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NOTATION

a	speed of sound in air (ft/sec)
VSOM	speed of sound in air (m/sec)
ax	longitudinal acceleration along the x-body axis at the center of gravity. (ft/sec2)
ay	lateral acceleration along the y-body axis at the center of gravity. (ft/sec2)
az	normal acceleration along the z-body axis at the center of gravity. (ft/sec2)
b	reference wing span. (ft)
MAC	meam aerodynamic chord. (ft)
grav	acceleration due to gravity. (ft/sec2)
hft	altitude. (ft)
h	altitude. (m)
hftp , $\dot{h}$	derivative of altitude relative to time. (ft/sec)
IX	moment of inertia referred to x-body axis. (slug-ft2)
IY	moment of inertia referred to y-body axis. (slug-ft2)
IZ	moment of inertia referred to z-body axis. (slug-ft2)
IXZ	product of inertia referred to x and z body axis. (slug-ft2)
LTH	perpendicular distance from c.g. to thrust line. (ft)
mass	mass of the aircraft. (slugs)
MACH	mach number.

P roll rate, angular velocity about x-body-axis (rad/sec)

Q pitch rate, angular velocity about y-body-axis (rad/sec)

R yaw rate, angular velocity about z-body-zxis (rad/sec)

U linear perturbed velocity along the x-body-axis (ft/sec)

V linear perturbed velocity along the y-body-axis (ft/sec)

W linear perturbed velocity along the z-body-zxis (ft/sec)

U0 linear steady-state velocity along the x-body-axis (ft/sec)

V0 linear steady-state velocity along the y-body-axis (ft/sec)

W0 linear steady-state velocity along the z-body-axis (ft/sec)

UT total linear velocity along the x-body-axis (ft/sec)

VT total linear velocity along the y-body-axis (ft/sec)

WT total linear velocity along the z-body-axis (ft/sec)

U1 total linear velocity of the aircraft. (ft/sec)

VT0 total linear steady-state velocity. (ft/sec)

S reference wing area. (ft 2)

Weight		weight of the aircraft. (lb)
ALFA	, α	perturbed angle of attack. (rad)
ALFAG		perturbed angle of attack. (deg)
ALFA0	, α_0	trim angle of attack. (rad)
ALFA0G		trim angle of attack. (deg)
ALFAT	, α_T	total angle of attack. (rad)
ALFATG		total angle of attack. (deg)
BETA	, β	perturbed sideslip angle. (rad)
BETAG		perturbed sideslip angle. (deg)
BETA0	, β_0	steady-state sideslip angle (rad)
BETA0G		steady-state sideslip angle (deg)
BETAT	, β_T	total sideslip angle (rad)
BETATG		total sideslip angle (deg)
GAMA0	, γ_0	steady-state flight path angle (rad)
GAMA0G		steady state flight path angle (deg)
GAMA	, γ	perturbed flight path angle (rad)
GAMAG		pertirbed flight path angle (deg)
GAMAT	, γ_T	total flight path angle (rad)
GAMATG		total flight path angle (deg)
TETA0	, θ_0	steady state pitch atitude (rad)
TETA0G		steady state pitch atitude (deg)
TETA	, θ	perturbed pitch angle (rad)
TETAG		perturbed pitch angle (deg)
TETAT	, θ_T	total pitch angle (rad)
TETATG		total pitch angle (deg)

