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Block 20 (Continued)

Concepts such as urgency for action, instrumentation thresholds, pure pilot delay, pilot prediction, pilot lag, and pilot motor noise are treated. The resulting all digital closed loop multi-axis, multi-input, multi-output system is applied to aircraft of various classes including the F-5, A-7, 707, and T-33. Results are presented in tabular and graphical form with statistical tests run to show simulation validity and comparability with actual man-in-the-loop simulations. Additional applications of the digital simulator are made showing its usefulness in the overall concept of aircraft simulation.

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FOREWORD

The need for an all digital completely automatic presimulation capability becomes readily apparent as one views the complexity required to provide a hybrid or analog simulation of today's aircraft systems. This work is intended merely as the stepping off point for others to follow in implementing more complex and technically precise systems. It is my hope that this work shows the feasibility and practicality of an in depth study of today's simulation problems using the digital computer as a tool to feed those systems where man must in the end make the acceptance or rejection decision.

This research was accomplished from 1 Jan 74 to 28 Feb 75 while the author was assigned to the Systems Dynamics Branch of the Flight Control Division. The job order number assigned was 19860212. This technical report constitutes the final report for that project. This research was accomplished as a dissertation for the Air Force Institute of Technology and has also been published by AFIT as DS/EE/75-1.

In this report wherever the words Mil Spec Turbulence or 8785B or Mil Spec 8785B appear, they refer directly to the Background Information and User Guides for Mil-F-8785B(ASG), "Military Specification Flying Qualities of Piloted Airplanes."

Copies of the FORTRAN IV digital program or listings are available on request from

AFFDL/FGD
Multi Axis Pilot Model (19860212)
Wright-Patterson AFB, Ohio 45433



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List of Symbols

A	-- J_{xz}/I_{xx} , a ratio of inertias
B	-- J_{xz}/I_{zz} , a ratio of inertias
C_e^b	-- transformation matrix from earth to body axes
$C_b^{b'}$	-- transformation matrix from body to perturbed body axes
\bar{F}	-- the total force vector
F_x, F_y, F_z	-- the components of force in the x, y, and z directions
G_θ	-- pitch SAS feedback gain on θ
G_ϕ	-- roll SAS feedback gain on ϕ
\bar{H}	-- angular momentum
I	-- product of inertia
J	-- cross product of inertia
K_q	-- pitch SAS feedback gain on q
$K_{\dot{q}}$	-- pitch SAS feedback gain on \dot{q}
K_{azs}	-- pitch SAS feedback gain on a_{zp}
K_{paug}	-- roll SAS feedback gain on p
K_{raug}	-- yaw SAS feedback gain on r
L	-- rolling moment
L_u, L_v, L_w	-- scale factors used in the gust model
M	-- pitching moment
N	-- yawing moment
P	-- total roll rate
Q	-- total pitch rate
R	-- total yaw rate
U	-- forward velocity
V	-- lateral velocity

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\bar{v}_T	-- total velocity of the aircraft
w	-- downward velocity
x	-- component of force in the x direction
y	-- component of force in the y direction
z	-- component of force in the z direction
a_{zp}	-- normal acceleration at the pilot's station
b	-- wingspan, feet
h	-- altitude, feet
l_x	-- distance from aircraft cg to pilot's station, feet
m	-- mass of the aircraft, slugs
m_a	-- actual mass
m_r	-- reference mass
p	-- perturbation roll rate
p_g	-- roll rate component of the gust model
q	-- perturbation pitch rate
q_g	-- pitch rate component of the gust model
r	-- perturbation yaw rate
r_g	-- yaw rate component of the gust model
u	-- perturbation forward velocity
u_g	-- forward velocity component of the gust model
v	-- perturbation lateral velocity
v_g	-- lateral velocity component of the gust model
w	-- perturbation downward velocity
w_g	-- downward velocity component of the gust model
t	-- time, seconds
t^*	-- time of application of a determined control effort
x,y,z	-- component directions along a body axis coordinate system

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α	-- angle of attack
α_g	-- w_g/V_T ; downward velocity component of the gust model
β	-- sideslip
β_g	-- v_g/V_T ; lateral velocity component of the gust model
γ	-- flight path angle
$\delta e, \delta a, \delta r$	-- control surface deflection of the elevator, aileron, or rudder
$\delta e_c, \delta a_c, \delta r_c$	-- commanded control surface deflection of the elevator, aileron, or rudder
$\delta e_{aug}, \delta a_{aug}, \delta r_{aug}$	-- augmentation caused control surface deflection of the elevator, aileron, or rudder
δr_{coord}	-- deflection of the rudder caused by the aileron interconnect
δx	-- aug control surface deflection
δx_c	-- aug commanded control surface deflection
ζ	-- damping ratio
η	-- noise source
θ	-- perturbation pitch angle
λ	-- localizer deviation angle
π	-- constant; 3.14159...
ρ_i	-- noise to signal ratio
σ	-- standard deviation
σ_i	-- standard deviation of i
τ_a	-- time constant of the elevator actuator
τ_q	-- time constant of the pitch damper
τ_{con}	-- time constant of the aileron actuator
τ_{con2}	-- time constant of the rudder actuator
τ_{raug}	-- time constant of the yaw damper

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ϕ	-- perturbation roll angle
ψ	-- perturbation yaw angle
ω	-- radial frequency
ω_b	-- break frequency of a linear differential equation
ω_n	-- natural frequency
$\Phi_i(\omega)$	-- power spectral density
θ	-- pitch angle of the aircraft
Φ	-- roll angle of the aircraft
Ψ	-- yaw angle of the aircraft
\circ	-- trim condition (subscript)
$\frac{d(\)}{dt}$	-- time derivative
-	-- primed axis system notation
-	-- vector
-	-- unit vector
() \times ()	-- cross product

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ALL DIGITAL SIMULATION FOR

MANNED FLIGHT IN TURBULENCE

I. Introduction

The man-machine interface problem which is exemplified by today's modern aerospace systems has been a subject of much discussion [1]. Yet a reliable method of predicting man's performance and his opinion of these complex systems is still not readily available although both conventional [2] and modern [3,4,5] control theory have been applied to provide digital, analog, and hybrid simulation with methods for closing the feedback control loop without resorting to actually placing the non-repeatable human subject in the control loop. Numerical difficulties, search techniques, and non-uniqueness have hindered progress using these methods.

This research addresses the particular problem of digitally simulating manned flight in modern conventional aircraft ranging in size and maneuverability from the Northrop F-5 to the Boeing 707. This multi-axis control problem is considered with the pilot assisted by conventional stability augmentation systems but hindered by a requirement to fly in a turbulent environment. The simulation pilot is taught to perform five different but common tasks: (1) a pitch attitude hold task, (2) a roll attitude hold task, (3) a heading attitude hold task, (4) an attitude hold task consisting of (1), (2), and (3) simultaneously, and (5) the power approach or landing task. The purpose of this study is to provide a completely automatic and reliable method of performing manned closed loop simulation including a simulated pilot in any conventional aircraft under turbulent environmental conditions using digital computation methods.

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This problem is attacked by designing a pilot model capable of decision making and constrained by the known human limitations. The model considers the control problem based on the urgency for action concept whereby the pilot considers his available alternatives and, weighing them one against the other, takes action on that alternative requiring his attention most urgently [6].

The following assumptions are made in conducting this study and are considered to be a good balance between reality and practicality:

- 1) The aircraft is assumed to be a constant mass rigid body possessing symmetry with respect to its centerline.
- 2) The earth is considered an inertial reference.
- 3) The aircraft is assumed to travel a steady-state or equilibrium path and is perturbed only slightly from this path during the flight time under consideration.
- 4) The aircraft equations of motion can be linearized and decoupled.
- 5) The pilot is presented a standard set of instrumentation from which he determines errors and control actions subject to the constraints that errors in pitch and glideslope tracking will be corrected by elevator deflections, errors in roll will be corrected by aileron deflections, and errors in heading and localizer tracking will be corrected by using the rudder. This assumption is made for practicality with the full realization that in some aircraft longitudinal errors will be corrected with power setting changes and some lateral errors corrected here by rudder would be corrected in reality by aileron deflections.
- 6) A turbulent environment is adequately represented by the Dryden Spectral Model described by Military Specification 8785B [7].

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The original contributions made by this research are:

- 1) the development of a multi-axis, multi-input, multi-output pilot/aircraft system with the pilots' actions coupling the aircraft loops
- 2) the development in Chapter V of a pilot model which uses concepts from both conventional and optimal control theory [8,9,10]
- 3) the development of a means of digitally solving the turbulence equations of Chapter IV [25]
- 4) the development of a pilot model capable of handling aircraft from different classes [7:10]
- 5) the application of statistical testing to verify the digital simulations adequately compare to actual manned simulations
- 6) the implementation of the above concepts on a high speed digital computer.

The digital simulator runs in near real time using a relatively small core requirement (50K octal) and thus provides a quick, accurate, and straightforward means to the investigation of aircraft in manned flight under turbulent conditions.

The method of presentation of this study is as follows: Chapter II will derive, as simply as possible, the necessary aircraft equations of motion. Chapter III will add on a common generalized stability augmentation system. In Chapter IV, the turbulent environment will be considered. Chapter V introduces the digital pilot model developed in this study. Chapter VI ties together the models presented in the first five chapters and discusses problems peculiar to computer implementation and other special topics. Chapter VII describes the four major aircraft systems studied in an attempt to validate the adequacy

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of the digital pilot model. Chapter VIII presents the results of studying the different aircraft using the digital simulation. Chapter IX treats some special applications of the developed digital simulator. Finally, Chapter X presents some conclusions and recommendations for further study.

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II. The Aircraft Equations of Motion

The first step in the engineering analysis of any system must be the modelling of the physical process involved by a set of mathematical equations which adequately represent the actual system. Newtonian force and torque equations are applied here in a six-degree-of-freedom environment along with a suitable set of assumptions to allow mathematical tractability. The notation of this chapter is included in the List of Symbols given on page x.

A. The Reference System

All physical processes are necessarily carried out within some given frame of reference. An inertial reference frame fixed in the stars is employed for wide area navigation of aircraft. However, for the short periods of flight considered here (generally about three minutes or less), a topocentric coordinate system fixed to the earth can be considered as an inertial frame. A set of commonly used axes for this reference system called the Earth Axis System is given as shown in Figure 1. The x-axis points North, the y-axis East, and the orthogonal triad is completed with the z-component down. With this as the basic frame to which all other frames will be referenced, the aircraft itself must be fitted with a suitable axis system.

A search of the literature [11,12,13,14] reveals that several suitable axis systems exist for the aircraft. All of the axis systems discussed here are body axis systems with their origin located at the center of gravity of the aircraft. This type of axis system has its x-axis oriented generally forward and out the nose of the aircraft, the y-axis out the right wing and the z-axis downward.

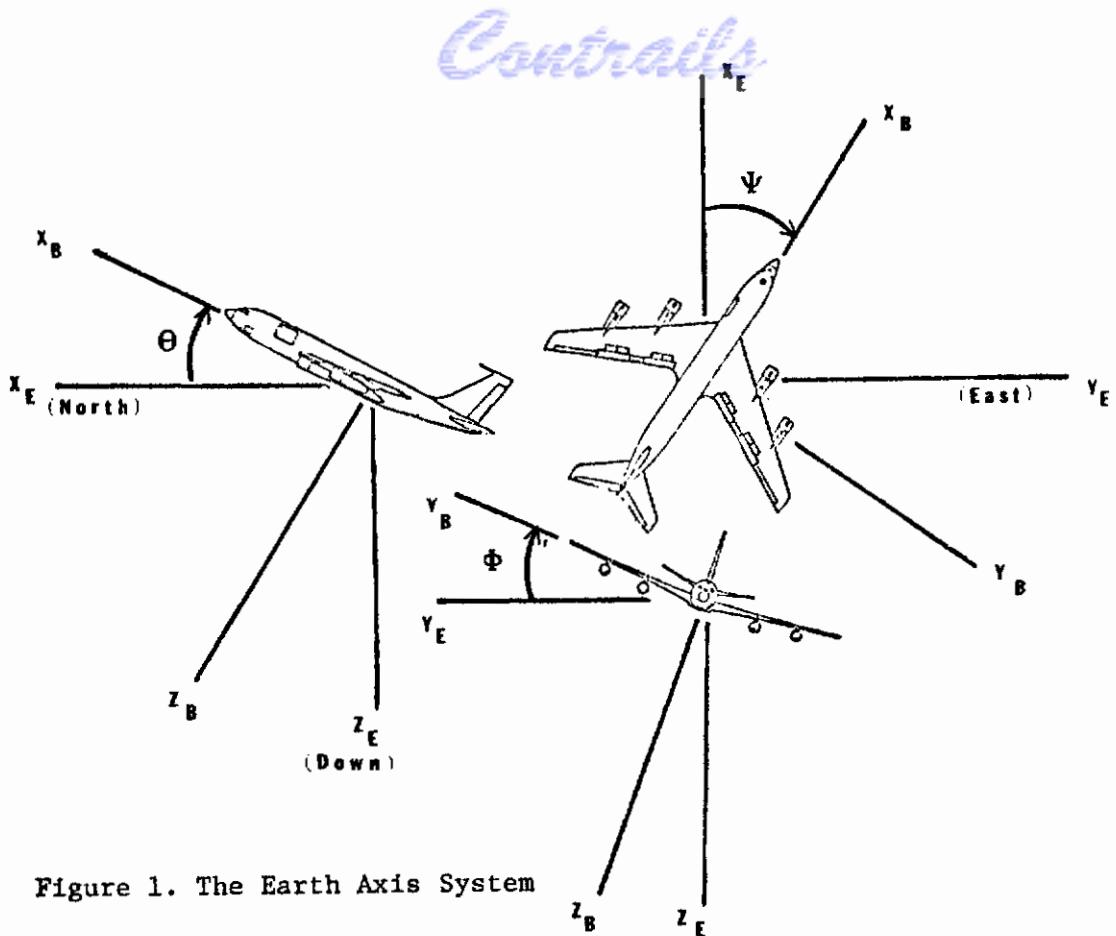


Figure 1. The Earth Axis System

Certain orientations of the many possible body axis systems have received special names and are useful in different types of analysis. One such system is called the body centerline axis system where the x-axis is oriented through the nose of the aircraft along the aircraft centerline. This axis system is fixed with respect to the aircraft.

A second system is called the principal axis system of the aircraft. Here the axes are the principal axes of inertia of the aircraft. The forward axis will normally approximate the centerline of the aircraft. This system also remains fixed with respect to the aircraft.

A third set of body fixed axes commonly used in stability and control analysis is called the stability axis system. This axis system aligns its x-axis with the projection of the total velocity of the aircraft on the plane of symmetry of the aircraft. The trim angle of

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attack, α_0 , is the angle between the x-axis of the stability axis system and the x-axis of the body centerline axis system described above.

For completeness, the wind axis system should also be mentioned here. The x-axis of this system aligns with the relative wind. The y and z axes are oriented similar to the above described systems. The major difference is that this system orients itself with respect to the flight path of the vehicle and thus has time varying moment of inertia and product of inertia terms. Thus, this axis system is unnecessarily complicated for analysis of rigid body motion. It is mentioned here since it occurs in the literature and it was desired to distinguish its definition from the three axis systems defined above.

An excellent treatment of axis systems is presented in AFFDL-TR-64-70 by Thelander of Douglas Aircraft [14]. The derivation of the aircraft equations of motion which follows will be accomplished for body centerline axes, noting that the stability axes equations exist as a special subset. Other derivations of similar equations have been done by other authors [11,12,13].

B. Application of Newton's Laws

The derivation of the aircraft equations of motion starts by applying Newton's 2nd Law. Here both the linear and rotational versions are used:

$$\sum \bar{F} = \frac{d}{dt} [m \bar{V}_T]_I \quad (1)$$

$$\sum \bar{M} = \frac{d}{dt} [\bar{H}]_I \quad (2)$$

where the I subscript denotes application is to occur in a non-accelerating inertial frame of reference, and \bar{V}_T is the total aircraft velocity.

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For the aircraft problem, there are both equilibrium or steady-state forces acting on the vehicle as well as perturbational forces. These forces are basically threefold in nature: aerodynamic, gravitational, and propulsive. In this study no propulsive or thrust changes are included in accordance with assumption 5 of Chapter I, although their inclusion is a simple extension [13].

Expanding equations (1) and (2) into the equilibrium and perturbation components, they become

$$\Sigma \bar{F} = \Sigma \bar{F}_0 + \Sigma \Delta \bar{F} = \frac{d}{dt} [m \bar{V}_T]_I \quad (3)$$

$$\Sigma \bar{M} = \Sigma \bar{M}_0 + \Sigma \Delta \bar{M} = \frac{d}{dt} [\bar{H}]_I \quad (4)$$

where the ₀ subscript indicates the equilibrium forces and moments.

With the assumption of a constant mass aircraft (a valid assumption for short intervals of flight during which no stores are expended) and considering the earth as an inertial reference frame, (3) and (4) become:

$$\Sigma \Delta \bar{F} = m \frac{d}{dt} \bar{V}_T|_E \quad (5)$$

$$\Sigma \Delta \bar{M} = \frac{d}{dt} \bar{H}|_E \quad (6)$$

where the equilibrium forces and moments have been eliminated since

$$\Sigma \bar{F}_0 = \bar{0} \quad (7)$$

and

$$\Sigma \bar{M}_0 = \bar{0} . \quad (8)$$

C. The Linear Acceleration Equations

Using the Theorem of Coriolis [16], the total derivative of the vector \bar{v}_T as seen from the E frame of Figure 1 is given by [15]

$$\frac{d \bar{v}_T}{dt} = \hat{i}_{v_T} \frac{d v_T}{dt} + \bar{\omega} \times \bar{v}_T \quad (9)$$

where $\bar{\omega}$ is the angular velocity of the aircraft with respect to the earth reference frame. Both the linear and rotational velocities can be written as the sum of their x, y, and z components, when coordinatized with respect to the body frame, as

$$\bar{v}_T = \hat{i}U + \hat{j}V + \hat{k}W \quad (10)$$

and

$$\bar{\omega} = \hat{i}P + \hat{j}Q + \hat{k}R \quad (11)$$

The derivative indicated on the right hand side of equation (9) is given by

$$\hat{i}_{v_T} \frac{d v_T}{dt} = \hat{i}\dot{U} + \hat{j}\dot{V} + \hat{k}\dot{W}. \quad (12)$$

The cross product is given by

$$\bar{\omega} \times \bar{v}_T = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ P & Q & R \\ U & V & W \end{vmatrix} = \hat{i}(WQ - VR) + \hat{j}(UR - WP) + \hat{k}(VP - UQ) \quad (13)$$

Similar to equations (10) and (11) the components of the perturbation force are written as

$$\Sigma \Delta \bar{F} = \hat{i}\Sigma \Delta F_x + \hat{j}\Sigma \Delta F_y + \hat{k}\Sigma \Delta F_z \quad (14)$$

Then equations (9), (12), and (13) can be combined to give

$$\Sigma \Delta \bar{F} = m[\hat{i}(\dot{U} + WQ - VR) + \hat{j}(\dot{V} + UR - WP) + \hat{k}(\dot{W} + VP - UQ)] \quad (15)$$

Centrally

Writing the components out explicitly using equation (14) results in

$$\begin{aligned}\Sigma \Delta F_x &= m(\dot{U} + WQ - VR) \\ \Sigma \Delta F_y &= m(\dot{V} + UR - WP) \\ \Sigma \Delta F_z &= m(\dot{W} + VP - UQ)\end{aligned}\tag{16}$$

Generally the following notation is used, although no firm standard has been established:

$$\begin{aligned}\Sigma \Delta F_x &= \Sigma \Delta X \\ \Sigma \Delta F_y &= \Sigma \Delta Y \\ \Sigma \Delta F_z &= \Sigma \Delta Z\end{aligned}\tag{17}$$

and so equation (16) becomes

$$\begin{aligned}\Sigma \Delta X &= m(\dot{U} + WQ - VR) \\ \Sigma \Delta Y &= m(\dot{V} + UR - WP) \\ \Sigma \Delta Z &= m(\dot{W} + VP - UQ)\end{aligned}\tag{18}$$

D. The Rotational Acceleration Equations

For a three dimensional rigid aircraft the angular momentum, \bar{H} , is defined by [16]

$$\bar{H} = I\bar{\omega}\tag{19}$$

where

$\bar{\omega}$ is the rotational rate of the aircraft with respect to the earth and

$$I = \begin{bmatrix} I_{xx} & -J_{xy} & -J_{xz} \\ -J_{xy} & I_{yy} & -J_{yz} \\ -J_{xz} & -J_{yz} & I_{zz} \end{bmatrix}$$

where each I is a moment of inertia and the J 's are products of inertia.

Applying Newton's 2nd Law given by equation (2), the torques are expressed as

$$\bar{M} = \frac{d}{dt}[I\bar{\omega}] = I \frac{d}{dt}\bar{\omega}|_I\tag{20}$$

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Transferring from the aircraft to the inertial earth axis system, equation (20) becomes

$$\Sigma \bar{M} = I \left[\hat{i} \omega \frac{d}{dt} \bar{\omega} + \bar{\omega} \times \bar{\omega} \right] \quad (21)$$

Equation (21) can be expanded by noting that

$$\hat{i} \omega \frac{d}{dt} \bar{\omega} = \hat{i} \dot{P} + \hat{j} \dot{Q} + \hat{k} \dot{R} \quad (22)$$

and

$$\bar{\omega} \times \bar{\omega} = \begin{bmatrix} \hat{i} & \hat{j} & \hat{k} \\ P & 0 & R \\ P & Q & R \end{bmatrix} = \bar{0}$$

Thus recalling equation (8) and substituting equations (22) and (23), equation (21) becomes

$$\Sigma \Delta \bar{M} = \begin{bmatrix} I_{xx} & -J_{xy} & -J_{xz} \\ -J_{xy} & I_{yy} & -J_{yz} \\ -J_{xz} & -J_{yz} & I_{zz} \end{bmatrix} \begin{bmatrix} \dot{P} \\ \dot{Q} \\ \dot{R} \end{bmatrix} \quad (23)$$

Expanding equation (23) leads to

$$\begin{aligned} \Sigma \Delta M_x &= I_{xx} \dot{P} - J_{xy} \dot{Q} - J_{xz} \dot{R} \\ \Sigma \Delta M_y &= I_{yy} \dot{Q} - J_{xy} \dot{P} - J_{yz} \dot{R} \\ \Sigma \Delta M_z &= I_{zz} \dot{R} - J_{xz} \dot{P} - J_{yz} \dot{Q} \end{aligned} \quad (24)$$

Assumption 1 in Chapter I was that the aircraft was symmetric about its centerline which implies

$$J_{xy} = J_{yz} = 0 . \quad (25)$$

With this assumption, the torque equations become

$$\begin{aligned} \Sigma \Delta M_x &= I_{xx} \dot{P} - J_{xz} \dot{R} \\ \Sigma \Delta M_y &= I_{yy} \dot{Q} \\ \Sigma \Delta M_z &= I_{zz} \dot{R} - J_{xz} \dot{P} \end{aligned} \quad (26)$$

Generally, the following notation is used for the aircraft problem

$$\begin{aligned}\Sigma \Delta M_x &= \Sigma \Delta L \\ \Sigma \Delta M_y &= \Sigma \Delta M \\ \Sigma \Delta M_z &= \Sigma \Delta N\end{aligned}\tag{27}$$

Substituting equation (27) into (26), the rotational acceleration equations become

$$\begin{aligned}\Sigma \Delta L &= I_{xx}\dot{P} - J_{xz}\dot{R} \\ \Sigma \Delta M &= I_{yy}\dot{Q} \\ \Sigma \Delta N &= I_{zz}\dot{R} - J_{xz}\dot{P}\end{aligned}\tag{28}$$

E. Linearization of the Aircraft Equations of Motion

Having developed equations (18) and (28), these equations are now linearized about a nominal trajectory. The nominal trajectory chosen is a non-accelerating wings-level flight with all components of velocity except U_0 and W_0 zero.

$$\begin{aligned}P_0 &= Q_0 = R_0 = V_0 = \dot{P}_0 = \dot{Q}_0 = \dot{R}_0 = \phi_0 = \dot{U}_0 = \dot{V}_0 = \dot{W}_0 \\ &= \psi_0 = 0\end{aligned}\tag{29}$$

Setting $\psi_0 = 0$ is purely arbitrary since the topocentric earth frame can be reoriented to any desired nominal heading.

Having chosen this nominal flight condition, the aircraft parameters become

$$\begin{array}{ll}P = p & \dot{P} = \dot{p} \\ Q = q & \dot{Q} = \dot{q} \\ R = r & \dot{R} = \dot{r} \\ \theta = \theta_0 + \theta & \dot{\theta} = \dot{\theta} \\ \Phi = \phi & \dot{\Phi} = \dot{\phi} \\ \Psi = \psi & \dot{\Psi} = \dot{\psi} \\ U = U_0 + u & \dot{U} = \dot{u} \\ V = v & \dot{V} = \dot{v} \\ W = W_0 + w & \dot{W} = \dot{w}\end{array}$$

Controls
where the capital letters designate the total aircraft parameter, the subscripted parameters represent the nominal condition, and the lower case letters represent perturbations from the nominal trajectory.

The common approximations for perturbation theory are made here to facilitate the linearization of the aircraft equations of motion:

- 1) products of perturbations and powers of perturbations higher than one will be ignored
- 2) the sine of a small angle is approximately equal to the small angle; the cosine of a small angle is approximately equal to one.

Further, assumption 4 from Chapter I will be used and the longitudinal and lateral aircraft axes considered decoupled, i.e., an elevator deflection causes changes only in the longitudinal system and aileron and rudder deflections cause changes only in the lateral system.

F. Gravitational Force Determination

Before proceeding, the contribution of the gravitational force in each of the aircraft axes must be determined. The coordinate transformation from the earth axis system to the nominal body axes is given by [14]

$$C_E^B = \begin{bmatrix} \cos\theta_0 \cos\psi_0 & \cos\theta_0 \sin\psi_0 & -\sin\theta_0 \\ \sin\phi_0 \sin\theta_0 \cos\psi_0 & \sin\phi_0 \sin\theta_0 \sin\psi_0 & \sin\phi_0 \cos\theta_0 \\ -\cos\phi_0 \sin\psi_0 & +\cos\phi_0 \cos\psi_0 & \\ \cos\phi_0 \sin\theta_0 \cos\psi_0 & \cos\phi_0 \sin\theta_0 \sin\psi_0 & \cos\phi_0 \cos\theta_0 \\ +\sin\phi_0 \sin\psi_0 & -\sin\phi_0 \cos\psi_0 & \end{bmatrix} \quad (31)$$

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Thus, the components due to gravity are

$$\begin{aligned}
 F_{gx} &= -mg \sin\theta_0 \\
 F_{gy} &= mg \sin\phi_0 \cos\theta_0 \\
 F_{gz} &= mg \cos\phi_0 \cos\theta_0 .
 \end{aligned} \tag{32}$$

G. Perturbation in the Gravitational Forces

The gravitational forces are perturbed by small changes in the orientation of the body axis system with respect to the earth axis system. This is reflected by perturbations of the transformation matrix described by equation (31). This perturbation can be treated as an orthogonal small angle transformation between almost coincident coordinate frames [15]. Thus for the transformation to the perturbed body axes, the transformation matrix is

$$C_B^{B'} = \begin{bmatrix} \cos\theta \cos\psi & \cos\theta \sin\psi & -\sin\theta \\ \sin\phi \sin\theta \cos\psi & \sin\phi \sin\theta \sin\psi & \sin\phi \cos\theta \\ -\cos\phi \sin\psi & +\cos\phi \cos\psi & \\ \cos\phi \sin\theta \cos\psi & \cos\phi \sin\theta \sin\psi & \cos\phi \cos\theta \\ +\sin\phi \sin\psi & -\sin\phi \cos\psi & \end{bmatrix} \tag{33}$$

Applying this to equation (32), the perturbed gravitational forces become

$$\begin{aligned}
 F_{gx} &= -mg \sin\theta_0 \cos\theta \cos\psi + mg \cos\theta_0 \sin\phi_0 \cos\theta \sin\psi \\
 &\quad -mg \cos\phi_0 \cos\theta_0 \sin\theta \\
 F_{gy} &= -mg \sin\theta_0 (\sin\phi \sin\theta \cos\psi - \cos\phi \sin\psi) + mg \cos\theta_0 \\
 &\quad \sin\phi_0 (\sin\phi \sin\theta \sin\psi + \cos\phi \cos\psi) + mg \cos\phi_0 \\
 &\quad \cos\theta_0 \sin\phi \cos\theta \\
 F_{gz} &= -mg \sin\theta_0 (\cos\phi \sin\theta \cos\psi + \sin\phi \sin\psi) + mg \cos\theta_0 \\
 &\quad \sin\phi_0 (\cos\phi \sin\theta \sin\psi - \sin\phi \cos\psi) + mg \cos\phi_0 \\
 &\quad \cos\theta_0 \cos\phi \cos\theta
 \end{aligned} \tag{34}$$

Removing the steady state value of the gravitational force given in equation (32) and considering only a disturbance in θ by setting $\phi=\psi=0$,

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the changes in the gravitational forces with respect to a change in θ are determined to be

$$\begin{aligned}\frac{\partial F_{g_x}}{\partial \theta} &= -mg \cos\theta_0 \\ \frac{\partial F_{g_y}}{\partial \theta} &= 0 \\ \frac{\partial F_{g_z}}{\partial \theta} &= -mg \sin\theta_0\end{aligned}\tag{35}$$

where the perturbation approximations have been used and the nominal value of $\phi_0 = 0$ has been substituted.

Similarly changes in the gravitational forces with respect to changes in ϕ and ψ are determined to be

$$\begin{aligned}\frac{\partial F_{g_x}}{\partial \phi} &= 0 & \frac{\partial F_{g_x}}{\partial \psi} &= 0 . \\ \frac{\partial F_{g_y}}{\partial \phi} &= mg \cos\theta_0 & \frac{\partial F_{g_y}}{\partial \psi} &= +mg \sin\theta_0 \\ \frac{\partial F_{g_z}}{\partial \phi} &= 0 . & \frac{\partial F_{g_z}}{\partial \psi} &= 0 .\end{aligned}\tag{36}$$

H. The Longitudinal Equations of Motion

Under the decoupling assumption, the longitudinal system inputs do not disturb the lateral system and hence

$$P = R = \dot{V} = V = 0 .\tag{37}$$

Recalling equation (30), the longitudinal variables and their derivatives are

$$\begin{aligned}U &= U_0 + u & \dot{U} &= \dot{u} \\ W &= W_0 + w & \dot{W} &= \dot{w} \\ Q &= q & \dot{Q} &= \dot{q}\end{aligned}\tag{38}$$

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Substitution of equations (37) and (38) into equations (18) and (28) leads to

$$\begin{aligned}
 \Sigma \Delta X &= m(\dot{u} + (W_0 + w) q) \\
 \Sigma \Delta Y &= 0 \\
 \Sigma \Delta Z &= m(\dot{w} - (U_0 + u) q) \\
 \Sigma \Delta L &= 0 \\
 \Sigma \Delta M &= I_{yy} \dot{q} \\
 \Sigma \Delta N &= 0
 \end{aligned} \tag{39}$$

Using the perturbation approximation, the non-zero elements of equation (39) are

$$\begin{aligned}
 \Sigma \Delta X &= m(\dot{u} + W_0 q) \\
 \Sigma \Delta Z &= m(\dot{w} - U_0 q) \\
 \Sigma \Delta M &= I_{yy} \dot{q}
 \end{aligned} \tag{40}$$

Now it is necessary to expand the left hand side of equation (40); a Taylor series expansion about the nominal flight condition is used so that, for example,

$$\Delta X = \frac{\partial X}{\partial u} u + \frac{\partial X}{\partial \dot{u}} \dot{u} + \frac{\partial X}{\partial w} w + \frac{\partial X}{\partial \dot{w}} \dot{w} + \frac{\partial X}{\partial q} q + \frac{\partial X}{\partial \delta e} \delta e \tag{41}$$

where the expansion has been truncated using the perturbation approximation. Terms accounting for $\frac{\partial X}{\partial \delta T}$, $\frac{\partial X}{\partial \delta F}$ and $\frac{\partial X}{\partial \delta SP}$ corresponding to throttle, flaps and spoilers could also be added as necessary.

Substituting the form of equation (41) into equation (40) and including the gravity perturbations from equation (35) explicitly, the linearized aircraft perturbation equations for the longitudinal system become

$$\begin{aligned}
 \frac{\partial X}{\partial u} u + \frac{\partial X}{\partial \dot{u}} \dot{u} + \frac{\partial X}{\partial w} w + \frac{\partial X}{\partial \dot{w}} \dot{w} + \frac{\partial X}{\partial q} q + \frac{\partial X}{\partial \delta e} \delta e - mg \cos\theta_0 \theta &= m(\dot{u} + W_0 q) \\
 \frac{\partial Z}{\partial u} u + \frac{\partial Z}{\partial \dot{u}} \dot{u} + \frac{\partial Z}{\partial w} w + \frac{\partial Z}{\partial \dot{w}} \dot{w} + \frac{\partial Z}{\partial q} q + \frac{\partial Z}{\partial \delta e} \delta e - mg \sin\theta_0 \theta &= m(\dot{w} - U_0 q) \\
 \frac{\partial M}{\partial u} u + \frac{\partial M}{\partial \dot{u}} \dot{u} + \frac{\partial M}{\partial w} w + \frac{\partial M}{\partial \dot{w}} \dot{w} + \frac{\partial M}{\partial q} q + \frac{\partial M}{\partial \delta e} \delta e &= I_{yy} \dot{q}
 \end{aligned} \tag{42}$$

Controls

These equations are awkward to handle and so the following definitions are made:

$$M_x \equiv \frac{1}{I_{yy}} \frac{\partial M}{\partial x}$$

$$Z_x \equiv \frac{1}{m} \frac{\partial Z}{\partial x} \quad (43)$$

$$X_x \equiv \frac{1}{m} \frac{\partial X}{\partial x}$$

where x represents any of the aircraft variables. Using these definitions and rearranging, equations (42) become

$$\begin{aligned}\dot{u} &= X_u u + X_u^* \dot{u} + X_w w + X_w^* \dot{w} + X_q q + X_{\delta e} \delta e - g\theta \cos\theta_0 - W_0 q \\ \dot{w} &= Z_u u + Z_u^* \dot{u} + Z_w w + Z_w^* \dot{w} + Z_q q + Z_{\delta e} \delta e - g\theta \sin\theta_0 + U_0 q \\ \dot{q} &= M_u u + M_u^* \dot{u} + M_w w + M_w^* \dot{w} + M_q q + M_{\delta e} \delta e\end{aligned} \quad (44)$$

The relative sizes of each of the partial derivatives represented in equation (40) must be weighed against each other; however, generally some of these coefficients are orders of magnitude smaller than others and can be safely eliminated [17,18]. From calculations based on wind tunnel testing, the following derivatives are set to zero

$$X_u^* = X_w^* = X_q^* = X_{\delta e}^* = Z_u^* = Z_q^* = Z_w^* = M_u^* = 0 \quad (45)$$

With these coefficients eliminated, equations (44) become

$$\begin{aligned}\dot{u} &= X_u u + X_w w - W_0 q - g\theta \cos\theta_0 \\ \dot{w} &= Z_u u + Z_w w + Z_{\delta e} \delta e - g\theta \sin\theta_0 + U_0 q \\ \dot{q} &= M_u u + M_w w + M_w^* \dot{w} + M_q q + M_{\delta e} \delta e\end{aligned} \quad (46)$$

and

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

where the last line follows from the definition of q

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Terms involving the velocity w can be converted to terms relating to the angle of attack, α , since by definition

$$\alpha = \frac{w}{V_T} . \quad (47)$$

Substituting into equations (46), the aircraft equations are

$$\begin{aligned}\dot{u} &= X_u u + X_\alpha \alpha - W_0 q - g\theta \cos\theta_0 \\ \dot{\alpha} &= Z_u^* u + Z_\alpha \alpha + Z_{\delta e}^* \delta e - \frac{g\theta}{V_T} \sin\theta_0 + \frac{U_0}{V_T} q \\ \dot{q} &= M_u u + M_\alpha \alpha + M_\alpha^* \dot{\alpha} + M_q q + M_{\delta e} \delta e \\ \dot{\theta} &= q\end{aligned} \quad (48)$$

where

$$\begin{aligned}X_\alpha &= V_T X_w & Z_{\delta e}^* &= Z_{\delta e}/V_T \\ Z_\alpha &= Z_w & M_\alpha &= M_w V_T \\ Z_u^* &= Z_u/V_T & M_\alpha^* &= M_w^* V_T\end{aligned} \quad (49)$$

I. The Lateral Equations of Motion

In a manner parallel to the derivation of the longitudinal equations, the lateral equations can be developed. Recalling from equation (29) that on the nominal trajectory

$$P_0 = R_0 = V_0 = 0 \quad (50)$$

and by the decoupling assumption

$$Q = w = u = \dot{U} = \dot{W} = 0 \quad (51)$$

the lateral aircraft variables and their perturbations are

$$\begin{aligned}P &= p & \dot{P} &= \dot{p} \\ R &= r & \dot{R} &= \dot{r} \\ V &= v & \dot{V} &= \dot{v}\end{aligned} \quad (52)$$

Controls

Substitution into the equations of motion (18) and (28) yields

$$\begin{aligned}
 \Sigma \Delta X &= 0 \\
 \Sigma \Delta Y &= m(\dot{v} + U_0 r - W_0 p) \\
 \Sigma \Delta Z &= 0 \\
 \Sigma \Delta L &= I_{xx} \dot{p} - J_{xz} \dot{r} \\
 \Sigma \Delta M &= 0 \\
 \Sigma \Delta N &= I_{zz} \dot{r} - J_{xz} \dot{p}
 \end{aligned} \tag{53}$$

Using the form of equation (41) and the non-zero equations in (53), the lateral perturbation equations are

$$\begin{aligned}
 \frac{\partial Y}{\partial v} v + \frac{\partial Y}{\partial \dot{v}} \dot{v} + \frac{\partial Y}{\partial r} r + \frac{\partial Y}{\partial p} p + \frac{\partial Y}{\partial \delta a} \delta a + \frac{\partial Y}{\partial \delta r} \delta r + mg\phi \cos\theta_0 \\
 + mg\psi \sin\theta_0 = m(\dot{v} + U_0 r - W_0 p) \\
 \frac{\partial L}{\partial v} v + \frac{\partial L}{\partial \dot{v}} \dot{v} + \frac{\partial L}{\partial r} r + \frac{\partial L}{\partial p} p + \frac{\partial L}{\partial \delta a} \delta a + \frac{\partial L}{\partial \delta r} \delta r = I_{xx} \dot{p} - J_{xz} \dot{r} \\
 \frac{\partial N}{\partial v} v + \frac{\partial N}{\partial \dot{v}} \dot{v} + \frac{\partial N}{\partial r} r + \frac{\partial N}{\partial p} p + \frac{\partial N}{\partial \delta a} \delta a + \frac{\partial N}{\partial \delta r} \delta r = I_{zz} \dot{r} - J_{xz} \dot{p} .
 \end{aligned} \tag{54}$$

Again to use more compact notation, the following variables are defined

$$\begin{aligned}
 Y_x &\equiv \frac{1}{m} \frac{\partial Y}{\partial x} \\
 L_x &\equiv \frac{1}{I_{xx}} \frac{\partial L}{\partial x} \\
 N_x &\equiv \frac{1}{I_{zz}} \frac{\partial N}{\partial x}
 \end{aligned} \tag{55}$$

Using equations (55), equations (54) are rewritten as

$$\begin{aligned}
 \dot{v} &= Y_v v + Y_{\dot{v}} \dot{v} + Y_r r + Y_p p + Y_{\delta a} \delta a + Y_{\delta r} \delta r + g\phi \cos\theta_0 \\
 &+ g\psi \sin\theta_0 - U_0 r + W_0 p
 \end{aligned}$$

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$$\dot{p} = \frac{J_{xz}}{I_{xx}} \dot{r} + L_v v + L_v^* \dot{v} + L_r r + L_p p + L_{\delta a} \delta a + L_{\delta r} \delta r \quad (56)$$

$$\dot{r} = \frac{J_{xz}}{I_{zz}} \dot{p} + N_v v + N_v^* \dot{v} + N_r r + N_p p + N_{\delta a} \delta a + N_{\delta r} \delta r$$

Considering the usual relative amplitudes of these coefficients in the tasks considered here, the following partial derivatives are set to zero:

$$Y_p = Y_r = Y_{\delta a} = Y_v^* = L_v^* = N_v^* = 0 \quad (57)$$

Further, the lateral equations can be written in terms of the sideslip, β , instead of the side velocity, v , since by definition

$$\beta = \frac{v}{V_T} . \quad (58)$$

Rewriting equations (56) incorporating the results of equations (57) and (58) leads to the following set of lateral perturbation equations:

$$\begin{aligned} \dot{\beta} &= Y_v \beta + Y_{\delta r}^* \delta r + \frac{g\phi}{V_T} \cos\theta_0 + \frac{g\psi}{V_T} \sin\theta_0 - \frac{U_0}{V_T} r + \frac{W_0}{V_T} p \\ \dot{p} &= \frac{J_{xz}}{I_{xx}} \dot{r} + L_\beta \beta + L_p p + L_r r + L_{\delta a} \delta a + L_{\delta r} \delta r \\ \dot{r} &= \frac{J_{xz}}{I_{zz}} \dot{p} + N_\beta \beta + N_p p + N_r r + N_{\delta a} \delta a + N_{\delta r} \delta r \end{aligned} \quad (59)$$

where

$$Y_{\delta r}^* = Y_{\delta r}/V_T$$

$$L_\beta = L_v V_T$$

$$N_\beta = N_v V_T$$

Using the inverse of the transformation matrix given in equation (31) along with small angle assumptions, the remaining dynamics are found

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to be [14:41]

$$\begin{aligned}\dot{\phi} &= p + r \tan\theta_0 \\ \dot{\psi} &= r \sec\theta_0\end{aligned}\tag{60}$$

using the nominal condition $\phi_0 = 0$.

J. The Stability Axes Equations

In the stability axes, the x axis is aligned with the velocity vector and so

$$U_0 = V_T \quad \text{and} \quad W_0 = 0 \tag{61}$$

Substituting this into equations (48) and (59) and using the small angle approximation, the aircraft perturbation equations in stability axes are

$$\begin{aligned}\dot{u} &= X_u u + X_\alpha \alpha - g\theta \cos\theta_0 \\ \dot{\alpha} &= Z_u^* u + Z_\alpha^* \alpha + Z_{\delta e}^* \delta e - \frac{g\theta}{U_0} \sin\theta_0 + q \\ \dot{q} &= M_u u + M_\alpha \alpha + M_\alpha^* \dot{\alpha} + M_q q + M_{\delta e} \delta e \\ \dot{\theta} &= q \\ \dot{\beta} &= Y_v \beta + Y_{\delta r}^* \delta r + \frac{g\phi}{U_0} \cos\theta_0 + \frac{g\psi}{U_0} \sin\theta_0 - r \\ \dot{p} &= \frac{J_{xz}}{I_{xx}} \dot{r} + L_\beta \beta + L_p p + L_r r + L_{\delta a} \delta a + L_{\delta r} \delta r \\ \dot{r} &= \frac{J_{xz}}{I_{zz}} \dot{p} + N_\beta \beta + N_p p + N_r r + N_{\delta a} \delta a + N_{\delta r} \delta r \\ \dot{\phi} &= p + r \tan\theta_0 \\ \dot{\psi} &= r \sec\theta_0\end{aligned}\tag{62}$$

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K. The Use of the Primed Stability Axis System [14]

Some flight simulation in this research will use an axis system that has not been discussed up to this point. The primed stability axis system is a mathematical construct which artificially eliminates the cross product of inertia terms which appear in the \dot{p} and \dot{r} equations. By careful definition, the following primed stability derivatives take into account the cross product of inertia terms when second order effects are ignored.

$$\begin{aligned}
 L_{\beta}' &= L_{\beta} + B N_{\beta} & N_{\beta}' &= N_{\beta} + A L_{\beta} \\
 L_p' &= L_p + B N_p & N_p' &= N_p + A L_p \\
 L_r' &= L_r + B N_r & N_r' &= N_r + A L_r \\
 L_{\delta a}' &= L_{\delta a} + B N_{\delta a} & N_{\delta a}' &= N_{\delta a} + A L_{\delta a} \\
 L_{\delta r}' &= L_{\delta r} + B N_{\delta r} & N_{\delta r}' &= N_{\delta r} + A L_{\delta r}
 \end{aligned} \tag{65}$$

where

$$A = J_{xz}/I_{xx}$$

$$\text{and } B = J_{xz}/I_{zz}$$

Substitution of these derivatives into equation (62) yields the aircraft perturbation equations in the primed stability axis system

$$\begin{aligned}
 \dot{u} &= X_u u + X_{\alpha} \alpha - g \theta \cos \theta_0 \\
 \dot{\alpha} &= Z_u^* u + Z_{\alpha}^* \alpha + Z_{\delta e}^* \delta e - \frac{g \theta}{U_0} \sin \theta_0 + q \\
 \dot{q} &= M_u u + M_{\alpha} \alpha + M_{\dot{\alpha}} \dot{\alpha} + M_q q + M_{\delta e} \delta e \\
 \dot{\theta} &= q \\
 \dot{\beta} &= Y_v \beta + Y_{\delta r}^* \delta r + \frac{g \theta}{U_0} \cos \theta_0 + \frac{g \psi}{U_0} \sin \theta_0 - r
 \end{aligned} \tag{66}$$

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$$\dot{p} = L_{\beta}' \beta + L_p' p + L_r' r + L_{\delta r}' \delta r + L_{\delta a}' \delta a$$

$$\dot{r} = N_{\beta}' \beta + N_p' p + N_r' r + N_{\delta r}' \delta r + N_{\delta a}' \delta a$$

$$\dot{\phi} = p + r \tan \theta_0$$

$$\dot{\psi} = r \sec \theta_0$$

Thus in equations (48), (59), (62), and (66), the aircraft perturbation equations have been written in the body centerline axis, stability axis, and primed stability axis systems, respectively.

Often these equations which adequately describe the bare airframe dynamics are found to have low damping coefficients and even instabilities. Thus it is often necessary to augment the bare airframe with a stability augmentation system to assist the pilot in accomplishing his mission. Mil Spec 8785B requires such automatic assistance to improve the flying qualities of military aircraft when the bare airframe alone is not adequate to provide good handling qualities.

