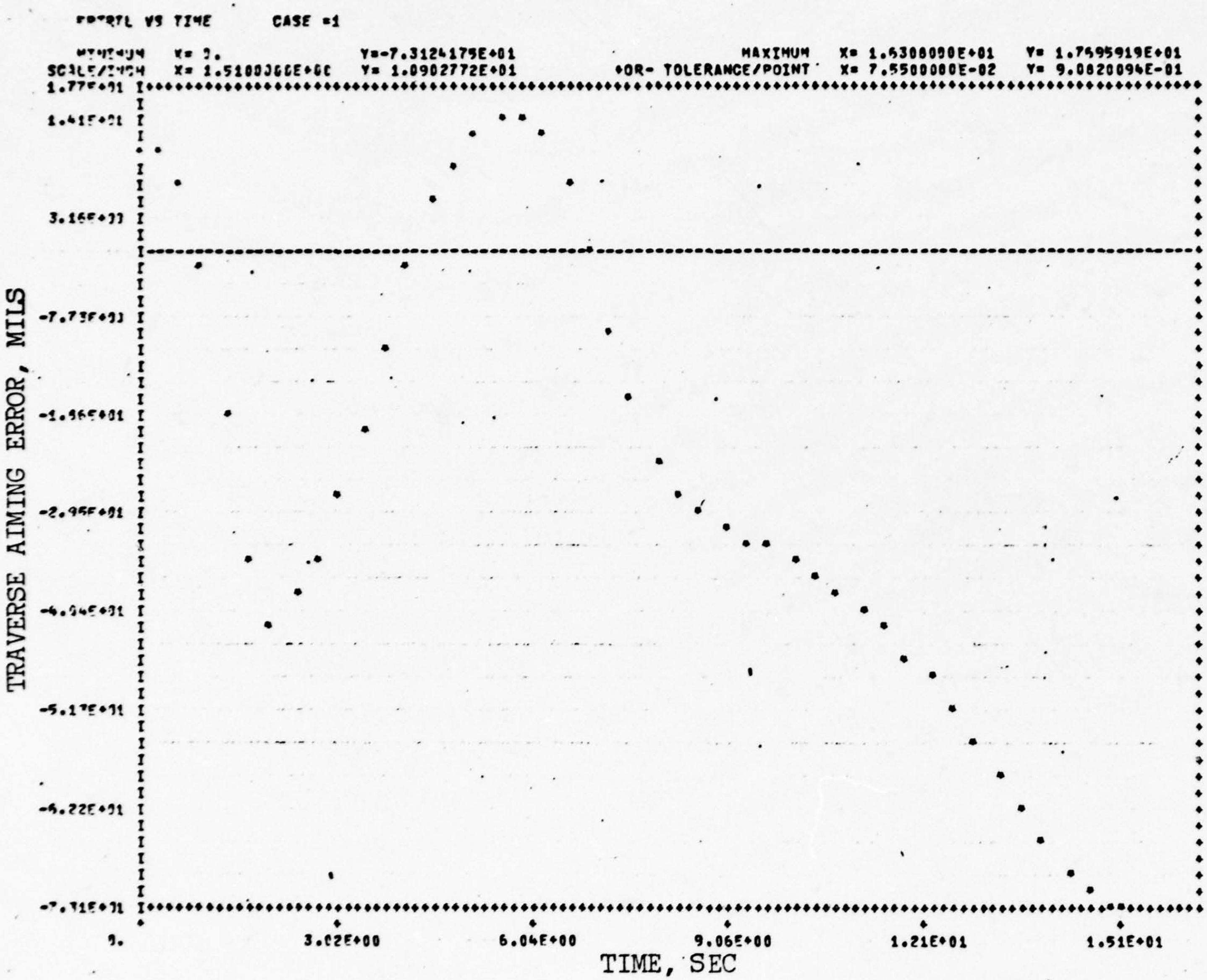

BETA VS TIME CASE =1
MINIMUM X= 0. Y=-1.0637047E-02
SCALE/INCH X= 1.5100000E+00 Y= 1.5917581E-01
MAXIMUM X= 1.6308000E+01 Y= 1.3152975E+00
+OR- TOLERANCE/POINT X= 7.5500000E-02 Y= 1.3259345E-02
1.32E+00
1.26E+00
1.10E+00
9.46E-01
7.35E-01
6.26E-01
4.57E-01
3.38E-01
1.48E-01
-1.06E-02
0.
3.02E+00
6.04E+00
9.06E+00
1.21E+01
1.51E+01
SIDESLIP ANGLE, DEGREES
TIME, SEC

