NASA Contractor Report 4231

4D-TECS Integration for NASA TSRV Airplane

I. Kaminer and P. R. O'Shaughnessy

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4D-TECS Integration for NASA TSRV Airplane

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1.0 SUMMARY

This document describes the integration of the Total Energy Control System (TECS) concept with 4D navigation to increase the operational capability of modern aircraft and encourage incorporation of this increased capability with the evolving National Airspace System (NAS). Herein is described the 4D profile smoothing technique, the basic concepts of TECS, the spoiler integration concept, an algorithm for nulling out time error, the speed and altitude profile modes, the manual spoiler implementation, the 4D mode logic, and finally, results of linear and nonlinear analyses.

2.0 INTRODUCTION

In 1979 NASA funded Boeing to begin the conceptual development of a fully integrated automatic flightpath and speed control system. The work was carried out under NASA contracts NAS1-14880 (1979-1980) and NAS1-16300 (1980-1981). Detailed design and simulator implementation were carried out under Boeing IR&D funding from 1979-1982. The outcome of this work was the Total Energy Control System (TECS).

Following successful detailed simulator development of TECS at Boeing, NASA awarded a contract (NAS1-17509) in 1983 for the flight test of TECS on NASA Langley's Transport Systems Research Vehicle (TSRV), a highly modified Boeing B737-100. Flight test of TECS took place in September 1985 at NASA Langley in a series of five flights over a 3-week period. Most of the original flight test plan was completed in the first three flights with the final two flights being TECS demonstration flights.

In 1985, NASA awarded Boeing the Advanced Transport Operating Systems (ATOPS) contract NAS1-18027. The objective of this contract was to increase the operational capability of modern aircraft and foster their integration into the evolving National Airspace System (NAS). Within this overall objective, Task 6 was initiated to integrate the TECS concept with 4D navigation (fig. 1). The 4D navigation algorithm developed under Boeing IR&D funds was further developed for adaptation to the TECS control concept. Within the contract, the TECS control laws were extended to employ spoilers as a negative thrust device to pre-process the 4D commands in providing smooth derivatives and computing command signals to null out any time error by the top-of-descent. This report covers these topics.

The second phase of Task 6 will be to develop both lateral and longitudinal control laws that will effectively integrate with a 4D navigation algorithm. In this phase, a model following regulator design concept will be employed with the specific goals of achieving a straight-forward design which both reduces

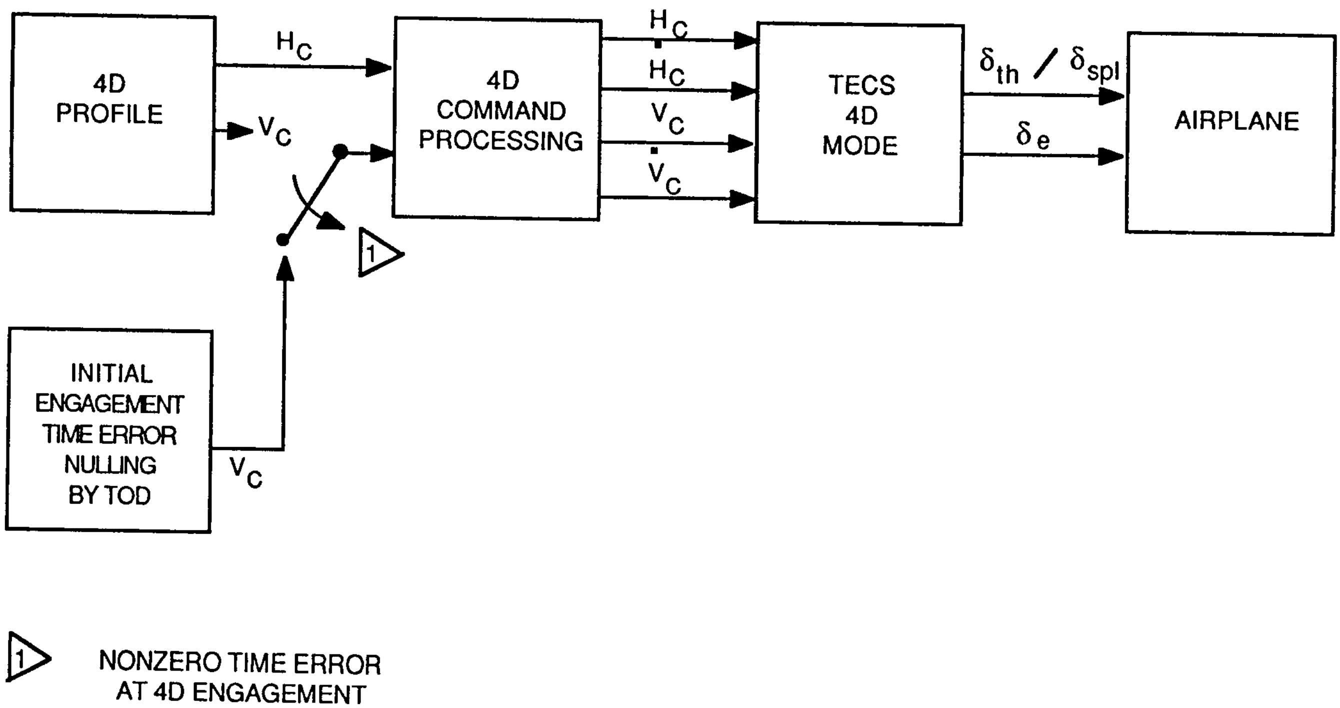


Figure 1. General Structure of 4D-TECS System

mode switching and the number of specific control law modes. Results of this phase will be reported in a separate document when phase 2 has been completed.

The important issues that must be resolved in successfully integrating TECS with 4D are:

(1) Smoothing the trajectory by introducing command processors driven by the 4D profile and with outputs fed to TECS. This will be needed because the profile generated by the 4D algorithm may have considerable discontinuities due to the algorithm using perturbation theory in simplifing the aircraft equations of motion. This approach has inherent discontinuities between inner and outer solutions resulting in discontinuities in speed and altitude profiles at transition points (climb-to-cruise, cruise-to-descent, and descent to bottom of descent at the metering fix).

(2) Having a 4D mode for TECS that should be able to null out any time errors to assure on-time arrival, and track speed and altitude profiles. Since the 4D profile may have nonzero altitude rate and longitudinal acceleration commands, TECS should develop command errors based on both position commands (altitude and speed) and rate commands (altitude rate and longitudinal acceleration).

(3) Investigating the use of spoilers during 4D descent to improve the trajectory tracking of the airplane when throttles are at idle.

3.0 SYMBOLS AND ABBREVIATIONS

4D	-	Four Dimentional Trajectory Generator
TECS	-	Total Energy Control System
ATOPS	-	Advanced Transport Operating System
FMC	-	Flight Management Computer
PGA	-	Profile Generator Algorithm
TSRV	-	Transport System Research Vehicle
B-737	-	Boeing 737 airplane
Vel-CWS	-	Velocity Control Wheel Steering
FPA	-	Flight Path Angle
h	-	altitude of the airplane
$\dot{h}$	-	vertical velocity of the airplane
h_c	-	altitude command
$\hat{h}_c$	-	filtered altitude command
V	-	airspeed of the airplane
$\dot{V}$	-	acceleration along flight path of the airplane
V_c	-	inertial speed command
$\hat{V}_c$	-	filtered inertial speed command
V_t	-	true airspeed
V_i	-	inertial airspeed
$\dot{V}_i$	-	inertial acceleration
E	-	energy of the airplane
$\dot{E}$	-	energy rate of the airplane
$\dot{E}_s$	-	specific energy rate of the airplane
$\dot{E}_d$	-	energy distribution rate of the airplane
T	-	thrust of the airplane
T_c	-	thrust command
D	-	drag of the airplane
W	-	weight of the airplane
g	-	gravity

γ	-	flight path angle (wrt to the air mass) of the airplane
w_n	-	natural freguency
s	-	complex frequency variable
S	-	wing surface area
q	-	dynamic pressure
τ	-	time constant
ξ	-	damping ratio
X_e	-	initial distance error
T_e	-	initial time error
δ_{tc}	-	throttle command
δ_{ec}	-	elevator command
δ_{splc}	-	spoiler command
K_{TP}	-	thrust command proportional gain
K_{TI}	-	thrust command integral gain
K_{EP}	-	elevator command proportional gain
K_{EI}	-	elevator command integral gain
K_{XP}	-	distance feedback proportional gain
K_{XI}	-	distance feedback integral gain
TOD	-	top of descent
TOA	-	time of arrival
t_1	-	intermediate time used in the computation of ground speed profile
t_d	-	time at which to initiate TOD speed capture
t_f	-	required time of arrival at TOD
t_{f1}	-	TOD arrival time under limit conditions

4.0 4D PROFILE SMOOTHING

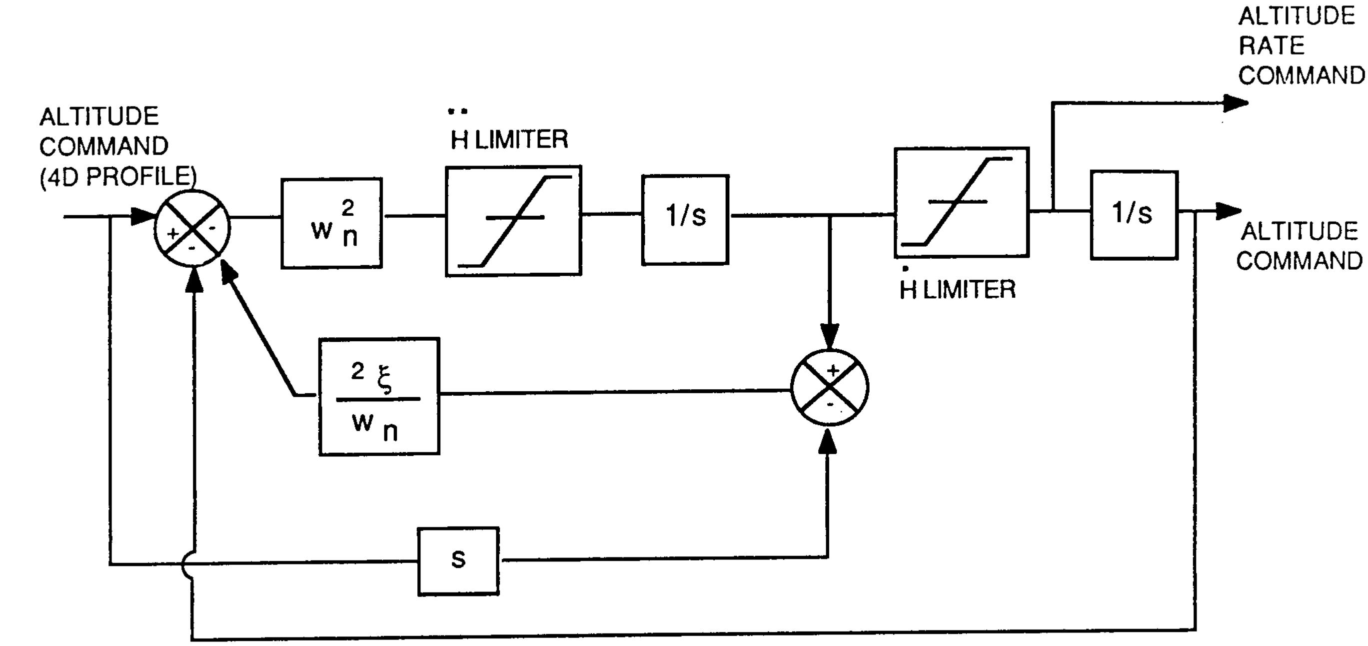
As previously mentioned, the 4D profile generated by the optimal trajectory generator has significant discontinuities. This problem is corrected by filtering the profile with second order filters, referred to here as command processors. The 4D profile consists of altitude and speed commands as a function of time or distance. These commands are sent to TECS every 100 ms by the profile generator. Filtering, therefore, must be done on-line. Figures 2 and 3 show diagrams of the altitude and speed command processors. The following transfer function describes the input output relationship of both processors:

$$\frac{\hat{V}_c}{V_c} = \frac{\hat{h}_c}{h_c} = \frac{w_n^2\left(\frac{2\xi}{w_n} s + 1\right)}{s^2 + 2\xi\ w_n s + w_n^2} \tag{1}$$

The zero in equation 1 is due to feeding-forward the profile command rate which provides tighter profile tracking by generating a lead term.

Command limiting is introduced to ensure passenger comfort, as in the case of the $\ddot{H}$ and $\ddot{V}$ limiters, and to distribute energy between altitude and speed, as is done by the $\dot{V}$ limiter. It should be noted, that limiting in the command processors is the same as inside the TECS feedback loops. The advantage of limiting before loop closure is to avoid undesirable stability effects due to the signal limiting inside the feedback loop.

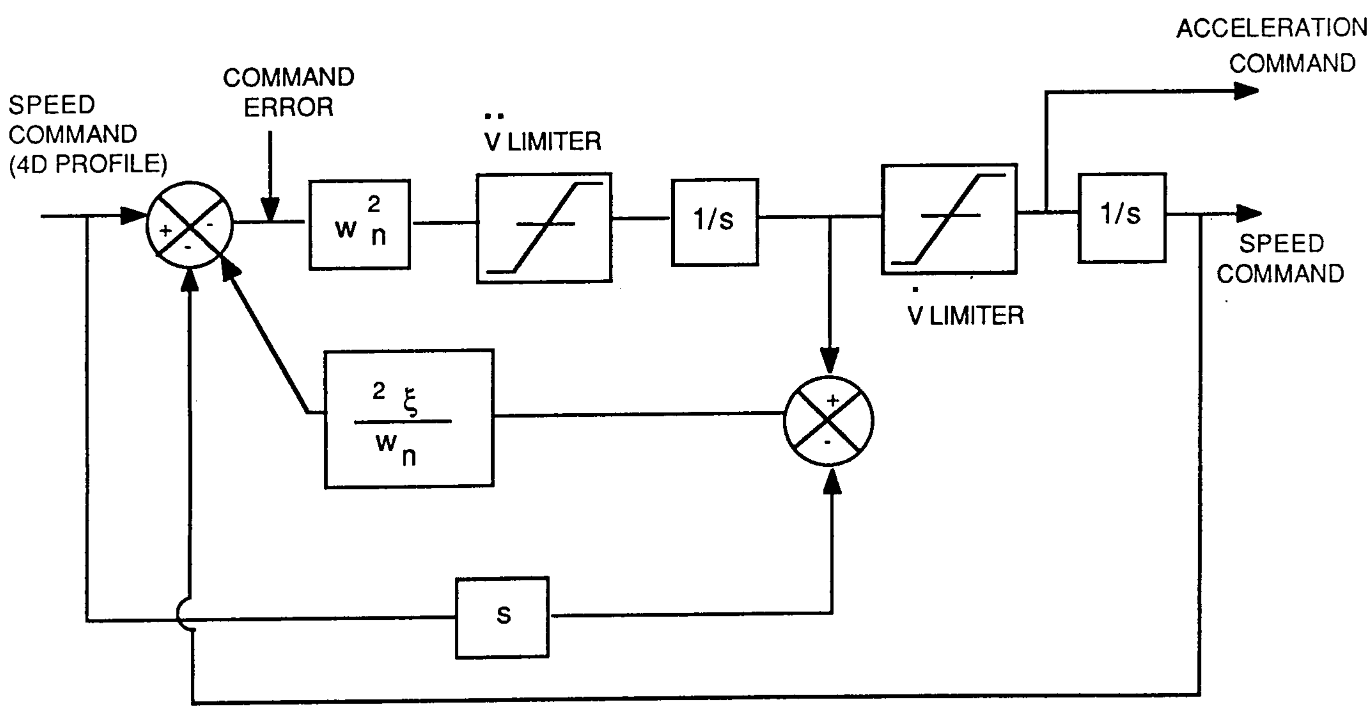
Figures 2 and 3, show the command processors generate altitude rate and acceleration commands as required by the TECS 4D mode. In both these figures, w_n and ξ are set to 1 and 12 respectively for both command processors.



$w_n = 1$ $\ddot{H}$ LIMITER = ± .1g

$\xi = 12$ $\dot{H}$ LIMITER = $|\dot{H}| + 10$

Figure 2. Altitude Command Processor



$w_n = 1$ $\xi = 12$ $\ddot{V}$ LIMITER $= \frac{100}{V_t}$ $\dot{V}$ LIMITER $= \frac{100}{V_t} + |\dot{V}_t|$

Figure 3. Speed Command Processor

5.0 BASIC CONCEPTS OF TECS

References 1 through 5 give a detailed discussion of TECS. However, since the purpose of this report is to integrate spoilers into TECS, a review of the design philosophy and theoretical concept is presented in this section based on Reference 4.

TECS is an integrated autopilot/autothrottle system whose main objective is to achieve decoupled altitude and speed response of the aircraft by coordinating the control of elevator and throttles.

The basic concept of TECS is to control total energy of the airplane, which can be expressed as follows:

$$E = Wh + \frac{1}{2}\frac{W}{g}V^2 \tag{2}$$

where

E = total energy of the airplane
h = altitude
W = weight
V = airspeed

The specific energy rate is given by:

$$\dot{E}_s = \frac{\dot{E}}{W} = \dot{h} + \frac{V\dot{V}}{g} \tag{3}$$

and normalizing by airspeed:

$$\frac{\dot{E}_s}{V} = \frac{\dot{h}}{V} + \frac{\dot{V}}{g} = \gamma + \frac{\dot{V}}{g} \tag{4}$$

where

γ = flight path angle (FPA) wrt air mass

$\dot{V}$, the acceleration of the airplane along the flight path for small values of flight path angle can be derived from the equations of motion for the airplane:

$$\dot{V} = g\frac{T - D}{W} - g\gamma \tag{5}$$

where

D = drag of the airplane

Substituting equation 5 for equation 4 gives:

$$\frac{\dot{E}_s}{V} = \frac{T - D}{W} \tag{6}$$

Hence, the required thrust is a function of the specific energy rate:

$$T_{req} = W\frac{\dot{E}_s}{V} + D \tag{7}$$

Since the variation in the drag of the airplane for transports is slow, the drag term can be neglected in equation 7:

$$T_{req} = W\frac{\dot{E}_s}{V} \cong W\left(\gamma + \frac{\dot{V}}{g}\right) \tag{8}$$

Equation 8 indicates that the required thrust is directly proportional to the specific energy rate. Alternatively, it can be stated that the throttles control the rate at which energy is added to or deleted from the system.

Equation 8 can be used to develop the throttle control law, which converts the aircraft command errors into a specific energy rate error:

$$\frac{\dot{E}_{se}}{V} = \gamma_e + \frac{\dot{V}_e}{g} \tag{9}$$

where

$$\dot{V}_e = \frac{V_c - V}{\tau} - \dot{V} \tag{10}$$

and γ_e can be computed based on altitude error, flight path angle error, VCWS angle command or glide slope angle command. For instance, in the case of altitude error:

$$\gamma_e = \frac{\dot{h}_e}{V} = \frac{1}{V} \left(\frac{h_c - h}{\tau} - \dot{h} \right) \tag{11}$$

In equations 10 and 11

h_c, V_c	=	commanded altitude and airspeed of the airplane
h, V	=	altitude and airspeed of the airplane
$\dot{h}$, $\dot{V}$	=	vertical velocity and flight path acceleration of the airplane
τ	=	time constant (determines the rate at which command errors are nulled)

Based on equations 8 and 11 the throttles control law takes the following form:

$$\delta_{tc} = -K_{TP} \frac{\dot{E}_s}{V} + \frac{K_{TI}}{s} \frac{\dot{E}_{se}}{V} \tag{12}$$

However, achieving a speed maneuver without flight path deviation or vice versa, requires coordinated speed and thrust responses. An energy rate distribution error can still exist (e.g., for too high a FPA and too low an acceleration). Correction of energy rate distribution error $\dot{E}_{de}$ can be accomplished by taking a difference of potential and kinetic components of energy error:

$$\dot{E}_{de} = \frac{\dot{V}_e}{g} - \gamma_e \tag{13}$$

and, correspondingly, energy rate distribution:

$$\dot{E}_d = \gamma - \frac{\dot{V}}{g} \tag{14a}$$

Using proportional plus integral structure, the elevator control is:

$$\delta_{ec} = K_{EP}\,\dot{E}_d + \frac{K_{EI}}{s}\,\dot{E}_{de} + \text{damping terms} \tag{14b}$$

where

K_{EI}, K_{EP} = integral and proportional gains

and the damping terms consist of pitch and pitch rate feedback to ensure short period damping.

This control law requires use of the elevator in redistributing energy rate error $\dot{E}_{de}$ between FPA and acceleration. This concept is shown in Figure 4.

The following analysis can help in understanding the dynamics of energy rate and energy distribution rate errors.

From equation 9

$$\frac{\dot{E}_{se}}{V} = \frac{\dot{h}_e}{V} + \frac{\dot{V}_e}{g} \tag{15}$$

$$= \left(\frac{h_c - h}{\tau} - \dot{h}\right)\frac{1}{V} + \left(\frac{V_c - V}{\tau} - \dot{V}\right)\frac{1}{g}$$

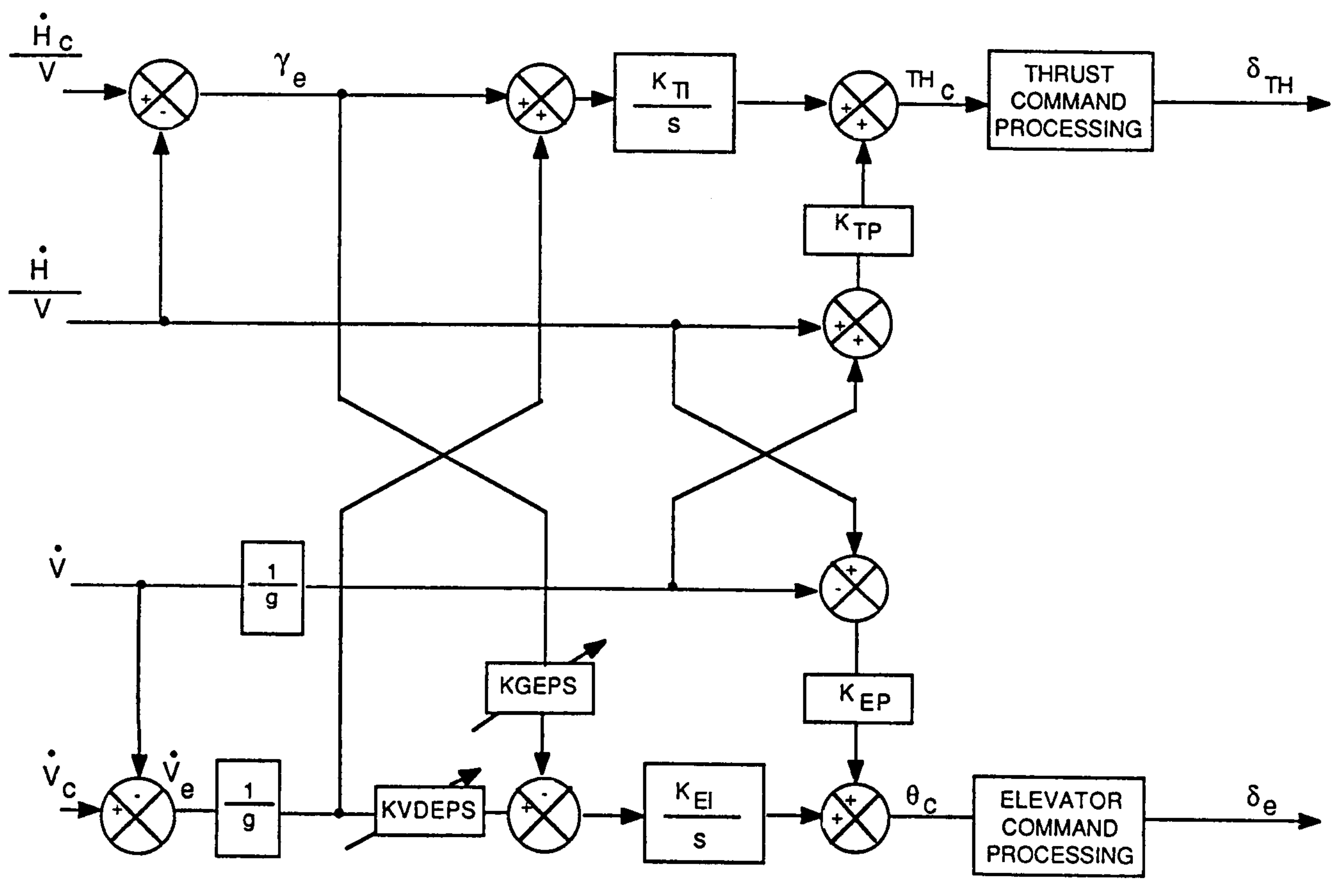


Figure 4. Total Energy Control System Concept

$$= \frac{h_c}{\tau V} + \frac{V_c}{\tau g} - \left(\frac{h}{\tau} + \dot{h}\right)\frac{1}{V} - \left(\frac{V}{\tau} + \dot{V}\right)\frac{1}{g}$$

Since $h = \frac{\dot{h}}{s}$ and $V = \frac{\dot{V}}{s}$ equation 15 becomes:

$$\frac{\dot{E}_{se}}{V} = \frac{h_c}{\tau V} + \frac{V_c}{\tau g} - \left(\frac{\dot{h}}{V} + \frac{\dot{V}}{g}\right)\frac{\tau s + 1}{\tau s}$$

$$= \frac{\dot{E}_{sc}}{V} - \frac{\tau s + 1}{\tau s}\frac{\dot{E}_s}{V} \tag{16}$$

By symmetry:

$$\dot{E}_{de} = \dot{E}_{dc} - \frac{\tau s + 1}{\tau s}\dot{E}_d \tag{17}$$

Based on equations 16 and 17, elevator and throttle commands can be rewritten:

$$\delta_{tc} = -K_{TP}\frac{\dot{E}_s}{V} + \frac{K_{TI}}{s}\frac{\dot{E}_{se}}{V} \tag{18}$$

$$= \frac{K_{TI}}{s}\frac{\dot{E}_{sc}}{V} - \left(\frac{\tau s + 1}{\tau s}\frac{K_{TI}}{s} + K_{TP}\right)\frac{\dot{E}_s}{V}$$

$$= \frac{K_{TI}}{s}\frac{\dot{E}_{sc}}{V} - \frac{K_{TP}\left[s^2 + \frac{K_{TI}}{K_{TP}}s + \frac{K_{TI}}{K_{TP}\tau}\right]}{s^2}\frac{\dot{E}_s}{V}$$

Similarly,

$$\delta_{ec} = \frac{K_{EI}}{s}\dot{E}_{dc} - \frac{s^2 + \frac{K_{EI}}{K_{EP}}s + \frac{K_{EI}}{K_{EP}\tau}}{\tau K_{EP}\ s^2}\dot{E}_d \tag{19}$$

Equations 18 and 19 show that $\dot{E}_{se}$ and $\dot{E}_{de}$ are driven to zero with second order dynamics imposed by TECS, which depend on the ratios: K_I/K_P and $K_I/K_P\tau$.

To provide an integrated throttle-elevator response, corresponding gains in equations 18 and 19 must be equal (i.e. $K_{EI} = K_{TI}$, $K_{EP} = K_{TP}$). This choice will result in both energy rate and energy distribution rate errors going to zero at the same rate.

The TSRV airplane for which TECS was designed has negligible pitching moment due to thrust. Therefore, throttle command implementation for the TSRV has no proportional $\dot{E}_s$ path:

$$\delta_{tc} = \frac{K_{TI}}{s} \dot{E}_{se} \quad (20)$$

TECS is basically an outer loop control system. By correctly designing pitch and thrust inner loops, and maintaining sufficient frequency separation between inner and outer loops, TECS can be thought of as driving a point mass airplane. This feature identifies TECS as a portable system, by functioning independent of the airplane it is controlling.

Figure 5 shows a simplified TECS in the 4D mode. Variable gains KVDEPS and KGEPS reflect control logic which splits the TECS modes into two groups: speed priority and path priority. For example, when throttle limits, then the speed profile mode has priority and KGEPS is set to zero, thus, eliminating γ_e cross coupling to the elevator.

In the 4D mode, Figure 5, V_e and γ_e are computed based on V_c, $\dot{V}_c$, and h_c, $\dot{h}_c$, respectively. These commands are generated by the filtered 4D profile described in Section 4.

$$\frac{\dot{V}_e}{g} = \left(\frac{V_c - V}{\tau} + \dot{V}_c - \dot{V}\right)\frac{1}{g} \quad (21)$$

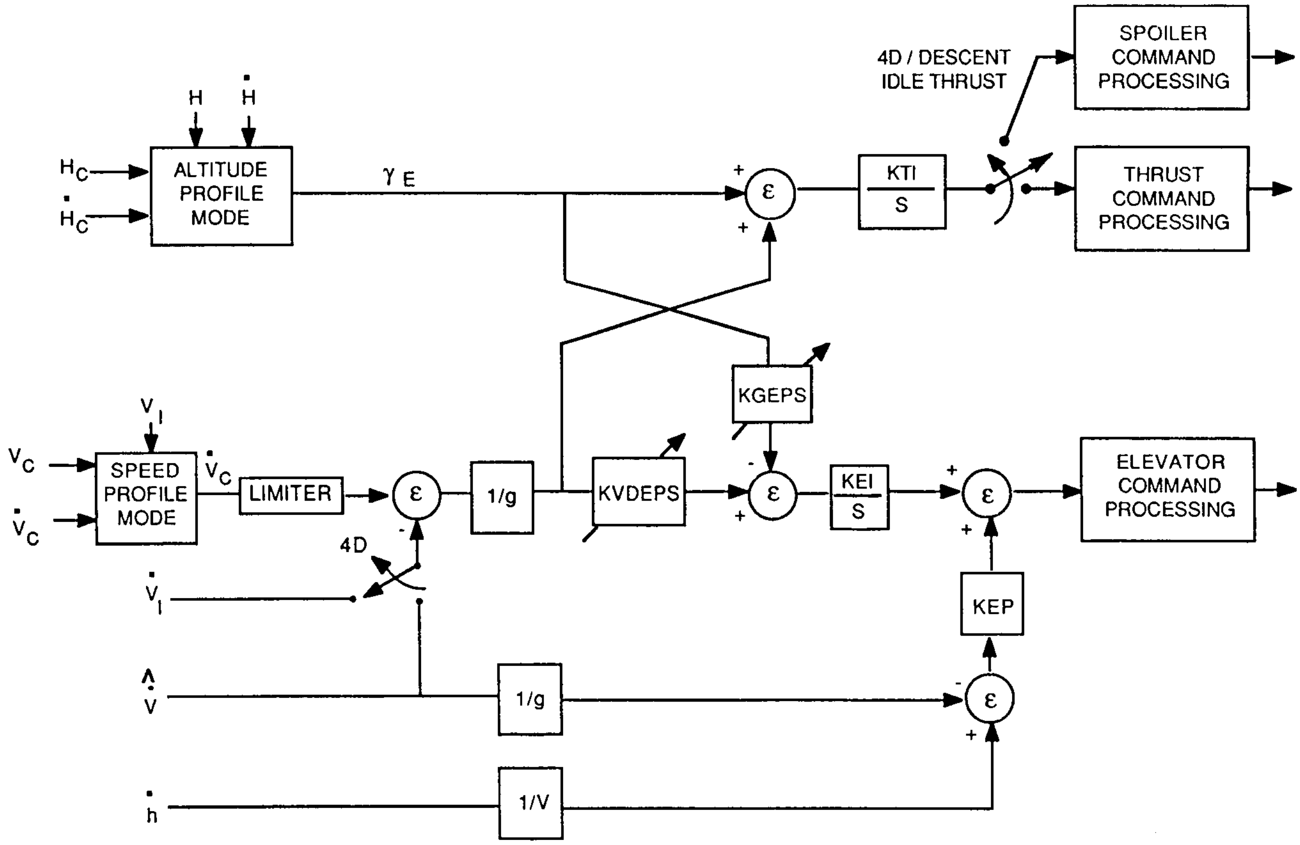


Figure 5. Simplified TECS in 4D

$$\gamma_e = \left(\frac{h_c - h}{\tau} + \dot{h}_c - h \right) \frac{1}{V} \tag{22}$$

Equations 21 and 22 are used to generate thrust and elevator commands, whereas equation 6 will be used to generate the spoiler command as described in Section 6.

6.0 USE OF SPOILERS IN 4D DESCENT

As mentioned in Section 5, TECS computes a throttle command based on specific energy error:

$$\frac{\dot{E}_{se}}{V} = \frac{T_{req}}{W} \tag{23}$$

This computation assumes a slow drag variation. This assumption is generally true, unless a drag device is employed to increase the drag of the airplane. In such cases, the drag term must be included in equation 23:

$$\frac{\dot{E}_{se}}{V} = \frac{T_{req} - D_{req}}{W} \tag{24}$$

Equation 24 represents a simple way of integrating spoilers into TECS. When the throttles are at idle ($T = const = T_{min}$) during descent, and when additional energy needs to be taken out of the system, the spoilers should be deployed to increase drag to achieve the desired result.

Therefore, in equation 24 any change in $\dot{E}_{se}$ will be caused by increased drag due to spoiler deflection:

$$\frac{\Delta\dot{E}_{se}}{V} \cong \frac{-\Delta D_{\delta_{spl}}}{W} \tag{25}$$

where

$\Delta D_{\delta_{spl}}$ is incremental drag due to spoiler deflection

In terms of speed and altitude errors, equation 25 can be rewritten as follows:

$$\frac{\Delta\dot{E}_{se}}{V} = \left(\frac{h_c - h}{\tau} + \dot{h}_c - \dot{h}\right)\frac{1}{V} + \left(\frac{V_c - V_i}{\tau} + \dot{V}_c - \dot{V}_i\right)\frac{1}{g} \tag{26}$$

and

$$\Delta D_{\delta_{spl}} = qSC_{D_{\delta_{spl}}} \tag{27}$$

Assume $C_{D_{\delta_{spl}}}$ is constant to derive

$$\delta_{splc} \cong K \cdot \frac{W}{q} \cdot \frac{\dot{E}_{se}}{V_i} \tag{28}$$

To implement the spoiler command, an integrator is required to achieve zero steady state energy error. A proportional path is then added to improve phugoid damping, which otherwise deteriorates as a result of spoiler deployment. Therefore, the spoiler command has the following form:

$$\delta_{splc} = \left[\frac{K_I}{s}\dot{E}_{se} + K_P\,\dot{E}_s\right] \cdot K\frac{W}{q} \tag{29}$$

where

K_I, K_P, K - gains to be determined by linear analysis
W - weight of the airplane
q - dynamic pressure
$\dot{E}_{se}$ - specific energy rate error of the airplane
$\dot{E}_s$ - specific energy rate

The PI (proportional + integral) structure in equation 29 is chosen in accordance with the PI structure already in TECS for the pitch command.

When compared with the thrust command definition in Section 5, the integral portion of the spoiler command is of identical form to that of the thrust command. Since the spoilers are used when the throttles are at the aft limit, the control logic as shown in Figure 6 was developed to automatically engage spoilers.

In Figure 6, the thrust command is passed through a limiter (limiter # 1), restricting it to a normalized (divided by weight) maximum and minimum achievable thrust. Therefore, when the engines achieve the lower thrust limit, the output of limiter #2 becomes positive. This result triggers switch ▷1 to close and the spoiler command is generated. The washout $\frac{100s}{100s + 1}$ in the spoiler proportional path is necessary to prevent spoiler activity for a constant energy rate, which occurs in descent. Hence, the spoilers only react to either changes in commanded energy rate or changes in inertial energy rate (due to winds).

Equation 29 shows the basic structure of the spoiler control law. It contains three gains K_I, K_p and K that should be determined by linear analysis. Initially K_I and K_p were set to .4 and .56, with .4 being the original value of the energy integrator gain and .56 being the value used in the proportional path for the pitch command. The value of K was selected to be 6 deg/rad to achieve the same crossover frequency in the spoiler command loop as in the pitch command loop (fig. 7). Further investigation indicated that the value of 6 deg/rad was too high for K, because it increases the crossover frequency in the speed loop (fig. 7) which should be around .08 rad/sec (12.5 sec per original TECS requirements). To achieve the desired crossover in the speed loop, the value of K was decreased to 3 rad/sec. The root locus analysis of the spoiler command proportional path loop showed that better damping of the short period mode can be achieved by reducing K_p to .28 (half of the original value). Therefore, gain values of 3, .28 and .4 for K, K_p and K_I, respectively, were used for nonlinear simulation testing.