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III. The Stability Augmentation System and Servo Actuator Linkages

The inclusion of inertial platforms in the navigation systems of many military aircraft and some commercial aircraft has greatly aided the design of stability augmentation systems for today's aircraft. The platform makes aircraft angles, angular rates, accelerations, and velocities readily available. These quantities can be used for implementing a stability augmentation system. An excellent example is a stability augmentation system which has been employed on the F-4B Phantom [18,19,20]. The pitch loop uses a washout circuit for the pitch rate, q . The roll loop uses roll rate feedback while the yaw loop uses lateral acceleration in conjunction with a washout circuit applied to the yaw rate, r .

The model chosen for implementation with this study is general in nature and allows the following variables to be fed back:

- 1) pitch angle
- 2) pitch rate
- 3) pitch acceleration
- 4) normal acceleration
- 5) roll angle
- 6) roll rate
- 7) yaw acceleration

Lateral acceleration could have been added with no difficulty [18] but was not needed for the aircraft investigated in this study. By setting the gains of undesired feedback variables to zero, any desired configuration of the above seven feedback variables can be achieved.

Controls

A. The Pitch Feedback Loop

The feedback designed for use with the pitch loop makes use of three pure gains and a washout circuit. Figure 2 shows a block diagram of the feedback loop.

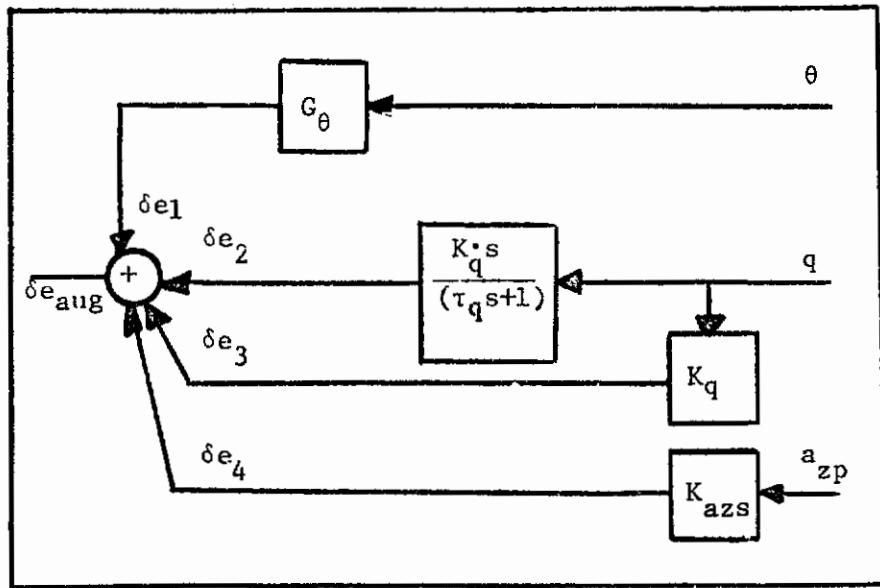


Figure 2. Pitch Feedback Loop

The equations which the block diagram represents are

$$\delta e_1 = G_\theta \theta \quad (67)$$

$$\delta e_2 = K_q^* s(q) / (\tau_q s + 1) \quad (68)$$

$$\delta e_3 = K_q q \quad (69)$$

$$\delta e_4 = K_{azs} a_{zp} \quad (70)$$

where the definition of a_{zp} , the normal acceleration at the pilot's station is given by [17:C-1]

$$a_{zp} = \dot{w} - U_o q + g \theta \sin \theta_o - l_x \dot{q} \quad (71)$$

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Summing the individual feedbacks in (67), (68), (69), and (70), the total elevator deflection commanded by the automatic stability augmentation system is

$$\delta e_{\text{aug}} = \delta e_1 + \delta e_2 + \delta e_3 + \delta e_4 \quad (72)$$

Only equation (68) presents any difficulty for implementation.

Johnson [21] manipulated equation (68) in the following manner.

Since

$$\delta e_2 = \frac{K_q \cdot s q}{\tau_q s + 1} \quad (68)$$

and defining

$$y_3 = \tau_q \delta e_2 - K_q \cdot q, \quad (73)$$

then by expansion and substitution equation (68) becomes

$$\delta e_2 = \frac{1}{\tau_q} y_3 + \frac{k_q \cdot}{\tau_q} q \quad (74)$$

Since from equation (68)

$$\tau_q \delta \dot{e}_2 + \delta e_2 = K_q \cdot \dot{q} \quad (75)$$

or, rearranging terms,

$$\delta e_2 = -\tau_q \delta \dot{e}_2 + K_q \cdot \dot{q} \quad (76)$$

Comparison with equation (73) shows that

$$\dot{y}_3 = -\delta e_2 \quad (77)$$

Substitution of (77) in (74) yields

$$\dot{y}_3 = -\frac{1}{\tau_q} y_3 - \frac{k_q \cdot}{\tau_q} q \quad (78)$$

which in conjunction with equation (74) gives a simple method for implementing the washout circuit. Thus equations (67), (69), (70), (72), (74), and (78) define the available feedback for the pitch loop.

B. The Roll Feedback Loop

The roll feedback loop is simple, having only pure gains applied to the roll angle and the roll rate. Figure 3 is a block diagram of the Roll Feedback Loop where the available feedbacks are fed through constant gain blocks and combined.

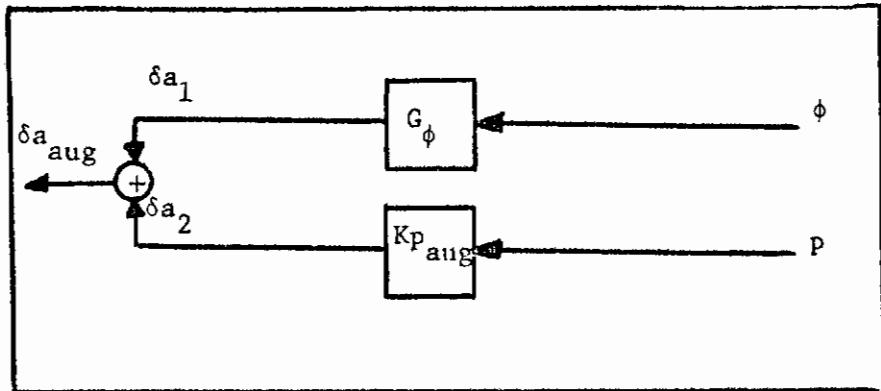


Figure 3. Roll Feedback Loop

The equations for this block diagram are

$$\delta a_1 = G_\phi \phi \quad (79)$$

$$\delta a_2 = K_{p\text{ aug}} p \quad (80)$$

and thus

$$\delta a_{\text{aug}} = G_\phi \phi + K_{p\text{ aug}} p \quad (81)$$

C. The Yaw Feedback Loop

The yaw feedback loop consists of a conventional yaw damper as shown in Figure 4.

Controls

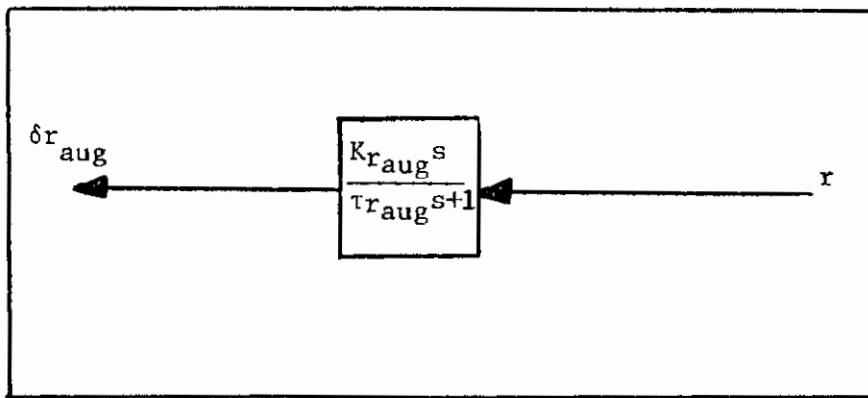


Figure 4. Yaw Feedback Loop

The equation of this yaw damper is

$$\delta r_{aug} = \frac{K_{r_{aug}} s r}{\tau_{r_{aug}} s + 1} \quad (82)$$

or in the time domain

$$\dot{\delta r}_{aug} = -\frac{1}{\tau_{r_{aug}}} \delta r_{aug} + \frac{K_{r_{aug}}}{\tau_{r_{aug}}} r . \quad (83)$$

By substitution of equation (66), this equation can be put in a form for state variable analysis [22:13].

D. The Aileron-Rudder Interconnect

Aileron to rudder coordination was accomplished using a conventional gain feed through loop from the aileron command to the rudder command as shown in Figure 5.

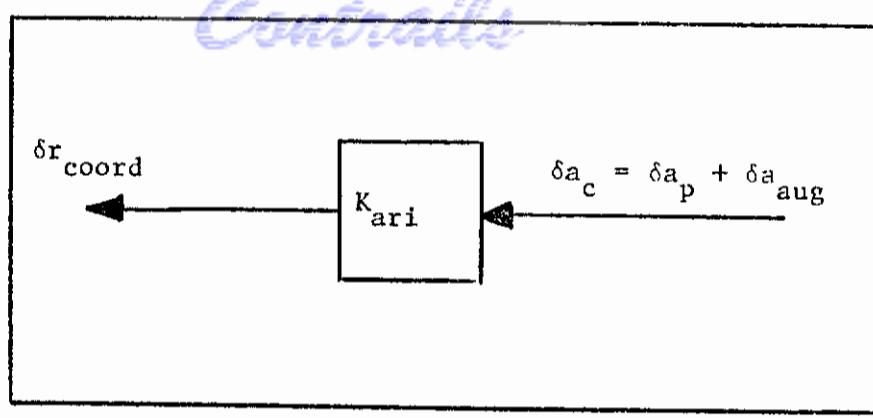


Figure 5. Aileron - Rudder Interconnect

Thus the interconnect equation is

$$\delta r_{\text{coord}} = K_{\text{ari}} (\delta a_p + \delta a_{\text{aug}}) \quad (84)$$

where

δa_p is the pilot's aileron command

and δa_{aug} is the augmentation system command

which together form the aileron command, δa_c .

E. The Servo Actuator Linkage

With the control augmentation determined, the problem of transmitting the commands of the augmentation as well as those of the pilot must be considered. A general diagram is presented in Figure 6 where the servo actuator is represented by a first order lag.

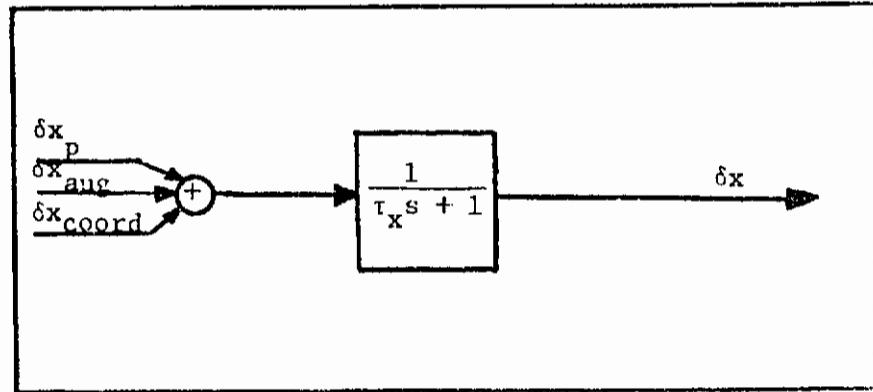


Figure 6. Sample Servo Actuator Linkage

Contrails

Here

δx_p is the pilot's commanded input

δx_{aug} is the augmentation system's input

and δx_{coord} is the surface interconnect (rudder only).

Such a servo actuator exists for the elevators, the ailerons, and the rudder in most aircraft.

In this study

τ_a = the elevator actuator time constant

τ_{con} = the aileron actuator time constant

τ_{con2} = the rudder actuator time constant

where the symbology of Johnson [21] and Taylor [22] has been retained.

The appropriate differential equation for Figure 6 is

$$\dot{\delta x} = -\frac{1}{\tau_x} \delta x + \frac{1}{\tau} (\delta x_p + \delta x_{aug} + \delta x_{coord}) \quad (85)$$

Contrails

IV. A Turbulent Environment

The controversy over what engineers should use as representative disturbances to evaluate an aircraft and its stability augmentation system remains very much alive at this time. The arbitrarily chosen Gaussian continuous colored noise dictated by Military Specification 8785B [7:419] is rejected by many purists as unrealistic from a theoretical point of view; yet, to date, it remains the only stochastic environment which engineers (and mathematicians) are able to handle with any facility or confidence. Optimal pilot modelling theory is tractable only for processes which are adequately described by their first and second moments since the assumptions of the Kalman filter [4,5] must be satisfied.

While there is no reason why any turbulent environment which can be represented by stochastic differential equations (not necessarily linear) could not have been used here, that environment specified in the Mil Spec was chosen as the most tractable and complete model currently available. It is also the model which must be satisfied for compliance to the Mil Spec for aircraft design. While pilots sometimes complain of the lack of accurate realism from the model, they readily accept its presence as a factor making any task more plausible since it increases the pilot's workload to a level comparable with that encountered in actual flight. Secondarily, a simpler longitudinal model used in other research [23] is treated since it had to be used to allow comparison of simulation data from that research.

Controls

A. The Mil Spec Turbulence Model

Confusion arises as one attempts to interpret the intent of the Mil Spec with regard to its turbulence model. The Mil Spec defines the steady state covariance or, equivalently, the rms (root mean square) intensity as

$$\sigma_i^2 = \int_0^\infty \Phi_i(\omega) d\omega \quad (86)$$

where $\Phi_i(\omega)$ is the power spectral density. Elsewhere [24], a more standard definition which is also based on Fourier Transforms with coefficients a, b such that $ab = \frac{1}{2\pi}$ is found to be

$$\sigma_i^2 = \frac{1}{\pi} \int_0^\infty \Phi_i(\omega) d\omega . \quad (87)$$

Apparently the equations employ different definitions of $\Phi_i(\omega)$. Since (87) is the more commonly accepted definition, the power spectral densities given in the Mil Spec must contain a factor of $1/\pi$ which is not actually part of the power spectral density. Removing this undesired factor, the power spectra of the Mil Spec for the linear components of the gust model become [7:424]

$$\Phi_{ug}(\omega) = \frac{2\sigma_u^2 L_u}{V_T} \frac{1}{1 + (\frac{L_u}{V_T} \omega)^2} \quad (88)$$

$$\Phi_{\alpha g}(\omega) = \frac{\sigma_w^2 L_w}{V_T} \frac{1 + 3(\frac{L_w}{V_T} \omega)^2}{[1 + (\frac{L_w}{V_T} \omega)^2]^2} \quad (89)$$

and

$$\Phi_{\beta g}(\omega) = \frac{\sigma_v^2 L_v}{V_T} \frac{1 + 3(\frac{L_v}{V_T} \omega)^2}{[1 + (\frac{L_v}{V_T} \omega)^2]^2} \quad (90)$$

Controls

where conversions from spatial to temporal frequency and from linear to angular measure have already been made. L_u , L_v , and L_w are called scale factors and will be defined later in this chapter. Converting the power spectral densities to transfer functions yields

$$X_{u_g}(s) = \sigma_u \frac{\sqrt{2L_u}}{V_T} \frac{1}{1 + \frac{L_u}{V_T} s} = \frac{u_g}{\eta_u} \quad (91)$$

$$X_{\alpha_g}(s) = \frac{\sigma_w}{V_T} \frac{\sqrt{L_w}}{\sqrt{V_T}} \frac{1 + \sqrt{3} \frac{L_w}{V_T} s}{(1 + \frac{L_w}{V_T} s)^2} = \frac{\alpha_g}{\eta_\alpha} \quad (92)$$

and, finally,

$$X_{\beta_g}(s) = \frac{\sigma_v}{V_T} \frac{\sqrt{L_v}}{\sqrt{V_T}} \frac{1 + \sqrt{3} \frac{L_v}{V_T} s}{(1 + \frac{L_v}{V_T} s)^2} = \frac{\beta_g}{\eta_\beta} \quad (93)$$

Thus in generating u_g , α_g , and β_g five first order differential equations and three independent noise generators are necessary.

From (91) the following differential equation for u_g is immediate

$$\frac{L_u}{V_T} \dot{u}_g + u_g = \sigma_u \frac{\sqrt{2L_u}}{V_T} \eta_u \quad (94)$$

In more standard form, this is

$$\dot{u}_g = - \frac{V_T}{L_u} u_g + \sigma_u \frac{\sqrt{2V_T}}{L_u} \eta_u \quad (95)$$

From [25], the steady state covariance of this first order linear stochastic differential equation is

$$\sigma_{u_g}^2 = \frac{\frac{2\sigma_u^2 V_T}{L_u}}{2 \frac{V_T}{L_u}} = \sigma_u^2 \quad (96)$$

as might be expected.

Controls

The problem of reducing the transfer function for α_g to state variable form is slightly more difficult since it is second order.

Equation (92) can be rearranged to

$$X_{\alpha_g} = \frac{\sigma_w}{V_T} \frac{\sqrt{3V_T}}{L_w} \frac{\left(\frac{\sqrt{3}}{3} \frac{V_T}{L_w} + s\right)}{\left(s + \frac{V_T}{L_w}\right)^2} \quad (97)$$

which has the form

$$X_{\alpha_g} = \frac{K(s + b)}{(s + a)^2} \quad (98)$$

In a manner similar to Heath [26] and discussed in [27], this form can be expanded by partial fractions as

$$X_{\alpha_g} = K\left(\frac{1}{s + a} + \frac{(b - a)}{(s + a)^2}\right). \quad (99)$$

This is the transfer function of the second order system given by

$$\dot{\bar{x}} = \begin{bmatrix} -a & 1 \\ 0 & -a \end{bmatrix} \bar{x} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} \eta_\alpha \quad (100)$$

and

$$\alpha_g = K[(b - a) 1] \bar{x}. \quad (101)$$

However, since a differential equation describing α_g is desired, the derivative of (101) is taken yielding

$$\begin{aligned} \dot{\alpha}_g &= K[(b - a) 1] \dot{\bar{x}} = K(b - a) (-ax_1 + x_2) + K(-ax_2) + K \eta_\alpha \\ &= -a[K(b - a)x_1 + Kx_2] + K(b - a)x_2 + K \eta_\alpha \\ &= -a \alpha_g + K(b - a)x_2 + K \eta_\alpha \end{aligned} \quad (102)$$

which implies

$$\begin{bmatrix} \dot{\alpha}_g \\ \ddot{\alpha}_g \end{bmatrix} = \begin{bmatrix} -a & 0 \\ K(b-a) & -a \end{bmatrix} \begin{bmatrix} \alpha_g \\ x_2 \end{bmatrix} + \begin{bmatrix} 1 \\ K \end{bmatrix} \eta_\alpha \quad (103)$$

Controls

where α_g' has replaced x_2 . Equation (103) can also be derived by inspection if equation (92) is placed in standard controllable form.

Writing out K, a, and b in equation (103) leads to

$$\begin{bmatrix} \dot{\alpha}_g \\ \dot{\alpha}_g' \end{bmatrix} = \begin{bmatrix} -V_T/L_w & 0 \\ \frac{\sigma_w}{V_T} \frac{\sqrt{V_T}}{L_w} (1 - \sqrt{3}) \frac{V_T}{L_w} & \frac{-V_T}{L_w} \end{bmatrix} \begin{bmatrix} \alpha_g \\ \alpha_g' \end{bmatrix} + \begin{bmatrix} 1 \\ \frac{\sigma_w}{V_T} \frac{\sqrt{3V_T}}{L_w} \end{bmatrix} \eta_\alpha \quad (104)$$

Almost identically, the equations for β_g become

$$\begin{bmatrix} \dot{\beta}_g \\ \dot{\beta}_g' \end{bmatrix} = \begin{bmatrix} -\frac{V_T}{L_v} & 0 \\ \frac{\sigma_v}{V_T} \frac{\sqrt{V_T}}{L_v} (1 - \sqrt{3}) \frac{V_T}{L_v} & \frac{-V_T}{L_v} \end{bmatrix} \begin{bmatrix} \beta_g \\ \beta_g' \end{bmatrix} + \begin{bmatrix} 1 \\ \frac{\sigma_v}{V_T} \frac{\sqrt{3V_T}}{L_v} \end{bmatrix} \eta_\beta \quad (105)$$

The rotational components of the gust model, p_g , q_g , and r_g have the following power spectra according to the Mil Spec [7:459]

$$\Phi_{p_g}(\omega) = \frac{\pi \sigma_w^2}{V_T L_w} \frac{.8 \left(\frac{\pi L_w}{4b} \right)^{1/3}}{1 + \left(\frac{4b}{\pi V_T} \omega \right)^2} \quad (106)$$

$$\Phi_{q_g}(\omega) = \frac{\omega^2}{V_T^2 + \left(\frac{4b}{\pi} \omega \right)^2} \Phi_{w_g}(\omega) \quad (107)$$

$$\Phi_{r_g}(\omega) = \frac{\omega^2}{V_T^2 + \left(\frac{3b}{\pi} \omega \right)^2} \Phi_{v_g}(\omega) \quad (108)$$

where a factor of π has been imbedded in (106) to account for the difference between (86) and (87) and b denotes the wingspan.

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The transfer function for p_g is then

$$X_{p_g}(s) = \frac{\frac{\sigma_w \sqrt{\frac{\pi}{L_w V_T}} \sqrt{.8} (\frac{\pi L_w}{4b})^{1/3}}{1 + \frac{4b}{\pi V_T} s}}{s + \frac{\pi V_T}{4b}} = \frac{\sqrt{\pi V_T}}{L_w} \frac{\pi \sigma_w \sqrt{.8} (\frac{\pi L_w}{4b})^{1/3}}{s + \frac{\pi V_T}{4b}} \quad (109)$$

Similar to the work for u_g , the differential equation for p_g is

$$\dot{p}_g = -\frac{\pi V_T}{4b} p_g + \frac{\sigma_w \pi \sqrt{\pi V_T}}{L_w} \frac{\sqrt{.8} (\frac{\pi L_w}{4b})^{1/3}}{\eta_p} \quad (110)$$

Now the transfer functions for r_g and q_g are treated slightly differently, although they are basically shaping filters. From (108)

$$\Phi_{r_g}(\omega) = \frac{\omega^2 / V_T^2}{1 + (\frac{3b}{\pi V_T} \omega)^2} \Phi_{v_g} \quad (111)$$

So

$$X_{r_g}(s) = \frac{-s}{1 + \frac{3b}{\pi V_T} s} \quad X_{\beta_g} = \frac{-s}{1 + \frac{3b}{\pi V_T} s} \frac{\beta_g}{\eta_\beta} \quad (112)$$

Although the minus sign of equation (112) is not required from spectral factorization, it is retained from other work [26]. Taking the derivative implied in equation (112), the following transfer function is determined

$$X_{r_g}(s) = \frac{r_g}{\eta_\beta} = \frac{-\dot{\beta}_g}{\eta_\beta (1 + \frac{3b}{\pi V_T} s)} \quad (113)$$

Multiplying this out yields

$$\frac{3b}{\pi V_T} \dot{r}_g + r_g = -\dot{\beta}_g \quad (114)$$

and hence

$$\dot{r}_g = -\frac{\pi V}{3b} r_g - \frac{\pi V}{3b} \dot{\beta}_g \quad (115)$$

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Similarly, for q_g the appropriate differential equation is

$$\dot{q}_g = -\frac{\pi V_T}{4b} q_g + \frac{\pi y}{4b} \dot{\alpha}_g \quad (116)$$

Thus equations (95), (104), (105), (110), (115), and (116) represent the six-degree-of-freedom Mil Spec turbulence model.

B. The Scale Factors

In all of the above equations L_u , L_v , and L_w are scale factors specified by the Mil Spec [7:444]. If h is the altitude of the aircraft given in feet, then the following Table shows the values for the scale factors.

Table I. Mil Spec Scale Factors

<u>Altitude (Feet)</u>	<u>Scale Factors</u>
$h \geq 1750$	$L_u = L_v = L_w = 1750$
$100 < h \leq 1750$	$L_w = h; L_u = L_v = 145h^{1/3}$
$h < 100$	$L_w = 100; L_u = L_v = 145h^{1/3}$

C. Intensities

The Mil Spec [7:435] further gives standard values of σ_u , σ_v , and σ_w to generate moderate turbulence:

$$\sigma_w = 5.25 - \log_{10} \left[\frac{h}{10000} \right]^{1.25} \quad (117)$$

Then the other intensities are found from

$$\frac{\sigma_u^2}{L_u} = \frac{\sigma_v^2}{L_v} = \frac{\sigma_w^2}{L_w} \quad (118)$$

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D. The Powered Approach: A Special Case

The Mil Spec treats the power approach as a special problem and uses fixed values of intensities and factors that are the same as determined for $h = 500$ ft.

E. A Simpler Longitudinal Model

In his thesis work, Major John Arnold [23] used a model based on concepts similar to those which the Mil Spec is based upon. However, an attempt to match his data using the Mil Spec model showed considerable differences. Thus his model was temporarily incorporated so his data could be used for comparison. Dealing only with a small aircraft (variable stability T-33) he eliminated u_g and q_g from the longitudinal gust model and simplified the w_g model from second to first order. His model was described by

$$\dot{\alpha}_g = -\omega_b \alpha_g + k n_\alpha \text{ where } \omega_b \equiv \sqrt{3} V_T / L_w \quad (119)$$

As in equation (96), the theoretical value for k can be determined for any given value of $\sigma_{\alpha_g}^2$

$$\sigma_{\alpha_g}^2 = \frac{k^2}{2\omega_b} = \frac{\sigma_{w_g}^2}{V_T^2} \quad (120)$$

For a particular case to be used in Chapter VIII, if $V_T = 488$ ft/sec and $h = 9500$ ft, then

$$\dot{\alpha}_g = -.483 \alpha_g + .0203 n_\alpha \quad (121)$$

where $\sigma_{w_g} = 10.15$ ft/sec. A similar model could, of course, be defined for the lateral system using β_g as first order only. Extreme caution must be employed when using this type of simplified model since elimination of the six-degree-of-freedom model may produce a truly

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unrealistic turbulence environment. A case in point will be treated in Chapter IX.

A comparison of the Mil Spec power spectrum and the Arnold spectrum, which is defined in equation (119), is shown for the particular case of equation (121) in Figure 7.

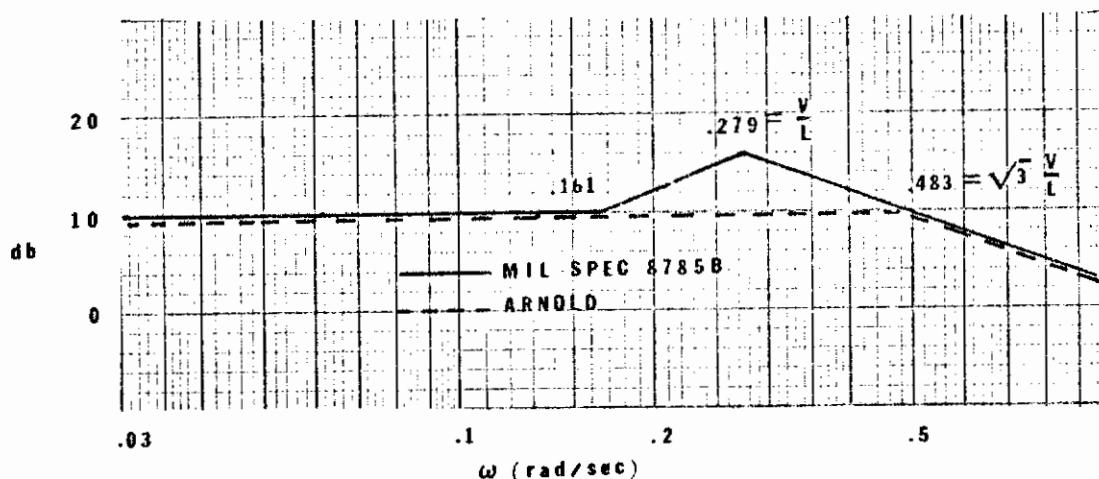


Figure 7. Spectrum Comparison for α_g

Controls

V. The Pilot Model

Many researchers have suggested methods of modelling the human pilot in the aircraft/control system problem. Specifically, two major models have emerged:

- 1) the crossover model introduced by Tustin [28] and further developed by McRuer and Krendel [9,29]. A state-of-the-art presentation for this model was made by Systems Technology Inc. [30]. This model is referred to as the conventional model in the following pages.
- 2) the optimal pilot model developed by Kleinman, Baron, and Levison [31,32].

Both of these models have advantages in given situations but they also involve inherent problems. Neither of these methods have been fully applied to the six-degree-of-freedom aircraft problem although theory for such has been postulated.

The conventional crossover model requires some method of determining the parameters K_p , T_L , T_I , and τ where the transfer function of the pilot model assumes the form

$$Y_p(s) = \frac{K_p(T_L s + 1)}{(T_I s + 1)} e^{-\tau s} \quad (122)$$

and where the Pade' approximation is often made to model the time delay in the pilot's transfer function.

Some [21,22] have fixed τ and T_I based on human factor limitations while others have considered the four parameters to be free. Anderson [33] and Dillow [34] have used the Paper Pilot concepts successfully for predicting these pilot parameters. Dillow's scheme employs a conjugate gradient minimization of a cost functional designed to yield pilot rating. Others have developed post-facto methods for parameter

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identification including Kugel [35] using a Newton-Raphson method and Walker [36] using filtering methods. Regardless of the method chosen, searching out the parameters is a time consuming and numerically difficult task.

On the other hand, the optimal pilot model has only been demonstrated on a simplified longitudinal system. Its capability and theoretical applicability to a multi-axis, multi output task has not been demonstrated. Further, the optimal pilot model is currently limited in its application because of the need for choosing weighting matrices in the optimal cost criterion. The model also encounters problems in the solution of the infinite time Riccati equation. One type of solver [49] using linear system theory has difficulty with multiple poles at or near the origin while another solver [49] cannot tolerate multiple roots. Both cases occur when considering the lateral equations of motion of an aircraft on approach.

The model implemented in this research avoids the above mentioned problems. It takes liberally from the concepts involved in both the conventional and optimal pilot models. Other points and concepts not addressed by either of the models are also incorporated. The model uses a two part approach. First, the displays to the pilot are interpreted and a decision made as to which variable requires attention most critical. Figure 8 shows a general block diagram of the decision making process. The second part of the model leans heavily upon the conventional pilot model for the form of the pilot control action to be implemented. However the parameters are determined differently and the results applied in a different manner than previously. Figure 9 presents a general block diagram of the control implementation scheme.

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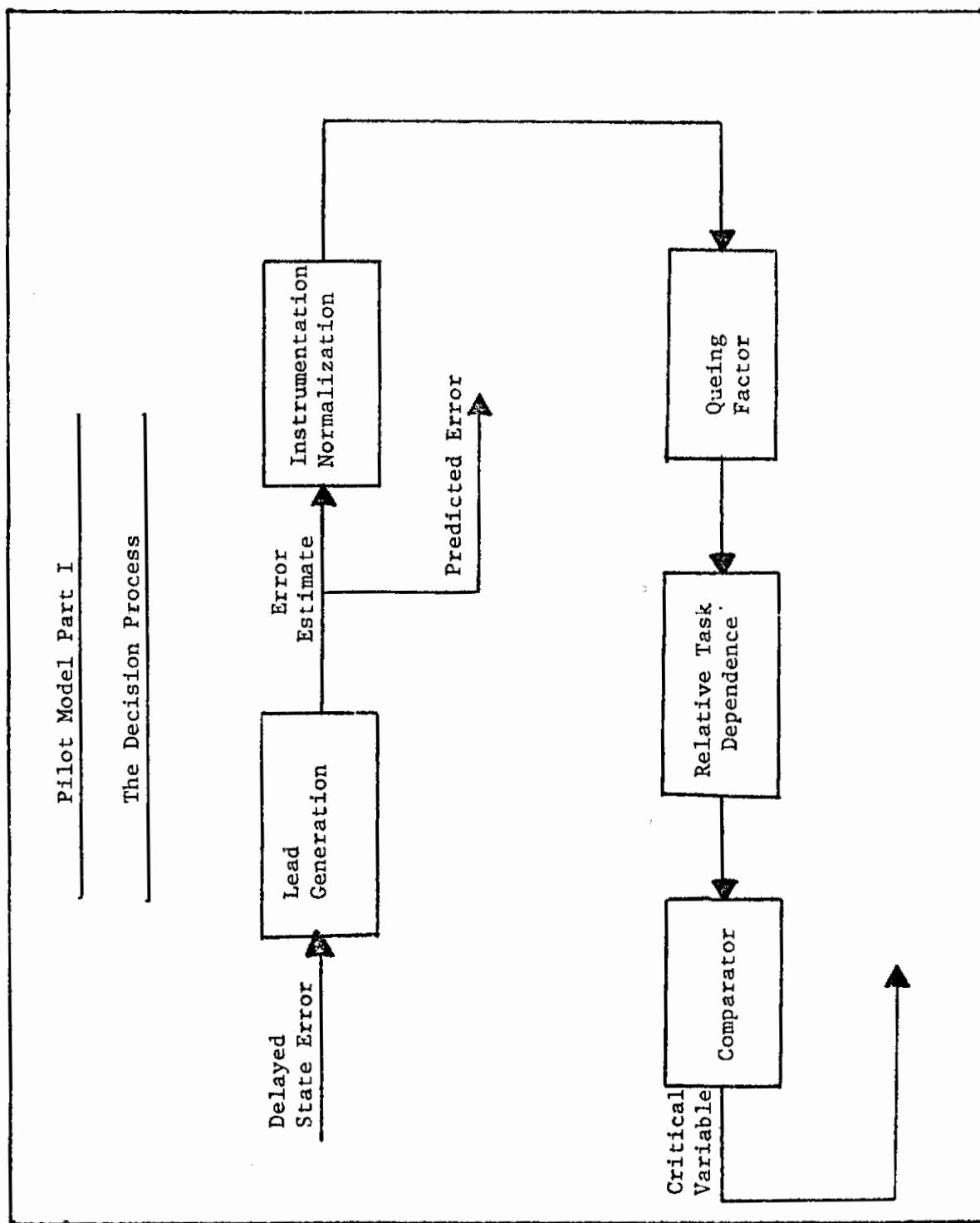


Figure 8. Block Diagram of the Pilot Model Decision Process

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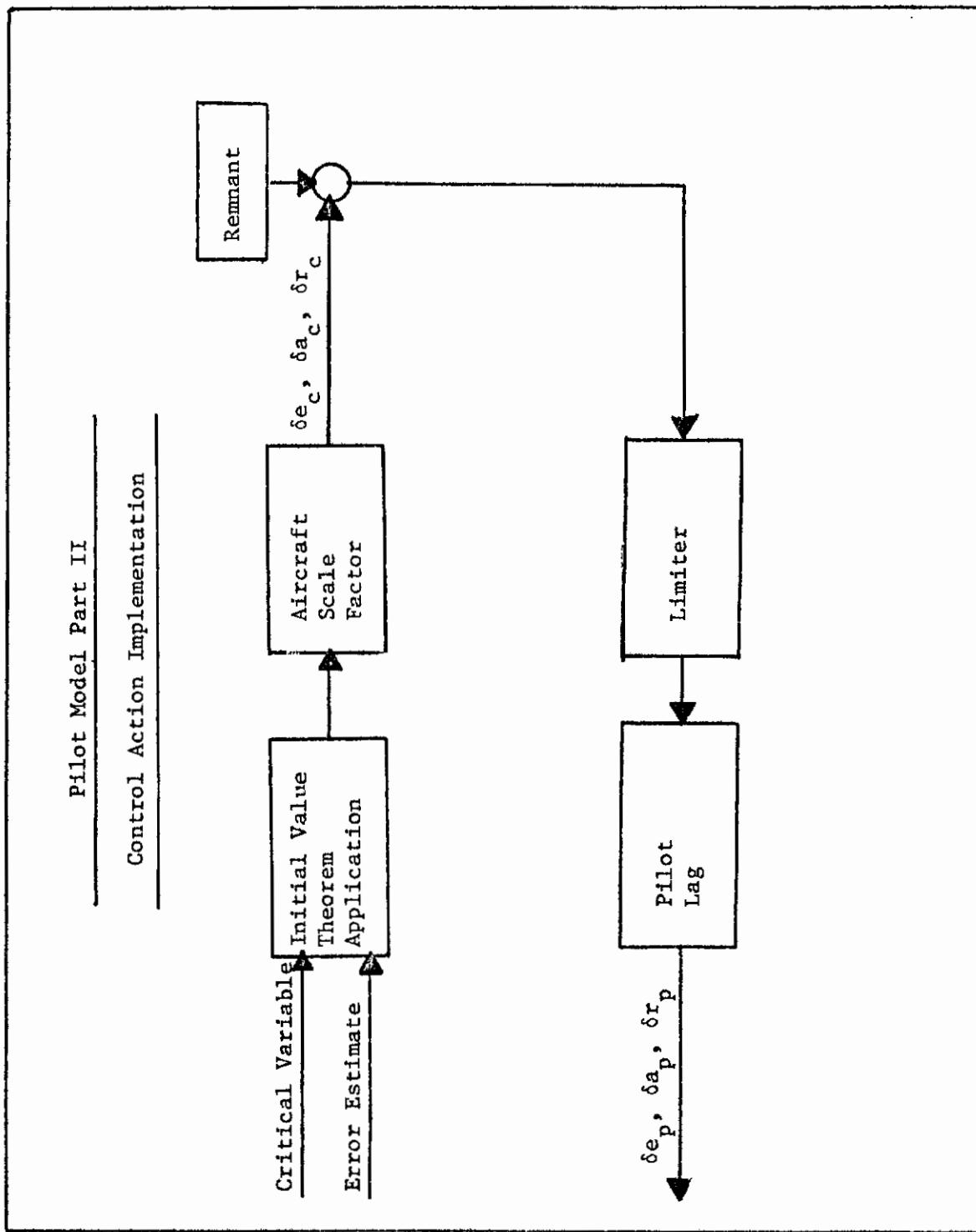


Figure 9. Block Diagram of Pilot Model Control Action Implementation

Control

A. The Pilot Model: Part I -- A Decision Making Model

B. Pilot Delay and Lead Generation

Human limitations hinder a pilot's capabilities to interpret and process displayed information which is changing in time. Previous research [37] has placed a value of between .1 and .5 seconds on the pure time delay associated with receptor delays, afferent transmission delays, and central processor delays. The latter value of .5 seconds appears representative only of a very sluggish pilot with more suitable values for the manual control problem lying between .15 and .25 seconds [38]. Commonly, a value of .3 seconds has been chosen; however, in this study an effective time delay of .175 seconds was used. Further discussion of the rationale for the selection of this value will occur later in this chapter.

To offset this delay, it is conjectured that the pilot has the capability to project his errors forward in time making use of rate information presented to him. For fast-moving signals he will not project much, perhaps only enough to compensate for his own delay. On slower moving signals, such as altitude error and localizer deviation, he is capable of projecting forward further with accuracy and thus take better advantage of his knowledge of the system's state. Such projections can be made mathematically using an equation of the form

$$x_{\text{new}} = x_{\text{delayed}} + k\tau \dot{x}_{\text{delayed}} \quad (123)$$

where

$$k = \begin{cases} 1 & \text{for rapidly moving signals such as pitch, roll, yaw error} \\ 2/\tau & \text{for slower signals such as altitude and localizer error} \end{cases}$$

and

τ = the pure time delay of the pilot.

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Equation (123) is equivalent to the $(T_L s + 1)$ term considered by the conventional pilot model.

C. Instrumentation Normalization Effects

The displays which the pilot uses to base his decisions on generally are not scaled such that a one inch displacement of one instrument corresponds to a one inch displacement of another instrument. Rather different scales appear and hence different displacements imply different errors. Additionally the distance between pointer tips and the instrument faces introduces differences in the interpretation of the displayed data. It is necessary to account for these effects upon the pilot's capability to make decisions. Pilots indicate they do not actually read numerical values from instruments but rather they obtain a measure of their error with a tendency to correlate larger displacement with larger error.

A survey conducted by the author of pilots and engineers familiar with standard flight instrumentation revealed that the minimum deviations they would react to would be 2° in pitch, 2° in roll, and 3° in yaw. While the roll and yaw scales are physically the same size, the pointer/indicator on the HSI (Heading Situation Indicator) is separated by a larger distance from the scale and hence the larger error before action is predicted.

The localizer and glideslope error indicators give angular information on error and thus have increased sensitivity as the runway is approached. The localizer error indicator generally has a maximum error indicated of about 2.5° . Thus a deviation of .5 degrees is easily detectable. The glideslope error indicator generally has a

maximum deviation of between .5° and .7°. A deviation of 1/16° was easily detectable.

These different angular displacements, which were indicated as minimum reaction values, lead to normalization of the raw data by dividing each error by its corresponding normalization factor. For example consider a 6° pitch error. This corresponds to a normalized error of 3 units ($6^\circ / 2^\circ$), whereas a 3° heading error is only a 1 unit ($3^\circ / 3^\circ$) error. Thus, the purpose of normalization is to determine how many units of deflection each instrument is indicating at any given time. Equations used for normalization are given in Figure 11.

Figure 10 shows the standard primary flight instruments considered.

D. Queing Factors

In addition to evaluating his displays, each pilot must treat in his own way the problem of correcting more than one axis of the aircraft system. In this regard, the human operator tends to become a queing system where the time since last corrective action tends to increase the importance of applying corrective action at the present time. Others [39] have previously addressed this problem of queing information.

To take account of this need, a factor of 2 was applied to each error that was not the last error acted upon. Thus the model places required emphasis upon those errors which are not the largest in absolute magnitude. Figure 11 shows the implementation of the queing concept.

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Figure 10. A Set of Standard Instruments

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E. Task Dependence

The pilot model was required to learn to perform five specific tasks related to the aircraft/control system problem:

- 1) a pitch attitude hold task in which the pilot was taught to hold pitch attitude while disregarding altitude errors but maintaining supervision of the lateral system
- 2) a roll attitude hold task in which attitude was disregarded but pitch and yaw control were to be maintained as secondary tasks
- 3) a heading attitude hold task in which attitude was disregarded but roll and pitch control were to be maintained as secondary tasks
- 4) a landing task where glideslope and localizer errors were to be minimized
- and 5) an attitude hold task in which equal emphasis was to be placed upon pitch, roll, and yaw control.

Emphasis was placed on the appropriate variables by using a particular set of actual simulation data and adjusting the relative weighting on each variable until the errors between the digitally generated data and the simulation data were satisfactorily minimized. With this one particular case optimized for each task, the relative weightings on the variable errors were fixed for the duration of the study. Table II shows the resulting relative weightings used to achieve the indicated task.

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Table II. Task Dependent Relative Error Weightings

Task	Relative Weightings				
	Pitch Error	Roll Error	Yaw Error	Glideslope Error	Localizer Error
Pitch Hold	1.25	1.00	1.00	0.	0.
Roll Hold	1.00	1.25	1.00	0.	0.
Heading Hold	1.00	1.00	1.25	0.	0.
Landing	1.50	1.00	1.00	.2	.2
Attitude Hold	1.00	1.00	1.00	0.	0.

F. Pilot Distraction

In normal flight a pilot can be expected to spend some of his time in side tasks not directly related to causing surface deflections. An example of this is required radio communications. Throughout this research the distraction rate was held at 10%. By using a random number generator, the pilot model was forced to take no control action on the average one of every ten attempts.

G. The Comparative Decision

Having attempted to quantify the decision making process, a comparison of the relatively weighted normalized errors is made with the largest magnitude error receiving the decision for control action. Figure 11 shows a flow diagram of the decision making process.

H. The Pilot Model: Part II -- Control Action Implementation

Having decided which variable requires the most urgent attention and a value for the predicted error having been determined, a method for control action determination is necessary.