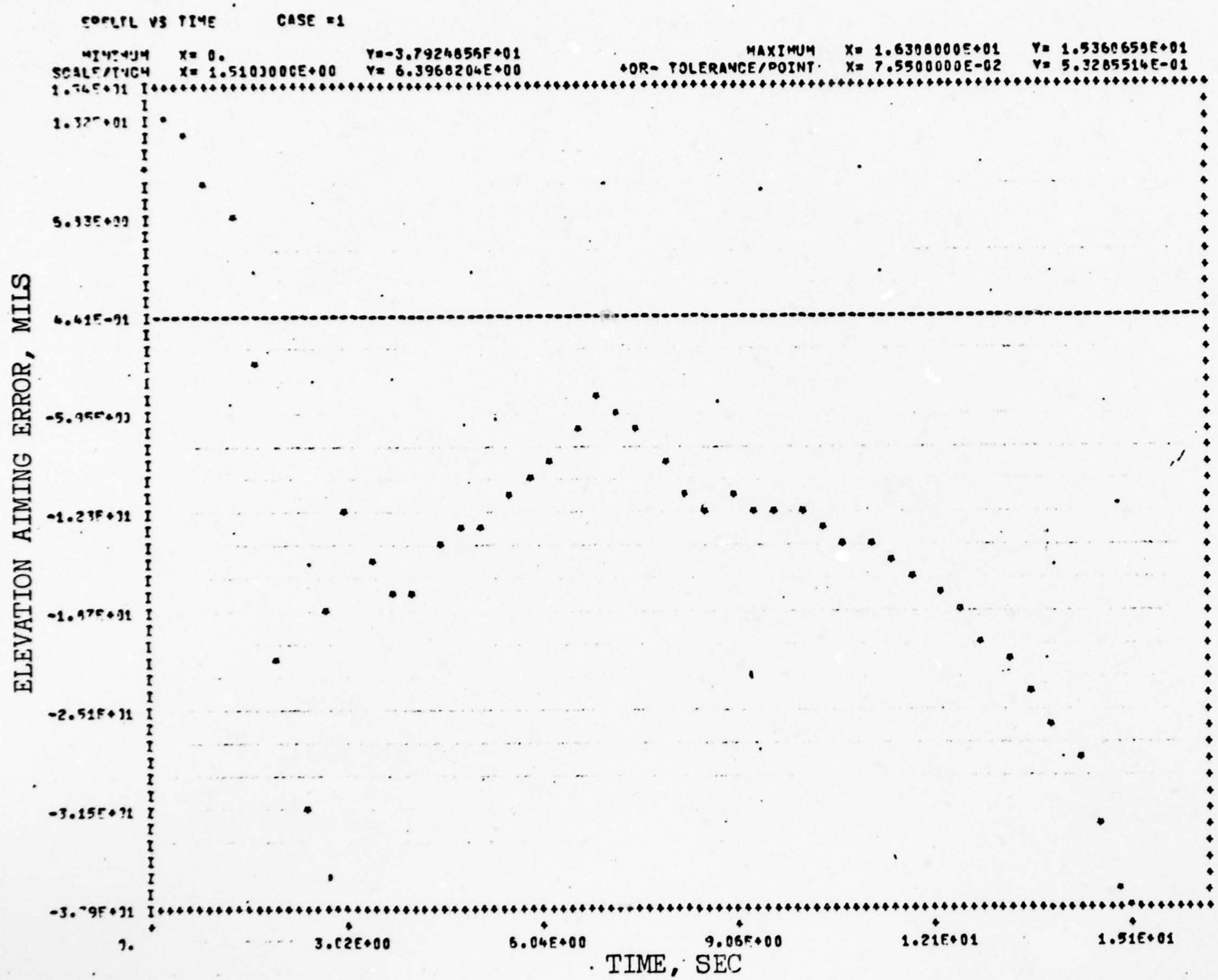


LONG STICK VS TIME CASE =1
MINIMUM X= 0. Y=-9.0649757E-01
SCALE/INCH X= 1.5100000E+00 Y= 2.9442047E+00
MAXIMUM X= 1.6308000E+01 Y= 2.3616729E+01
+OR- TOLERANCE/POINT X= 7.5500000E-02 Y= 2.4525225E-01
2.26E+01
1.97E+01
1.68E+01
1.39E+01
1.09E+01
7.92E+00
4.98E+00
2.14E+00
0.
3.02E+00
6.04E+00
9.06E+00
1.21E+01
1.51E+01
TIME, SEC
LONGITUDINAL STICK FORCE, POUNDS



LAT STICK VS TIME CASE =1
X= 0. Y=-1.2377190E+00
SCALE/INCH X= 1.5100000E+00 Y= 1.3392453E+00
MAXIMUM X= 1.6308000E+01 Y= 9.9181947E+00
+OR- TOLERANCE/POINT X= 7.5500000E-02 Y= 1.1155914E-01
0.
3.02E+00
6.04E+00
9.06E+00
1.21E+01
1.51E+01
TIME, SEC
LATERAL STICK FORCE, POUNDS


PORTL VS TIME CASE =1
MINIMUM X= 0. Y=-7.3124175E+01
MAXIMUM X= 1.6308090E+01 Y= 1.7595919E+01
SCALE/INCH X= 1.5100000E+00 Y= 1.0902772E+01
-OR- TOLERANCE/POINT X= 7.5500000E-02 Y= 9.0820094E-01
1.77E+01
1.41E+01
3.16E+00
-7.73E+00
-1.86E+01
-2.95E+01
-4.04E+01
-5.13E+01
-6.22E+01
-7.31E+01
0.
3.02E+00
6.04E+00
9.06E+00
1.21E+01
1.51E+01
TIME, SEC
TRAVERSE AIMING ERROR, MILS