Lightly damped oscillations in the spoiler command were observed during nonlinear simulation runs. When flight conditions used in non-linear testing were analyzed for stability, it was found that the spoiler command crossover frequency was at 9 rad/sec, compared with .2 rad/sec for the nominal flight condition. The major difference between the nominal flight

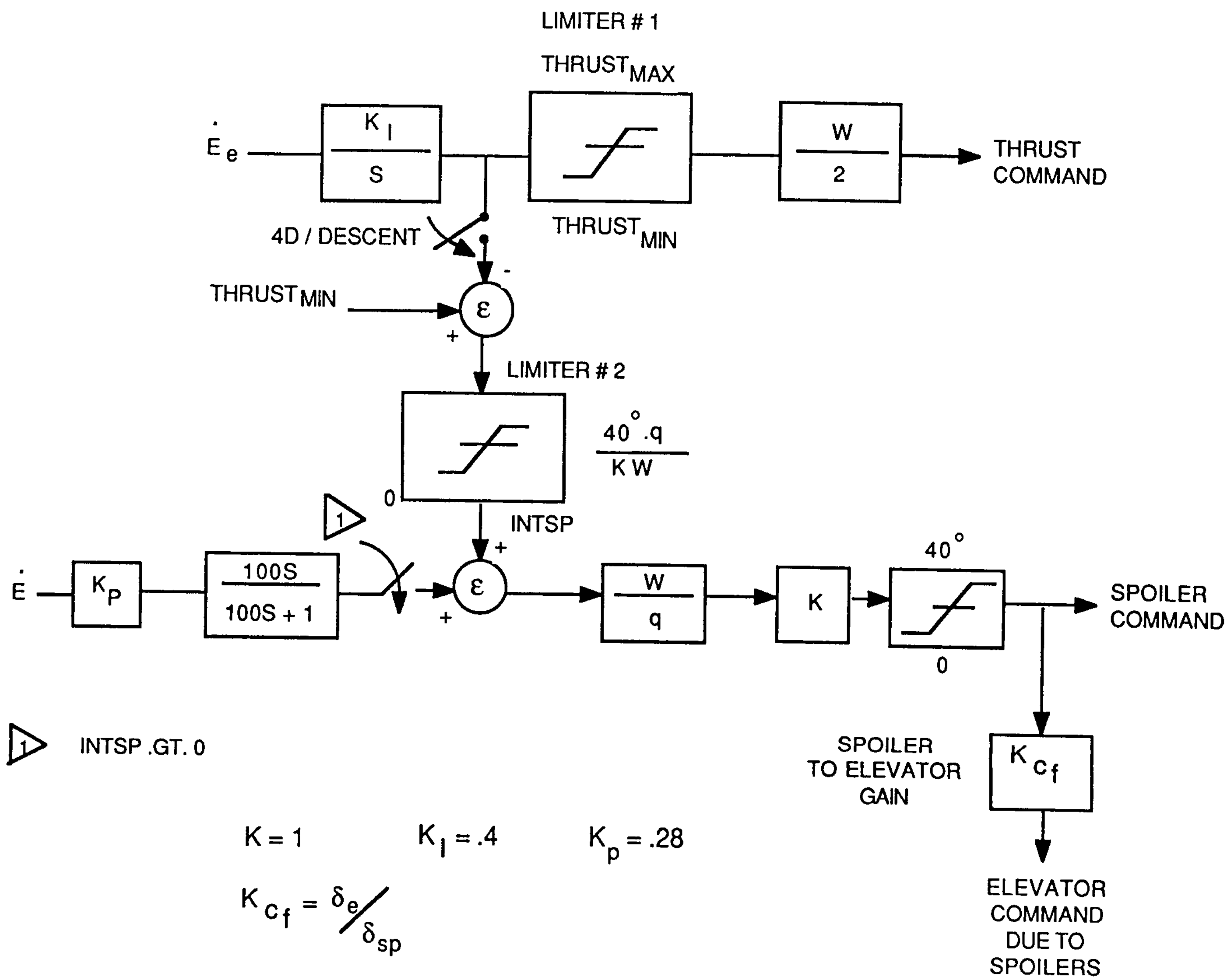


Figure 6. Spoiler Command Implementation

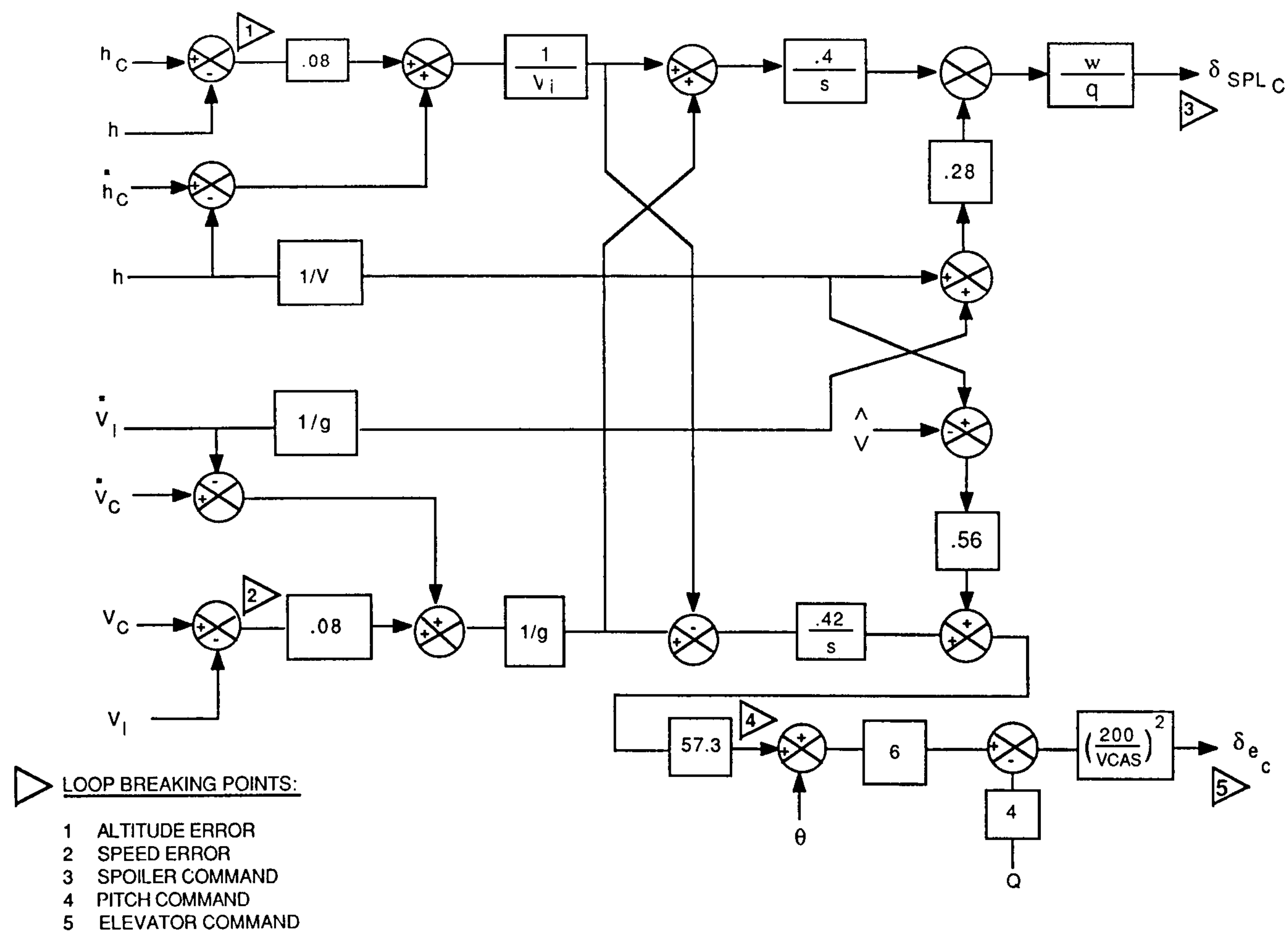


Figure 7. TECS in Spoiler Configuration (Linear Model)

condition and the ones tested on the nonlinear simulation was the c.g. location, 20% for the former and 10% for the latter. Therefore, to reduce excessive spoiler command bandwidth in the forward c.g. conditions, the value of gain K was reduced further to 1 deg/rad. This change did not effect the speed loop crossover much, except in the extreme conditions, making it satisfactory for the final spoiler command configuration.

In the 4D mode, the airplane follows an inertial trajectory. Therefore, as can be deduced from equation 26, the inertial speed and acceleration are used to compute the spoiler command integral component. The spoiler command proportional path also uses inertial acceleration, thus, making spoilers track a purely inertial path:

$$\delta_{splc} = \left(\frac{.4}{s} E_{se} + .28\,\dot{E}_s\right) K \frac{W}{q} \qquad (30)$$

where

$$\dot{E}_{se} = \frac{1}{V_i}\left(\frac{h_c - h}{\tau} + \dot{h}_c - \dot{h}\right) + \frac{1}{g}\left(\frac{V_c - V_i}{\tau} + \dot{V}_c - \dot{V}_i\right)$$

$$\dot{E}_s = \frac{\dot{V}_i}{g} + \frac{\dot{h}}{V_i}$$

The elevator command contrarily, uses inertial speed in the integral path and estimated airmass acceleration in the proportional path:

$$\delta_{ec} = \frac{.42}{s}\,\dot{E}_{de} + .56\,\dot{E}_d \qquad (31)$$

where

$$\dot{E}_{de} = \frac{1}{g}\left(\frac{V_c - V_i}{\tau} + \dot{V}_c - \dot{V}_i\right)$$

$$- \frac{1}{V_i}\left(\frac{h_c - h}{\tau} + \dot{h}_c - \dot{h}\right)$$

$$\dot{E}_d = \frac{1}{V}\dot{h} - \frac{1}{g}\hat{\dot{V}}$$

This arrangement allows the elevator to track the airmass energy distribution rate in the short term, thus, minimizing the chance of stalling the airplane.

The decision to make spoilers control the inertial energy rate was based on linear time response analysis. Initially it was decided that airmass acceleration should be used for both spoiler and elevator commands, but analysis of the linear response to horizontal tail wind showed that the throttles came up first, followed by the spoilers. This kind of response is clearly undesirable. Hence, it was corrected by using the inertial acceleration in the integral paths for both the spoiler and elevator commands, and in the proportional path for the spoiler command.

Spoiler deployment has a direct effect on the pitching moment of the aircraft. Since lift is reduced aft of the spoilers on the wing, the aircraft pitches up. This behavior may result in unnecessary elevator activity unless the elevator command can anticipate the change. A crossfeed from the spoiler command to the pitch command provided this anticipation as shown in Figure 6. The crossfeed gain K_{CF} is computed based on how much elevator deflection is required to compensate for spoiler deflection. Its value is a function of altitude, mach and alpha, and was derived using a least squares curve fit to flight manual data. The Fortran routine that computes K_{CF} is shown in Figure 8.

Print file "elauth1.ftn"

```
      SUBROUTINE ELAUTH1(ALFA,MACH,H,DSPL,DE)
C
C THIS SUBROUTINE COMPUTES ELEVATOR DEFLECTION REQUIRED TO
C COMPENSATE FOR PITHCING MOMENT DUE TO SPOILERS
C IT COMPUTES PITCHING MOMENT GENERATED BY GIVEN SPOILER DEFLECTION
C AND PITCHING MOMENT GENERATED BY ONE DEGREE ELEVATOR DEFLECTION
C THEN DIVIDES THE TWO TO GET TOTAL ELEVATOR DEFLECTION NECESSARY
C TO NULL OUT PITHING MOMENT DUE TO SPOILERS
C INPUTS: ANGLE OF ATTACK (ALFA) MACH NUMBER (MACH) ALTITUDE (H) SPOILER DEFLECTION (DSPL)
C OUTPUT: ELEVATOR DEFLECTION (DE)
C
      REAL ALFA,MACH,H,KALFA,KDE
      DIMENSION X(100,100),Y(100)
      INTEGER M(4),P(4),R
C
C  COMPUTE PITHING MOMENT DUE TO SPOILERS: CMDSP
C  CMDSP = .025*CMSPA*CMSPMA*DSPL
C  WHERE CMSPA,CMSPMA ARE LEAST SQUARE APPROXIMATIONS
C  OF FLIGHT MANUAL DATA
C  DSPL = CURRENT SPOILER POSITION
C  .025 = SPOILER EFFECTIVENESS COEFFICIENT
C
C  COMPUTE CMSPA
C
      X1 = .0218
      X2 = .3166
      X3 = -1.1388
      CMSPA = X1 + X2*(ALFA/100) + X3*(ALFA/100)**2
C
C COMPUTE CMSPMA
C
      X(1,1) =  1.2564
      X(1,2) = -0.7208
      X(1,3) = -1.3695
      X(1,4) =  3.7242
      X(2,1) = -4.9714
      X(2,2) =  2.2002
      X(2,3) =  30.3760
      X(2,4) = -32.8295
      X(3,1) =  10.5334
      X(3,2) = -42.0536
      X(3,3) =  53.2351
      X(3,4) = -21.1124
      X(4,1) = -1.7343
      X(4,2) =  7.4250
      X(4,3) = -10.3040
      X(4,4) =  4.6295
      CMSPMA = 0
      DO 50 I = 1,4
        DO 60 J = 1,4
         CMSPMA = CMSPMA + X(I,J)*MACH**(J-1)*ALFA**(I-1)
 60     CONTINUE
 50   CONTINUE
      IF (MACH .LE. 0.4) CMSPMA = 1
C
C COMPUTE PITCHING MOMENT PER DEGREE ELEVATOR
C CM = KALFA*CMDEMH
C WHERE KALFA AND CMDEMH ARE LEAST SQUARE APPROXIMATIONS
C OF FLIGHT MANUAL DATA
C
C COMPUTE KALFA
C
      X1 = .964
      X2 = .013
      KALFA = X1 + X2*ALFA
      IF (ALFA .LT. 2) KALFA = 2
C
C COMPUTE CMDEMH
C
      X(1,1) =   -0.0305
      X(1,2) =    0.0177
      X(1,3) =   -0.0478
      X(1,4) =    0.0720
      X(2,1) =    0.0073
      X(2,2) =   -0.0139
      X(2,3) =   -0.0219
      X(2,4) =   -0.0801
      X(3,1) =   -0.0359
      X(3,2) =    0.0557
      X(3,3) =    0.0409
      X(3,4) =    0.0203
      X(4,1) =    0.0400
      X(4,2) =    0.0259
      X(4,3) =   -0.0798
      X(4,4) =    0.0578
      CMDEMH = 0
      DO 80 I = 1,4
        DO 90 J = 1,4
         CMDEMH = CMDEMH + X(I,J)*MACH**(J-1)*(H/1E+05)**(I-1)
 90     CONTINUE
 80   CONTINUE
C
C COMPUTE ELEVATOR ANGLE:
C DE = - CMSP/CMDE
C
         CMSP = .025*CMSPA*CMSPMA*DSPL
         CMDE =  KALFA*CMDEMH
         DE   = -CMSP/CMDE
      RETURN
      END
```

Figure 8. Fortran Subroutine - Spoiler to Elevator Gain

In the 4D mode, the inertial acceleration and speed are always used independently of whether throttles or spoilers are active (fig. 5). In the case of throttles, this means that inertial instead of airmass energy rate error is used to compute the throttle command (see Section 5).

As previously mentioned, TECS estimates the airmass acceleration. This estimation is based on the following formula:

$$\hat{\dot{V}} = \frac{s}{\tau s + 1} V_t + \frac{\tau s}{\tau s + 1} g\left(\frac{T_c}{W} - \gamma\right) \tag{32}$$

In equation 32, τ is a function of altitude. This formula assumes slow drag variation. Such an assumption is not valid when spoilers are deployed, in which case a drag term should be included in equation 32:

$$\hat{\dot{V}} = \frac{s}{\tau s + 1} V_t + \frac{\tau s}{\tau s + 1} g\left(\frac{T_c - D_c}{W} - \gamma\right) \tag{33}$$

In equation 33, D_c is the drag due to spoilers estimated from the spoiler command:

$$D_c = \frac{13.7}{s + 13.7} \frac{q}{W} \delta_{splc} \tag{34}$$

D_c is switched into the $\hat{\dot{V}}$ filter when the 4D descent flag is set. Figure 9 shows a diagram of the $\hat{\dot{V}}$ filter with proposed changes.

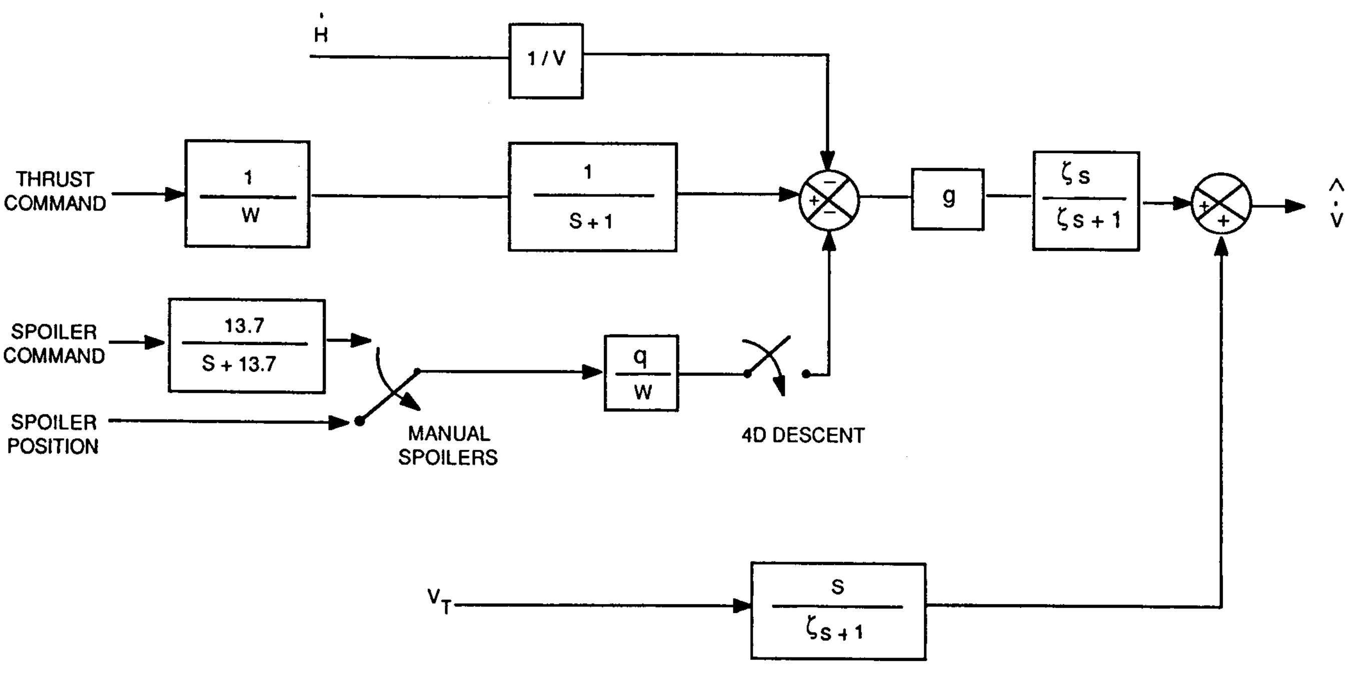


Figure 9. VDOT Filter

7.0 INITIAL DISTANCE/TIME ERROR NULLING

During conversations with NASA, it was decided that if there is a time error when the 4D mode is engaged, it will be nulled by top-of-descent, (i.e., no time error nulling from the cruise phase is to take place in the descent phase of the flight).

The first approach to accomplish time error nulling by top-of-descent was to adjust the distance feedback controller gains (fig. 10) based on the distance error information.

The distance controller generates an inertial speed command based on the distance error:

$$V_c = \left(\frac{K_{IX}}{s} + K_{PX}\right) \cdot X_e - V_i \qquad (35)$$

where

$$X_e = V_i \cdot T_e \qquad (36)$$

and

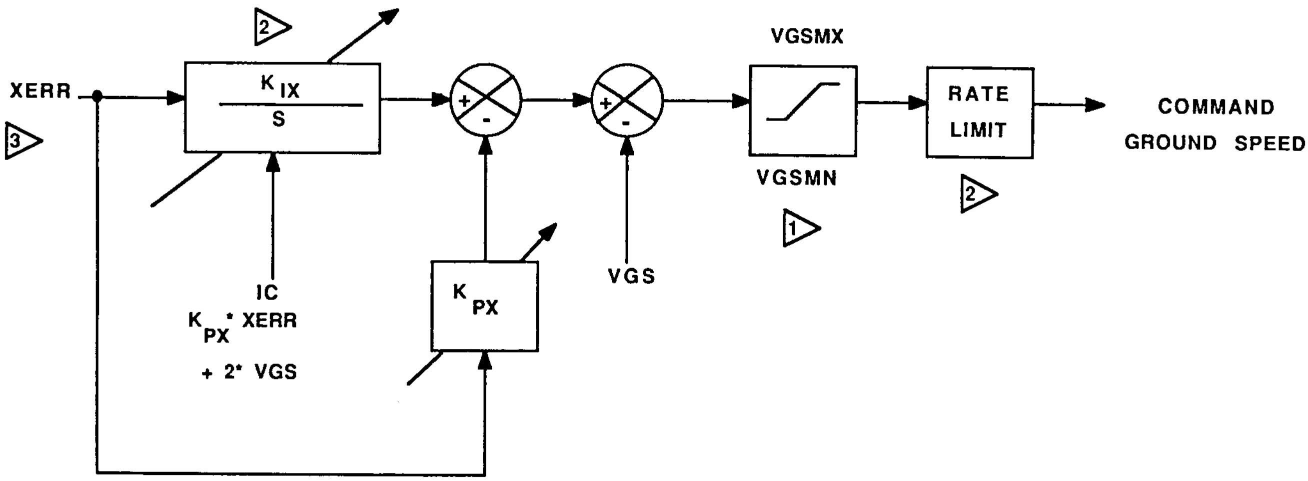
T_e - time error

The speed command in equation 35 drives the TECS speed profile mode, which generates acceleration command error to drive the inner loop:

$$\dot{V}_e = \frac{V_c - V_i}{\tau} - \dot{V}_i \qquad (37)$$

Combining equation 37 and 35 derives:

$$\dot{V}_e = \frac{1}{\tau}\left[\left(\frac{K_{IX}}{s} + K_{PX}\right)X_e - 2\,V_i\right] - \dot{V}_i \qquad (38)$$



1 IF (DFLAG.EQ.0) VGSLIM = VGS
VGSMX = VGSLIM + 100
VGSMN = VGSLIM - 100

2 104/V

3 XERR = VGS*TERR

Figure 10. Distance Feedback Controller

Ignoring the damping terms, the elevator and throttles are driven to satisfy:

$$0 = \frac{1}{\tau}\left(\left(\frac{K_{IX}}{s} + K_{PX}\right)X_e - 2V_i\right) - \dot{V}_i \qquad (39)$$

The solution to the differential equation 39 describes the speed profile the airplane is going to track to null out the time error.

By definition:

$$X_e = X_c - X$$

$$\dot{X}_e = \dot{X}_c - \dot{X} = V_c - V_i \qquad (40)$$

$$\ddot{X}_e = \ddot{X}_c - \ddot{X} = \dot{V}_c - \dot{V}_i$$

or

$$\dot{V}_i = \ddot{X}_c - \ddot{X}_e \text{ and } V_i = \dot{X}_c - \dot{X}_e \qquad (41)$$

Substituting equation 41 into equation 39:

$$\frac{1}{\tau}\int K_{IX} X_e \, dt + \frac{K_{PX}}{\tau} X_e + \frac{2}{\tau}\dot{X}_e$$

$$- \frac{2}{\tau}\dot{X}_c + \ddot{X}_e - \ddot{X}_c = 0 \qquad (42)$$

And by differentiating equation 42 derives:

$$\frac{K_{IX}}{\tau} X_e + \frac{K_{PX}}{\tau}\dot{X}_e + \frac{2}{\tau}\ddot{X}_e + \dddot{X}_e = \frac{2}{\tau}\ddot{X}_c + \dddot{X}_c \qquad (43)$$

It is reasonable to assume that $\dddot{X}_c = \ddot{X}_c = 0$ and $\dddot{X}_e \cong 0$. Therefore, the simplified differential equation is obtained describing the distance error behavior:

$$K_{IX} X_e + K_{PX} \dot{X}_e + 2\ddot{X}_e = 0 \tag{44}$$

The solution of equation 44 has the following form:

$$X_e = C_1 e^{\lambda_1 \tau} + C_2 e^{\lambda_2 \tau} \tag{45}$$

where

$$K_{IX} = -2\lambda_1 \lambda_2$$

$$K_{PX} = -2(\lambda_1 + \lambda_2)$$

C_1 and C_2 can be obtained from the initial conditions:

$$X_{eo} = C_1 + C_2 \tag{46}$$

$$\dot{X}_{eo} = C_1\lambda_1 + C_2\lambda_2$$

Since λ_1, λ_2 are zeroes of the distance feedback controller, an additional constraint is imposed on them: $\lambda_2 = 2\lambda_1 < 0$ making them both real and negative.

Combining equation 45 and 46 derives a system of four equations with four unknowns:

$$X_{eo} = C_1 + C_2$$

$$\dot{X}_{eo} = C_1\lambda_1 + C_2\lambda_2 \tag{47}$$

$$X_{ef} = C_1 e^{\lambda_1 T} + C_2 e^{\lambda_2 T}$$

$$\lambda_2 = 2 \lambda_1$$

Where X_{ef} and T are final distance error at TOD and time required to get to TOD, respectively.

By using algebraic manipulation equation 47 can be reduced to one equation:

$$X_{ef} = C_1 e^{\lambda_1 T} + C_2 e^{2\lambda_1 T}$$

where

$$C_1 = \frac{-\dot{X}_{eo}}{\lambda_1} + 2 X_{eo} \tag{48}$$

$$C_2 = \frac{\dot{X}_{eo}}{\lambda_1} - X_{eo}$$

Equation 48 is solved numerically by selecting a small value for X_{ef} and rewriting it as a function of λ1:

$$g(\lambda_1) = C_1 e^{\lambda_1 T} + C_2 e^{\lambda_2 T} - X_{ef} \tag{49}$$

Equation 49 is solved using a binary search routine. For the routine to work the following condition must be satisfied:

$$g(-\infty)\, g(0) < 0$$

Therefore, values of $g(-\infty)$ and $g(0)$ must be obtained from:

$$g(0) = \lim_{\lambda_1 \to 0} g(\lambda_1) = \dot{X}_{eo} T + X_{eo} - X_{ef} \tag{50}$$

$$g(-\infty) = \lim_{\lambda_1 \to \infty} g(\lambda_1) = -\dot{X}_{ef}$$

Since g (- ∞) and g (0) must have opposite signs, the value of g (- ∞), which is $-\dot{X}_{ef}$, is set accordingly with the correct sign. This ensures that the binary search converges.

When the 4D mode is engaged, an initial check is done to ensure that the specified TOA is within the aircraft capacity and the initial time error is large enough to justify using the distance feedback to null it out.

Unfortunately, one major drawback of the distance feedback solution is its exponential nature, which means that 60% of the time error is taken out during the first one third of the 4D cruise (fig. 11). This behavior results in higher throttle activity. Thus, a second approach was developed to reduce throttle activity.

For the second approach, equations were developed to uniformly distribute time error reduction over the 4D cruise to minimize throttle activity. This task is successfully accomplished by the algorithm described in the following:

A ground speed profile to null out the initial distance error is generated from the following constraints:

V_o - initial ground speed

V_f - final ground speed per 4D profile

t_f - time to TOD per 4D profile

a - flight path acceleration limit

X_{crz} - cruise distance per 4D profile

X_{eo} - initial distance error

X_f - $X_{crz} + X_{eo}$

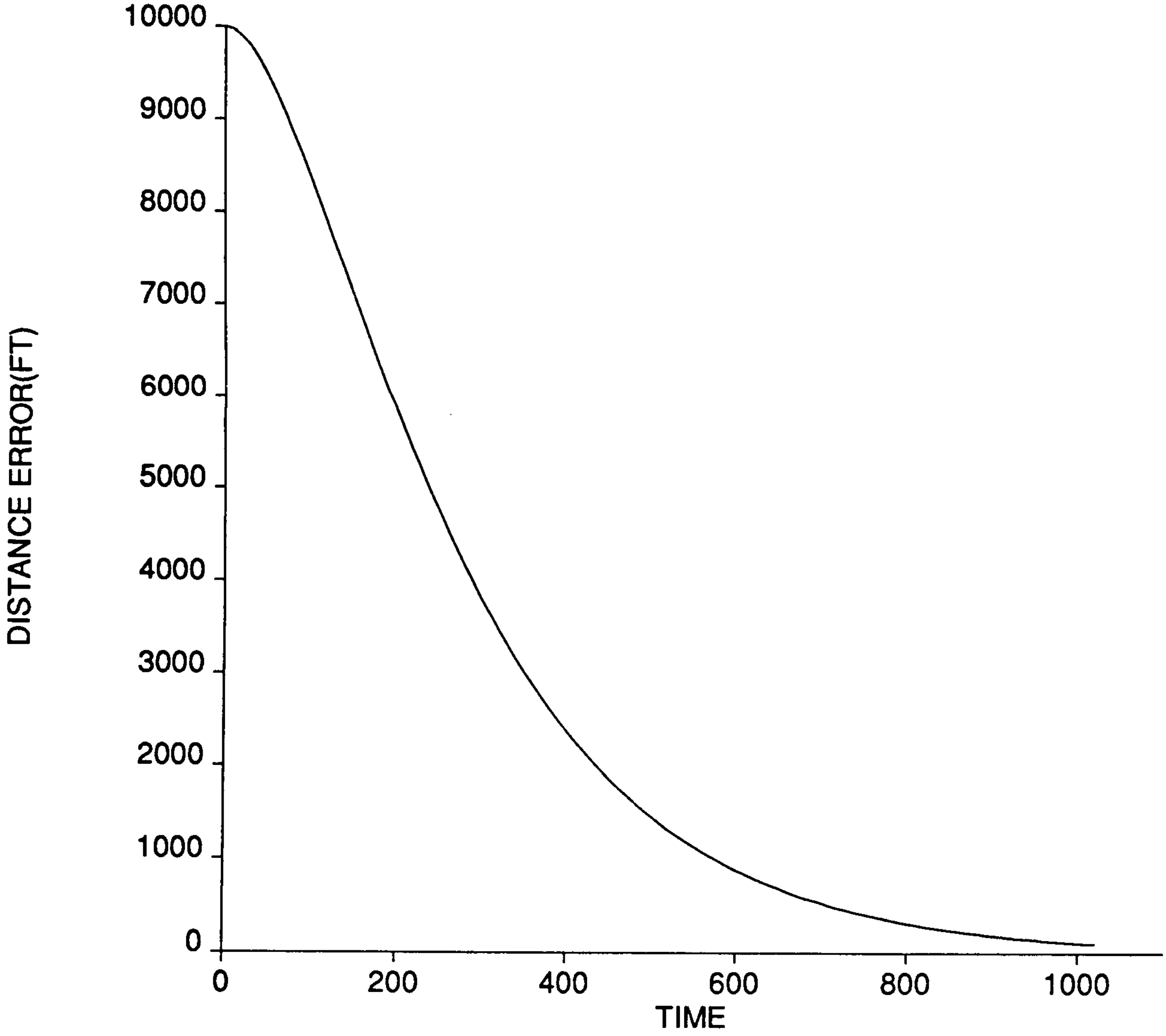


Figure 11. Distance Error Nulling By Adjusting Distance Feedback Control Gains

Without considering the speed limitations of the airplane, a quick analysis is performed to determine if a solution exists for the given constraints: V_o, V_f, t_f. Figures 12a and 12b show maximum range and minimum range ground speed profiles. Equations 51 through 53 describe these profiles. A simultaneous solution for X_{fm} yields equation 54. The value X_{fm} is the maximum range possible (a > 0) or minimum range possible (a < 0) for the given constraints. If the range to be covered, X_f, falls within the maximum and minimum ranges then a solution exists.

$$V_s = V_o + a\, t_d \tag{51}$$

$$V_f = V_s - a\,(t_f - t_d) \tag{52}$$

$$X_f = \int_0^{t_d} (V_o + at)\, dt + \int_{t_d}^{t_f} \left(V_s - a\left(t - t_d\right)\right) dt \tag{53}$$

$$X_{fm} = -\left(V_o^2 + V_f^2\right) / 4a + V_o V_f \,/ 2a + V_o\, t_f / 2$$

$$+ V_f\, t_f / 2 + a t_f^2 / 4 \tag{54}$$

Should a solution not exist, the final ground speed constraint V_f is met and a TOD arrival time error is computed and displayed.

If it is found that a solution exists, one of the four ground speed profiles shown in Figure 13 is selected using the following logic.

If the airplane continues to fly at its initial ground speed, it will arrive at TOD early, late, or on time. If it is going to arrive late, it must speed up. In this case, the ground speed profile of either Figure 13a or 13c is required. Profile 13a will be selected for significant time errors. Profile 13c will be selected for small time errors - typically this profile is selected only as a result of periodic recomputation while tracking a 13a profile. Similar rational is used to select profiles 13b or 13d.

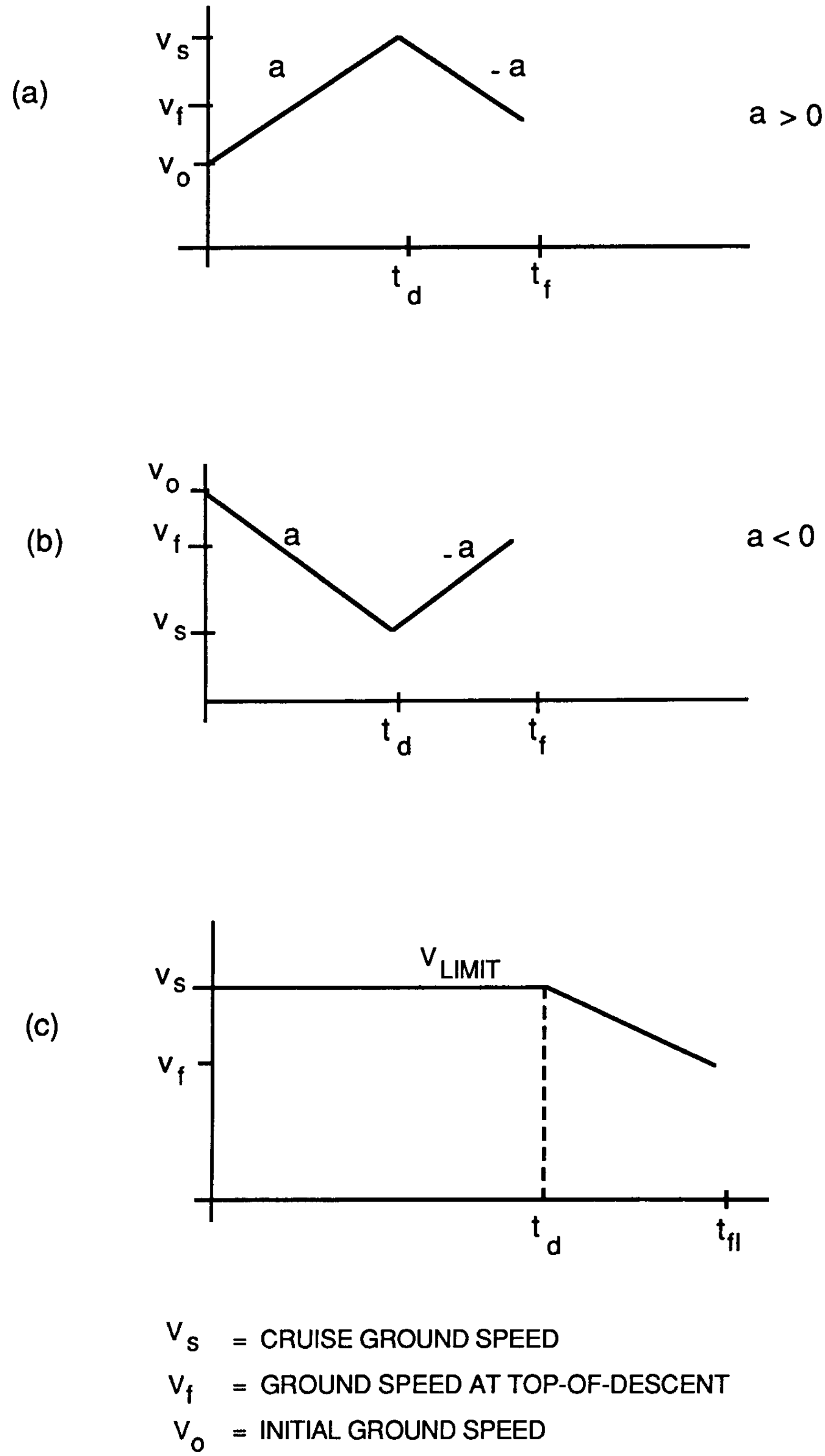


Figure 12. Ground Speed Profiles Under Limit Conditions

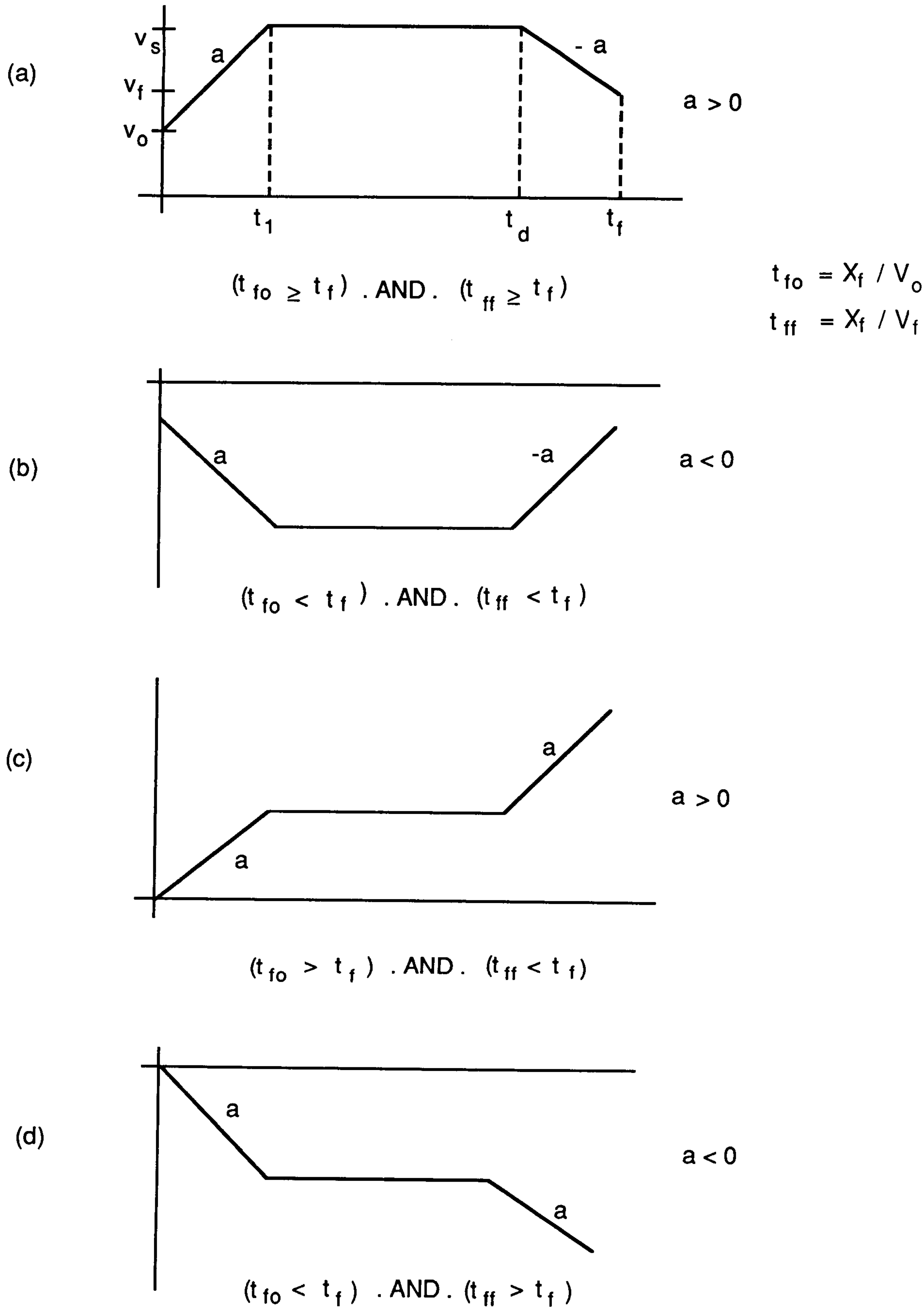


Figure 13. Ground Speed Profiles

Once a ground speed profile has been selected, two unknowns must be determined. First, the necessary cruise speed V_s must be calculated. The second unknown is t_d. This is the time at which a deceleration/acceleration must be initiated to bring the ground speed of the airplane from V_s to the required final ground speed V_f. These values are derived from the equations describing the selected ground speed profile.

The equations describing the profiles of Figures 13a and 13b are:

$$V_s = V_o + at_1 \tag{55}$$

$$V_f = V_s - a(t_f - t_d) \tag{56}$$

$$X_f = \int_0^{t_1} (V_o + at)dt + \int_{t_1}^{t_d} V_s dt + \int_{t_d}^{t_f} (V_s - a(t - t_d))dt \tag{57}$$

which reduce to:

$$V_s = \frac{1}{2}(at_f + V_o + V_f) + \rho\frac{1}{2}\left(a^2t_f^2 + 2at_fV_o + 2at_fV_f + 2V_oV_f - V_f^2 - V_o^2 - 4aX_f\right)^{\frac{1}{2}} \tag{58}$$

$$t_d = t_f + (V_f - V_s) / a \tag{59}$$

The solution of interest for profile 13a has $\rho = -1$, and for profile 13b has $\rho = +1$.