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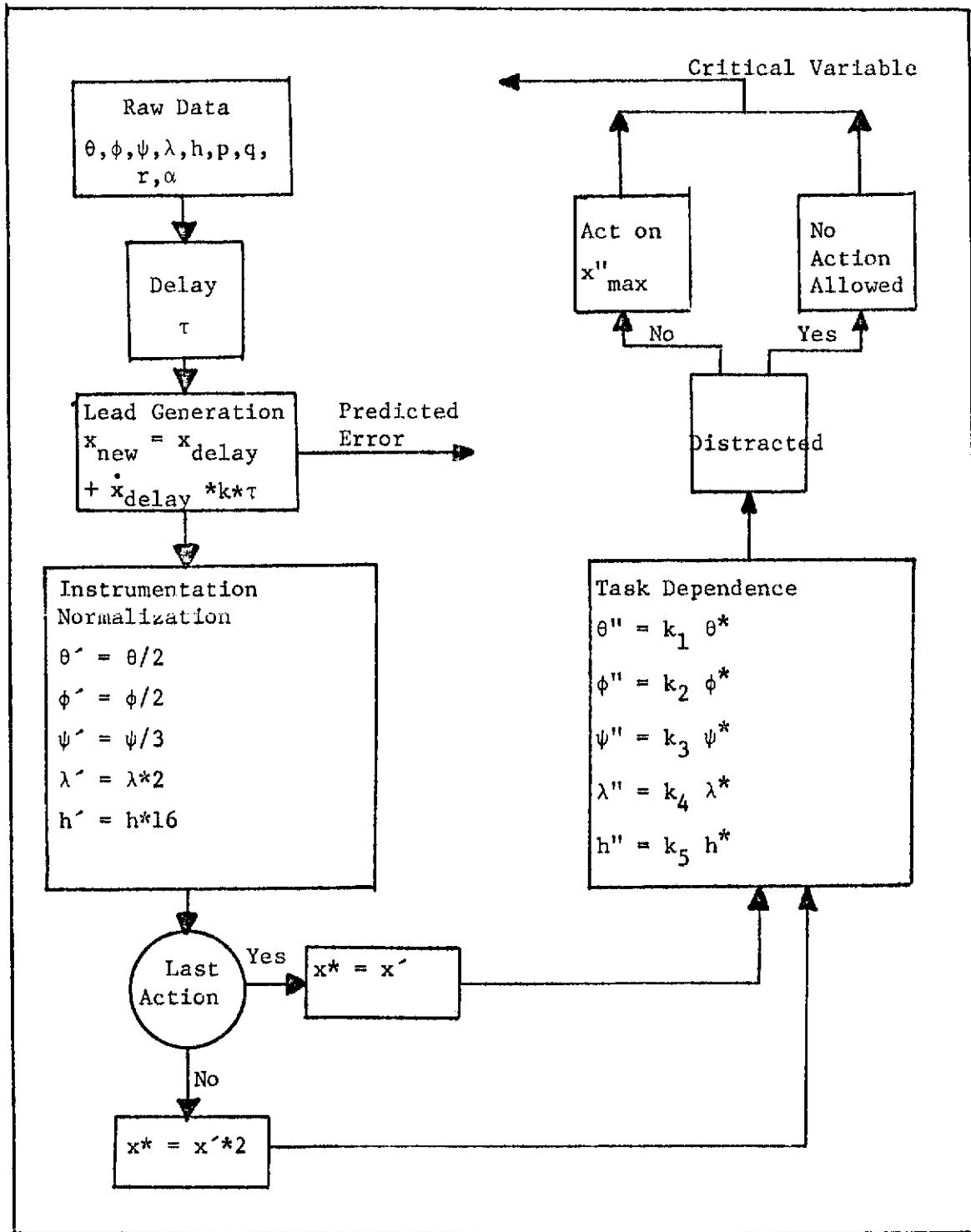


Figure 11. Flow Diagram, Part I

I. Initial Value Theorem Application

Since the pilot acts continuously and is commanding control surface deflections almost continuously, the aircraft will generally be in a transient state in which information can be obtained by applying the initial value theorem from conventional control theory [2:92]. This theorem states that

$$\lim_{s \rightarrow \infty} sF(s) = \lim_{t \rightarrow \infty} f(t) \text{ if } \lim_{t \rightarrow \infty} f(t) \text{ exists.} \quad (124)$$

J. Aircraft Transfer Functions

From [13:III-7], the following transfer functions describe the ratio of pitch angle and angle of attack to elevator deflection

$$\frac{\theta(s)}{\delta e(s)} = \frac{(M_{\delta e} + Z_{\delta e} M_w) s + (Z_{\delta e} M_w - M_{\delta e} Z_w)}{s(s^2 - (U_0 M_w + Z_w + M_q) s + (M_q Z_w - U_0 M_w))} \quad (125)$$

and

$$\frac{\alpha(s)}{\delta e(s)} = \frac{(1/U_0) (Z_{\delta e} s + (U_0 M_{\delta e} - Z_{\delta e} M_q))}{s(s^2 - (U_0 M_w + Z_w + M_q) s + (M_q Z_w - U_0 M_w))} \quad (126)$$

Additionally the yaw, sideslip and roll transfer functions are

[13:III-59]

$$\frac{\psi(s)}{\delta r(s)} = \frac{A_\psi s^3 + B_\psi s^2 + C_\psi s + D_\psi}{D_2} \quad (127)$$

where

$$A_\psi = N_{\delta r} + B_1 L_{\delta r}$$

$$B_\psi = Y_{\delta r}^* (N_\beta + B_1 L_\beta) + L_{\delta r} (N_p - B_1 Y_v) - N_{\delta r} (Y_v + L_p)$$

$$C_\psi = Y_{\delta r}^* (L_\beta N_p - N_\beta L_p) - L_{\delta r} (Y_v N_p) + N_{\delta r} (L_p Y_v)$$

$$D_\psi = (g/U_0) (L_{\delta r} N_\beta - N_{\delta r} L_\beta)$$

$$D_2 = s(A s^4 + B s^3 + C s^2 + D s + E)$$

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$$B_1 = J_{xz}/I_{zz}$$

$$A_1 = J_{xz}/I_{xx}$$

$$A = 1 - A_1 B_1$$

$$B = -Y_v(1 - A_1 B_1) - L_p - N_r - A_1 N_p - B_1 L_r$$

$$C = N_\beta + L_p(Y_v + N_r) + N_p(A_1 Y_v - L_r) + Y_v(B_1 L_r + N_r) + B_1 L_\beta$$

$$D = -N_\beta L_p + A_1 g/U_o + N_p(L_\beta + Y_v L_r) - L_p N_r Y_v - L_\beta g/U_o$$

and $E = (g/U_o)(L_\beta N_r - N_r L_\beta)$

$$\frac{\beta(s)}{\delta r(s)} = \frac{s(A_\beta s^3 + B_\beta s^2 + C_\beta s + D_\beta)}{D_2} \quad (128)$$

where

$$A_\beta = Y_{\delta r}^*(1 - A_1 B_1)$$

$$B_\beta = -Y_{\delta r}^*(L_p + N_r + A_1 N_p + B_1 L_r) - L_{\delta r} B_1 - N_{\delta r}$$

$$C_\beta = Y_{\delta r}^*(L_p N_r - N_p L_r) + L_{\delta r}(g/U_o - N_p) + N_{\delta r}(A_1 g/U_o + L_p)$$

$$D_\beta = N_{\delta r}(g/U_o) L_r - L_{\delta r}(g/U_o) N_r$$

and finally

$$\frac{\phi(s)}{\delta a(s)} = \frac{s(A_\phi s^2 + B_\phi s + C_\phi)}{D_2} \quad (129)$$

where the variables are defined as above and further

$$A_\phi = L_{\delta a} + A_1 N_{\delta a}$$

$$B_\phi = -L_{\delta a}(N_r + Y_v) + N_{\delta a}(L_r - A_1 Y_v)$$

$$C_\phi = L_{\delta a}(Y_v N_r + N_\beta) - N_{\delta a}(L_\beta - Y_v L_r)$$

Controls

It is also necessary to define the ratio $h(s)/\delta e(s)$ to control altitude errors. From [40:13]

$$sh(s) = u \sin\theta_0 - w \cos\theta_0 + l_{xp} s\theta + U_0 \cos\theta_0 \theta + W_0 \sin\theta_0 \theta \quad (130)$$

where l_{xp} is the distance from the aircraft center of gravity to the pilot's station. Under the assumption that θ_0 is small and second order effects can be ignored

$$sh(s) = -w + l_{xp} q + U_0 \theta \quad (131)$$

Further, if altitude error is measured with respect to the center of gravity ($l_{xp} = 0$), then

$$sh(s) = -w + U_0 \theta \quad (132)$$

or in the time domain

$$\dot{h} = -w + U_0 \theta \quad (133)$$

Considering now the velocity vector heading angle, λ ,

$$s\lambda = \frac{V_{T_0}}{U_0 \epsilon_0} s\beta - \frac{W_0}{U_0 \epsilon_0} p + \frac{1}{\epsilon_0} r \quad (134)$$

where $\epsilon_0 = \cos\theta_0 + (W_0/U_0) \sin\theta_0$

In stability axes, $W_0 = 0$ and $V_{T_0} = U_0$ so that

$$\dot{\lambda} = \dot{\beta} + r \approx \dot{\beta} + \dot{\psi} \quad (135)$$

or by integration

$$\lambda = \beta + \psi \quad (136)$$

where the initial conditions are assumed zero.

Controls

Taking the ratio of the altitude error and velocity heading error to surface deflection, their respective transfer functions are determined to be

$$\frac{sh(s)}{\delta e(s)} = \frac{-W(s)}{\delta e(s)} + \frac{U_0 \theta(s)}{\delta e(s)} \quad (137)$$

where

$$w(s) = \alpha(s) U_0$$

and

$$\frac{s\lambda(s)}{\delta r(s)} = \frac{s\beta(s)}{\delta r(s)} + \frac{s\psi(s)}{\delta r(s)} \quad (138)$$

Localizer error is controlled by maintaining the desired velocity vector heading.

K. Application of the Initial Value Theorem

The initial value theorem will now be applied to equations (125), (126), (127), (128), (129), (137), and (138) in order to obtain their approximate transient response to an impulse of control surface deflection.

In the case of equation (125), for example,

$$F(s) = \frac{q(s)}{\delta e(s)} = \frac{s(M_{\delta e} + Z_{\delta e} M_w)}{s^2 - (U_0 M_w + Z_w + M_q)s + (M_q Z_w - U_0 M_w)} \quad (139)$$

where the substitution $q(s) = s\theta(s)$ has been made.

Then

$$sF(s) = \frac{sq(s)}{\delta e(s)} = \frac{s^2(M_{\delta e} + Z_{\delta e} M_w) + (Z_{\delta e} M_w - M_{\delta e} Z_w)}{s^2 - (U_0 M_w + Z_w + M_q)s + (M_q Z_w - U_0 M_w)} \quad (140)$$

Now applying the initial value theorem to equation (140) by dividing through by s^2 and taking the limit or by repeated usage of l'Hospital's rule

$$\lim_{s \rightarrow \infty} sF(s) = M_{\delta e} + Z_{\delta e} M_w = \lim_{t \rightarrow 0} f(t) \quad (141)$$

Controls

Considering that normally $M_{\delta e} \gg Z_{\delta e} M_w$, equation (141) implies that

$$\frac{q}{\delta e} \Big|_{t \rightarrow 0} \approx M_{\delta e} \quad (142)$$

Thus in this case, an impulse of surface deflection is actually a commanded rate. In a similar manner using similar approximations,

$$\frac{p}{\delta a} \Big|_{t \rightarrow 0} \approx L_{\delta a} \quad (143)$$

$$\frac{r}{\delta r} \Big|_{t \rightarrow 0} \approx N_{\delta r} \quad (144)$$

$$\frac{\alpha}{\delta e} \Big|_{t \rightarrow 0} \approx 0 \quad (145)$$

$$\frac{\beta}{\delta r} \Big|_{t \rightarrow 0} \approx Y_{\delta r}^* \quad (146)$$

$$\dot{h}_{\delta e} \Big|_{t \rightarrow 0} \approx U_0 M_{\delta e} \quad (147)$$

$$\dot{\lambda}_{\delta r} \Big|_{t \rightarrow 0} \approx Y_{\delta r}^* + N_{\delta r} \quad (148)$$

Thus relations have been obtained which relate impulses in surface deflection to the rates of aircraft variables

L. Validation of the Initial Value Theorem Applicability

To show the validity of equations similar to equation (142), the actual time response of an impulse was obtained for equation (125) and is here compared with the initial value theorem approximation, $\dot{\theta} = M_{\delta e} \delta e$. Derivatives for the 707 described in Chapter VII were used.

Controls
Table III. Initial Value Theorem Approximation

<u>t (seconds)</u>	<u>Actual Response</u>	<u>IVT Response</u>	<u>% error</u>
0.	0.	0.	
.025	-.261	-.263	.8
.05	-.517	-.525	1.6
.1	-1.015	-1.050	3.3
.15	-1.492	-1.575	5.3
.20	-1.942	-2.100	7.7
.25	-2.365	-2.625	10.0
.30	-2.757	-3.15	12.5

M. The Control Action Criteria

Using equations (142) through (148), the problem of what control action the pilot should take is now ready to be solved. The required and accepted assumption is that the pilot will act to minimize his errors or deviations from the desired equilibrium conditions. Thus considering again the pitch error, an equation indicating the pilot's desire to minimize his errors is

$$\theta_e + \dot{\theta}_c t^* = 0 \quad (149)$$

where t^* is the expected duration of the commanded pitch rate. Equation (149) is notationally rewritten as

$$\theta_e + q_c t^* = 0 \quad (150)$$

Thus solving equation (150), the necessary value of q_c can be determined to be

$$q_c = -\frac{\theta_e}{t^*} \quad (151)$$

Using equation (142), and substituting in (151) for q_c , the necessary elevator deflection is found to be

$$\delta e_c = \frac{q_c}{M_{\delta e}} = \frac{-\theta_e}{M_{\delta e} t^*} \quad (152)$$

Control

Similarly the equations for the other aircraft error variables are

$$\delta a_c = \frac{-\theta e}{L_{\delta a} t^*} \quad (153)$$

$$\delta r_c = \frac{-\psi e}{N_{\delta r} t^*} \quad (154)$$

$$\delta e_c = \frac{-he}{U_o M_{\delta e} t^*} \quad (155)$$

$$\delta r_c = \frac{-\lambda e}{Y_{\delta r}^* + N_{\delta r}} \quad (156)$$

N. Determination of t^*

The time of application of the commanded surface deflections is determined from strip chart recordings of actual simulations. Figure 12 shows recordings of δe vs. time for three different aircraft. As might be expected, the time of application is a function of the aircraft involved. The YF-16 with a nominal landing weight of about 20,000 lbs. shows control application durations of about .25 - .50 seconds. The B-1 and the 707 with gross landing weights of about 190,000 lbs. show corrections lasting from 2.5 to 4.0 seconds. Graphing these three points against the aircraft weight leads to the conjecture that control application duration and aircraft mass may be linearly related. Considering this relation, equations (152) to (156) take the form

$$\delta x_c = \frac{-x_e}{(Y_x)} \frac{(m_{ref})}{(m_a)} \cdot .85 \quad (157)$$

where

δx_c is the commanded surface deflection

x_e is the aircraft variable error

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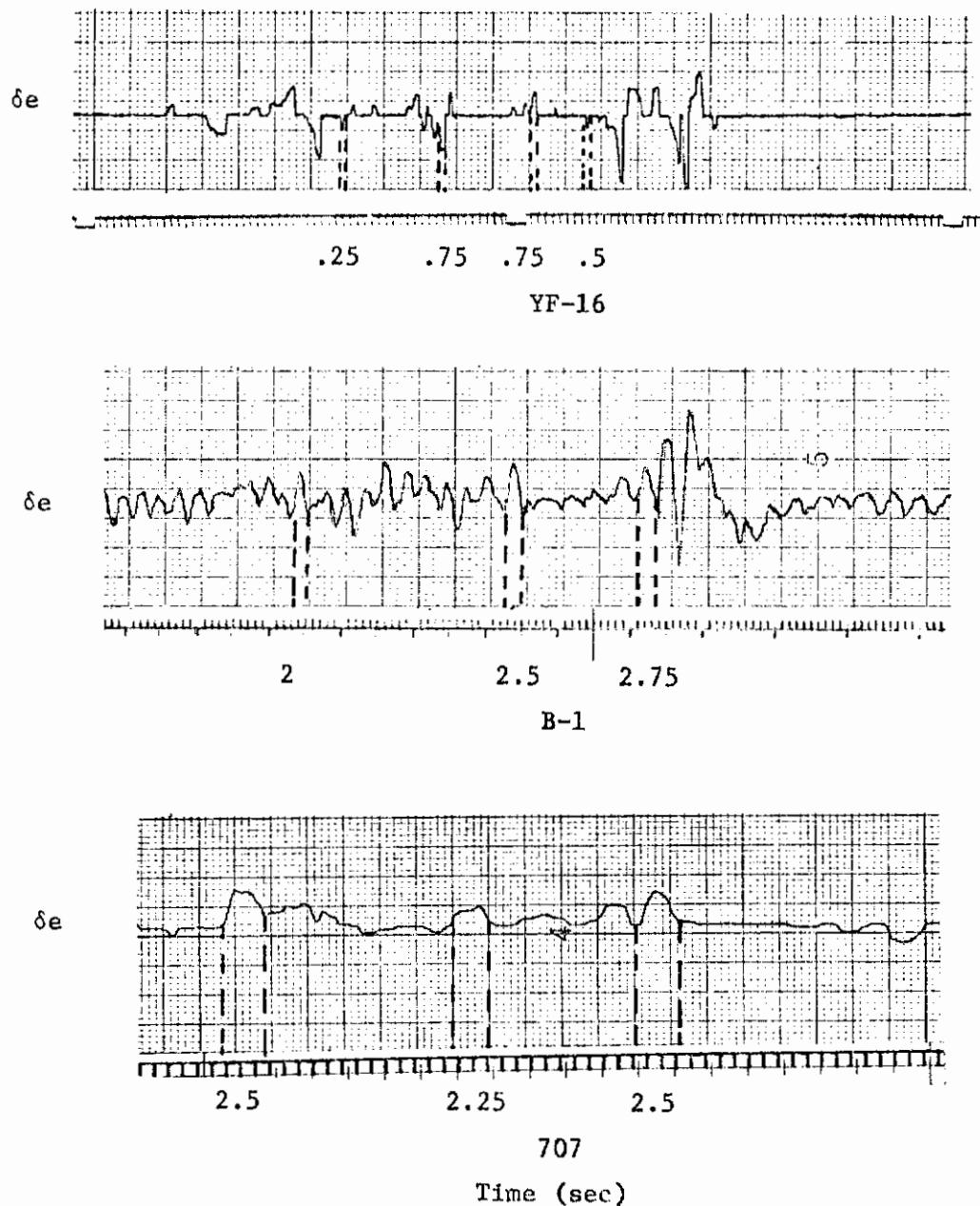


Figure 12. Determination of t^* from Strip Chart Data

Controls
 Y_x is the appropriate stability derivative combination

m_{ref} is set at 350 slugs

m_a is the aircraft mass

τ is the pilot time delay $\approx .125$ seconds

and the .85 factor has been determined from experimental data matching.

O. Remnant

With the parameters for the determination of control action now defined, the effects of processing inaccuracy as well as neuromuscular noise need to be accounted for. A typical form for the statistics of such noise is given by [10]

$$v_m = \rho_i \cdot E[\delta c^2] \quad (158)$$

where

v_m is the variance of the motor noise

δc is the commanded deflection

and ρ_i is the motor noise to signal ratio.

Here ρ_i was used as .01 yielding a 1 to 5% variability in the motor noise.

Additionally a minimum value or threshold value was established such that the minimum value of σ_{v_m} was $.1^\circ$ as shown in Figure 13.

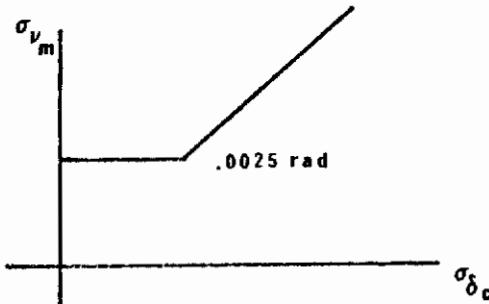


Figure 13. A Threshold on Motor Noise

Controls

This effect was necessary to account for results seen in longitudinal systems where errors tend to be small.

P. Physical Limitations

In addition to other constraints already considered, the physical limits of a control surface to maximum deflection should be incorporated to avoid misleading results. For an aircraft with good aerodynamic behavior, these limits will not be reached during flight in moderate turbulence. Typical values of such limits are

<u>Variable</u>	<u>Limit</u>
δ_e	$\pm 26.5^\circ$
δ_a	$\pm 25^\circ$
δ_r	$\pm 24^\circ$

The above values are for an A-7D on power approach [41]. For the cases in this study, the physical limits for all control surfaces were artificially fixed at $\pm 16^\circ$.

Q. Pilot Lag

In addition to his pure time delay, the human pilot possesses the undesirable attribute that he cannot instantaneously input his desired commands into an aircraft system. Rather a definite lag of .08 to .2 seconds is encountered [37]. Thus a typical control input sequence might appear as shown in Figure 14.



Figure 14. Control Input Sequence

The labeled points can be interpreted as follows:

- A - control action begins
- B - peak achieved; no further action required
- C - action begins
- D - additional action required
- E - further action required
- F - no further action required.

From the urgency for action concept, control actions are prohibited in the non-critical variables other than a return to neutral position while control action is occurring in the critical variable.

R. An Engineering Approximation

To facilitate programming of the concepts presented here, an "engineering approximation" that the pilot lag equals the pilot delay was made. Looking more closely at this approximation (as in Figure 15) allows differing implications to be drawn.

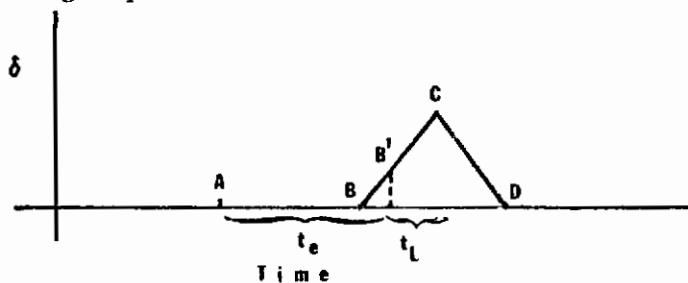


Figure 15. A Single Pulse

Somewhere between points B and C effective control begins. For purposes of this study, the time between A and B' will be called the effective time delay and defined by equation (159)

$$\tau_e = 1.4\tau \quad (159)$$

where τ is the pure time delay of the pilot. This leaves an effective lag time of

$$\tau_{l.e} = .6\tau \quad (160)$$

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For the cases shown here,

$$\tau = .125 \text{ seconds}$$

$$\tau_e = .175 \text{ seconds}$$

$$\tau_{Le} = .075 \text{ seconds}$$

Figure 16 presents an overall flow diagram of the control action implementation.

S. The Pilot Rating

Many simulations and flight tests have made use of the subjective Cooper Harper rating scale to obtain pilot opinion either of aircraft performance or task difficulty. Many others have quantified this rating in terms of both performance errors and lead generation requirements [21,22,23,33,34] for a single axis control task.

Based on equations (142 - 148) an attempt was made to determine pilot rating quantitatively based solely on rotational angular rates. Some background on this idea is given by Systems Technology Inc. [40] who give some ideas of the acceptable limits of certain variables during power approach.

Other observations from psychologists concerning the assignment of maximum and minimum ratings also seem pertinent [42]. The tendency to avoid extremes clearly stems from the unknown of the next occasion which could significantly affect the opinion of the current situation. Thus over mid-range ratings a more gentle slope is experienced than at the extremes. With these factors in mind, the piecewise linear relationship shown on Figure 17 was determined through data matching.

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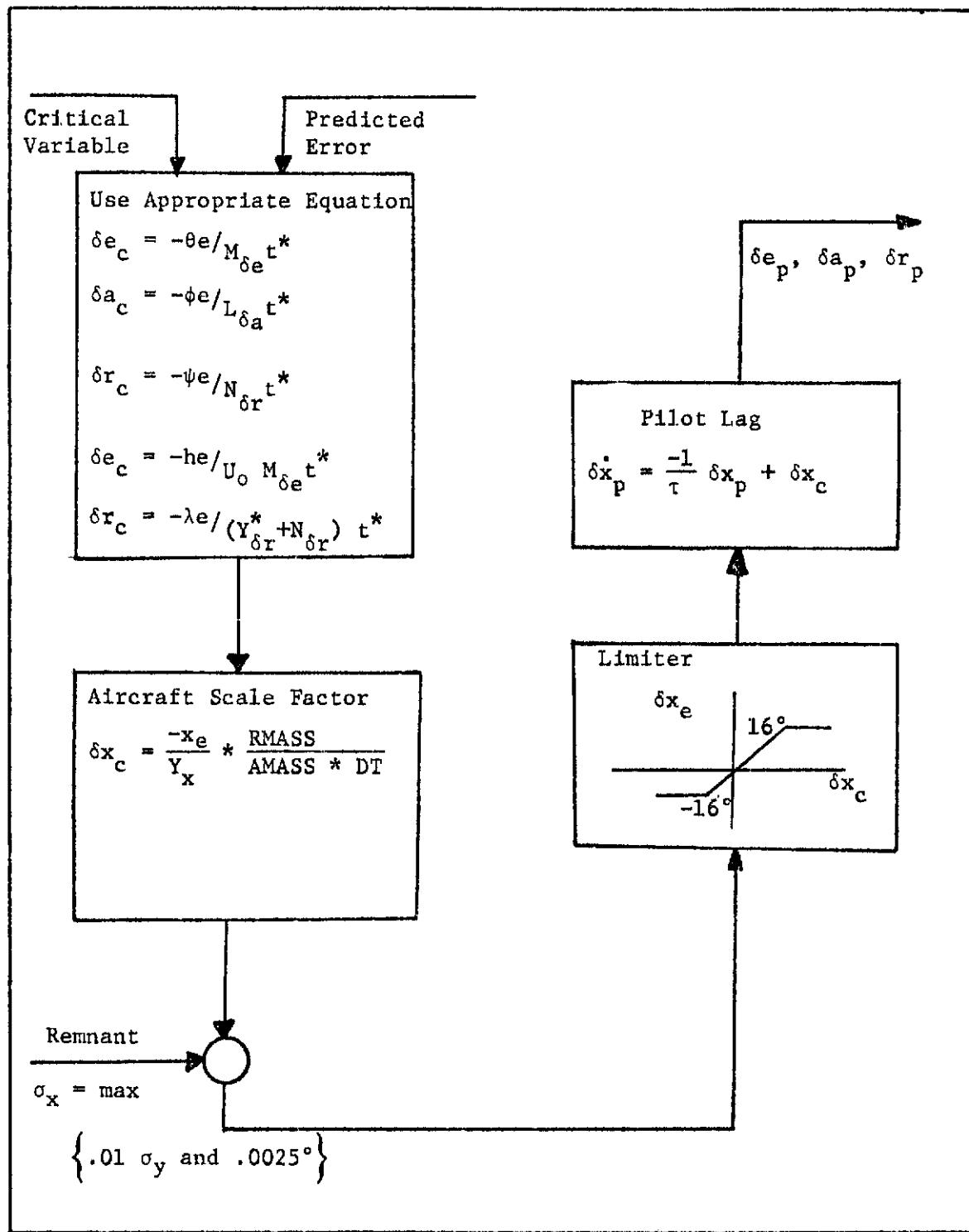


Figure 16. Flow Diagram Part II

Contrails

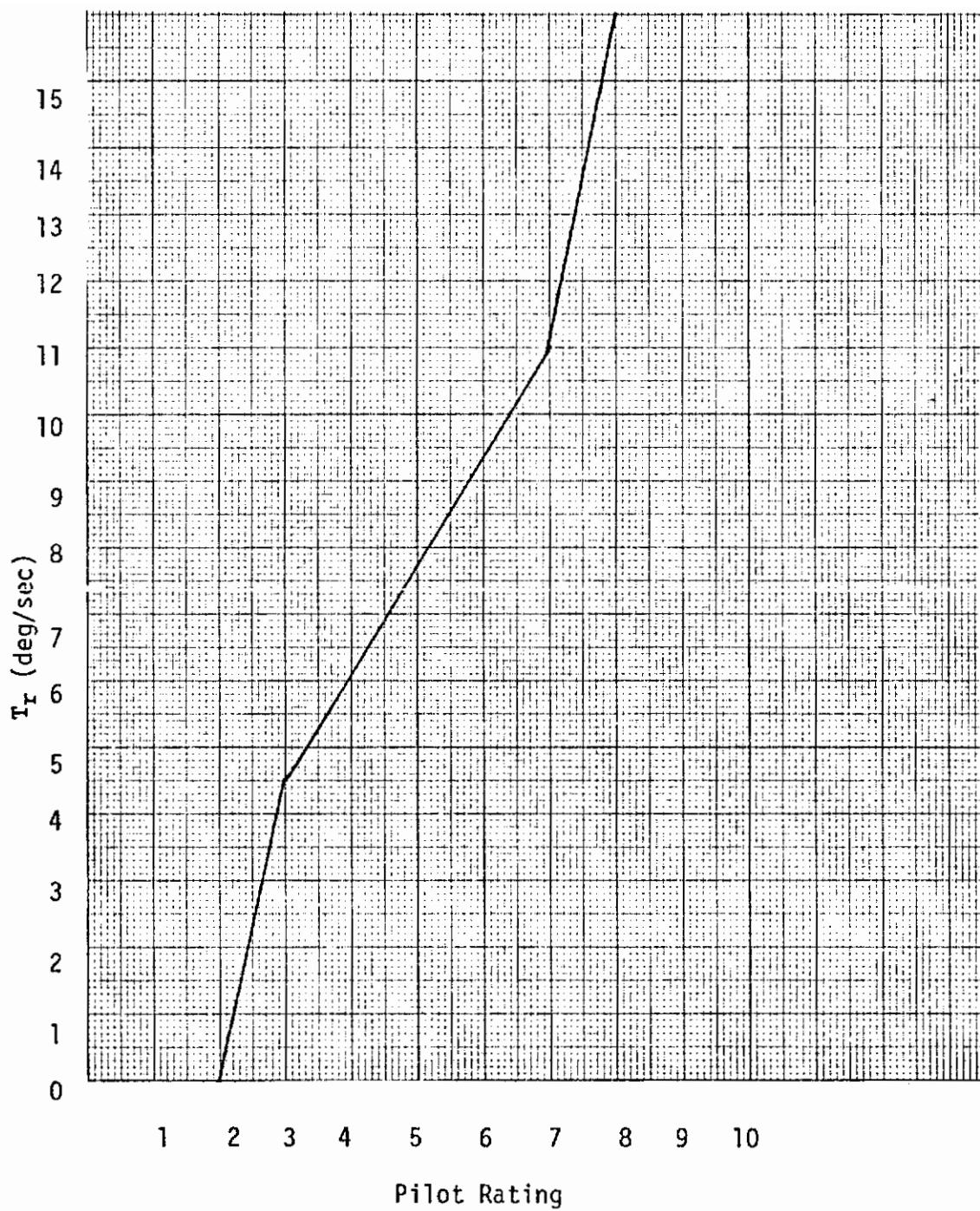


Figure 17. A Pilot Rating Curve

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The equations represented by the figure are

$$T_r = \sqrt{\sigma_p^2 + \sigma_q^2 + \sigma_r^2} = \text{the total rotational rate}$$

For $T_r < 4.5$ $P_r = 2. + .22 T_r$

$4.5 < T_r < 11$ $P_r = .615 T_r + .35$ (161)

$11 < T_r < 23$ $P_r = .25 T_r + 4.25$

$T_r > 23$ $P_r = 10$

With this formula the pilot rating seems predictable within ±1 rating unit which is about the expected inter-pilot deviation in ratings.

Data on this subject is presented in Chapter VIII.

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VI. System Integration and Special Requirements

The models described in Chapters I through V were incorporated in a digital computer program using the Fortran IV language. The program was compiled and executed using a Control Data Corporation Cyber 74 configuration. Implementing these models into a computer program introduces several requirements not mentioned up to this point.

A. The Turbulent Environment

The solution of linear stochastic differential equations of the type discussed in Chapter IV in conjunction with the turbulence model is not a straightforward process. Understanding of both the method of time propagation of the driving white noise sequence as well as the method of integration are essential in order to obtain correct statistical results from the solution of these equations. Here the noise process was propagated by linear interpolation between two Gaussian distributed points across the integration interval which was equal to the pilot's pure time delay. The integration routine used was a fourth order Runge Kutta routine with an Adams-Moulton predictor corrector. The method of solution used was researched as part of this study and is presented in [25].

B. Generation of the Pilot's Commands

The pilot's commands are generated by linear interpolation from present position to the desired position across the integration interval. Whenever the pilot's command is for a different control surface, the remaining two surfaces are returned to a neutral trimmed position and are disturbed only by the remnant injection. If the command is for

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additional input in the same channel, it is implemented without returning to the null position as depicted in Figure 14. These pulses provide impulse-like inputs to control the system.

C. The Complete State Model

The aerodynamics of the aircraft, the stability augmentation system equations, and the localizer and glideslope deviation equations were combined with those of the turbulence model to give the complete state model as shown below.

The following additional definitions are needed:

$$z_1 = u + u_{\text{gust}} = x_2 + x_{15} \quad (162)$$

$$z_2 = \alpha + \alpha_{\text{gust}} = x_3 + x_{17} \quad (163)$$

$$z_3 = \beta + \beta_{\text{gust}} = x_8 + x_{21} \quad (164)$$

$$z_4 = p + p_{\text{gust}} = x_{11} + x_{19} \quad (165)$$

$$z_5 = r + r_{\text{gust}} = x_{10} + x_{22} \quad (166)$$

The coefficients c_n of the gust model were determined in Chapter IV and are repeated here for convenience

$$c_1 = -V_T / L_u$$

$$c_2 = \sigma_u \sqrt{2V_T} / L_u$$

$$c_3 = -V_T / L_w$$

$$c_4 = 1$$

$$c_5 = \frac{\sigma_w}{L_w} \frac{\sqrt{V_T}}{L_w} (1 - \sqrt{3})$$

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$$c_6 = \frac{\sigma_w}{V_T} \frac{\sqrt{3}V_T}{L_w} \quad (167)$$

$$c_7 = -\frac{\pi V_T}{4b}$$

$$c_8 = \frac{\sigma_{w\pi}}{4b} \frac{\sqrt{\pi V_T}}{\sigma_w} - \frac{\sqrt{.8}}{(4b)} \frac{\pi L_w}{\sigma_w}^{1/3}$$

$$c_9 = -\frac{V_T}{L_v}$$

$$c_{10} = \frac{\sigma_v}{L_v} \frac{\sqrt{V_T}}{L_v} (1 - \sqrt{3})$$

$$c_{11} = \frac{\sigma_v}{V_T} \frac{\sqrt{3}V_T}{L_v}$$

$$c_{12} = \frac{\pi V_T}{3b}$$

With these definitions the complete state model employed was:

<u>Variable</u>	<u>State Equation</u>	<u>Equation #</u>
$\theta = x_1$	$\dot{x}_1 = x_4$	46
$u = x_2$	$\dot{x}_2 = x_y z_1 + x_\alpha z_2 - g x_1 \cos\theta_0 - w_o x_4$	48
$\alpha = x_3$	$\dot{x}_3 = z_u^* z_1 + z_\alpha z_2 + z_{\delta e}^* x_6 - g \sin\theta_0 x_1/v_A + u_o x_4/v_A$	48
$q = x_4$	$\dot{x}_4 = M_\alpha^* z_u z_1 + (M_\alpha + M_\alpha^* z_\alpha) z_2 + (M_q + M_\alpha^*) x_4 + M_q x_{18} + (M_{\delta e} + M_\alpha^* z_{\delta e}) x_6$	48
$y_3 = x_5$	$\dot{x}_5 = -1/t_q x_5 - K_q/t_q x_4$	78

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<u>Variable</u>	<u>State Equation</u>	<u>Equation #</u>
$\delta e_2 = \delta e_z$	$\dot{\delta e}_2 = \frac{1}{tq} x_5 + \frac{Kq}{tq} x_4$	73
$\delta e_{aug} = \delta e_{aug}$	$\dot{\delta e}_{aug} = \delta e_1 + \delta e_2 + \delta e_3 + \delta e_4$	72
$\delta e = x_6$	$\dot{x}_6 = -\frac{1}{ta} x_6 + \frac{1}{ta} (\delta e_{aug} + \delta e_c)$	85
$\psi = x_7$	$\dot{x}_7 = 1/10 \sec \theta_o$	66
$\beta = x_8$	$\dot{x}_8 = Y_v z_3 + (g x_9/v_A) \cos \theta_o + Y_{\delta r} x_{14}$ $- U_o z_5/v_A + (g x_7/v_A) \sin \theta_o + W_o x_{11}/v_A$	66
$\phi = x_9$	$\dot{x}_9 = x_{11} + x_{10} \tan \theta_o$	66
$r = x_{10}$	$\dot{x}_{10} = N_\beta z_3 + N_r z_5 + N_{\delta a} x_{12} + N_{\delta r} x_{14} + N_p z_4$	66
$\nu = x_{11}$	$\dot{x}_{11} = L_\beta z_3 + L_r z_5 + L_{\delta a} x_{12} + L_{\delta r} x_{14} + L_p z_4$	66
$\delta a = x_{12}$	$\dot{x}_{12} = -\frac{1}{t_{con}} x_{12} + \frac{1}{t_{con}} (\delta a_{aug} + \delta a_c)$	85
$\delta r_{aug} = x_{13}$	$\dot{x}_{13} = \frac{K_{r_{aug}}}{t_{r_{aug}}} [N_\beta z_3 + N_r z_5 + (N_p + K_{p_{aug}}) N_{\delta a}$ $+ K_{p_{aug}} K_{ari} N_{\delta r}) z_4 + (N_{\delta a} + K_{ari} N_{\delta r})$ $\delta a_c + (N_{\delta r} - \frac{1}{K_{r_{aug}}}) x_{13}]$	83
$\delta r = x_{14}$	$\dot{x}_{14} = -\frac{1}{t_{con2}} x_{14} + \frac{1}{t_{con2}} [x_{13} + \delta r_e$ $+ \delta r_{coord}]$	85
$u_g = x_{15}$	$\dot{x}_{15} = c_1 x_{15} + c_2 f(\eta_u)$	95

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<u>Variable</u>	<u>State Equation</u>	<u>Equation #</u>
$\alpha_g' = x_{16}$	$\dot{x}_{16} = c_3 x_{16} + c_4 f(\eta_\alpha)$	104
$\alpha_g = x_{17}$	$\dot{x}_{17} = c_3 x_{17} + c_5 x_{16} + c_6 f(\eta_\alpha)$	104
$q_g = x_{18}$	$\dot{x}_{18} = c_7 x_{18} - c_7 \dot{x}_{17}$	116
$p_g = x_{19}$	$\dot{x}_{19} = c_7 x_{19} + c_8 f(\eta_p)$	110
$\beta_g' = x_{20}$	$\dot{x}_{20} = c_9 x_{20} + f(\eta_\beta)$	105
$\beta_g = x_{21}$	$\dot{x}_{21} = c_9 x_{21} + c_{10} x_{20} + c_{11} f(\eta_\beta)$	105
$r_g = x_{22}$	$\dot{x}_{22} = c_{12} (x_{22} + \dot{x}_{21})$	115
$d = x_{23}$	$\dot{x}_{23} = -x_3 V_A + V_A x_1$	132
$h = x_{24}$	$\dot{x}_{24} = x_2 \sin\theta_o - x_3 V_A \cos\theta_o + U_o x_1 \cos\theta_o$ + $W_o x_1 \sin\theta_o$	130
$\lambda_1 = x_{25}$	$\dot{x}_{25} = (\dot{x}_8 + \dot{x}_7) \sec\theta_o$	134
$\lambda_2 = x_{26}$	$\dot{x}_{26} = \frac{V_T}{R} (\psi + \beta)$	[40]
	where $f(\eta_i) = \frac{\sqrt{T}}{\omega_b T} (\dot{\eta}_i + \omega_b \eta_i)$	
	where ($i:i = u, \alpha, p, \beta$)	
	and $\omega_b = 1.8/T$ where T is the integration step size.	

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D. Integration of the State Equations

Integration of the state equations was performed using a variable step size 4th order predictor corrector scheme. Credit for the programming of this routine goes to Major James Funk, formerly of the Air Force Institute of Technology. The integration routine is quick, accurate, and dependable allowing the system of equations to be integrated in near-real time. This routine as well as the program created by this study can be obtained through the Air Force Flight Dynamics Laboratory as described in the foreword.

E. Statistical Computations

The statistics computed in the program are simple. The mean was calculated from [43:12]

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i \quad (168)$$

while the variance was determined from

$$\sigma^2 = \frac{1}{n(n-1)} [n \sum_{i=1}^n x_i^2 - (\sum_{i=1}^n x_i)^2] = \frac{1}{n-1} [\sum (x_i - \bar{x})^2] . \quad (169)$$

The standard deviation, σ , is the square root of the variance. The data, x_i , for these computations was taken at 8 samples/second ($1/\tau$) with no data taken during the first few seconds in order to avoid transients. The maximum and minimum of each variable were also stored during the runs.

Contrails
VII. Aircraft Investigated

Several different aircraft were investigated during the course of this research. The primary criteria for selection of the aircraft to be studied were:

- a) suitable aerodynamic and control system information was readily available
- b) the aircraft were from different classes [7:10] (i.e. trainer, fighter, fighter bomber, and transport)
- c) the aircraft had been simulated using a man-in-the-loop simulation and a sufficient set of data was collected to make a comparative analysis possible.

With these criteria in mind, four aircraft were selected. They are shown in Table IV.

Table IV. Aircraft Investigated

Aircraft	Data Source	Reference
F-5	Northrop Corporation	[44]
A-7	Northrop Corporation	[44]
707	AFFDL/FGD	[45]
T-33	AFIT -- AFFDL/FGD	[23]

Some other aircraft for which a comparative performance data set was lacking were also processed.

A. The F-5 and A-7 Aircraft

Both the F-5 and A-7 aircraft were investigated by Mr. E. D. Onstott of Northrop Corporation. The research was performed for the Air Force Flight Dynamics Laboratory as reported in [44]. Basically three tasks were flown: pitch, roll, and heading hold. Both the

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lateral and the longitudinal axes were always flown simultaneously although lateral tasks had only lateral gusts and the pitch task had only longitudinal gusts. A gust model which employed only w_{gust} , v_{gust} , q_{gust} , and r_{gust} was used. Since both of these aircraft have short wingspans, p_{gust} , can be eliminated and u_{gust} contributes negligibly to performance degradation.

Specifically, the tasks can be described as:

<u>Task</u>	<u>Requirement</u>
Pitch	Hold pitch altitude, wings approximately level
Roll	Hold approximate altitude, maintain wings level, ignore heading
Heading	Hold approximate altitude, maintain heading

Duration of the simulated flights on the moving base simulator was about 120 seconds with data recording beginning after a 10 second lapse to allow acquisition of the task. Instrumentation was standard for IFR flight with the notable exception of the presentation of the roll error during the roll task. No visual display was used providing a strictly IFR condition.

The variables recorded and presented were θ, ϕ, ψ , and β . Pilot ratings were taken based on the Cooper Harper rating scale. However, the pilots were instructed to rate the difficulty of the task without trying to compensate the rating for the turbulence level. The pilots defined the turbulence levels they flew as light, moderate, or heavy for each flight condition [44:23] and hence were probably aware of the turbulence level by the time data recording began.

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For the F-5 and A-7 the pilots chose the following intensities as corresponding to light, moderate and heavy turbulence:

<u>Level</u>	<u>Intensity</u>
Light	3 - 5 ft/sec
Moderate	6 - 11 ft/sec
Heavy	11 - 15 ft/sec

These choices are only approximate and varied somewhat depending on the aircraft and the flight condition. The moderate level agrees approximately with the levels given in Mil Spec 8785B. Twice the nominal Mil Spec level corresponds with the heavy turbulence condition indicated above.

Table V gives the values used for the physical, geometric, aerodynamic, and control system parameters of the F-5 and A-7 aircraft in the flight configurations of this study. The A-7 values were validated by comparison with another published report [17]. This crosscheck revealed that the stability derivatives given were for body centerline axes and so the additional variable, α_0 , is necessarily included in Table V. Other work [22] has assumed the body and stability axes to coincide which may be valid for α_0 small but in several cases considered here this assumption causes a marginally stable (unaugmented) Dutch Roll to become unstable or nearly neutrally stable and hence less desirable for analysis and realism. With this in mind, the F-5 data was assumed body axis also and comparisons with the root loci of [44] confirms this assumption. From the root loci, α_0 , for the F-5 was estimated. Additionally, one typographical error was found in F-5 Case #4 where L_p' should be -1.360 instead of -.1360. Conversations with Mr. Onstott confirmed this error.

Table V. F-5/A-7 System Parameters

Aircraft	<u>F-5</u>				<u>A-7</u>			
Flight Condition	#1	#2	#3	#4	#1	#2	#3	#4
x_u	-.082	-.009	-.022	-.006	-.006	-.044	.003	-.019
x_α	-66.194	-75.867	83.801	-84.379	34.1	32.273	8.526	27.682
Z_u^*	-.000	-.001	-.000	-.000	-.000	.000	-.000	-.000
Z_α	-1.717	-.924	-1.993	-.681	-1.16	-2.12	-.554	-1.01
$Z_{\delta e}^*$	-.435	-.221	-.459	-.148	-.157	-.220	-.074	-.114
M_α	-10.3	-3.59	-11.4	-4.11	-9.081	-27.8	-4.15	-13.14
$M_{\delta e}$	-47.2	-10.5	-64.4	-15.48	-18.9	-41.7	-8.19	-20.20
M_q	-1.35	-.478	-2.04	-4.93	-.696	-1.07	-.330	-.539
M_a	-.065	-.004	-.152	-.028	-.133	-.267	-.065	-.143
Mass	350.	350.	350.	350.	680.	680.	680.	680.
U_o	889.	439.	988.	789.	635.	952.	584.	876.
α_o	0.8	8.0	0.0	6.0	4.0	2.5	7.5	3.8
K_q	.055	.123	.055	.09	.25	.25	.25	.25
$K_{\dot{q}}$	.008	-.031	.008	-.031	0.00	0.00	0.00	0.00
t_a	.01	.01	.01	.01	.01	.01	.01	.01
t_q	.08	.08	.08	.08	.10	.10	.10	.10
Y_v	-.584	-.288	-.787	-.192	-.187	-.310	-.085	-.145
$Y_{\delta r}^*$	.095	.061	.086	.041	.054	.055	.027	.035

Controls
Table V. Continued

<u>Aircraft</u>	<u>F-5</u>				<u>A-7</u>			
Flight Condition	#1	#2	#3	#4	#1	#2	#3	#4
L_{β}	-74.8	-22.4	-102.1	-27.6	-29.2	-66.0	-14.90	-30.6
$L_{\delta r}$	13.8	4.23	12.28	5.16	7.27	11.20	3.09	6.55
$L_{\delta a}$	28.0	8.43	26.5	12.01	17.60	24.10	7.96	14.20
L_p	-3.28	-1.746	-3.57	-1.36	-2.73	-6.19	-1.40	-3.00
L_r	.801	.395	1.028	.231	.868	.843	.599	.563
N_{β}	39.6	7.43	56.3	11.54	3.12	10.20	1.38	4.72
$N_{\delta r}$	-12.15	-3.74	-12.34	-4.75	-5.54	-8.80	-2.54	-5.11
$N_{\delta a}$	2.04	.193	2.80	.619	1.37	1.64	.652	1.01
N_p	.154	.062	.188	.051	-.116	-.207	-.080	-.112
N_r	-.839	-.365	-1.02	-.283	-.541	-.975	-.247	-.455
t_{con}	.01	.01	.01	.01	.01	.01	.01	.01
t_{con2}	.01	.01	.01	.01	.01	.01	.01	.01
t_{raug}	.50	.50	.50	.50	.10	.10	.10	.10
K_{raug}	.31	.62	.27	.52	.25	.25	.25	.25
K_{paug}	0.00	0.00	0.00	0.00	-.10	-.10	-.10	-.10
K_{ari}	0.00	0.00	0.00	0.00	.147	.153	.20	.20
b	25.3	25.3	25.3	25.3	38.7	38.7	38.7	38.7
G_θ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Contrails

Table V. Concluded

<u>Aircraft</u>	<u>F-5</u>				<u>A-7</u>			
Flight Condition	#1	#2	#3	#4	#1	#2	#3	#4
G_ϕ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Altitude	5135.	4950.	5000.	32150.	15000.	15000.	35000.	35000.
K_{azs}	0.00	0.00	0.00	0.00	-.00054	-.00054	-.00054	-.00054
ℓ_x	12.0	12.0	12.0	12.0	16.0	16.0	16.0	16.0

Note: Derivatives are body centerline axis derivatives.

Contrails

Figures 18 and 19 show the appropriate stability augmentation for the F-5 and A-7 respectively. They are both rather conventional systems employing a pitch damper, a yaw damper, and roll rate feedback.