FI , ϕ	perturbed bank angle (rad)
FIG	perturbed bank angle (deg)
PSI, ψ	perturbed yaw angle (rad)
PSIG	perturbed yaw angle (deg)
$\dot{P}$, PP	angular acceleration about x-body-axis (rad/sec2)
PPG	angular acceleration about x-body-axis (deg/sec2)
$\dot{Q}$, QP	angular acceleration about y-body-axis (rad/sec2)
QPG	angular acceleration about y-body-axis (deg/sec2)
$\dot{R}$, RP	angular acceleration about z-body-axis (rad/sec2)
RPG	angular acceleration about z-body-axis (deg/sec2)
$\dot{U}$, UP	linear acceleration along x-body-axis (ft/sec2)
$\dot{V}$, VP	linear acceleration along y-body-axis (ft/sec2)
$\dot{W}$, WP	linear acceleration along z-body-axis (ft/sec2)
$\dot{\alpha}$, ALFAP	derivative of angle of attack relative to time (rad/sec)
ALFAPG	derivative of angle of attack relative to time (deg/sec)
$\dot{\beta}$, BETAP	derivative of sideslip angle relative to time (rad/sec)

BETAPG	derivative of sideslip angle relative to time (deg/sec)
DR , dr	rudder deflection (rad)
DRG	rudder deflection (deg)
DA , da	deflection of aileron (rad)
DAG	deflection of aileron (deg)
DE , de	deflection of elevator (rad)
DEG	deflection of elevator (deg)
ROSL	mass density of air at sea level (Kg/m3)
ROSI	mass density of air (Kg/m3)
RO , ρ	mass density of air (slug/ft3)
ITH	inclination of thrust line relative to FRL (rad)
ITHG	inclination of thrust line relative to FRL (deg)
KSI	ALFA0 + ITH
XE	aircraft displacement along x-earth axis (ft)
YE	aircraft displacement along y-earth axis (ft)
ZE	aircraft displacement along z-earth axis (ft)
$\dot{XE}$, XEP	aircraft linear velocity relative to x-earth-axis (ft/sec)
$\dot{YE}$, YEP	aircraft linear velocity relative to y-earth-axis (ft/sec)
$\dot{ZE}$, ZEP	aircraft linear velocity relative to z-earth axis (ft/sec)
LT14	distance betwen 25% of meam aerodynamic chord of wing and 25% meam aerodynamic chord of horizontal empenage. (ft)
NX	load factor along x-body-axis (g)
NY	load factor along y-body-axis (g)
NZ	load factor along z-body-axis (g)

NLF	NLF = - NZ
HFTO	initial altitude (ft)
HO	initial altitude (m)
XEI	initial position of the aircraft relative to x-earth-axis (ft)
YEI	initial position of the aircraft relative to y-earth-axis (ft)
ZEI	initial position of the aircraft relative to z-earth-axis (ft)
XO	steady-state X force in x-body-axis (lb)
YO	steady-state Y force in y-body-axis (lb)
ZO	steady-state Z force in z-body-axis (lb)
UI	initial perturbed velocity along x-body-axis (ft/sec)
VI	initial perturbed velocity along y-body-axis (ft/sec)
WI	initial perturbed velocity along z-body-axis (ft/sec)
PI	initial perturbed roll rate about x-body-axis (rad/sec)
QI	initial perturbed pitch rate about y-body-axis (rad/sec)
RI	initial perturbed yaw rate about z-body-axis (rad/sec)

FII	initial perturbed bank angle about x-body-axis (rad)
PSII	initial perturbed yaw angle about z-body-axis (rad)
TETAI	initial perturbed pitch angle about y-body-axis (rad)
FIP , $\dot{\phi}$	derivative of perturbed bank angle relative to time . (rad/sec)
FIPG	derivative of perturbed bank angle relative to time . (deg/sec)
PSIP , $\dot{\psi}$	derivative of perturbed yaw angle relative to time . (rad/sec)
PSIPG	derivative of perturbed yaw angle relative to time. (deg/sec)
ss	speed of sound in air (ft/sec)
ALFTR	trim angle of attack (deg)
FRL	fuselage reference line
c.g.	center of gravity
DAZ	delta of normal aceleration due to a maneuver