The equations describing the profiles of Figures 13c and 13d are:

$$V_s = V_o + at_1 \tag{60}$$

$$V_f = V_s + a(t_f - t_d) \tag{61}$$

$$X_f = \int_0^{t_1} (V_o + at)dt + \int_{t_1}^{t_d} V_s dt + \int_{t_d}^{t_f} (V_s + a(t - t_d))dt \qquad (62)$$

which reduce to:

$$V_s = \left(X_f + \left(V_o^2 - V_f^2\right) / 2a\right) / \left(t_f + (V_o - V_f) / a\right) \qquad (63)$$

$$t_d = t_f + (V_f - V_s) / a \qquad (64)$$

Equations 59 and 64 are identical functions of V_s.

When throttles reach the set throttle authority limits or air speed limiting occurs, the airplane is held at the corresponding ground speed. The resulting arrival time is:

$$t_{fl} = (X_f / V_o) + (V_o / 2a) + \left(V_f^2 / 2aV_o\right) - (V_f / a) \qquad (65)$$

which is derived from (fig. 12c):

$$V_f = V_s - a(t_{fl} - t_d) \qquad (66)$$

$$X_f = \int_0^{t_d} V_s dt + \int_{t_d}^{t_{fl}} (V_s - a(t - t_d))dt \qquad (67)$$

Under limit conditions, the airplane will be at a ground speed other than the desired cruise speed V_s. To meet the final ground speed constraint V_f, a new value of t_d must be generated. To accommodate both the desired/unlimited ($V_{gs} = V_s$) and limited ($V_{gs} \neq V_s$) flight conditions, the following substitutions are made:

equation 59: $t_d = t_f + (V_f - V_s) / a \qquad (68)$

is implemented by: $t_d = t_{fl} + (V_f - V_{gs}) / a$ (69)

This approach eliminates the final ground speed error (at the expense of a larger time error). The corresponding TOD arrival error is:

$$t_{ef} = t_{fl} - t_f$$

A TOD arrival time error message is displayed to the pilot.

8.0 ALTITUDE PROFILE AND SPEED PROFILE MODES

The smoothed 4D altitude and speed profiles are fed to the TECS altitude and speed profile modes. Since the 4D altitude and speed profiles may contain nonzero acceleration and altitude rate commands, the corresponding TECS profile modes develop command errors from both position and rate commands.

The altitude profile mode generates an inertial flight path angle error γ_e using the altitude command processor outputs h_c and $\dot{h}_c$ (figs. 5 and 14):

$$\gamma_e = \left[\left(\frac{h_c - h}{\tau}\right) + \left(\dot{h}_c - \dot{h}\right)\right]\frac{1}{V_i} \qquad (70)$$

The speed profile mode generates an inertial acceleration error $\dot{V}_E$ using the speed command processor outputs V_c and $\dot{V}_c$ (figs. 4, 5 and 15):

$$\dot{V}_e = \left(\frac{V_c - V_i}{\tau}\right) + \left(\dot{V}_c - \dot{V}_i\right) \qquad (71)$$

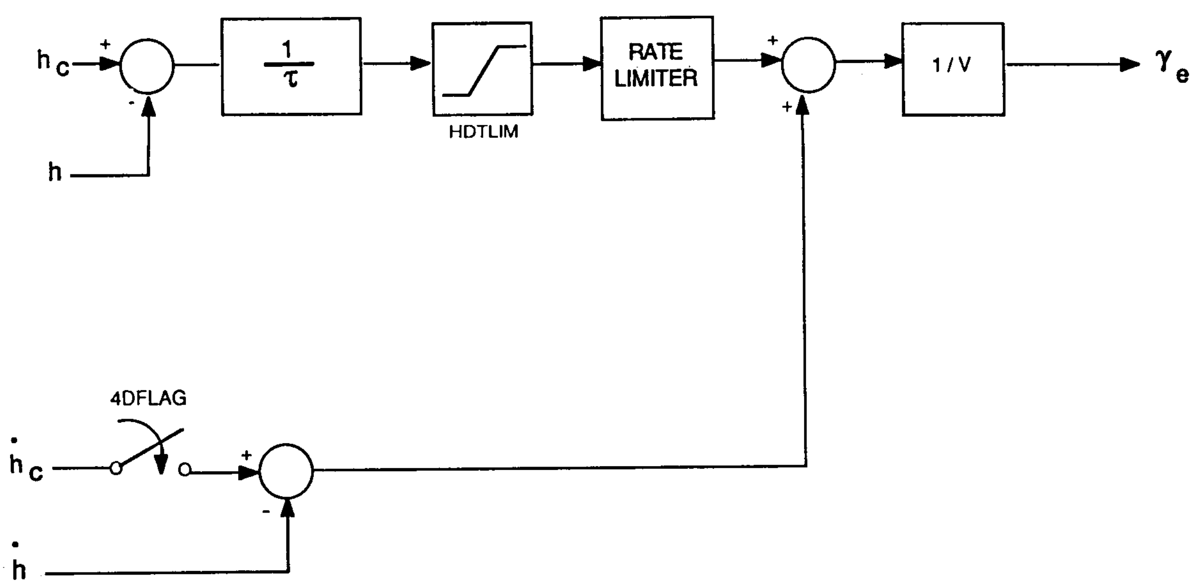


Figure 14. Gamma Error Computation

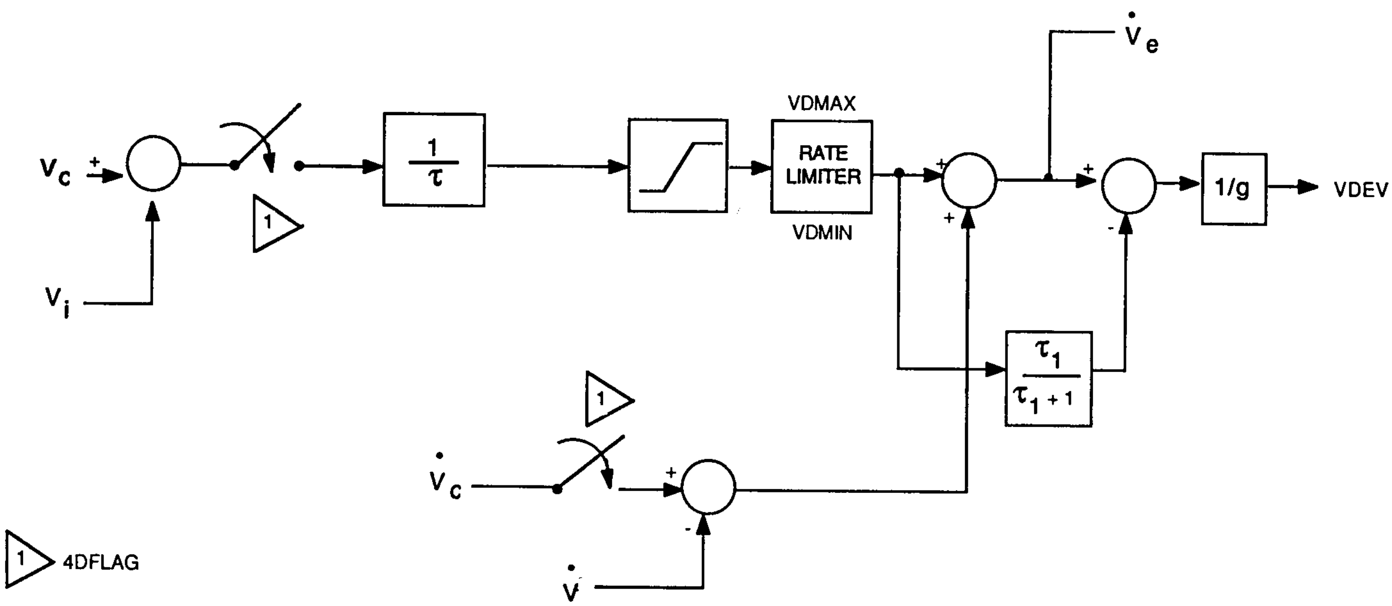


Figure 15. Acceleration Error Computation

9.0 MANUAL SPOILERS

Due to hardware constraints, the only way to control the spoilers on the NASA TSRV airplane is by adjusting the speedbrake handle in the forward cockpit. Therefore, the automatic spoiler command is converted into a speedbrake setting advisory for the pilot as shown in Figure 16.

In the manual spoiler mode, the TECS structure reduces to speed on elevator for basic safety reasons (i.e., should the pilot choose not to deploy spoilers). However, the spoiler command remains coupled to the speed error and does not reduce to an altitude on spoilers mode. This configuration was found to reduce the magnitude of path deviations resulting from changes in pitch with the cross coupling of speed error to spoilers providing sufficient anticipation to allow the spoilers to remove altitude errors (caused by changes in pitch) as they occur.

The spoiler command bandwidth is low enough for the pilot to easily follow.

Figure 16 also shows the spoiler position feedback to the elevator command required to retrim the aircraft in the manual spoiler mode. Spoiler to elevator gain is computed based on the amount of elevator deflection required to compensate for the pitching moment generated by the spoilers and is a function of altitude, mach, and angle of attack. The system in Figure 7 was analyzed for stability and found to be stable with sufficient phase and gain margins.

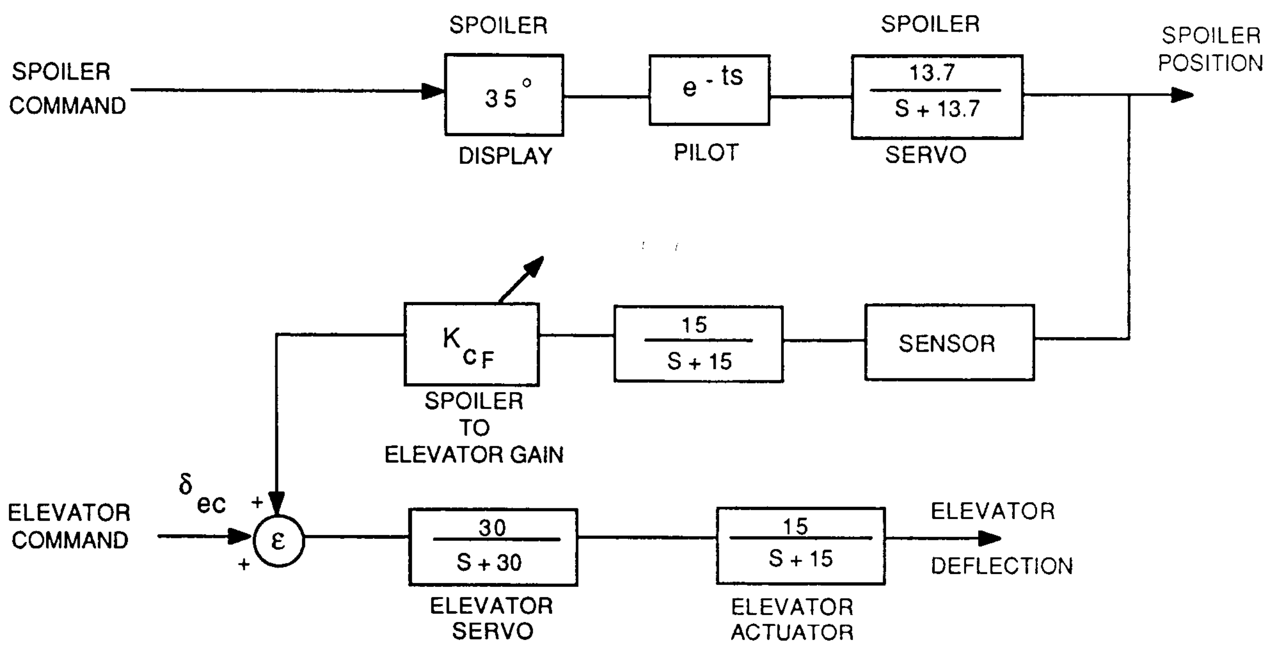


Figure 16. Manual Spoilers

10.0 4D MODE LOGIC

New logic had to be added and some existing logic changed to properly integrate the 4D mode into TECS. The following new logic was added:

(1) 4D mode flag
(2) 4D cruise flag
(3) 4D descent flag

The 4D mode flag enables altitude and speed profile modes and spoilers in a 4D descent. It also makes changes to existing logic, such as, the AFTLIM flag definition and the energy integrator offloader logic.

The AFTLIM flag is set when throttles reach aft limit. This, in turn, forces the KGEPS gain to zero (Figure 5), and TECS into a speed on elevator configuration for speed priority modes. In a 4D descent, the spoilers are enabled, providing extended range for energy bleed-off. Therefore, the AFTLIM flag should be set only when spoilers are at their limit in a 4D descent.

The offloader circuit is used to keep the energy integrator from saturating when throttles are at their limit. Since the same integrator drives the spoilers in a 4D descent, it is necessary that the offloader circuit not be turned on while the spoilers are active. This change is shown in Figure 17. It should be noted, that the offloader circuit is a survivor of the analog days and can be replaced by simply turning off the integrator when spoilers limit in a 4D descent or as throttles limit when the 4D mode is not engaged.

In the 4D mode, the airplane tracks an inertial profile. Hence, when in the 4D mode, inertial acceleration is used to compute integral commands in both energy and energy distribution paths. The switch from the TECS estimated acceleration to the inertial one is accomplished when the 4D flag is set.

The 4D cruise and the 4D descent flags are to be provided with the 4D flag. All three are enabled or disabled by the PGA or the FMC, depending on which one is driving TECS in the 4D mode.

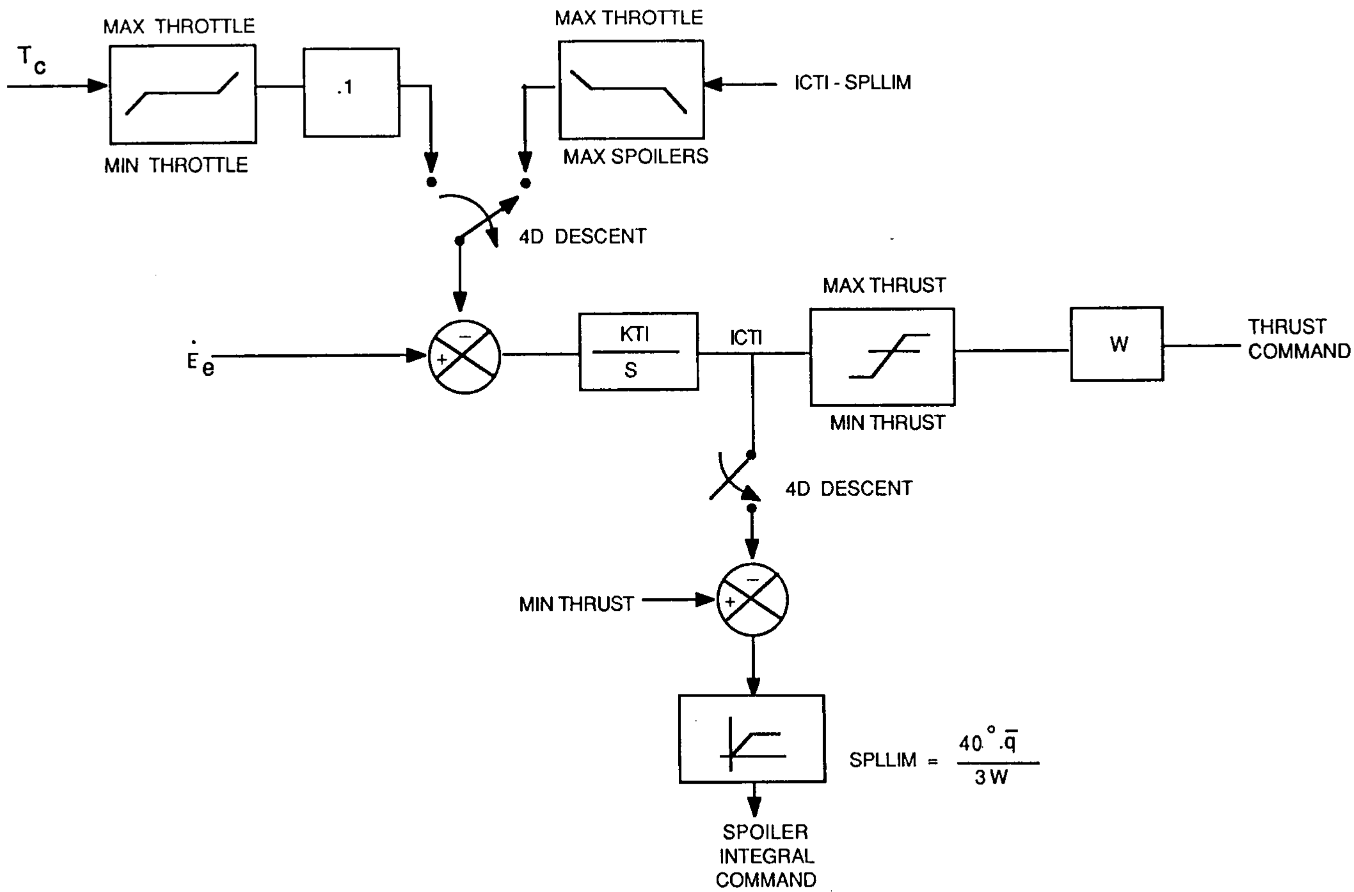


Figure 17. Energy Integrator Limiting

11.0 RESULTS OF LINEAR AND NONLINEAR ANALYSES

Extensive linear and nonlinear analyses were performed on the spoiler control law described in the previous sections.

Linear analysis was done for TECS in manual, automatic spoiler and speed-on-elevator configurations where the latter is a result of spoiler limiting.

Nonlinear testing on the Harris simulator (simulation of B737-200) was conducted for TECS with automatic spoilers, which includes the speed-on-elevator mode.

The nominal flight condition used for most of the linear analysis and design is shown on page 54. Both automatic and manual spoilers, as well as speed-on-elevator mode, were analyzed for this flight condition. Once the final design configuration was achieved, linear analyses were performed for 32 flight conditions containing the extreme values of the following variables:

H	-	10,000 - 35,000 ft.
M	-	min - max
cg	-	.05 - .31
W	-	80,000 - 110,000 lbs
spoilers	-	0 - 30°

All of the conditions are summarized in Table 1.

The linear analyses consisted of tabulating closed-loop poles and the phase and gain margins for: pitch command, spoiler command, altitude error, speed error and elevator command loops (fig. 7).

For the manual spoilers and the speed-on-elevator configurations of TECS, a linear analysis was performed for the nominal flight condition only. Automatic spoilers were tested for all 32 flight conditions previously discussed.

When the 4D mode is disabled, the selected PGA or FMC determines the next mode for TECS to fly and informs the pilot of its decision.

Table 1. Linear Analysis Flight Conditions

CONDITION NO. (SPOILERS = 0)	CONDITION NO. (SPOILERS = 30)	MACH	ALTITUDE	WEIGHT	CG
25	41	.31	10,000	80,000	.05
26	42	.64	10,000	80,000	.05
27	43	.55	35,000	80,000	.05
28	44	.84	35,000	80,000	.05
29	45	.37	10,000	110,000	.05
30	46	.64	10,000	110,000	.05
31	47	.66	35,000	110,000	.05
32	48	.84	35,000	110,000	.05
33	49	.31	10,000	80,000	.31
34	50	.64	10,000	80,000	.31
35	51	.55	35,000	80,000	.31
36	52	.84	35,000	80,000	.31
37	53	.37	10,000	110,000	.31
38	54	.64	10,000	110,000	.31
39	55	.66	35,000	110,000	.31
40	56	.84	35,000	110,000	.31

TECS in the throttle configuration was designed to satisfy the following frequency domain requirements:

(1) Elevator command crossover frequency between 5 and 10 rad/s.

(2) Inner/outer loop decoupling by a factor of 10 separation in the crossover frequencies maintained between elevator loop and pitch and throttle loops, (i.e., crossover frequency in pitch and throttle loops not greater than .5 - 1 rad/s).

(3) To achieve a 12.5 sec time constant response with both speed and altitude error loop having crossovers around .08 rad/s

(4) Throttle loop crossover frequency significantly lower (5-10 times) than engine bandwidth.

In selecting the spoiler configuration of the TECS control law the same requirements were followed. Since spoilers are used as reverse thrust, the throttle loop crossover requirements were applied to the spoiler loop crossover to maintain it between .07 and .2 rad/sec.

Pages 55 - 62 present the results of the linear analysis of the automatic spoilers for the nominal flight condition. Due to high inner loop gains (elevator command crossover at 7.2 rad/s) short period damping is .46. The pitch loop crossover is at .6 rad/s which is more than a factor of 10 slower than elevator loop. Spoiler loop crossover is at .2 rad/s consistent with requirements. Both altitude and speed error loops have crossovers at .071 and .076 rad/s, respectively, which are reasonably close to the required .08 rad/sec. All loops show good stability margins. Pages 58 - 63 contain plots of the frequency responses of each loop. Pages 63 - 72 are print outs of the eigenvalues and stability margins of the automatic spoilers for the remaining flight conditions.

Flight conditions 31, 35 and 29 have lower phase margins in the elevator loop, around 38°. Flight conditions 32, 35 and 40 indicate low damping in the complex integrator pair (between .43 and .48), and condition 36 displays low damping of the phugoid mode. All these cases are for flight conditions derived by trimming the airplane at zero spoiler setting. Similar behavior was noticed for the airplane trimmed at a spoiler setting of 30°.

The flight conditions described were tested on the non-linear simulation. The airplane was trimmed at a given condition and was made to track a precomputed 4D profile. At 200 seconds into the flight the airplane was subjected to a tail wind shearing from 0 up to 50 knots in 50 seconds. The following variables were plotted on pages 126 through 142:

altitude profile, altitude
ground speed profile, ground speed
spoiler
energy integrator, energy integrator throttle limit
vertical acceleration (NZCG)
elevator position
horizontal wind profile

If there are two variables on one plot, the second variable is plotted using dashed lines.

For flight conditions 31, 32, 39 and 40, the airplane shows sluggishness in tracking of speed profile, while spoilers do not attain their maximum value. This behavior is attributed to the fact that the combination of commanded slow down in speed, tail wind shear and heavy weight make the aircraft pitch up, invoking the alpha protection mode, which limits the rate at which speed can be bled off.

The remaining flight conditions exhibit excellent profile tracking by the aircraft in the presence of a substantial tail wind.

The remainder of the linear analyses were done for manual spoiler and speed on elevator modes of TECS for nominal flight conditions. These results can be found on pages 143 through 153. There are no surprises, proving that manual spoilers as an alternative to automatic spoilers can be easily implemented.

The speed on elevator mode is identical to the one in the throttle configuration of TECS and, hence, was thoroughly investigated before. Linear analysis and limiting cases on the non-linear simulation show that it functions just as well in the spoiler configuration.

The nonlinear simulation results for nulling an initial distance/time error are shown on pages 154 through 161. Four test conditions are presented with initial distance/time errors of: 50,000 ft/73.6 sec, - 50,000 ft/-73.6 sec, 100,000 ft/147.2 sec, and -100,00 ft/-147.2 sec.

The airplane tracks the generated ground speed profiles accurately. With the exception of minor overshoot/undershoot, the flight path acceleration (i.e., UDOT) does not exceed the specified .5 feet per second squared limit.

For the first two test conditions, no airspeed limiting occurs and no TOD arrival time error is predicted (TOD TIME ERR is the annotation used). The time error should null parabolically during the acceleration and deceleration portions, and linearly during the constant cruise portion. This is confirmed by the plot variable TIMERR.

The ground speed profile for the second flight condition (page 156) exemplifies an inherent drawback to using only the cruise protion of flight to null out the time error, and ignoring the descent profile. The nulling algorithm is constrained to meet the TOD ground speed of the 4D profile. This results in an unnecessary speed up/slow down maneuver in which the nulling profile forces the aircraft to speed up from 625 fps (at 930 sec) to 679 fps (at TOD) with the 4D profile immediately forcing it to slow down to 637 fps (at 1200 sec).

In the third test condition, airspeed limiting occurs and an estimated TOD arrival error (TOD TIMERR) of 45 seconds is generated. This value is confirmed by the actual time error plot (TIMERR).

The ground speed necessary to null out the time error for the fourth case results in angle of attack limiting. SWAOA is set (page 161) by leaving a 21 second TOD time error by which the correct ground speed at TOD is achieved.

12.0 CONCLUSIONS

The integration of the 4D profile generator with TECS has been developed and evaluated in detail. The feasability of 4D-TECS integration has been demonstrated by meeting all design objectives in such a way as to minimize the volume of interface and mode switching logic.

The design created a 4D mode in TECS, which includes the following features:

(1) Altitude and speed profile command processors to smooth out 4D commands according to available airplane bandwidth and passenger comfort requirements.

(2) Spoiler integration into TECS during 4D descent.

(3) Time error nulling algorithm to eliminate time error by top-of-descent.

(4) Mode switching logic to allow for smooth integration of 4D mode into the overall TECS structure.

APPENDIX A: LINEAR ANALYSIS OF TECS - AUTOMATIC SPOILER


```
----------------------------------------------------------------------
NOMINAL FLIGHT CONDITION USED FOR LINEAR ANALYSIS OF TECS
IN SPOILER CONFIGURATION
----------------------------------------------------------------------

  MACH              0.4848800
  FLAPS             0.0
  H                 15000.00
  GAMMAD           -4.943000
  VTAS              512.6700
  VCAS              244.0000
  CG                0.2
  WEIGHT            84645.00
  ALFA              4.335100
  Q                 208.5100
  SPOILERS          20.00
```

TECS IN AUTOMATIC SPOILER CONFIGURATION
STABILITY MARGINS
NOMINAL FLIGHT CONDITION

******** EIGENVALUES OF CLOSED-LOOP SYSTEM **********

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9901E-03	0.0000	1.000	9.9901E-03	1.5900E-03
2	-2.5208E-02	0.0000	1.000	2.5208E-02	4.0121E-03
3	-2.5243E-02	0.0000	1.000	2.5243E-02	4.0176E-03
4	-0.1011	0.0000	1.000	0.1011	1.6088E-02
5	-8.4285E-02	7.4458E-02	0.7494	0.1125	1.7899E-02
6	-8.4285E-02	-7.4458E-02	0.7494	0.1125	1.7899E-02
7	-0.5000	0.0000	1.000	0.5000	7.9577E-02
8	-0.4919	0.3514	0.8137	0.6045	9.6216E-02
9	-0.4919	-0.3514	0.8137	0.6045	9.6216E-02
10	-2.630	0.0000	1.000	2.630	0.4186
11	-4.452	8.535	0.4624	9.627	1.532
12	-4.452	-8.535	0.4624	9.627	1.532
13	-13.70	0.0000	1.000	13.70	2.180
14	-15.33	0.0000	1.000	15.33	2.440
15	-35.06	0.0000	1.000	35.06	5.579

== PITCH LOOP GAIN MARGIN ==

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	DB
1	7.189	0.1412	17.00

== PITCH LOOP PHASE MARGIN ==

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6686	-106.5	73.49

== SPOILER LOOP GAIN MARGIN ==

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

== SPOILER LOOP PHASE MARGIN ==

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.2042	-96.79	83.21

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ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	DB
1	0.5484	0.8469E-01	21.44
2	16.79	0.8876E-06	121.0

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7680E-01	-108.7	71.34

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	DB
1	4.732	0.3314E-02	49.59

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7134E-01	-105.2	74.76

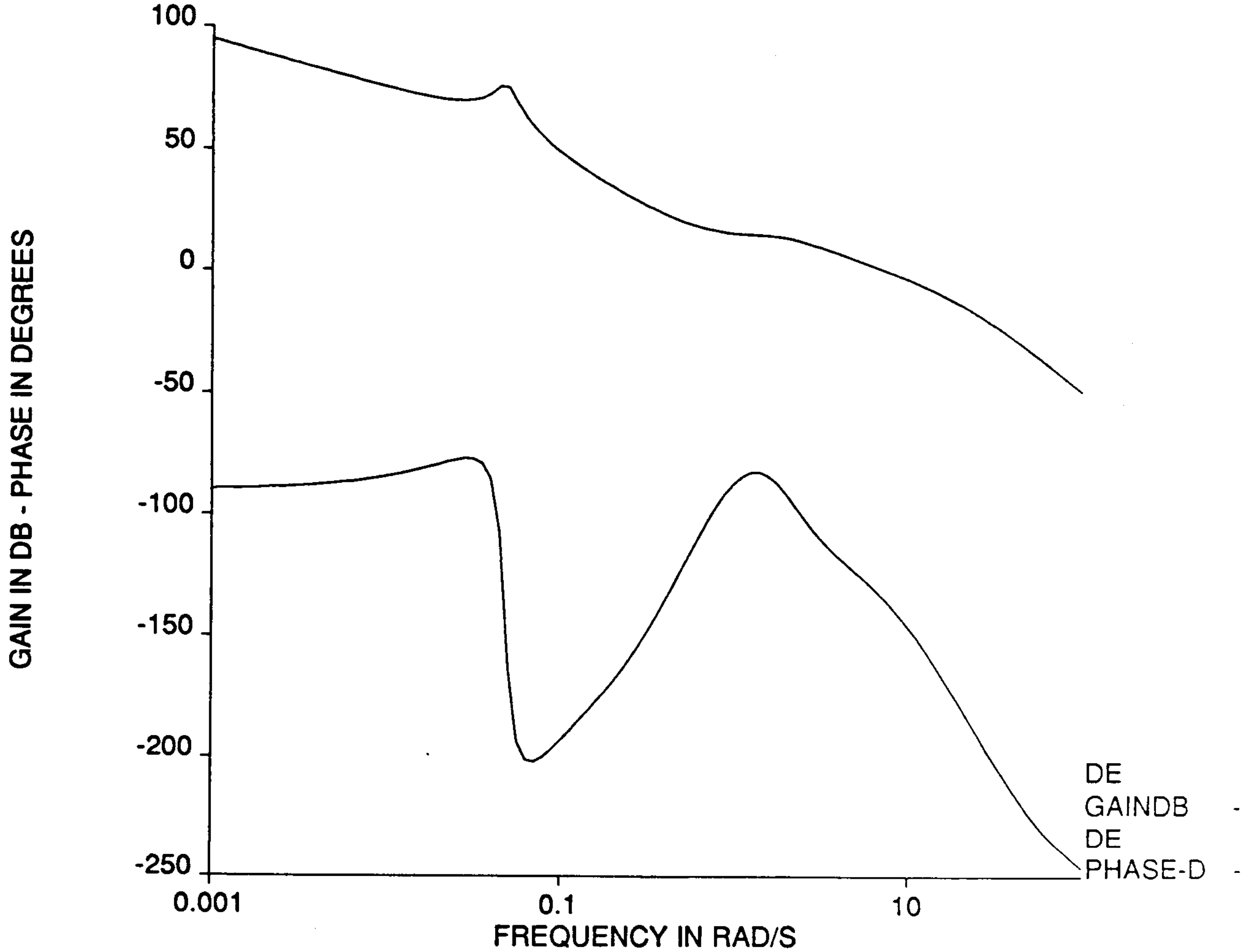
ELEVATOR LOOP GAIN MARGIN

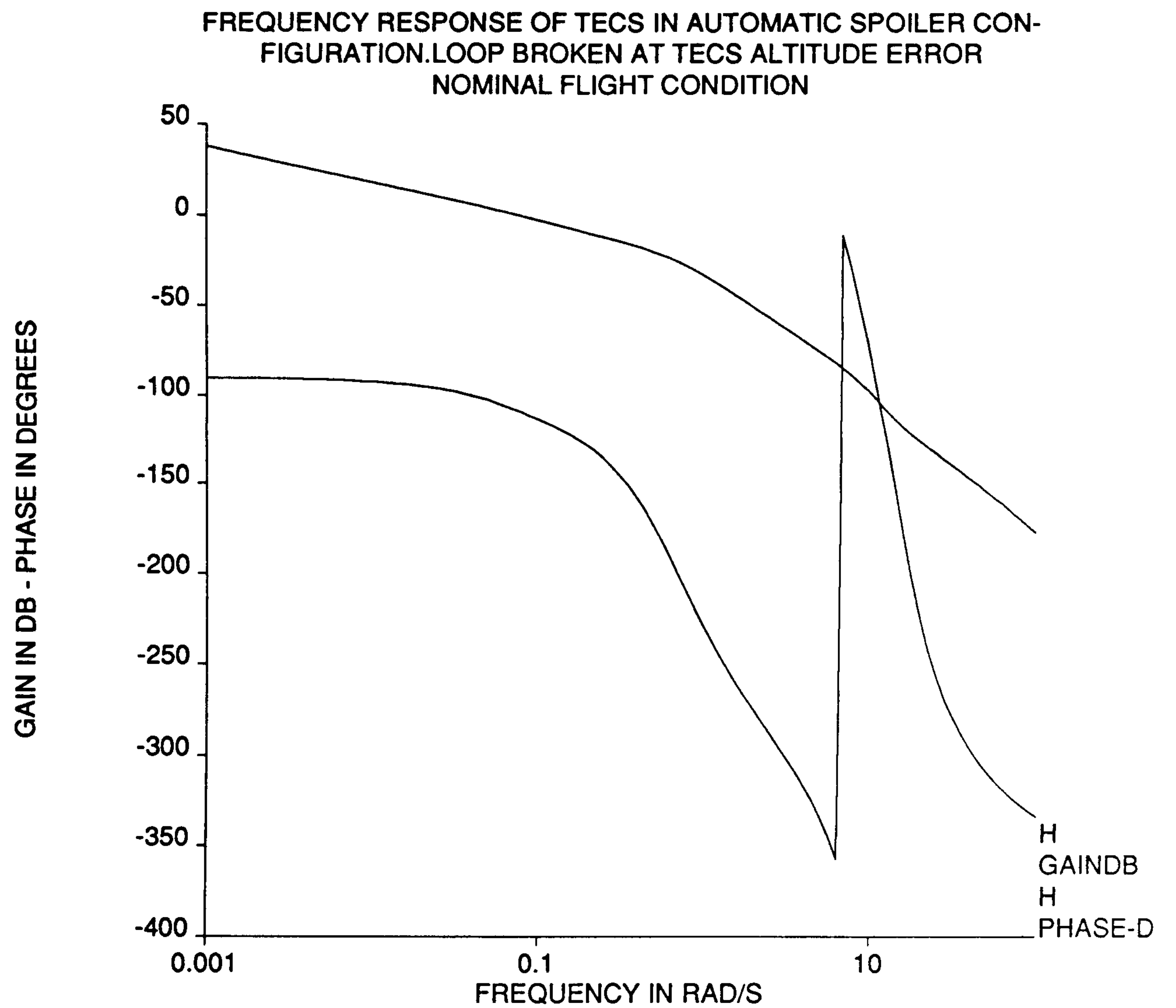
NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	DB
1	0.5254E-01	4292.	-72.65
2	0.1471	104.4	-40.38
3	20.50	0.1899	14.43

ELEVATOR LOOP PHASE MARGIN

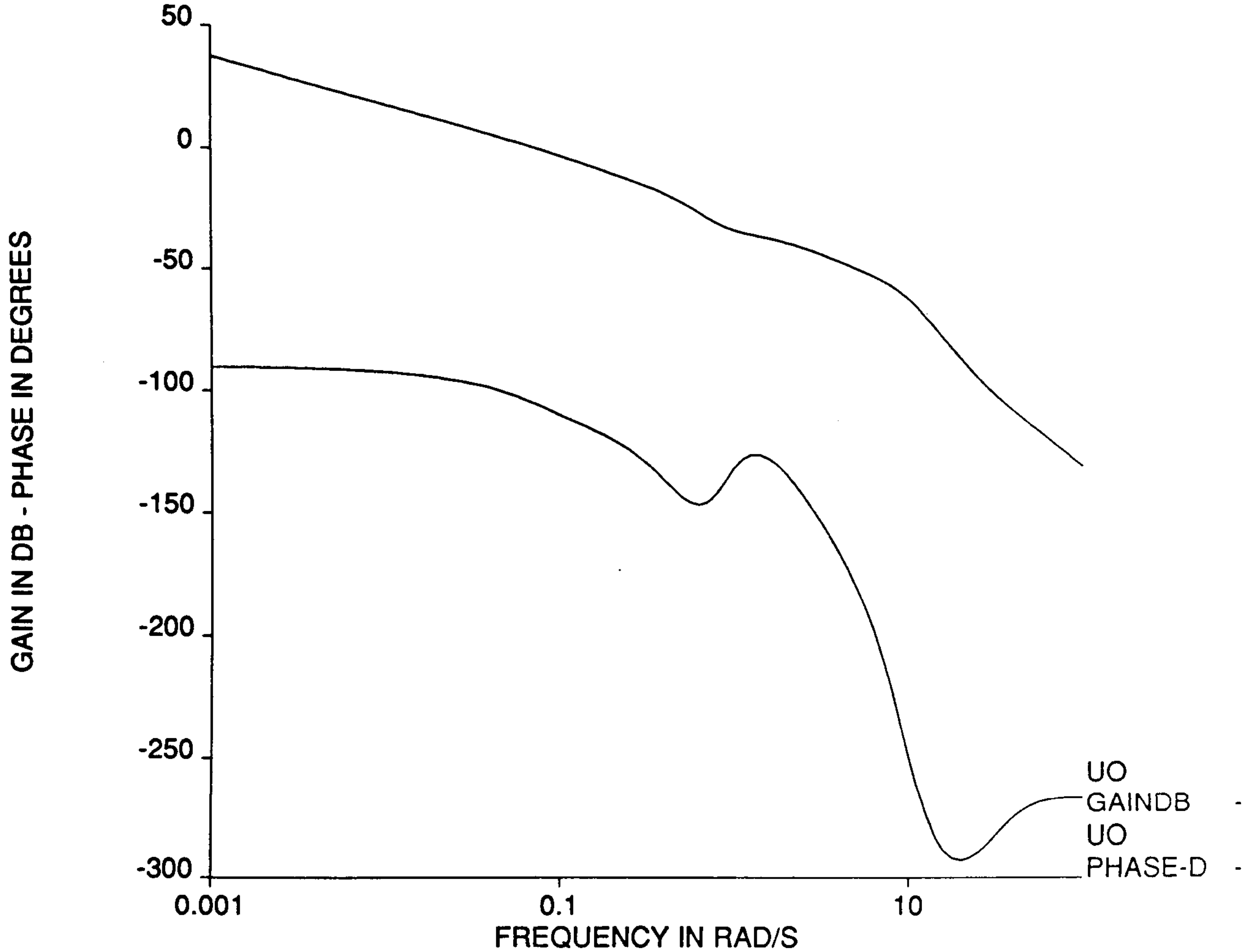
NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	7.283	-134.1	45.86