B. Boeing 707 Aircraft

The Boeing 707 was simulated on a moving base simulator by the Flight Dynamics Laboratory for the Federal Aviation Administration (FAA). As part of the research work, the author in conjunction with other members of the Systems Dynamics Branch of the Flight Dynamics Laboratory developed a high sample rate digital magnetic tape data collection system which allowed 50 aircraft related state variables to be sampled at a rate of 10 samples/second. A task group headed by Captain R. V. Gressang made preliminary investigations of visibility effects upon the pilot's powered approach performance of a task in the 707. Among the data collected were 10 approaches each by 2 USAF pilots in dense fog (100 ft breakout/1200 ft runway visual range). These IFR runs provide a basis for the analysis of the 707 in powered approach made here. Light turbulence (2 ft/sec rms) was used in conjunction with this experiment in order to provide a turbulence which might normally be encountered in fog without decisively increasing the workload of the pilots. A complete six-degree-of-freedom gust model was used with the following average intensities:

$$\sigma_{ugust} = 2 \text{ ft/sec} \quad \sigma_{pgust} = .4 \text{ deg/sec}$$

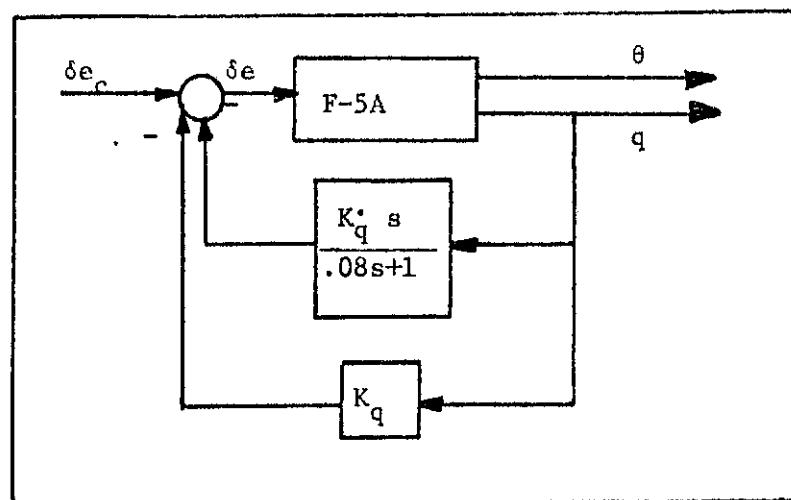
$$\sigma_{vgust} = 2 \text{ ft/sec} \quad \sigma_{qgust} = .3 \text{ deg/sec}$$

$$\sigma_{wgust} = 1.4 \text{ ft/sec} \quad \sigma_{rgust} = .4 \text{ deg/sec}$$

A value of approximately .25 times the Mil Spec nominal value produces this light turbulence.

Controls

The Longitudinal Feedback



The Lateral Feedback

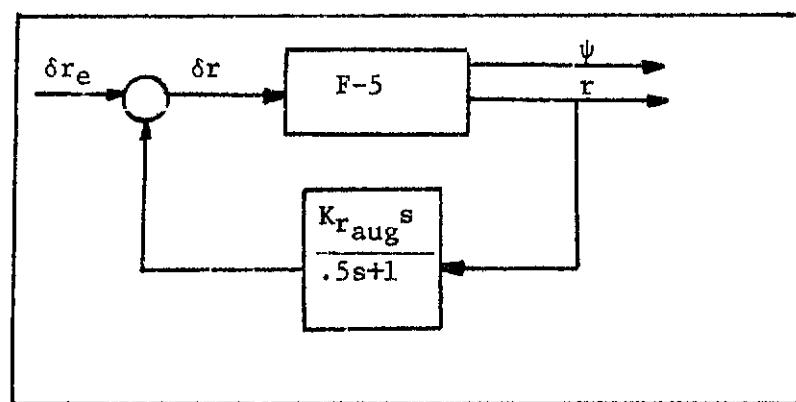
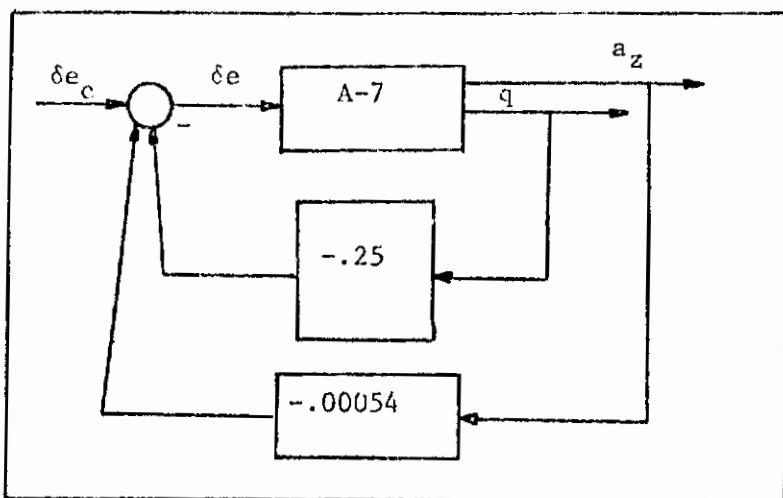


Figure 18. F-5 Stability Augmentation System

Controls

The Longitudinal System



The Lateral System

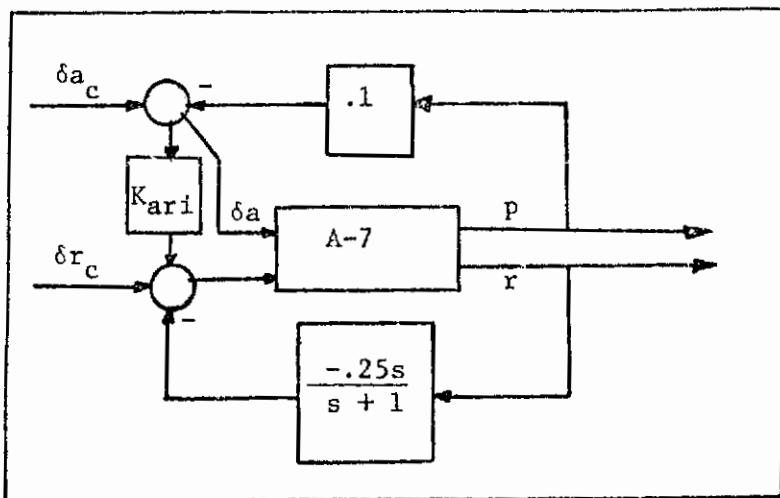


Figure 19. A-7 Stability Augmentation System

Contrails

The powered approach was simulated from approximately 3 miles from the GPIP (Glide Path Intercept Point) to touchdown. An American Airlines Redifon Visual System was used; however, until breakout at 100 ft altitude (2000 ft range), there were no visual cues available and thus strictly instruments were used for flying the approach down to breakout. All landings were made in daylight using a strobe marked approach.

Instrumentation included an ADI (Attitude Director Indicator) and HSI (Horizontal Situation Indicator) incorporating the FD-109 flight director system. Additionally radar and barometric altimeters, air-speed, angle of attack, g, and mach meters were available in the 707 simulator cockpit.

The pilot's assigned task was to land the aircraft using those procedures he would have used in an actual aircraft. A pilot rating of aircraft performance under the given conditions was obtained using the Cooper Harper rating scale.

C. System Parameters for the Boeing 707

The Boeing 707 was simulated as an unaugmented aircraft although the actual aircraft may employ a stability augmentation system (yaw damper). Particularly the yaw damper adds increased stability to the lateral system in the actual aircraft. Accordingly the lateral system was modified by changing L_p to yield improved handling qualities without a yaw damper.

The stability derivatives for the 707 are presented in Table VI. These derivatives are given in the primed stability axis system. Note these derivatives are for power approach where the flight path angle is -3° .

Controls

Table VI. 707 System Parameters

x_u	-.040	$L_{\delta r}'$	.211
x_α	19.115	$L_{\delta a}'$	.141
z_u^*	-.001	L_p'	-2.026
z_α	-.597	L_r'	.610
$z_{\delta e}^*$	-.030	N_β'	.567
M_α	-1.003	$N_{\delta r}'$	-.382
$M_{\delta e}$	-.863	$N_{\delta a}'$	.011
M_q	-.687	N_p'	-.136
M_α^*	-.271	N_r'	-.248
Mass	5900.	τ_{con}	.01
U_o	233.	τ_{con2}	.01
K_q	0.	τ_{raug}	1.
K_q^*	0.	K_{raug}	0.
τ_a	.01	K_{paug}	0.
τ_q	.50	K_{ari}	0.
Y_v	-.095	b	130.8
$Y_{\delta r}^*$	.033	$G\phi$	0.
L_β'	-1.628		

Note: Derivatives are primed stability axis derivatives.

Contrails

D. NT-33 Aircraft

The NT-33 aircraft was simulated by Major John Arnold for his master's thesis [23]. The simulation was performed using a fixed base simulator at the Air Force Flight Dynamics Laboratory. Instrumentation was an oscilloscope with the horizontal trace representing pitch angle displacement much as an ADI. Air Force pilots were used and an average set of deviations for the variables $\theta, q, \alpha, \delta e$ and $\dot{\delta e}$ was obtained for different longitudinal configurations of the variable stability NT-33. The gust model used was described earlier in Chapter IV. The gust intensity level was set at 10 ft/sec. Pilot ratings based on the Cooper Harper scale were taken. This was a one-axis simulation.

E. System Parameters for the NT-33

The longitudinal parameters for eight different longitudinal configurations of interest are presented in Table VII. The longitudinal axis of the aircraft is unaugmented and represents varying degrees of damping and different natural frequencies. Configurations 9, 10, and 11 are heavily overdamped and not generally representative of typical aircraft dynamics. A typical set of lateral dynamics [46] for the NT-33 was chosen and a yaw damper added to provide a system which would not detract from the pilot's capability to control the longitudinal system. Table VIII shows the parameters used for the lateral axis of the NT-33.

F. Other Aircraft Simulated

Although comparative analysis data was not available, the DC-8, F-4B, YQM-98A, and the A-7D in power approach were digitally simulated. The stability derivatives and augmentation systems employed are given in Table IX.

Controls

Table VII. NT-33 Longitudinal Dynamics

Case	1D	2D	3A	4A	5A	9	10	11
x_u	.007	.007	.007	.007	.007	.007	.007	.007
x_α	22.287	22.287	22.287	22.287	22.287	22.287	22.287	22.287
Z_u^*	-.000	-.000	-.000	-.000	-.000	-.000	-.000	-.000
Z_α	-1.59	-1.59	-1.59	-1.59	-1.59	-1.59	-1.59	-1.59
$Z_{\delta e}^*$	-.091	-.091	-.091	-.091	-.091	-.091	-.091	-.091
M_α	-6.64	-6.64	-6.64	-6.64	-6.64	-6.64	-6.64	-6.64
$M_{\delta e}$	-14.54	-14.54	-14.54	-14.54	-14.54	-14.54	-14.54	-14.54
M_q	1.13	-10.92	-54.99	-11.55	-12.18	.850	.850	-2.672
M_α^*	-2.579	5.653	44.367	10.336	11.935	-7.080	-4.78	-2.998
ξ	.69	.70	.63	.28	.18	1.7	1.2	1.1
ω_n	2.2	4.9	9.7	5.0	5.1	2.3	2.3	3.3
U_o	488	488	488	488	488	488	488	488
h	9500	9500	9500	9500	9500	9500	9500	9500
λ_x	6.53	6.53	6.53	6.53	6.53	6.53	6.53	6.53
mass	425	425	425	425	425	425	425	425

Note: Derivatives are stability axis derivatives

Controls

Table VIII. NT-33 Lateral Dynamics

Y_v	- .128
$Y_{\delta r}^*$	.036
L_β	-7.42
$L_{\delta r}$	1.39
$L_{\delta a}$	11.70
L_p	-1.56
L_r	.256
N_β	2.60
$N_{\delta r}$	-3.21
$N_{\delta a}$	.121
N_p	- .038
N_r	- .204
$K_{r_{aug}}$	1.0
$\tau_{r_{aug}}$	1.0
b	37.5

Note: Derivatives are stability axis derivatives.

Contrails

Table IX. Other Aircraft Longitudinal Parameters

Aircraft:	<u>DC-8</u>	<u>F-4B</u>	<u>YQM98A</u>	<u>A-7D</u>
X _u	-.037	-.071	-.058	-.046
X _α	31.008	6.70	10.917	21.075
Z _u	-.001	-.001	-.002	-.000
Z _α	-.750	-.373	-2.451	-.708
Z _{δe}	-.04 1	-.041	-.088	-.111
M _α	-1.051	-1.962	-2.697	-2.5
M _{δe}	-.923	-1.702	-4.642	-3.86
M _q	-.594	-.285	-1.232	-.388
M _α	-.194	-.134	-.292	-.075
U _o	228.	226.	169.	253.
h	500.	500.	500.	500.
l _x	25.2	17.8	0.	16.
a _o		14.7		
Mass	5580	1031	177	642
k _q	0.	0.	0.	.250
k _q	0.	.65	0.	0.
τ _a	.01	.02	.01	.01
τ _q	.01	1.00	.01	.55
K _{azs}	0.	0.	0.	-.00212

Note: Derivatives are stability axis derivatives except for the F-4B which are body centerline axis.

Contrails

Table IX. Other Aircraft Lateral Parameters

Aircraft:	<u>DC-8</u>	<u>F-4B</u>	<u>YQM98A</u>	<u>A-7D</u>
Y_v	- .089	- .086	- .156	- .251
$Y_{\delta r}^*$	.031	.017	.041	.045
L_β	-1.40	-6.94	-2.174	-11.80
$L_{\delta r}$	.159	- .470	.030	2.24
$L_{\delta a}$	1.13	2.567	3.364	14.4
L_p	-1.04	-1.095	-10.62	-2.24
L_r	.47	.846	.096	.915
N_β	.368	2.228	1.379	2.43
$N_{\delta r}$	- .368	- .773	- .940	-1.69
$N_{\delta a}$	0.00	- .058	- .166	.045
N_p	- .029	- .022	-1.204	- .143
N_r	- .257	- .252	- .274	- .405
$K_{r_{aug}}$	.000	4.	0.	1.
$\tau_{r_{aug}}$	.01	2.	.01	.55
b	142.4	38.7	81.2	38.7
$K_{p_{aug}}$	- .2	- .4	0.	- .4
K_{ari}	0.	0.	0.	.075
G_ϕ	- .24	- .5	0.	0.

Contrails

VIII. Results of the Digital Simulation

All of the aircraft described in Chapter VII were simulated using the digital computer program developed by this research. The output of each of these cases is included in the Appendix. The various parameters available for comparative analysis will be presented in both tabular and graphical form showing the correspondence between the hybrid man-in-the-loop simulation and the digital simulation of this research. Appropriate statistical tests are performed which verify the data match between the different methods of simulation.

A. F-5/A-7 Comparative Analysis

Since the F-5 and the A-7 were both simulated by Northrop Corporation, their comparative analysis will be treated simultaneously. Three particular environmental conditions were chosen for analysis:

<u>Condition</u>	<u>Description</u>
1	Augmented Aircraft/Mil Spec Turbulence
2	Augmented Aircraft/Double Mil Spec Turbulence
3	Unaugmented Aircraft/Mil Spec Turbulence

Since the digital simulation, like the man-in-the-loop simulation, produces one realization of a stochastic process using a particular noise set, the results of each digital run were compared with the available Northrop data sets. The set of Northrop data which most closely approximated the digital data was chosen for comparison when more than one set of Northrop data was available. For example,

Controls

for the augmented A-7 #1 with Mil Spec Turbulence, the following Northrop data was considered:

Run #	σ_ϕ	σ_ψ	σ_β	σ_{vg}	Pilot
732	4.08	.70	.60	4.66	WWK
733	2.88	.63	.64	4.89	WWK
738	4.20	.59	.64	4.94	JBJ
739	3.41	.57	.66	5.03	JBJ

The digital results were

2.85 .91 .67 4.84

Thus run #733 was chosen as the best data match. The results of these data matches were plotted for the various condition considered. The heading and pitch tasks were flown. Figures 20, 21, and 22 show the results of the individual conditions while Figure 23 provides a composite of all three conditions. The plots show one sigma values of θ, ϕ, ψ and β with the digital simulation always on the vertical axis and the manned simulation on the horizontal axis. Tables X, XI, and XII show the plotted data in tabular form. The run numbers referred to are the Northrop designators given in [44].

Statistical F tests were performed on each of the runs [43:74]. Performance of this test requires determination of the number of degrees-of-freedom inherent in the data. Since the largest time constant of the system was about 7 seconds, a value of 10 seconds was chosen to imply the addition of a degree-of-freedom. Hence, with a total run time of 100 seconds both the digital and Northrop data were considered to have 9 degrees-of-freedom. $F_{9,9} = 3.18$ at the .05 level of significance and Table XIII shows the resulting F test ratios.

Contrails

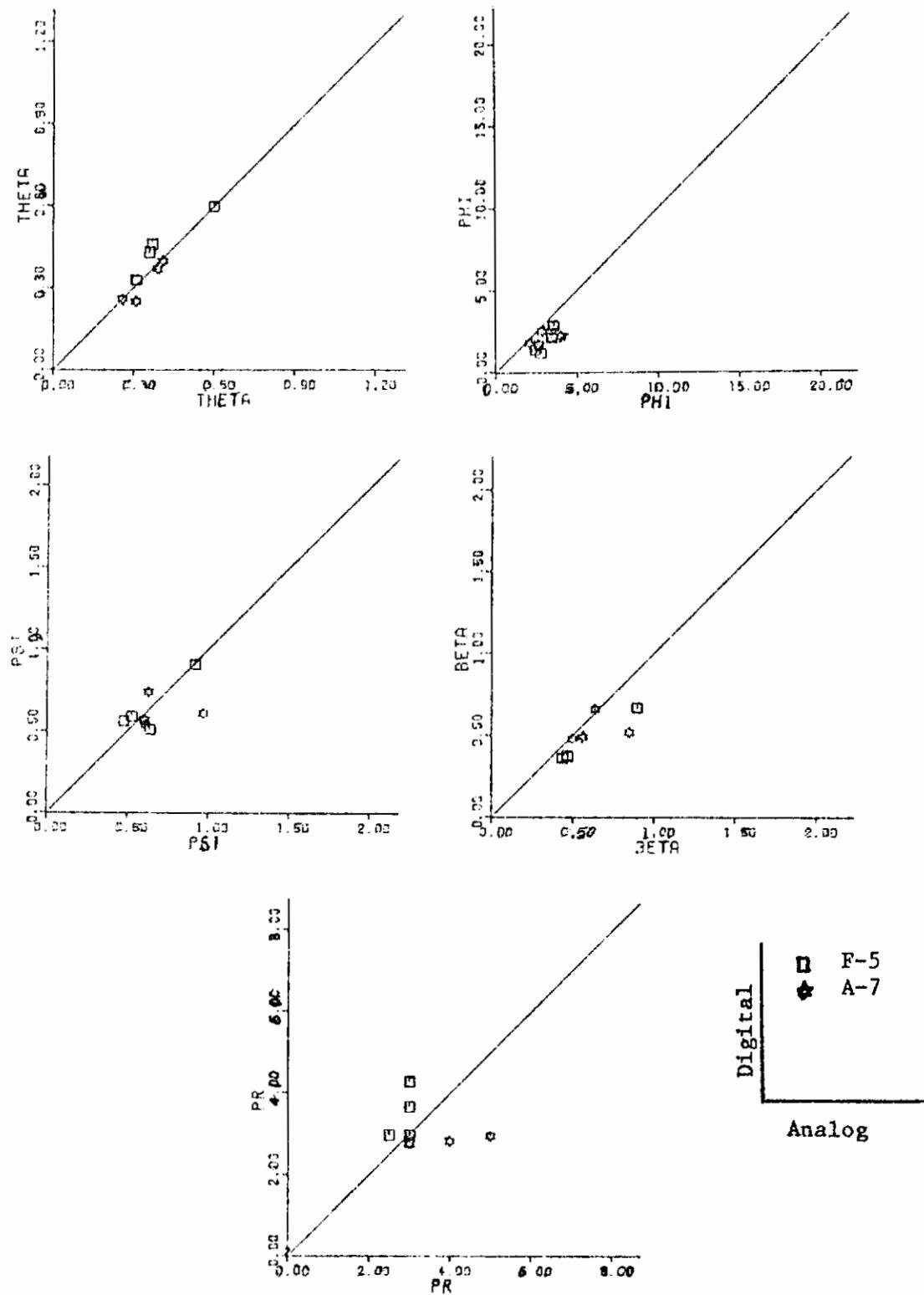


Figure 20. Comparison of F-5/A-7 Data (Augmented, Mil Spec Turbulence)

Contrails

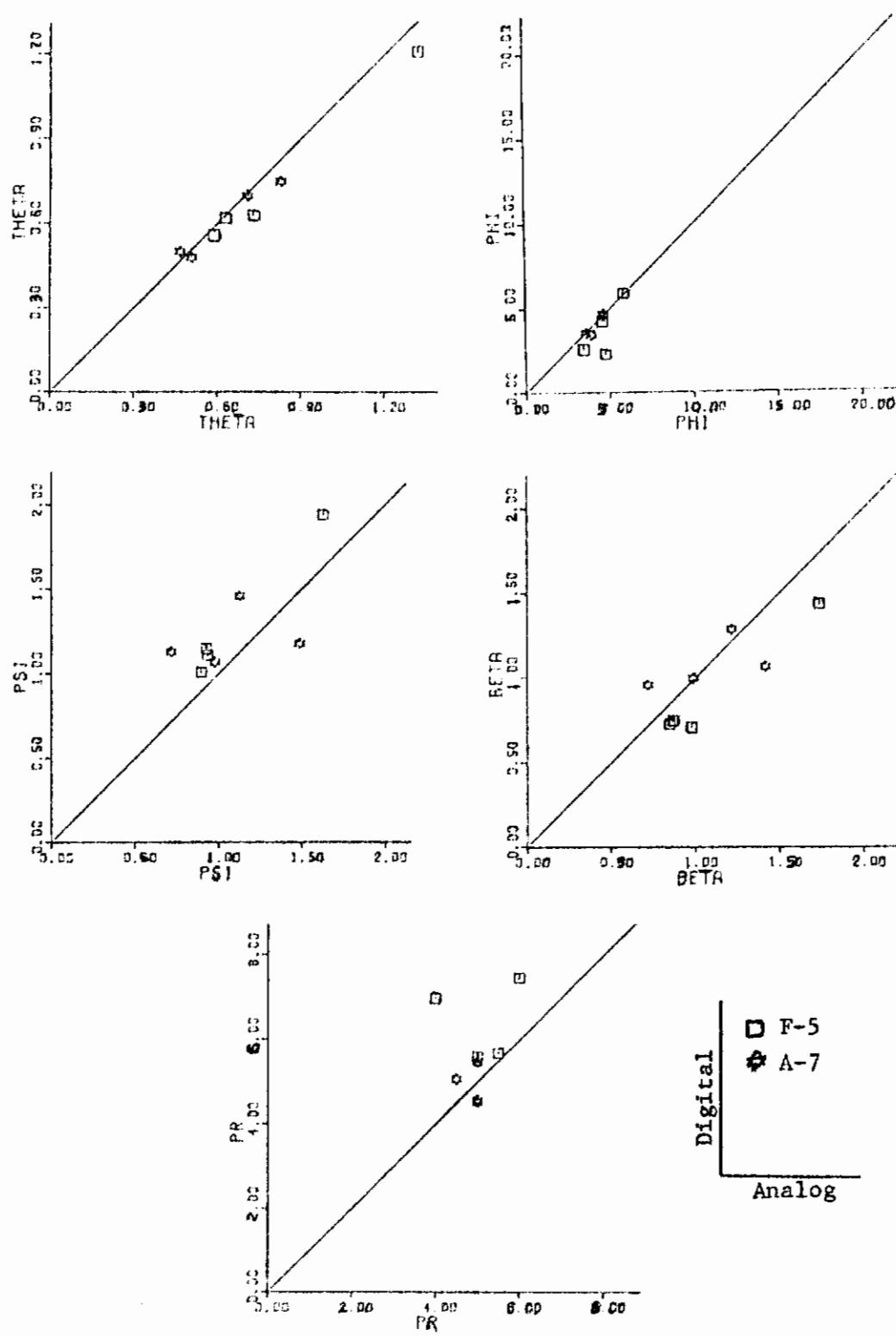


Figure 21. Comparison of F-5/A-7 Data (Augmented, Double Mil Spec Turbulence)

Contrails

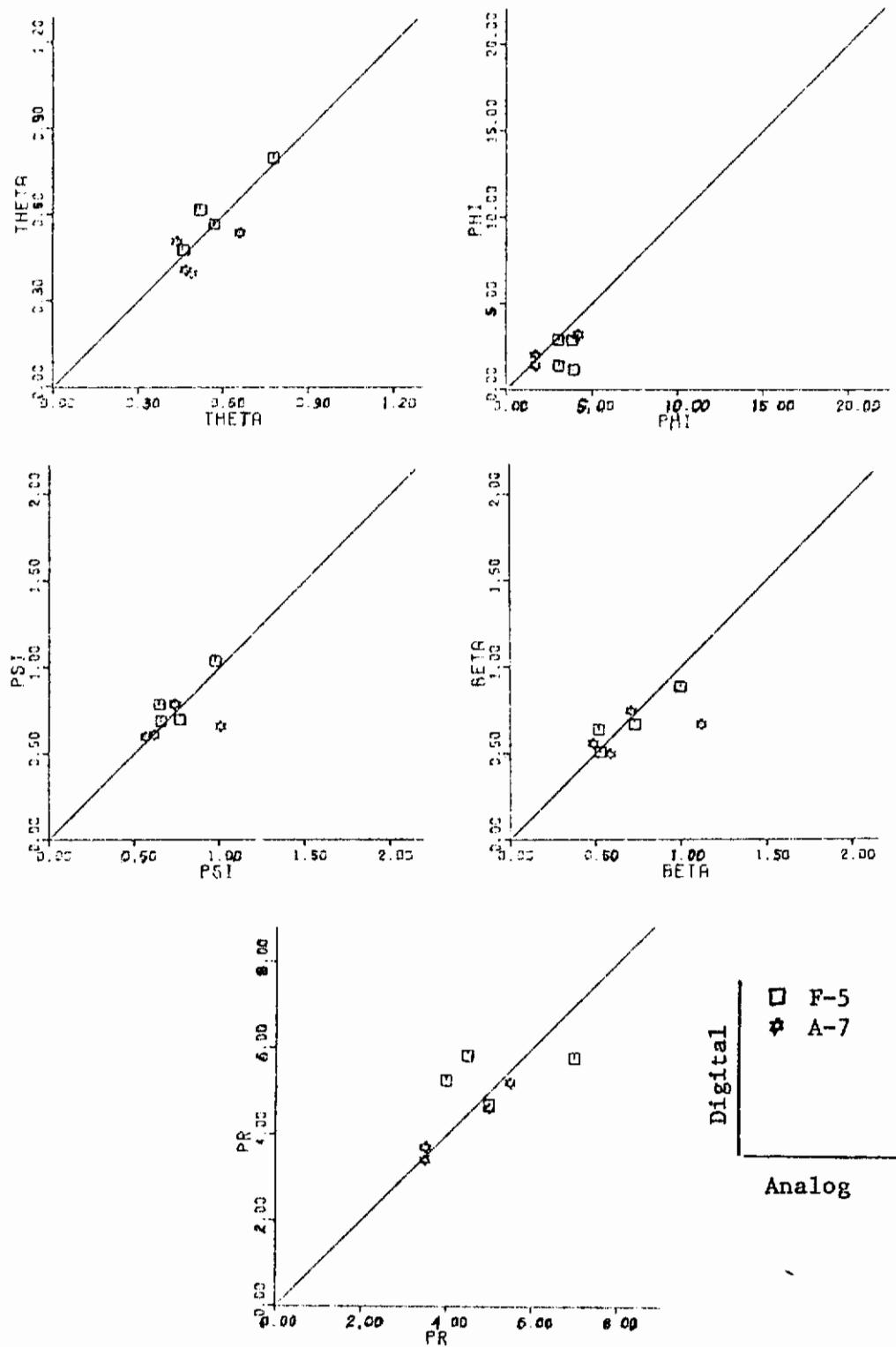


Figure 22. Comparison of F-5/A-7 Data (Unaugmented, Mil Spec Turbulence)

Controls

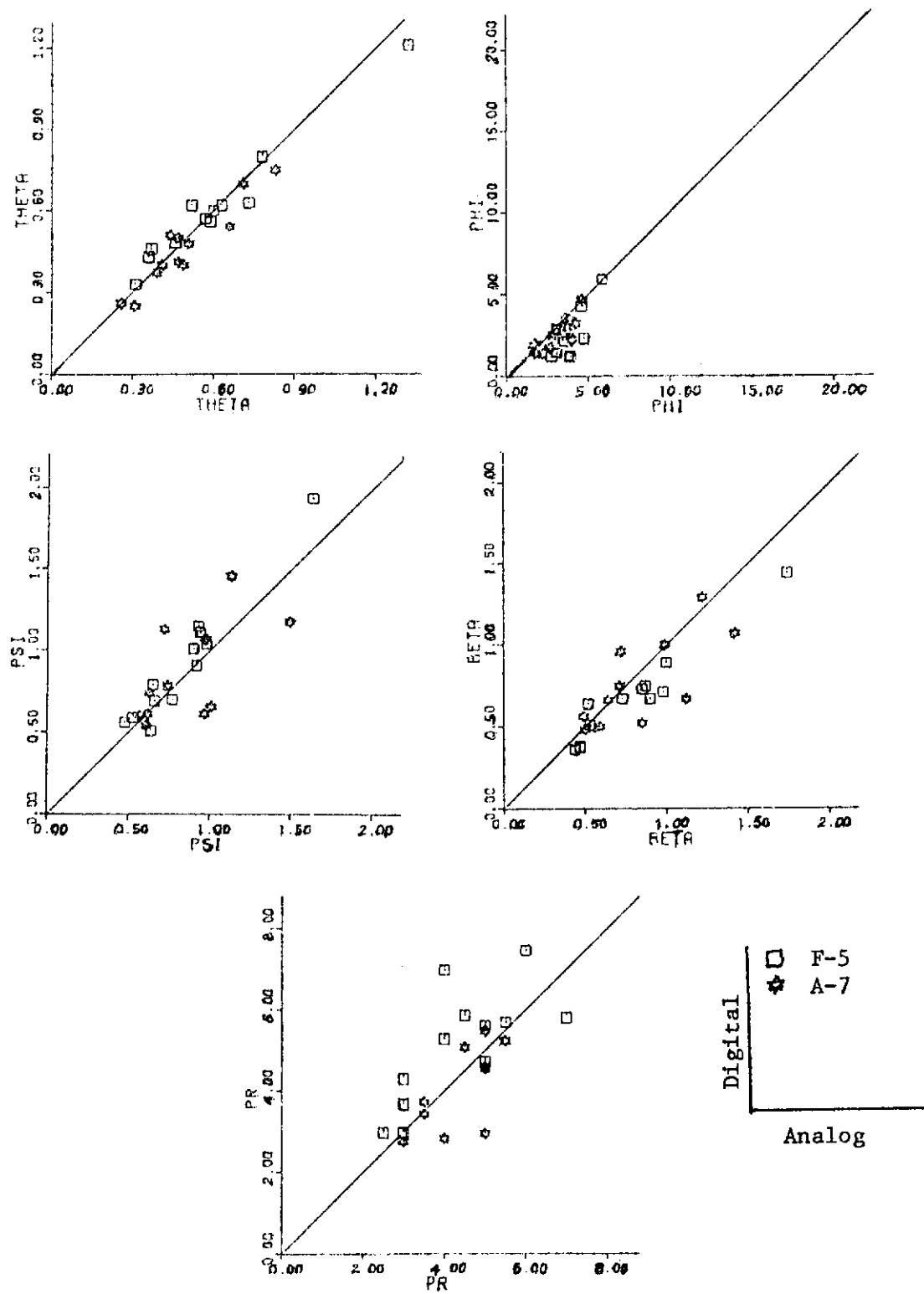


Figure 23. Comparison of F-5/A-7 Data (Composite)

Flight		σ_θ	σ_ϕ	σ_ψ	σ_β	$\sigma_{w\text{gust}}$	$\sigma_{v\text{gust}}$	$\sigma_{10\text{ft}}$	Pilot Rating
F-5 #1 MIL SPEC	RUNS 1063/611	.43	1.39	.59	.38	5.77	5.91	2.97	
		.36	2.44	.53	.47	5.91	5.47	2.5	
F-5 #2 MIL SPEC	RUNS 1064/645	.60	2.85	.91	.67	5.66	4.84	4.29	
		.60	3.58	.92	.93	5.28	4.37	3.	
F-5 #3 MIL SPEC	RUNS 1057/673	.46	1.21	.56	.36	5.79	5.07	2.98	
		.37	2.78	.48	.44	5.79	5.50	3.	
F-5 #4 MIL SPEC	R S F 3.6)	.33	2.15	.51	.37	4.75	4.08	3.67	
		.31	3.46	.64	.47	4.39	4.44	3.	
A-7 #1 MIL SPEC	RUNS 1161/733	.37	2.56	.74	.66	4.39	5.14	2.95	
		.39	2.88	.63	.64	4.66	4.89	5.	
A-7 #2 MIL SPEC	RUNS 1201/838	.25	1.86	.57	.48	5.18	4.51	2.76	
		.31	2.12	.63	.50	5.73	6.17	3.	
A-7 #3 MIL SPEC	RUNS 1248/868	.40	2.25	.61	.52	4.66	3.97	2.83	
		.41	4.06	.97	.85	5.46	4.29	4.	
A-7 #4 MIL SPEC	RUNS 1288-9/918	.26	1.74	.54	.49	4.70	4.08	2.74	
		.26	2.66	.61	.56	4.97	5.12	3.	

Table X. F-5/A-7 Data Comparison: Augmented, Mil Spec

Contrails

Flight		σ_θ	σ_ϕ	σ_ψ	σ_β	$\sigma_{v_{gust}}$	$\sigma_{v_{gust}}$	Pilot Rating
F-5 #1 HIGH TURB	.63	2.58	4.15	.75	11.55	10.02	5.60	
RUNS 970/619	.73	3.46	.93	.87	10.66	10.16	5.	
F-5 #2 HIGH TURB	1.21	5.89	1.94	1.44	11.33	9.68	7.46	
RUNS 1005*/642	1.32	5.84	1.63	1.74	11.55	8.81	6.	
F-5 #3 HIGH TURB	.62	2.30	1.11	.71	11.58	10.13	5.68	
RUNS 1960/671	.63	4.75	.94	.98	10.55	11.25	5.5	
F-5 #4 HIGH TURB	.56	4.26	1.01	.73	9.50	8.17	6.98	
RUNS 1096-99/710	.59	4.53	.93	.85	9.50	8.06	4.	
A-7 #1 HIGH TURB	.70	4.71	1.46	1.29	10.29	8.77	5.47	
RUNS 1146/735	.71	4.63	1.13	1.22	9.74	9.74	5.	
A-7 #2 HIGH TURB	.48	3.44	1.13	.96	10.36	9.93	4.53	
RUNS 1202/805	.51	3.90	.72	.72	9.11	9.20	5.	
A-7 #3 HIGH TURB	.75	4.55	1.18	1.07	9.32	7.93	5.97	
RUNS 1251/874	.83	4.59	1.49	1.42	11.44	7.89	4.5	
A-7 #4 HIGH TURB	.50	3.54	1.07	1.00	9.40	8.15	4.58	
RUNS 1292/916	.47	3.61	.98	.93	9.32	10.42	5.	

Table XI. F-5/A-7 Data Comparison: Augmented, Double Mill Spec

Controls

Flight	σ_θ	σ_ϕ	σ_ψ	σ_β	σ_w gust	σ_v gust	Pilot Rating
F-5 #1 NO AUGMENT	.57	1.39	.79	.64	5.78	5.01	5.27
RUNS 996/635	.57	3.10	.65	.52	5.69	5.02	4.
F-5 #2 NO AUGMENT	.80	2.90	1.04	.89	5.67	4.84	5.79
RUNS 1027/655	.78	3.98	.98	1.00	5.20	4.69	7.
F-5 #3 NO AUGMENT	.62	1.15	.69	.51	5.79	5.06	4.71
RUNS 1081/686	.52	3.94	.65	.53	5.43	5.52	5.
F-5 #4 NO AUGMENT	.48	2.91	.70	.67	4.75	4.08	5.85
RUNS 1140/721	.46	3.95	.77	.73	4.34	4.66	4.5
A-7 #1 NO AUGMENT	.54	3.23	.79	.75	5.15	4.39	5.22
RUNS 1169/750	.66	4.25	.74	.71	5.57	4.83	5.5
A-7 #2 NO AUGMENT	.41	1.40	.60	.50	5.18	4.52	3.42
RUNS 1219-20/827	.47	1.72	.57	.59	4.62	6.49	3.5
A-7 #3 NO AUGMENT	.51	3.18	.66	.67	4.66	3.97	4.62
RUNS 1254/878	.44	4.24	1.01	1.12	5.77	4.69	5.
A-7 #4 NO AUGMENT	.40	1.99	.61	.56	4.70	4.08	3.72
RUNS 1220-22/928	.49	1.70	.62	.49	4.52	4.13	3.5

Table XII. F-5/A-7 Data Comparison: Unaugmented, Mil Spec

Contrails

DS/EE/75-1

Table XIII. F Tests of the F-5/A-7 Data F Test Ratio for

<u>Condition</u>	<u>θ</u>	<u>Ψ</u>	<u>Ψ</u>	<u>β</u>	<u>Comments</u>
F-5 #1	1.43	3.08	1.23	1.53	
#2	1.00	1.58	1.03	1.80	
#3	1.50	5.28*	1.35	1.46	
#4	1.00	2.59	1.58	1.57	
A-7 #1	1.07	1.27	1.37	1.07	Augmented; Mil Spec Turbulence
#2	1.67	1.39	1.13	1.09	
#3	1.06	3.25*	2.54	2.67	
#4	1.00	2.34	1.28	1.29	
F-5 #1	1.33	1.80	1.53	1.36	
#2	1.19	1.02	1.41	1.46	
#3	1.05	4.26*	1.40	1.92	
#4	1.13	1.16	1.26	1.36	
A-7 #1	1.02	1.03	1.66	1.11	Augmented Double Mil Spec Turbulence
#2	1.13	1.29	2.46	1.77	
#3	1.23	1.06	1.60	1.40	
#4	1.14	1.04	1.19	1.02	
F-5 #1	1.00	4.97*	1.48	1.52	
#2	1.05	1.13	1.13	1.27	
#3	1.41	11.75*	1.09	1.08	
#4	1.10	1.80	1.20	1.18	
A-7 #1	1.48	1.73	1.13	1.18	Unaugmented Mil Spec Turbulence
#2	1.29	1.51	1.13	1.40	
#3	1.37	1.91	2.32	2.77	
#4	1.50	1.37	1.03	1.29	

* Hypothesis rejected at .05 level of significance

Controls

Asterisks mark test points where hypothesis rejection occurs. All of these tests for θ , ψ , and β accept the hypothesis that the variances are representative of the same population. Almost 80% of the values for the secondary variable ϕ pass the F test. Based on these tests, the data sets were accepted as matching.

Additionally, the graphical data shows the degree of correlation with the 45° line on each graph representing the line of perfect agreement. Symmetric dispersions occur for θ , ψ , and β while ϕ appears to have a tendency to be lower in the digital simulation. The pilot ratings, being subjective in the manned simulation, show the widest dispersion. The F-5 digital pilot ratings tend to be slightly higher than the manned simulation while the A-7's were slightly lower in two instances. However, considering interpilot variability, the dispersion is not intolerable.

B. Boeing 707 Comparative Analysis

Since the author was personally involved in the simulation of the 707, more comparative data were available on the 707 to test the validity of the digital simulation. The following variables in particular were studied: θ , q , δe , ϕ , ψ , β , α , p , r , δa , δr , h , and y . If reasonable comparisons can be shown here, then a degree of confidence can be established for the digital simulation method.

To make comparison of the digitally obtained data and the actual manned simulation data as easy as possible, ten digitally simulated power approaches were made using the computer program developed in this study. The one-sigma values for the studied variables are presented in Table XIV. Also presented in Table XIV are the average one-sigma values

Controls

Manned Simulation
Averages Digital Simulation Runs

	<u>YAR</u>	<u>RUN 1</u>	<u>RUN 2</u>	<u>RUN 3</u>	<u>RUN 4</u>	<u>RUN 5</u>	<u>RUN 6</u>	<u>RUN 7</u>	<u>RUN 8</u>	<u>RUN 9</u>	<u>RUN 10</u>
THETA	.73	.54	.53	.41	.58	.52	.52	.49	.45	.53	.54
DE	.57	.55	.32	.24	.30	.25	.31	.30	.28	.34	.27
PHI	1.57	1.26	1.29	1.37	1.08	1.05	1.40	1.04	1.65	1.31	1.48
PSI	.91	1.05	1.12	.83	.97	1.03	1.24	1.21	1.43	1.16	1.56
BETA	.66	.63	.87	.65	.86	.94	.79	.71	1.09	.79	.89
ALPHA	.58	.53	.58	.38	.48	.43	.57	.48	.44	.56	.43
P	.80	.97	.74	.57	.70	.79	.76	.71	1.09	.79	.89
Q	.67	.57	.69	.52	.67	.77	.66	.58	1.08	.76	.84
RA	2.57	3.82	2.94	2.41	2.03	2.38	2.81	2.08	3.81	1.85	2.99
DR	.03	.05	.87	.72	.54	.71	.81	.90	1.10	.82	1.16
H	5.77	3.65	5.84	4.54	5.56	4.93	6.15	5.62	5.01	4.72	6.28
Y	27.13	13.90	23.27	19.32	17.12	12.90	26.57	27.46	29.05	20.45	31.18
U GUST	2.00	2.61	2.39	2.07	2.16	1.75	1.98	1.71	1.70	1.98	2.11
V GUST	2.03	2.61	1.54	1.60	2.09	1.70	1.82	2.31	2.09	2.60	1.84
W GUST	1.43	1.40	1.42	1.15	1.39	1.52	1.81	1.42	1.44	1.81	1.54
PR	2.60	2.69	2.23	2.18	2.22	2.25	2.23	2.21	2.34	2.25	2.27

Table XIV. Digital Simulation Results

Controls

for each of the variables for each of the two pilots who flew the actual manned simulation. More complete data on the individual pilots is presented in [45]. These average standard deviations are also presented in Table XV along with average values of the digital simulations and the extreme values of the manned simulations. The most noteworthy difference between the average standard deviations is in the rudder deflection. An assumption was made in Chapter I that the pilot would tend to correct localizer and heading errors using the rudder. The Dutch Roll mode of the 707 is easily excited by the human pilots using the rudder. For this reason, they are trained not to use the rudder during powered approach. They make the necessary corrections rather by using the ailerons. On several runs not considered by this study, the pilot chose to depart his training and use the rudder to make lateral corrections. When he did, the resulting one-sigma value for the rudder deflection closely matched those determined by the digital model. The method of control aside, the performance variables ϕ , ψ and β remain consistent with expectations.

The data of Table XIV are also presented graphically using bar charts in Figure 24. Here the ten experimental values for each variable from the digital simulation are plotted as circles and the average values for the individual pilots are represented by a triangle and a star. The object, clearly, is to imbed the triangle and star among the circles. The tick marks to the right of the axis indicate the extreme values achieved by the human pilots and given previously in Table XV. As can be seen, except for q and δ_r , all values from the digital simulation fall within the extremes achieved by the manned simulation.