AERODYNAMIC COEFICIENTS AND DERIVATIVES IN STABILITY AXIS

CL	Lift coeficient
CD	Drag coeficient
CM	Pitch moment coeficient
CLDE	derivative of lift coeficient relative to elevator deflection
CMDE	derivative of pitch moment coeficient relative to elevator deflection
CLM	derivative of lift coeficient relative to mach number
CDM	derivative of drag coeficient relative to mach number
CMM	derivative of pitch moment coeficient relative to mach number
CMA	derivative of pitch moment coeficient relative to angle of attack
CMAP	derivative of pitch moment coeficient relative to angle of attack rate
CMQ	derivative of pitch moment coeficient relative to pitch rate
CLA	derivative of lift coeficient relative to angle of attack

CY	lateral force coeficient
CN	yaw moment coeficient
CR	roll moment coeficient
CYB	derivative of lateral force coeficient relative to sideslip angle
CNB	derivative of yaw moment coeficient relative to sideslip angle
CRB	derivative of roll moment coeficient relative to sideslip angle
CRP	derivative of roll moment coeficient relative to roll rate
CNP	derivative of yaw moment coeficient relative to roll rate
CRR	derivative of roll moment coeficient relative to yaw rate
CNR	derivative of yaw moment coeficient relative to yaw rate
CRDA	derivative of roll moment coeficient relative to aileron deflection
CNDA	derivative of yaw moment coeficient relative to aileron deflection

CYDR derivative of lateral force coeficient relative to rudder deflection

CNDR derivative of yaw moment coeficient relative to rudder deflection

CRDR derivative of roll moment coeficient relative to rudder deflection

AERODYNAMIC COEFICIENTS AND DERIVATIVES IN BODY-AXIS

CN	Normal force coeficient
CX	Axial force coeficient
CNA	derivative of normal force coeficient relative to angle of attack
CNAP	derivative of normal force coeficient relative to angle of attack rate
CNQ	derivative of normal force coeficient relative to pitch rate
CNM	derivative of normal force coefficient relative to mach number
CNDE	derivative of normal force coefficient relative to elevator deflection
CXA	derivative of axial force coefficient relative to angle of attack
CXAP	derivative of axial force coefficient relative to angle of attack rate
CXQ	derivative of axial force coefficient relative to pitch rate
CXM	derivative of axial force coefficient relative to mach number
CXDE	derivative of axial force coefficient relative to elevator deflection

CRBB	derivative of roll moment coeficient relative to sideslip angle
CRPB	derivative of roll moment coeficient relative to roll rate
CRRB	derivative of roll moment coeficient relative to yaw rate
CRDAB	derivative of roll moment coeficient relative to aileron deflection
CRDRB	derivative of roll moment coeficient relative to rudder deflection
CNBB	derivative of yaw moment coefficient relative to sideslip angle
CNPB	derivative of yaw moment coefficient relative to roll rate
CNRB	derivative of yaw moment coefficient relative to yaw rate
CNDAB	derivative of yaw moment coefficient relative to aileron deflection
CNDRB	derivative of yaw moment coefficient relative to rudder deflection

1. INTRODUCTION

This report describes a computer simulation model of the Boeing B-747 aircraft which is intended for use as a general purpose tool for research into advanced flight control systems for civil aircraft. The previously published model reference [1] , has been adapted with little change and implemented in the Advanced Continuous Simulation Language (ACSL), for use on an appropriate personal computer. Three distinct computer models of the aircraft have been produced, a decoupled linear longitudinal model , a decoupled linear lateral-directional model and a fully coupled non-linear model. All of the aerodynamic data used in the models was obtained from reference [1] since this was considered to be the most convenient starting point. It should be noted that standard imperial units are used throughout.