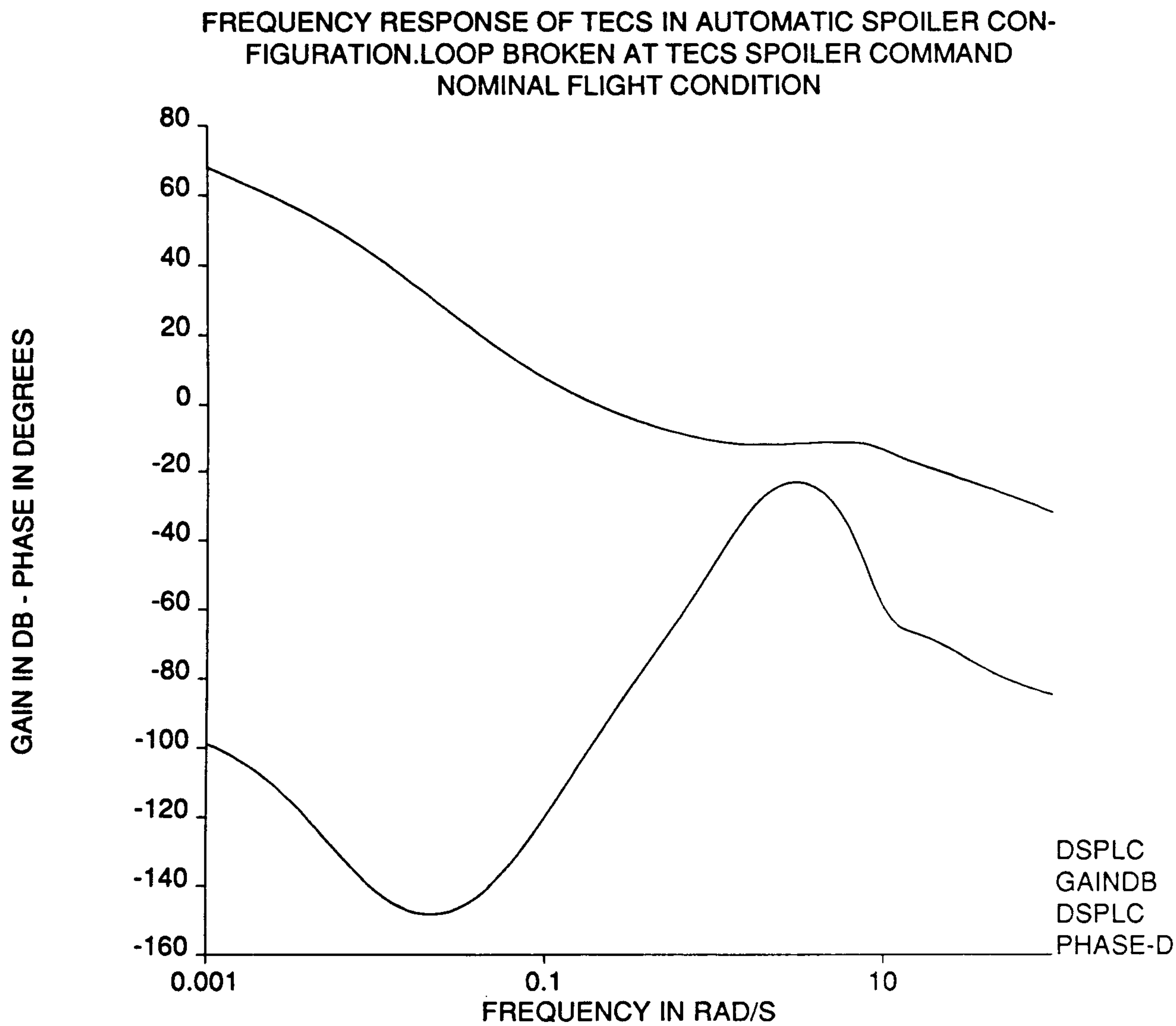
FREQUENCY RESPONSE OF TECS IN AUTOMATIC SPOILER CONFIGURATION.LOOP BROKEN AT TECS ELEVATOR COMMAND
NOMINAL FLIGHT CONDITION



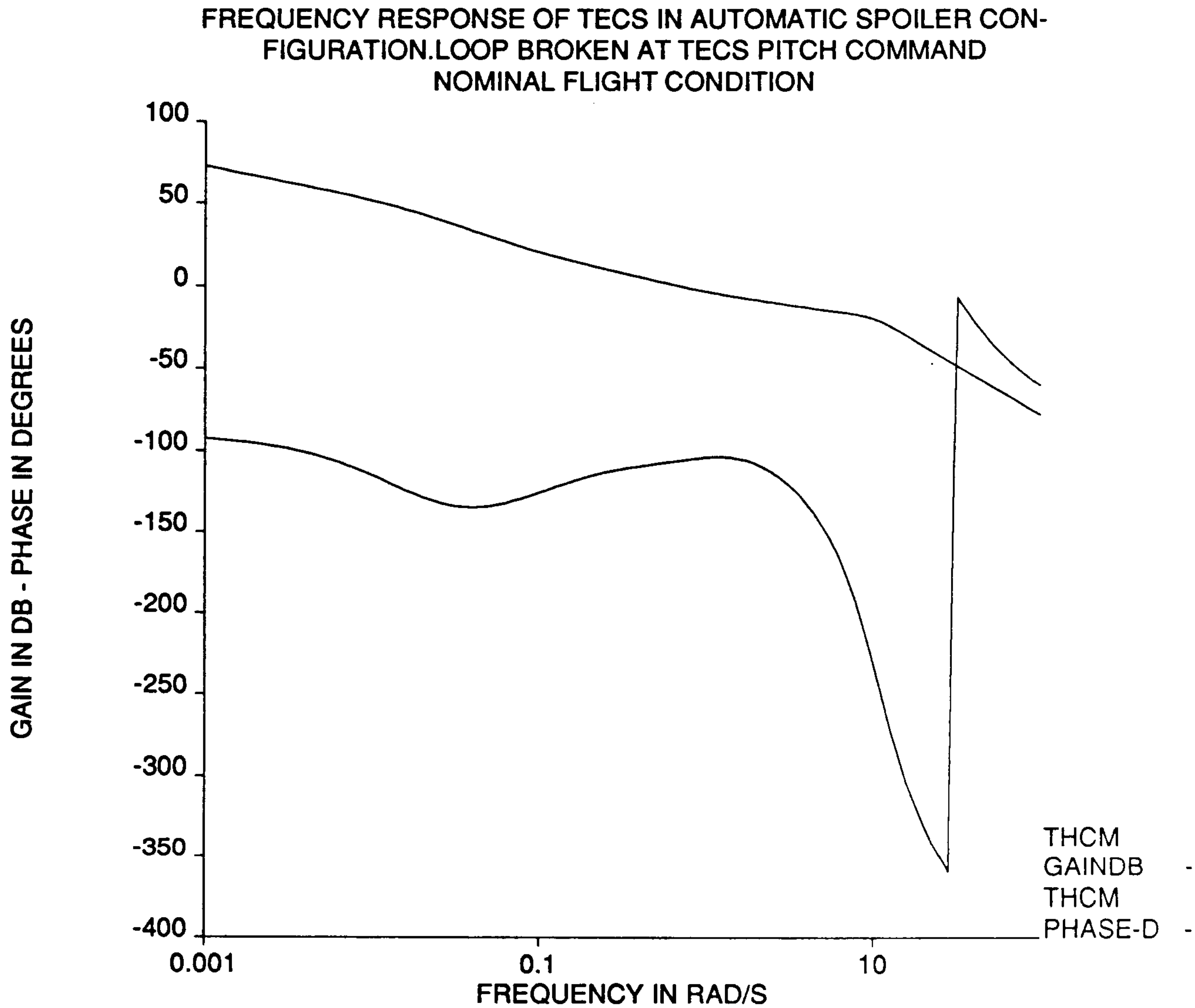

FREQUENCY RESPONSE OF TECS IN AUTOMATIC SPOILER CON-
FIGURATION.LOOP BROKEN AT TECS ALTITUDE ERROR
NOMINAL FLIGHT CONDITION
GAIN IN DB - PHASE IN DEGREES
50
0
-50
-100
-150
-200
-250
-300
-350
-400
0.001
0.1
10
FREQUENCY IN RAD/S
H
GAINDB -
H
PHASE-D -

FREQUENCY RESPONSE OF TECS IN AUTOMATIC SPOILER CON-
FIGURATION.LOOP BROKEN AT TECS SPEED ERROR
NOMINAL FLIGHT CONDITION





FREQUENCY RESPONSE OF TECS IN AUTOMATIC SPOILER CON-
FIGURATION.LOOP BROKEN AT TECS SPOILER COMMAND
NOMINAL FLIGHT CONDITION
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
GAIN IN DB - PHASE IN DEGREES
0.001
0.1
10
FREQUENCY IN RAD/S
DSPLC
GAINDB
DSPLC
PHASE-D



FREQUENCY RESPONSE OF TECS IN AUTOMATIC SPOILER CON-
FIGURATION.LOOP BROKEN AT TECS PITCH COMMAND
NOMINAL FLIGHT CONDITION
GAIN IN DB - PHASE IN DEGREES
100
50
0
-50
-100
-150
-200
-250
-300
-350
-400
0.001
0.1
10
FREQUENCY IN RAD/S
THCM
GAINDB -
THCM
PHASE-D -

APPENDIX B: TECS EXTREME FLIGHT CONDITIONS LINEAR ANALYSIS

:	COND	25
:	SPOILERS	0
:	MACH	0.4848800
:	H	15000.00
:	GAMMAD	-4.937700
:	VCAS	244.0000
:	CG	0.1500000
:	WEIGHT	84645.00
:	ALFA	4.402500
:	Q	208.5100

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9901E-03	0.0000	1.000	9.9901E-03	1.5900E-03
2	-2.5208E-02	0.0000	1.000	2.5208E-02	4.0121E-03
3	-2.5243E-02	0.0000	1.000	2.5243E-02	4.0176E-03
4	-0.1008	0.0000	1.000	0.1008	1.6039E-02
5	-8.3931E-02	7.4381E-02	0.7484	0.1121	1.7849E-02
6	-8.3931E-02	-7.4381E-02	0.7484	0.1121	1.7849E-02
7	-0.5000	0.0000	1.000	0.5000	7.9577E-02
8	-0.4633	0.3613	0.7886	0.5876	9.3513E-02
9	-0.4633	-0.3613	0.7886	0.5876	9.3513E-02
10	-2.708	0.0000	1.000	2.708	0.4310
11	-4.442	8.733	0.4533	9.798	1.559
12	-4.442	-8.733	0.4533	9.798	1.559
13	-13.70	0.0000	1.000	13.70	2.180
14	-15.33	0.0000	1.000	15.33	2.440
15	-35.11	0.0000	1.000	35.11	5.589

========== PITCH LOOP GAIN MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	7.332	0.1385	17.17

========== PITCH LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6516	-107.3	72.68

========== SPOILER LOOP GAIN MARGIN ==========

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

========== SPOILER LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.2038	-96.70	83.30

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.5405	0.8719E-01	21.19
2	16.79	0.8953E-06	121.0

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7680E-01	-108.7	71.30

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	5.309	0.2780E-02	51.12

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7129E-01	-105.2	74.76

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.5778E-01	3007.	-69.56
2	0.1495	90.47	-39.13
3	20.57	0.1921	14.33

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	7.422	-133.7	46.27

:	COND	26
:	SPOILERS	0
:	MACH	0.4848800
:	H	15000.00
:	GAMMAD	-4.942500
:	VCAS	244.0000
:	CG	0.2000000
:	WEIGHT	84645.00
:	ALFA	4.335000
:	Q	208.5100

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9901E-03	0.0000	1.000	9.9901E-03	1.5900E-03
2	-2.5208E-02	0.0000	1.000	2.5208E-02	4.0121E-03
3	-2.5243E-02	0.0000	1.000	2.5243E-02	4.0176E-03
4	-0.1011	0.0000	1.000	0.1011	1.6088E-02
5	-8.4289E-02	7.4465E-02	0.7494	0.1125	1.7900E-02
6	-8.4289E-02	-7.4465E-02	0.7494	0.1125	1.7900E-02
7	-0.5000	0.0000	1.000	0.5000	7.9577E-02
8	-0.4919	0.3514	0.8137	0.6045	9.6209E-02
9	-0.4919	-0.3514	0.8137	0.6045	9.6209E-02
10	-2.629	0.0000	1.000	2.629	0.4185
11	-4.452	8.537	0.4624	9.628	1.532
12	-4.452	-8.537	0.4624	9.628	1.532
13	-13.70	0.0000	1.000	13.70	2.180
14	-15.33	0.0000	1.000	15.33	2.440
15	-35.06	0.0000	1.000	35.06	5.579

========== PITCH LOOP GAIN MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	7.189	0.1411	17.01

========== PITCH LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6686	-106.5	73.48

========== SPOILER LOOP GAIN MARGIN ==========

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

========== SPOILER LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.2041	-96.82	83.18

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.5484	0.8466E-01	21.45
2	16.79	0.8874E-06	121.0

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7680E-01	-108.7	71.33

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	4.732	0.3315E-02	49.59

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7137E-01	-105.2	74.76

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.5209E-01	4389.	-72.85
2	0.1468	104.6	-40.39
3	20.50	0.1900	14.43

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	7.283	-134.1	45.87

:	COND	27
:	SPOILERS	0
:	MACH	0.4848800
:	H	15000.00
:	GAMMAD	-4.947200
:	VCAS	244.0000
:	CG	0.2500000
:	WEIGHT	84645.00
:	ALFA	4.267600
:	Q	208.5100

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9901E-03	0.0000	1.000	9.9901E-03	1.5900E-03
2	-2.5208E-02	0.0000	1.000	2.5208E-02	4.0121E-03
3	-2.5243E-02	0.0000	1.000	2.5243E-02	4.0175E-03
4	-0.1014	0.0000	1.000	0.1014	1.6135E-02
5	-8.4514E-02	7.4553E-02	0.7499	0.1127	1.7936E-02
6	-8.4514E-02	-7.4553E-02	0.7499	0.1127	1.7936E-02
7	-0.5000	0.0000	1.000	0.5000	7.9577E-02
8	-0.5268	0.3366	0.8427	0.6251	9.9488E-02
9	-0.5268	-0.3366	0.8427	0.6251	9.9488E-02
10	-2.529	0.0000	1.000	2.529	0.4025
11	-4.467	8.361	0.4712	9.479	1.509
12	-4.467	-8.361	0.4712	9.479	1.509
13	-13.70	0.0000	1.000	13.70	2.180
14	-15.33	0.0000	1.000	15.33	2.440
15	-35.01	0.0000	1.000	35.01	5.572

========== PITCH LOOP GAIN MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	7.041	0.1440	16.83

========== PITCH LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6888	-105.7	74.31

========== SPOILER LOOP GAIN MARGIN ==========

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

========== SPOILER LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.2043	-96.92	83.08

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.5583	0.8172E-01	21.75
2	16.79	0.8781E-06	121.1

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7680E-01	-108.6	71.36

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	4.732	0.3307E-02	49.61

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7142E-01	-105.3	74.74

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.4515E-01	6908.	-76.79
2	0.1429	125.7	-41.98
3	20.46	0.1877	14.53

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	7.155	-134.5	45.47

:	COND	28
:	SPOILERS	0
:	MACH	0.4848800
:	H	15000.00
:	GAMMAD	-4.953000
:	VCAS	244.0000
:	CG	0.3100000
:	WEIGHT	84645.00
:	ALFA	4.186600
:	Q	208.5100

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9901E-03	0.0000	1.000	9.9901E-03	1.5900E-03
2	-2.5208E-02	0.0000	1.000	2.5208E-02	4.0121E-03
3	-2.5243E-02	0.0000	1.000	2.5243E-02	4.0175E-03
4	-0.1017	0.0000	1.000	0.1017	1.6187E-02
5	-8.5283E-02	7.4711E-02	0.7522	0.1134	1.8045E-02
6	-8.5283E-02	-7.4711E-02	0.7522	0.1134	1.8045E-02
7	-0.5000	0.0000	1.000	0.5000	7.9577E-02
8	-0.5787	0.3067	0.8836	0.6549	0.1042
9	-0.5787	-0.3067	0.8836	0.6549	0.1042
10	-2.395	0.0000	1.000	2.395	0.3812
11	-4.482	8.111	0.4836	9.267	1.475
12	-4.482	-8.111	0.4836	9.267	1.475
13	-13.70	0.0000	1.000	13.70	2.180
14	-15.34	0.0000	1.000	15.34	2.441
15	-34.94	0.0000	1.000	34.94	5.561

PITCH LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	6.866	0.1482	16.58

PITCH LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7168	-104.7	75.33

SPOILER LOOP GAIN MARGIN

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

SPOILER LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.2056	-97.00	83.00

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.5746	0.7722E-01	22.25
2	16.79	0.8677E-06	121.2

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7680E-01	-108.6	71.42

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	4.732	0.3302E-02	49.62

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7158E-01	-105.2	74.80

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.3118E-01	0.1865E+05	-85.41
2	0.1359	164.9	-44.34
3	20.31	0.1861	14.61

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	6.980	-135.1	44.91

:	COND	29
:	SPOILERS	0
:	MACH	0.3699900
:	H	10000.00
:	GAMMAD	-3.635800
:	VCAS	204.0100
:	CG	5.000000
:	WEIGHT	110000.0
:	ALFA	7.835600
:	Q	144.3000

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9902E-03	0.0000	1.000	9.9902E-03	1.5900E-03
2	-3.3999E-02	0.0000	1.000	3.3999E-02	5.4111E-03
3	-3.4037E-02	0.0000	1.000	3.4037E-02	5.4172E-03
4	-3.4842E-02	6.0835E-02	0.4970	7.0106E-02	1.1158E-02
5	-3.4842E-02	-6.0835E-02	0.4970	7.0106E-02	1.1158E-02
6	-9.8946E-02	0.0000	1.000	9.8946E-02	1.5748E-02
7	-0.2986	0.3553	0.6435	0.4641	7.3865E-02
8	-0.2986	-0.3553	0.6435	0.4641	7.3865E-02
9	-0.5000	0.0000	1.000	0.5000	7.9577E-02
10	-3.526	0.0000	1.000	3.526	0.5613
11	-4.037	8.850	0.4150	9.727	1.548
12	-4.037	-8.850	0.4150	9.727	1.548
13	-13.66	0.0000	1.000	13.66	2.174
14	-13.70	0.0000	1.000	13.70	2.180
15	-35.41	0.0000	1.000	35.41	5.635

========== PITCH LOOP GAIN MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	8.044	0.1715	15.31

========== PITCH LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.5663	-104.0	75.99

========== SPOILER LOOP GAIN MARGIN ==========

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

========== SPOILER LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.9218E-01	-120.9	59.14

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.4647	0.1033	19.72
2	18.84	0.8974E-06	120.9

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6485E-01	-115.8	64.22

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	5.309	0.3625E-02	48.81

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.5954E-01	-117.8	62.24

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	19.85	0.2171	13.27

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	7.791	-139.0	40.99

:	COND	30
:	SPOILERS	0
:	MACH	0.6399900
:	H	10000.00
:	GAMMAD	-5.280700
:	VCAS	356.2600
:	CG	5.000000
:	WEIGHT	110000.0
:	ALFA	1.710600
:	Q	461.7600

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9901E-03	0.0000	1.000	9.9901E-03	1.5900E-03
2	-3.3999E-02	0.0000	1.000	3.3999E-02	5.4111E-03
3	-3.4196E-02	0.0000	1.000	3.4196E-02	5.4425E-03
4	-3.2141E-02	6.0474E-02	0.4693	6.8485E-02	1.0900E-02
5	-3.2141E-02	-6.0474E-02	0.4693	6.8485E-02	1.0900E-02
6	-9.9887E-02	0.0000	1.000	9.9887E-02	1.5898E-02
7	-0.5000	0.0000	1.000	0.5000	7.9577E-02
8	-0.3719	0.3913	0.6889	0.5399	8.5928E-02
9	-0.3719	-0.3913	0.6889	0.5399	8.5928E-02
10	-3.089	0.0000	1.000	3.089	0.4916
11	-4.915	8.094	0.5190	9.469	1.507
12	-4.915	-8.094	0.5190	9.469	1.507
13	-13.70	0.0000	1.000	13.70	2.180
14	-13.91	0.0000	1.000	13.91	2.214
15	-34.54	0.0000	1.000	34.54	5.497

========== PITCH LOOP GAIN MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	6.287	0.8345E-01	21.57

========== PITCH LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.5667	-120.0	60.04

========== SPOILER LOOP GAIN MARGIN ==========

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

========== SPOILER LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.8235E-01	-128.3	51.75

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.5021	0.8404E-01	21.51
2	16.79	0.5563E-06	125.1

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6176E-01	-119.6	60.42

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.7182	0.2681E-01	31.43
2	0.9441	0.1142E-01	38.85
3	4.732	0.1368E-02	57.28

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.5737E-01	-117.6	62.36

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.6455E-01	2303.	-67.25
2	0.1722	27.40	-28.76
3	21.67	0.1446	16.79

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	6.764	-120.2	59.83

:	COND	31
:	SPOILERS	0
:	MACH	0.6599900
:	H	35000.00
:	GAMMAD	-3.119600
:	VCAS	220.5100
:	CG	5.000000
:	WEIGHT	110000.0
:	ALFA	6.091100
:	Q	169.2500

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9902E-03	0.0000	1.000	9.9902E-03	1.5900E-03
2	-2.0000E-02	0.0000	1.000	2.0000E-02	3.1831E-03
3	-2.0067E-02	0.0000	1.000	2.0067E-02	3.1938E-03
4	-2.9064E-02	4.8488E-02	0.5141	5.6531E-02	8.9972E-03
5	-2.9064E-02	-4.8488E-02	0.5141	5.6531E-02	8.9972E-03
6	-9.6061E-02	0.0000	1.000	9.6061E-02	1.5289E-02
7	-0.1747	0.3417	0.4553	0.3838	6.1079E-02
8	-0.1747	-0.3417	0.4553	0.3838	6.1079E-02
9	-0.5000	0.0000	1.000	0.5000	7.9577E-02
10	-5.012	0.0000	1.000	5.012	0.7976
11	-3.713	7.768	0.4313	8.610	1.370
12	-3.713	-7.768	0.4313	8.610	1.370
13	-13.14	0.0000	1.000	13.14	2.091
14	-13.70	0.0000	1.000	13.70	2.180
15	-34.89	0.0000	1.000	34.89	5.553

========== PITCH LOOP GAIN MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	7.760	0.2014	13.92

========== PITCH LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.4327	-114.4	65.58

========== SPOILER LOOP GAIN MARGIN ==========

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

========== SPOILER LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7462E-01	-114.7	65.33

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.4032	0.1548	16.21
2	18.84	0.4362E-06	127.2

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6027E-01	-110.8	69.21

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	5.309	0.4750E-02	46.47

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.5050E-01	-116.8	63.16

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.1827	32.05	-30.12
2	19.74	0.1958	14.16

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	7.308	-141.2	38.75

:	COND	32
:	SPOILERS	0
:	MACH	0.8399900
:	H	35000.00
:	GAMMAD	-12.73700
:	VCAS	287.2200
:	CG	5.000000
:	WEIGHT	110000.0
:	ALFA	3.530000
:	Q	292.7100

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9892E-03	0.0000	1.000	9.9892E-03	1.5898E-03
2	-2.0000E-02	0.0000	1.000	2.0000E-02	3.1831E-03
3	-2.0552E-02	0.0000	1.000	2.0552E-02	3.2709E-03
4	-5.9815E-02	0.0000	1.000	5.9815E-02	9.5199E-03
5	-0.1097	0.0000	1.000	0.1097	1.7458E-02
6	-5.4559E-02	9.6962E-02	0.4904	0.1113	1.7707E-02
7	-5.4559E-02	-9.6962E-02	0.4904	0.1113	1.7707E-02
8	-0.5000	0.0000	1.000	0.5000	7.9577E-02
9	-2.203	1.110	0.8930	2.467	0.3926
10	-2.203	-1.110	0.8930	2.467	0.3926
11	-4.796	6.045	0.6216	7.717	1.228
12	-4.796	-6.045	0.6216	7.717	1.228
13	-11.97	0.0000	1.000	11.97	1.905
14	-13.70	0.0000	1.000	13.70	2.180
15	-34.16	0.0000	1.000	34.16	5.437

PITCH LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	5.538	0.2420	12.32

PITCH LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	1.299	-104.9	75.07

SPOILER LOOP GAIN MARGIN

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

SPOILER LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.9021E-01	-118.5	61.50

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.2890	0.1026	19.78
2	18.84	0.3339E-06	129.5

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7352E-01	-124.5	55.55

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	2.901	0.1327E-01	37.54

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.4224E-01	-101.1	78.91

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.7848E-01	32.62	-30.27
2	21.29	0.1361	17.32

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	6.042	-131.2	48.82

:	COND	33
:	SPOILERS	0
:	MACH	0.3099900
:	H	10000.00
:	GAMMAD	-3.236600
:	VCAS	170.6700
:	CG	0.3100000
:	WEIGHT	80000.00
:	ALFA	7.445100
:	Q	100.2700

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9902E-03	0.0000	1.000	9.9902E-03	1.5900E-03
2	-3.3999E-02	0.0000	1.000	3.3999E-02	5.4111E-03
3	-3.4134E-02	0.0000	1.000	3.4134E-02	5.4326E-03
4	-3.0355E-02	5.5920E-02	0.4771	6.3628E-02	1.0127E-02
5	-3.0355E-02	-5.5920E-02	0.4771	6.3628E-02	1.0127E-02
6	-9.8209E-02	0.0000	1.000	9.8209E-02	1.5631E-02
7	-0.5000	0.0000	1.000	0.5000	7.9577E-02
8	-0.4271	0.3840	0.7436	0.5743	9.1402E-02
9	-0.4271	-0.3840	0.7436	0.5743	9.1402E-02
10	-3.485	0.0000	1.000	3.485	0.5546
11	-4.184	6.186	0.5603	7.468	1.189
12	-4.184	-6.186	0.5603	7.468	1.189
13	-13.70	0.0000	1.000	13.70	2.180
14	-14.06	0.0000	1.000	14.06	2.238
15	-34.28	0.0000	1.000	34.28	5.455

PITCH LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	6.287	0.1814	14.83

PITCH LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6621	-104.0	76.01

SPOILER LOOP GAIN MARGIN

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

SPOILER LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7997E-01	-123.3	56.70

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.5444	0.8151E-01	21.78
2	18.84	0.9497E-06	120.4

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6121E-01	-115.5	64.51

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	4.732	0.3821E-02	48.36

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.5502E-01	-119.2	60.80

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	18.97	0.1687	15.46

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	5.901	-137.0	43.03

:	COND	34
:	SPOILERS	0
:	MACH	0.6399900
:	H	10000.00
:	GAMMAD	-6.897500
:	VCAS	356.2600
:	CG	0.3100000
:	WEIGHT	80000.00
:	ALFA	0.6808400
:	Q	461.7600

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9900E-03	0.0000	1.000	9.9900E-03	1.5900E-03
2	-3.3999E-02	0.0000	1.000	3.3999E-02	5.4111E-03
3	-3.4279E-02	0.0000	1.000	3.4279E-02	5.4557E-03
4	-3.3536E-02	6.0891E-02	0.4824	6.9515E-02	1.1064E-02
5	-3.3536E-02	-6.0891E-02	0.4824	6.9515E-02	1.1064E-02
6	-0.1020	0.0000	1.000	0.1020	1.6236E-02
7	-0.4688	0.0000	1.000	0.4688	7.4612E-02
8	-0.5000	0.0000	1.000	0.5000	7.9577E-02
9	-1.240	1.102	0.7477	1.659	0.2640
10	-1.240	-1.102	0.7477	1.659	0.2640
11	-5.402	7.609	0.5789	9.331	1.485
12	-5.402	-7.609	0.5789	9.331	1.485
13	-13.70	0.0000	1.000	13.70	2.180
14	-14.07	0.0000	1.000	14.07	2.239
15	-34.42	0.0000	1.000	34.42	5.479

========== PITCH LOOP GAIN MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	4.213	0.1484	16.57

========== PITCH LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.8242	-112.6	67.40

========== SPOILER LOOP GAIN MARGIN ==========

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

========== SPOILER LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.8292E-01	-127.5	52.49

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.6541	0.4926E-01	26.15
2	18.84	0.4976E-06	126.1

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6187E-01	-119.6	60.36

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.8660	0.2564E-01	31.82

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.5720E-01	-116.1	63.90

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.6984E-01	1530.	-63.70
2	0.1836	72.03	-37.15
3	21.60	0.1392	17.13

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	5.891	-120.3	59.68

:	COND	35
:	SPOILERS	0
:	MACH	0.5499900
:	H	35000.00
:	GAMMAD	-2.466500
:	VCAS	181.5900
:	CG	0.3100000
:	WEIGHT	80000.00
:	ALFA	6.387800
:	Q	113.7600

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9902E-03	0.0000	1.000	9.9902E-03	1.5900E-03
2	-2.0000E-02	0.0000	1.000	2.0000E-02	3.1831E-03
3	-2.0016E-02	0.0000	1.000	2.0016E-02	3.1857E-03
4	-2.8720E-02	5.3570E-02	0.4725	6.0783E-02	9.6740E-03
5	-2.8720E-02	-5.3570E-02	0.4725	6.0783E-02	9.6740E-03
6	-9.9509E-02	0.0000	1.000	9.9509E-02	1.5837E-02
7	-0.2533	0.3611	0.5743	0.4411	7.0208E-02
8	-0.2533	-0.3611	0.5743	0.4411	7.0208E-02
9	-0.5000	0.0000	1.000	0.5000	7.9577E-02
10	-4.454	0.0000	1.000	4.454	0.7089
11	-3.600	6.588	0.4795	7.508	1.195
12	-3.600	-6.588	0.4795	7.508	1.195
13	-13.70	0.0000	1.000	13.70	2.180
14	-13.90	0.0000	1.000	13.90	2.212
15	-34.55	0.0000	1.000	34.55	5.498

PITCH LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	7.221	0.1946	14.22

PITCH LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.5254	-104.0	75.95

SPOILER LOOP GAIN MARGIN

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

SPOILER LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7840E-01	-121.3	58.66

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.4523	0.1171	18.63
2	18.84	0.6226E-06	124.1

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6048E-01	-114.2	65.81

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	5.158	0.4823E-02	46.33

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.5460E-01	-120.0	59.95

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.1079	598.1	-55.54
2	0.1700	122.8	-41.78
3	18.34	0.1950	14.20

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	6.391	-142.7	37.34

:	COND	36
:	SPOILERS	0
:	MACH	0.8399900
:	H	35000.00
:	GAMMAD	-10.19600
:	VCAS	287.2200
:	CG	0.3100000
:	WEIGHT	80000.00
:	ALFA	1.908600
:	Q	292.7100

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9894E-03	0.0000	1.000	9.9894E-03	1.5899E-03
2	-2.0000E-02	0.0000	1.000	2.0000E-02	3.1831E-03
3	-2.0352E-02	0.0000	1.000	2.0352E-02	3.2391E-03
4	-6.5976E-02	0.0000	1.000	6.5976E-02	1.0500E-02
5	-0.1234	0.0000	1.000	0.1234	1.9633E-02
6	-7.0930E-02	0.1089	0.5458	0.1299	2.0682E-02
7	-7.0930E-02	-0.1089	0.5458	0.1299	2.0682E-02
8	-0.5000	0.0000	1.000	0.5000	7.9577E-02
9	-1.017	2.183	0.4223	2.408	0.3833
10	-1.017	-2.183	0.4223	2.408	0.3833
11	-5.789	6.165	0.6845	8.457	1.346
12	-5.789	-6.165	0.6845	8.457	1.346
13	-12.48	0.0000	1.000	12.48	1.987
14	-13.70	0.0000	1.000	13.70	2.180
15	-34.12	0.0000	1.000	34.12	5.431

========== PITCH LOOP GAIN MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	3.988	0.3392	9.391

========== PITCH LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	1.720	-130.1	49.92

========== SPOILER LOOP GAIN MARGIN ==========

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

========== SPOILER LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.1175	-117.4	62.56

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.3731	0.7439E-01	22.57
2	18.84	0.4136E-06	127.7

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7687E-01	-119.0	60.98

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	2.354	0.2660E-01	31.50

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.4948E-01	-100.4	79.57

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.4173E-01	6981.	-76.88
2	0.8277E-01	145.6	-43.26
3	21.52	0.1285	17.82

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	5.107	-128.9	51.11

:	COND	38
:	SPOILERS	0
:	MACH	0.6399900
:	H	10000.00
:	GAMMAD	-5.280500
:	VCAS	356.2600
:	CG	0.3100000
:	WEIGHT	110000.0
:	ALFA	1.492300
:	Q	461.7600

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9901E-03	0.0000	1.000	9.9901E-03	1.5900E-03
2	-3.3999E-02	0.0000	1.000	3.3999E-02	5.4111E-03
3	-3.4192E-02	0.0000	1.000	3.4192E-02	5.4419E-03
4	-3.2524E-02	6.0947E-02	0.4708	6.9082E-02	1.0995E-02
5	-3.2524E-02	-6.0947E-02	0.4708	6.9082E-02	1.0995E-02
6	-0.1021	0.0000	1.000	0.1021	1.6250E-02
7	-0.5000	0.0000	1.000	0.5000	7.9577E-02
8	-0.8214	0.1969	0.9725	0.8446	0.1344
9	-0.8214	-0.1969	0.9725	0.8446	0.1344
10	-1.394	0.0000	1.000	1.394	0.2219
11	-5.281	7.200	0.5914	8.929	1.421
12	-5.281	-7.200	0.5914	8.929	1.421
13	-13.70	0.0000	1.000	13.70	2.180
14	-13.93	0.0000	1.000	13.93	2.218
15	-34.30	0.0000	1.000	34.30	5.459

PITCH LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	5.214	0.1047	19.60

PITCH LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7083	-114.2	65.76

SPOILER LOOP GAIN MARGIN

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

SPOILER LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.8312E-01	-128.2	51.78

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.5808	0.6368E-01	23.92
2	16.79	0.5387E-06	125.4

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6196E-01	-119.5	60.53

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	3.758	0.1882E-02	54.51

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.5779E-01	-117.6	62.39

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.7806E-01	1074.	-60.62
2	0.1828	58.56	-35.35
3	21.21	0.1390	17.14

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	5.849	-122.0	57.97

:	COND	39
:	SPOILERS	0
:	MACH	0.6599900
:	H	35000.00
:	GAMMAD	-3.119400
:	VCAS	220.5100
:	CG	0.3100000
:	WEIGHT	110000.0
:	ALFA	5.578100
:	Q	169.2500

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9902E-03	0.0000	1.000	9.9902E-03	1.5900E-03
2	-2.0000E-02	0.0000	1.000	2.0000E-02	3.1831E-03
3	-2.0100E-02	0.0000	1.000	2.0100E-02	3.1990E-03
4	-2.4672E-02	4.3127E-02	0.4966	4.9686E-02	7.9077E-03
5	-2.4672E-02	-4.3127E-02	0.4966	4.9686E-02	7.9077E-03
6	-9.7309E-02	0.0000	1.000	9.7309E-02	1.5487E-02
7	-0.2145	0.3642	0.5075	0.4226	6.7262E-02
8	-0.2145	-0.3642	0.5075	0.4226	6.7262E-02
9	-0.5000	0.0000	1.000	0.5000	7.9577E-02
10	-5.021	0.0000	1.000	5.021	0.7991
11	-3.715	6.773	0.4810	7.725	1.229
12	-3.715	-6.773	0.4810	7.725	1.229
13	-13.12	0.0000	1.000	13.12	2.088
14	-13.70	0.0000	1.000	13.70	2.180
15	-34.66	0.0000	1.000	34.66	5.516

PITCH LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	7.124	0.2070	13.68

PITCH LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.4782	-109.4	70.59

SPOILER LOOP GAIN MARGIN

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

SPOILER LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6288E-01	-117.5	62.51

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.4403	0.1334	17.50
2	16.79	0.7213E-06	122.8

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.5625E-01	-108.9	71.07

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	4.732	0.5424E-02	45.31

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.4553E-01	-117.8	62.16

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.2097	58.92	-35.40
2	19.53	0.1841	14.70

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	6.650	-142.6	37.40

:	COND	40
:	SPOILERS	0
:	MACH	0.8399900
:	H	35000.00
:	GAMMAD	-12.73700
:	VCAS	287.2200
:	CG	0.3100000
:	WEIGHT	110000.0
:	ALFA	3.188500
:	Q	292.7100

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9893E-03	0.0000	1.000	9.9893E-03	1.5898E-03
2	-2.0000E-02	0.0000	1.000	2.0000E-02	3.1831E-03
3	-2.0479E-02	0.0000	1.000	2.0479E-02	3.2594E-03
4	-6.2028E-02	0.0000	1.000	6.2028E-02	9.8721E-03
5	-0.1099	0.0000	1.000	0.1099	1.7495E-02
6	-5.5680E-02	9.9892E-02	0.4869	0.1144	1.8201E-02
7	-5.5680E-02	-9.9892E-02	0.4869	0.1144	1.8201E-02
8	-0.5000	0.0000	1.000	0.5000	7.9577E-02
9	-1.392	2.066	0.5586	2.491	0.3965
10	-1.392	-2.066	0.5586	2.491	0.3965
11	-5.693	5.200	0.7383	7.711	1.227
12	-5.693	-5.200	0.7383	7.711	1.227
13	-11.93	0.0000	1.000	11.93	1.899
14	-13.70	0.0000	1.000	13.70	2.180
15	-33.94	0.0000	1.000	33.94	5.401

========== PITCH LOOP GAIN MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	4.622	0.2983	10.51

========== PITCH LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	1.680	-123.0	56.95

========== SPOILER LOOP GAIN MARGIN ==========

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

========== SPOILER LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.9666E-01	-119.6	60.38

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.3185	0.8573E-01	21.34
2	18.84	0.3187E-06	129.9

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7470E-01	-123.5	56.45

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	2.623	0.2149E-01	33.35

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.4442E-01	-101.1	78.90

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.7545E-01	48.84	-33.78
2	21.44	0.1231	18.20

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	5.087	-132.2	47.83

:	COND	41
:	SPOILERS	30
:	MACH	0.3099900
:	H	10000.00
:	GAMMAD	-4.517800
:	VCAS	170.6700
:	CG	5.000000
:	WEIGHT	80000.00
:	ALFA	9.384800
:	Q	100.2700

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9901E-03	0.0000	1.000	9.9901E-03	1.5900E-03
2	-3.3999E-02	0.0000	1.000	3.3999E-02	5.4111E-03
3	-3.4012E-02	0.0000	1.000	3.4012E-02	5.4132E-03
4	-9.7683E-02	0.0000	1.000	9.7683E-02	1.5547E-02
5	-9.1236E-02	6.6740E-02	0.8071	0.1130	1.7991E-02
6	-9.1236E-02	-6.6740E-02	0.8071	0.1130	1.7991E-02
7	-0.5000	0.0000	1.000	0.5000	7.9577E-02
8	-0.3491	0.3761	0.6803	0.5132	8.1681E-02
9	-0.3491	-0.3761	0.6803	0.5132	8.1681E-02
10	-3.424	0.0000	1.000	3.424	0.5449
11	-4.418	7.599	0.5026	8.790	1.399
12	-4.418	-7.599	0.5026	8.790	1.399
13	-13.70	0.0000	1.000	13.70	2.180
14	-16.17	0.0000	1.000	16.17	2.574
15	-34.62	0.0000	1.000	34.62	5.510

PITCH LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	7.442	0.1705	15.36

PITCH LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6415	-101.6	78.37

SPOILER LOOP GAIN MARGIN

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

SPOILER LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.3400	-74.22	105.8

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.5304	0.1075	19.37
2	14.96	0.1312E-05	117.6