Controls

Table XV. Digital and Manned Averages and Manned Extremes

<u>10 Runs</u>	<u>Average</u>	<u>STD DEV</u>	<u>Average</u>	<u>Average</u>	<u>Pilot 1</u>	<u>Pilot 2</u>	<u>Min</u>	<u>Max</u>	<u>Min</u>	<u>Max</u>	<u>Variable</u>
<u>Average</u>	<u>STD DEV</u>		<u>Pilot 1</u>	<u>Pilot 2</u>	<u>Min</u>	<u>Max</u>					
.51	.05		.70	.54	.49	.91	.33	1.01			THETA
.29	.03		.57	.55	.41	.72	.28	.84			Q
.55	.07		.87	.95	.40	1.27	.44	1.40			DE
1.22	.22		1.57	1.20	.81	3.36	.54	2.20			PHI
1.18	.21		.91	1.05	.22	1.94	.30	2.22			PSI
.82	.14		.66	.63	.20	1.11	.43	.86			BETA
.48	.06		.58	.53	.36	.85	.39	.82			ALPHA
.76	.15		.80	.97	.54	1.22	.80	1.28			P
.71	.16		.67	.57	.39	1.14	.35	.80			R
2.51	.62		2.57	3.82	1.74	3.38	2.83	5.40			DA
.84	.18		.00	.00	.00	.00	.00	.00			DR
5.57	.79		5.77	3.65	1.27	11.34	1.32	10.62			H
23.24	5.74		27.18	18.90	5.39	53.42	2.51	43.27			Y
2.00	.26		2.	2.							U GUST
1.96	.33		2.	2.							V GUST
1.49	.20		1.4	1.4							W GUST
2.24	.05		2.6	2.6							PR

Controls

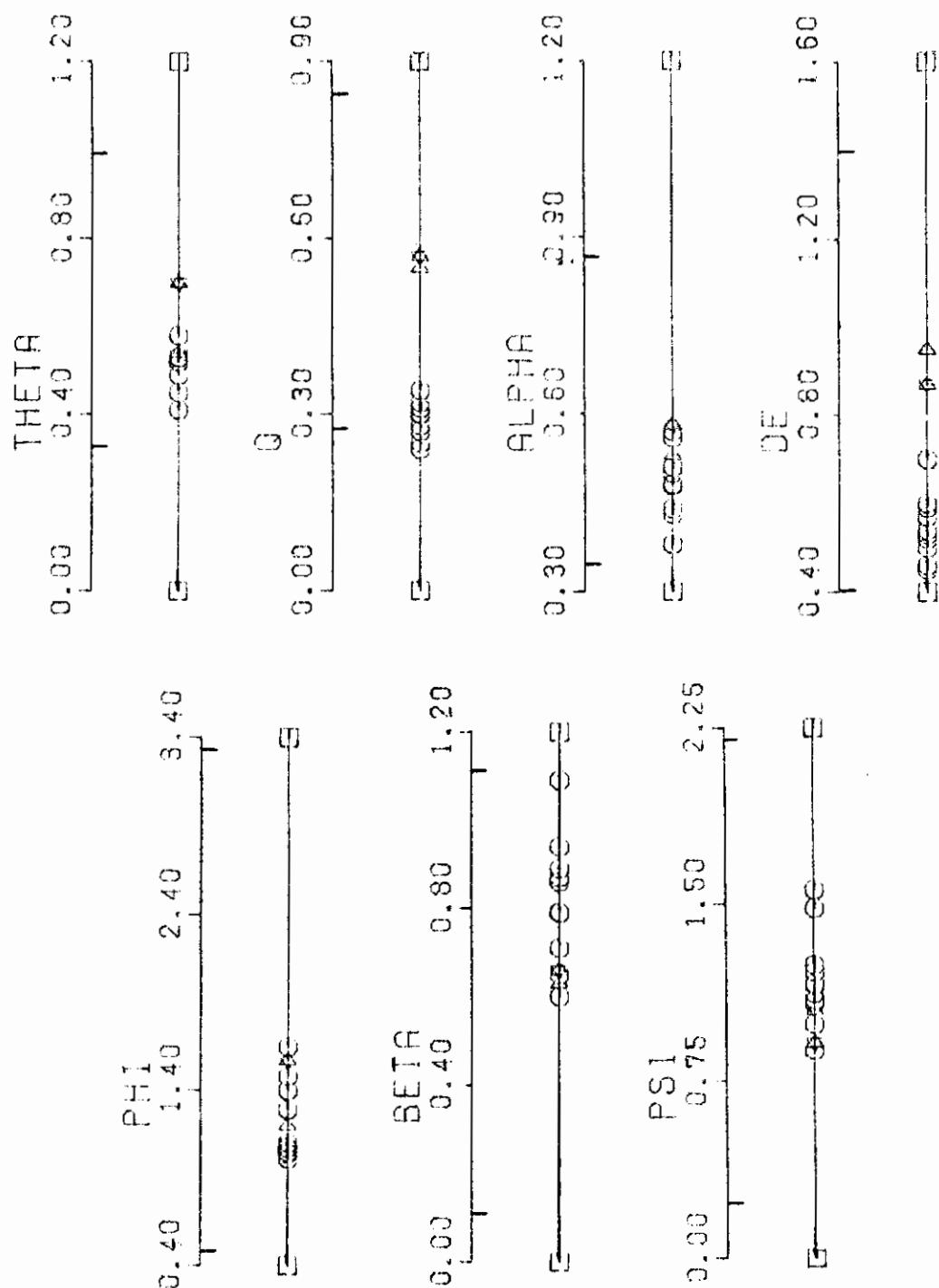


Figure 24. 707 Bar Chart Comparison

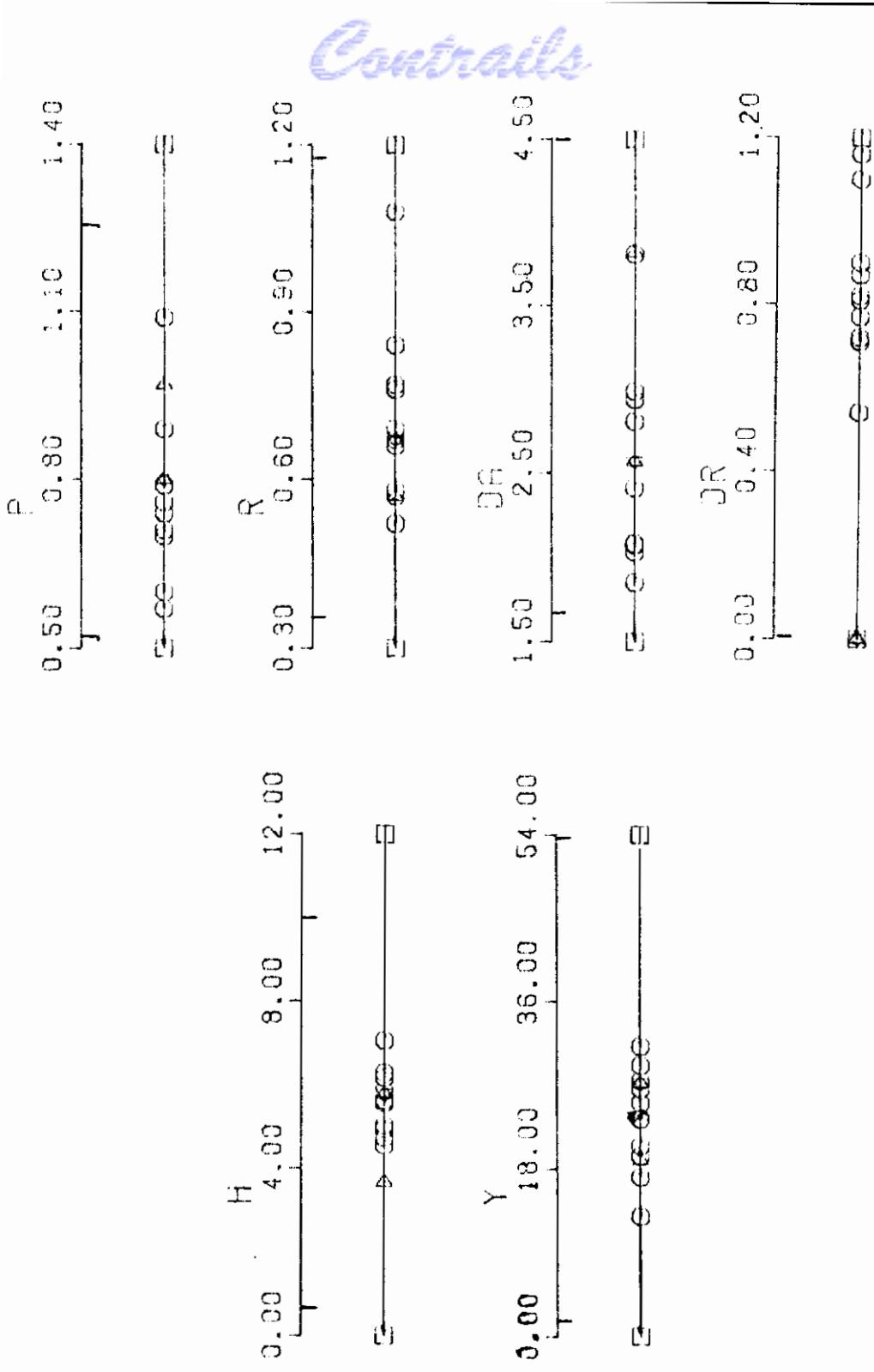


Figure 24 (continued). 707 Bar Chart Comparison

Contrails

Various statistical tests of both a parametric and non-parametric nature were run upon the 707 data to test the hypothesis that the variances determined by the digital simulation were representative of the same population as those of the actual manned simulation. The statistical M-test [43:78] was run using the digital data alone, each of the pilots alone, the digital data in union with each pilot, and the digital data in union with both pilots. The results are shown in Table XVI. The M test found the digital data homogeneous as was pilot 2 data. However, non-homogeneity was detected in the variables h and y of the pilot 1 data. With this in mind, the only clearcut areas of difficulty between the digital data and the piloted data was the variable δr which was known to differ because of technique as described above.

The nonparametric Mann-Whitney U Test [47:140] for samples having the same median was run against the data and found difficulty only in q , δe , and δr as might have been expected from the bar graphs. A Bhapkar V Test [48] for scale was also run on the data. The results are presented in Table XVII. The only areas of difficulty added by the digital data are q , δe , and δr . A Kruskal Wallis [48] test yielded identical results.

A possible reason for difficulty with q and δe is failure of the linearized equations and constant stability derivatives to describe the longitudinal situation adequately. Optimal pilot modeling efforts working on the same data are encountering similar difficulty in this area.

Controls

Table XVI. M-Tests of the 707 Data

Variable	Digital	Pilot 1	Pilot 2	Digital + Pilot 1	Digital + Pilot 2	Digital + Pilot 1 + Pilot 2
θ	1.5	7.5	2.6	10.01	8.51	16.16
q	1.9	7.6	3.1	34.77	28.53	46.20
δe	2.9	6.1	5.2	26.63	20.54	35.81
ϕ	5.3	8.7	10.	14.06	20.36	29.17
ψ	4.9	14.	14.	19.44	19.38	35.81
β	5.0	3.6	13.	12.98	18.62	26.15
α	2.3	4.9	4.1	7.94	7.83	13.00
p	5.8	1.6	3.8	10.69	9.84	14.47
r	7.9	2.8	7.3	12.72	15.17	20.03
δa	9.3	1.9	2.5	21.01	11.85	24.37
δr	7.6	0.	0.	240.2*	240.2*	465.2*
h	3.2	21.*	16.	26.97	21.66	47.01
y	10.	30.*	14.	40.64*	26.80	57.24*

* Hypothesis rejected at the .025 level of significance.

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Table XVII. 707 Bhapkar V Test Results

Variable	Pilot 1 + Pilot 2	Digital + Pilot 1 + Pilot 2 (3 way Test)	Digital + (Pilot 1 + Pilot 2) (2 way Test)
θ	.088	.077	.210
q	.816	.000*	.000*
δe	.535	.002*	.001*
ϕ	.152	.368	.671
ψ	.752	.092	.042
β	.535	.067	.027
α	.757	.092	.576
p	.048	.054	.077
r	.439	.206	.123
δa	.000*	.020*	.040
δr	1.000	.000*	.000*
h	.018*	.000*	.054
y	.188	.236	.929

* Hypothesis rejected at the .025 level of significance.

Controls

As a final view of the relation between the digital and manned results, a set of time histories for both the digital and manned simulations are presented. Figures 25 - 31 have the digitally produced time history on the left and the manned simulation time history on the right. The digital data was sampled at a rate of 8/second while the manned data was sampled at 10/second which produces some higher frequency content in the manned simulation graphs.

Based on the above analysis of the digital and manned data, the digital simulator is considered to have accurately simulated the 707 under the given conditions.

C. NT-33 Fixed Base Simulation Comparative Analysis

The analog fixed base longitudinal simulation by Major John Arnold [23] of the variable stability NT-33 was repeated digitally in the hope of attaining further data comparison. Major Arnold's gust model was employed for the longitudinal system. Values available for comparison included θ , q , and δe . The results of the digital simulation are compared graphically with those of the analog simulation in Figure 32. The pitch rate and elevator deflection appear to match reasonably well; however, a clear offset of about $.25^\circ$ exists in the rms value of the pitch angle, θ , with the digital simulation providing the higher result. Conjecture as to the cause of the offset ranges from amplifier malfunction, display offset or other mechanical problems in the analog simulation to using the multiaxis model in the digital simulator with single axis data.

Contrails

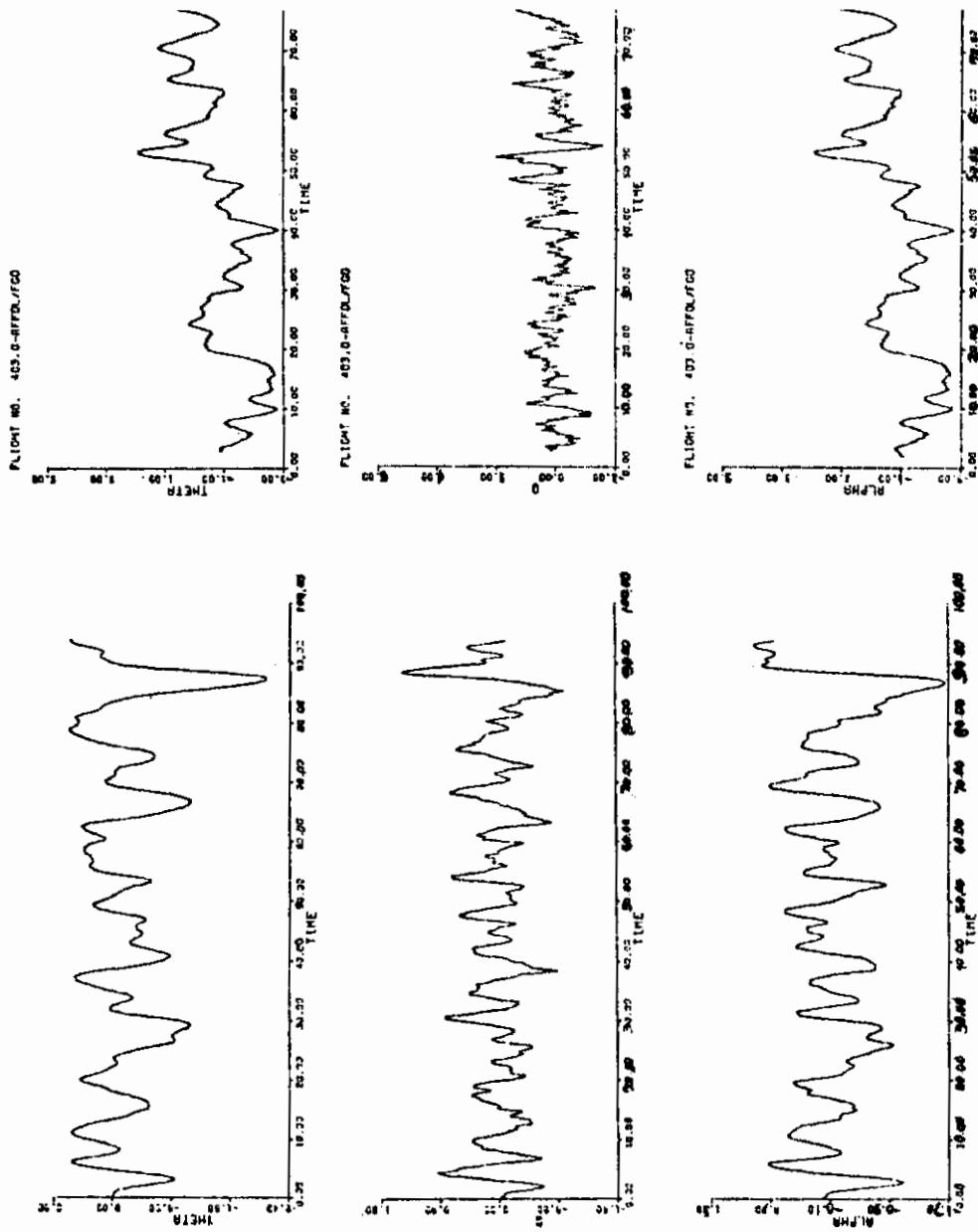


Figure 25. 707 Time Histories: θ , q , and α .

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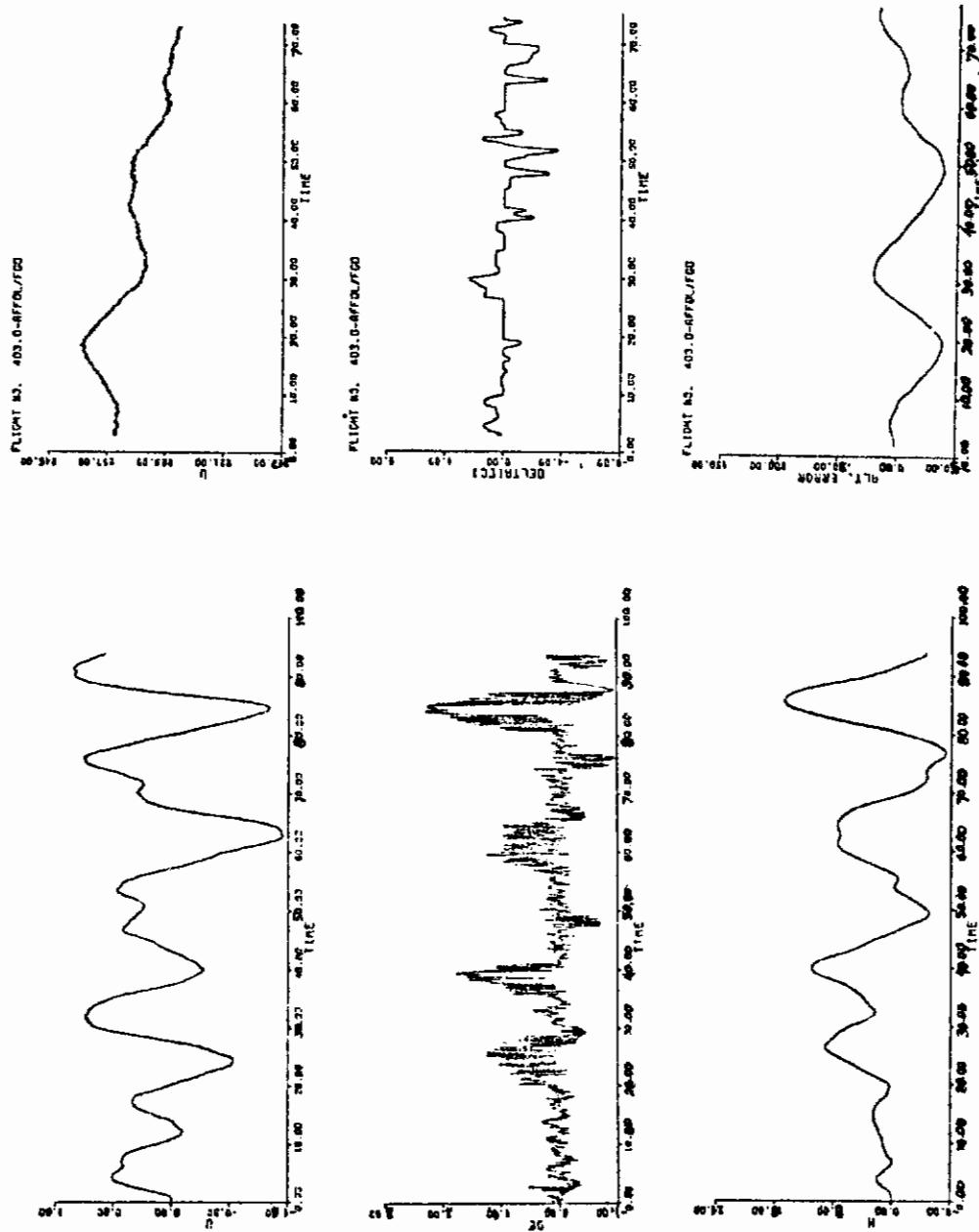


Figure 26. 707 Time Histories: u , δ_e , and h

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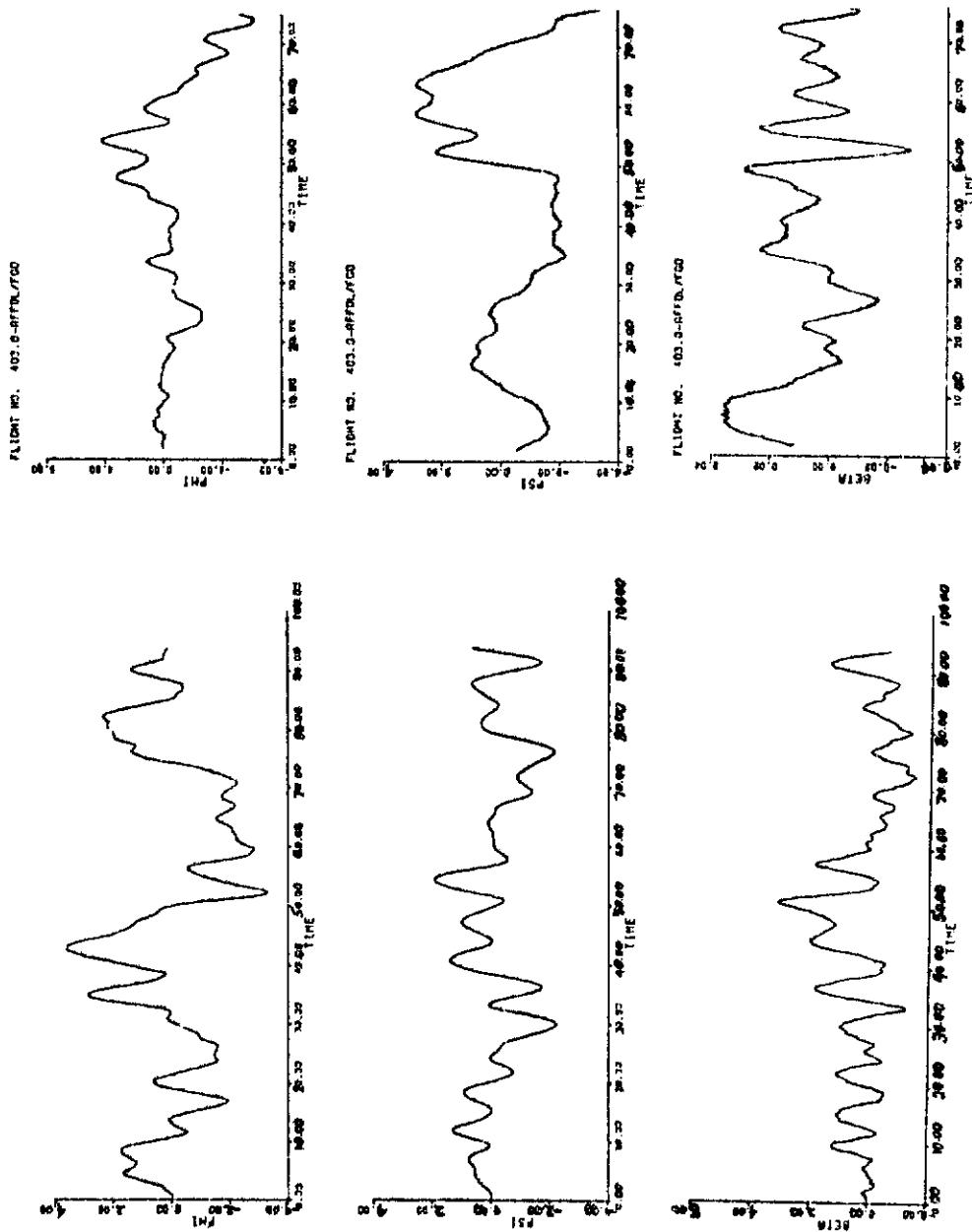


Figure 27. 707 Time Histories: ϕ , ψ , and β

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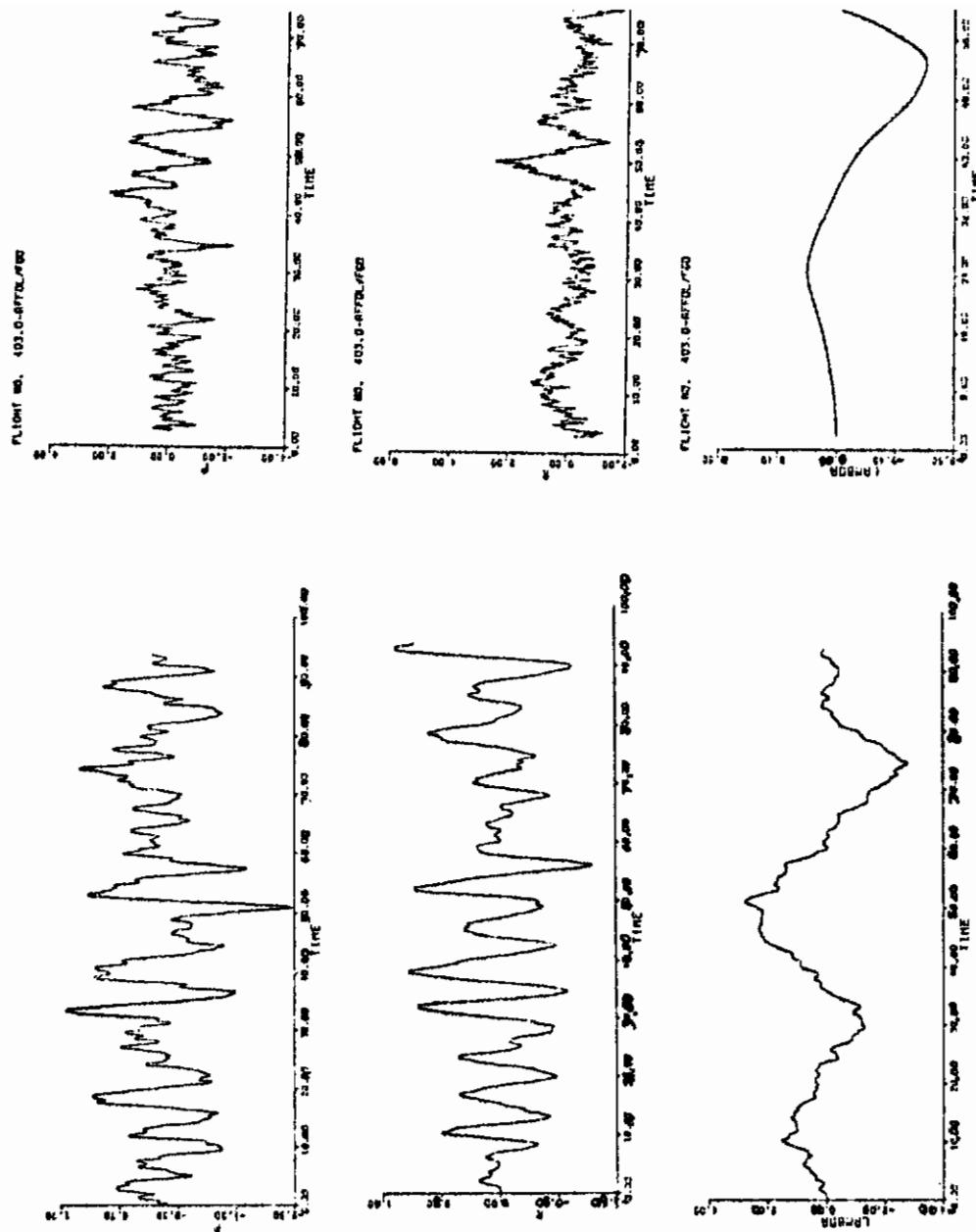


Figure 28. 707 Time Histories: P , R , and λ

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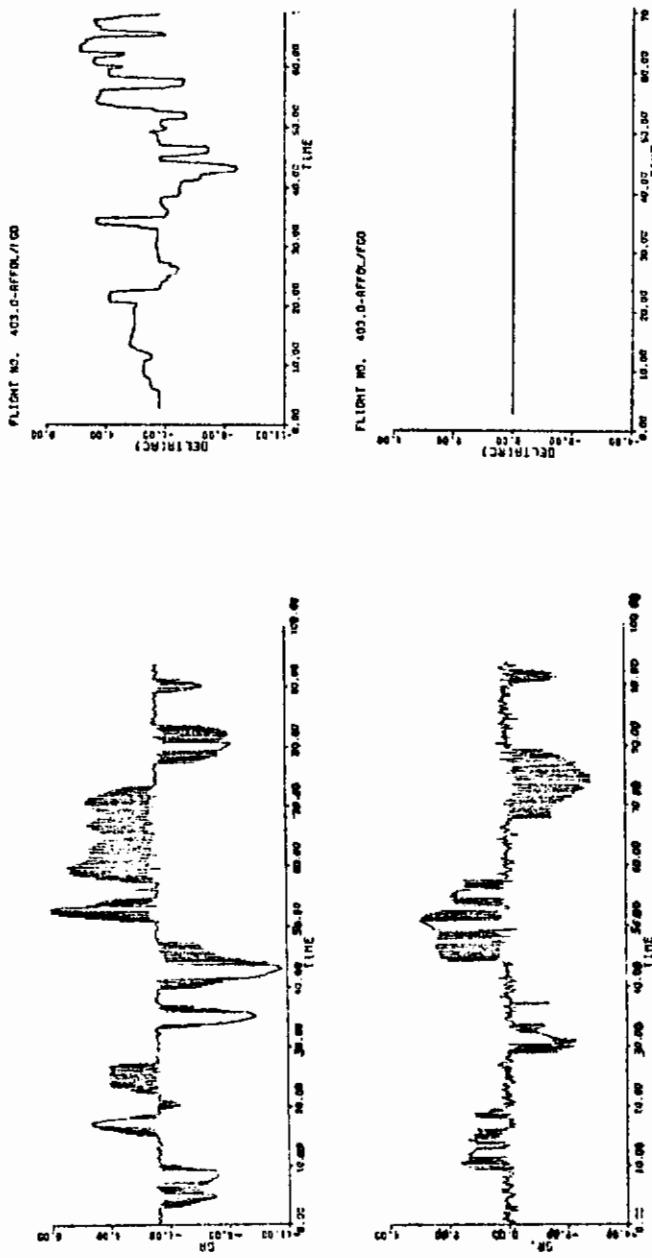


Figure 29. 707 Time Histories: 6a and 6r

Contrails

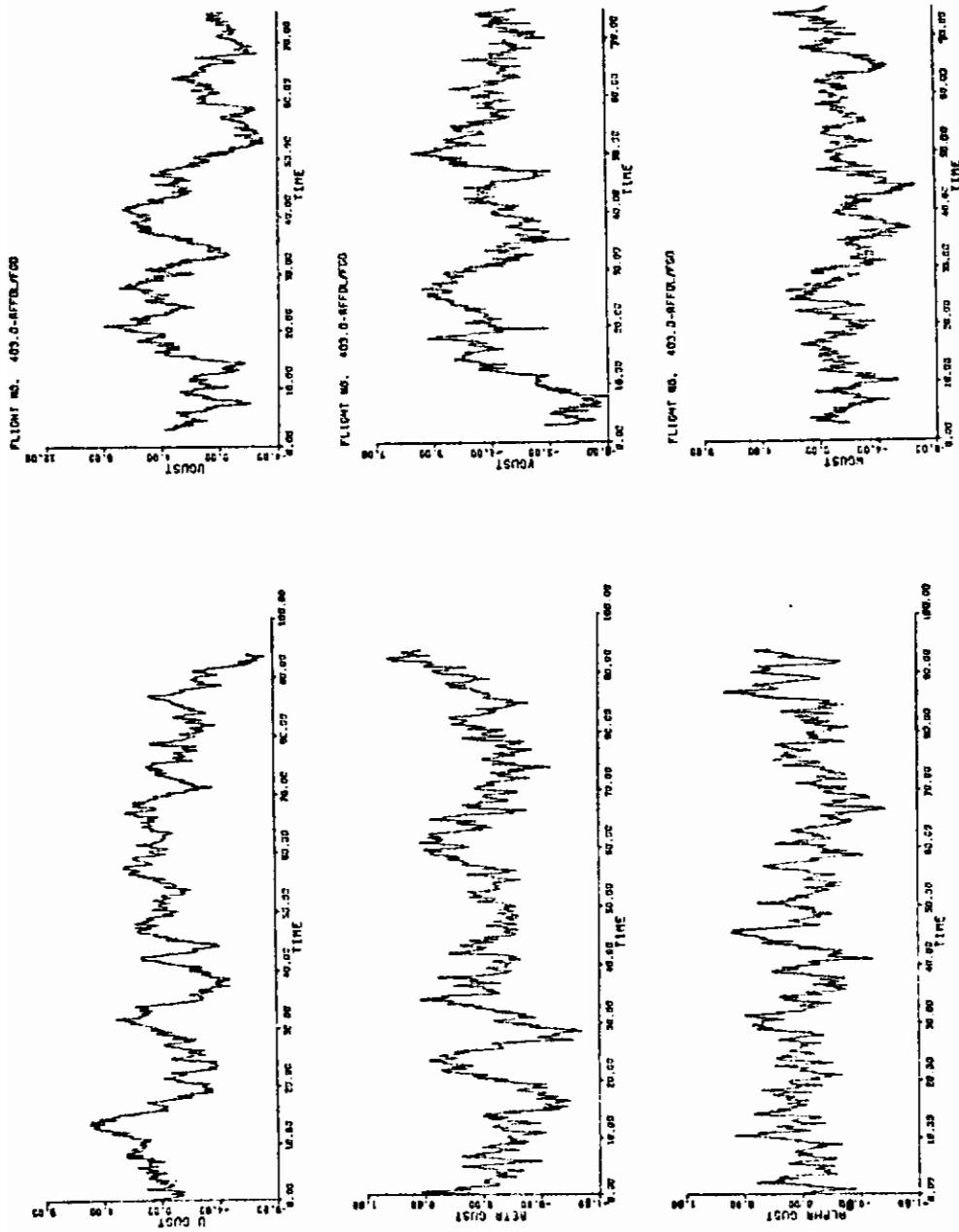


Figure 30. 707 Time Histories: u_g , v_g , and w_g

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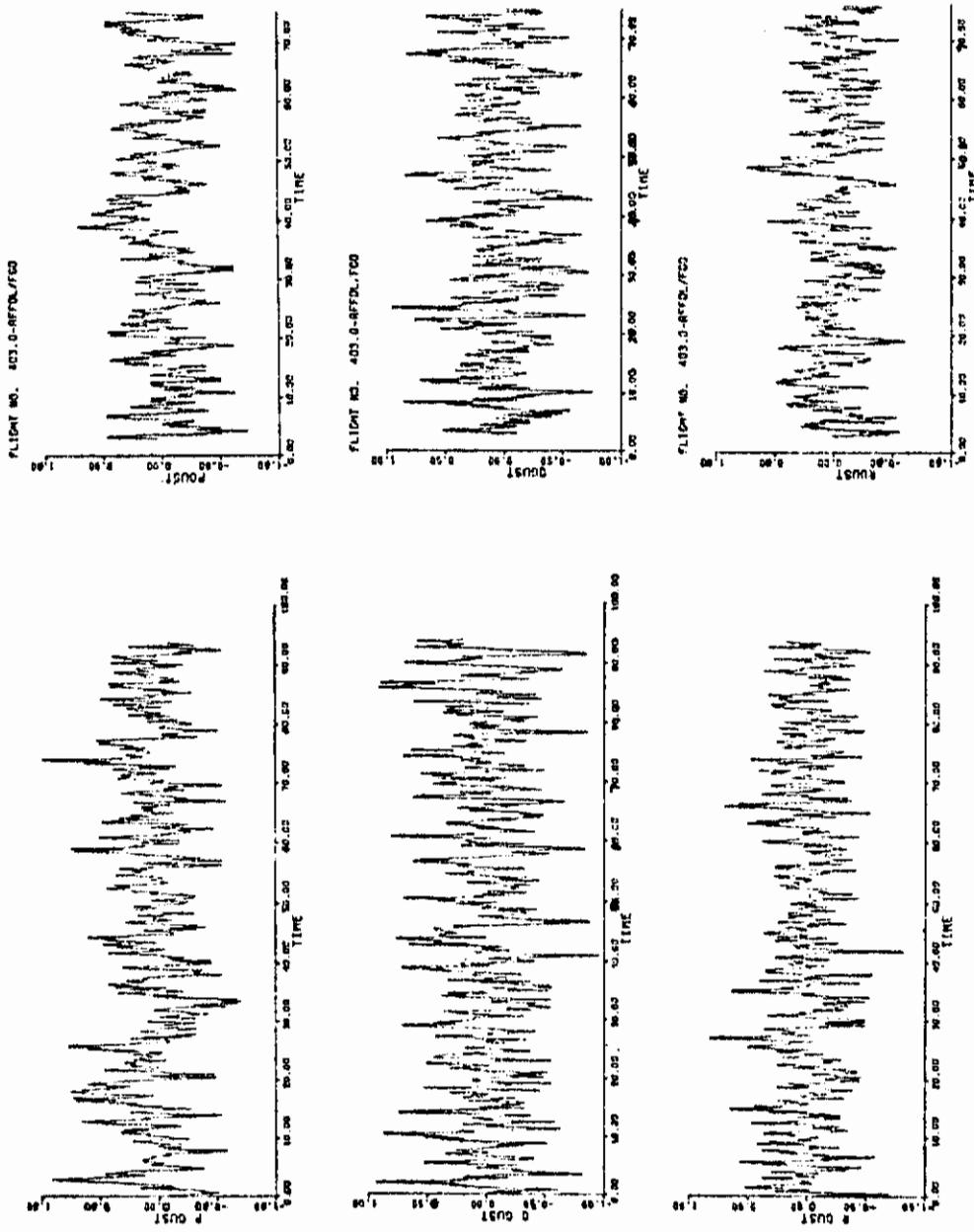


Figure 31. 707 Time Histories: P_g , q_g , and r_g

Controls

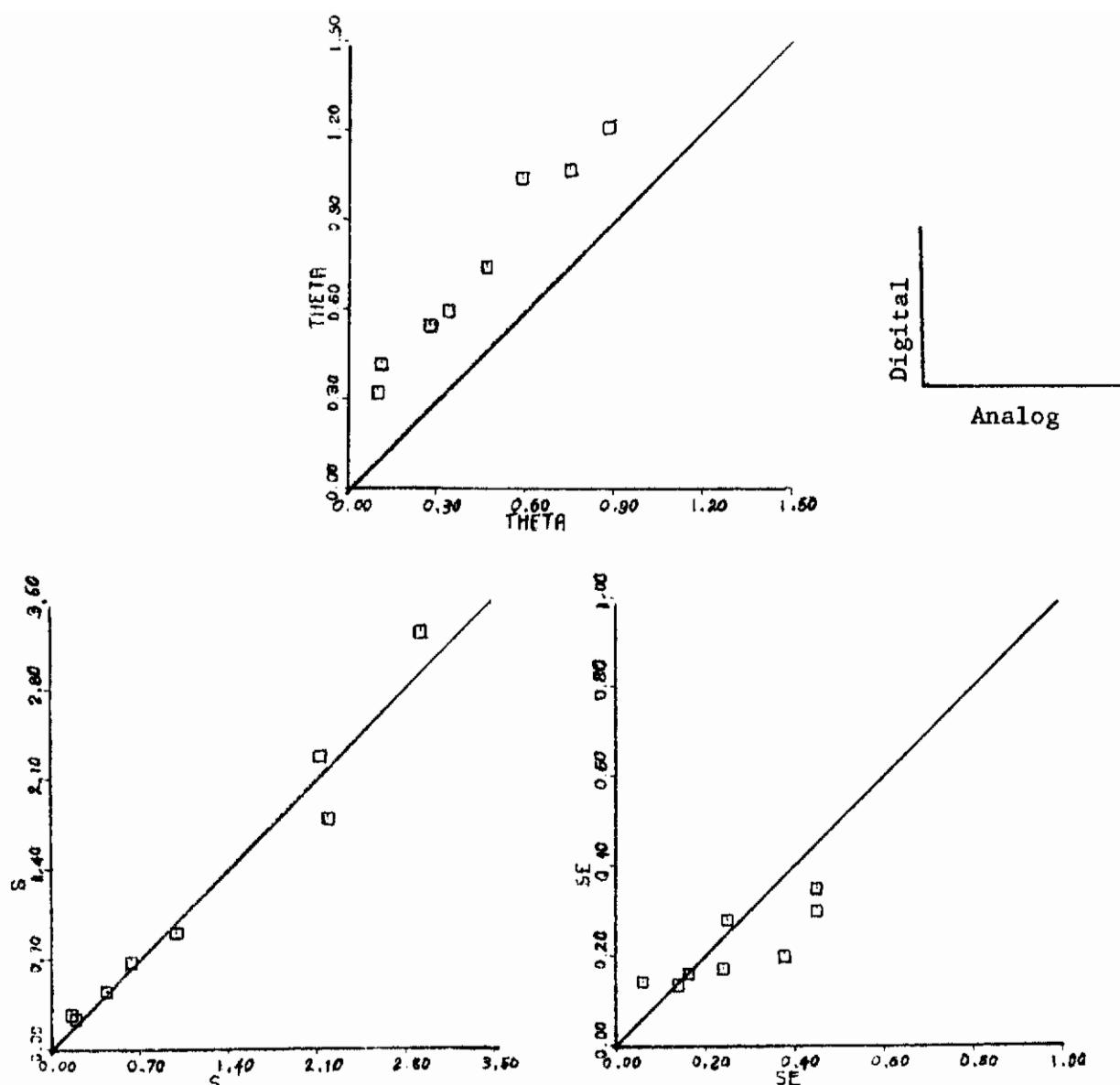


Figure 32. NT-33 Data Comparison

Controls

Tabular comparisons of the data are presented in Tables XVIII and XIX. Good data matches are noted for q and δe where problems occurred in the 707 data. It is significant to note the dynamics represented here do not necessarily reflect those of conventional aircraft.

Statistical F Tests of the comparison data were made similar to those done for the F-5/A-7 data. Table XX shows the ratios and the rejected points. Each set of data had 9 degrees of freedom.

Table XVIII. Comparison of the NT-33 Data with Average Analog Results

Source	Case	σ_θ	σ_q	$\sigma_{\delta e}$
Digital	1D	.548	.677	.160
Analog	1D	.275	.639	.163
Digital	2D	.742	.902	.199
Analog	2D	.461	.996	.378
Digital	3A	1.039	1.788	.280
Analog	3A	.593	2.172	.252
Digital	4A	1.067	2.275	.300
Analog	4A	.752	2.133	.453
Digital	5A	1.208	3.245	.349
Analog	5A	.877	2.903	.461
Digital	9	.596	.449	.171
Analog	9	.337	.446	.235
Digital	10	.420	.270	.142
Analog	10	.108	.155	.057
Digital	11	.322	.235	.135
Analog	11	.102	.195	.136

Note: This table compares the average rms values of Arnold's data to one Monte Carlo run of the digital simulation.

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Table XIX. Comparison of the NT-33 Data with the Range of the Analog Results

Source	Case	σ_θ	σ_q	σ_{δ_e}
Digital	1D	.548	.677	.160
Analog	1D	.20-.37	.55-.77	.11-.20
Digital	2D	.742	.902	.199
Analog	2D	.33-.60	.93-1.03	.27-.48
Digital	3A	1.039	1.788	.280
Analog	3A	.55-.65	1.76-2.61	.18-.30
Digital	4A	1.067	2.275	.300
Analog	4A	.71-.84	1.95-2.25	.38-.49
Digital	5A	1.208	3.245	.349
Analog	5A	.80-.93	2.31-3.12	.22-.60
Digital	9	.596	.449	.171
Analog	9	.15-.67	.42-.46	.19-.27
Digital	10	.420	.270	.142
Analog	10	.07-.15	.13-.17	.02-.07
Digital	11	.322	.235	.135
Analog	11	.07-.13	.16-.25	.09-.22

Note: This compares the maximum and minimum values of Arnolds data
with one sample Monte Carlo run from the digital simulation.

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Table XX. F-Test Ratios For NT-33 Data

Case	σ_{θ}	σ_q	σ_{δ_e}
1D	3.75	1.12	1.50
2D	2.59	1.22	3.55
3A	3.27	1.48	1.33
4A	2.00	1.14	2.28
5A	1.90	1.25	1.75
9	3.00	1.00	1.83
10	18.*	2.92	10.*
11	10.*	1.45	1.00

* Rejected at .025 level of significance.

Note: Cases 9, 10, 11 represent overdamped systems.

D. Other Aircraft Investigated

The DC-8 and A-7D Aircraft were simulated digitally in the landing task. Systems Technology Incorporated [40] used the Mil Spec gust model in the design of an automatic control system for use with the Microwave Landing System (MLS). Since their simulation was for an automatic system, there can be no direct comparison so the results are merely presented here in Table XXI.

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Table XXI. DC-8 and A-7D in Power Approach

Variable	<u>DC-8</u>			<u>A-7D</u>		
	Automatic System	Digital Pilot	Units	Automatic System	Digital Pilot	
σ_θ	1.64	2.01	deg	.70	1.23	
σ_u	3.83	3.74	ft/sec	3.99	3.36	
σ_h	6	20	ft	18	6	
σ_{δ_e}	2.41	1.99	deg	.71	.85	
σ_y	10	48	ft	32	53	
σ_p	2.10	3.96	deg/sec	3.12	3.64	
σ_ϕ	5.47	5.28	deg	3.81	3.41	
σ_r	-	2.05	deg/sec	1.95	4.54	
σ_ψ	2.44	3.38	deg	2.50	2.44	
σ_{δ_a}	2.69	2.66	deg	2.90	1.54	
σ_{δ_r}	5.67	1.91	deg	-	4.53	

These results appear representative considering known differences.

An RPV (YQM-98A) as well as an F-4B were also simulated but no comparison data was available. Results are included in the Appendix.

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IX. Special Program Applications

Simulation comparison is clearly not the only intended use for the digital program developed here. Other proposed uses include:

- 1) Verification that proposed aerodynamic data are sufficient for analog simulation.
- 2) Determination of the number of degrees of freedom for an appropriate gust model in a given simulation.
- 3) Choosing or delimiting proposed simulation conditions for analog testing.
- 4) Preliminary verification of automatic or stability augmentation control system designs.
- 5) Preliminary comparison of aircraft under identical conditions.
- 6) System checkout for hybrid simulation.

Simulation of advanced design or preliminary design aircraft can be extremely costly. Furthermore, analog/hybrid simulation, in addition to being costly, contains many pitfalls such as patchboard failure, trunking failure, amplifier failure, or even merely wire fatigue.

Considering these factors, extensive presimulation analysis should be performed to verify system operation and accuracy. Those modes which appear critical in digital simulation should then be examined extensively in analog simulation.

Two special applications of this digital program have already been made. The first involved the verification of the aerodynamic data for the 707 simulation discussed in Chapters VII and VIII. This unaugmented aircraft as originally proposed was found unsuitable for flight by the digital program, yielding unreasonable values for

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the lateral performance measures. This was subsequently verified on the hybrid system and corrections to the aerodynamic data were made. The digital program with the revised data generated the results presented in Chapter VIII. If this digital program had not been in its developmental stages before confidence in its result had been established, then considerable time and effort might have been saved in the simulation set up.

The second program application involved the choice of a gust model for use in an RPV (Remotely Piloted Vehicle) simulation. A gust model based only on V_g and W_g was originally proposed. However, the following tables shows the difference between gust models having two, three, and six-degrees-of-freedom with an unaugmented airframe:

Table XXII. YQM-98A Lateral Axis Results

Gust Model	σ_ϕ (deg)	σ_ψ (deg)	σ_r (deg/sec)	σ_p (deg/sec)	σ_β (deg)	σ_λ (deg)
v_g, w_g	.120	.87	.75	.13	.93	.12
v_g, w_g, p_g	1.63	3.37	5.21	2.74	3.44	2.74
$u_g, v_g, w_g, q_g, r_g, p_g$	2.35	3.26	4.73	3.14	3.52	3.14

Apparently the inclusion of p_g causes a significant change in the aircrafts' controllability and hence should be considered in any hybrid simulation. This might have been expected considering the large wing-span of the RPV considered.

These two examples only begin to show the possible uses of the digital program. Its careful and cautious use can provide insight into many aircraft and control system problems.

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X. Conclusions and Recommendations

A. Conclusions

The study described in Chapters I to IX allows the following conclusions to be drawn:

- 1) The all digital simulation of conventional aircraft in manned flight through a turbulent environment is both feasible and extremely practical.
- 2) Digital simulation can be accomplished reliably without numerical difficulties, search patterns, or large amounts of matrix manipulation.
- 3) The all digital simulation runs in near real time and its cost is insignificant compared to the cost of man-in-the-loop hybrid simulation.
- 4) The digital simulation of this study, the hybrid study of the Systems Dynamics Branch of the Flight Dynamics Laboratory, and the analog studies of Major John Arnold and Northrop Corporation concur in performance results.
- 5) The actual value of the pilot time delay seems most appropriately determined as lying between .125 and .25 seconds. Larger values add significantly to system instability and detract from data matching capabilities.
- 6) A pilot rating based solely on the total aircraft rotational rate is demonstrated as adequately matching the opinions of actual pilots for certain tasks.
- 7) A pilot model employing two parts (a) a logical (mental) decision making model and (b) a control implementation (physical) model is shown to model the human pilot adequately.