CASE =1
MAXIMUM X= 1.6308000E+01 Y= 1.5360659E+01
X= 1.5103000E+00 Y= 6.3968204E+00
+OR- TOLERANCE/POINT X= 7.5500000E-02 Y= 5.3285514E-01
1.32E+01
-5.95E+00
-1.23E+01
-2.51E+01
-3.15E+01
3.02E+00
6.04E+00
9.06E+00
1.21E+01
1.51E+01
TIME, SEC
ELEVATION AIMING ERROR, MILS

```
*ID OCT20
*DELETE FCEXEC.183
      IF (ITGCNT.LT.5000) GO TO 200
*DELETE FCEXEC.186
  190 FORMAT(1H0,30H ERROR --- ITGCNT EXCEEDS 5000)
*DELETE PRINT.183
      RPRI22( 2) = QCOM
*DELETE PRINT.184
      RPRI22( 3) = PHIC
*DELETE PRINT.262
     .,2F8.1,F10.1,5F8.2,F6.2)
*DELETE PRINT.276
  821 FORMAT(1X,F6.2,1X,F8.1,5F8.3,F8.1,7F8.2,2F6.2)
*INSERT AIRFI1.366
      PARAM(480)=RHO
*D PILTI1.64
      DTHE= -ERELTL*1000.
*D PILTI1.65
      DTHT=-ERTRTL*1000.
*DELETE INDAC1.26
     .,              ( ERELTLC , DUM3( 13))
*DELETE INDAC1.27
     .,              ( ERTRTLC , DUM3( 14))
*DELETE TARGET.92
     .     ALTDCO/-1.4,0.0,1.4,2.8,4.2,5.5,7.0,8.4,9.8,10.0 /
*DELETE TARGET.93
     .    ,DTHYCD/-100.,-80.,-60.,-45.,0.,30.,45.,60.,80.,100. /
*DELETE TARGET.94
     .    ,XTHTDC/20)0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0/
*DELETE TARGET.95
*DELETE ICNMPR.90
     .     545403373,
*DELETE ICNMPR.91
     .     545403374,
*DELETE ICNMPR.92
     .     545403372,
*DELETE ICNMPR.93
     .     545403372,
*DELETE ICNMPR.94
     .     545403392,
*DELETE ICNMPR.95
     .     545403391,
*DELETE ICNMPR.96
     .     545403392,
*DELETE ICNMPR.97
     .     545403391/
*DELETE ICNMPR.106
     .0.,2.,6.,8.,10.,11.,12.,13.,14.,15. /
*DELETE ICNMPR.134
     .        30..        40..        50..        60..        70.  /
```

```
*DELETE ICNMPR.146
      ITMX(1,1)=660   $ ITMX(1,2)=410  $ ITMX(1,4)=410  $ ITMX(1,5)=410
*DELETE ICNMPR.147
      ITMX(2,1)=370   $ ITMX(2,2)=410  $ ITMX(2,5)=310  $ ITMX(2,7)=410
*DELETE ICNMPR.148
      ITMX(3,1)=370   $ ITMX(3,2)=410  $ ITMX(3,7)=610  $ ITMX(3,8)=410
*DELETE ICNMPR.149
      ITMX(4,1)=660   $ ITMX(4,2)=410  $ ITMX(4,4)=610  $ ITMX(4,5)=410
*DELETE ICNMPR.150
      ITMX(5,1)=670   $ ITMX(5,2)=410  $ ITMX(5,4)=610  $ ITMX(5,5)=410
*DELETE ICNMPR.151
      ITMX(6,1)=350   $ ITMX(6,2)=410  $ ITMX(6,4)=310  $ ITMX(6,5)=410
*DELETE ICNMPR.152
      ITMX(7,1)=380   $ ITMX(7,2)=410  $ ITMX(7,3)=310  $ ITMX(7,4)=410
*DELETE ICNMPR.153
      ITMX(8,1)=650   $ ITMX(8,2)=410  $ ITMX(8,3)=610  $ ITMX(8,4)=410
*DELETE ICNMPR.171
   21 ITM(I)=410
*DELETE AUTSI1.2,365
      SUBROUTINE AUTSI1
      COMMON   /CFDATA/  DUM(530), DUM1(270), DUM2(300)
      COMMON   /IDATA/   IDUM1(200) , IDUM3(50)
      COMMON /INTVAR/  PARAM(460), TIME, INTDEX
      COMMON /CINT/ T,HMAX
      REAL MACH
      DIMENSION ALPHA(4),H(4),P(4),Q(4),R(4),INDDR(23)
      DIMENSION
     1 CBNZ(2), CCNZ(2), DVNZ(8), CBQQ(2), CCQQ(2), DVQQ(8)
     2,CBCOML(3), CCCOML(3), DVCOML(12), CBSE(2), CCSE(2), DVSE(8)
     3,CBRE(2), CCRE(2), DVRE(8),CBYR(2), CCYR(2), DVYR(8)
     4,CBNY(2),CCNY(2), DVNY(8), DVER2(8), DVERS(8), DVPHX(8), DVEPS(8)
      EQUIVALENCE
     A ( GKNZ2    ,DUM(105)),( GKFB     ,DUM(117)),( GKNZ1    ,DUM(119))
     B,( GKNL1    ,DUM(120)),( GKMECH   ,DUM(125)),( GKNL2    ,DUM(126))
     C,( GK6      ,DUM(143)),( GKF      ,DUM(152)),( GKNZ3    ,DUM(106))
      EQUIVALENCE
     A (CBNZ(1)   ,DUM(109)),(CCNZ(1)   ,DUM(111)),(CBQQ(1)   ,DUM(113))
     B,(CCQQ(1)   ,DUM(115)),(CBSE(1)   ,DUM(121)),(CCSE(1)   ,DUM(123))
     C,(CBCOML(1),DUM(153)),(CCCOML(1),DUM(156))
      EQUIVALENCE  ( DR              ,  DUM(  3))
      EQUIVALENCE  ( MACH            ,  DUM(038))
      EQUIVALENCE  ( GKQ             ,   DUM(131))
      EQUIVALENCE  ( GGNS            ,   DUM(425))
      EQUIVALENCE  ( GGNA            ,   DUM(426))
      EQUIVALENCE  ( DA              , DUM1( 94))