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7959E-01	-104.8	75.19

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	5.309	0.3924E-02	48.12

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7089E-01	-104.5	75.52

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	19.46	0.1789	14.95

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	6.535	-131.3	48.66

:	COND	42
:	SPOILERS	30
:	MACH	0.6399900
:	H	10000.00
:	GAMMAD	-10.90000
:	VCAS	356.2600
:	CG	5.000000
:	WEIGHT	80000.00
:	ALFA	2.659700
:	Q	461.7600

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9900E-03	0.0000	1.000	9.9900E-03	1.5900E-03
2	-3.3999E-02	0.0000	1.000	3.3999E-02	5.4111E-03
3	-3.4199E-02	0.0000	1.000	3.4199E-02	5.4430E-03
4	-9.7937E-02	0.0000	1.000	9.7937E-02	1.5587E-02
5	-8.1284E-02	7.4469E-02	0.7373	0.1102	1.7545E-02
6	-8.1284E-02	-7.4469E-02	0.7373	0.1102	1.7545E-02
7	-0.5000	0.0000	1.000	0.5000	7.9577E-02
8	-0.4465	0.3777	0.7634	0.5848	9.3080E-02
9	-0.4465	-0.3777	0.7634	0.5848	9.3080E-02
10	-3.352	0.0000	1.000	3.352	0.5335
11	-4.958	8.548	0.5017	9.882	1.573
12	-4.958	-8.548	0.5017	9.882	1.573
13	-13.70	0.0000	1.000	13.70	2.180
14	-15.31	0.0000	1.000	15.31	2.437
15	-34.68	0.0000	1.000	34.68	5.520

========== PITCH LOOP GAIN MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	7.092	0.1018	19.84

========== PITCH LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6117	-113.6	66.39

========== SPOILER LOOP GAIN MARGIN ==========

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

========== SPOILER LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.1798	-101.1	78.88

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.5290	0.8579E-01	21.33
2	14.96	0.6841E-06	123.3

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7604E-01	-110.0	70.02

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	5.309	0.1963E-02	54.14

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6888E-01	-105.0	75.05

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.1828	27.23	-28.70
2	21.79	0.1497	16.49

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	6.900	-118.8	61.20

:	COND	43
:	SPOILERS	30
:	MACH	0.5499900
:	H	35000.00
:	GAMMAD	-3.628600
:	VCAS	181.5900
:	CG	5.000000
:	WEIGHT	80000.00
:	ALFA	8.406000
:	Q	113.7600

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9901E-03	0.0000	1.000	9.9901E-03	1.5900E-03
2	-2.0000E-02	0.0000	1.000	2.0000E-02	3.1831E-03
3	-2.0007E-02	0.0000	1.000	2.0007E-02	3.1842E-03
4	-9.8825E-02	0.0000	1.000	9.8825E-02	1.5729E-02
5	-7.6620E-02	6.2894E-02	0.7729	9.9128E-02	1.5777E-02
6	-7.6620E-02	-6.2894E-02	0.7729	9.9128E-02	1.5777E-02
7	-0.2397	0.3556	0.5589	0.4288	6.8251E-02
8	-0.2397	-0.3556	0.5589	0.4288	6.8251E-02
9	-0.5000	0.0000	1.000	0.5000	7.9577E-02
10	-4.392	0.0000	1.000	4.392	0.6990
11	-3.937	7.991	0.4420	8.909	1.418
12	-3.937	-7.991	0.4420	8.909	1.418
13	-13.70	0.0000	1.000	13.70	2.180
14	-15.93	0.0000	1.000	15.93	2.535
15	-34.73	0.0000	1.000	34.73	5.528

PITCH LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	8.168	0.1968	14.12

PITCH LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.5285	-101.5	78.50

SPOILER LOOP GAIN MARGIN

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

SPOILER LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.3873	-74.44	105.6

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.4622	0.1392	17.13
2	16.79	0.6301E-06	124.0

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7899E-01	-104.9	75.06

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	5.788	0.4712E-02	46.54

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6967E-01	-105.4	74.64

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.7146E-01	1685.	-64.53
2	0.1681	48.01	-33.63
3	19.18	0.1979	14.07

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	7.102	-136.5	43.52

:	COND	44
:	SPOILERS	30
:	MACH	0.8399900
:	H	35000.00
:	GAMMAD	-14.22700
:	VCAS	287.2200
:	CG	5.000000
:	WEIGHT	80000.00
:	ALFA	2.912700
:	Q	292.7100

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9897E-03	0.0000	1.000	9.9897E-03	1.5899E-03
2	-2.0000E-02	0.0000	1.000	2.0000E-02	3.1831E-03
3	-2.0165E-02	0.0000	1.000	2.0165E-02	3.2093E-03
4	-7.3119E-02	0.0000	1.000	7.3119E-02	1.1637E-02
5	-0.1206	0.0000	1.000	0.1206	1.9198E-02
6	-9.1226E-02	0.1482	0.5242	0.1740	2.7699E-02
7	-9.1226E-02	-0.1482	0.5242	0.1740	2.7699E-02
8	-0.5000	0.0000	1.000	0.5000	7.9577E-02
9	-2.132	1.881	0.7499	2.843	0.4524
10	-2.132	-1.881	0.7499	2.843	0.4524
11	-4.759	7.014	0.5614	8.476	1.349
12	-4.759	-7.014	0.5614	8.476	1.349
13	-12.44	0.0000	1.000	12.44	1.981
14	-13.70	0.0000	1.000	13.70	2.180
15	-34.25	0.0000	1.000	34.25	5.451

PITCH LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	5.439	0.2707	11.35

PITCH LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	1.419	-103.8	76.22

SPOILER LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	59.57	0.2518E-02	51.98

SPOILER LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.1757	-117.5	62.47

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.3128	0.1386	17.16
2	16.79	0.6980E-06	123.1

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.8164E-01	-113.8	66.19

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	2.985	0.1365E-01	37.30

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6132E-01	-98.30	81.70

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.1135	26.12	-28.34
2	21.52	0.1407	17.03

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	6.450	-128.6	51.37

:	COND	45
:	SPOILERS	30
:	MACH	0.3699900
:	H	10000.00
:	GAMMAD	-4.567500
:	VCAS	204.0100
:	CG	5.000000
:	WEIGHT	110000.0
:	ALFA	9.114000
:	Q	144.3000

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9901E-03	0.0000	1.000	9.9901E-03	1.5900E-03
2	-3.3999E-02	0.0000	1.000	3.3999E-02	5.4111E-03
3	-3.4022E-02	0.0000	1.000	3.4022E-02	5.4148E-03
4	-9.8221E-02	0.0000	1.000	9.8221E-02	1.5632E-02
5	-8.6273E-02	6.5954E-02	0.7944	0.1086	1.7283E-02
6	-8.6273E-02	-6.5954E-02	0.7944	0.1086	1.7283E-02
7	-0.2874	0.3650	0.6187	0.4645	7.3934E-02
8	-0.2874	-0.3650	0.6187	0.4645	7.3934E-02
9	-0.5000	0.0000	1.000	0.5000	7.9577E-02
10	-3.351	0.0000	1.000	3.351	0.5334
11	-4.272	9.595	0.4068	10.50	1.672
12	-4.272	-9.595	0.4068	10.50	1.672
13	-13.70	0.0000	1.000	13.70	2.180
14	-15.83	0.0000	1.000	15.83	2.519
15	-35.45	0.0000	1.000	35.45	5.642

PITCH LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	8.801	0.1646	15.67

PITCH LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.5797	-101.8	78.21

SPOILER LOOP GAIN MARGIN

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

SPOILER LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.3424	-74.77	105.2

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.4896	0.1227	18.22
2	16.79	0.8640E-06	121.3

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7954E-01	-105.3	74.73

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	5.957	0.3527E-02	49.05

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7057E-01	-104.6	75.38

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	20.13	0.2178	13.24

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	7.988	-133.6	46.38

:	COND	46
:	SPOILERS	30
:	MACH	0.6399900
:	H	10000.00
:	GAMMAD	-8.190600
:	VCAS	356.2600
:	CG	5.000000
:	WEIGHT	110000.0
:	ALFA	3.577300
:	Q	461.7600

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9900E-03	0.0000	1.000	9.9900E-03	1.5900E-03
2	-3.3999E-02	0.0000	1.000	3.3999E-02	5.4111E-03
3	-3.4135E-02	0.0000	1.000	3.4135E-02	5.4328E-03
4	-9.8934E-02	0.0000	1.000	9.8934E-02	1.5746E-02
5	-7.9985E-02	7.2723E-02	0.7399	0.1081	1.7205E-02
6	-7.9985E-02	-7.2723E-02	0.7399	0.1081	1.7205E-02
7	-0.3112	0.3788	0.6348	0.4902	7.8017E-02
8	-0.3112	-0.3788	0.6348	0.4902	7.8017E-02
9	-0.5000	0.0000	1.000	0.5000	7.9577E-02
10	-3.673	0.0000	1.000	3.673	0.5846
11	-4.904	8.426	0.5030	9.749	1.552
12	-4.904	-8.426	0.5030	9.749	1.552
13	-13.70	0.0000	1.000	13.70	2.180
14	-15.32	0.0000	1.000	15.32	2.439
15	-34.53	0.0000	1.000	34.53	5.495

PITCH LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	7.690	0.1037	19.69

PITCH LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.5352	-116.9	63.12

SPOILER LOOP GAIN MARGIN

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

SPOILER LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.1902	-97.33	82.67

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.4809	0.1118	19.03
2	13.34	0.2391E-06	132.4

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7680E-01	-108.8	71.24

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	5.309	0.2585E-02	51.75

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6938E-01	-105.8	74.15

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.1870	19.81	-25.94
2	21.67	0.1467	16.67

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	6.829	-118.0	62.01

:	COND	47
:	SPOILERS	30
:	MACH	0.6599900
:	H	35000.00
:	GAMMAD	-3.762700
:	VCAS	220.5100
:	CG	5.000000
:	WEIGHT	110000.0
:	ALFA	7.903400
:	Q	169.2500

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9901E-03	0.0000	1.000	9.9901E-03	1.5900E-03
2	-2.0000E-02	0.0000	1.000	2.0000E-02	3.1831E-03
3	-2.0005E-02	0.0000	1.000	2.0005E-02	3.1838E-03
4	-7.0377E-02	5.9442E-02	0.7640	9.2121E-02	1.4661E-02
5	-7.0377E-02	-5.9442E-02	0.7640	9.2121E-02	1.4661E-02
6	-9.9047E-02	0.0000	1.000	9.9047E-02	1.5764E-02
7	-0.2232	0.3508	0.5367	0.4158	6.6174E-02
8	-0.2232	-0.3508	0.5367	0.4158	6.6174E-02
9	-0.5000	0.0000	1.000	0.5000	7.9577E-02
10	-4.641	0.0000	1.000	4.641	0.7386
11	-3.868	8.644	0.4085	9.470	1.507
12	-3.868	-8.644	0.4085	9.470	1.507
13	-13.70	0.0000	1.000	13.70	2.180
14	-16.05	0.0000	1.000	16.05	2.554
15	-34.94	0.0000	1.000	34.94	5.561

========== PITCH LOOP GAIN MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	8.699	0.2042	13.80

========== PITCH LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.5147	-100.9	79.05

========== SPOILER LOOP GAIN MARGIN ==========

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

========== SPOILER LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.4325	-77.55	102.5

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.4564	0.1481	16.59
2	16.79	0.3444E-06	129.3

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7997E-01	-103.7	76.31

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	5.957	0.4787E-02	46.40

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6852E-01	-106.4	73.62

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.7168E-01	2322.	-67.32
2	0.1940	30.01	-29.55
3	19.49	0.2086	13.61

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	7.618	-137.2	42.76

:	COND	48
:	SPOILERS	30
:	MACH	0.8399900
:	H	35000.00
:	GAMMAD	-14.85900
:	VCAS	287.2200
:	CG	5.000000
:	WEIGHT	110000.0
:	ALFA	4.005900
:	Q	292.7100

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9897E-03	0.0000	1.000	9.9897E-03	1.5899E-03
2	-2.0000E-02	0.0000	1.000	2.0000E-02	3.1831E-03
3	-2.0203E-02	0.0000	1.000	2.0203E-02	3.2154E-03
4	-7.2156E-02	0.0000	1.000	7.2156E-02	1.1484E-02
5	-0.1141	0.0000	1.000	0.1141	1.8162E-02
6	-7.2669E-02	0.1378	0.4666	0.1558	2.4790E-02
7	-7.2669E-02	-0.1378	0.4666	0.1558	2.4790E-02
8	-0.5000	0.0000	1.000	0.5000	7.9577E-02
9	-2.048	0.0000	1.000	2.048	0.3259
10	-3.044	0.0000	1.000	3.044	0.4844
11	-4.370	6.834	0.5387	8.112	1.291
12	-4.370	-6.834	0.5387	8.112	1.291
13	-12.27	0.0000	1.000	12.27	1.953
14	-13.70	0.0000	1.000	13.70	2.180
15	-34.10	0.0000	1.000	34.10	5.427

========== PITCH LOOP GAIN MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	6.178	0.2272	12.87

========== PITCH LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	1.152	-94.35	85.65

========== SPOILER LOOP GAIN MARGIN ==========

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

========== SPOILER LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.1500	-122.0	57.99

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.2729	0.1645	15.68
2	16.79	0.4825E-06	126.3

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.8201E-01	-117.2	62.80

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	3.447	0.9898E-02	40.09

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.5827E-01	-99.16	80.84

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.1053	16.89	-24.55
2	21.21	0.1400	17.08

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	6.510	-129.4	50.61

:	COND	49
:	SPOILERS	30
:	MACH	0.3099900
:	H	10000.00
:	GAMMAD	-4.112600
:	VCAS	170.6700
:	CG	0.3100000
:	WEIGHT	80000.00
:	ALFA	8.685600
:	Q	100.2700

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9901E-03	0.0000	1.000	9.9901E-03	1.5900E-03
2	-3.3999E-02	0.0000	1.000	3.3999E-02	5.4111E-03
3	-3.4043E-02	0.0000	1.000	3.4043E-02	5.4181E-03
4	-9.8438E-02	0.0000	1.000	9.8438E-02	1.5667E-02
5	-8.2641E-02	6.7746E-02	0.7734	0.1069	1.7007E-02
6	-8.2641E-02	-6.7746E-02	0.7734	0.1069	1.7007E-02
7	-0.5000	0.0000	1.000	0.5000	7.9577E-02
8	-0.4335	0.3704	0.7603	0.5702	9.0748E-02
9	-0.4335	-0.3704	0.7603	0.5702	9.0748E-02
10	-3.544	0.0000	1.000	3.544	0.5641
11	-4.200	6.597	0.5371	7.820	1.245
12	-4.200	-6.597	0.5371	7.820	1.245
13	-13.70	0.0000	1.000	13.70	2.180
14	-16.33	0.0000	1.000	16.33	2.600
15	-34.34	0.0000	1.000	34.34	5.466

PITCH LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	6.823	0.1866	14.58

PITCH LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7089	-98.98	81.02

SPOILER LOOP GAIN MARGIN

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

SPOILER LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.2702	-75.57	104.4

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.5767	0.9095E-01	20.82
2	14.96	0.1264E-05	118.0

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7865E-01	-105.2	74.81

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	4.732	0.4609E-02	46.73

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6963E-01	-105.8	74.24

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	18.90	0.1737	15.20

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	6.063	-135.6	44.42

:	COND	50
:	SPOILERS	30
:	MACH	0.6399900
:	H	10000.00
:	GAMMAD	-10.96000
:	VCAS	356.2600
:	CG	0.3100000
:	WEIGHT	80000.00
:	ALFA	2.489800
:	Q	461.7600

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9900E-03	0.0000	1.000	9.9900E-03	1.5900E-03
2	-3.3999E-02	0.0000	1.000	3.3999E-02	5.4111E-03
3	-3.4195E-02	0.0000	1.000	3.4195E-02	5.4423E-03
4	-9.9334E-02	0.0000	1.000	9.9334E-02	1.5809E-02
5	-8.2759E-02	7.4917E-02	0.7414	0.1116	1.7767E-02
6	-8.2759E-02	-7.4917E-02	0.7414	0.1116	1.7767E-02
7	-0.5000	0.0000	1.000	0.5000	7.9577E-02
8	-0.6802	0.0000	1.000	0.6802	0.1083
9	-0.9185	0.0000	1.000	0.9185	0.1462
10	-2.172	0.0000	1.000	2.172	0.3457
11	-5.147	7.396	0.5712	9.010	1.434
12	-5.147	-7.396	0.5712	9.010	1.434
13	-13.70	0.0000	1.000	13.70	2.180
14	-15.34	0.0000	1.000	15.34	2.441
15	-34.44	0.0000	1.000	34.44	5.481

PITCH LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	6.153	0.1243	18.11

PITCH LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7447	-107.1	72.95

SPOILER LOOP GAIN MARGIN

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

SPOILER LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.1824	-101.1	78.89

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.6000	0.6652E-01	23.54
2	14.96	0.6796E-06	123.4

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7597E-01	-109.8	70.18

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	4.732	0.2353E-02	52.57

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6925E-01	-104.9	75.14

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.5802E-01	9792.	-79.82
2	0.1953	49.10	-33.82
3	21.21	0.1445	16.80

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	6.067	-123.6	56.38

:	COND	51
:	SPOILERS	30
:	MACH	0.5499900
:	H	35000.00
:	GAMMAD	-3.380500
:	VCAS	181.5900
:	CG	0.3100000
:	WEIGHT	80000.00
:	ALFA	7.853100
:	Q	113.7600

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9901E-03	0.0000	1.000	9.9901E-03	1.5900E-03
2	-2.0000E-02	0.0000	1.000	2.0000E-02	3.1831E-03
3	-2.0010E-02	0.0000	1.000	2.0010E-02	3.1848E-03
4	-7.2583E-02	6.3111E-02	0.7546	9.6184E-02	1.5308E-02
5	-7.2583E-02	-6.3111E-02	0.7546	9.6184E-02	1.5308E-02
6	-0.1001	0.0000	1.000	0.1001	1.5928E-02
7	-0.2913	0.3644	0.6244	0.4665	7.4248E-02
8	-0.2913	-0.3644	0.6244	0.4665	7.4248E-02
9	-0.5000	0.0000	1.000	0.5000	7.9577E-02
10	-4.795	0.0000	1.000	4.795	0.7631
11	-3.593	6.846	0.4647	7.732	1.231
12	-3.593	-6.846	0.4647	7.732	1.231
13	-13.70	0.0000	1.000	13.70	2.180
14	-16.14	0.0000	1.000	16.14	2.569
15	-34.49	0.0000	1.000	34.49	5.489

========== PITCH LOOP GAIN MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	7.452	0.2187	13.20

========== PITCH LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.5901	-95.73	84.27

========== SPOILER LOOP GAIN MARGIN ==========

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

========== SPOILER LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.3720	-66.78	113.2

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.5007	0.1191	18.48
2	16.79	0.5776E-06	124.8

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7826E-01	-105.0	75.04

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	5.309	0.5460E-02	45.26

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6882E-01	-106.3	73.72

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.4959E-01	4391.	-72.85
2	0.1657	96.58	-39.70
3	18.70	0.1895	14.45

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	6.530	-141.5	38.49

:	COND	52
:	SPOILERS	30
:	MACH	0.8399900
:	H	35000.00
:	GAMMAD	-14.69500
:	VCAS	287.2200
:	CG	0.3100000
:	WEIGHT	80000.00
:	ALFA	2.727900
:	Q	292.7100

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9898E-03	0.0000	1.000	9.9898E-03	1.5899E-03
2	-2.0000E-02	0.0000	1.000	2.0000E-02	3.1831E-03
3	-2.0146E-02	0.0000	1.000	2.0146E-02	3.2063E-03
4	-7.4470E-02	0.0000	1.000	7.4470E-02	1.1852E-02
5	-0.1196	0.0000	1.000	0.1196	1.9037E-02
6	-9.6257E-02	0.1508	0.5381	0.1789	2.8468E-02
7	-9.6257E-02	-0.1508	0.5381	0.1789	2.8468E-02
8	-0.5000	0.0000	1.000	0.5000	7.9577E-02
9	-1.243	2.740	0.4132	3.009	0.4789
10	-1.243	-2.740	0.4132	3.009	0.4789
11	-5.915	5.897	0.7082	8.353	1.329
12	-5.915	-5.897	0.7082	8.353	1.329
13	-12.02	0.0000	1.000	12.02	1.913
14	-13.70	0.0000	1.000	13.70	2.180
15	-34.07	0.0000	1.000	34.07	5.422

PITCH LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	4.471	0.3879	8.226

PITCH LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	2.053	-127.4	52.61

SPOILER LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	94.41	0.6640E-03	63.56

SPOILER LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.1874	-116.6	63.39

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.3423	0.1159	18.72
2	16.79	0.6477E-06	123.8

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.8159E-01	-112.7	67.28

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	2.839	0.2377E-01	32.48

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6284E-01	-98.12	81.88

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.1079	45.07	-33.08
2	21.60	0.1267	17.95

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	5.122	-132.5	47.49

:	COND	53
:	SPOILERS	30
:	MACH	0.3699900
:	H	10000.00
:	GAMMAD	-4.261200
:	VCAS	204.0100
:	CG	0.3100000
:	WEIGHT	110000.0
:	ALFA	8.483100
:	Q	144.3000

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9901E-03	0.0000	1.000	9.9901E-03	1.5900E-03
2	-3.3999E-02	0.0000	1.000	3.3999E-02	5.4111E-03
3	-3.4049E-02	0.0000	1.000	3.4049E-02	5.4190E-03
4	-9.9095E-02	0.0000	1.000	9.9095E-02	1.5771E-02
5	-7.8924E-02	6.6553E-02	0.7645	0.1032	1.6431E-02
6	-7.8924E-02	-6.6553E-02	0.7645	0.1032	1.6431E-02
7	-0.5000	0.0000	1.000	0.5000	7.9577E-02
8	-0.3534	0.3709	0.6899	0.5123	8.1539E-02
9	-0.3534	-0.3709	0.6899	0.5123	8.1539E-02
10	-3.404	0.0000	1.000	3.404	0.5418
11	-4.096	8.522	0.4332	9.455	1.505
12	-4.096	-8.522	0.4332	9.455	1.505
13	-13.70	0.0000	1.000	13.70	2.180
14	-16.01	0.0000	1.000	16.01	2.549
15	-35.16	0.0000	1.000	35.16	5.596

========== PITCH LOOP GAIN MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	8.109	0.1802	14.89

========== PITCH LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6410	-98.16	81.84

========== SPOILER LOOP GAIN MARGIN ==========

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

========== SPOILER LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.2779	-73.16	106.8

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.5318	0.1040	19.66
2	16.79	0.8076E-06	121.9

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7851E-01	-105.6	74.40

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	5.788	0.3679E-02	48.68

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6939E-01	-105.8	74.22

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	19.46	0.2125	13.45

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	7.402	-137.8	42.18

:	COND	54
:	SPOILERS	30
:	MACH	0.6399900
:	H	10000.00
:	GAMMAD	-8.254900
:	VCAS	356.2600
:	CG	0.3100000
:	WEIGHT	110000.0
:	ALFA	3.352900
:	Q	461.7600

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9900E-03	0.0000	1.000	9.9900E-03	1.5900E-03
2	-3.3999E-02	0.0000	1.000	3.3999E-02	5.4111E-03
3	-3.4134E-02	0.0000	1.000	3.4134E-02	5.4327E-03
4	-0.1009	0.0000	1.000	0.1009	1.6053E-02
5	-8.1721E-02	7.3266E-02	0.7446	0.1098	1.7468E-02
6	-8.1721E-02	-7.3266E-02	0.7446	0.1098	1.7468E-02
7	-0.5000	0.0000	1.000	0.5000	7.9577E-02
8	-0.4848	0.3568	0.8053	0.6019	9.5798E-02
9	-0.4848	-0.3568	0.8053	0.6019	9.5798E-02
10	-3.013	0.0000	1.000	3.013	0.4796
11	-4.983	7.048	0.5773	8.632	1.374
12	-4.983	-7.048	0.5773	8.632	1.374
13	-13.70	0.0000	1.000	13.70	2.180
14	-15.36	0.0000	1.000	15.36	2.445
15	-34.31	0.0000	1.000	34.31	5.461

PITCH LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	6.756	0.1229	18.21

PITCH LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6554	-108.3	71.70

SPOILER LOOP GAIN MARGIN

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

SPOILER LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.1924	-97.61	82.39

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.5503	0.8513E-01	21.40
2	13.34	0.3072E-06	130.3

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7666E-01	-108.6	71.39

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	4.732	0.3097E-02	50.18

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6980E-01	-105.7	74.27

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.2025	36.02	-31.13
2	21.06	0.1414	16.99

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	6.023	-124.8	55.22

:	COND	55
:	SPOILERS	30
:	MACH	0.6599900
:	H	35000.00
:	GAMMAD	-3.522100
:	VCAS	220.5100
:	CG	0.3100000
:	WEIGHT	110000.0
:	ALFA	7.410200
:	Q	169.2500

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9901E-03	0.0000	1.000	9.9901E-03	1.5900E-03
2	-2.0000E-02	0.0000	1.000	2.0000E-02	3.1831E-03
3	-2.0004E-02	0.0000	1.000	2.0004E-02	3.1838E-03
4	-7.0563E-02	6.0284E-02	0.7603	9.2808E-02	1.4771E-02
5	-7.0563E-02	-6.0284E-02	0.7603	9.2808E-02	1.4771E-02
6	-0.1008	0.0000	1.000	0.1008	1.6038E-02
7	-0.2772	0.3583	0.6119	0.4530	7.2090E-02
8	-0.2772	-0.3583	0.6119	0.4530	7.2090E-02
9	-0.5000	0.0000	1.000	0.5000	7.9577E-02
10	-5.307	0.0000	1.000	5.307	0.8446
11	-3.307	7.157	0.4195	7.884	1.255
12	-3.307	-7.157	0.4195	7.884	1.255
13	-13.70	0.0000	1.000	13.70	2.180
14	-16.29	0.0000	1.000	16.29	2.593
15	-34.75	0.0000	1.000	34.75	5.530

========== PITCH LOOP GAIN MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	7.770	0.2443	12.24

========== PITCH LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6035	-90.40	89.60

========== SPOILER LOOP GAIN MARGIN ==========

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

========== SPOILER LOOP PHASE MARGIN ==========

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.4674	-73.69	106.3

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.5003	0.1242	18.12
2	16.79	0.2931E-06	130.7

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.7975E-01	-103.4	76.60

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	5.309	0.6004E-02	44.43

SPEED LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6872E-01	-106.9	73.12

ELEVATOR LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.2272	57.48	-35.19
2	18.57	0.2067	13.69

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	6.905	-145.3	34.69

:	COND	56
:	SPOILERS	30
:	MACH	0.8399900
:	H	35000.00
:	GAMMAD	-15.11100
:	VCAS	287.2200
:	CG	0.3100000
:	WEIGHT	110000.0
:	ALFA	3.717700
:	Q	292.7100

******************** EIGENVALUES OF CLOSED-LOOP SYSTEM ********************

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	-9.9898E-03	0.0000	1.000	9.9898E-03	1.5899E-03
2	-2.0000E-02	0.0000	1.000	2.0000E-02	3.1831E-03
3	-2.0174E-02	0.0000	1.000	2.0174E-02	3.2108E-03
4	-7.4153E-02	0.0000	1.000	7.4153E-02	1.1802E-02
5	-0.1131	0.0000	1.000	0.1131	1.8001E-02
6	-7.6801E-02	0.1411	0.4781	0.1606	2.5566E-02
7	-7.6801E-02	-0.1411	0.4781	0.1606	2.5566E-02
8	-0.5000	0.0000	1.000	0.5000	7.9577E-02
9	-1.808	2.121	0.6487	2.787	0.4436
10	-1.808	-2.121	0.6487	2.787	0.4436
11	-5.295	5.412	0.6993	7.571	1.205
12	-5.295	-5.412	0.6993	7.571	1.205
13	-12.02	0.0000	1.000	12.02	1.912
14	-13.70	0.0000	1.000	13.70	2.180
15	-33.90	0.0000	1.000	33.90	5.396

PITCH LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	5.144	0.2901	10.75

PITCH LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	1.692	-113.7	66.28

SPOILER LOOP GAIN MARGIN

GAIN MARGIN IS INFINITE IN THE FREQUENCY RANGE SPECIFIED

SPOILER LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.1606	-121.4	58.58

ALTITUDE LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.2953	0.1417	16.97
2	16.79	0.4455E-06	127.0

ALTITUDE LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.8208E-01	-115.7	64.27

SPEED LOOP GAIN MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	2.964	0.1736E-01	35.21

SPEED LOOP PHASE MARGIN

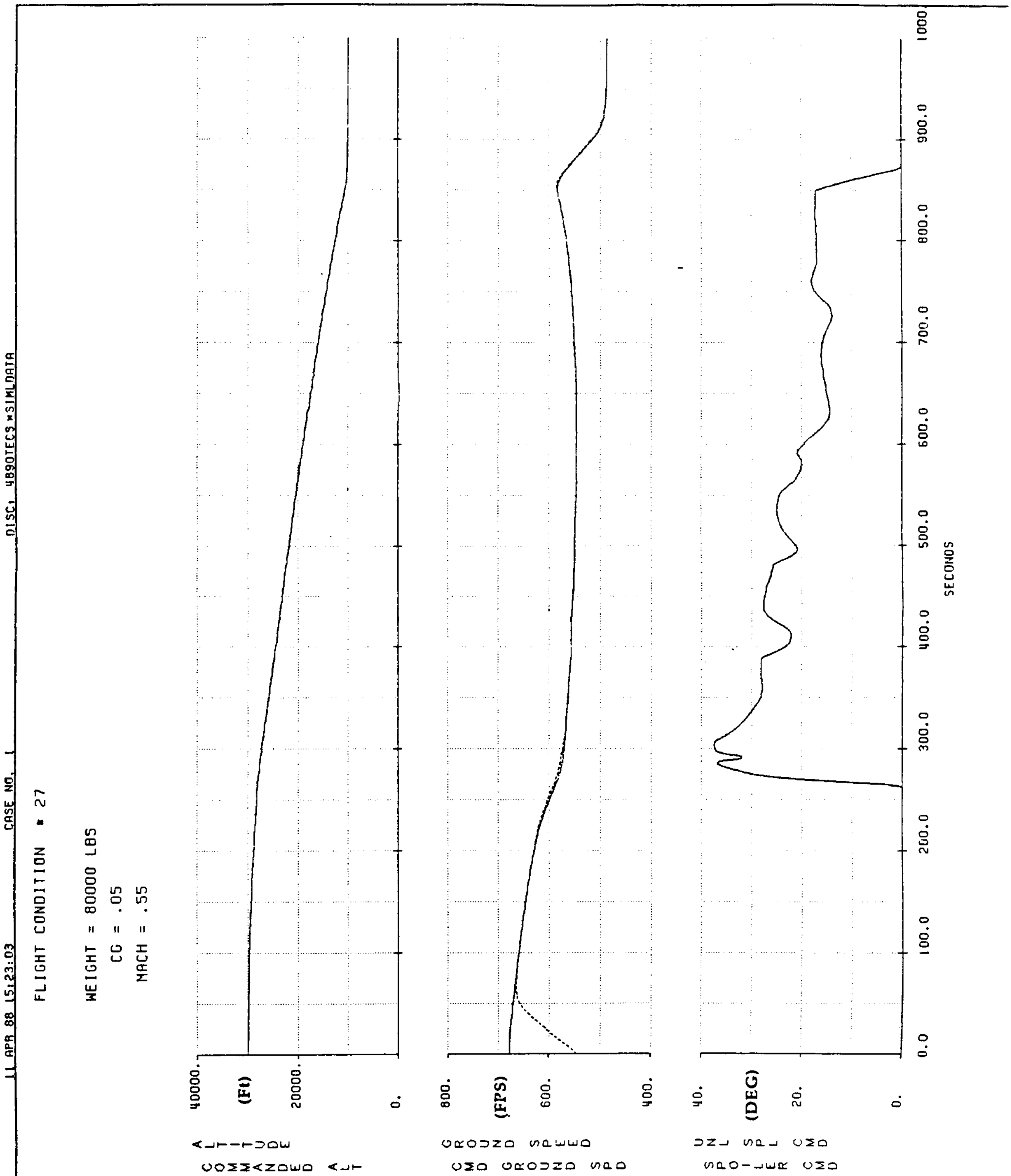
NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	0.6044E-01	-98.99	81.01

ELEVATOR LOOP GAIN MARGIN

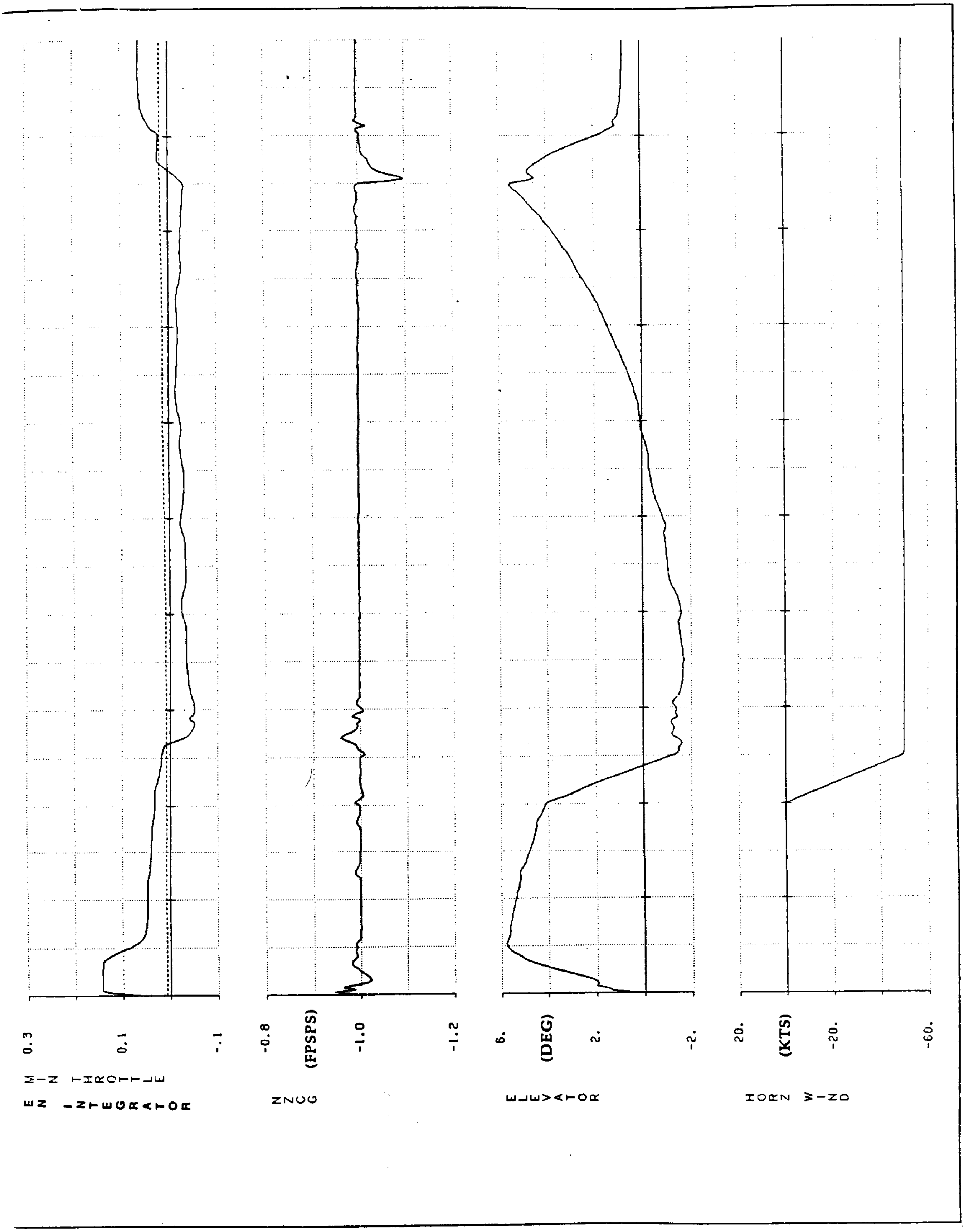
NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	GAIN MARGIN (DB)
1	0.1030	24.26	-27.70
2	21.21	0.1272	17.91

ELEVATOR LOOP PHASE MARGIN

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)
1	5.408	-132.0	48.00



CALC	RORY O'SHAUGHNESSY	REVISED	DATE	-* TECS AUTOSPOILERS *- **RESPONSE TO 50 KNOT TAIL WIND SHEAR** 737-200 **AT MACH .55**	CASE NO. 1
CHK	737-200-TECS 11 APR 88				DISC DATA
APP				THE *BOEING* COMPANY	PAGE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MIN THROTTLE
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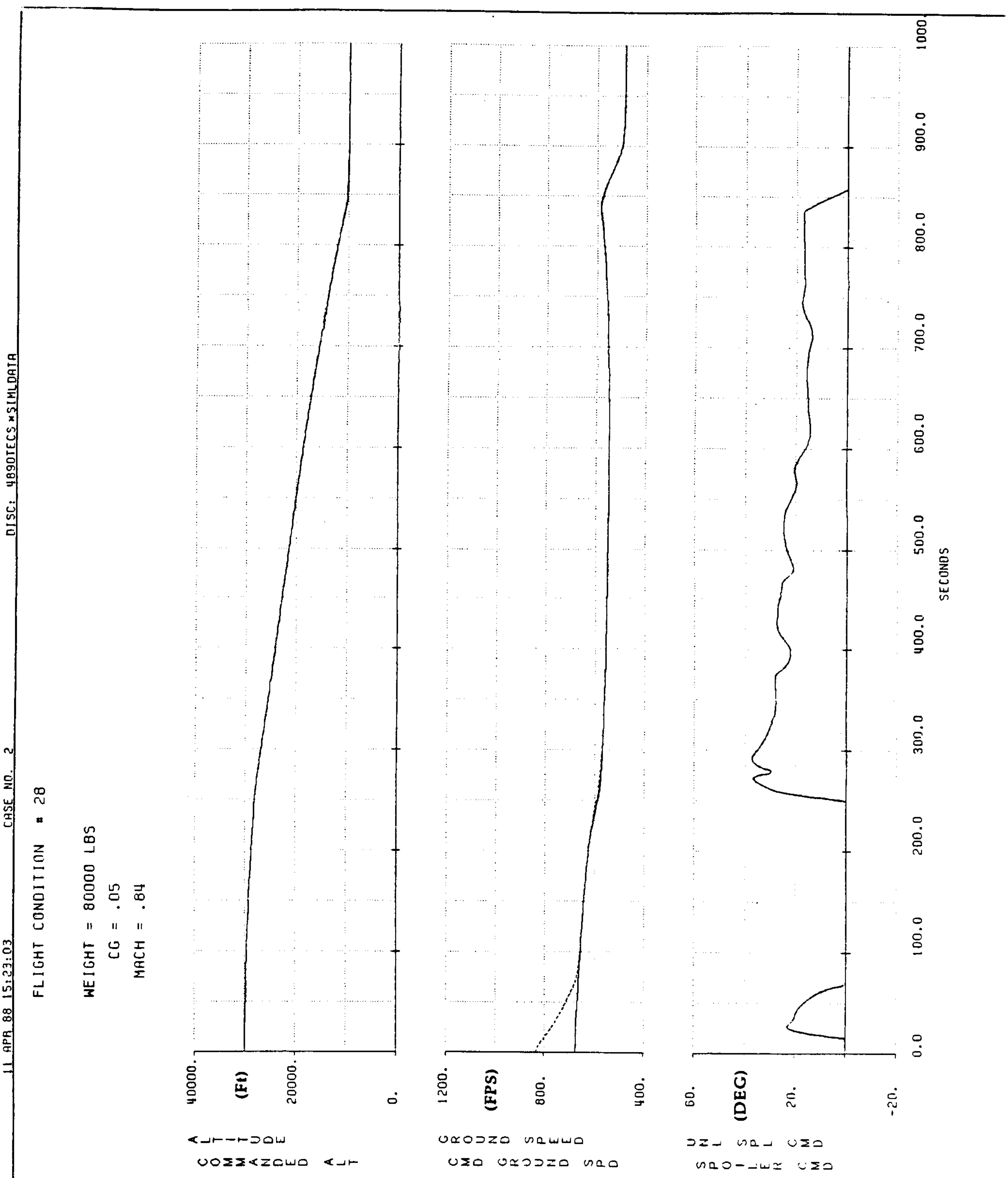
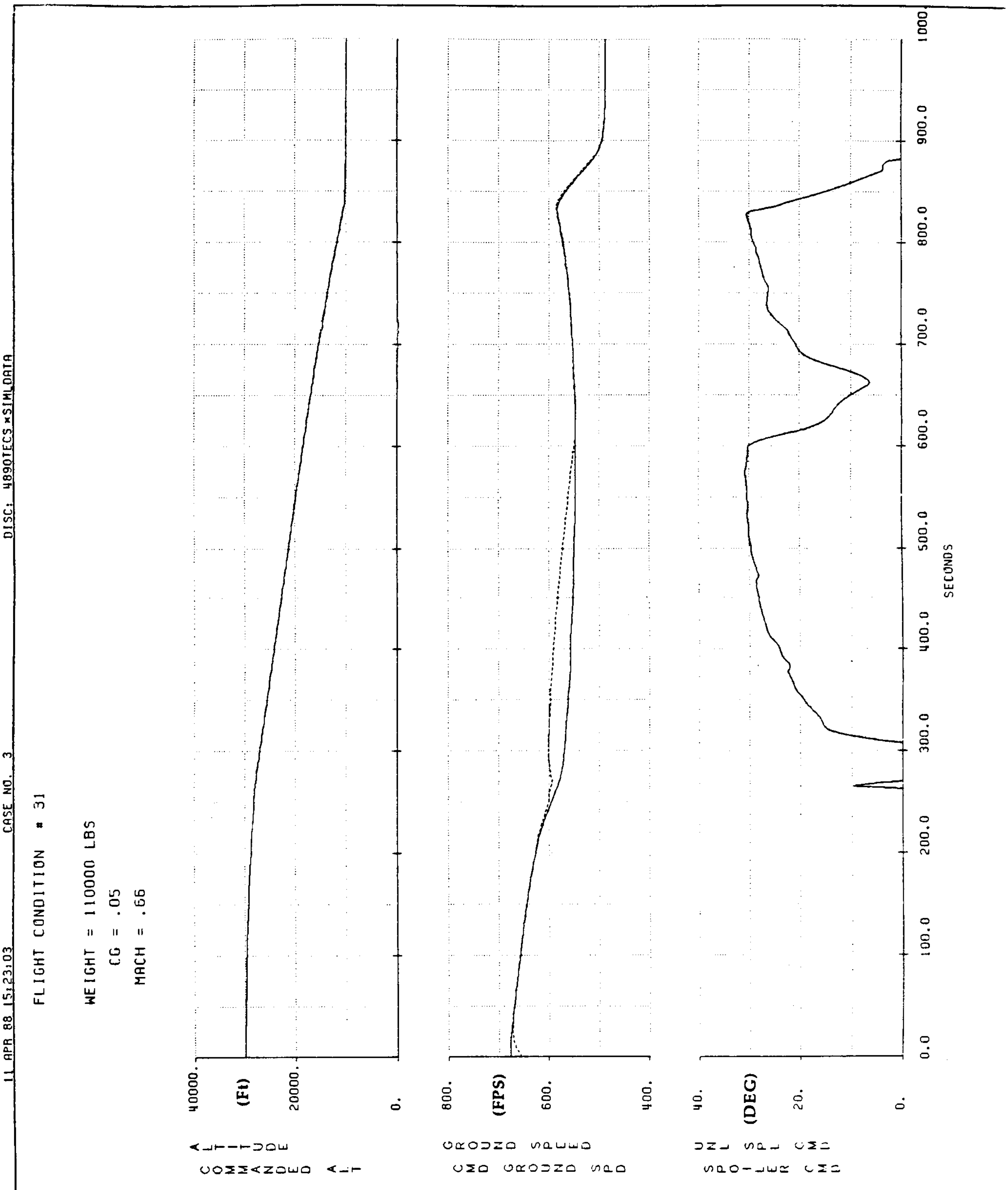
0.1
-.1
NZCG
(FPSPS)
-0.8
-1.0
-1.2
ELEVATOR
(DEG)
6.
2.
-2.
HORZ WIND
(KTS)
20.
-20.
-60.