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8) The capability of digital simulation to assist in hybrid simulation design is demonstrated by the special applications of Chapter IX.

B. Recommendations

The following recommendations are made for continued study in the area investigated here:

1) The aerodynamic coefficients should be studied in order to determine the best method for including time varying coefficients in the digital simulation.

2) Continued application of the digital simulator to assist in hybrid simulation design and to verify hybrid and analog simulation studies should be made.

3) A similar program should be designed for use with hybrid simulator systems in order to assist in simulation checkout.

4) Effects of VFR flight conditions, motion base vs fixed base simulation, poor but not IFR visibility conditions and other realistic conditions should be further investigated for possible implementation.

5) The program should be expanded to allow the pilot to execute the flare task as data becomes available.

6) Expansion of the program to cover non-conventional aircraft seems straightforward.

7) The applicability of such a digital simulation to remotely piloted vehicles should be verified as data becomes available.

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Appendix: Digital Program Results

This appendix presents the actual output of the digital program developed in this study. These pages directly contain the data presented in Chapter VIII.

Contrails

F-5 #1 (AFFDL-TR-71-162) MIL SPEC TURBULENCE

THE ASSIGNED TASK IS HEADING
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU = -.082	XA = -66.194	MASS= 350.	SPAN= 25.3	IAS = 889.
ZU = -.000	ZA = -1.717	ZDE = -.435	ALT = 5135.	ALPHA= .800
G = 32.200	MA = -10.300	MDE = -47.200	MQ = -1.350	MADOT= -.065
YV = -.584	YDR= .095			
LBETA=-74.800	LDR= 13.800	LDA = 28.000	LP = -3.280	LR = .801
NBETA= 39.600	NDR=-12.150	NDA = 2.040	NP = .154	NR = -.839

AUGMENTATION SYSTEM PARAMETERS ARE					
TA = .010	TQ = .080	TCON = .010	TCON2= .010	TRAUG= .500	
KRAUG= .310	KPAUG= 0.000	KARI = 0.000	KQ = .055	KQDOT= .008	
KAZS = 0.00000	ELX = 12.000	GTHETA= 0.000	GPHI = 0.000		

GUST PARAMETERS ARE SU= 5.612 SV = 5.612 SW = 5.612					
EXPECTED STANDARD DEVIATIONS ARE					
SUG= 5.612	SAG= .362	SQG= 1.640			
SPG= 2.958	SBG= .362	SRG= 1.900			

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	.002	.428	-1.108	1.384
U	(FT/SEC)	1.788	1.464	-1.576	5.415
ALPHA	(DEG)	-.000	.387	-.907	.947
Q	(DEG/SEC)	.000	.712	-2.713	2.060
DE	(DEG)	-.000	.110	-.390	.446
PSI	(DEG)	.025	.587	-1.575	1.524
BETA	(DEG)	-.070	.378	-1.190	.979
PHI	(DEG)	-.046	1.386	-3.439	3.493
R	(DEG/SEC)	-.012	1.464	-3.971	4.067
P	(DEG/SEC)	.031	4.100	-11.300	12.279
DA	(DEG)	.012	.349	-1.021	1.134
DRAUG	(DEG)	.023	.707	-2.061	2.242
DR	(DEG)	.032	.720	-1.895	2.088
U GUST	(FT/SEC)	-1.773	5.309	-16.930	16.603
ALPHA GUST	(DEG)	.002	.372	-1.005	.865
Q GUST	(DEG/SEC)	.002	1.550	-5.849	4.820
P GUST	(DEG/SEC)	.013	2.709	-8.036	8.658
BETA GUST	(DEG)	.078	.323	-.855	1.163
R GUST	(DEG/SEC)	.002	1.706	-6.069	4.788
D	(FT)	3.465	21.242	-36.682	56.011
H	(FT)	4.699	21.385	-34.943	58.314
LAMBDA	(DEG)	-.045	.333	-1.157	.949
SVG = 5.01	SWG = 5.77				
THE NUMBER OF DECISIONS ON EACH VARIABLE WAS					
PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
104	486	128	0	0	90
THE PILOT RATING IS 2.97					

Contrails

F-5 #2 (AFFDL-TR-71-162) MIL SPEC TURBULENCE

THE ASSIGNED TASK IS HEADING
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU	=	-.009	XA	=	-75.867	MASS	=	350.	SPAN	=	25.3	IAS	=	439.
ZU	=	-.001	ZA	=	-.924	ZDE	=	-.221	ALT	=	4950.	ALPHA	=	8.000
G	=	32.200	MA	=	-3.590	MDE	=	-10.500	MQ	=	-.478	MADOT	=	-.004
YV	=	-.288	YDR	=	.061									
LBETA	=	-22.400	LDR	=	4.230	LDA	=	8.430	LP	=	-1.746	LR	=	.395
NBETA	=	7.430	NDR	=	-3.740	NOA	=	.193	NP	=	.062	NR	=	-.365

AUGMENTATION SYSTEM PARAMETERS ARE														
TA	=	.010	TQ	=	.080	TCON	=	.010	TCON2	=	.010	TRAUG	=	.500
KRAUG	=	.620	KPAUG	=	0.000	KARI	=	0.000	KQ	=	.123	KQDOT	=	-.031
KAZS	=	0.00000	ELX	=	12.000	GTHETA	=	0.000	GPHI	=	0.000			

GUST PARAMETERS ARE SU= 5.632 SV = 5.632 SW = 5.632														
EXPECTED STANDARD DEVIATIONS ARE														
SUG	=	5.632	SAG	=	.735	SQG	=	1.646						
SPG	=	2.969	SBG	=	.735	SRG	=	1.906						

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	-.134	.604	-1.552	1.434
U	(FT/SEC)	1.905	.979	-.230	4.067
ALPHA	(DEG)	.038	.695	-1.835	1.601
Q	(DEG/SEC)	-.003	.737	-2.318	2.158
DE	(DEG)	-.015	.260	-1.053	1.046
PSI	(DEG)	.006	.906	-2.288	2.652
BETA	(DEG)	-.198	.667	-2.534	2.061
PHI	(DEG)	-.139	2.850	-9.737	7.382
R	(DEG/SEC)	.003	1.387	-5.352	4.205
P	(DEG/SEC)	.042	6.204	-19.749	18.430
DA	(DEG)	.039	2.129	-5.908	8.266
DRAUG	(DEG)	.027	.953	-3.167	3.425
DR	(DEG)	.045	1.279	-4.161	4.787
U GUST	(FT/SEC)	-2.565	4.856	-14.848	12.779
ALPHA GUST	(DEG)	.008	.739	-1.961	1.640
Q GUST	(DEG/SEC)	.000	1.706	-6.309	5.516
P GUST	(DEG/SEC)	.019	2.963	-8.696	9.436
BETA GUST	(DEG)	.215	.632	-1.439	2.546
R GUST	(DEG/SEC)	-.003	1.978	-6.815	5.157
D	(FT)	-107.082	50.213	-181.740	1.519
H	(FT)	-95.910	48.057	-170.603	1.534
LAMBDA	(DEG)	-.194	.724	-1.957	2.133

SVG = 4.84 SWG = 5.66
 THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
80	516	117	0	0	90

THE PILOT RATING IS 4.29

Controls

F-5 #3 (AFFDL-TR-71-162) MIL SPEC TURBULENCE

THE ASSIGNED TASK IS HEADING
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU = -.022	XA = 83.801	MASS= 350.	SPAN= 25.3	IAS = 988.
ZU = -.000	ZA = -1.993	ZDE = -.459	ALT = 5000.	ALPHA= 0.000
G = 32.200	MA =-11.400	MDE =-64.400	MQ = -2.040	MADOT= -.152
YV = -.787	YDR= .086			
LBETA=*****	LDR= 12.280	LDA = 26.500	LP = -3.570	LR = 1.028
NBETA= 56.300	NDR=-12.340	NDA = 2.800	NP = .188	NR = -1.020

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010	TQ = .080	TCON = .010	TCON2= .010	TRAUG= .500
KRAUG= .270	KPAUG= 0.000	KARI = 0.000	KQ = .055	KQDOT= .008
KAZS = 0.00000	ELX = 12.000	GTHETA= 0.000	GPHI = 0.000	

GUST PARAMETERS ARE SU= 5.626	SV = 5.626	SW = 5.626
EXPECTED STANDARD DEVIATIONS ARE		
SUG= 5.626	SAG= .326	SQG= 1.644
SPG= 2.966	SBG= .326	SRG= 1.905

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	-.031	.463	-1.248	1.506
U	(FT/SEC)	1.936	1.562	-.436	4.732
ALPHA	(DEG)	-.000	.357	-.849	.901
Q	(DEG/SEC)	.001	.740	-2.582	2.167
DE	(DEG)	-.000	.101	-.295	.375
PSI	(DEG)	.037	.562	-1.426	1.600
BETA	(DEG)	-.063	.356	-1.085	.977
PHI	(DEG)	-.033	1.212	-3.027	3.022
R	(DEG/SEC)	-.012	1.655	-4.541	4.610
P	(DEG/SEC)	.026	4.045	-12.240	13.948
DA	(DEG)	.010	.322	-1.009	1.104
DRAUG	(DEG)	.017	.739	-2.316	2.326
DR	(DEG)	.025	.732	-2.062	2.266
U GUST	(FT/SEC)	-1.677	5.369	-17.502	17.069
ALPHA GUST	(DEG)	.002	.336	-.900	.798
Q GUST	(DEG/SEC)	.002	1.512	-5.696	4.668
P GUST	(DEG/SEC)	.012	2.649	-7.908	8.453
BETA GUST	(DEG)	.067	.294	-.792	1.029
R GUST	(DEG/SEC)	.002	1.651	-5.868	4.643
D	(FT)	-24.472	34.587	-98.878	28.086
H	(FT)	-24.472	34.587	-98.878	28.086
LAMBDA	(DEG)	-.026	.292	-.914	.840

SVG = 5.07 SWG = 5.79

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
145	452	123	0	0	90

THE PILOT RATING IS 2.98

Contrails

F-5 #4 (AFFDL-TR-71-162) MIL SPEC TURBULENCE

THE ASSIGNED TASK IS HEADING
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU = -.006	XA == 84.379	MASS= 350.	SPAN= 25.3	IAS = 789.
ZU = -.000	ZA = -.681	ZDE = -.148	ALT = 32150.	ALPHA= 6.000
G = 32.200	MA = -4.110	MDE = -15.480	MQ = -.493	MADOT= -.028
YV = -.192	YDR= .041			
LBETA=-27.600	LDR= 5.160	LDA = 12.010	LP = -1.360	LR = .231
NBETA= 11.540	NDR= -4.750	NDA = .619	NP = .051	NR = -.283

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010	TQ = .080	TCON = .010	TCON2= .010	TRAUG= .500
KRAUG= .520	KPAUG= 0.000	KARI = 0.000	KQ = .090	KQDOT= -.031
KAZS = 0.00000	ELX = 12.000	GTHETA= 0.000	GPHI = 0.000	

GUST PARAMETERS ARE SU= 4.616 SV = 4.616 SW = 4.616
 EXPECTED STANDARD DEVIATIONS ARE
 SUG= 4.616 SAG= .335 SQG= 1.349
 SRG= 2.433 SBG= .335 SRG= 1.563

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	-.014	.334	-.870	1.038
U	(FT/SEC)	.511	1.001	-1.954	2.723
ALPHA	(DEG)	.006	.349	-.929	.896
Q	(DEG/SEC)	-.003	.708	-2.603	2.142
DE	(DEG)	-.002	.201	-.725	.851
PSI	(DEG)	.044	.514	-1.277	1.560
BETA	(DEG)	-.057	.371	-.955	.881
PHI	(DEG)	-.053	2.148	-5.223	5.828
R	(DEG/SEC)	-.004	.898	-2.613	2.943
P	(DEG/SEC)	.032	5.283	-14.438	14.898
DA	(DEG)	.028	1.167	-3.242	3.184
DRAUG	(DEG)	.037	.588	-1.369	1.838
DR	(DEG)	.057	.658	-2.204	2.525
U GUST	(FT/SEC)	-1.557	4.322	-13.432	13.225
ALPHA GUST	(DEG)	.002	.345	-.934	.778
Q GUST	(DEG/SEC)	.001	1.309	-4.947	4.102
P GUST	(DEG/SEC)	.011	2.283	-6.714	7.308
BETA GUST	(DEG)	.077	.297	-.768	1.099
R GUST	(DEG/SEC)	.001	1.454	-5.172	4.066
D	(FT)	-20.868	19.531	-48.582	14.378
H	(FT)	-19.288	19.421	-47.777	13.195
LAMBDA	(DEG)	-.014	.336	-1.161	1.069
SVG =	4.08	SWG =	4.75		
THE NUMBER OF DECISIONS ON EACH VARIABLE WAS					
PITCH	ROLL	YAW GLIDESLOPE LOCALIZER NO ACTION			
70	559	92	0	0	90
THE PILOT RATING IS		3.67			

Contrails

A-7 #1 (AFFDL-TR-71-162) MIL SPEC TURBULENCE

THE ASSIGNED TASK IS HEADING
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU	=	-.006	XA = 34.100	MASS= 680.	SPAN= 38.7	IAS = 635.
ZU	=	-.000	ZA = -1.160	ZDE = -.157	ALT = 15000.	ALPHA= 4.000
G	=	32.200	MA = -9.081	MDE =-18.900	MQ = -.696	MADOT= -.133
YV	=	-.187	YDR= .054			
LBETA=-29.200	LDR= 7.270	LDA = 17.600	LP = -2.730	LR = .868		
NBETA= 3.120	NDR= -5.540	NDA = 1.370	NP = -.116	NR = -.541		

AUGMENTATION SYSTEM PARAMETERS ARE
 TA = .010 TQ = .100 TCON = .010 TCON2= .010 TRAUG= .100
 KRAUG= .250 KPAUG= -.100 KARI = .147 KQ = .250 KQDOT= 0.000
 KAZS =-.00054 ELX = 16.000 GTHETA= 0.000 GPHT = 0.100

GUST PARAMETERS ARE SU=	5.030	SV =	5.030	SW =	5.030
EXPECTED STANDARD DEVIATIONS ARE					
SUG=	5.030	SAG=	.454	SQG=	1.180
SPG=	1.995	SRG=	.454	SRG=	1.369

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	-.015	.365	-.864	.840
U	(FT/SEC)	1.851	1.450	-.556	4.834
ALPHA	(DEG)	-.002	.448	-.984	1.080
Q	(DEG/SEC)	.001	.499	-1.681	1.544
DE	(DEG)	-.000	.126	-.411	.515
PSI	(DEG)	.115	.737	-1.949	2.371
BETA	(DEG)	-.101	.662	-2.144	1.636
PHT	(DEG)	-.090	2.560	-.8.529	6.908
R	(DEG/SEC)	.003	1.024	-3.567	2.620
P	(DEG/SEC)	-.016	4.153	-10.593	11.537
DA	(DEG)	.021	.587	-1.605	2.038
DRAUG	(DEG)	.005	.316	-.899	.949
DR	(DEG)	.016	.397	-1.088	1.131
U GUST	(FT/SEC)	-1.896	4.596	-14.052	13.393
ALPHA GUST	(DEG)	.003	.464	-1.256	1.006
Q GUST	(DEG/SEC)	.001	1.225	-4.520	3.980
P GUST	(DEG/SEC)	.013	1.995	-5.855	6.335
BETA GUST	(DEG)	.114	.396	-.984	1.528
R GUST	(DEG/SEC)	.000	1.428	-4.856	3.681
D	(FT)	-13.207	6.544	-26.054	0.000
H	(FT)	-8.803	6.905	-19.995	5.482
LAMBDA	(DEG)	.015	.470	-1.370	1.248

SVG = 4.39 SWG = 5.14
 THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
58	549	107	0	0	90

THE PILOT RATING IS 2.95

Contrails

A-7 #2 (AFFOL-TR-71-162) MIL SPEC TURBULENCE

THE ASSIGNED TASK IS HEADING

THE PARAMETERS USED IN THIS ANALYSIS WERE

PILOT DELAY .175 SECONDS. DISTRACTION RATE .10

FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU = -.044	XA = 32.273	MASS= 680.	SPAN= 38.7	IAS = 952.
ZU = .000	ZA = -2.120	ZDE = -.220	ALT = 15000.	ALPHA= 2.500
G = 32.200	MA = -27.800	MDE = -41.700	MQ = -1.070	MADOT= -.267
YV = -.310	YDR= .055			
LBETA=-66.000	LDR= 11.200	LDA = 24.100	LP = -6.190	LR = .843
NBETA= 10.200	NDR= -8.800	NDA = 1.640	NP = -.207	NR = -.975

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010	TQ = .100	TCON = .010	TCON2= .010	TRAUG= .100
KRAUG= .250	KPAUG= -.100	KARI = .153	KQ = .250	KQDOT= 0.000
KAZS =-.00054	ELX = 16.000	GTHETA= 0.000	GPHI = 0.000	

GUST PARAMETERS ARE SU= 5.030 SV = 5.030 SW = 5.030

EXPECTED STANDARD DEVIATIONS ARE

SUG= 5.030	SAG= .303	SQG= 1.180
SPG= 1.995	SBG= .303	SRG= 1.369

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	-.004	.251	-.577	.648
U	(FT/SEC)	1.544	.871	-.085	3.235
ALPHA	(DEG)	-.001	.307	-.674	.757
Q	(DEG/SEC)	-.001	.586	-2.015	1.749
DE	(DEG)	-.000	.105	-.327	.419
PSI	(DEG)	-.012	.566	-1.529	1.624
BETA	(DEG)	-.062	.482	-1.606	1.233
PHI	(DEG)	-.091	1.799	-5.440	4.742
R	(DEG/SEC)	-.004	1.011	-2.837	2.818
P	(DEG/SEC)	.011	3.272	-8.343	10.378
DA	(DEG)	.009	.385	-1.230	1.137
DRAUG	(DEG)	.001	.467	-1.530	1.370
DR	(DEG)	.007	.496	-1.772	1.464
U GUST	(FT/SEC)	-1.532	4.785	-15.473	15.117
ALPHA GUST	(DEG)	.002	.312	-.839	.735
Q GUST	(DEG/SEC)	.002	1.188	-4.456	3.763
P GUST	(DEG/SEC)	.010	1.939	-5.615	6.219
BETA GUST	(DEG)	.064	.272	-.729	.961
R GUST	(DEG/SEC)	.002	1.348	-4.710	3.667
D	(FT)	.645	7.264	-10.201	15.446
H	(FT)	3.560	7.657	-9.200	17.881
LAMBDA	(DEG)	-.074	.327	-.927	.675

SVG = 4.51 SWG = 5.18

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
60	539	118	0	0	90

THE PILOT RATING IS 2.76

Contrails

A-7 #3 (AFFOL-TR-71-162) MIL SPEC TURBULENCE

THE ASSIGNED TASK IS HEADING
THE PARAMETERS USED IN THIS ANALYSIS WERE
PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU = .003	XA = 8.526	MASS= 680.	SPAN= 38.7	IAS = 584.
ZU = -.000	ZA = -.554	ZDE = -.074	ALT = 35000.	ALPHA= 7.500
G = 32.200	MA = -4.150	MDE = -8.190	MQ = -.330	MADOT= -.065
YV = -.085	YDR= .027			
LBETA=-14.900	LDR= 3.090	LDA = 7.960	LP = -1.400	LR = .599
NBETA= 1.380	NDR= -2.540	NDA = .652	NP = -.080	NR = -.247

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010	TQ = .100	TCON = .010	TCON2= .010	TRAUG= .100
KRAUG= .250	KPAUG= -.100	KARI = .200	KQ = .250	KQDOT= 0.000
KAZS =-.00054	ELX = 16.000	GTHETA= 0.000	GPHI = 0.000	

GUST PARAMETERS ARE SU= 4.570 SV = 4.570 SW = 4.570
EXPECTED STANDARD DEVIATIONS ARE

SUG= 4.570	SAG= .448	SQG= 1.072	
SPG= 1.812	SBG= .448	SRG= 1.244	

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	-.018	.403	-.945	.980
U	(FT/SEC)	1.655	1.879	-1.655	5.269
ALPHA	(DEG)	.000	.433	-1.019	.982
Q	(DEG/SEC)	.001	.405	-1.124	1.204
DE	(DEG)	-.001	.147	-.447	.574
PSI	(DEG)	.085	.608	-1.770	1.569
BETA	(DEG)	-.081	.524	-1.732	1.434
PHI	(DEG)	-.137	2.245	-5.812	6.312
R	(DEG/SEC)	.001	.684	-1.704	2.554
P	(DEG/SEC)	.002	3.707	-9.381	10.101
DA	(DEG)	.068	.939	-3.109	2.567
DRAUG	(DEG)	.009	.185	-.514	.484
DR	(DEG)	.039	.456	-2.237	1.723
U GUST	(FT/SEC)	-1.799	4.129	-12.649	11.785
ALPHA GUST	(DEG)	.003	.457	-1.234	.995
Q GUST	(DEG/SEC)	.001	1.115	-4.085	3.674
P GUST	(DEG/SEC)	.012	1.817	-5.322	5.739
BETA GUST	(DEG)	.117	.389	-.949	1.522
R GUST	(DEG/SEC)	-.000	1.304	-4.393	3.302
D	(FT)	-20.095	12.997	-39.081	1.234
H	(FT)	-14.194	11.918	-32.413	2.398
LAMBDA	(DEG)	.004	.463	-1.308	1.151

SVG = 3.97 SWG = 4.66

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW GLIDESLOPE LOCALIZER NO ACTION
61	564	93 0 0 90

THE PILOT RATING IS 2.83

Controls

A-7 #4 (AFFDL-TR-71-162) MIL SPEC TURBULENCE

THE ASSIGNED TASK IS HEADING

THE PARAMETERS USED IN THIS ANALYSIS WERE

PILOT DELAY .175 SECONDS. DISTRACTION RATE .10

FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU	=	-.019	XA	=	27.682	MASS=	680.	SPAN=	38.7	IAS =	876.
ZU	=	-.000	ZA	=	-1.010	ZDE =	-.114	ALT =	35000.	ALPHA=	3.800
G	=	32.200	MA	=	-13.140	MDE =	-20.200	MQ =	-.539	MADOT=	-.143
YV	=	-.145	YDR=	.035							
L	BETA=-30.600	LDR=	6.550	LDA =	14.200	LP =	-3.000	LR =	.563		
N	BETA= 4.720	NDR=	-5.110	NDA =	1.010	NP =	-.112	NR =	-.455		

AUGMENTATION SYSTEM PARAMETERS ARE

TA	=	.010	TQ	=	.100	TCON	=	.010	TCON2=	.010	TRAUG=	.100
KRAUG=	.250	KPAUG=	-.100	KARI =	.200	KQ =	.250	KQDOT=	0.000			
KAZS =	-.00054	ELX =	16.000	GTHETA=	0.000	GPHI =	0.000					

GUST PARAMETERS ARE SU= 4.570 SV = 4.570 SW = 4.570

EXPECTED STANDARD DEVIATIONS ARE

SUG=	4.570	SAG=	.299	SQG=	1.072
SPG=	1.812	SBG=	.299	SRG=	1.244

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	-.020	.261	-.609	.611
U	(FT/SEC)	1.556	1.026	-.395	3.579
ALPHA	(DEG)	-.002	.301	-.650	.762
Q	(DEG/SEC)	-.001	.460	-1.621	1.518
DE	(DEG)	.000	.120	-.396	.470
PSI	(DEG)	.035	.535	-1.463	1.725
BETA	(DEG)	-.058	.487	-1.562	1.238
PHI	(DEG)	-.071	1.736	-4.260	4.600
R	(DEG/SEC)	.001	.860	-2.390	2.469
P	(DEG/SEC)	-.002	3.226	-8.067	9.402
DA	(DEG)	.017	.481	-1.250	1.343
DRAUG	(DEG)	.004	.317	-.966	.870
DR	(DEG)	.014	.371	-1.428	.966
U GUST	(FT/SEC)	-1.455	4.319	-13.743	13.459
ALPHA GUST	(DEG)	.002	.308	-.831	.714
Q GUST	(DEG/SEC)	.001	1.090	-4.085	3.474
P GUST	(DEG/SEC)	.010	1.777	-5.172	5.597
BETA GUST	(DEG)	.065	.267	-.704	.964
R GUST	(DEG/SEC)	.001	1.245	-4.338	3.363
D	(FT)	-12.865	9.422	-29.441	1.499
H	(FT)	-9.104	6.772	-22.131	1.951
LAMBDA	(DEG)	-.023	.293	-.898	.699

SVG = 4.08 SWG = 4.70

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
63	538	120	0	0	90

THE PILOT RATING IS 2.74

Controls

F-5 #1 (AFFDL-TR-71-162) HIGH TURBULENCE

THE ASSIGNED TASK IS HEADING
THE PARAMETERS USED IN THIS ANALYSIS WERE
PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU	=	-.082	XA	=	-66.194	MASS=	350.	SPAN=	25.3	IAS =	889.
ZU	=	-.000	ZA	=	-1.717	ZDE =	-.435	ALT =	5135.	ALPHA=	.800
G	=	32.200	MA	=	-10.300	MDE =	-47.200	MQ =	-1.350	MADOT=	-.065
YV	=	-.584	YDR=	.	.095						
LBETA=	-74.800	LDR=	13.800	LDA =	28.000	LP =	-3.280	LR =	.801		
NBETA=	39.600	NDR=-12.150	NDA =	2.040	NP =	.154	NR =	-.839			

AUGMENTATION SYSTEM PARAMETERS ARE
TA = .010 TQ = .080 TCON = .010 TCON2= .010 TRAUG= .500
KRAUG= .310 KPAUG= 0.000 KARI = 0.000 KQ = .055 KQDOT= .008
KAZS = 0.00000 ELX = 12.000 GTHETA= 0.000 GPHI = 0.000

GUST PARAMETERS ARE SU= 11.224 SV = 11.224 SW = 11.224
EXPECTED STANDARD DEVIATIONS ARE
SUG= 11.224 SAG= .723 SQG= 3.280
SPG= 5.917 SBG= .723 SRG= 3.799

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	.021	.632	-1.504	1.862
U	(FT/SEC)	3.495	2.728	-3.037	10.282
ALPHA	(DEG)	-.002	.726	-1.603	1.799
Q	(DEG/SEC)	-.002	.965	-3.629	2.736
DE	(DEG)	-.000	.118	-.356	.514
PSI	(DEG)	.069	1.149	-2.918	3.122
BETA	(DEG)	-.146	.751	-2.441	1.902
PHI	(DEG)	-.088	2.584	-6.443	6.179
R	(DEG/SEC)	-.019	2.905	-7.775	7.968
P	(DEG/SEC)	.051	7.967	-21.853	22.844
UA	(DEG)	.017	.622	-1.733	1.917
DRAUG	(DEG)	.029	1.398	-4.134	3.786
DR	(DEG)	.041	1.406	-4.374	3.801
U GUST	(FT/SEC)	-3.547	10.623	-33.932	33.186
ALPHA GUST	(DEG)	.005	.744	-2.009	1.730
Q GUST	(DEG/SEC)	.003	3.100	-11.701	9.641
P GUST	(DEG/SEC)	.025	5.418	-16.073	17.316
BETA GUST	(DEG)	.156	.646	-1.712	2.326
R GUST	(DEG/SEC)	.003	3.411	-12.137	9.576
D	(FT)	8.868	32.419	-37.682	96.007
H	(FT)	11.343	33.347	-36.629	100.590
LAMBDA	(DEG)	-.077	.632	-1.983	1.878

SVG = 10.02 SWG = 11.55
THE NUMBER OF DECISIONS ON EACH VARIABLE WAS
PITCH ROLL YAW GLIDESLOPE LOCALIZER NO ACTION
77 494 143 0 0 90
THE PILOT RATING IS 5.60

Contrails

F-5 #2 (AFFDL-TR-71-162) HIGH TURBULENCE

THE ASSIGNED TASK IS HEADING
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU = - .009	XA = -75.867	MASS= 350.	SPAN= 25.3	IAS = 439.
ZU = -.001	ZA = -.924	ZDE = -.221	ALT = 4950.	ALPHA= 8.000
G = 32.200	MA = -3.590	MDE = -10.500	MQ = -.478	MADOT= -.004
YV = -.288	YDR= .061			
LBETA=-22.400	LDR= 4.230	LDA = 8.430	LP = -1.746	LR = .395
NBETA= 7.430	NDR= -3.740	NDA = .193	NP = .062	NR = -.365

AUGMENTATION SYSTEM PARAMETERS ARE
 TA = .010 TQ = .080 TCON = .010 TCON2= .010 TRAUG= .500
 KRAUG= .620 KPAUG= 0.000 KARI = 0.000 KQ = .123 KQDOT= -.031
 KAZS = 0.00000 ELX = 12.000 GTHETA= 0.000 GPHI = 0.000

GUST PARAMETERS ARE SU= 11.263 SV = 11.263 SW = 11.263
 EXPECTED STANDARD DEVIATIONS ARE
 SUG= 11.263 SAG= 1.470 SQG= 3.292
 SPG= 5.938 SBG= 1.470 SRG= 3.813

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	-.335	1.208	-2.949	2.754
U	(FT/SEC)	3.705	1.708	-.593	7.252
ALPHA	(DEG)	.090	1.350	-3.344	3.346
Q	(DEG/SEC)	-.002	1.363	-3.853	5.994
DE	(DEG)	-.036	.450	-2.009	1.809
PSI	(DEG)	-.170	1.941	-5.607	5.207
BETA	(DEG)	-.409	1.444	-4.659	4.218
PHI	(DEG)	-.217	5.891	-19.330	16.795
R	(DEG/SEC)	.007	2.891	-11.729	8.068
P	(DEG/SEC)	.059	12.441	-40.099	38.086
DA	(DEG)	.054	4.325	-13.818	15.436
DRAUG	(DEG)	.034	2.005	-6.432	7.360
DR	(DEG)	.060	2.612	-10.853	9.625
U GUST	(FT/SEC)	-5.129	9.711	-29.700	25.560
ALPHA GUST	(DEG)	.015	1.479	-3.924	3.278
Q GUST	(DEG/SEC)	.000	3.411	-12.619	11.033
P GUST	(DEG/SEC)	.038	5.926	-17.392	18.873
BETA GUST	(DEG)	.430	1.263	-2.878	5.093
R GUST	(DEG/SEC)	-.006	3.955	-13.630	10.315
D	(FT)	-238.014	104.374	-373.738	4.711
H	(FT)	-217.964	96.183	-354.523	4.553
LAMBDA	(DEG)	-.585	1.536	-5.339	3.922

SVG = 9.68 SWG = 11.33

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
83	513	118	0	0	90

THE PILOT RATING IS 7.46

Contrails

F-5 #3 (AFFDL-TR-71-162) HIGH TURBULENCE

THE ASSIGNED TASK IS HEADING
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU	=	-.022	XA	=	83.801	MASS=	350.	SPAN=	25.3	IAS =	988.
ZU	=	-.000	ZA	=	-1.993	ZDE =	-.459	ALT =	5000.	ALPHA=	0.000
G	=	32.200	MA	=	-11.400	MDE =	-64.400	MQ =	-2.040	MADOT=	-.152
YV	=	-.787	YDR=	.086							
LBETA=*****	LDR=	12.280	LDA =	26.500	LP =	-3.570	LR =	1.028			
NBETA=	56.300	NDR=-12.340	NDA =	2.800	NP =	.188	NR =	-1.020			

AUGMENTATION SYSTEM PARAMETERS ARE
 TA = .010 TQ = .080 TCON = .010 TCON2= .010 TRAUG= .500
 KRAUG= .270 KPAUG= 0.000 KARI = 0.000 KQ = .055 KQDOT= .008
 KAZS = 0.00000 ELX = 12.000 GTHETA= 0.000 GPHI = 0.000

GUST PARAMETERS ARE SU= 11.253 SV = 11.253 SW = 11.253
 EXPECTED STANDARD DEVIATIONS ARE
 SUG= 11.253 SAG= .653 SGU= 3.289
 SPG= 5.932 SBG= .653 SRG= 3.809

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	-.056	.615	-1.636	1.858
U	(FT/SEC)	3.851	2.400	-.183	7.996
ALPHA	(DEG)	-.002	.659	-1.456	1.632
Q	(DEG/SEC)	.001	.951	-3.519	2.639
DE	(DEG)	-.000	.111	-.365	.450
PSI	(DEG)	.078	1.110	-2.755	3.045
BETA	(DEG)	-.129	.705	-2.069	1.905
PHI	(DEG)	-.052	2.296	-6.493	5.452
R	(DEG/SEC)	-.020	3.311	-9.279	10.412
P	(DEG/SEC)	.045	7.948	-21.149	24.904
DA	(DEG)	.016	.580	-1.597	2.007
DRAUG	(DEG)	.023	1.461	-4.516	4.520
DR	(DEG)	.034	1.429	-4.032	4.376
U GUST	(FT/SEC)	-3.359	10.738	-35.116	34.082
ALPHA GUST	(DEG)	.004	.672	-1.801	1.595
Q GUST	(DEG/SEC)	.003	3.025	-11.392	9.335
P GUST	(DEG/SEC)	.024	5.299	-15.815	16.906
BETA GUST	(DEG)	.135	.587	-1.584	2.057
R GUST	(DEG/SEC)	.004	3.302	-11.736	9.284
D	(FT)	-51.077	41.434	-135.030	23.011
H	(FT)	-51.077	41.434	-135.030	23.011
LAMBDA	(DEG)	-.051	.581	-1.777	1.649
SVG =	10.13	SWG =	11.58		
THE NUMBER OF DECISIONS ON EACH VARIABLE WAS					
PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
79	476	161	0	0	90
THE PILOT RATING IS		5.68	139		

Contrails

F-5 #4 (AFFDL-TR-71-162) HIGH TURBULENCE

THE ASSIGNED TASK IS HEADING

THE PARAMETERS USED IN THIS ANALYSIS WERE

PILOT DELAY .175 SECONDS. DISTRACTION RATE .10

FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU = -.006	XA = -84.379	MASS = 350.	SPAN = 25.3	IAS = 789.
ZU = -.000	ZA = -.681	ZDE = -.148	ALT = 32150.	ALPHA = 6.000
G = 32.200	MA = -4.110	MDE = -15.480	MQ = -.493	MDOT = -.028
YV = -.192	YDR = .041			
LBETA = -27.600	LDR = 5.160	LUA = 12.010	LP = -1.360	LR = .231
NBETA = 11.540	NDR = -4.750	NDA = .619	NP = .051	NR = -.283

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010	TQ = .080	TCON = .010	TCON2 = .010	TRAUG = .500
KRAUG = .520	KPAUG = 0.000	KARI = 0.000	KQ = .090	KQDOT = -.031
KAZS = 0.00000	ELX = 12.000	GTHETA = 0.000	GPHI = 0.000	

GUST PARAMETERS ARE SU= 9.232 SV = 9.232 SW = 9.232

EXPECTED STANDARD DEVIATIONS ARE

SUG = 9.232	SAG = .670	SGG = 2.698
SPG = 4.867	SBG = .670	SRG = 3.125

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	-.029	.560	-1.345	1.602
U	(FT/SEC)	1.011	1.232	-2.366	4.465
ALPHA	(DEG)	.013	.640	-1.553	1.537
Q	(DEG/SEC)	-.007	.990	-4.269	3.401
DE	(DEG)	-.004	.231	-.970	1.064
PSI	(DEG)	.138	1.013	-2.367	3.445
BETA	(DEG)	-.113	.727	-1.950	1.816
PHI	(DEG)	-.138	4.255	-11.814	11.076
R	(DEG/SEC)	-.010	1.780	-4.469	5.845
P	(DEG/SEC)	.042	10.588	-33.342	28.845
DA	(DEG)	.060	2.291	-6.202	6.198
DRAUG	(DEG)	.077	1.126	-2.469	3.657
DR	(DEG)	.115	1.247	-4.233	5.123
U GUST	(FT/SEC)	-3.111	8.645	-26.864	26.448
ALPHA GUST	(DEG)	.004	.690	-1.867	1.555
Q GUST	(DEG/SEC)	.003	2.618	-9.893	8.205
P GUST	(DEG/SEC)	.022	4.565	-13.427	14.615
BETA GUST	(DEG)	.153	.593	-1.537	2.199
R GUST	(DEG/SEC)	.002	2.908	-10.345	8.132
D	(FT)	-38.688	30.716	-85.517	3.061
H	(FT)	-34.622	31.059	-84.077	7.710
LAMBDA	(DEG)	.026	.671	-2.067	2.141
SVG = 8.17	SWG = 9.50				

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
50	567	94	0	0	90

THE PILOT RATING IS 6.98

Controls

A-7 #1 (AFFDL-TR-71-162) HIGH TURBULENCE

THE ASSIGNED TASK IS HEADING
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU = -.006 XA = 34.100 MASS= 680. SPAN= 38.7 IAS = 635.
 ZU = -.000 ZA = -1.160 ZDE = -.157 ALT = 15000. ALPHA= 4.000
 G = 32.200 MA = -9.081 MOE =-18.900 MQ = -.696 MADOT= -.133
 YV = -.187 YDR= .054
 LBETA=-29.200 LDR= 7.270 LDA = 17.600 LP = -2.730 LR = .868
 NBETA= 3.120 NDR= -5.540 NDA = 1.370 NP = -.116 NR = -.541

AUGMENTATION SYSTEM PARAMETERS ARE
 TA = .010 TQ = .100 TCON = .010 TCON2= .010 TRAUG= .100
 KRAUG= .250 KPAUG= -.100 KARI = .147 KQ = .250 KQDOT= 0.000
 KAZS =-.00054 ELX = 16.000 GTHETA= 0.000 GPHI = 0.000

GUST PARAMETERS ARE SU= 10.060 SV = 10.060 SW = 10.060
 EXPECTED STANDARD DEVIATIONS ARE
 SUG= 10.060 SAG= .908 SQG= 2.360
 SPG= 3.989 SBG= .908 SRG= 2.738

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	.036	.695	-1.411	1.771
U	(FT/SEC)	2.160	2.206	-1.512	6.542
ALPHA	(DEG)	-.001	.890	-1.890	2.117
Q	(DEG/SEC)	.001	.923	-2.953	3.148
DE	(DEG)	-.002	.175	-.614	.647
PSI	(DEG)	.170	1.457	-3.874	4.650
BETA	(DEG)	-.212	1.291	-4.457	3.440
PHI	(DEG)	-.111	4.712	-14.355	15.111
R	(DEG/SEC)	.008	1.958	-6.434	5.255
P	(DEG/SEC)	-.014	8.041	-21.569	21.914
DA	(DEG)	.028	1.083	-3.362	3.223
DRAUG	(DEG)	.006	.606	-1.600	1.900
DR	(DEG)	.022	.711	-1.991	2.055
U GUST	(FT/SEC)	-3.788	9.188	-28.102	26.798
ALPHA GUST	(DEG)	.006	.929	-2.513	2.013
Q GUST	(DEG/SEC)	.002	2.449	-9.040	7.958
P GUST	(DEG/SEC)	.026	3.990	-11.709	12.671
BETA GUST	(DEG)	.228	.791	-1.965	3.057
R GUST	(DEG/SEC)	.001	2.856	-9.713	7.362
D	(FT)	9.431	20.986	-20.551	48.474
H	(FT)	14.795	25.978	-19.756	62.493
LAMBDA	(DEG)	-.043	.928	-2.768	2.241
SVG = 8.77	SWG = 10.29				
THE NUMBER OF DECISIONS ON EACH VARIABLE WAS					
PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
54	549	109	0	0	90
THE PILOT RATING IS 5.47					

Contrails

A-7 #2 (AFFDL-TR-71-162) HIGH TURBULENCE

THE ASSIGNED TASK IS HEADING
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU = -.044 XA = 32.273 MASS= 680. SPAN= 38.7 IAS = 952.
 ZU = .000 ZA = -2.120 ZOE = -.220 ALT = 15000. ALPHA= 2.500
 G = 32.200 MA =-27.800 MDE =-41.700 MQ = -1.070 MADOT= -.267
 YV = -.310 YDR= .055
 LBETA=-66.000 LDR= 11.200 LDA = 24.100 LP = -6.190 LR = .843
 NBETA= 10.200 NDR= -8.800 NDA = 1.640 NP = -.207 NR = -.975

AUGMENTATION SYSTEM PARAMETERS ARE
 TA = .010 TQ = .100 TCON = .010 TCON2= .010 TRAUG= .100
 KRAUG= .250 KPAUG= -.100 KARI = .153 KQ = .250 KQDOT= 0.000
 KAZS =-.00054 ELX = 16.000 GTTHETA= 0.000 GPHI = 0.000

GUST PARAMETERS ARE SU= 10.060 SV= 10.060 SW= 10.060
 EXPECTED STANDARD DEVIATIONS ARE
 SUG= 10.060 SAG= .605 SQG= 2.360
 SPG= 3.989 SBG= .605 SRG= 2.738

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	.037	.479	-.996	1.300
U	(FT/SEC)	2.678	1.673	-.777	6.404
ALPHA	(DEG)	-.002	.609	-1.321	1.501
Q	(DEG/SEC)	-.002	1.087	-3.927	3.261
DE	(DEG)	-.000	.157	-.586	.525
PSI	(DEG)	.012	1.127	-2.771	3.195
BETA	(DEG)	-.120	.959	-3.046	2.535
PHI	(DEG)	-.153	3.442	-10.929	11.406
R	(DEG/SEC)	-.007	2.001	-5.577	5.686
P	(DEG/SEC)	-.001	6.403	-16.080	19.821
DA	(DEG)	.019	.716	-2.318	2.121
DRAUG	(DEG)	.005	.914	-2.867	2.557
DR	(DEG)	.017	.942	-3.172	2.753
U GUST	(FT/SEC)	-3.071	9.573	-31.013	30.221
ALPHA GUST	(DEG)	.003	.623	-1.678	1.470
Q GUST	(DEG/SEC)	.003	2.376	-8.917	7.525
P GUST	(DEG/SEC)	.021	3.878	-11.233	12.437
BETA GUST	(DEG)	.127	.544	-1.458	1.923
R GUST	(DEG/SEC)	.003	2.695	-9.419	7.335
D	(FT)	29.409	23.850	-5.422	69.445
H	(FT)	34.690	27.522	-4.715	80.156
LAMBOA	(DEG)	-.109	.629	-1.832	1.456

SVG = 9.03 SWG = 10.36
 THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
66	530	126	0	0	90

THE PILOT RATING IS 4.53

Contrails

A-7 #3 (AFFDL-TR-71-162) HIGH TURBULENCE

THE ASSIGNED TASK IS HEADING
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU	=	.003	XA	=	8.526	MASS=	680.	SPAN=	38.7	IAS =	584.
ZU	=	-.000	ZA	=	-.554	ZDE =	-.074	ALT =	35000.	ALPHA=	7.500
G	=	32.200	MA	=	-4.150	MDE =	-8.190	MQ =	-.330	MADOT =	-.065
YY	=	-.085	YDR=	=	.027						
L	BETA=-14.900	LDR=	3.090	LDA =	7.960	LP =	-1.400	LR =	.599		
N	BETA=	1.380	NDR=	-2.540	NDA =	.652	NP =	-.080	NR =	-.247	

AUGMENTATION SYSTEM PARAMETERS ARE

TA	=	.010	TQ	=	.100	TCON	=	.010	TCON2=	.010	TRAUG=	.100
KRAUG=	.250	KPAUG=	-.100	KARI=	.200	KQ=	.250	KQDOTE=	0.000			
KAZS =	-.00054	ELX =	16.000	GTHETA=	0.000	GPHI =	0.300					

GUST PARAMETERS ARE SU= 9.140 SV = 9.140 SW = 9.140
 EXPECTED STANDARD DEVIATIONS ARE

SUG=	9.140	SAGE=	.897	SQG=	2.144							
SPG=	3.624	SBG=	.897	SRG=	2.487							

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEGT)	.004	.753	-1.505	2.006
U	(FT/SEC)	2.931	2.618	-1.893	8.289
ALPHA	(DEG)	.002	.853	-1.914	2.086
Q	(DEG/SEC)	.003	.764	-2.192	2.053
DE	(DEG)	-.003	.207	-.643	.722
PSI	(DEG)	.115	1.183	-3.468	3.078
BETA	(DEG)	-.174	1.067	-3.783	2.658
PHI	(DEG)	-.271	4.547	-11.175	9.893
R	(DEG/SEC)	.003	1.365	-3.721	4.452
P	(DEG/SEC)	.002	7.509	-19.518	18.057
DA	(DEG)	.117	1.902	-4.569	5.015
DRAUG	(DEG)	.015	.377	-.947	1.022
DR	(DEG)	.065	.886	-4.300	3.221
U GUST	(FT/SEC)	-3.599	8.258	-25.299	23.576
ALPHA GUST	(DEG)	.007	.915	-2.469	1.990
Q GUST	(DEG/SEC)	.002	2.229	-8.170	7.349
P GUST	(DEG/SEC)	.025	3.633	-10.645	11.478
BETA GUST	(DEG)	.233	.778	-1.898	3.044
R GUST	(DEG/SEC)	-.000	2.609	-8.786	6.605
D	(FT)	-32.354	23.282	-69.721	4.604
H	(FT)	-17.868	31.564	-62.480	40.807
LAMBDA	(DEG)	-.059	.898	-2.876	2.053

SVG = 7.93 SWG = 9.32

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
66	560	88	0	0	90

THE PILOT RATING IS 5.07

Contrails

A-7 #4 (AFFDL-TR-71-162) HIGH TURBULENCE

THE ASSIGNED TASK IS HEADING
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU	=	-.019	XA	=	27.682	MASS=	680.	SPAN=	38.7	IAS =	876.
ZU	=	-.000	ZA	=	-1.010	ZDE =	-.114	ALT =	35000.	ALPHA=	3.800
G	=	32.200	MA	=	-13.140	MDE =	-20.200	MQ =	-.539	MAODT=	-.143
YV	=	-.145	YDR=	.035							
LBETA=	-30.600	LDR=	6.550	LDA =	14.200	LP =	-3.000	LR =	.563		
NBETA=	4.720	NDR=	-5.110	NDA =	1.010	NP =	-.112	NR =	-.455		

AUGMENTATION SYSTEM PARAMETERS ARE
 TA = .010 TQ = .100 TCON = .010 TCON2= .010 TRAUG= .100
 KRAUG=.250 KPAUG= -.100 KARI = .200 KQ = .250 KQDOT= 0.000
 KAZS =-.00054 ELX = 16.000 GTHETA= 0.000 GPHI = 0.000

GUST PARAMETERS ARE SU= 9.140 SV = 9.140 SW = 9.140
 EXPECTED STANDARD DEVIATIONS ARE
 SUG= 9.140 SAG= .598 SQG= 2.144
 SPG= 3.624 SBG= .598 SRG= 2.487