      EQUIVALENCE  ( DAHI            , DUM1(112))
      EQUIVALENCE  ( DALO            , DUM1(113))
      EQUIVALENCE  ( DSLU            , DUM1(114))
      EQUIVALENCE  ( DSLL            , DUM1(115))
      EQUIVALENCE  ( DSHI            , DUM1(116))
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      EQUIVALENCE  ( DSLO           , DUM1(117))
      EQUIVALENCE   ( RUDHI ,   DUM1(121)) , (RUDLO , DUM1(122))
      EQUIVALENCE  ( PHIC           , DUM1(159))
      EQUIVALENCE  ( QCOM           , DUM1(162))
     *,(RUDCOM,DUM1(165))
      EQUIVALENCE  ( DDS            , DUM1(166))
      EQUIVALENCE   ( FP1,   DUM(530))
      EQUIVALENCE
     A ( CBSE(1) ,DUM2(041)),( CORE(1) ,DUM2(043)),( CRYR(1) ,DUM2(056))
     B,( CCYR(1) ,DUM2(058)),( CRNY(1) ,DUM2(062)),( CCNY(1) ,DUM2(064))
      EQUIVALENCE    ( IRUNNO, IDUM3(32))
      EQUIVALENCE (IPRNT,IDUM1(132))
      EQUIVALENCE
     1 (  IDNZ , INDOR( 1)) , (  IDQQ   , INDOR( 2)), ( IDSE  ,INDOR( 3))
     2,( IDCOML, INDOR( 8)) , ( IDYR    , INDOR(12)), ( IDNY  ,INDOR(13))
      EQUIVALENCE
     A (DVER2(1),PARAM(129)),(DVERS(1),PARAM(137)),(DVPHX(1),PARAM(145))
     B,(DVEPS(1),PARAM(153))
      EQUIVALENCE ( ER2X , DVER2(5) ) , ( ER2I , DVER2(1) )
      EQUIVALENCE ( ERSX , DVERS(5) ) , ( ERSI , DVERS(1) )
      EQUIVALENCE ( EPHX , DVPHX(5) ) , ( EPHI , DVPHX(1) )
      EQUIVALENCE ( EPSX , DVEPS(5) ) , ( EPSI , DVEPS(1) )
      EQUIVALENCE (H(1)    ,PARAM(73)),(ALPHA(1),PARAM(17))
     *             ,(P(1)    ,PARAM(25)),(Q(1)     ,PARAM(33))
     *             ,(R(1)    ,PARAM(41))
      DATA  DDR / 57.2957795131/
      DATA      ERRAUT/ 8HAUTSI1  /
      RETURN
C
      ENTRY AUTSI2
      CALL INUPD (129,ADUMXX,IDUMXX)
      CALL INUPD (133,ADUMXX,IDUMXX)
      CALL INUPD (137,ADUMXX,IDUMXX)
      CALL INUPD (141,ADUMXX,IDUMXX)
      CALL INUPD (145,ADUMXX,IDUMXX)
      CALL INUPD (149,ADUMXX,IDUMXX)
      CALL INUPD (153,ADUMXX,IDUMXX)
      CALL INUPD (157,ADUMXX,IDUMXX)
      ISAVTR = 1
      DO 100 I = 1, 23
  100 INDOR(I) = -1
      NSWIT = 0
      RETURN
      ENTRY AUTS
      IF( ISAVTR.NE.1 )  GO TO 110
      IF (GKNL2.LT.1.0) GO TO 2
      II=GKNL2
      DEL=HMAX*FLOAT(II)
      DELT=0.0
      GO TO 4
```

```
    2 DELT=1000000.
    4 CONTINUE
      IF (IRUNNO.GT.1)  GO TO 6
C  RECONVERT LIMITS FROM RADIANS TO DEGREES  (CONVERTED TO RADIANS IN
C  SUBROUTINE DATAIN)
      DSHI=DSHI*DDR
      DSLO=DSLO*DDR
      DSLU=DSLU*DDR
      DSLL=DSLL*DDR
      DAHI=DAHI*DDR
      DALO=DALO*DDR

      RUDHI=RUDHI*DDR
      RUDLO=RUDLO*DDR
      DSTAB=DDS*DDR
C-----    INITIAL  CONDITIONS
    6 IF (DSTAB.GT.DSHI) DSTAB=DSHI
      IF (DSTAB.LT.DSLO) DSTAB=DSLO
      R501=ALPHA(1)*DDR
      C501=R501*CBNZ(1)
      X5=C501
      R502=Q(1)*DDR
      C502=R502*CBQQ(1)
      X4=C502
      AZ3=GGNA*GKNZ2+X4*GKF
C QB IS COMPACT PRESSURE  PS IS STATIC PRESSURE
      PS=PARAM(480)*1715.0*(518.7-0.003565*H(1))
      QB=PS*(((0.2*MACH**2+1.0)**3.5)-1.0)
      IF (QB.GT.3000.) GKNZ1=.083
      IF (QB.LE.3000.) GKNZ1=-.0002*QB+.683
      IF (QB.LE.800.)  GKNZ1=-.00089*QB+1.25
      IF (QB.LE.280.)  GKNZ1=1.0
      AX4=GKNZ1*X4*.7
      AU3=(-15.0 + AX4 + X5)*GKFB
      IF (AU3.LT.0.0) AU3=0.0
      IF (AU3.GT.999.0) AU3=999.0
      U3=AZ3+AU3
      R508=U3
      C508=CRCOML(1)*R508
C  FIX TO SET PITCH INPUT TO ZERO BY BIASING TRIM
C     X3=C508
C     X1=X3
C     C503=C508
C     R503=0.0
C     IF (CRSE(1).NE.0.0) R503=C503/CRSE(1)
C     U1=R503
C     DCOMD=(U1-.44)/0.318+7.25
      X1TRIM=-X3
      C503=0.0
      R503=0.0
```

```
      U1=0.0
      OCOMO=0.0
      X1=0.0
      AX1=0.0
      AX5=(X5+AX4-20.4)*GKNZ3
      IF (AX5.LT.0.0)   AX5=0.0
      IF (AX5.GT.999.0) AX5=999.0