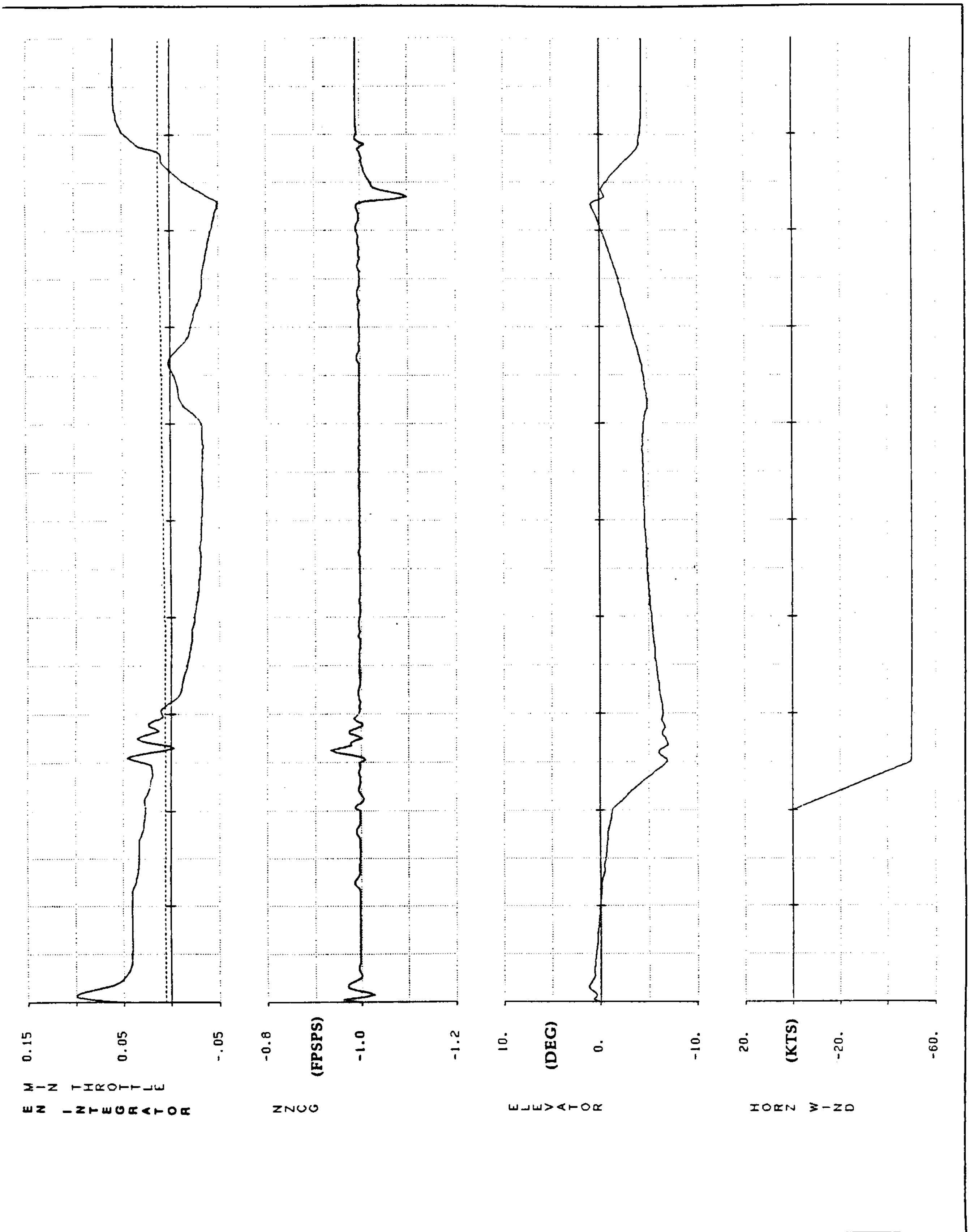
CALC	RORY O'SHAUGHNESSY	REVISED	DATE	-* TECS AUTOSPOILERS *-	CASE NO. 2
CHK	737-200-TECS 11 APR 88			**RESPONSE TO 50 KNOT TAIL WIND SHEAR** 737-200 **AT MACH .84**	DISC DATA
APP				THE BOEING COMPANY	PAGE

0.3
0.1
-.1
MIN THROTTLE
EN INTEGRATOR
-0.95
(FPSPS)
-1.05
-1.15
NZCG
5.
(DEG)
-5.
-15.
ELEVATOR
20.
(KTS)
-20.
-60.
HORZ WIND



CALC	ROBT O'SHAUGHNESSY	REVISED	DATE	-* TECS AUTOSPOILERS *- **RESPONSE TO 50 KNOT TAIL WIND SHEAR** 737-200 **AT MACH .66**	CASE NO. 3
CHK	737-200-TECS 11 APR 88				DISC DATA
APP				THE *BOEING* COMPANY	PAGE

RFSC


0.15
0.05
-.05
THROTTLE
INTEGRATOR
-0.8
(FPSPS)
-1.0
-1.2
NZCG
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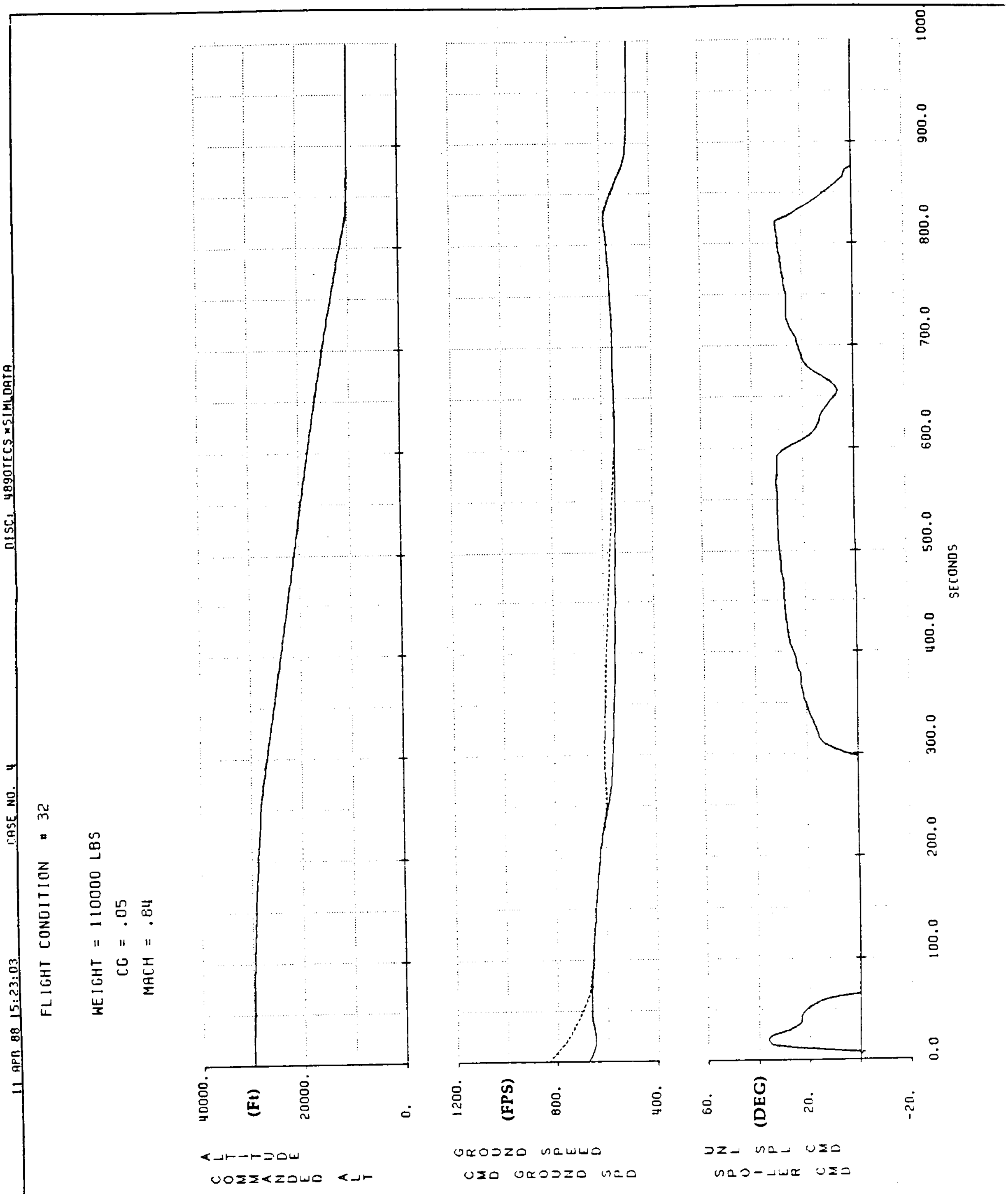
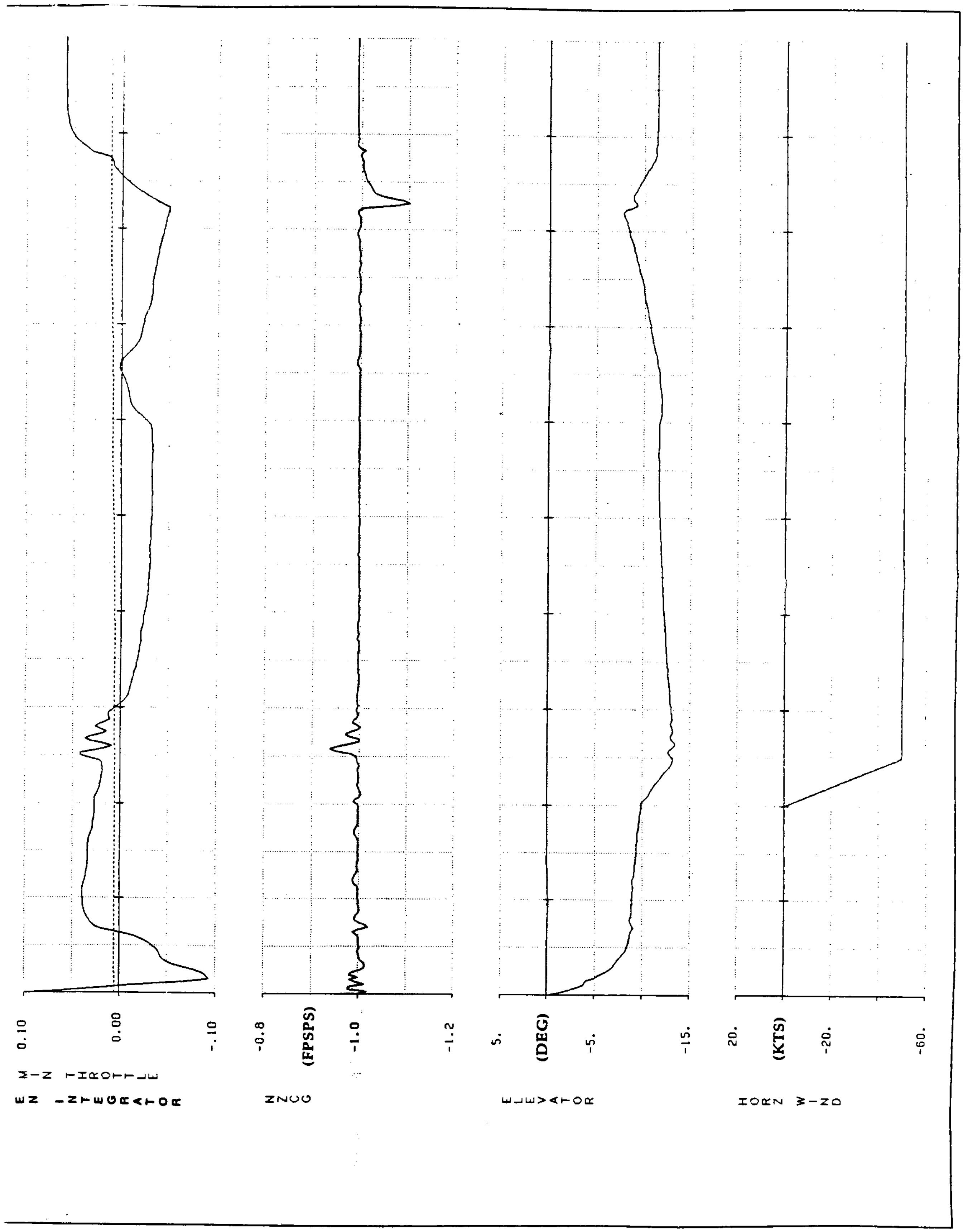
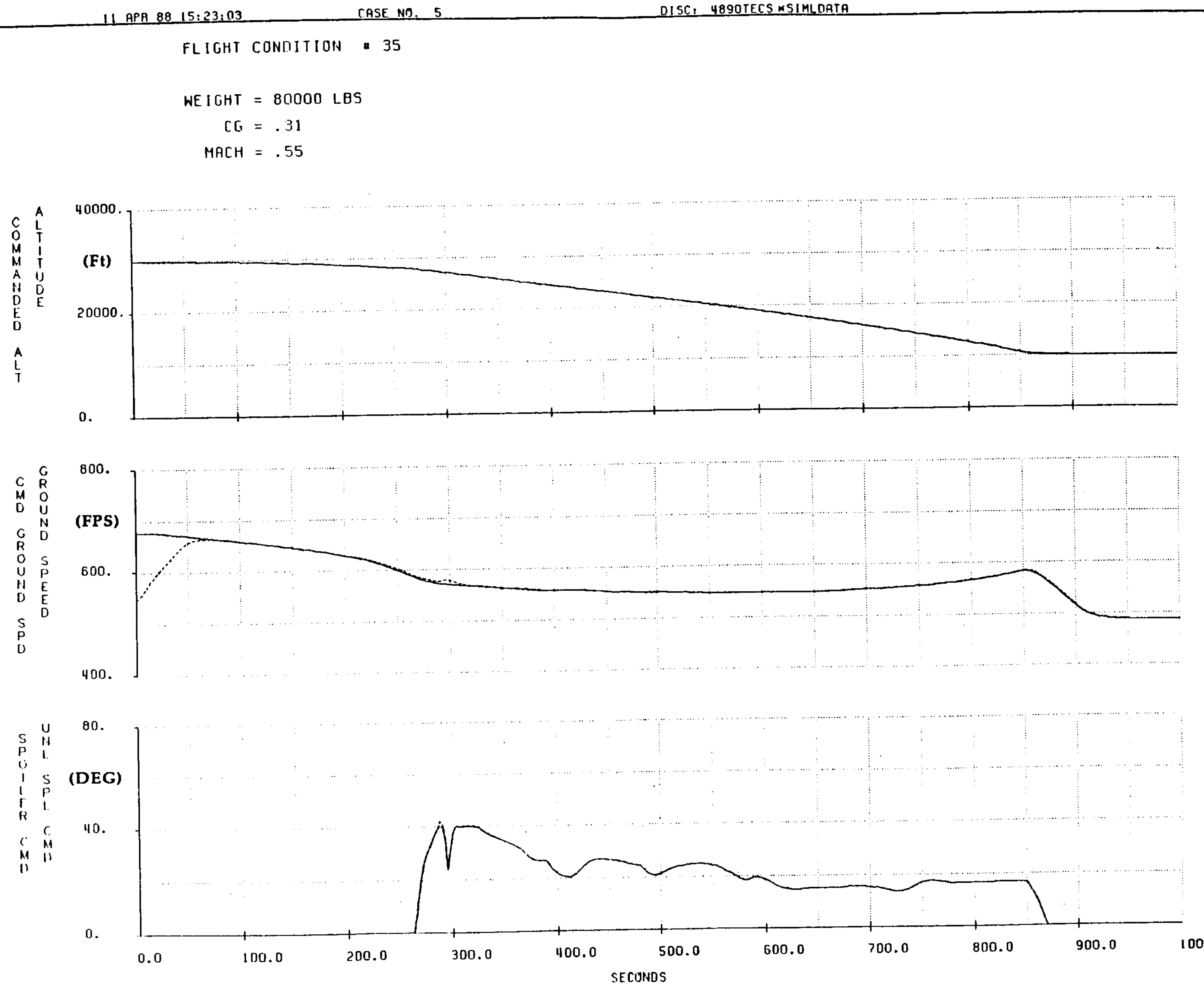
(DEG)
0.
-10.
ELEVATOR
20.
(KTS)
-20.
-60.
HORZ WIND



CALC	RORY O'SHAUGHNESSY	REVISED	DATE	-* TECS AUTOSPOILERS *- RESPONSE TO 50 KNOT TAIL WIND SHEAR, 737-200 HEAVY WEIGHT	CASE NO. 4
CHK	737-200-TECS 11 APR 88				DISC DATA
APP				THE BOEING COMPANY	PAGE



MIN THROTTLE
EN INTEGRATOR
0.10
0.00
-.10
NZCG
-0.8
(FPSPS)
-1.0
-1.2
ELEVATOR
5.
(DEG)
-5.
-15.
HORZ WIND
20.
(KTS)
-20.
-60.



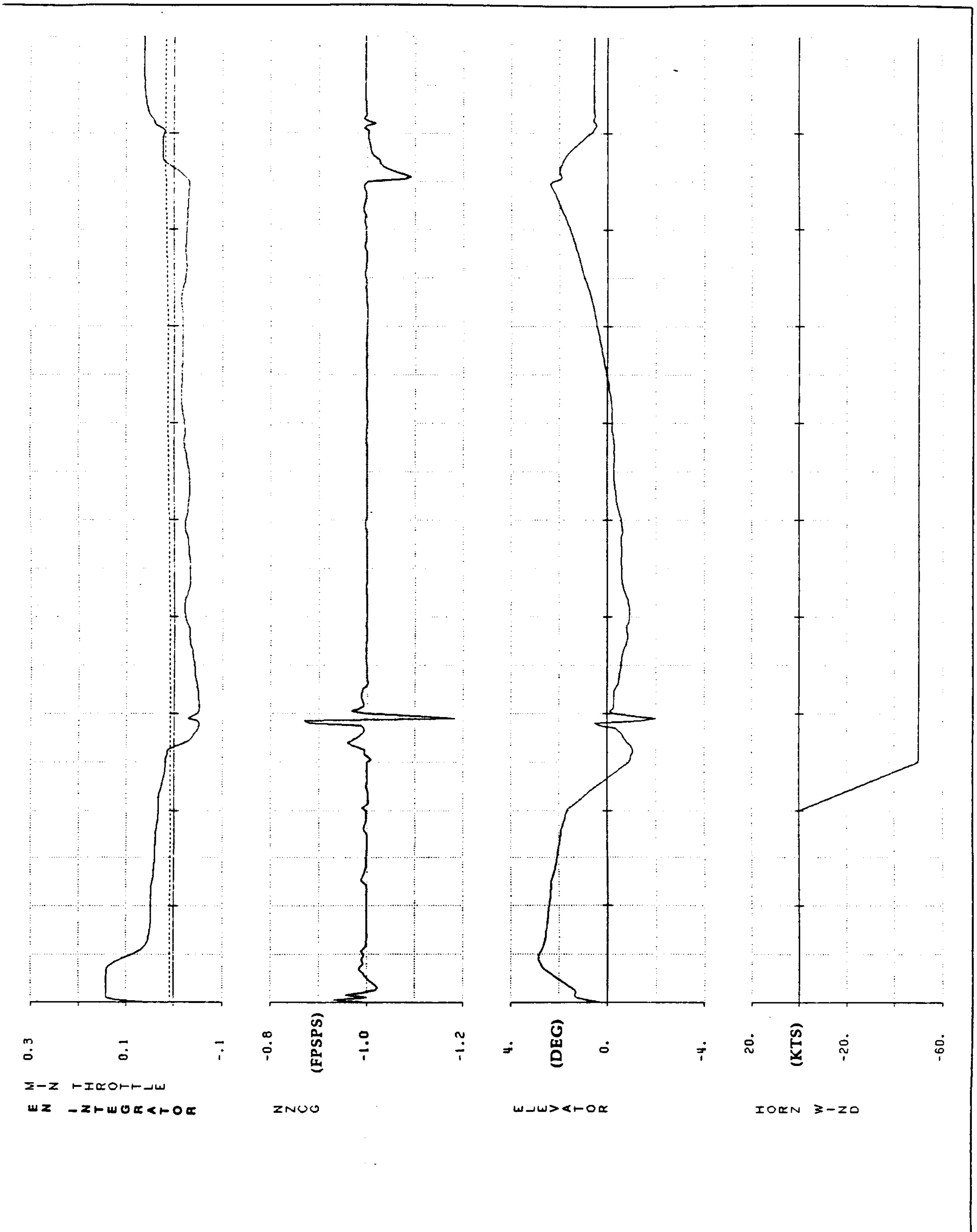
CALC	RORY O'SHAUGHNESSY	REVISED	DATE
CHK	737-200-TECS 11 APR 88		
APP			

-* TECS AUTOSPOILERS --
RESPONSE TO 50 KNOT TAIL WIND SHEAR,
737-200 **AFT CG, MACH .55**

THE *BOEING* COMPANY

CASE NO. 5
DISC DATA
PAGE

RFSC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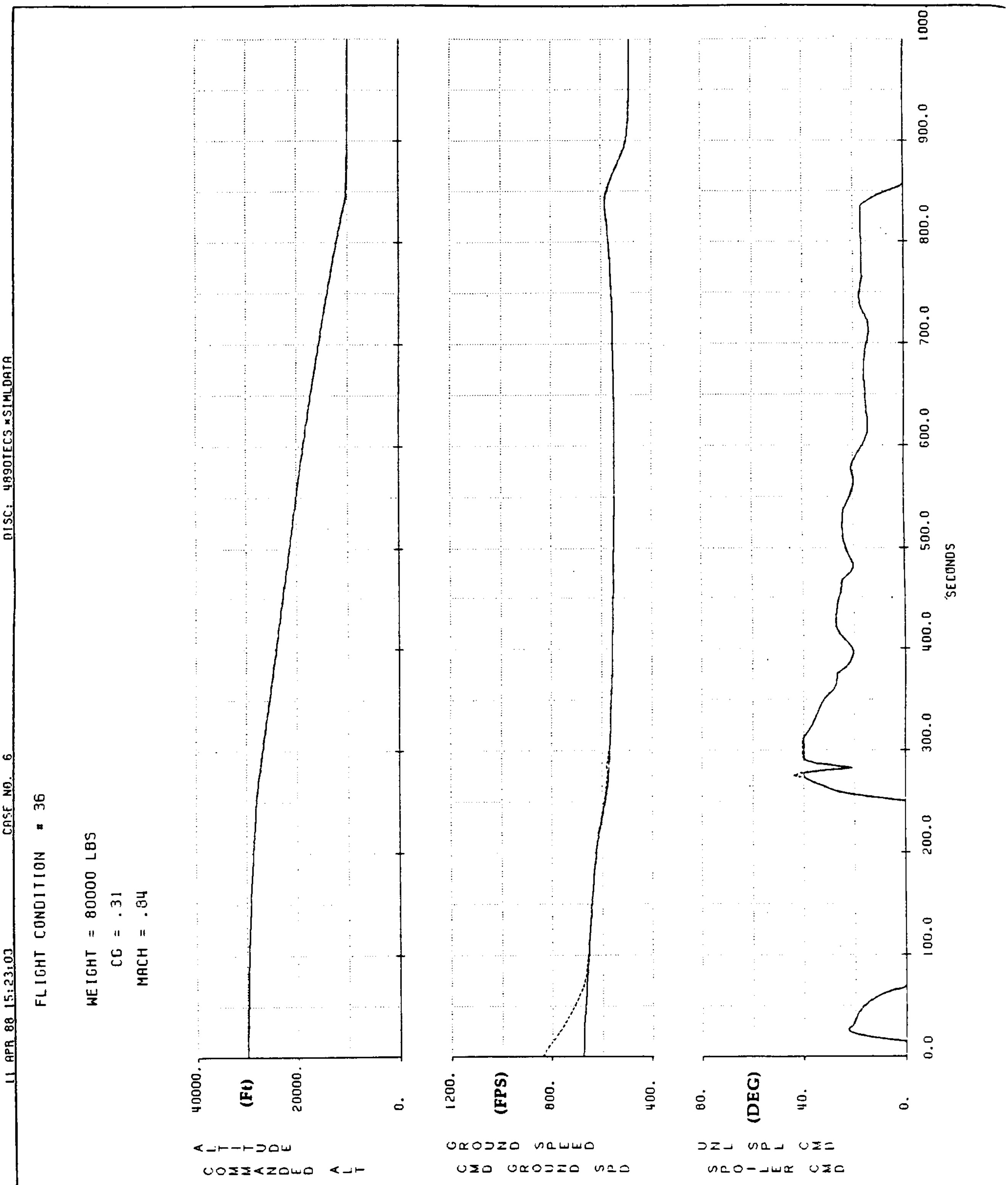
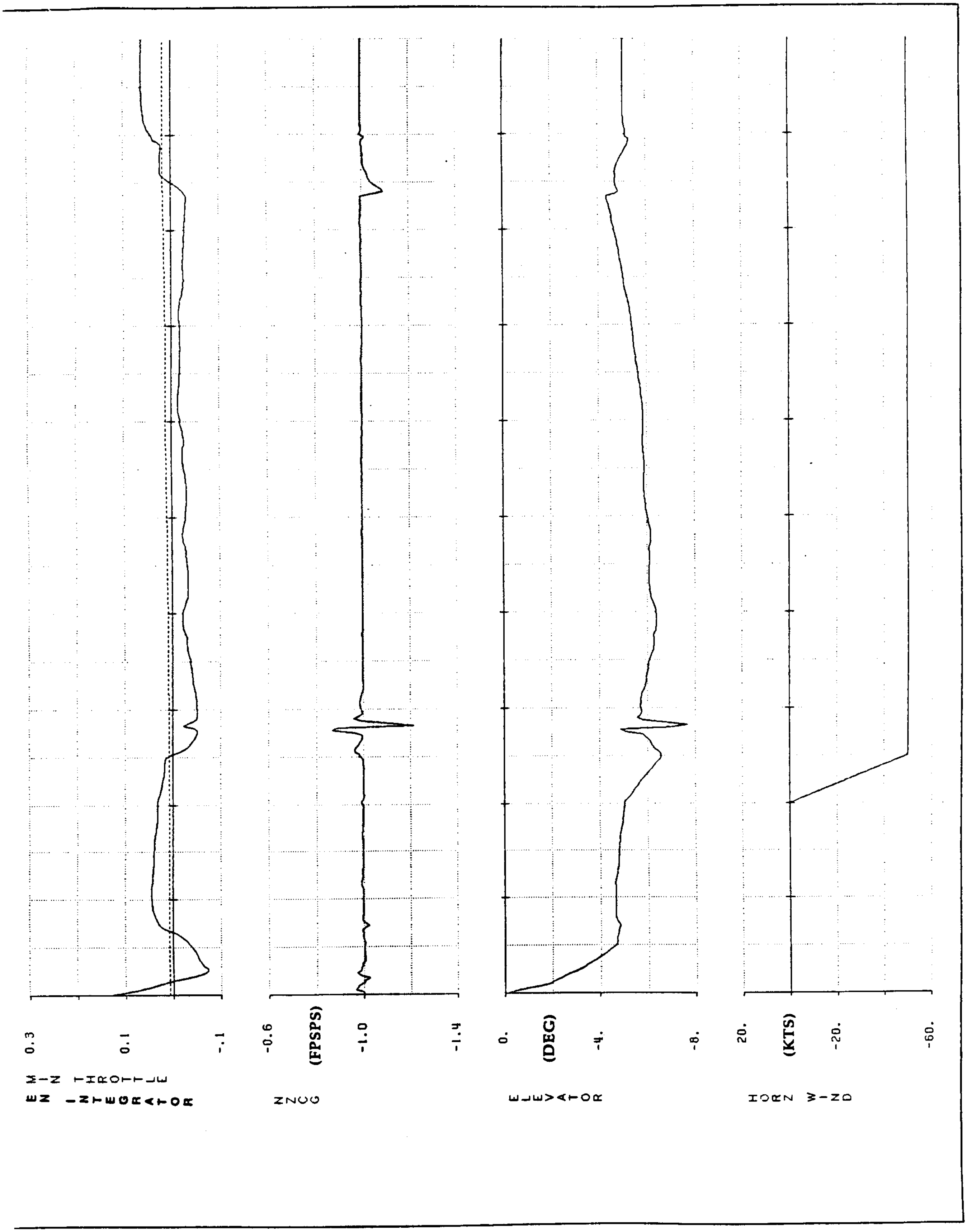
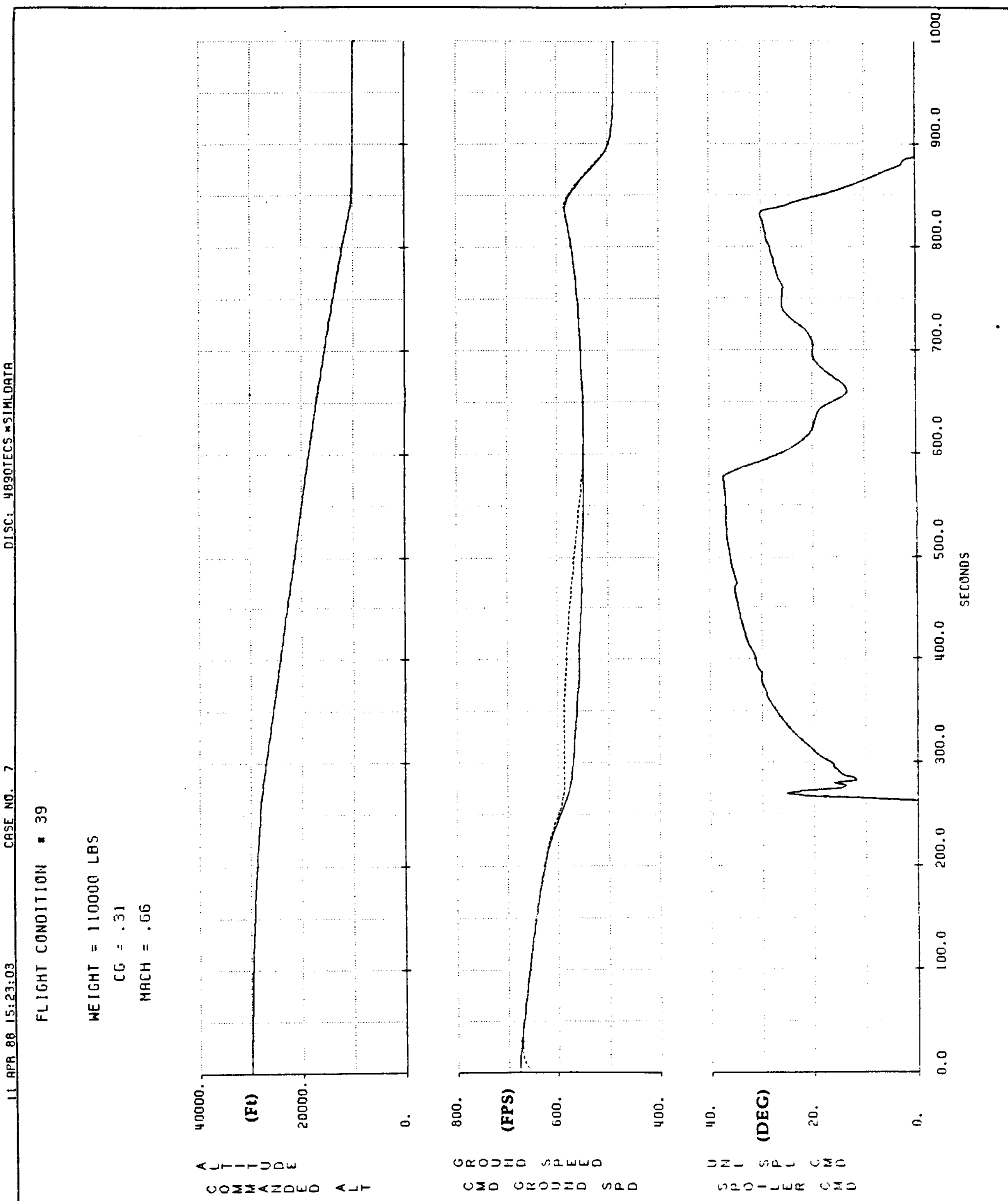
0.1
-.1
MIN THROTTLE
EN INTEGRATOR
-0.8
(FPSPS)
-1.0
-1.2
NZCG
4.
(DEG)
0.
-4.
ELEVATOR
20.
(KTS)
-20.
-60.
HORZ WIND



CALC	RORY O'SHAUGHNESSY	REVISED	DATE	-* TECS AUTOSPOILERS *- RESPONSE TO 50 KNOT TAIL WIND SHEAR, 737-200 AFT CG, MACH .84	CASE NO. 6
CHK	737-200-TECS 11 APR 88				DISC DATA
APP	.			THE BOEING COMPANY	PAGE

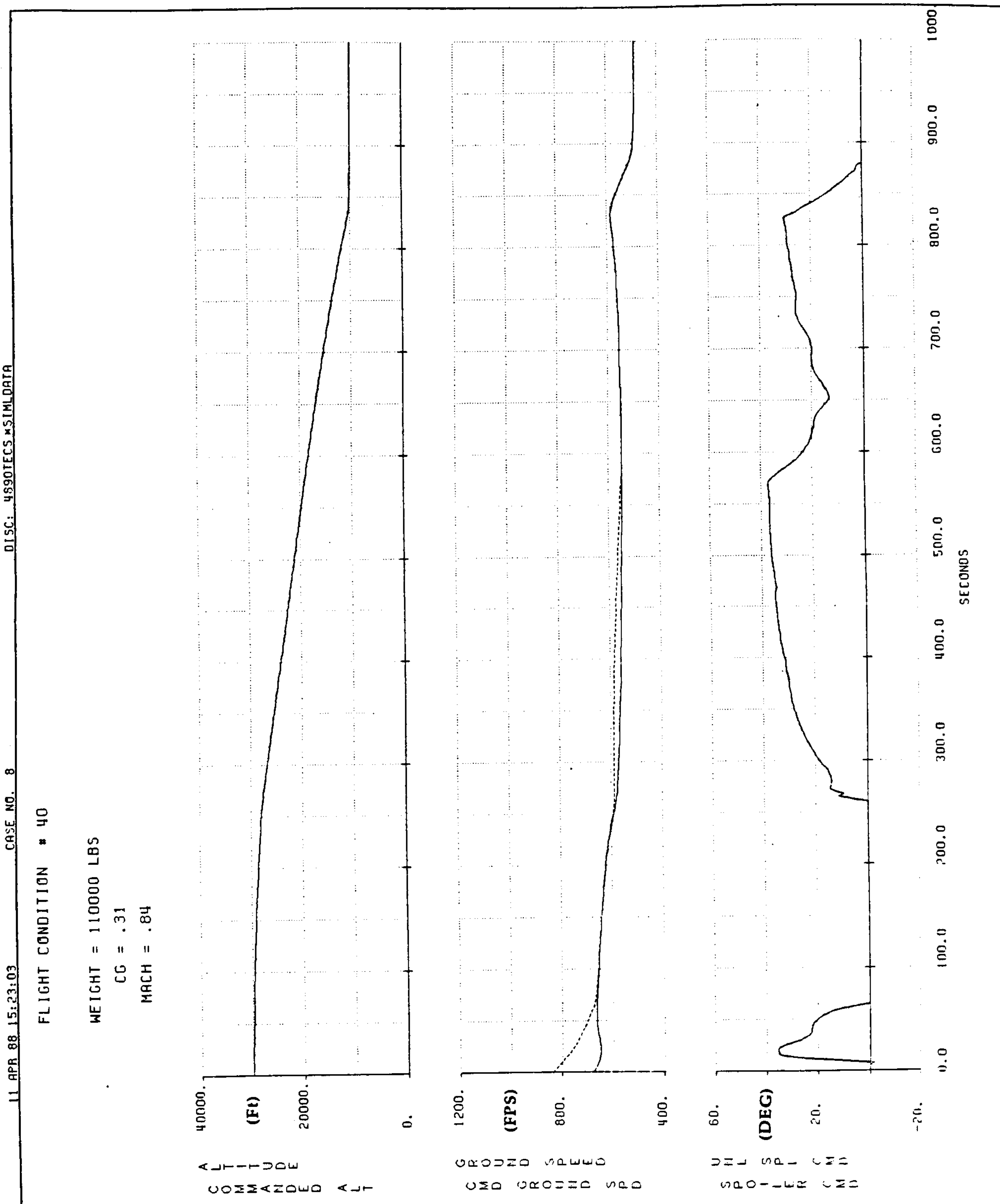

THROTTLE
INTEGRATOR
0.3
0.1
-.1
NZCG
-0.6
(FPSPS)
-1.0
-1.4
ELEVATOR
0.
(DEG)
-4.
-8.
HORZ WIND
20.
(KTS)
-20.
-60.