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	-.010	.500	-.1079	1.258
U	(FT/SEC)	2.798	1.793	-.767	6.012
ALPHA	(DEG)	-.002	.593	-.1.223	1.475
Q	(DEG/SEC)	-.001	.831	-2.743	2.840
DE	(DEG)	-.000	.165	-.595	.585
PSI	(DEG)	.053	1.066	-2.996	3.336
BETA	(DEG)	-.114	.995	-.3.331	2.590
PHI	(DEG)	-.143	3.538	-9.059	10.605
R	(DEG/SEC)	-.001	1.726	-.5.088	4.969
P	(DEG/SEC)	-.014	6.607	-16.861	18.884
DA	(DEG)	.034	.954	-2.813	2.466
DRAUG	(DEG)	.008	.646	-1.913	1.809
DR	(DEG)	.028	.701	-2.308	1.781
U GUST	(FT/SEC)	-2.906	8.636	-27.425	26.895
ALPHA GUST	(DEG)	.003	.615	-1.661	1.427
Q GUST	(DEG/SEC)	.003	2.180	-8.171	6.949
P GUST	(DEG/SEC)	.020	3.555	-10.344	11.395
BETA GUST	(DEG)	.130	.533	-1.409	1.928
R GUST	(DEG/SEC)	.003	2.489	-8.675	6.726
D	(FT)	-16.610	10.450	-31.713	.943
H	(FT)	-9.311	11.792	-26.747	13.222
LAMBDA	(DEG)	-.061	.578	-1.763	1.385
SVG =	8.15	SWG =	9.40		

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
52	548	113	0	0	90

THE PILOT RATING IS 4.58

Contrails

F-5 #1 (AFFDL-TR-71-162) NO AUGMENTATION

THE ASSIGNED TASK IS HEADING

THE PARAMETERS USED IN THIS ANALYSIS WERE

PILOT DELAY .175 SECONDS. DISTRACTION RATE .10

FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU = -.082	XA = -66.194	MASS= 350.	SPAN= 25.3	IAS = 889.
ZU = +.000	ZA = -1.717	ZDE = -.435	ALT = 5135.	ALPHA= +.800
G = 32.200	MA = -10.300	MDE = -47.200	MQ = -1.350	MADOT= -.065
YV = -.584	YDR= .095			
LBETA=-74.800	LDR= 13.800	LDA = 28.000	LP = -3.280	LR = .801
NBETA= 39.600	NDR=-12.150	NDA = 2.040	NP = .154	NR = -.839

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010	TQ = .080	TCON = .010	TCON2= .010	TRAUG= .500
KRAUG= .000	KPAUG= 0.000	KARI = 0.000	KQ = 0.000	KQDOT= 0.000
KAZS=0.00000	ELX = 12.000	GTHETA= 0.000	GPHI = 0.000	

GUST PARAMETERS ARE SU= 5.612 SV = 5.612 SW = 5.612

EXPECTED STANDARD DEVIATIONS ARE

SUG= 5.612	SAG= .362	SQG= 1.640
SPG= 2.958	SRG= .362	SRG= 1.900

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	-.065	.568	-1.585	1.672
U	(FT/SEC)	2.208	1.464	-1.016	6.176
ALPHA	(DEG)	-.002	.471	-1.110	1.362
Q	(DEG/SEC)	-.002	1.322	-4.990	4.460
DE	(DEG)	.000	.143	-.416	.573
PST	(DEG)	.073	.794	-1.879	3.063
BETA	(DEG)	-.072	.635	-2.243	1.435
PHT	(DEG)	-.050	1.385	-4.558	3.939
R	(DEG/SEC)	-.010	3.559	-10.237	10.697
P	(DEG/SEC)	.009	7.038	-21.869	20.000
DA	(DEG)	.007	.358	-1.243	1.463
TRAUG	(DEG)	.000	.001	-.002	.002
DR	(DEG)	.022	.314	-1.250	1.587
U GUST	(FT/SEC)	-1.771	5.311	-16.953	16.616
ALPHA GUST	(DEG)	.002	.372	-1.005	.865
Q GUST	(DEG/SEC)	.002	1.550	-5.850	4.820
P GUST	(DEG/SEC)	.013	2.709	-8.036	8.658
BETA GUST	(DEG)	.078	.323	-.855	1.163
R GUST	(DEG/SEC)	.002	1.706	-6.069	4.788
D	(FT)	-36.909	33.474	-119.968	20.769
H	(FT)	-35.471	32.725	-117.013	20.950
LAMBDA	(DEG)	.000	.303	-.947	.928

SVG = 5.01 SWG = 5.78

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
150	417	155	0	0	90

THE PILOT RATING IS 5.27

Contrails

F-5 #2 (AFFDL-TR-71-162) NO AUGMENTATION

THE ASSIGNED TASK IS HEADING
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS, DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS, FLIGHT PATH ANGLE 0.0 DEGREES

XU = -.009	XA = -75.867	MASS = 350.	SPAN = 25.3	IAS = 439.
ZU = -.001	ZA = -.924	ZDE = -.221	ALT = 4950.	ALPHA = 8.000
G = 32.200	MA = -3.590	MDE = -10.500	MQ = -.478	MADOT = -.004
YV = -.288	YDR = .061			
LBETA = -22.400	LOR = 4.230	LDA = 8.430	LP = -1.746	LR = .395
NBETA = 7.430	NDR = -3.740	NDA = .193	NP = .062	NR = -.365

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010	TQ = .080	TCON = .010	TCON2 = .010	TRAUG = .500
KRAUG = .000	KPAUG = 0.000	KARI = 0.000	KQ = 0.000	KQDOT = 0.000
KAZS = 0.00000	ELX = 12.000	GTHETA = 0.000	GPHI = 0.000	

GUST PARAMETERS ARE SU = 5.632 SV = 5.632 SW = 5.632
 EXPECTED STANDARD DEVIATIONS ARE

SUG = 5.632	SAG = .735	SQG = 1.646
SPG = 2.969	SBG = .735	SRG = 1.906

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	-.044	.801	-1.865	2.007
U	(FT/SEC)	2.559	1.386	-.825	5.726
ALPHA	(DEG)	-.001	.779	-1.912	1.873
Q	(DEG/SEC)	.003	1.047	-3.755	3.039
DE	(DEG)	-.000	.269	-1.206	1.451
PST	(DEG)	.113	1.039	-2.625	2.966
BETA	(DEG)	-.201	.889	-2.647	2.304
PHT	(DEG)	-.105	2.898	-7.408	8.742
R	(DEG/SEC)	.001	2.006	-6.486	6.043
P	(DEG/SEC)	.039	8.554	-22.521	28.551
DA	(DEG)	.048	2.252	-7.817	6.330
DRAUG	(DEG)	.000	.000	-.001	.001
OR	(DEG)	.044	1.066	-4.705	5.028
U GUST	(FT/SEC)	-2.564	4.856	-14.849	12.781
ALPHA GUST	(DEG)	.008	.740	-1.962	1.640
Q GUST	(DEG/SEC)	.000	1.706	-6.310	5.516
P GUST	(DEG/SEC)	.019	2.963	-8.696	9.436
BETA GUST	(DEG)	.215	.632	-1.439	2.547
R GUST	(DEG/SEC)	-.003	1.978	-6.815	5.158
D	(FT)	-67.537	54.465	-156.907	.263
H	(FT)	-52.029	58.448	-148.068	23.446
LAMBDA	(DEG)	-.089	.687	-2.275	1.802

SVG = 4.84 SWG = 5.67
 THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
96	503	115	0	0	90

THE PILOT RATING IS 5.79

Contrails

F-5 #3 (AFFOL-TR-71-162) NO AUGMENTATION

THE ASSIGNED TASK IS HEADING
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU = -.022	XA = 83.801	MASS= 350.	SPAN= 25.3	IAS = 988.
ZU = -.000	ZA = -1.993	ZDE = -.459	ALT = 5000.	ALPHA= 0.000
G = 32.200	MA =-11.400	MDE =-64.400	MQ = -2.040	MADOT= -.152
YV = -.787	YDR= .086			
LBETA=*****	LDR= 12.280	LDA = 26.500	LP = -3.570	LR = 1.028
NBETA= 56.300	NDR=-12.340	NDA = 2.800	NP = .188	NR = -1.020

AUGMENTATION SYSTEM PARAMETERS ARE
 TA = .010 TQ = .080 TCON = .010 TCON2= .010 TRAUG= .500
 KRAUG= .000 KPAUG= 0.000 KARI = 0.000 KQ = 0.000 KQDOT= 0.000
 KAZS =0.00000 ELX = 12.000 GTHETA= 0.000 GPHI = 0.000

GUST PARAMETERS ARE SU= 5.626 SV = 5.626 SW = 5.626
 EXPECTED STANDARD DEVIATIONS ARE
 SUG= 5.626 SAG= .326 SQG= 1.644
 SPG= 2.966 SBG= .326 SRG= 1.905

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	-.066	.618	-1.748	1.847
U	(FT/SEC)	2.452	1.742	-.646	5.300
ALPHA	(DEG)	-.001	.451	-1.115	1.299
Q	(DEG/SEC)	-.001	1.437	-4.978	4.243
DE	(DEG)	-.000	.139	-.455	.474
PSI	(DEG)	.083	.692	-1.816	2.264
BETA	(DEG)	-.063	.514	-1.983	1.422
PHI	(DEG)	-.017	1.153	-5.178	3.704
R	(DEG/SEC)	-.009	3.299	-10.704	12.054
P	(DEG/SEC)	-.001	6.108	-22.414	19.254
DA	(DEG)	.007	.325	-1.324	1.476
DRAUG	(DEG)	.000	.001	-.002	.003
DR	(DEG)	.020	.282	-1.059	1.326
U GUST	(FT/SEC)	-1.677	5.369	-17.516	17.074
ALPHA GUST	(DEG)	.002	.336	-.901	.795
Q GUST	(DEG/SEC)	.002	1.512	-5.695	4.668
P GUST	(DEG/SEC)	.012	2.649	-7.908	8.453
BETA GUST	(DEG)	.067	.294	-.792	1.028
R GUST	(DEG/SEC)	.002	1.651	-5.868	4.642
D	(FT)	-52.679	48.084	-145.513	24.796
H	(FT)	-52.679	48.084	-145.513	24.796
LAMBDA	(DEG)	.020	.273	-.785	.833

SVG = 5.06 SWG = 5.79

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
172	387	158	0	0	90

THE PILOT RATING IS 4.71

Contrails

F-5 #4 (AFFDL-TR-71-162) NO AUGMENTATION

THE ASSIGNED TASK IS HEADING
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU = -.006	XA = -84.379	MASS= 350.	SPAN= 25.3	IAS = 789.
ZU = -.000	ZA = -.681	ZOE = -.148	ALT = 32150.	ALPHA= 6.000
G = 32.200	MA = -4.110	MDE = -15.480	MQ = -.493	MADOT= -.028
YV = -.192	YDR= .041			
LBETA=-27.600	LDR= 5.160	LDA = 12.010	LP = -1.360	LR = .231
NBETA= 11.540	NDR= -4.750	NDA = .619	NP = .051	NR = -.283

AUGMENTATION SYSTEM PARAMETERS ARE
 TA = .010 TQ = .080 TCON = .010 TCON2= .010 TRAUG= .500
 KRAUG= .000 KPAUG= 0.000 KARI = 0.000 KQ = 0.000 KQDOT= 0.000
 KAZS = 0.00000 ELX = 12.000 GTHETA= 0.000 GFHT = 0.000

GUST PARAMETERS ARE SU= 4.616 SV = 4.616 SW = 4.616
 EXPECTED STANDARD DEVIATIONS ARE
 SUG= 4.616 SAG= .335 SQG= 1.349
 SPG= 2.433 SBG= .335 SRG= 1.563

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	.016	.475	-1.265	1.662
U	(FT/SEC)	.055	1.192	-4.347	3.529
ALPHA	(DEG)	.015	.463	-1.348	1.174
Q	(DEG/SEC)	-.004	.842	-3.754	2.272
DE	(DEG)	-.003	.159	-.508	1.129
PSI	(DEG)	.147	.702	-1.637	2.223
BETA	(DEG)	-.053	.674	-1.924	1.610
PHI	(DEG)	.001	2.911	-7.459	8.616
R	(DEG/SEC)	-.003	2.010	-6.670	5.612
P	(DEG/SEC)	.030	8.668	-22.150	26.499
DA	(DEG)	.031	1.620	-5.309	4.756
DRAUG	(DEG)	.000	.000	-.001	.001
DR	(DEG)	.065	.588	-2.433	3.315
U GUST	(FT/SEC)	-1.557	4.323	-13.435	13.225
ALPHA GUST	(DEG)	.002	.345	-.934	.778
Q GUST	(DEG/SEC)	.001	1.309	-4.947	4.103
P GUST	(DEG/SEC)	.011	2.283	-6.714	7.308
BETA GUST	(DEG)	.077	.297	-.769	1.099
R GUST	(DEG/SEC)	.001	1.454	-5.172	4.066
D	(FT)	-13.095	17.664	-34.439	22.747
H	(FT)	-11.850	17.828	-33.738	24.729
LAMBDA	(DEG)	.094	.406	-1.144	1.350

SVG = 4.08 SWG = 4.75
 THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
55	563	95	0	0	90

THE PILOT RATING IS 5.85

Contrails

A-7 #1 (AFFDL-TR-71-162) NO AUGMENTATION

THE ASSIGNED TASK IS HEADING

THE PARAMETERS USED IN THIS ANALYSIS WERE

PILOT DELAY .175 SECONDS. DISTRACTION RATE .10

FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU	=	-.006	XA	=	34.100	MASS=	680.	SPAN=	38.7	IAS =	635.
ZU	=	-.000	ZA	=	-1.160	ZOE =	-.157	ALT =	15000.	ALPHA=	4.000
G	=	32.200	MA	=	-9.081	MDE =	-18.900	MQ =	-.696	MADOT=	-.133
YV	=	-.187	YDR=	=	.054						
LBETA	=	-29.200	LDR	=	7.270	LDA =	17.600	LP =	-2.730	LR =	.868
NBETA	=	3.120	NDR	=	-5.540	NDA =	1.370	NP =	-.116	NR =	-.541

AUGMENTATION SYSTEM PARAMETERS ARE

TA	=	.010	TQ	=	.100	TCON	=	.010	TCON2=	.010	TRAUG=	.100
KRAUG	=	.000	KPAUG	=	0.000	KARI	=	.147	KQ =	0.000	KQDOT=	0.000
KAZS	=	0.00000	ELX	=	16.000	GTHETA	=	0.000	GFHI	=	0.000	

GUST PARAMETERS ARE SU= 5.030 SV = 5.030 SW = 5.030

EXPECTED STANDARD DEVIATIONS ARE

SUG	=	5.030	SAG	=	.454	SQG=	1.180
SPG	=	1.995	SBG	=	.454	SRG=	1.369

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	.064	.542	-1.383	1.600
U	(FT/SEC)	-.277	1.513	-3.003	2.718
ALPHA	(DEG)	-.002	.519	-1.369	1.323
Q	(DEG/SEC)	-.007	.886	-2.753	2.421
DE	(DEG)	-.000	.134	-.360	.425
Psi	(DEG)	.107	.792	-2.061	2.620
BETA	(DEG)	-.109	.754	-2.261	1.931
Pht	(DEG)	-.085	3.227	-9.340	10.617
R	(DEG/SEC)	-.004	1.437	-3.562	4.182
P	(DEG/SEC)	.025	7.730	-19.084	24.158
DA	(DEG)	.011	.629	-2.142	1.889
DRAUG	(DEG)	-.000	.000	-.001	.001
DR	(DEG)	.011	.290	-1.419	1.556
U GUST	(FT/SEC)	-1.894	4.596	-14.051	13.401
ALPHA GUST	(DEG)	.003	.464	-1.257	1.005
Q GUST	(DEG/SEC)	.001	1.225	-4.520	3.979
P GUST	(DEG/SEC)	.013	1.995	-5.855	6.335
BETA GUST	(DEG)	.114	.396	-.983	1.528
R GUST	(DEG/SEC)	.000	1.428	-4.856	3.681
D	(FT)	38.027	22.154	-4.462	89.611
H	(FT)	36.646	22.315	-4.411	88.862
LAMBDA	(DEG)	-.002	.416	-1.319	1.130

SVG = 4.39 SWG = 5.15

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
69	561	84	0	0	90

THE PILOT RATING IS 5.22

Contrails

A-7 #2 (AFFDL-TR-71-162) NO AUGMENTATION

THE ASSIGNED TASK IS HEADING
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU = -.044	XA = 32.273	MASS= 680.	SPAN= 38.7	IAS = 952.
ZU = .000	ZA = -2.120	ZDE = -.220	ALT = 15000.	ALPHA= 2.500
G = 32.200	MA = -27.800	MDE = -41.700	MQ = -1.070	MADOT= -.267
YV = -.310	YDR= .055			
LBETA=-66.000	LDR= 11.200	LDA = 24.100	LP = -6.190	LR = .843
NBETA= 10.200	NDR= -8.800	NDA = 1.640	NP = -.207	NR = -.975

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010	TQ = .100	TCON = .010	TCON2= .010	TRAUG= .100
KRAUG= .000	KPAUG= 0.000	KARI = .153	KQ = 0.000	KQDOT= 0.000
KAZS = 0.00000	ELX = 16.000	GTHETA= 0.000	GPHI = 0.000	

GUST PARAMETERS ARE SU= 5.030 SV = 5.030 SW = 5.030

EXPECTED STANDARD DEVIATIONS ARE

SUG= 5.030	SAG= .303	SQG= 1.180
SPG= 1.995	SBG= .303	SRG= 1.369

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	-.046	.414	-1.079	1.028
U	(FT/SEC)	2.027	1.223	-.407	4.411
ALPHA	(DEG)	-.001	.367	-.937	.953
Q	(DEG/SEC)	.000	1.133	-3.579	3.468
DE	(DEG)	-.000	.127	-.357	.378
PSI	(DEG)	.080	.602	-1.401	1.616
BETA	(DEG)	-.060	.497	-1.274	1.193
PHI	(DEG)	-.037	1.398	-3.764	3.251
R	(DEG/SEC)	-.011	1.591	-4.060	3.987
P	(DEG/SEC)	-.005	4.593	-12.836	12.492
DA	(DEG)	.008	.239	-.669	.651
DRAUG	(DEG)	.000	.001	-.001	.001
DR	(DEG)	.010	.197	-.670	.754
U GUST	(FT/SEC)	-1.533	4.787	-15.478	15.118
ALPHA GUST	(DEG)	.002	.312	-.838	.735
Q GUST	(DEG/SEC)	.002	1.188	-4.458	3.765
P GUST	(DEG/SEC)	.010	1.939	-5.615	6.219
BETA GUST	(DEG)	.063	.272	-.728	.961
R GUST	(DEG/SEC)	.002	1.348	-4.710	3.667
D	(FT)	-41.225	29.936	-92.503	.215
H	(FT)	-37.356	27.682	-87.031	.862
LAMBDA	(DEG)	.020	.264	-.924	.710

SVG = 4.52 SWG = 5.18

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
103	484	134	0	0	90

THE PILOT RATING IS 3.42

Controls

A-7 #3 (AFFDL-TR-71-162) NO AUGMENTATION

THE ASSIGNED TASK IS HEADING

THE PARAMETERS USED IN THIS ANALYSIS WERE

PILOT DELAY .175 SECONDS. DISTRACTION RATE .10

FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU = .003	XA = 8.526	MASS= 680.	SPAN= 38.7	IAS = 584.
ZU = -.000	ZA = -.554	ZDE = -.074	ALT = 35000.	ALPHA= 7.500
G = 32.200	MA = -4.150	MOE = -8.190	MQ = -.330	MADOT= -.065
YV = -.085	YDR= .027			
LBETA=-14.900	LDR= 3.090	LDA = 7.960	LP = -1.400	LR = .599
NBETA= 1.380	NDR= -2.540	NDA = .652	NP = -.080	NR = -.247

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010	TQ = .100	TCON = .010	TCON2= .010	TRAUG= .100
KRAUG= .000	KPAUG= 0.000	KARI = .200	KQ = 0.000	KQDOT= 0.000
KAZS = 0.00000	ELX = 16.000	GTTHETA= 0.000	GPHI = 0.000	

GUST PARAMETERS ARE SU= 4.570 SV = 4.570 SW = 4.570

EXPECTED STANDARD DEVIATIONS ARE

SUG= 4.570	SAG= .448	SQG= 1.072
SPG= 1.812	SBG= .448	SRG= 1.244

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	.036	.507	-1.142	1.321
U	(FT/SEC)	-.543	1.159	-3.246	2.546
ALPHA	(DEG)	.013	.518	-1.273	1.213
Q	(DEG/SEC)	-.008	.714	-2.113	1.888
DE	(DEG)	-.005	.157	-.518	.715
PSI	(DEG)	.127	.663	-1.940	2.124
BETA	(DEG)	-.086	.673	-2.041	1.710
PHI	(DEG)	-.090	3.177	-9.416	9.359
R	(DEG/SEC)	.005	.842	-2.331	2.234
P	(DEG/SEC)	.035	6.860	-18.641	21.540
DA	(DEG)	.062	1.353	-4.121	4.342
DRAUG	(DEG)	.000	.000	-.000	.000
DR	(DEG)	.037	.481	-2.522	2.787
U GUST	(FT/SEC)	-1.798	4.129	-12.649	11.792
ALPHA GUST	(DEG)	.003	.457	-1.235	.995
Q GUST	(DEG/SEC)	.001	1.115	-4.085	3.674
P GUST	(DEG/SEC)	.013	1.817	-5.322	5.739
BETA GUST	(DEG)	.117	.389	-.949	1.522
R GUST	(DEG/SEC)	-.000	1.304	-4.393	3.302
D	(FT)	10.639	14.128	-10.178	36.193
H	(FT)	7.763	13.879	-14.321	32.321
LAMBDA	(DEG)	.041	.534	-1.624	1.599

SVG = 3.97 SWG = 4.66

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESCOPE	LOCALIZER	NO ACTION
80	572	66	0	0	90

THE PILOT RATING IS 4.62

Controls

A-7 #4 (AFFOL-TR-71-162) NO AUGMENTATION

THE ASSIGNED TASK IS HEADING
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU	=	-.019	XA	=	27.682	MASS=	680.	SPAN=	38.7	IAS =	876.
ZU	=	-.000	ZA	=	-1.010	ZDE =	-.114	ALT =	35000.	ALPHA=	3.800
G	=	32.200	MA	=	-13.140	MDE =	-20.200	MQ =	-.539	MADOT=	-.143
YV	=	-.145	YDR=	.035							
LBETA	=	-30.600	LDR=	6.550	LDA =	14.200	LP =	-3.000	LR =	.563	
NBETA	=	4.720	NDR=	-5.110	NDA =	1.010	NP =	-.112	NR =	-.455	

AUGMENTATION SYSTEM PARAMETERS ARE
 TA = .010 TQ = .100 TCON = .010 TCON2= .010 TRAUG= .100
 KRAUG= .000 KPAUG= 0.000 KARI = .200 KQ = 0.000 KQDOT= 0.000
 KAZS = 0.00000 ELX = 16.000 GTHETA= 0.000 GPHI = 0.000

GUST PARAMETERS ARE SU= 4.570 SV = 4.570 SW = 4.570
 EXPECTED STANDARD DEVIATIONS ARE
 SUG= 4.570 SAG= .299 SQG= 1.072
 SPG= 1.812 SBG= .299 SRG= 1.244

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	.017	.397	-1.161	1.180
U	(FT/SEC)	1.080	1.133	-1.005	3.368
ALPHA	(DEG)	-.002	.380	-1.047	1.070
Q	(DEG/SEC)	-.003	.937	-2.647	2.400
DE	(DEG)	-.000	.132	-.360	.425
PSI	(DEG)	.047	.610	-1.624	1.511
BETA	(DEG)	-.063	.561	-1.470	1.297
PHI	(DEG)	-.069	1.989	-5.190	5.027
R	(DEG/SEC)	-.001	1.265	-3.113	3.157
P	(DEG/SEC)	-.003	5.247	-13.582	12.488
DA	(DEG)	.009	.501	-1.479	1.432
DRAUG	(DEG)	.000	.000	-.001	.001
DR	(DEG)	.008	.260	-1.122	1.203
U GUST	(FT/SEC)	-1.453	4.319	-13.719	13.465
ALPHA GUST	(DEG)	.002	.308	-.831	.713
Q GUST	(DEG/SEC)	.002	1.090	-4.085	3.475
P GUST	(DEG/SEC)	.010	1.777	-5.172	5.697
BETA GUST	(DEG)	.065	.267	-.705	.964
R GUST	(DEG/SEC)	.001	1.245	-4.337	3.363
D	(FT)	6.331	13.315	-14.528	37.526
H	(FT)	9.147	14.500	-10.468	44.296
LAMBOA	(DEG)	-.016	.285	-1.022	.710

SVG = 4.08 SWG = 4.70
 THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW GLIDESLOPE	LOCALIZER	NO ACTION
76	544	100	0	90

THE PILOT RATING IS 3.72

Contrails

BOEING 707 FAA SIMULATION 2000 FT 50 DEGREES FLAPS

THE ASSIGNED TASK IS LANDING

THE PARAMETERS USED IN THIS ANALYSIS WERE

PILOT DELAY .175 SECONDS. DISTRACTION RATE .10

FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE -3.0 DEGREES

XU = -.040	XA = 19.115	MASS= 5900.	SPAN= 130.8	IAS = 233.
ZU = -.001	ZA = -.597	ZOE = -.030	ALT = 500.	
G = 32.200	MA = -1.003	MOE = -.863	MQ = -.687	MADOT= -.271
YV = -.095	YDR= .033			
LBETA= -1.628	LDR= .211	LOA = .141	LP = -2.026	LR = .610
NBETA= .567	NDR= -.382	NDA = .011	NP = -.136	NR = -.248

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010	TQ = .500	TCON = .010	TCON2= .010	TRAUG= 1.000
KRAUG= .000	KPAUG= 0.000	KARI = 0.000	KQ = 0.100	KQDOT= 0.000
KAZS = 0.00000	ELX = 25.000	GTHETA= 0.000	GPHI = 0.000	

GUST PARAMETERS ARE SU= 2.608	SV = 2.608	SH = 1.719
EXPECTED STANDARD DEVIATIONS ARE		
SUG= 2.608	SAG= .423	SQG= .347
SPG= .460	SBG= .641	SRG= .451

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	.060	.533	-1.002	2.189
U	(FT/SEC)	-.975	.960	-2.798	1.125
ALPHA	(DEG)	.073	.498	-1.073	2.498
Q	(DEG/SEC)	-.001	.316	-.890	1.480
DE	(DEG)	-.054	.590	-3.075	1.300
PSI	(DEG)	.392	1.126	-2.168	3.024
BETA	(DEG)	.165	.868	-2.421	1.969
PHI	(DEG)	.057	1.294	-3.056	3.198
R	(DEG/SEC)	.004	.694	-1.841	1.970
P	(DEG/SEC)	-.027	.742	-1.614	2.277
DA	(DEG)	.011	2.938	-9.154	8.776
DRAUG	(DEG)	.000	.000	-.000	.000
DR	(DEG)	.259	.867	-2.395	3.191
U GUST	(FT/SEC)	.626	2.607	-9.137	8.490
ALPHA GUST	(DEG)	-.026	.349	-1.056	1.048
Q GUST	(DEG/SEC)	.002	.326	-1.030	.836
P GUST	(DEG/SEC)	-.063	.491	-1.575	1.196
BETA GUST	(DEG)	-.022	.494	-2.092	1.053
R GUST	(DEG/SEC)	.011	.431	-1.155	1.223
D	(FT)	-3.151	6.342	-24.862	8.835
H	(FT)	-.991	5.848	-20.803	9.625
LAMBDA	(DEG)	.558	.889	-2.114	2.372
SVG = 2.01	SWG = 1.42				

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW GLIDESLOPE LOCALIZER NO ACTION
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83	267	101	183	106	68
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THE PILOT RATING IS 2.23

Controls

BOEING 707 FAA SIMULATION 2000 FT 50 DEGREES FLAPS

THE ASSIGNED TASK IS LANDING

THE PARAMETERS USED IN THIS ANALYSIS WERE

PILOT DELAY .175 SECONDS. DISTRACTION RATE .10

FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE -3.0 DEGREES

XU = -.040 XA = 19.115 MASS= 5900. SPAN= 130.8 IAS = 233.
 ZU = -.001 ZA = -.597 ZDE = -.030 ALT = 500.
 G = 32.200 MA = -1.003 MDE = -.863 MQ = -.687 MADOT= -.271
 YV = -.095 YDR= .033
 LBETA= -1.628 LDR= .211 LDA = .141 LP = -2.026 LR = .610
 NBETA= .567 NDR= -.382 NDA = .011 NP = -.136 NR = -.248

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010 TQ = .500 TCON = .010 TCON2= .010 TRAUG= 1.000
 KRAUG= .000 KPAUG= 0.000 KARI = 0.000 KQ = 0.000 KQDOT= 0.000
 KAZS = 0.00000 ELX = 25.000 GTTHETA= 0.000 GPHI = 0.000

GUST PARAMETERS ARE SU= 2.000 SV = 2.000 SW = 1.400

EXPECTED STANDARD DEVIATIONS ARE

SUG=	2.000	SAG=	.344	SQG=	.282
SPG=	.374	SBG=	.492	SRG=	.346

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	.054	.406	-.766	1.547
U	(FT/SEC)	-.784	.761	-2.297	.650
ALPHA	(DEG)	.062	.379	-.818	1.840
Q	(DEG/SEC)	-.001	.240	-.571	1.100
DE	(DEG)	-.046	.445	-2.272	1.061
PSI	(DEG)	.365	.880	-1.857	2.479
BETA	(DEG)	.139	.650	-1.879	1.567
PHI	(DEG)	.049	1.072	-2.577	2.441
R	(DEG/SEC)	.004	.523	-1.568	1.257
P	(DEG/SEC)	-.022	.566	-1.270	1.766
DA	(DEG)	.051	2.410	-6.960	7.443
DRAUG	(DEG)	.000	.000	-.000	.000
DR	(DEG)	.219	.715	-2.008	2.617
U GUST	(FT/SEC)	.480	2.000	-7.006	6.508
ALPHA GUST	(DEG)	-.022	.284	-.860	.854
Q GUST	(DEG/SEC)	.001	.265	-.838	.680
P GUST	(DEG/SEC)	-.051	.399	-1.283	.974
BETA GUST	(DEG)	-.017	.379	-1.603	.808
R GUST	(DEG/SEC)	.008	.330	-.886	.937
D	(FT)	-2.574	4.922	-18.329	7.399
H	(FT)	-.865	4.548	-15.090	8.027
LAMBDA	(DEG)	.504	.739	-1.465	2.072

SVG = 1.54 SWG = 1.15

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
91	262	101	190	104	68

THE PILOT RATING IS 2.18

Controls

BOEING 707 FAA SIMULATION 2000 FT 50 DEGREES FLAPS

THE ASSIGNED TASK IS LANDING
THE PARAMETERS USED IN THIS ANALYSIS WERE

PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE -3.0 DEGREES

XU = -.040 XA = 19.115 MASS= 5900. SPAN= 130.8 IAS = 233.
ZU = -.001 ZA = -.597 ZDE = -.030 ALT = 500.
G = 32.200 MA = -1.003 MDE = -.863 MQ = -.687 MADOT= -.271
YV = -.095 YDR= .033
LBETA= -1.628 LDR= .211 LDA = .141 LP = -2.026 LR = .610
NBETA= .567 NDR= -.382 NDA = .011 NP = -.136 NR = -.248

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010 TQ = .500 TCON = .010 TCON2= .010 TRAUG= 1.000
KRAUG= .000 KPAUG= 0.000 KARI = 0.000 KQ = 0.000 KQDOT= 0.000
KAZS = 0.00000 ELX = 25.000 GTHETA= 0.000 GPHI = 0.000

GUST PARAMETERS ARE SU= 2.000 SV = 2.000 SW = 1.400

EXPECTED STANDARD DEVIATIONS ARE

SUG= 2.000	SAG= .344	SQG= .282
SPG= .374	SBG= .492	SRG= .346

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	-.224	.577	-1.802	.822
U	(FT/SEC)	.338	1.119	-1.877	2.325
ALPHA	(DEG)	-.221	.477	-2.003	.643
Q	(DEG/SEC)	-.006	.296	-1.336	.711
DE	(DEG)	.169	.568	-1.379	2.436
PSI	(DEG)	.101	.987	-2.157	2.929
BETA	(DEG)	-.044	.857	-2.284	2.123
PHI	(DEG)	-.032	1.082	-2.069	2.386
R	(DEG/SEC)	-.005	.671	-1.697	1.656
P	(DEG/SEC)	.004	.702	-1.577	2.024
DA	(DEG)	-.152	2.025	-6.787	5.970
DRAUG	(DEG)	.000	.000	-.000	.000
DR	(DEG)	.022	.545	-2.166	2.908
U GUST	(FT/SEC)	.799	2.076	-4.786	5.915
ALPHA GUST	(DEG)	.077	.341	-.837	1.011
Q GUST	(DEG/SEC)	.003	.272	-.947	.834
P GUST	(DEG/SEC)	-.014	.331	-1.053	.905
BETA GUST	(DEG)	.046	.393	-.921	1.157
R GUST	(DEG/SEC)	.003	.342	-.963	.883
D	(FT)	4.075	5.874	-9.092	16.102
H	(FT)	3.164	5.561	-9.017	14.858
LAMBDA	(DEG)	.056	.654	-1.129	1.668

SVG = 1.60 SWG = 1.39

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
143	229	59	252	48	75

THE PILOT RATING IS 2.22

Controls

BOEING 707 FAA SIMULATION 2000 FT 50 DEGREES FLAPS

THE ASSIGNED TASK IS LANDING

THE PARAMETERS USED IN THIS ANALYSIS WERE

PILOT DELAY .175 SECONDS. DISTRACTION RATE .10

FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE -3.0 DEGREES

XU = -.040	XA = 19.115	MASS= 5900.	SPAN= 130.8	IAS = 233.
ZU = -.001	ZA = -.597	ZDE = -.030	ALT = 500.	
G = 32.200	MA = -1.003	MDE = -.863	MQ = -.687	MADOT= -.271
YV = -.095	YDR= .033			
LBETA= -1.628	LDR= .211	LDA = .141	LP = -2.026	LR = .610
NBETA= .567	NDR= -.382	NDA = .011	NP = -.136	NR = -.248

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010	TQ = .500	TCON = .010	TCON2= .010	TRAUG= 1.000
KRAUG= .000	KPAUG= 0.000	KARI = 0.000	KQ = 0.000	KQDOT= 0.000
KAZS = 0.00000	ELX = 25.000	GTHETA= 0.000	GPHI = 0.000	

GUST PARAMETERS ARE SU= 2.200 SV = 2.200 SW = 1.600

EXPECTED STANDARD DEVIATIONS ARE

SUG= 2.200	SAG= .393	SQG= .323
SPG= .428	SBG= .541	SRG= .380

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	.183	.507	-.683	1.434
U	(FT/SEC)	-1.256	1.150	-4.142	.802
ALPHA	(DEG)	.202	.478	-.915	1.679
Q	(DEG/SEC)	-.002	.249	-.795	.814
DE	(DEG)	-.189	.529	-2.201	1.013
PSI	(DEG)	-.239	1.077	-2.846	2.590
BETA	(DEG)	.022	.944	-2.790	2.099
PHI	(DEG)	.020	1.047	-2.372	2.696
R	(DEG/SEC)	-.021	.770	-2.118	1.754
P	(DEG/SEC)	-.001	.787	-2.152	1.605
DA	(DEG)	-.048	2.082	-7.937	6.528
DRAUG	(DEG)	-.000	.000	-.000	.000
DR	(DEG)	-.056	.712	-2.941	2.709
U GUST	(FT/SEC)	-.021	2.166	-6.253	4.269
ALPHA GUST	(DEG)	-.041	.375	-1.152	.923
Q GUST	(DEG/SEC)	.007	.301	-.935	.978
P GUST	(DEG/SEC)	-.002	.428	-1.231	1.250
BETA GUST	(DEG)	-.027	.513	-1.290	1.471
R GUST	(DEG/SEC)	.006	.386	-1.135	1.188
D	(FT)	-6.014	5.360	-16.316	4.581
H	(FT)	-3.620	4.934	-15.638	4.972
LAMBDA	(DEG)	-.217	.493	-1.516	1.107
SVG = 2.09	SWG = 1.52				
THE NUMBER OF DECISIONS ON EACH VARIABLE WAS					
PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
138	216	120	211	43	84
THE PILOT RATING IS 2.25					

Controls

BOEING 707 FAA SIMULATION 2000 FT 50 DEGREES FLAPS

THE ASSIGNED TASK IS LANDING

THE PARAMETERS USED IN THIS ANALYSIS WERE

PILOT DELAY .175 SECONDS. DISTRACTION RATE .10

FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE -3.0 DEGREES

XU = -.040	XA = 19.115	MASS= 5900.	SPAN= 130.8	IAS = 233.
ZU = -.001	ZA = -.597	ZDE = -.030	ALT = 500.	
G = 32.200	MA = -1.003	MDE = -.863	MQ = -.687	MADOT= -.271
YV = -.095	YDR= .033			
LBETA= -1.628	LDR= .211	LDA = .141	LP = -2.026	LR = .610
NBETA= .567	NDR= -.382	NDA = .011	NP = -.136	NR = -.248

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010	TQ = .500	TCON = .010	TCON2= .010	TRAUG= 1.000
KRAUG= .000	KPAUG= 0.000	KARI = 0.000	KQ = 0.000	KQDOT= 0.000
KAZS = 0.00000	ELX = 25.000	GTHETA= 0.000	GPHI = 0.000	

GUST PARAMETERS ARE SU= 2.200 SV = 2.200 SW = 1.600

EXPECTED STANDARD DEVIATIONS ARE

SUG= 2.200	SAG= .393	SQG= .323
SPG= .428	SBG= .541	SRG= .380

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	-.240	.517	-1.938	.905
U	(FT/SEC)	1.382	.851	-.701	3.172
ALPHA	(DEG)	-.269	.568	-2.563	1.023
Q	(DEG/SEC)	-.002	.311	-.984	.985
DE	(DEG)	.243	.603	-1.000	2.866
PSI	(DEG)	-.247	1.246	-3.533	2.666
BETA	(DEG)	.080	.791	-1.967	2.123
PHI	(DEG)	.069	1.397	-3.060	2.793
R	(DEG/SEC)	.007	.661	-1.703	1.616
P	(DEG/SEC)	-.007	.765	-1.909	2.172
DA	(DEG)	-.197	2.811	-8.232	9.065
DRAUG	(DEG)	-.000	.000	-.000	.000
DR	(DEG)	-.042	.814	-3.592	2.704
U GUST	(FT/SEC)	.279	1.750	-5.128	4.904
ALPHA GUST	(DEG)	.071	.444	-.987	1.631
Q GUST	(DEG/SEC)	.001	.346	-1.029	1.020
P GUST	(DEG/SEC)	.009	.416	-1.116	1.363
BETA GUST	(DEG)	-.098	.418	-1.245	.926
R GUST	(DEG/SEC)	-.005	.365	-1.256	1.075
D	(FT)	9.631	5.699	-1.489	21.368
H	(FT)	5.386	6.157	-7.329	20.063
LAMBDA	(DEG)	-.167	1.015	-2.375	1.804
SVG = 1.70	SWG= 1.81				

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
79	256	87	218	97	75

THE PILOT RATING IS 2.23

Contrails

BOEING 707 FAA SIMULATION 2000 FT 50 DEGREES FLAPS

THE ASSIGNED TASK IS LANDING

THE PARAMETERS USED IN THIS ANALYSIS WERE

PILOT DELAY .175 SECONDS. DISTRACTION RATE .10

FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE -3.0 DEGREES

XU = -.040	XA = 19.115	MASS= 5900.	SPAN= 130.8	IAS = 233.
ZU = -.001	ZA = -.597	ZDE = -.030	ALT = 500.	
G = 32.200	MA = -1.003	MDE = -.863	MQ = -.687	MADOT= -.271
YV = -.095	YDR= .033			
LBETA= -1.628	LDR= .211	LDA = .141	LP = -2.026	LR = .610
NBETA= .567	NDR= -.382	NDA = .011	NP = -.136	NR = -.248

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010	TQ = .500	TCON = .010	TCON2= .010	TRAUG= 1.000
KRAUG= .000	KPAUG= 0.000	KARI = 0.000	KQ = 0.000	KQDOT= 0.000
KAZS = 0.00000	ELX = 25.000	GTHETA= 0.000	GPHI = 0.000	

GUST PARAMETERS ARE SU= 2.200 SV = 2.200 SW = 1.600

EXPECTED STANDARD DEVIATIONS ARE

SUG= 2.200	SAG= .393	SQG= .323
SPG= .428	SBG= .541	SRG= .380

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	.002	.494	-1.189	1.026
U	(FT/SEC)	.711	.792	-1.423	2.161
ALPHA	(DEG)	.010	.484	-1.181	1.449
Q	(DEG/SEC)	.002	.298	-.874	1.034
DE	(DEG)	-.012	.499	-1.546	1.510
PSI	(DEG)	.102	1.214	-2.014	2.656
BETA	(DEG)	-.245	.710	-1.601	1.493
PHI	(DEG)	-.159	1.038	-2.312	2.355
R	(DEG/SEC)	-.001	.584	-1.556	1.363
P	(DEG/SEC)	-.005	.707	-1.561	1.545
DA	(DEG)	.076	2.080	-6.903	6.848
DRAUG	(DEG)	.000	.000	-.000	.000
DR	(DEG)	.007	.896	-2.210	2.926
U GUST	(FT/SEC)	-.763	1.980	-5.808	4.606
ALPHA GUST	(DEG)	-.003	.350	-1.148	1.016
Q GUST	(DEG/SEC)	.000	.311	-1.041	.834
P GUST	(DEG/SEC)	.011	.413	-1.332	1.188
BETA GUST	(DEG)	.236	.448	-.863	1.537
R GUST	(DEG/SEC)	-.002	.354	-1.095	1.022
D	(FT)	1.160	4.969	-7.680	9.858
H	(FT)	-.236	5.615	-10.086	8.930
LAMBDA	(DEG)	-.144	1.049	-1.959	2.083

SVG = 1.82 SWG = 1.42

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
104	180	105	209	136	73

THE PILOT RATING IS 2.21

Contrails

BOEING 707 FAA SIMULATION 2000 FT 50 DEGREES FLAPS

THE ASSIGNED TASK IS LANDING
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE -3.0 DEGREES

XU	=	-.040	XA	=	19.115	MASS=	5900.	SPAN=	130.8	IAS =	233.
ZU	=	-.001	ZA	=	-.597	ZDE =	-.030	ALT =	500.		
G	=	32.200	MA	=	-1.003	MDE =	-.863	MQ =	-.687	MADOT=	-.271
YV	=	-.095	YDR=	.033							
LBETA=	-1.628	LDR=	.211	LDA =	.141	LP =	-2.026	LR =	.610		
NBETA=	.567	NDR=	-.382	NDA =	.011	NP =	-.136	NR =	-.248		

AUGMENTATION SYSTEM PARAMETERS ARE
 TA = .010 TQ = .500 TCON = .010 TCON2= .010 TRAUG= 1.000
 KRAUG= .000 KPAUG= 0.000 KARI = 0.000 KQ = 0.000 KQDOT= 0.000
 KAZS = 0.00000 ELX = 25.000 GTHETA= 0.000 GPHI = 0.000

GUST PARAMETERS ARE SU= 2.200 SV = 2.200 SW = 1.600
 EXPECTED STANDARD DEVIATIONS ARE
 SUG= 2.200 SAG= .393 SQG= .323
 SPG= .428 SBG= .541 SRG= .380

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	.018	.447	-1.017	1.321
U	(FT/SEC)	-.157	.862	-1.857	1.262
ALPHA	(DEG)	.015	.442	-1.072	1.087
Q	(DEG/SEC)	.001	.282	-.734	.879
DE	(DEG)	-.034	.464	-2.045	1.997
PSI	(DEG)	-.054	1.483	-3.912	2.544
BETA	(DEG)	.249	1.313	-3.012	2.971
PHI	(DEG)	.168	1.653	-3.887	3.911
R	(DEG/SEC)	.032	1.079	-2.318	2.571
P	(DEG/SEC)	-.010	1.094	-2.841	2.250
DA	(DEG)	-.387	3.806	-11.236	11.317
DRAUG	(DEG)	.000	.000	-.000	.000
DR	(DEG)	.137	1.102	-3.739	2.673
U GUST	(FT/SEC)	-.145	1.708	-4.156	4.673
ALPHA GUST	(DEG)	.014	.354	-.968	.805
Q GUST	(DEG/SEC)	-.003	.312	-.934	1.013
P GUST	(DEG/SEC)	-.073	.450	-1.259	1.322
BETA GUST	(DEG)	-.154	.567	-1.652	1.357
R GUST	(DEG/SEC)	-.007	.435	-1.263	1.100
D	(FT)	-1.553	5.197	-13.801	12.337
H	(FT)	-.628	5.017	-12.460	12.569
LAMBDA	(DEG)	.195	1.110	-2.383	2.246

SVG = 2.31 SWG = 1.44

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
57	290	137	129	116	73

THE PILOT RATING IS 2.34

Contrails

BOEING 707 FAA SIMULATION 2000 FT 50 DEGREES FLAPS

THE ASSIGNED TASK IS LANDING
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS, DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS, FLIGHT PATH ANGLE -3.0 DEGREES

XU = -.340	XA = 19.115	HASS = 5900.	SPAN = 130.3	IAS = 233.
ZU = -.001	ZA = -.597	ZDE = -.030	ALT = 500.	
G = 32.200	MA = -1.003	MDE = -.863	MQ = -.637	MADOT = -.271
YJ = -.095	YDR = .033			
LBETA = -1.628	LDR = .211	LDA = .141	LP = -2.026	LR = .610
NBETA = .567	NDR = -.382	NDA = .011	NP = -.136	NR = -.248

AUGMENTATION SYSTEM PARAMETERS ARE
 TA = .010 TQ = .500 TCON = .010 TCON2 = .010 TRAUG = 1.000
 KRAUG = .030 KPAUG = 0.000 KARI = 0.000 KQ = 0.030 KQDOT = 0.000
 KA2S = 0.00000 ELX = 25.000 GTHETA = 0.000 GPHI = 0.000

GUST PARAMETERS ARE SU = 2.200 SV = 2.200 SW = 1.600
 EXPECTED STANDARD DEVIATIONS ARE
 SUG = 2.200 SAG = .393 SQG = .323
 SPG = .428 SBG = .541 SRG = .380