C     GKNL1 IS FUNCTION OF DYNAMIC PRESSURE, QB
C     GAIN FACTOR OF 3.0 IS INCLUDED IN FUNCTION
      IF (QB.GT.3000.) GKNL1=3.*(.083)
      IF (QB.LE.3000.) GKNL1=3.*(-.0002*QB+.683)
      IF (QB.LE.800.)  GKNL1=3.*(-.00089*QB+1.25)
      IF (QB.LE.280.)  GKNL1=3.0
      AX6=(AX1+AX5)*GKNL1
      RATIO=QB/PS
      IF (RATIO.LE..53)  TRFAC=.5
      IF (RATIO.GT..53)  TRFAC=-1.19*RATIO+1.13
      IF (RATIO.GT.1.79)  TRFAC=-1.0
      X6=X5*TRFAC
      ERSI=DSTAB
      X2=ERSI-X6-AX6
      ER2I=X2
      IF (GK6.NE.0.0) ER2I=X2/GK6
      AX2=0.0
      FPHI=0.0
      FPSI=0.0
      ISAVTR = 0
      IF (IRUNNO.GT.1)  GO TO 110
      CALL LINES(14)
      WRITE (IPRNT,30)
   30 FORMAT (1H1,1X,26HAUGMENTATION VARIABLE DUMP,//)
      WRITE(IPRNT,31) R501,C501,R502,C502,R503,C503,R508,C508
   31 FORMAT(1H0,5X,6H  R501,7X,6H  C501,7X,6H  R502,7X,6H  C502,7X,
     A  6H  R503,7X,6H  C503,7X,6H  R508,7X,6H  C508,/,1X,8E13.6,/)
      WRITE(IPRNT,33) AZ3,AU3,AX1,AX5,AX6,X6,DSTAB,X2
   33 FORMAT          (7X,6HAZ3   ,7X,6HAU3   ,7X,6HAX1   ,7X,6HAX5    ,
     A    7X,6HAX6   ,7X,6HX6    ,7X,6HDSTAB ,7X,6HX2     ,/,1X,8E13.6,/)
  110 CONTINUE
C-----     AS OF THE DATA  15 AUGUST, 1975 , THIS PROGRAM  USES
C          368 LOCATIONS  OF THE PARAM ARRAY. THE BREAKDOWN  IS
C                        PILTI1   -   52  LOCATIONS
C                        AUTSI1   -  188  LOCATIONS
C                        AIRFI1   -  128  LOCATIONS
C          WITHOUT  ALTERING  THE  PARAM  ARRAY AND  CONSEQUENT  PROGRAM
C          LOGIC, AN ADDITIONAL  14  INTEGRATION VARIABLES CAN BE ADDED.
C          THESE  VARIABLES CAN BE INTEGRATED BY EXECUTING THE CALL  TO
C          EITHER INTEG  OR  TRANFR. IF ONE CHOOSES TO CALL INTEG, THEN
C          THE PARAMETER INTDEX MUST BE INCREASED BY 8 FOR EACH
C          ADDITIONAL  CALL TO INTEG.THAT IS INCORPORATED IN THE PROGRAM.
C          THE PARAMETER INTDEX IS INITIALIZED IN THE AIRFI1 SUBROUTINE.
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C          LONGITUDINAL   CHANNEL   AUGMENTATION
C*****
      U5=ALPHA(1)*DDR
      IF (U5.GT.30.0) U5=30.0
      IF (U5.LT.-5.0) U5=-5.0
      CALL TFANFR( 2, CBNZ, 2, CCNZ, 8, DVNZ, ERRAUT, 501, U5,
     A           IDNZ, X5, R501, 0.0, C501, 0.0)
      U4=Q(1)*DDR
      CALL TFANFR( 2, CBQQ, 2, CCQQ, 8, DVQQ, ERRAUT, 502, U4,
     A           IDQQ, X4, R502, 0.0, C502, 0.0)
      AZ3=GGMA*GKNZ2+X4*GKF
C QB IS COMPACT PRESSURE  PS IS STATIC PRESSURE
      PS=PARAM(480)*1715.0*(518.7-0.003565*H(1))
      QB=PS*((((0.2*MACH**2+1.0)**3.5)-1.0)
      IF (QB.GT.3000.) GKNZ1=.083
      IF (QB.LE.3000.) GKNZ1=-.0002*QB+.683
      IF (QB.LE.800.)  GKNZ1=-.00089*QB+1.25
      IF (QB.LE.290.)  GKNZ1=1.0
      AX4=GKNZ1*X4*.7
      AU3=(-15.0 + AX4 + X5)*GKFB
      IF (AU3.LT.0.0) AU3=0.0
      IF (AU3.GT.999.0) AU3=999.0
      U3=AZ3+AU3
      CALL TFANFR( 3, CBCOML, 3, CCCOML, 12, DVCOML, ERRAUT, 508, U3,
     A        IDCOML , X3, R508, 0.0, C508, 0.0)
      FP1=QCOM+QCOMO
      IF (FP1.GT. 7.25)  U1=.318*(FP1-7.25)+.44
C  REMOVE DEADBAND BETWEEN -1.75 AND 1.75
      IF (FP1.LE. 7.25)  U1=.06069*FP1
C     IF (FP1.LE. 7.25)  U1=.08*(FP1-1.75)
C     IF (FP1.LE. 1.75)  U1=0.
C     IF (FP1.LE.-1.75)  U1=.08*(FP1+1.75)
      IF (FP1.LE.-7.25)  U1=.342*(FP1+7.25)-.44
      IF (U1.LT.-4.0) U1=-4.0
      IF (U1.GT.8.0) U1=8.0
      CALL TFANFR( 2,CBSE, 2, CCSE, 8, DVSE, ERRAUT, 503, U1,
     A          IDSE , X1, P503, 0.0 , C503, 0.0)
      AX1=X3-X1+X1TRIM
      AX5=(X5+AX4-20.4)*GKNZ3
      IF (AX5.LT.0.0)   AX5=0.0
      IF (AX5.GT.399.0) AX5=999.0
C     GKNL1 IS FUNCTION OF DYNAMIC PRESSURE, QB
C     GAIN FACTOR OF 3.0 IS INCLUDED IN FUNCTION
      IF (QB.GT.3000.) GKNL1=3.*(.083)