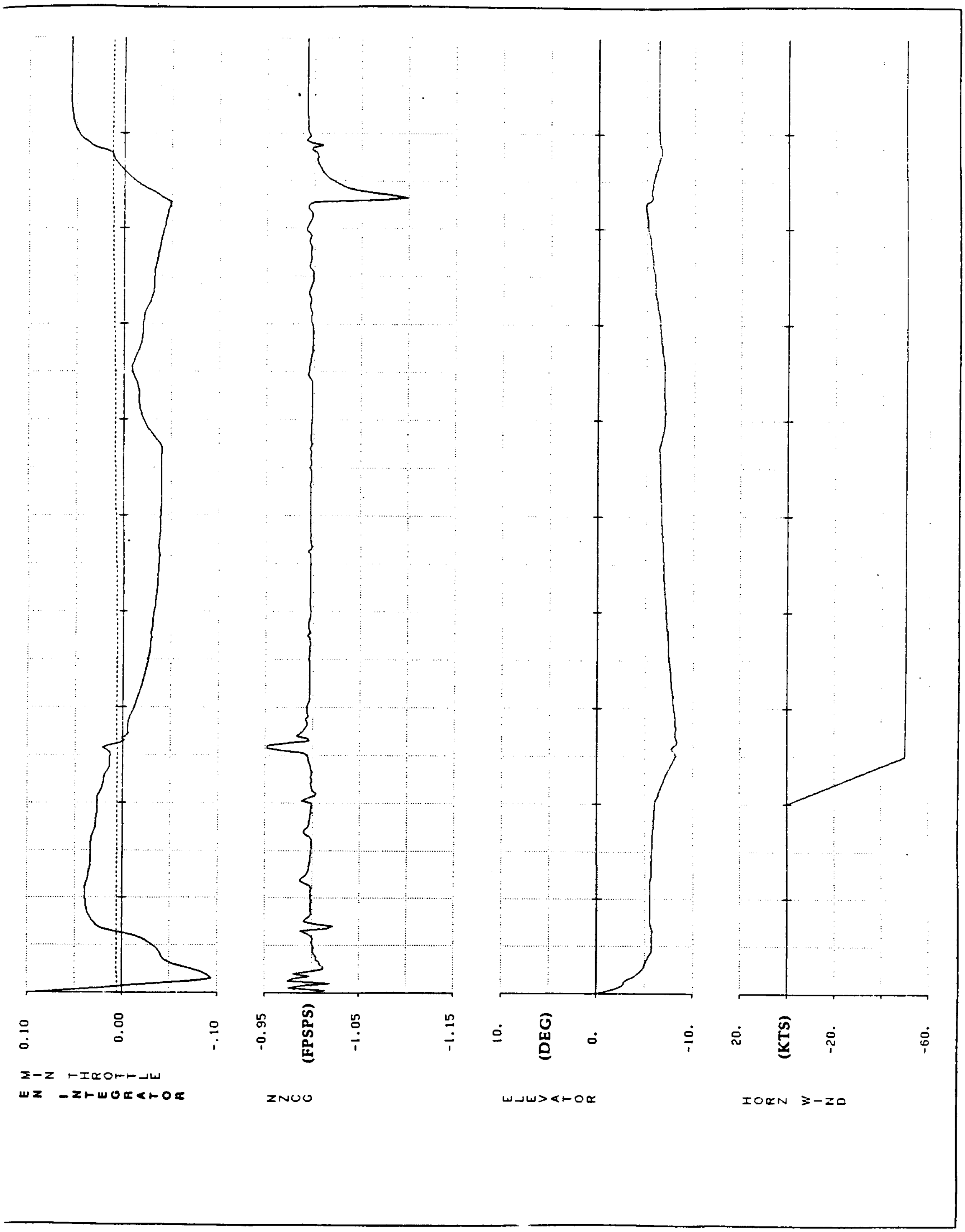
CALC	RORY O'SHAUGHNESSY	REVISED	DATE	-* TECS AUTOSPOILERS *- **RESPONSE TO 50 KNOT TAIL WIND SHEAR, HEAVY,** 737-200 **AFT CG, MACH .66**	CASE NO. 7
CHK	737-200-TECS 11 APR 88				DISC DATA
APP				THE BOEING COMPANY	PAGE

AFSC

0.15
0.05
-.05
MIN THROTTLE
INTEGRATOR
-0.8
(FPSPS)
-1.0
-1.2
NZCG
4.
(DEG)
0.
-4.
ELEVATOR
20.
(KTS)
-20.
-60.
HORZ WIND



CALC	RORY O'SHAUGHNESSY	REVISED	DATE	-- TECS AUTOSPOILERS -- RESPONSE TO 50 KNOT TAIL WIND SHEAR, HEAVY, 737-200 AFT CG, MACH .84	CASE NO. 8
CHK	737-200-TECS 11 APR 88				DISC DATA
APP				THE BOEING COMPANY	PAGE


0.10
0.00
-.10
-0.95
(FPSPS)
-1.05
-1.15
10.
(DEG)
0.
-10.
20.
(KTS)
-20.
-60.
NZCG
ELEVATOR
HORZ WIND

APPENDIX D: LINEAR ANALYSIS OF TECS - MANUAL SPOILERS

Print file "margins.txt" ***Page 1***

NOMINAL FLIGHT CONDITION

TECS IN MANUAL SPOILER MODE

STABILITY MARGINS

LOOP BROKEN AT PITCH COMMAND INPUT TO INNER LOOP

== GAIN MARGIN FROM THF TO THCM- ==

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	DB	FREQUE
1	8.249	0.9982E-01	20.02	1

== PHASE MARGIN FROM THF TO THCM- ==

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)	FREQUEN
1	0.5107	-81.91	98.09	0.

LOOP BROKEN AT SPOILER COMMAND OUTPUT TO PILOT DISPLAY

== GAIN MARGIN FROM DLYIN TO DSPLC- ==

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	DB	FREQUE
1	5.541	0.1701	15.39	0.

== PHASE MARGIN FROM DLYIN TO DSPLC- ==

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)	FREQUEN
1	0.6544	-93.44	86.56	0.

LOOP BROKEN AT SPEED COMMAND ERROR

== GAIN MARGIN FROM UI TO UOI- ==

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	DB	FREQUE
1	3.350	0.9873E-02	40.11	0.
2	18.84	0.6665E-04	83.52	2

== PHASE MARGIN FROM UI TO UOI- ==

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)	FREQUEN
1	0.7349E-01	-99.16	80.84	0.

LOOP BROKEN AT ALTITUDE COMMAND ERROR

== GAIN MARGIN FROM HI TO HO- ==

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	DB	FREQUE
1	0.5347	0.6553E-01	23.67	0.
2	13.34	0.1026E-04	99.78	2

== PHASE MARGIN FROM HI TO HO- ==

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)	FREQUEN
1	0.7819E-01	-110.2	69.84	0.

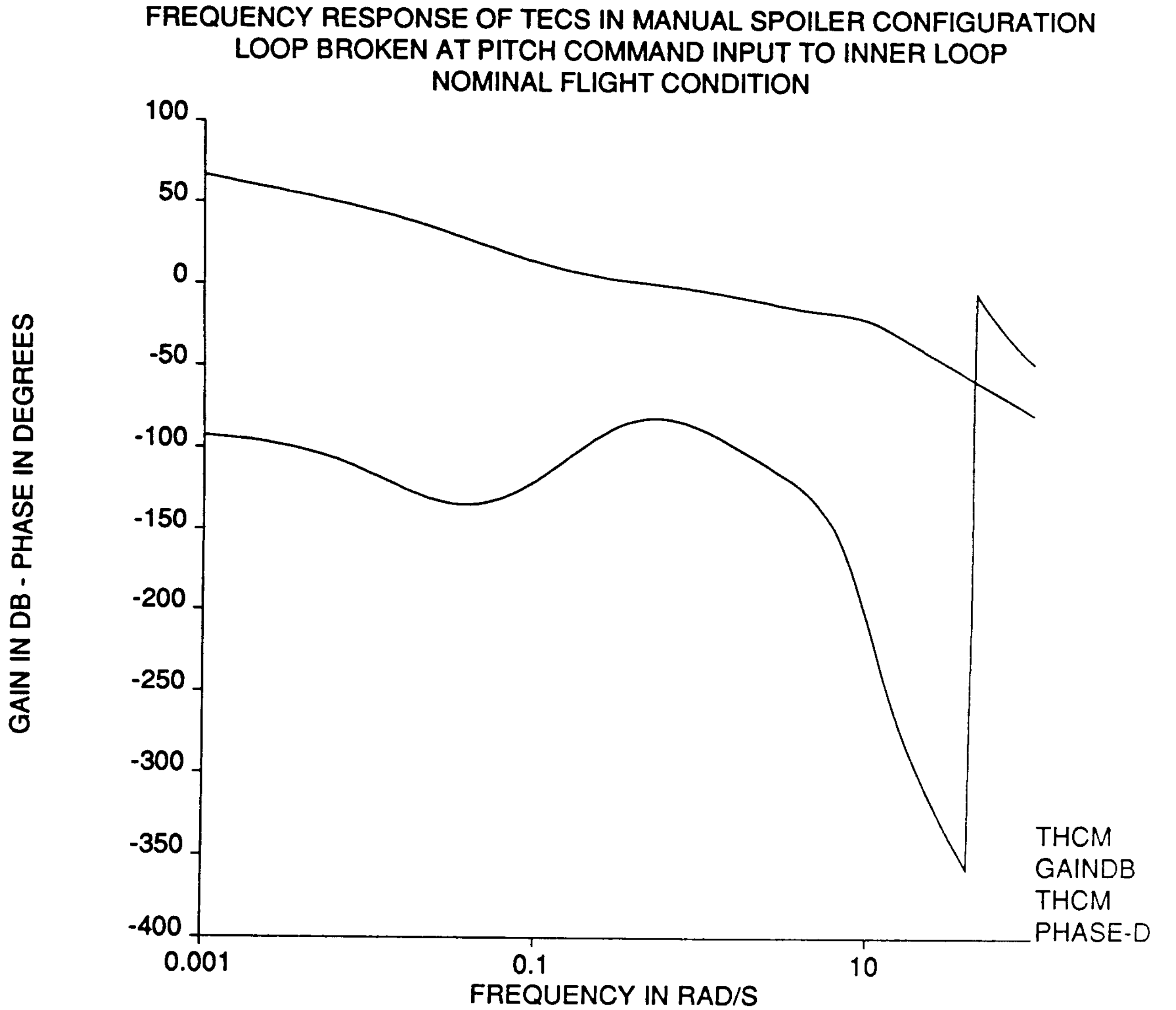
LOOP BROKEN AT ELEVATOR COMMAND

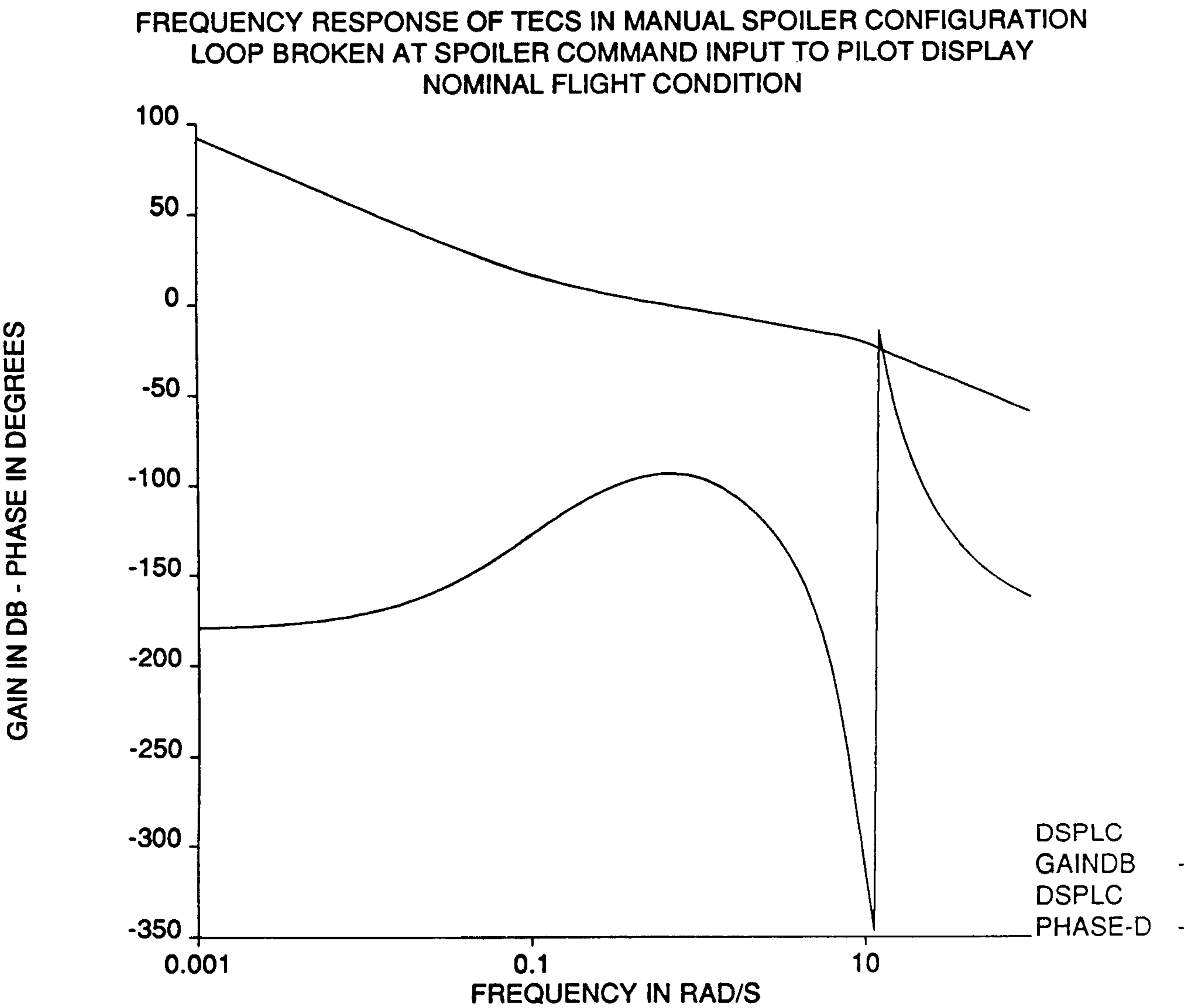
== GAIN MARGIN FROM DE TO DEC- ==

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	DB	FREQUE
1	0.5432E-01	3170.	-70.02	0.
2	0.1187	84.83	-38.57	0.
3	22.51	0.2053	13.75	3

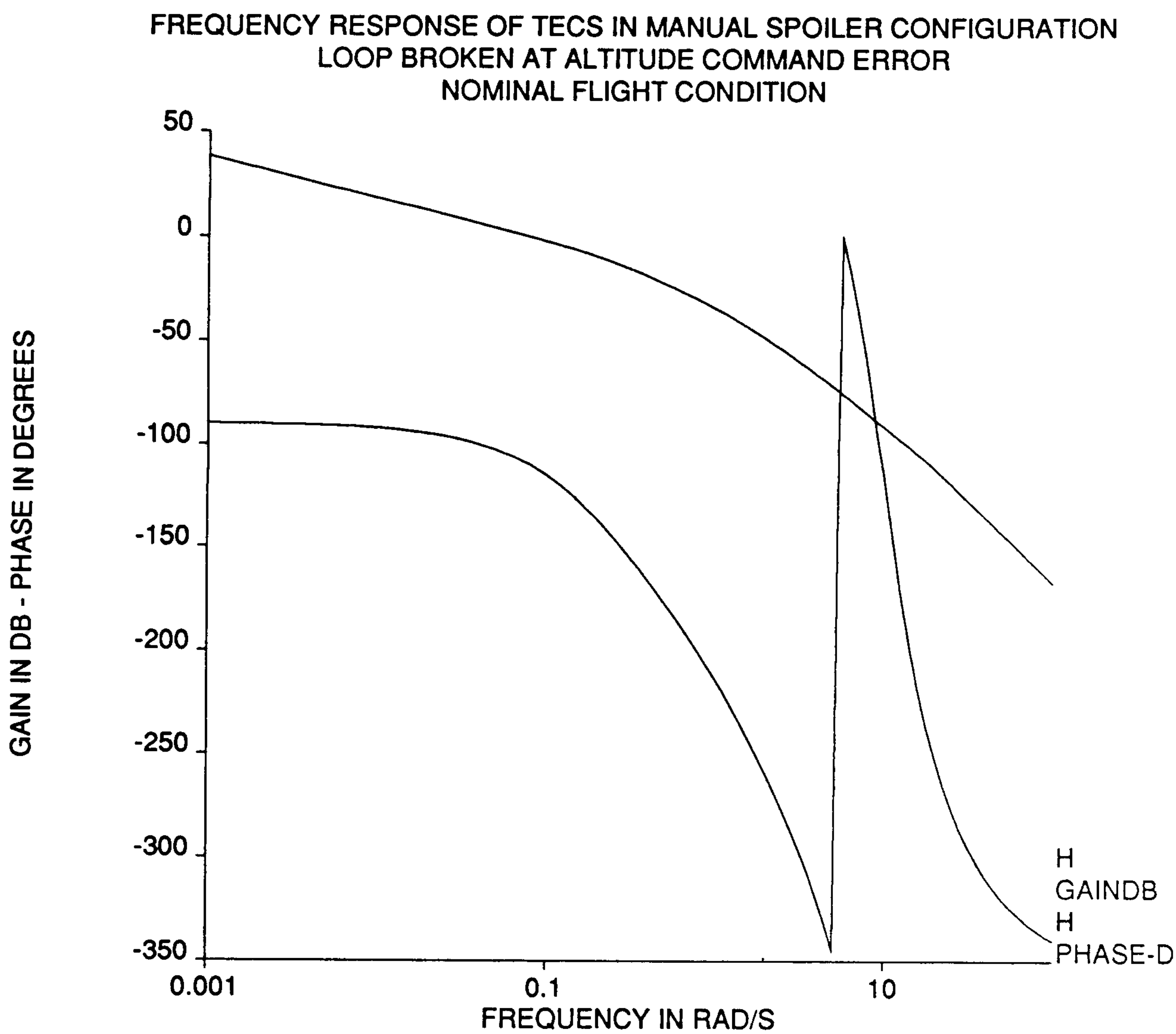
== PHASE MARGIN FROM DE TO DEC- ==

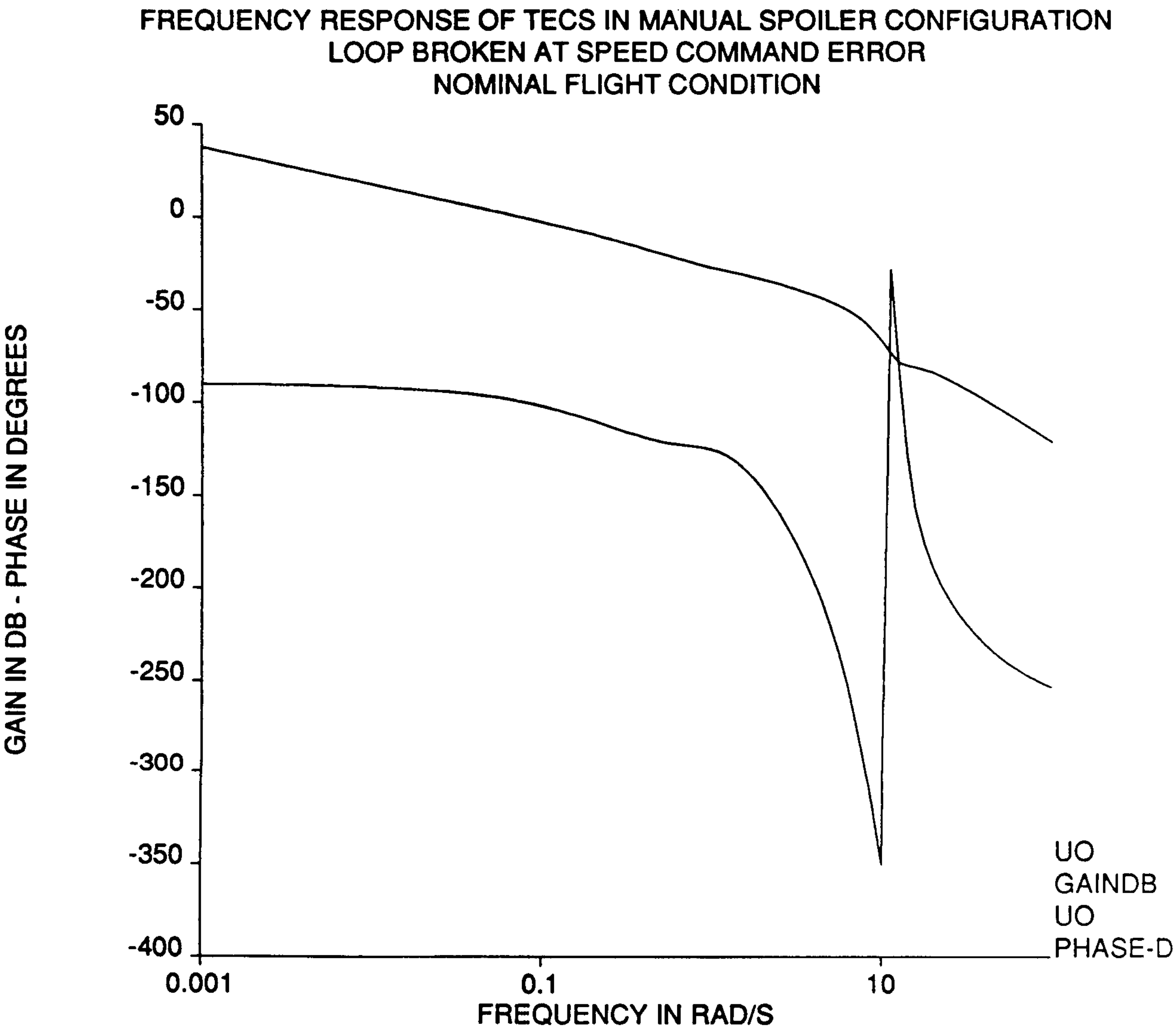
NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)	FREQUEN
1	8.046	-134.4	45.55	1


FREQUENCY RESPONSE OF TECS IN MANUAL SPOILER CONFIGURATION
LOOP BROKEN AT PITCH COMMAND INPUT TO INNER LOOP
NOMINAL FLIGHT CONDITION
GAIN IN DB - PHASE IN DEGREES
100
50
0
-50
-100
-150
-200
-250
-300
-350
-400
0.001
0.1
10
FREQUENCY IN RAD/S
THCM
GAINDB
THCM
PHASE-D

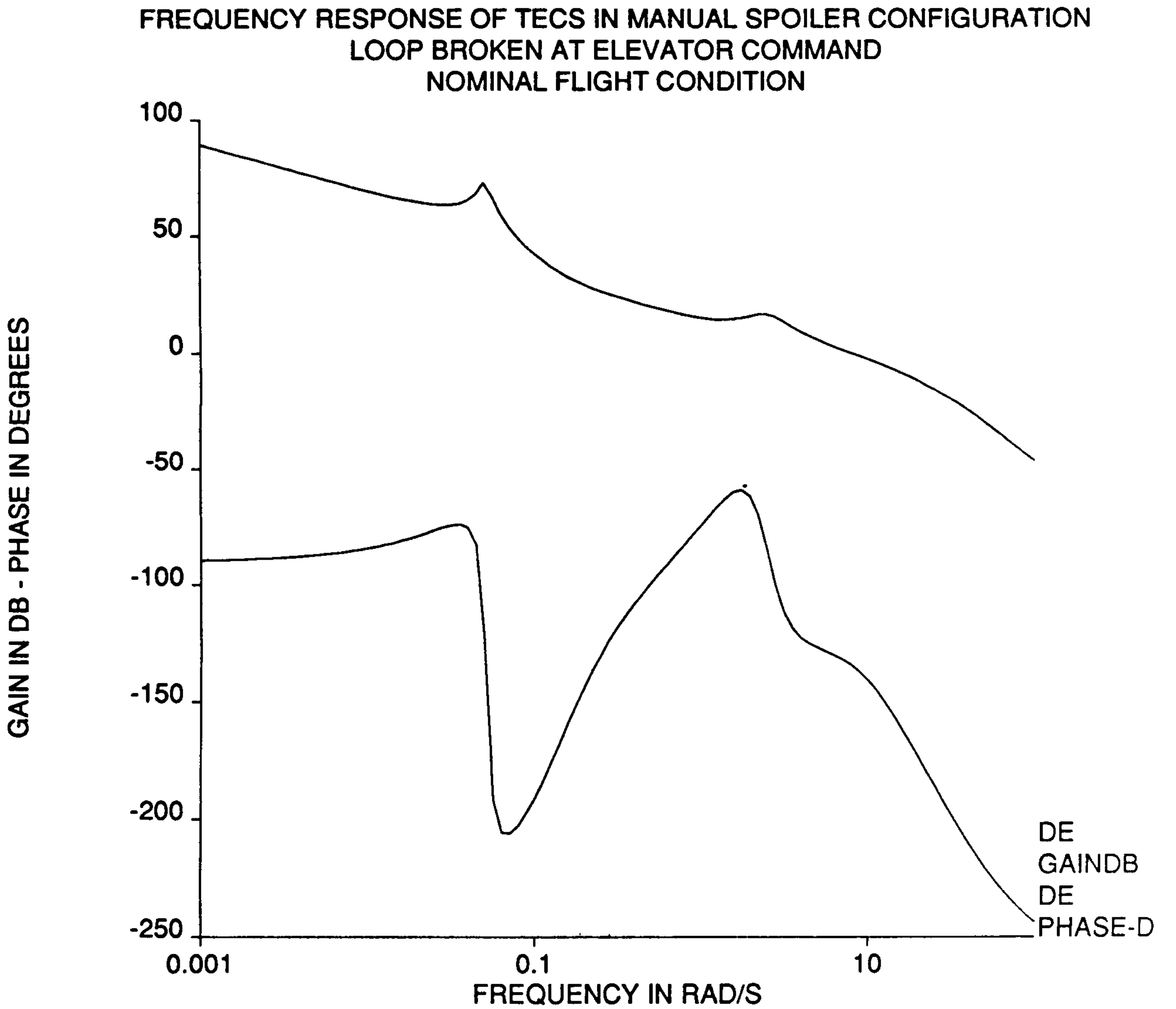


FREQUENCY RESPONSE OF TECS IN MANUAL SPOILER CONFIGURATION
LOOP BROKEN AT SPOILER COMMAND INPUT TO PILOT DISPLAY
NOMINAL FLIGHT CONDITION
GAIN IN DB - PHASE IN DEGREES
100
50
0
-50
-100
-150
-200
-250
-300
-350
0.001
0.1
10
FREQUENCY IN RAD/S
DSPLC
GAINDB -
DSPLC
PHASE-D -


FREQUENCY RESPONSE OF TECS IN MANUAL SPOILER CONFIGURATION
LOOP BROKEN AT ALTITUDE COMMAND ERROR
NOMINAL FLIGHT CONDITION
GAIN IN DB - PHASE IN DEGREES
50
0
-50
-100
-150
-200
-250
-300
-350
0.001
0.1
10
FREQUENCY IN RAD/S
H
GAINDB
H
PHASE-D



FREQUENCY RESPONSE OF TECS IN MANUAL SPOILER CONFIGURATION
LOOP BROKEN AT SPEED COMMAND ERROR
NOMINAL FLIGHT CONDITION
50
0
-50
-100
-150
-200
-250
-300
-350
-400
GAIN IN DB - PHASE IN DEGREES
0.001
0.1
10
FREQUENCY IN RAD/S
UO
GAINDB
UO
PHASE-D


FREQUENCY RESPONSE OF TECS IN MANUAL SPOILER CONFIGURATION
LOOP BROKEN AT ELEVATOR COMMAND
NOMINAL FLIGHT CONDITION
GAIN IN DB - PHASE IN DEGREES
100
50
0
-50
-100
-150
-200
-250
0.001
0.1
10
FREQUENCY IN RAD/S
DE
GAINDB
DE
PHASE-D

NOMINAL FLIGHT CONDITION

TECS IN SPEED ON ELEVATOR MODE

CLOSED LOOP EIGENVALUES

******** EIGENVALUES OF CLOSED-LOOP SYSTEM **********

COUNT	REAL PART	IMAG PART	DAMPING	FREQ (RAD/S)	FREQ (HZ)
1	0.0000	0.0000	0.0000	0.0000	0.0000
2	-2.1214E-02	0.0000	1.000	2.1214E-02	3.3764E-03
3	-2.5208E-02	0.0000	1.000	2.5208E-02	4.0121E-03
4	-0.1311	8.2393E-02	0.8467	0.1548	2.4642E-02
5	-0.1311	-8.2393E-02	0.8467	0.1548	2.4642E-02
6	-0.5000	0.0000	1.000	0.5000	7.9577E-02
7	-1.152	0.8524	0.8039	1.433	0.2281
8	-1.152	-0.8524	0.8039	1.433	0.2281
9	-4.646	8.824	0.4658	9.972	1.587
10	-4.646	-8.824	0.4658	9.972	1.587
11	-13.70	0.0000	1.000	13.70	2.180
12	-35.12	0.0000	1.000	35.12	5.589

STABILITY MARGINS

LOOP BROKEN AT ELEVATOR COMMAND

-- GAIN MARGIN FROM DE TO DEC- --

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	DB	FREQUE
1	20.83	0.1880	14.51	3

-- PHASE MARGIN FROM DE TO DEC- --

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)	FREQUEN
1	7.316	-132.1	47.87	1

LOOP BROKEN AT PITCH COMMAND INPUT TO INNER LOOP

-- GAIN MARGIN FROM THF TO THCM- --

NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	DB	FREQUE
1	4.068	0.1151	18.78	0

-- PHASE MARGIN FROM THF TO THCM- --

NO. OF CROSSING FREQUENCY (RAD/S) PHASE (DEG) PHASE MARGIN (DEG) FREQUEN

1	0.5181	-98.03	81.97	0.

LOOP BROKEN AT SPEED COMMAND ERROR

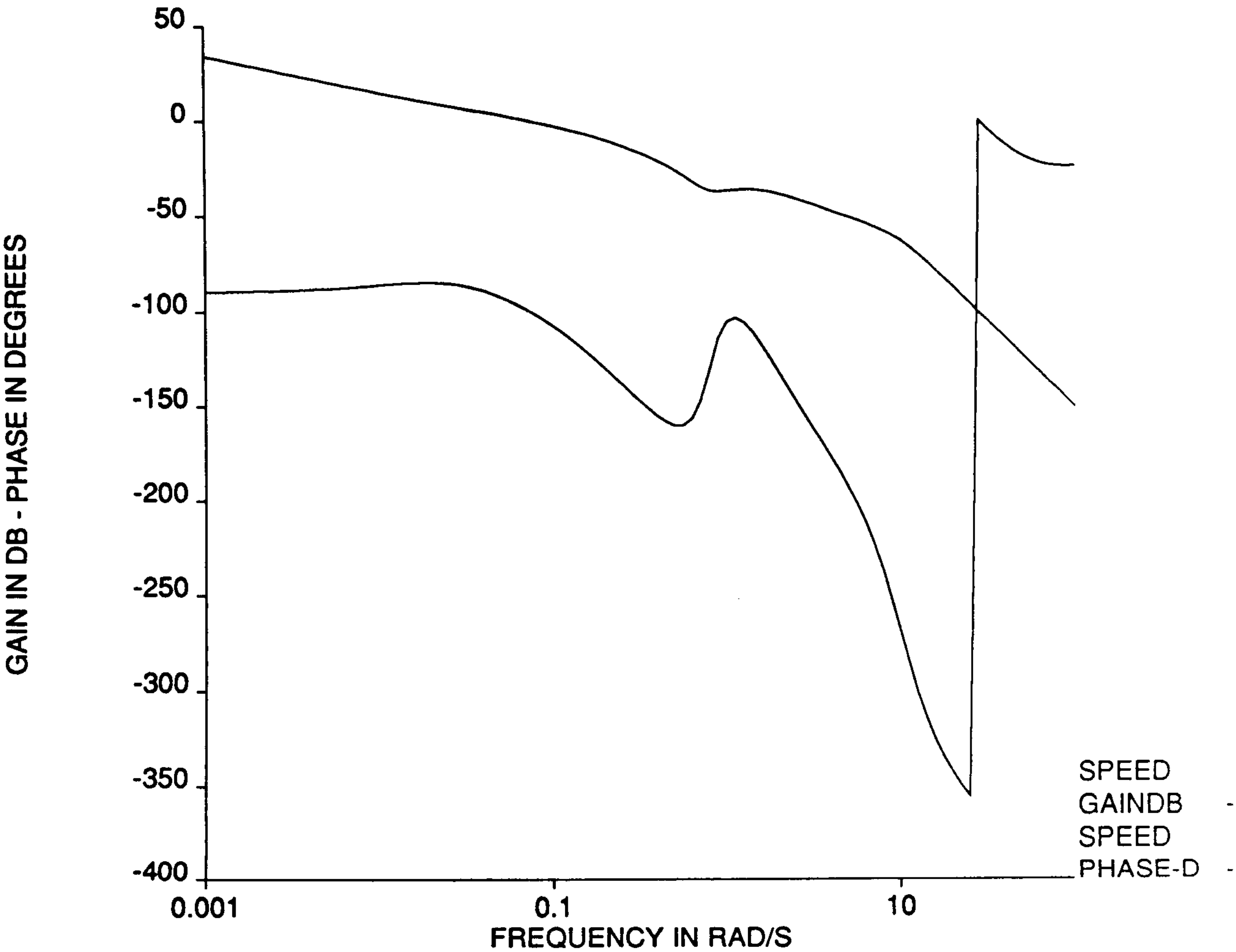
== GAIN MARGIN FROM UI TO UO- ==

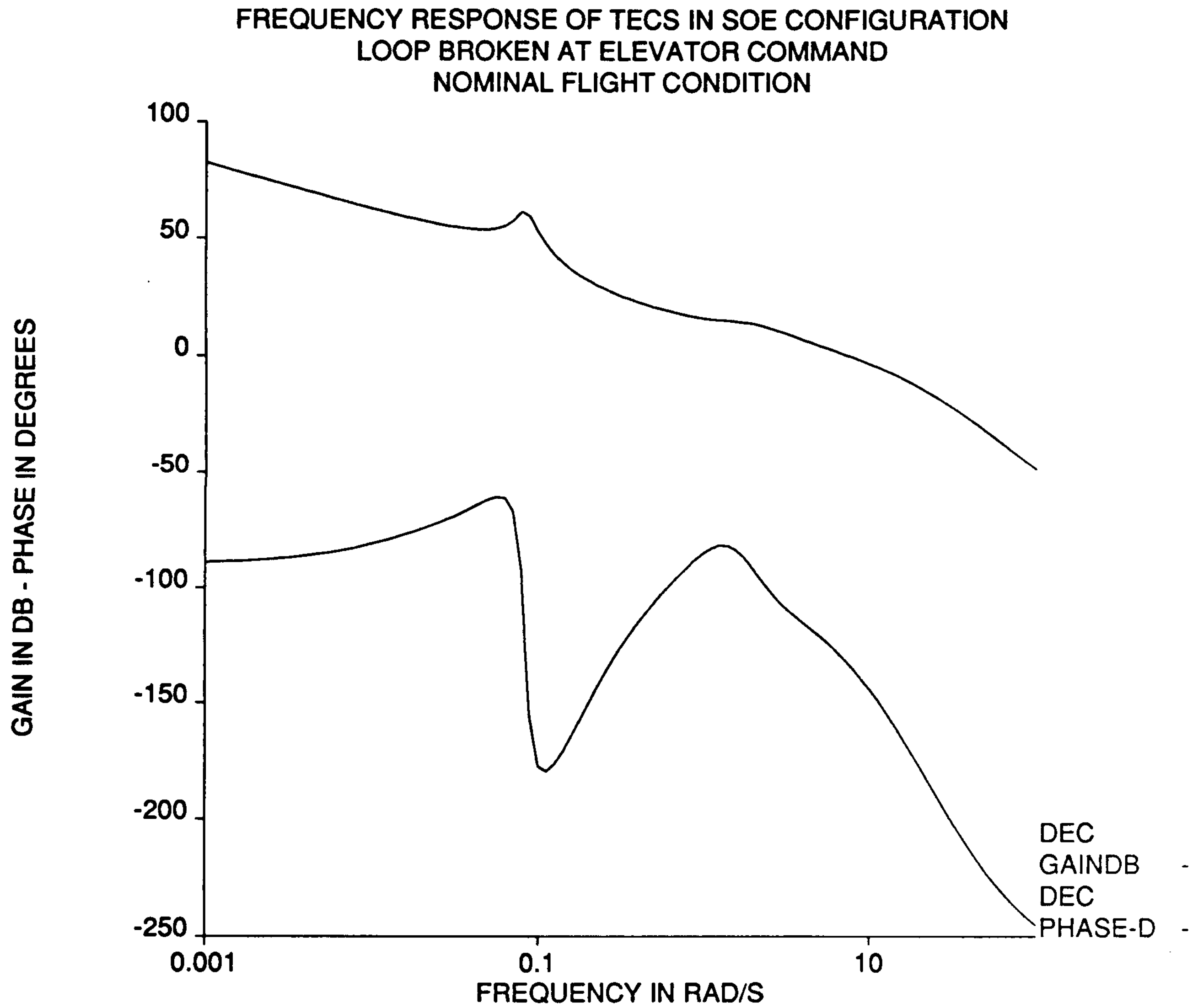
NO. OF CROSSING	FREQUENCY (RAD/S)	AMPLITUDE	DB	FREQUE
1	4.217	0.3683E-02	48.68	0.