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	.030	.529	-1.121	1.468
U	(FT/SEC)	.051	.914	-1.865	1.862
ALPHA	(DEG)	.003	.561	-1.449	1.748
Q	(DEG/SEC)	-.017	.342	-1.021	.889
DE	(DEG)	-.030	.524	-2.259	2.060
PSI	(DEG)	.007	1.162	-3.525	2.761
BETA	(DEG)	-.217	.931	-2.722	2.382
PHI	(DEG)	-.033	1.014	-2.724	2.081
R	(DEG/SEC)	-.007	.762	-2.520	1.813
P	(DEG/SEC)	.029	.789	-2.358	2.505
DA	(DEG)	.119	1.851	-5.616	7.306
DRAUG	(DEG)	-.000	.000	-.000	.000
DR	(DEG)	-.118	.823	-3.655	2.746
U GUST	(FT/SEC)	-.399	1.702	-4.243	6.422
ALPHA GUST	(DEG)	.037	.446	-.909	1.283
Q GUST	(DEG/SEC)	.008	.350	-.929	1.065
P GUST	(DEG/SEC)	.033	.444	-1.120	1.371
BETA GUST	(DEG)	.122	.515	-1.238	1.699
R GUST	(DEG/SEC)	.013	.371	-1.109	1.151
D	(FT)	-1.347	4.884	-14.554	11.622
H	(FT)	-.949	4.725	-13.846	11.861
LAMBDA	(DEG)	-.210	.781	-1.931	1.316

SVG = 2.09 SWG = 1.81
 THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
171	194	118	164	99	72

THE PILOT RATING IS 2.25

Controls

BOEING 707 FAA SIMULATION 2000 FT 50 DEGREES FLAPS

THE ASSIGNED TASK IS LANDING
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE -3.0 DEGREES

XU = -.040 XA = 19.115 MASS= 5900. SPAN= 130.8 IAS = 233.
 ZU = -.001 ZA = -.597 ZDE = -.030 ALT = 500.
 G = 32.200 MA = -1.003 MDE = -.863 MQ = -.687 MADOT= -.271
 YV = -.095 YDR=.033
 LBETA= -1.628 LDR= .211 LDA = .141 LP = -2.026 LR = .610
 NBETA= .567 NDR= -.382 NDA = .011 NP = -.136 NR = -.248

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010 TQ = .500 TCON = .010 TCON2= .010 TRAUG= 1.000
 KRAUG= .000 KPAUG= 0.000 KARI = 0.000 KQ = 0.000 KQDOT= 0.000
 KAZS = 0.00000 ELX = 25.000 GTHETA= 0.000 GPHI = 0.000

GUST PARAMETERS ARE SU= 2.200 SV= 2.200 SW= 1.600

EXPECTED STANDARD DEVIATIONS ARE

SUG= 2.200 SAG= .393 SQG= .323
 SPG= .428 SBG= .541 SRG= .380

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	-.012	.528	-1.325	1.197
U	(FT/SEC)	.677	1.150	-1.355	3.102
ALPHA	(DEG)	-.042	.427	-1.441	.986
Q	(DEG/SEC)	.006	.272	-.725	.686
DE	(DEG)	.015	.535	-1.809	1.682
PSI	(DEG)	-.382	1.561	-3.561	3.440
BETA	(DEG)	-.258	.983	-2.468	2.178
PHI	(DEG)	.020	1.479	-2.783	3.842
R	(DEG/SEC)	-.006	.835	-2.216	2.150
P	(DEG/SEC)	.013	.885	-2.366	2.675
DA	(DEG)	-.132	2.991	-11.101	7.489
DRAUG	(DEG)	-.000	.000	-.000	.000
DR	(DEG)	-.316	1.158	-3.602	3.545
U GUST	(FT/SEC)	-.501	1.984	-6.929	5.031
ALPHA GUST	(DEG)	.027	.352	-1.010	1.285
Q GUST	(DEG/SEC)	-.003	.326	-.948	1.135
P GUST	(DEG/SEC)	.068	.417	-1.505	1.068
BETA GUST	(DEG)	.109	.640	-1.707	1.924
R GUST	(DEG/SEC)	.006	.413	-1.262	1.295
D	(FT)	1.086	6.150	-12.755	13.825
H	(FT)	.272	6.276	-12.514	14.191
LAMBDA	(DEG)	-.641	1.189	-3.159	2.304
SVG =	2.60	SWG =	1.43		

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
72	237	126	162	134	84

THE PILOT RATING IS 2.27

Controls

BOEING 707 FAA SIMULATION 2000 FT 50 DEGREES FLAPS

THE ASSIGNED TASK IS LANDING
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE -3.0 DEGREES

XU	=	-.040	XA	=	19.115	MASS=	5900.	SPAN=	130.8	IAS =	233.
ZU	=	-.001	ZA	=	-.597	ZDE =	-.030	ALT =	500.	ALPHA=	0.000
G	=	32.200	MA	=	-1.003	MDE =	-.863	MQ =	-.687	MADOT=	-.271
YV	=	-.095	YDR=	.033							
LBETA=	-1.628	LDR=	.211	LDA =	.141	LP =	-2.026	LR =	.610		
NBETA=	.567	NDR=	-.382	NDA =	.011	NP =	-.136	NR =	-.248		

AUGMENTATION SYSTEM PARAMETERS ARE											
TA	=	.010	TQ	=	.500	TCON	=	.010	TCON2=	.010	TRAUG= 1.000
KRAUG=	.000	KPAUG=	0.000	KARI =	0.000	KQ =	0.000	KQDOT=	0.000		
KAZS =	0.00000	ELX =	25.000	GTHETA=	0.000	GPHI =	0.000				

GUST PARAMETERS ARE SU= 2.200 SV = 2.200 SW = 1.600											
EXPECTED STANDARD DEVIATIONS ARE											
SUG=	2.200	SAG=	.393	SQG=	.323						
SPG=	.428	SBG=	.541	SRG=	.380						

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	.177	.543	-.973	1.468
U	(FT/SEC)	-.191	1.141	-1.977	2.316
ALPHA	(DEG)	.195	.510	-.893	1.524
Q	(DEG/SEC)	.003	.313	-.769	1.009
DE	(DEG)	-.145	.695	-2.378	1.881
PSI	(DEG)	-.291	1.096	-3.109	2.377
BETA	(DEG)	-.025	.729	-1.747	1.978
PHI	(DEG)	-.101	1.095	-2.806	2.917
R	(DEG/SEC)	-.008	.566	-1.302	1.365
P	(DEG/SEC)	.003	.597	-2.044	1.445
DA	(DEG)	.177	2.066	-7.712	8.163
DRAUG	(DEG)	-.000	.000	-.000	.000
DR	(DEG)	-.191	.770	-3.206	2.300
U GUST	(FT/SEC)	-.800	2.110	-7.447	4.995
ALPHA GUST	(DEG)	-.066	.378	-1.166	1.051
Q GUST	(DEG/SEC)	.000	.326	-.957	.927
P GUST	(DEG/SEC)	.072	.424	-1.140	1.585
BETA GUST	(DEG)	-.082	.454	-1.365	1.313
R GUST	(DEG/SEC)	.004	.363	-1.303	1.340
D	(FT)	-2.513	7.226	-14.147	12.855
H	(FT)	-2.739	7.065	-14.855	11.773
LAMBDA	(DEG)	-.317	.958	-2.428	1.704

SVG = 1.84 SWG = 1.54
 THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
110	161	82	283	88	86

THE PILOT RATING IS 2.19

Contrails

T-33 ARNOLO GUST MODEL CASE # 1D

THE ASSIGNED TASK IS PITCH

THE PARAMETERS USED IN THIS ANALYSIS WERE

PILOT DELAY .175 SECONDS. DISTRACTION RATE .10

FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU = .007	XA = 22.287	MASS = 425.	SPAN = 37.5	TAS = 488.
ZU = -.000	ZA = -1.590	ZDE = -.091	ALT = 9500.	ALPHA = 0.000
G = 32.200	MA = -6.642	MDE = -14.541	MO = 1.133	MADOT = -2.579
YV = -.128	YDR = .036			
LBETA = -7.420	LDR = 1.390	LDA = 11.700	LP = -1.560	LR = .256
NBETA = 2.600	NDR = -3.210	NDA = .121	NP = -.038	NR = -.204

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010	TQ = .010	TCON = .010	TCON2 = .010	TRAUG = 1.000
KRAUG = 1.000	KPAUG = -.100	KARI = 0.000	KQ = 0.100	KQDOT = 0.000
KAZS = 0.00000	ELX = 6.53E	GTHETA = 0.000	GPHI = 0.100	

GUST PARAMETERS ARE SU= 10.150 SV = 10.150 SW = 10.150

EXPECTED STANDARD DEVIATIONS ARE

SUG= 10.150	SAG= 1.193	SQG= 2.419
SPG= 4.108	SBG= 1.193	SRG= 2.806

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	.028	.548	-1.260	1.428
U	(FT/SEC)	-1.891	1.808	-5.293	1.756
ALPHA	(DEG)	.194	1.223	-3.281	3.998
Q	(DEG/SEC)	-.000	.677	-1.998	2.355
DE	(DEG)	-.006	.160	-.660	.628
PSI	(DEG)	.080	1.349	-3.398	3.072
BETA	(DEG)	-.197	1.509	-4.504	3.481
PHI	(DEG)	-.149	2.940	-8.076	10.389
R	(DEG/SEC)	.018	2.138	-5.650	6.005
P	(DEG/SEC)	-.051	4.643	-12.605	14.641
DA	(DEG)	.045	1.346	-4.991	4.006
DRAUG	(DEG)	.059	1.179	-4.148	2.982
DR	(DEG)	.049	1.566	-4.881	5.676
U GUST	(FT/SEC)	0.000	0.000	0.000	0.000
ALPHA GUST	(DEG)	-.180	1.292	-4.553	3.660
Q GUST	(DEG/SEC)	0.000	0.000	0.000	0.000
P GUST	(DEG/SEC)	-.061	4.233	-12.155	11.859
BETA GUST	(DEG)	.285	.959	-2.649	2.827
R GUST	(DEG/SEC)	.003	2.871	-8.081	9.296
D	(FT)	-66.053	79.426	-203.214	68.916
H	(FT)	-66.053	79.426	-203.214	68.916
LAMBDA	(DEG)	-.117	1.022	-2.804	1.980
SVG =	8.16	SWG = 11.00			

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
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81	499	155	0	0	68
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THE PILOT RATING IS 3.52

Contrails

T-33 ARNOLD GUST MODEL CASE # 2D

THE ASSIGNED TASK IS PITCH
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU = .007	XA = 22.287	MASS= 425.	SPAN= 37.5	IAS = 488.
ZU = -.000	ZA = -1.590	ZDF = -.091	ALT = 9500.	ALPHA= 0.000
G = 32.200	MA = -6.642	MDE = -14.541	MQ = -10.923	MADOT= 5.653
YV = -.128	YDR= .036			
LBETA= -7.420	LDR= 1.390	LDA = 11.700	LP = -1.560	LR = .256
NBETA= 2.600	NDR= -3.210	NDA = .121	NP = -.038	NR = -.204

AUGMENTATION SYSTEM PARAMETERS ARE

IA = .020	TQ = .010	TCON = .010	TCON2= .010	TRAUG= 1.000
KRAUG= 1.000	KPAUG= -.100	KARI = 0.000	KQ = 0.000	KQDOT= 0.000
KAZS = 0.00000	ELX = 6.530	GTHETA= 0.000	GPHT = 0.000	

GUST PARAMETERS ARE SU= 10.150 SV = 10.150 SW = 10.150
 EXPECTED STANDARD DEVIATIONS ARE

SUG= 10.150	SAG= 1.193	SQG= 2.419
SPG= 4.108	SRG= 1.193	SRG= 2.806

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	-.005	.616	-2.237	1.315
U	(FT/SEC)	-.341	1.331	-4.325	2.117
ALPHA	(DEG)	.183	1.182	-2.955	3.960
Q	(DEG/SEC)	-.000	.924	-2.686	3.046
OE	(DEG)	-.001	.229	-.895	.625
Psi	(DEG)	.053	.200	-.436	.538
BETA	(DEG)	-.005	.176	-.645	.380
Phi	(DEG)	.005	.450	-1.360	1.285
R	(DEG/SEC)	.002	.165	-.494	.719
P	(DEG/SEC)	.006	.470	-1.281	1.431
DA	(DEG)	-.002	.184	-.772	.524
DRAUG	(DEG)	-.003	.112	-.414	.238
DR	(DEG)	-.004	.182	-.649	.899
U GUST	(FT/SEC)	0.000	0.000	0.000	0.000
ALPHA GUST	(DEG)	-.180	1.292	-4.554	3.661
Q GUST	(DEG/SEC)	0.000	0.000	0.000	0.000
P GUST	(DEG/SEC)	0.000	0.000	0.000	0.000
BETA GUST	(DEG)	0.000	0.000	0.000	0.000
R GUST	(DEG/SEC)	0.000	0.000	0.000	0.000
D	(FT)	-84.959	92.831	-237.904	61.119
H	(FT)	-84.959	92.831	-237.904	61.119
LAMBDA	(DEG)	.048	.147	-.244	.422

SVG = 0.00 SWG = 11.00
 THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
462	255	30	0	0	68

THE PILOT RATING IS 2.23

Contrails

T-33 ARNOLD GUST MODEL CASE # 3A

THE ASSIGNED TASK IS PITCH

THE PARAMETERS USED IN THIS ANALYSIS WERE

PILOT DELAY .175 SECONDS. DISTRACTION RATE .10

FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU = .107	XA = 22.287	MASS = 425.	SPAN = 37.5	IAS = 488.
ZU = -.000	ZA = -1.590	ZDE = -.091	ALT = 9500.	ALPHA = 0.000
G = 32.200	MA = -6.642	MDE = -14.541	MQ = -54.999	MADOT = 44.367
YV = -.128	YDR = .036			
LBETA= -7.420	LD2= 1.390	LDA = 11.700	LP = -1.560	LR = .256
NBETA= 2.600	NDR= -3.210	NDA = .121	NP = -.038	NR = -.204

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010	TQ = .010	TCON = .010	TCON2= .010	TRAUG= 1.000
KRAUG= 1.000	KPAUG= -.100	KART = 0.000	KQ = 0.000	KDDOT= 0.000
KAZS = 0.00000	ELX = 6.530	GTHETA= 0.000	GPHI = 0.300	

GUST PARAMETERS ARE SU= 10.150 SV = 10.150 SW = 10.150

EXPECTED STANDARD DEVIATIONS ARE

SUG= 10.150	SAG= 1.193	SQG= 2.419
SPG= 4.108	SBG= 1.193	SRG= 2.806

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	-.063	1.039	-3.219	3.166
U	(FT/SEC)	-1.470	3.160	-8.519	3.079
ALPHA	(DEG)	.189	1.251	-3.407	4.351
Q	(DEG/SEC)	-.003	1.788	-5.861	5.248
DE	(DEG)	.006	.280	-1.161	1.187
PSI	(DEG)	.006	1.388	-4.510	3.713
BETA	(DEG)	-.137	1.464	-4.560	3.635
PHI	(DEG)	-.106	2.988	-8.278	11.216
R	(DEG/SEC)	.013	2.115	-8.516	7.240
P	(DEG/SEC)	-.052	4.637	-14.949	15.183
DA	(DEG)	.075	1.307	-5.396	4.104
DRAUG	(DEG)	.097	1.128	-3.989	2.934
DR	(DEG)	.099	1.523	-6.455	5.587
U GUST	(FT/SEC)	0.000	0.000	0.000	0.000
ALPHA GUST	(DEG)	-.180	1.292	-4.553	3.660
Q GUST	(DEG/SEC)	0.000	0.000	0.000	0.000
P GUST	(DEG/SEC)	-.061	4.233	-12.155	11.859
BETA GUST	(DEG)	.285	.959	-2.648	2.826
R GUST	(DEG/SEC)	.003	2.871	-8.081	9.288
D	(FT)	-71.938	78.988	-204.256	26.482
H	(FT)	-71.938	78.988	-204.256	26.482
LAMBDA	(DEG)	-.131	1.031	-2.842	2.155
SVG = 8.16	SWG = 11.00				

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
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162	465	114	0	0	68
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THE PILOT RATING IS 3.67

Contrails

T-33 ARNOLD GUST MODEL CASE # 4A

THE ASSIGNED TASK IS PITCH

THE PARAMETERS USED IN THIS ANALYSIS WERE
PILOT DELAY .175 SECONDS. DISTRACTION RATE .10

FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU = .337	XA = 22.287	MASS= 425.	SPAN= 37.5	IAS = 488.
ZU = -.300	ZA = -1.590	ZDE = -.091	ALT = 9500.	ALPHA= 0.000
G = 32.200	MA = -6.642	MDE = -14.541	MQ = -11.546	MADOT= 10.336
YV = -.128	YDR= .036			
LBETA= -7.420	LDR= 1.390	LOA = 11.700	LP = -1.560	LR = .256
NBETA= 2.600	NDR= -3.210	NDA = .121	NP = -.038	NR = -.204

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010	TQ = .010	TCON = .010	TCON2= .010	TRAUG= 1.000
KRAUG= 1.000	KPAUG= -.100	KART = 0.000	KQ = 0.100	KQDOT= 0.000
KAZS = 0.00000	ELX = 6.530	GTHETA= 0.000	GPHI = 0.000	

GUST PARAMETERS ARE SU= 10.150 SV = 10.150 SW = 10.150

EXPECTED STANDARD DEVIATIONS ARE

SUG= 10.150	SAG= 1.193	SGG= 2.419
SPG= 4.108	SBG= 1.193	SRG= 2.806

/EHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	.012	1.067	-3.390	2.644
U	(FT/SEC)	-1.758	2.538	-7.685	1.601
ALPHA	(DEG)	.194	1.272	-3.449	4.469
Q	(DEG/SEC)	-.003	2.275	-5.867	7.942
DE	(DEG)	-.007	.300	-1.340	1.121
PSI	(DEG)	.088	1.359	-3.225	3.450
BETA	(DEG)	-.197	1.399	-4.290	3.512
PHI	(DEG)	-.123	2.806	-7.915	10.285
R	(DEG/SEC)	.021	2.057	-7.269	5.478
P	(DEG/SEC)	-.041	4.489	-12.702	14.663
DA	(DEG)	.045	1.233	-4.969	3.890
DRAUG	(DEG)	.059	1.067	-3.994	2.639
DR	(DEG)	.050	1.449	-5.427	6.328
U GUST	(FT/SEC)	0.000	0.000	0.000	0.000
ALPHA GUST	(DEG)	-.180	1.292	-4.553	3.660
Q GUST	(DEG/SEC)	0.000	0.000	0.000	0.000
P GUST	(DEG/SEC)	-.061	4.233	-12.155	11.859
BETA GUST	(DEG)	.285	.959	-2.649	2.826
R GUST	(DEG/SEC)	.003	2.871	-8.081	9.296
D	(FT)	-68.878	80.612	-191.327	57.167
H	(FT)	-68.878	80.612	-191.327	57.167
LAMBDA	(DEG)	-.109	.991	-2.853	1.966
SVG =	8.16	SWG =	11.00		

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW GLIDESLOPE	LOCALIZER	NO ACTION
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184	438	116	0	0	68
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THE PILOT RATING IS 3.69

Contrails

T-33 ARNOLD GUST MODEL CASE # 5A

THE ASSIGNED TASK IS PITCH

THE PARAMETERS USED IN THIS ANALYSIS WERE

PILOT DELAY .175 SECONDS. DISTRACTION RATE .10

FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU = .007 XA = 22.287 MASS= 425. SPAN= 37.5 TAS = 488.
 ZU = -.000 ZA = -1.590 ZOE = -.091 ALT = 9500. ALPHA= 0.000
 G = 32.200 MA = -6.642 MDE =-14.541 MQ =-12.181 MADOT= 11.935
 YV = -.128 YDR= .336
 LBETA= -7.420 LDR= 1.390 LDA = 11.700 LP = -1.560 LR = .256
 NBETA= 2.600 NDR= -3.210 NDA = .121 NP = -.038 NR = -.204

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .310 TQ = .010 TCON = .010 TCON2= .010 TRAUG= 1.000
 KRAUG= 1.000 KPAUG= -.100 KARI = 0.000 KQ = 0.100 KQDOT= 0.000
 KAZS = 0.00000 ELX = 6.530 GTHETA= 0.000 GPHI = 0.000

GUST PARAMETERS ARE SU= 10.150 SV = 10.150 SW = 10.150
 EXPECTED STANDARD DEVIATIONS ARE
 SUG= 10.150 SAG= 1.193 SQG= 2.419
 SPG= 4.108 SBG= 1.193 SRG= 2.806

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	-.022	1.208	-3.792	3.022
U	(FT/SEC)	-.638	2.577	-7.268	2.609
ALPHA	(DEG)	.186	1.332	-3.458	4.651
Q	(DEG/SEC)	-.005	3.245	-9.014	10.396
DF	(DEG)	-.004	.349	-1.513	1.251
PSI	(DEG)	.036	1.408	-3.238	3.773
BETA	(DEG)	-.178	1.390	-3.872	4.050
PHI	(DEG)	-.080	2.808	-9.003	8.135
R	(DEG/SEC)	.026	2.027	-5.971	5.566
P	(DEG/SEC)	-.050	4.336	-12.582	11.363
DA	(DEG)	.055	1.197	-3.912	4.386
DRAUG	(DEG)	.072	1.042	-3.545	3.001
DR	(DEG)	.062	1.442	-5.474	6.099
U GUST	(FT/SEC)	0.000	0.000	0.000	0.000
ALPHA GUST	(DEG)	-.180	1.292	-4.553	3.660
Q GUST	(DEG/SEC)	0.000	0.000	0.000	0.000
P GUST	(DEG/SEC)	-.061	4.233	-12.155	11.859
BETA GUST	(DEG)	.285	.959	-2.649	2.827
R GUST	(DEG/SEC)	.003	2.871	-8.081	9.296
D	(FT)	-81.098	85.976	-213.767	47.311
H	(FT)	-81.098	85.976	-213.767	47.311
LAMBDA	(DEG)	-.142	1.022	-2.821	1.964
SVG =	8.16	SWG =	11.00		
THE NUMBER OF DECISIONS ON EACH VARIABLE WAS					
PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
218	416	104	0	0	68
THE PILOT RATING IS 3.91					

Controls

T-33 ARNOLD GUST MODEL CASE # 9

THE ASSIGNED TASK IS PITCH
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU = .007	XA = 22.287	MASS= 425.	SPAN= 37.5	IAS = 488.
ZU = -.000	ZA = -1.590	ZDE = -.091	ALT = 9500.	ALPHA= 0.000
G = 32.200	MA = -6.642	MDE = -14.541	MQ = .850	MADOT= -7.080
YV = -.128	YDR= .036			
LBETA= -7.420	LDR= 1.390	LDA = 11.700	LP = -1.560	LR = .256
NBETA= 2.600	NDR= -3.210	NDA = .121	NP = -.038	NR = -.204

AUGMENTATION SYSTEM PARAMETERS ARE				
TA = .010	TQ = .010	TCON = .010	TCON2= .010	TRAUG= 1.000
KRAUG= 1.000	KPAUG= -.100	KARI = 0.000	KQ = 0.000	KQDOT= 0.000
KAZS = 0.00000	ELX = 6.530	GTHETA= 0.000	GPHI = 0.000	

GUST PARAMETERS ARE SU= 10.150 SV = 10.150 SW = 10.150				
EXPECTED STANDARD DEVIATIONS ARE				
SUG= 10.150	SAG= 1.193	SQG= 2.419		
SPG= 4.108	SBG= 1.193	SRG= 2.806		

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	-.029	.596	-1.233	1.728
U	(FT/SEC)	.818	1.080	-1.804	3.073
ALPHA	(DEG)	.171	1.196	-2.614	3.830
Q	(DEG/SEC)	-.005	.449	-1.405	1.267
DE	(DEG)	.004	.171	-.501	.692
PSI	(DEG)	.012	1.413	-3.445	3.267
BETA	(DEG)	-.167	1.487	-4.275	3.481
PHI	(DEG)	-.181	2.867	-8.076	9.793
R	(DEG/SEC)	.004	2.270	-6.231	5.377
P	(DEG/SEC)	-.057	4.668	-12.616	14.759
DA	(DEG)	.058	1.309	-4.782	4.006
DRAUG	(DEG)	.078	1.134	-3.978	3.052
DR	(DEG)	.077	1.583	-5.326	5.706
U GUST	(FT/SEC)	0.000	0.000	0.000	0.000
ALPHA GUST	(DEG)	-.180	1.292	-4.553	3.660
Q GUST	(DEG/SEC)	0.000	0.000	0.000	0.000
P GUST	(DEG/SEC)	-.061	4.234	-12.155	11.859
BETA GUST	(DEG)	.285	.959	-2.649	2.826
R GUST	(DEG/SEC)	.003	2.871	-8.081	9.296
D	(FT)	-96.140	97.348	-270.400	66.273
H	(FT)	-96.140	97.348	-270.400	66.273
LAMBDA	(DEG)	-.155	.990	-2.745	1.911
SVG = 8.16	SWG = 11.00				
THE NUMBER OF DECISIONS ON EACH VARIABLE WAS					
PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
91	494	150	0	0	68
THE PILOT RATING IS 3.55					

Contrails

T-33 ARNOLD GUST MODEL CASE # 10

THE ASSIGNED TASK IS PITCH

THE PARAMETERS USED IN THIS ANALYSIS WERE

PILOT DELAY .175 SECONDS. DISTRACTION RATE .10

FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU = .007	XA = 22.287	MASS= 425.	SPAN= 37.5	IAS = 488.
ZU = -.000	ZA = -1.590	ZDE = -.091	ALT = 9500.	ALPHA= 0.000
G = 32.200	MA = -6.642	MDE = -14.541	MQ = .850	MADOT= -4.780
YV = -.128	YDR= .036			
LBETA= -7.420	LDR= 1.390	LDA = 11.700	LP = -1.560	LR = .256
NBETA= 2.600	NDR= -3.210	NDA = .121	NP = -.038	NR = -.204

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010	TQ = .010	TCON = .010	TCON2= .010	TRAUG= 1.000
KRAUG= 1.000	KPAUG= -.100	KARI = 0.000	KQ = 0.100	KQDOT= 0.000
KAZS = 0.00000	ELX = 6.530	GTHETA= 0.000	GPHI = 0.300	

GUST PARAMETERS ARE SU= 10.153 SV= 10.150 SW= 10.150

EXPECTED STANDARD DEVIATIONS ARE

SUG= 10.150	SAG= 1.193	SQG= 2.419
SPG= 4.108	SBG= 1.193	SRG= 2.806

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA (DEG)		.117	.420	-.928	1.323
U (FT/SEC)		-1.839	1.393	-4.721	1.285
ALPHA (DEG)		.191	1.186	-2.770	3.893
Q (DEG/SEC)		-.004	.270	-.940	.718
DF (DEG)		-.005	.142	-.506	.390
PSI (DEG)		.056	1.463	-4.446	3.419
BETA (DEG)		-.150	1.600	-3.933	3.766
PHI (DEG)		-.159	3.055	-8.076	8.480
R (DEG/SEC)		.014	2.493	-8.466	6.700
P (DEG/SEC)		-.047	5.105	-12.605	13.272
DA (DEG)		.069	1.392	-4.284	4.016
DRAUG (DEG)		.089	1.212	-3.518	2.982
DR (DEG)		.087	1.664	-6.115	6.054
U GUST (FT/SEC)		0.000	0.000	0.000	0.000
ALPHA GUST (DEG)		-.180	1.292	-4.553	3.660
Q GUST (DEG/SEC)		0.000	0.000	0.000	0.000
P GUST (DEG/SEC)		-.061	4.233	-12.155	11.859
BETA GUST (DEG)		.285	.959	-2.649	2.826
R GUST (DEG/SEC)		.003	2.871	-8.081	9.296
D (FT)		-68.444	92.647	-237.720	103.157
H (FT)		-68.444	92.647	-237.720	103.167
LAMBDA (DEG)		-.095	1.018	-2.920	2.091
SVG = 8.15	SWG = 11.00				

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW GLIDESLOPE LOCALIZER NO ACTION
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43	536	157	0	0	68
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THE PILOT RATING IS 3.85

Controls

T-33 ARNOLD GUST MODEL CASE # 11

THE ASSIGNED TASK IS PITCH

THE PARAMETERS USED IN THIS ANALYSIS WERE

PILOT DELAY .175 SECONDS. DISTRACTION RATE .10

FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE 0.0 DEGREES

XU = .007	XA = 22.287	MASS= 425.	SPAN= 37.5	IAS = 488.
ZU = -.006	ZA = -1.590	ZDE = -.091	ALT = 9500.	ALPHA= 0.000
G = 32.200	MA = -6.642	MDE =-14.541	MQ = -2.672	MADOT= -2.998
YV = -.128	YDR= .036			
LBETA= -7.420	LDR= 1.390	LDA = 11.700	LP = -1.560	LR = .256
NBETA= 2.600	NDR= -3.210	NDA = .121	NP = -.038	NR = -.204

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010	TQ = .010	TCON = .010	TCON2= .010	TRAUG= 1.000
KRAUG= 1.000	KPAUG= -.100	KARI = 0.000	KQ = 0.000	KQDOT= 0.000
KAZS = 0.00000	ELX = 6.530	GTHETA= 0.000	GPHI = 0.100	

GUST PARAMETERS ARE SU= 10.150 SJ = 10.150 SW = 10.150

EXPECTED STANDARD DEVIATIONS ARE

SUG= 10.150	SAG= 1.193	SQG= 2.419
SPG= 4.108	SBG= 1.193	SRG= 2.806

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA (DEG)		-.002	.322	-.698	.614
U (FT/SEC)		-2.312	1.701	-5.193	1.148
ALPHA (DEG)		.194	1.187	-2.945	3.852
Q (DEG/SEC)		-.004	.235	-.725	.752
DE (DEG)		-.006	.135	-.426	.387
PSI (DEG)		.142	1.482	-3.087	3.236
BETA (DEG)		-.181	1.579	-4.275	3.876
PHI (DEG)		-.169	2.917	-8.076	9.793
R (DEG/SEC)		.028	2.405	-6.592	5.910
P (DEG/SEC)		-.041	4.605	-12.605	14.759
DA (DEG)		.056	1.336	-4.782	4.006
DRAUG (DEG)		.070	1.187	-3.978	2.982
DR (DEG)		.058	1.661	-5.008	5.864
U GUST (FT/SEC)		0.000	0.000	0.000	0.000
ALPHA GUST (DEG)		-.180	1.292	-4.553	3.660
Q GUST (DEG/SEC)		0.000	0.000	0.000	0.000
P GUST (DEG/SEC)		-.061	4.233	-12.155	11.859
BETA GUST (DEG)		.285	.959	-2.649	2.826
R GUST (DEG/SEC)		.003	2.871	-8.081	9.296
D (FT)		-64.232	87.311	-209.063	91.282
H (FT)		-64.232	87.311	-209.063	91.282
LAMBDA (DEG)		-.039	1.032	-2.745	2.151
SVG = 8.16	SWG = 11.00				

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
34	533	170	0	0	68

THE PILOT RATING IS 3.55

Contrails

F-4B BODY AXIS WITH FC8-H1 CONTROL SYSTEM

THE ASSIGNED TASK IS LANDING
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE -3.0 DEGREES

XU = -.071	XA = 6.700	MASS= 1031.	SPAN= 38.7	IAS = 226.
ZU = -.001	ZA = -.373	ZDE = -.041	ALT = 500.	ALPHA= 14.700
G = 32.200	MA = -1.962	MDE = -1.702	MQ = -.285	MADOT= -.134
YV = -.086	YDR= .017			
LBETA= -6.940	LDR= -.470	LOA = 2.567	LP = -1.095	LR = .846
NBETA= 2.228	NDR= -.773	NDA = -.058	NP = -.022	NR = -.252

AUGMENTATION SYSTEM PARAMETERS ARE					
TA = .020	TQ = 1.000	TCON = .010	TCON2= .010	TRAUG= 2.000	
KRAUG= 4.000	KPAUG= -.400	KARI = 0.000	KQ = 0.000	KQDOT= .650	
KAZS = 0.00000	ELX = 17.800	GTHETA= 0.000	GPHI = -.500		

GUST PARAMETERS ARE SU= 10.432 SV = 10.432 SW = 6.876					
EXPECTED STANDARD DEVIATIONS ARE					
SUG= 10.432	SAG= 1.743	SQG= 2.890			
SPG= 4.142	SBG= 2.645	SRG= 3.477			

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	1.116	2.342	-3.976	7.292
U	(FT/SEC)	-.666	3.598	-8.944	7.113
ALPHA	(DEG)	1.181	2.727	-4.360	8.168
Q	(DEG/SEC)	.052	2.433	-7.926	8.870
DE	(DEG)	-1.385	4.217	-14.716	9.107
PSI	(DEG)	.314	3.748	-7.139	11.924
BETA	(DEG)	-.803	2.598	-8.332	4.605
PHI	(DEG)	-.206	5.635	-16.156	18.749
R	(DEG/SEC)	.025	2.833	-6.914	8.738
P	(DEG/SEC)	-.096	6.425	-17.332	20.488
DA	(DEG)	.226	6.757	-26.444	23.514
DRAUG	(DEG)	.125	4.018	-11.367	11.618
DR	(DEG)	.200	5.621	-22.571	18.632
U GUST	(FT/SEC)	-5.359	8.543	-25.861	21.166
ALPHA GUST	(DEG)	.010	1.792	-4.858	4.053
Q GUST	(DEG/SEC)	.003	2.955	-10.412	11.158
P GUST	(DEG/SEC)	.052	4.176	-11.651	12.830
BETA GUST	(DEG)	.856	2.272	-4.837	9.257
R GUST	(DEG/SEC)	-.020	3.584	-10.356	9.403
D	(FT)	-13.632	18.254	-56.535	30.591
H	(FT)	-15.143	16.555	-51.293	21.333
LAMBDA	(DEG)	-.499	2.557	-7.881	5.185
SVG = 8.96	SWG = 7.07				
THE NUMBER OF DECISIONS ON EACH VARIABLE WAS					
PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
142	269	62	200	41	90
THE PILOT RATING IS 4.92					

Contrails

RPV-500 FT, GEAR DWN, STAB 45 DEG, ALL FAIL MODE, STAB AXIS

THE ASSIGNED TASK IS LANDING

THE PARAMETERS USED IN THIS ANALYSIS WERE

PILOT DELAY .175 SECONDS. DISTRACTION RATE .10

FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE -3.0 DEGREES

XU = -.058	XA = 10.917	MASS= 177.	SPAN= 81.2	IAS = 169.
ZU = -.002	ZA = -2.451	ZDE = -.088	ALT = 500.	ALPHA= 0.000
G = 32.200	MA = -2.697	MDE = -4.642	MQ = -1.232	MADOT= -.292
YV = -.156	YDR= .041			
LBETA= -2.174	LDR= .030	LOA = 3.364	LP = -10.620	LR = .096
NBETA= 1.379	NDR= -.940	NDA = -.166	NP = -1.204	NR = -.274

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010	TQ = .010	TCON = .010	TCON2= .010	TRAUG= .010
KRAUG= .000	KPAUG= 0.000	KARI = 0.000	KQ = 0.000	KQDOT= 0.000
KAZS = 0.00000	ELX = 0.000	GTHETA= 0.000	GPHI = 0.000	

GUST PARAMETERS ARE SU= 10.432 SV = 10.432 SW = 6.876

EXPECTED STANDARD DEVIATIONS ARE

SUG= 10.432	SAG= 2.331	SQG= 1.876
SPG= 2.526	SBG= 3.537	SRG= 2.347

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	.050	4.073	-11.246	12.880
U	(FT/SEC)	6.129	5.046	-4.230	14.791
ALPHA	(DEG)	-.012	3.547	-11.208	9.385
Q	(DEG/SEC)	.001	8.804	-28.504	24.705
DE	(DEG)	.001	6.509	-15.997	15.997
PSI	(DEG)	1.585	4.505	-10.992	13.779
BETA	(DEG)	-1.300	5.444	-14.761	11.568
PHI	(DEG)	.405	4.057	-8.998	8.987
R'	(DEG/SEC)	.146	4.508	-11.174	11.222
P	(DEG/SEC)	-.068	2.599	-8.355	7.490
DA	(DEG)	-.086	4.585	-15.188	15.997
DRAUG	(DEG)	.000	.000	-.000	.000
DR	(DEG)	.043	8.442	-15.997	15.997
U GUST	(FT/SEC)	-6.191	7.921	-23.689	17.670
ALPHA GUST	(DEG)	.017	2.380	-6.427	5.177
Q GUST	(DEG/SEC)	-.009	1.920	-6.143	5.718
P GUST	(DEG/SEC)	.042	2.612	-7.493	7.599
BETA GUST	(DEG)	1.290	3.070	-5.914	12.391
R GUST	(DEG/SEC)	-.045	2.279	-6.683	5.979
D	(FT)	11.882	13.913	-28.200	40.904
H	(FT)	-.672	10.093	-31.239	23.317
LAMBDA	(DEG)	.285	5.548	-11.183	12.852

SVG = 9.06 SWG = 7.02

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW GLIDESLOPE LOCALIZER NO ACTION
230	138	80 101 166 90

THE PILOT RATING IS 6.64

Contrails

DC-8-60 (AFFOL-TR- 70-102)

THE ASSIGNED TASK IS LANDING

THE PARAMETERS USED IN THIS ANALYSIS WERE

PILOT DELAY .175 SECONDS. DISTRACTION RATE .10

FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE -3.0 DEGREES

XU	=	-.037	XA	=	31.008	MASS=	5580.	SPAN=	142.4	IAS =	228.
ZU	=	-.001	ZA	=	-.750	ZDE =	-.041	ALT =	500.	ALPHA=	0.000
G	=	32.200	MA	=	-1.051	MDE =	-.923	MQ =	-.594	MADOT=	-.194
YV	=	-.089	YDR=	.031							
LBETA	=	-1.400	LDR=	.159	LOA =	1.130	LP =	-1.040	LR =	.474	
NBETA	=	.368	NDR=	-.368	NDA =	0.000	NP =	-.029	NR =	-.257	

AUGMENTATION SYSTEM PARAMETERS ARE

TA	=	.010	TQ	=	.010	TCON =	.010	TCON2=	.010	TRAUG=	.010
KRAUG	=	.000	KPAUG=	-.200	KARI =	0.000	KQ =	0.000	KQDOT=	0.000	
KAZS	=	0.00000	ELX =	25.200	GTHETA=	0.000	GPHI =	-.240			

GUST PARAMETERS ARE SU= 10.000 SV = 10.000 SW = 6.000

EXPECTED STANDARD DEVIATIONS ARE

SUG=	10.000	SAG=	1.508	SQG=	1.144
SPG=	1.516	SBG=	2.513	SRG=	1.648

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	.076	2.012	-3.681	5.004
U	(FT/SEC)	4.631	3.740	-2.484	12.999
ALPHA	(DEG)	.040	2.031	-4.893	5.315
Q	(DEG/SEC)	.010	1.234	-2.497	3.716
DE	(DEG)	-.057	1.991	-6.819	7.856
PSI	(DEG)	.580	3.380	-6.975	8.794
BETA	(DEG)	-.826	3.755	-10.766	6.936
PHI	(DEG)	-.118	5.281	-13.424	13.069
R	(DEG/SEC)	.067	2.051	-5.453	4.478
P	(DEG/SEC)	-.008	3.967	-8.877	9.175
DA	(DEG)	-.020	2.663	-8.070	8.079
DRAUG	(DEG)	-.000	.000	-.000	.000
DR	(DEG)	.064	1.907	-7.847	10.342
U GUST	(FT/SEC)	-5.125	8.207	-24.857	20.370
ALPHA GUST	(DEG)	.009	1.550	-4.199	3.513
Q GUST	(DEG/SEC)	-.005	1.172	-3.690	3.392
P GUST	(DEG/SEC)	.023	1.570	-4.512	4.366
BETA GUST	(DEG)	.809	2.160	-4.601	8.791
R GUST	(DEG/SEC)	-.032	1.583	-4.754	4.254
D	(FT)	6.681	24.258	-42.043	66.051
H	(FT)	-3.845	20.860	-45.073	53.595
LAMBDA	(DEG)	-.246	1.844	-5.418	2.913

SVG = 8.60 SWG = 6.17

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
139	285	54	204	30	90

THE PILOT RATING IS 3.20

Controls

DC-8-60 (AFFDL-TR- 70-102)

THE ASSIGNED TASK IS LANDING

THE PARAMETERS USED IN THIS ANALYSIS WERE

PILOT DELAY .175 SECONDS. DISTRACTION RATE .10

FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE -3.0 DEGREES

XU = -.037	XA = 31.008	MASS= 5580.	SPAN= 142.4	IAS = 228.
ZU = -.001	ZA = -.750	ZDE = -.041	ALT = 500.	ALPHA= 0.000
G = 32.200	MA = -1.051	MDE = -.923	MQ = -.594	MADOT= -.194
YV = -.089	YDR= .031			
LBETA= -1.400	LDR= .159	LDA = 1.130	LP = -1.040	LR = .474
NBETA= .368	NDR= -.368	NOA = 0.000	NP = -.029	NR = -.257

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010	TQ = .010	TCON = .010	TCON2= .010	TRAUG= .010
KRAUG= .000	KPAUG= -.200	KARI = 0.000	KQ = 0.300	KQDOT= 0.000
KAZS = 0.00000	FLX = 25.200	GTHETA= 0.000	GPHT = -.240	

GUST PARAMETERS ARE SU= 5.216 SV = 5.216 SW = 3.438
EXPECTED STANDARD DEVIATIONS ARE

SUG= 5.216	SAG= .864	SQG= .655
SPG= .869	SBG= 1.311	SRG= .859

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	.027	1.103	-1.952	2.655
U	(FT/SEC)	2.487	1.970	-1.238	7.006
ALPHA	(DEG)	.014	1.152	-2.777	2.890
Q	(DEG/SEC)	.007	.705	-1.616	2.140
DE	(DEG)	-.025	1.054	-3.672	4.235
PSI	(DEG)	.306	1.773	-3.877	4.598
BETA	(DEG)	-.424	1.977	-5.580	3.649
PHI	(DEG)	-.056	2.813	-7.356	7.043
R	(DEG/SEC)	.035	1.070	-2.729	2.357
P	(DEG/SEC)	-.008	2.115	-4.663	4.883
DA	(DEG)	-.006	1.423	-4.592	4.540
DRAUG	(DEG)	-.000	.000	-.000	.000
DR	(DEG)	.032	.991	-4.264	5.442
U GUST	(FT/SEC)	-2.672	4.279	-12.966	10.617
ALPHA GUST	(DEG)	.005	.888	-2.406	2.013
Q GUST	(DEG/SEC)	-.003	.672	-2.115	1.944
P GUST	(DEG/SEC)	.013	.899	-2.586	2.501
BETA GUST	(DEG)	.422	1.126	-2.400	4.585
R GUST	(DEG/SEC)	-.017	.826	-2.479	2.218
D	(FT)	3.525	12.502	-21.792	34.518
H	(FT)	-2.050	10.721	-23.395	28.014
LAMBDA	(DEG)	-.119	1.053	-3.057	1.650

SVG = 4.48 SWG = 3.54

THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
146	284	49	204	32	90

THE PILOT RATING IS 2.54

Contrails

DC-8-60 (AFFOL-TR- 70-102)

THE ASSIGNED TASK IS LANDING
 THE PARAMETERS USED IN THIS ANALYSIS WERE
 PILOT DELAY .175 SECONDS. DISTRACTION RATE .10
 FLIGHT TIME 100.0 SECONDS. FLIGHT PATH ANGLE -3.0 DEGREES

XU = -.037	XA = 31.008	MASS= 5580.	SPAN= 142.4	IAS = 228.
ZU = -.001	ZA = -.750	ZDE = -.041	ALT = 500.	ALPHA= 0.000
G = 32.200	MA = -1.051	MDE = -.923	MQ = -.594	MADOT= -.194
YV = -.089	YDR= .031			
LBETA= -1.400	LDR= .159	LDA = 1.130	LP = -1.040	LR = .474
NBETA= .368	NDR= -.368	NDA = 0.000	NP = -.029	NR = -.257

AUGMENTATION SYSTEM PARAMETERS ARE

TA = .010	TQ = .010	TCON = .010	TCON2= .010	TRAUG= .010
KRAUG= .000	KPAUG= -.200	KARI = 0.000	KQ = 0.000	KQDOT= 0.000
KAZS = 0.00000	ELX = 25.200	GTHETA= 0.000	GPHI = -.240	

GUST PARAMETERS ARE SU= 5.000 SV = 5.000 SW = 3.000
 EXPECTED STANDARD DEVIATIONS ARE

SUG= 5.000	SAG= .754	SQG= .572
SPG= .758	SBG= 1.256	SRG= .824

VEHICLE IS UNDER PILOT CONTROL

VARIABLE	UNITS	MEAN	STD DEV	MINIMUM	MAXIMUM
THETA	(DEG)	.039	.992	-2.095	2.570
U	(FT/SEC)	2.330	1.823	-1.129	6.302
ALPHA	(DEG)	.020	1.016	-2.478	2.736
Q	(DEG/SEC)	.006	.622	-1.322	1.622
DE	(DEG)	-.029	.995	-3.555	4.099
PSI	(DEG)	.359	1.707	-3.354	4.523
BETA	(DEG)	-.411	1.872	-5.342	3.385
PHI	(DEG)	-.051	2.617	-6.990	6.464
R	(DEG/SEC)	.029	1.033	-2.646	2.312
P	(DEG/SEC)	-.005	1.972	-4.174	4.643
DA	(DEG)	-.013	1.330	-3.964	4.137
DRAUG	(DEG)	-.000	.000	-.000	.000
DR	(DEG)	.036	.957	-3.983	5.085
U GUST	(FT/SEC)	-2.562	4.102	-12.429	10.176
ALPHA GUST	(DEG)	.004	.775	-2.099	1.757
Q GUST	(DEG/SEC)	-.003	.586	-1.845	1.696
P GUST	(DEG/SEC)	.012	.785	-2.256	2.183
BETA GUST	(DEG)	.404	1.080	-2.301	4.395
R GUST	(DEG/SEC)	-.016	.791	-2.376	2.126
D	(FT)	3.264	11.801	-20.894	32.757
H	(FT)	-1.994	10.150	-22.400	26.576
LAMBDA	(DEG)	-.053	.894	-2.577	1.523

SVG = 4.30 SWG = 3.08
 THE NUMBER OF DECISIONS ON EACH VARIABLE WAS

PITCH	ROLL	YAW	GLIDESLOPE	LOCALIZER	NO ACTION
145	293	57	194	26	90

THE PILOT RATING IS 2.51

Contracts