      IF (QB.LE.3000.) GKNL1=3.*(-.0002*QB+.683)
      IF (QB.LE.800.)  GKNL1=3.*(-.00089*QB+1.25)
      IF (QB.LE.280.)  GKNL1=3.0
      AX6=(AX1+AX5)*GKNL1
      RATIO=QB/PS
      IF (RATIO.LE..53)  THFAC=.5
```

```
      IF (RATIO.GT..53)  TRFAC=-1.19*RATIO+1.13
      IF (RATIO.GT.1.79)  TRFAC=-1.0
      X6=X5*TRFAC
      X7=AX6+X2
      X8=X6+X7
      IF (X8.GT.DSLU) GO TO 40
      IF (X8.LT.DSLL) GO TO 42
      X9=0.0
      GO TO 44
   40 X9=GK6*(X8+DSLL)
      GO TO 44
   42 X9=GK6*(X8+DSLU)
   44 U2=AX6-X9-AX2
      ER2X=U2
      CALL INTEG(ER2X,ER2I)
      X2=GK6*ER2I
      IF (X2.GT.DSLU) GO TO 46
      IF (X2.LT.DSLL) GO TO 48
      AX2=0.0
      GO TO 49
   46 AX2=2000.*(X2+DSLL)
      GO TO 49
   48 AX2=2000.*(X2+DSLU)
   49 CONTINUE
      STACOM=X6+X7
      RSTB=20.0*(STACOM-ERSI)
      IF (RSTB.GT. 60.0) RSTB= 60.0
      IF (RSTB.LT.-60.0) RSTB=-60.0
      ERSX=RSTB
      CALL INTEG(ERSX,ERSI)
      DST=ERSI
      IF (DST.GT.DSHI) DST=DSHI
      IF (DST.LT.DSLO) DST=DSLO
      DDS=DST/DDR
C----------
C                LATERAL - DIRECTIONAL  AUGMENTATION
C----------
C  AILERON  CHANNEL COMMANDS
      FA=PHIC
      IF (FA.LT.-11.0) PHIC1=38.0*FA+338.0
      IF (FA.GE.-11.0) PHIC1=12.0*FA+52.0
      IF (FA.GE. -6.0) PHIC1= 3.333333333*FA
      IF (FA.GE.  6.0) PHIC1=12.0*FA-52.0
      IF (FA.GT. 11.0) PHIC1=38.0*FA-338.0
      CALL TFANFF( 2, CDRE, 2, CCRE, 8, DVRE, ERRAUT, 511, PHIC1,
     *        IDRE , PHIC2, 0., 0., 0., 0.)
      PHIC3=0.12*(P(1)*DDR-PHIC2)
      FPHA=20.0*(PHIC3-FPHI)
      IF (FPHA.LT.-80.0) FPHA=-80.0
      IF (FPHA.GT. 80.0) FPHA= 80.0
```

```
      FPHX=FPHA
      CALL INTEG(FPHX,FPHI)
      DDA=FPHI
      IF (DDA.GT.DAHI) DDA=DAHI
      IF (DDA.LT.DALO) DDA=DALO
      DA=DDA/DDR
C   RUDDER CHANNEL COMMANDS
      RUDC1=RUDCOM
      IF (RUDC1.GE. 15.0) RUDC2=0.316*RUDC1-64.75
      IF (RUDC1.LT. 15.0) RUDC2=0.0
      IF (RUDC1.LE.-15.0) RUDC2=0.316*RUDC1+64.76
      YAWFB=R(1)*DDR-X5*P(1)
      R1=R(1)
      P1=P(1)
      CALL TRANFR(2 ,CBNY, 2, CCNY, 8 , DVNY , ERRAUT , 513 , YAWFB,
     *           IDNY , RFB1,  0., 0., 0., 0. )
      CALL TRANFR ( 2,CBYR, 2, CCYR, 8, DVYR , ERRAUT, 512, RFB1,
     *           IDYR , RFB2,  0., 0., 0., 0. )
      F8=RFB2+0.6*GGNS
      IF (RATIO.GT.3.3) AKF8=F8
      IF (RATIO.LE.3.3) AKF8=F8*(0.435*RATIO-0.305)
      IF (RATIO.LE.2.0) AKF8=0.5*F8
      RUDDC=AKF8-RUDC2
      FPSA=2..0*(RUDDC-FPSI)
      IF (FPSA.GT. 120.0) FPSA= 120.0
      IF (FPSA.LT.-120.0) FPSA=-120.0
      FPSX=FPSA
      CALL INTEG(FPSX,FPSI)
      DRR=FPSI
      IF (DRR.GT.RUDHI) DRR= RUDHI
      IF (DRR.LT.RUDLO) DRR= RUDLO
      DR=DRR/DDR
      IF (IRUNNO.GT.1)  GO TO 80
      IF (DELT.GT.T) GO TO 90
   60 IF (DELT.GT.0.0) GO TO 65
      WRITE(IPRNT,51)
   51 FORMAT(1H1,25H1AUGMENTATION TIME HISTORY,//,5X,6HTIME  ,7X,6HU1
     A    ,7X,6HGGNA  ,7X,6HU4    ,7X,6HU5    ,7X,5HAX6   ,7X,6HX6    ,
     B     7X,6HSTACOM,7X,6HERSX  ,7X,6HERSI  )
      WRITE(IPRNT,53)
   53 FORMAT      (18X,6HPHIC1 ,7X,6HP1    ,7X,6HPHIC2 ,7X,6HPHIC3 ,
     A     7X,6HFPHI  ,7X,6HR1    ,7X,6HYAWFB ,7X,5HRFB1  ,7X,6HRFB2  )
      WRITE(IPRNT,57)
   57 FORMAT      (18X,6HF8    ,7X,6HAKF8  ,7X,6HRUDCOM,7X,6HRUDC2 ,
     A     7X,6HX5    ,7X,6HRUDDC ,7X,6HFPSA  ,7X,5HPHSI  ,7X,6HGGNS  )
      WRITE(IPRNT,59)
   59 FORMAT      (18X,6HPS    ,7X,6HQ3    ,//)
   65 DELT=DELT+DEL
   70 WRITE(IPRNT,71) T,U1,GGNA,U4,U5,AX6,X6,STACOM,RSTB,DST
   71 FORMAT(1X,10E13.6)
```

```
      WRITE(IPRNT,73) PHIC1,P1,PHIC2,PHIC3,DDA,R1,YAWFB,RFB1,RFB2
   73 FORMAT(14X,9E13.6)
      WRITE(IPRNT,73) F8,AKF8,RUDCOM,RUDC2,X5,RUDDC,FPSA,DRR,GGNS
      WRITE(IPRNT,77) PS,QB
   77 FORMAT(14X,2E13.6)
   60 CONTINUE
      RETURN
      END
```