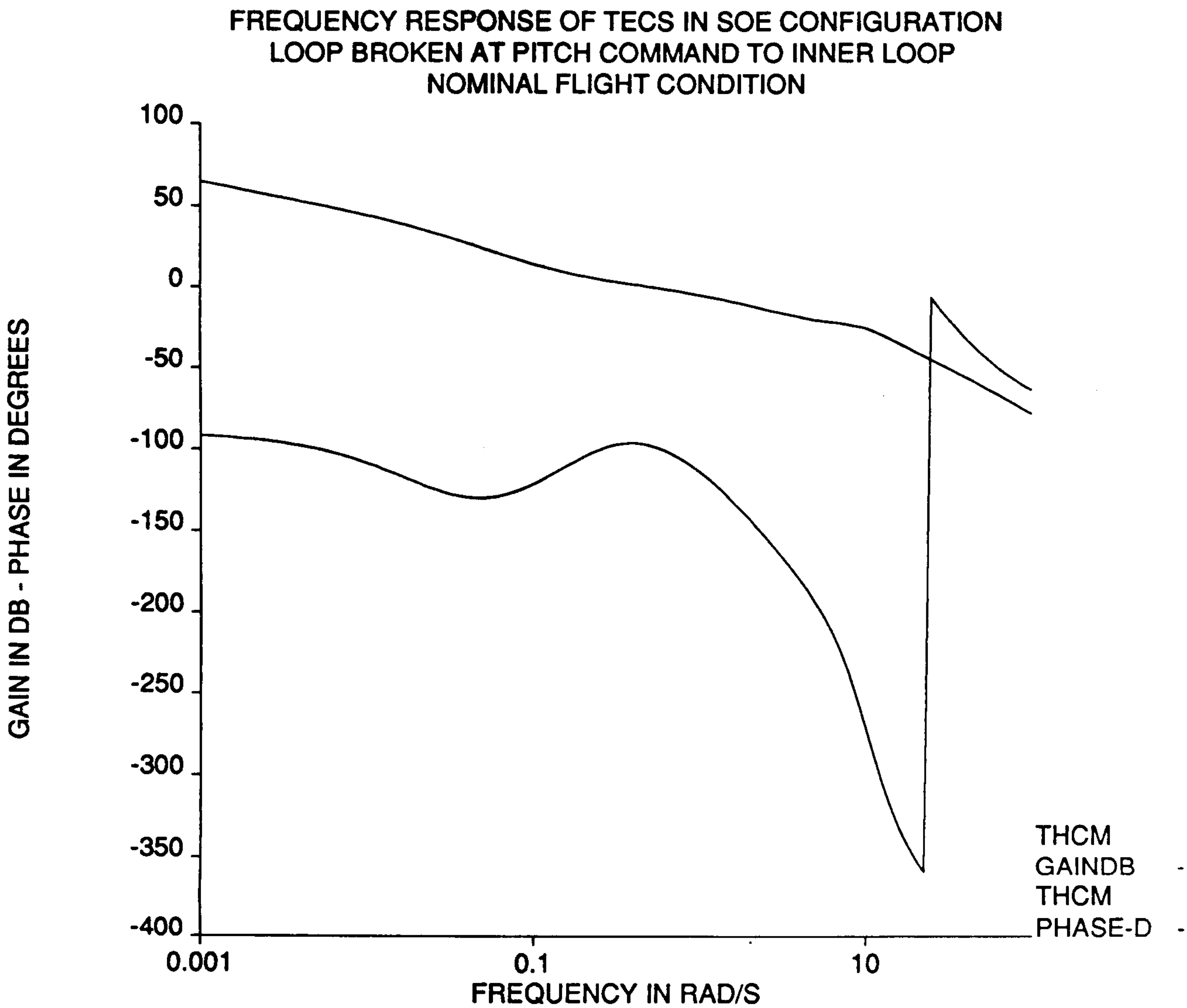
== PHASE MARGIN FROM UI TO UO- ==

NO. OF CROSSING	FREQUENCY (RAD/S)	PHASE (DEG)	PHASE MARGIN (DEG)	FREQUEN
1	0.7019E-01	-98.88	81.12	0.

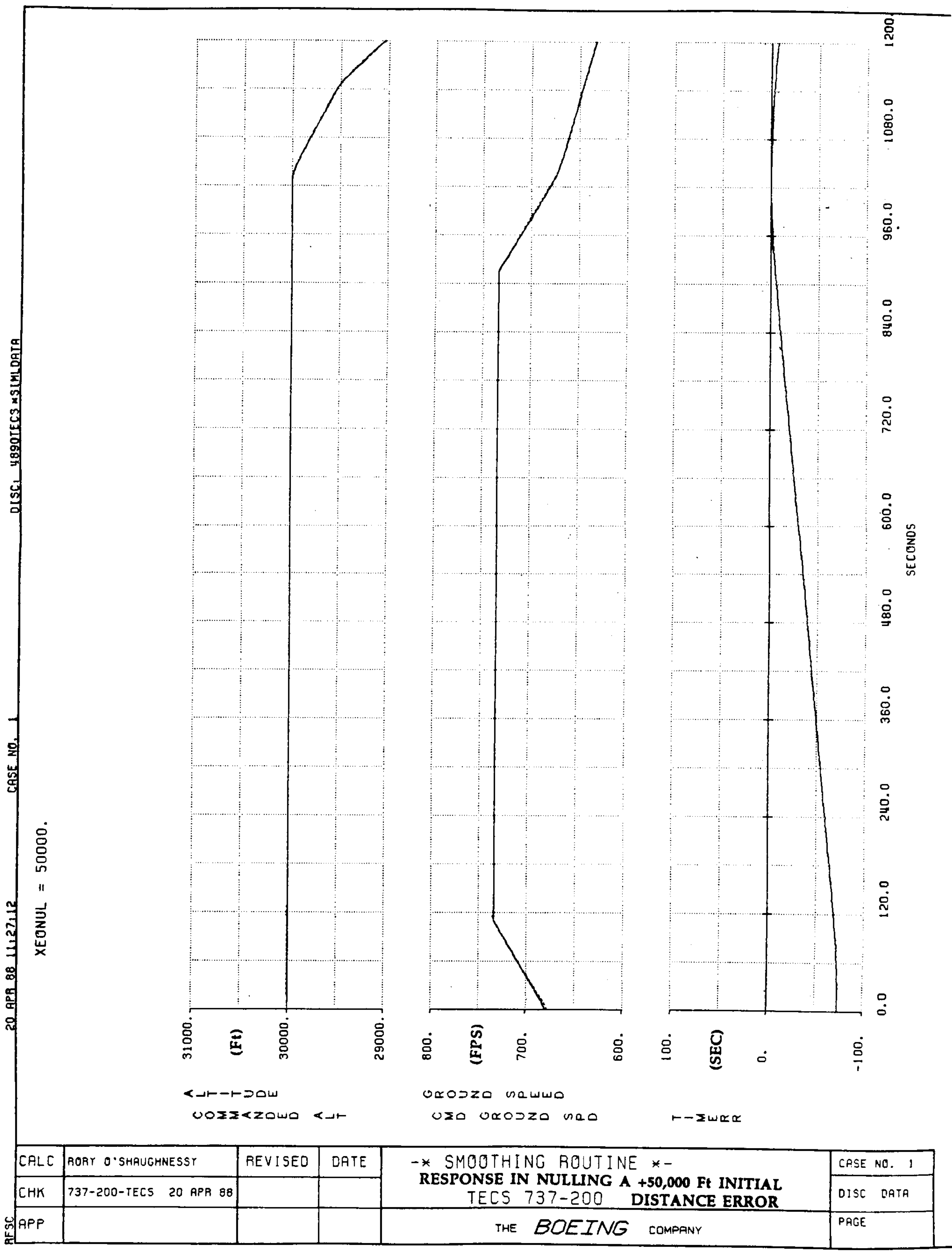
FREQUENCY RESPONSE OF TECS IN SOE CONFIGURATION
LOOP BROKEN AT SPEED COMMAND ERROR
NOMINAL FLIGHT CONDITION

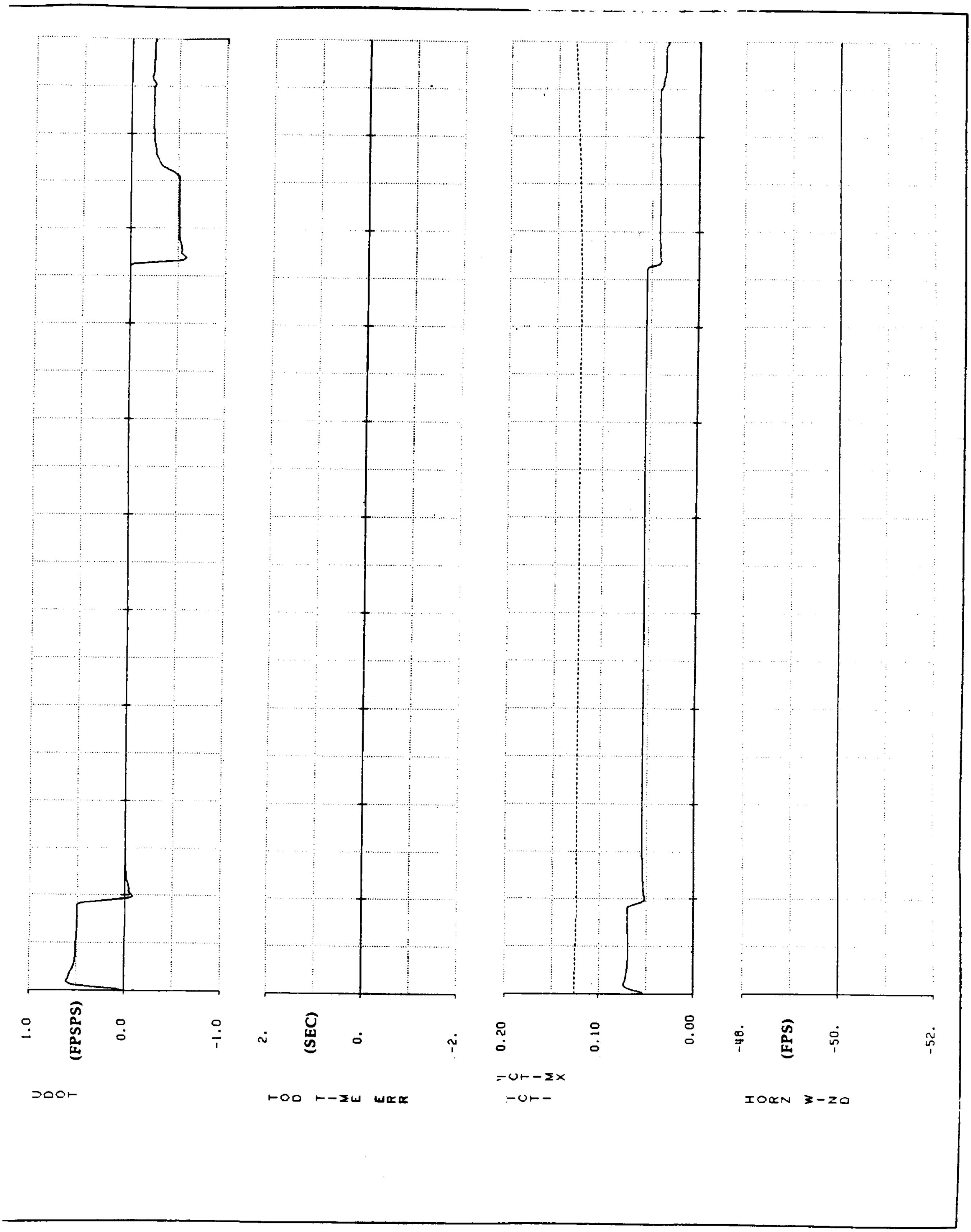


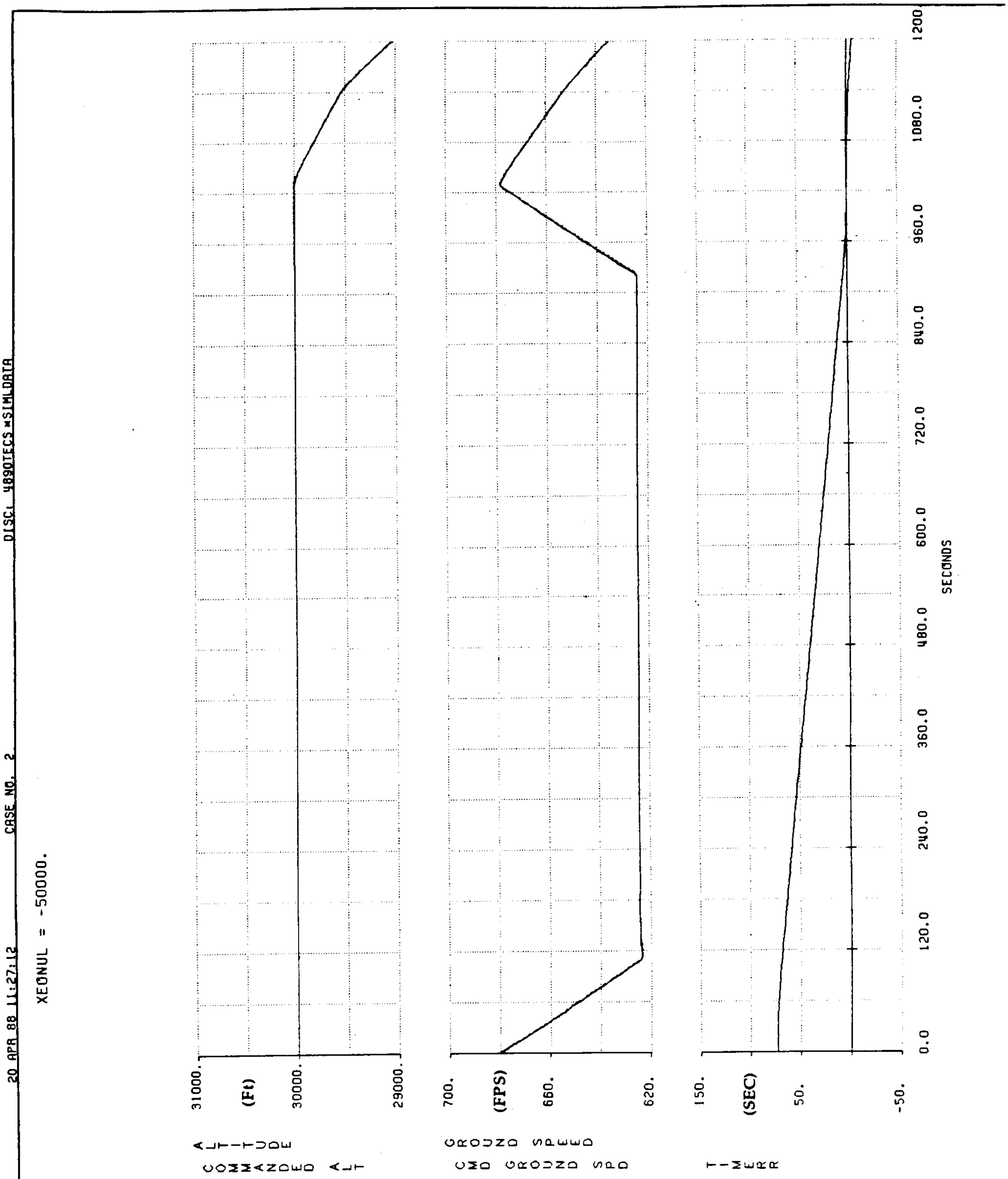

FREQUENCY RESPONSE OF TECS IN SOE CONFIGURATION
LOOP BROKEN AT ELEVATOR COMMAND
NOMINAL FLIGHT CONDITION
GAIN IN DB - PHASE IN DEGREES
100
50
0
-50
-100
-150
-200
-250
0.001
0.1
10
FREQUENCY IN RAD/S
DEC
GAINDB
DEC
PHASE-D


FREQUENCY RESPONSE OF TECS IN SOE CONFIGURATION
LOOP BROKEN AT PITCH COMMAND TO INNER LOOP
NOMINAL FLIGHT CONDITION
GAIN IN DB - PHASE IN DEGREES
100
50
0
-50
-100
-150
-200
-250
-300
-350
-400
0.001
0.1
10
FREQUENCY IN RAD/S
THCM
GAINDB -
THCM
PHASE-D -

APPENDIX E: NONLINEAR SIMULATION PLOTS - DISTANCE ERROR NULLING

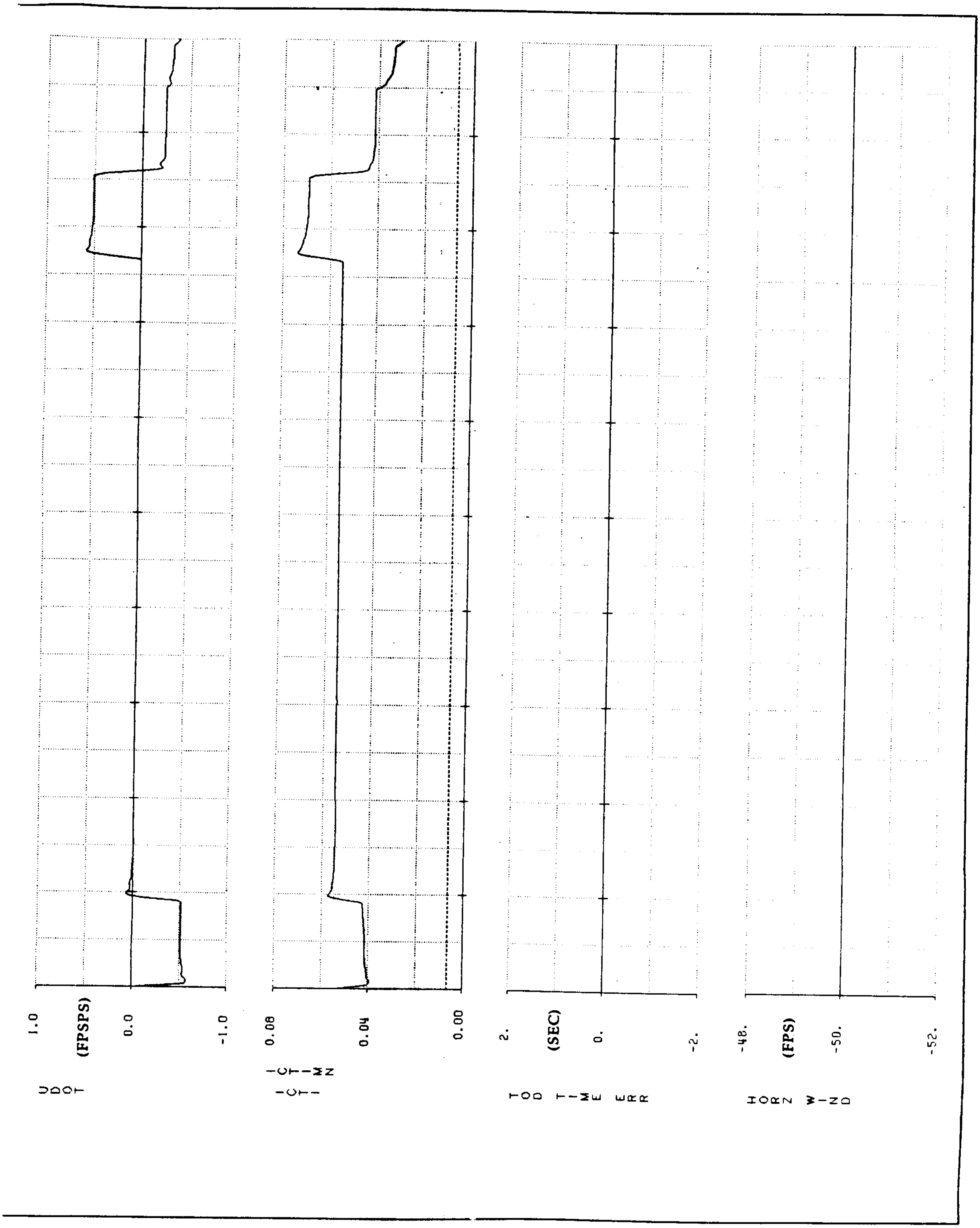



1.0
(FPSPS)
0.0
-1.0
UDOT
2.
(SEC)
0.
-2.
TOD TIME ERR
0.20
0.10
0.00
-48.
(FPS)
-50.
-52.
HORZ WIND

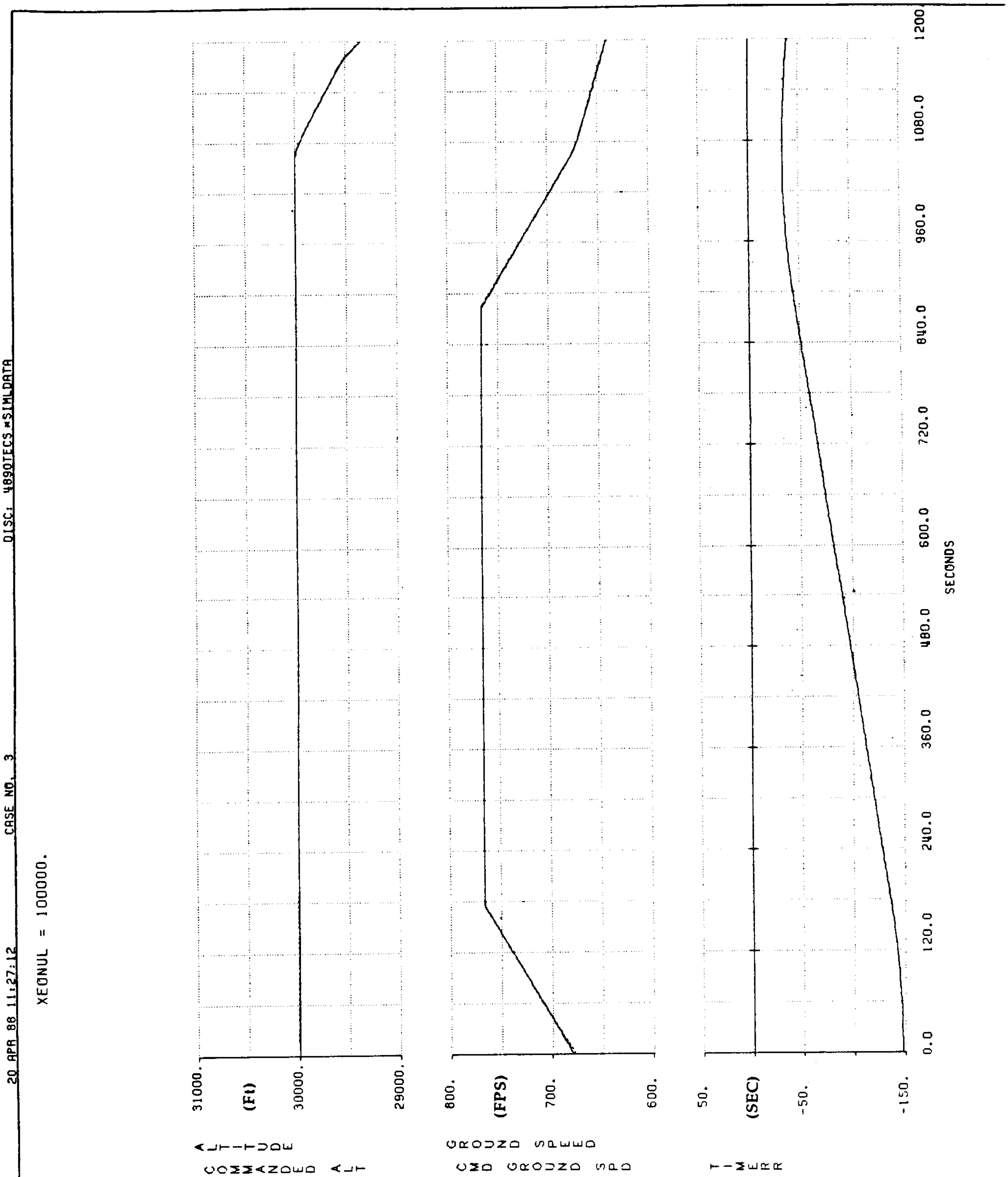


CALC	RORY O'SHAUGHNESSY	REVISED	DATE	-* SMOOTHING ROUTINE *- RESPONSE IN NULLING A -50,000 Ft INITIAL TECS 737-200 DISTANCE ERROR	CASE NO. 2
CHK	737-200-TECS 20 APR 88				DISC DATA
APP				THE BOEING COMPANY	PAGE

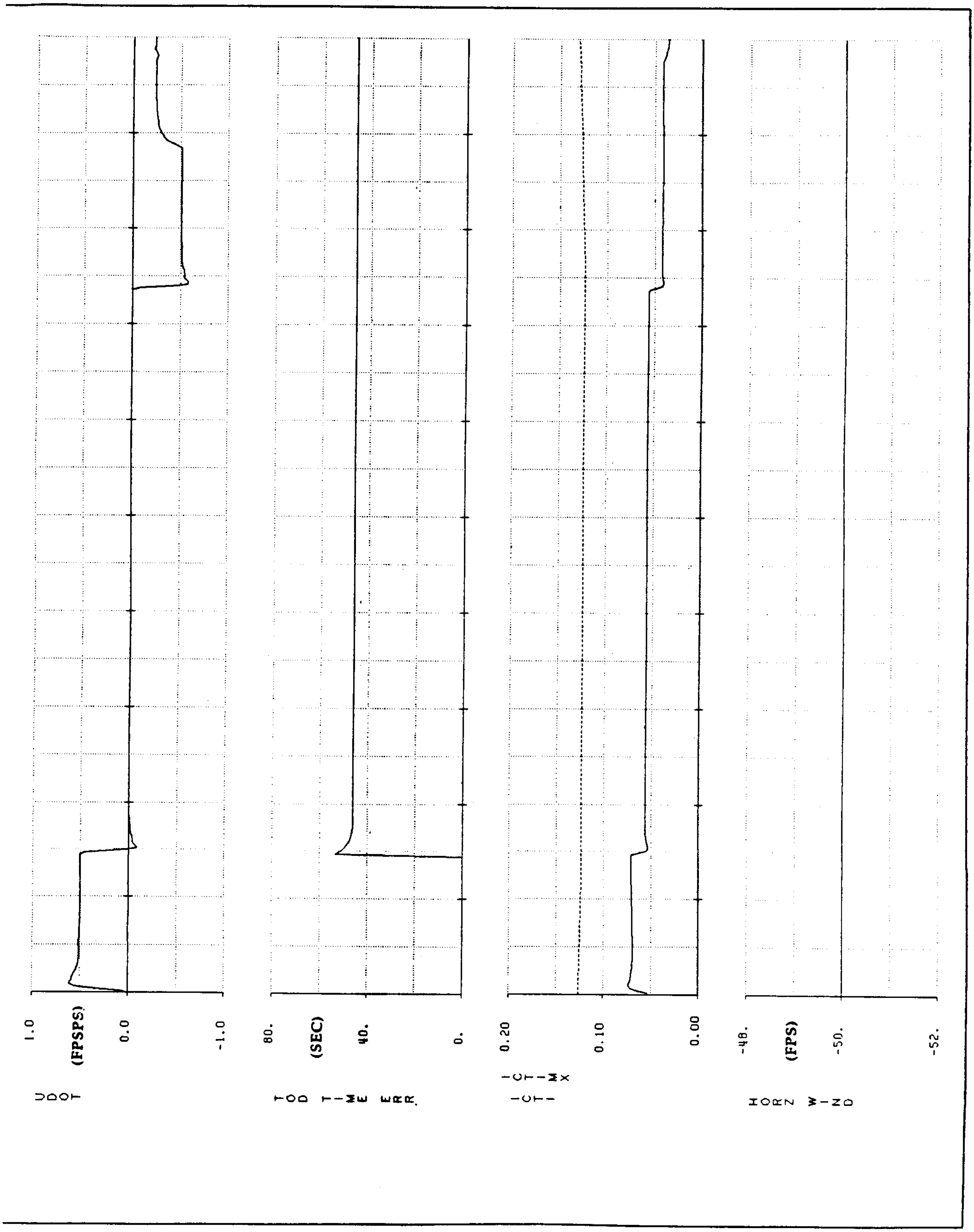
RFSC

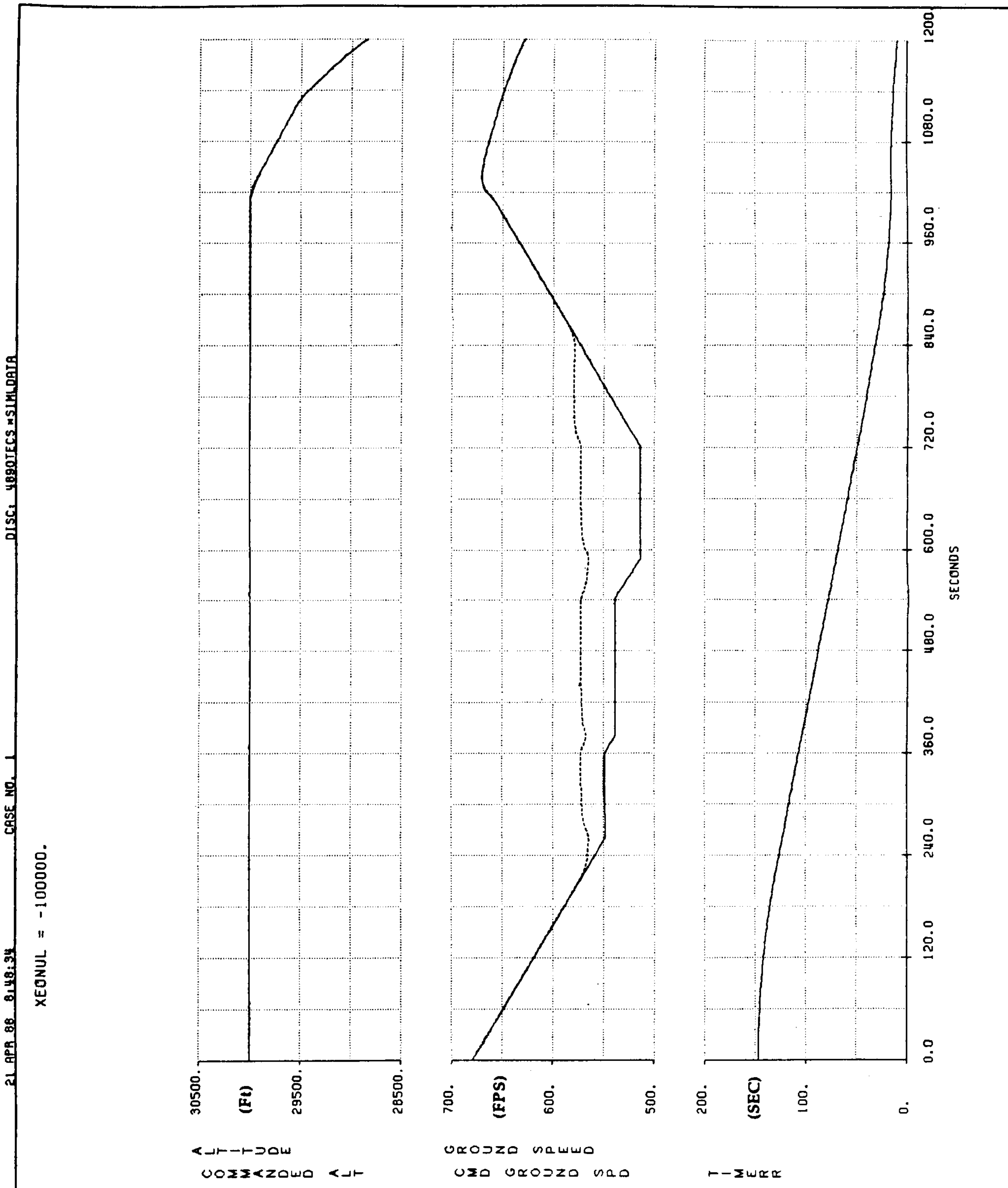


UDOT
1.0
(FPSPS)
0.0
-1.0
ICTMN
ICTI
0.08
0.04
0.00
TOD TIME ERR
2.
(SEC)
0.
-2.
HORZ WIND
-48.
(FPS)
-50.
-52.

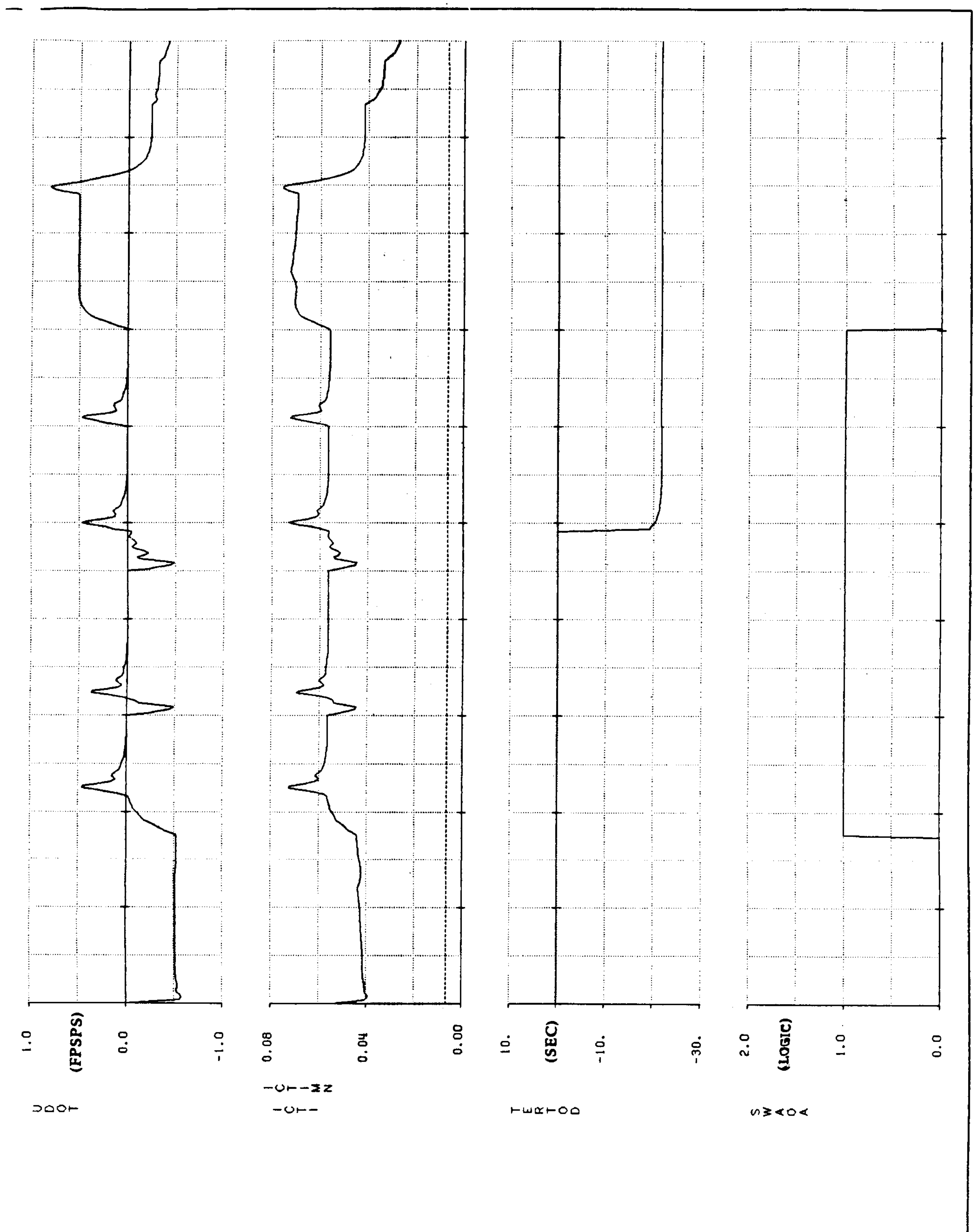


CALC	RORY O'SHAUGHNESSY	REVISED	DATE	-* SMOOTHING ROUTINE *- **RESPONSE IN NULLING A +100,000 Ft INITIAL** TECS 737-200 **DISTANCE ERROR**	CASE NO. 3
CHK	737-200-TECS 20 APR 88				DISC DATA
AFSC APP				THE *BOEING* COMPANY	PAGE


UDOT
(FPSPS)
1.0
0.0
-1.0
TOD TIME ERR.
(SEC)
80.
40.
0.
ICTMX
ICTI
0.20
0.10
0.00
HORZ WIND
(FPS)
-48.
-50.
-52.



CALC	RORY O'SHAUGHNESSY	REVISED	DATE	-* SMOOTHING ROUTINE *- **RESPONSE IN NULLING A -100,000 Ft INITIAL**	CASE NO. 1
CHK	737-200-TECS 21 APR 88			TECS 737-200 **DISTANCE ERROR**	DISC DATA
APP				THE BOEING COMPANY	PAGE


UDOT
1.0
(FPSPS)
0.0
-1.0
0.08
0.04
0.00
10.
(SEC)
-10.
-30.
2.0
(LOGIC)
1.0
0.0

REFERENCES

1 Lambregts, A. A., "Vertical Flightpath and Speed Control Autopilot Design Using Total Energy Principles", AIAA Paper 83-2239CP, August 1983.

2. Lambregts, A. A., "Operation of the Integrated Vertical Flightpath and Speed Control System", SAE Paper 831420, October 1983.

3. Lambregts, A. A., "Integrated System Design for Flight and Propulsion Control Using Total Energy Principles", AIAA Paper 83-2561, October 1983.

4. Bruce, K. R., Kelly, J. R. and Person, L. H., Jr., "NASA B737 Flight Test Results of the Total Energy Control System", AIAA Guidance, Navigation and Control Conference, AIAA 86-2143CP, August 1986.

5. Bruce, K. R., "Integrated Autopilot/Autothrottle based on Total Energy Control Concept: Design and Evaluation of Additonal Autopilot Modes", NASA CR-4131, April 1988.

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Final Report

16. Abstract

The integration of the Total Energy Control System (TECS) concept with 4D navigation is described. This integration was made to increase the operational capacity of modern aircraft and encourage incorporation of this increased capability with the evolving National Airspace System (NAS). Described herein is: 4D smoothing, the basic concepts of TECS, the spoiler integration concept, an algorithm for nulling out time error, speed and altitude profile modes, manual spoiler implementation, 4D logic, and the results of linear and nonlinear analysis.

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