Appendix D
EASY Analysis Program Data

The program commands of the EASY Analysis program are included in Appendix D.

Table parameters specify the independent and dependent variables for the table look-up gain parameters of the system model. The parameter values which satisfy the input requirements of the standard components are listed following the tabular entries.

The longitudinal axis stability derivatives for the F-16 aircraft at the selected flight condition of .8 Mach and 20,000 feet are shown on page 157. In addition, page 157 shows the commands necessary for generating a steady state system solution and establishing the aircraft trim condition.

The frequency domain analysis is completed with program commands to establish a pseudo tracking task. Program commands for both closed loop and open loop analysis are completed on pages 157 and 158.

The EASY Analysis program data list is concluded with program commands to generate a closed loop system time response to a reference step input.

```
TABLE,FTAFUE1,4
-17.65,-7.25,7.25,40.
-4.,-.44,.44,10.36
TABLE,FTAFUE2,4
0.,34.,184.,280.
-1.,-1.,-4.,-4.
TABLE,FTAFUE3,5
0.,280.,800.,3000.,6000.
.7,.7,.3731,.0581,.0581
TABLE,FTAFUE4,5
0.,280.,800.,3000.,6000.
3.,3.,1.599,.249,.0581
TABLE,FTAFUE5,4
0.,.53,1.79,2.0
.5,.5,-1.0,-1.0
TABLE,FTAFUE6,4
-50.,-25.,25.,50.
-25.,0.,0.,25.
PARAMETER VALUES
AN FUE1=-1,AN FUE2=-1,AN FUE3=-1,AN FUE4=-1
AN FUE5=-1,AN FUE6=1
C1 MAF1=1.
C1 SAE2=.5,C3 SAE2=8.,C4 SAE2=.5
C3 SAE3=30.,C6 SAE3=-5.
Z0 LGE1=10.,P0 LGE1=10.
GAILEE2=1.,Z0 LEE2=0.,P0 LEE2=1.
C2 MCE1=1.,C3 MCE1=1.,C4 MCE1=0.,X3 MCE1=-20.4
C2 MCE2=1.,C3 MCE2=1.,C4 MCE2=0.,X3 MCE2=-15.
C6 SAE4=0.
C1 MCE3=.161,C2 MCE3=.167,C3 MCE3=0.5,C4 MCE3=0.
C1 SAE5=.5,C6 SAE5=0.
GAILEE3=3.0,Z0 LEE3=4.,P0 LEE3=12.
C1 MCE4=1.,C2 MCE4=1.,C3 MCE4=-1.,C4 MCE4=0.
C2 MCE5=-5.,C3 MCE5=0.,C4 MCE5=0.,X3 MCE5=0.
GKIITE1=5.,GKLITE1=2000.,AMAITE1=25.,AMIITE1=-25.
C2 MAE2=0.
C3 MCE6=0.,C4 MCE6=0.,X3 MCE6=0.
C1 MAE3=1.
C1 MAF4=1.
Z1 TFF1=0.,Z0 TFF1=2704.,P1 TFF1=72.8,P0 TFF1=2704.
C1 MAF3=-1.
C1 SAF1=20.,C3 SAF1=3.,C4 SAF1=20.,C6 SAF1=-3.
Z0 LGF1=1.,P0 LGF1=0.
C3 SAF2=25.,C6 SAF2=-25.
C1 MAE2=.0010282
```

```
GAILEPL=349.040      Z0 LEPL=0.0      P0 LEPL=20.0
GAILAPL=2.1815       TC LAPL=.05
 C1 SAPL=1.0E-06,C2 SAPL=1.0,C3 SAPL=0.0,C4 SAPL=1.0E-06
C5 SAPL=1.0           C6 SAPL=0.0
Z1 TFPL=0.0     Z0 TFPL=1.0     P1 TFPL=1.2     P0 TFPL=1.0
C1 MCPL=1.0     C2 MCPL=1.0     C3 MCPL=1.0     C4 MCPL=0.0
Z0 LGPL=.25          P0 LGPL=0.0
C1 MAPL=-1.0     C2 MAPL=5.5
TX SD=0.,VD SD=0.,TZ SD=0.
IXXSD=9007.5      IYYSD=49955.      IZZSD=55770.      IXZSD=198.
ID1AV=3.
VS AV=829.5       ALSAV=2.1039       S  AV=300.
X0 LO=-.0250     XA LO=-.0201     XU LO=-.0746     XDELO=.0525
Z0 LO=-.1443     ZA LO=-4.8159    ZADLO=.5500      ZQ LO=-2.5965
ZU LO=-.1215     ZDELO=-.4965     M0 LO=-.0182     MALLO=.0943
MADLO=-.9550     MQ LO=-2.3137    MU LO=-.0145     MDELO=-.6659
MA1LO=590.5      C  LO=11.32
XP1LO=0.0,FZ1LO=0,TY1LO=0
C1 MCZ1=.0311,C2 MCZ1=-.0311,C3 MCZ1=0.,C4 MCZ1=-1,X3 MCZ1=0.
C1 MAET=-1.,C2 MAET=20000.
Z0 LGET=.1,P0 LGET=0.
C1 MAEN=-1.,C2 MAEN=829.5,Z0 LGEN=10.,P0 LGEN=0.
Z0 LGE2=8.3,P0 LGE2=8.3
INT CONTROLS
V  SD=0.,P  SD=0.,R  SD=0.,ROLSD=0.,YAWSD=0.
ERROR CONTROLS=   U  SD=.8,W  SD=.06,Q  SD=.1E-03
   X2 LGEN=4.,X2 LGET=.2E-05,X2 LGE2=.9E-05,X2 LGE1=.4E-02
   X2 TFF1=.001,X2 LGF1=.001,PITSD=.4E-02,ALTSD=20.
   XI LEE3=.2E-05,X2 ITE1=.004,XI TFF1=.1
   XI LEPL=.8,X2 LAPL=.005,XI TFPL=.006,X2 TFPL=.005
   X2 LGPL=.002,XI LEE2=.4E-05
INITIAL CONDITIONS
ALTSD=20000,U  SD=829.5
PRINT CONTROL=3
PLOT ON
PRINTER PLOTS
INT CONTROL= X2 LGPL=0
STEADY STATE
XIC-X
INT CONTROL= X2 LGEN=0, X2 LGET=0
INT CONTROL= X2 LGPL=1
LINEAR ANALYSIS
TITLE=THETA/THETAREF CLOSED LOOP NORMAL ACCEL
TF INPUT= C2 MAPL
TF OUTPUT= PITSD
```

```
TF MANUAL SCALES
FREQ MIN=.001
FREQ MAX=100.
BODE,TRANSFER FUNCTION
TITLE=THETA/THETAREF OPEN LOOP NORMAL ACCEL
PARAMETER VALUES= C1 MAPL=0.0
TF INPUT= C2 MAPL
TF OUTPUT= PITSD
TF MANUAL SCALES
FREQ MIN=.01
FREQ MAX=100.
BODE,TRANSFER FUNCTION
PARAMETER VALUES= C1 MAPL=-1.0
TINC=.05
TMAX=20.0
OUTRATE=1.0
PRATE=20
INT MODE=2
TITLE=CLOSED LOOP STEP RESPONSE
DISPLAY1
PITSD      VS      TIME
Q  SD      VS      TIME
ALTSD      VS      TIME
X2 LGF1    VS      TIME
SIMULATE
```

Vita

Michael Marchand was born in Gonzales, Louisiana on April 6, 1948. He attended Gonzales High School there and graduated as valedictorian of his class in 1966. He entered undergraduate studies at Louisiana State University and received his B.S. degree in Electrical Engineering and his ROTC Air Force commission in 1971. Later that year, he began active duty in the Air Force as an Undergraduate Pilot Training student at Laughlin AFB, Texas. After receiving his wings, he attended Pilot Instructor Training at Randolph AFB and then spent the next two years at Laughlin as an instructor in the T-37 aircraft. From 1974-76, he enjoyed a tour at Mather AFB as an instructor pilot in Undergraduate Navigator Training, being a member of the first T-37 squadron. While at Mather, he accepted the additional duty of Functional Check Flight pilot for the T-37 maintenance squadron. In 1976, he entered the Air Force Institute of Technology at Wright-Patterson AFB to attain a Masters degree in Electrical Engineering, specializing in aircraft guidance and control. He is married and has two children.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFIT/GGC/EE/77-7	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) PITCH RATE FLIGHT CONTROL FOR THE F-16 AIRCRAFT TO IMPROVE AIR-TO-AIR COMBAT		5. TYPE OF REPORT & PERIOD COVERED MS Thesis
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Michael A. Marchand Capt USAF		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Institute of Technology(AFIT-EN) Wright-Patterson AFB, Ohio 45433		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project 7071-00-12
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Flight Dynamics Laboratory/FGLC Wright-Patterson AFB OH 45433		12. REPORT DATE December, 1977
		13. NUMBER OF PAGES 173
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Approved for public release; IAW AFR 190-17

Jerral F. Guess, Captain, USAF
Director of Information

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Digital simulations were developed to implement a pitch rate control system for the F-16 aircraft engaged in aerial gunnery. First, the EASY Modelling and Analysis Program by Boeing Computer Services was adapted to implement a longitudinal axis F-16 aircraft, flight control system, and pilot model. Comparison of closed loop system responses indicated a proposed pitch rate flight control configuration would improve target tracking

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performance. The Terminal Aerial Weapon Delivery Simulation (TAWDS) program by McDonnell Douglas Corporation was adapted for the F-16 aircraft. A non-linear, six-degree-of-freedom aircraft model, multi-axis flight control system, and multi-axis pilot model were developed to demonstrate target tracking capabilities. Eight different air-to-air scenarios were developed to simulate evasive encounters with an F-4 target aircraft. Time history target tracking errors indicated the improved tracking performance of the proposed pitch rate flight control configuration over the present normal acceleration configuration of the F-16 aircraft.