2. THE DECOUPLED LINEAR LONGITUDINAL MODEL

2.1 Equations of motion

The small perturbation equations of motion for the linear longitudinal model were obtained directly from appendix C of reference [1] as follows ,

$$\begin{bmatrix} (1-X_{\dot{u}})s-X_u^* & -X_{\dot{w}}s-X_w & (-X_q+W_0)s+g*\cos\theta_0 \\ -Z_{\dot{u}}s-Z_u^* & (1-Z\ )s-Z & (-Z\ -U\ )s+g*\sin\theta_0 \\ -M_{\dot{u}}s-M_u^* & -(M_{\dot{w}}s+M_w) & s^2-M_q s \end{bmatrix} \begin{bmatrix} u \\ w \\ \theta \end{bmatrix} = \begin{bmatrix} X_{\delta_E} \\ Z_{\delta_E} \\ M_{\delta_E} \end{bmatrix} \delta_E$$

(1)

$$q = s\theta \qquad (2)$$

where s is the Laplace operator. The equivalent time domain equations may be expressed in state space form as follows ,

$$\begin{bmatrix} \dot{u} \\ \dot{w} \\ \dot{q} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} a11 & a12 & a13 & a14 \\ a21 & a22 & a23 & a24 \\ a31 & a32 & a33 & a34 \\ a41 & a42 & a43 & a44 \end{bmatrix} \begin{bmatrix} u \\ w \\ q \\ \theta \end{bmatrix} + \begin{bmatrix} b11 \\ b21 \\ b31 \\ b41 \end{bmatrix} de$$

(3)

These are the linearised longitudinal equations of motion with constant coefficients referred to a generalized body-axis system in the model.

2.2 Aerodynamic coefficients

The constant coefficients in equations (3) are defined in terms of aerodynamic , thrust and control derivatives as follows ,

a11 = XUST

a12 = XW

a13 = XQ - W0

a14 = - grav * cos(θ_0)

a21 = ZUST / (1 - ZWP)

a22 = ZW / (1 - ZWP)

a23 = (ZQ + U0) / (1 - ZWP)

a24 = - grav * sin(θ_0) / (1 - ZWP)

a31 = MUST + (MWP * ZUST) / (1 - ZWP)

a32 = MW + (ZW * MWP) / (1 - ZWP)

a33 = MQ + MWP * (ZQ + U0) / (1 - ZWP)

a34 = -MWP * grav * sin(θ_0) / (1 - ZWP)

a41 = 0.0

a42 = 0.0

a43 = 1.0

a44 = 0.0

b11 = XDE

b21 = ZDE / (1 - ZWP)

b31 = MDE + (MWP * ZDE) / (1 - ZWP)

b41 = 0.0

The aerodynamic stability and control derivatives are referred to stability axes in reference [1] and were transformed to body axes using the transformation relations given in appendix B of reference [1].

2.3 Auxiliary equations

The auxiliary equations required to complete the longitudinal computer model are as follows :

$$
\begin{aligned}
ax &= \dot{u} + WT * q + grav * \sin(\theta_T) \\
az &= \dot{w} - UT * q - grav * \cos(\theta_T) \\
\dot{xe} &= UT * \cos(\theta_T) + WT * \sin(\theta_T) \\
\dot{ze} &= -UT * \sin(\theta_T) + WT * \cos(\theta_T) \\
\dot{h} &= UT * \sin(\theta_T) - WT * \cos(\theta_T) \\
UT &= U0 + U \\
WT &= W0 + W \\
\theta_T &= \theta_0 + \theta \qquad\qquad (4) \\
\alpha_T &= \mathrm{arctg}(WT / UT) \\
\alpha &= \alpha_T - \alpha_0 \\
U1 &= \sqrt{UT * UT + WT * WT} \\
\dot{\alpha} &= \dot{W} / UT \\
\gamma_T &= \theta_T - \alpha_T \\
\gamma &= \gamma_T - \gamma_0
\end{aligned}
$$

2.4 Computer simulation

The equations (3) and (4) were coded in the ACSL language and a full listing is contained in appendix 2. The simulation was tested by obtaining the longitudinal response transfer functions ,

$$\frac{\theta(s)}{de(s)}, \quad \frac{U(s)}{de(s)}, \quad \frac{W(s)}{de(s)}, \quad \frac{sH(s)}{de(s)}, \text{ and } \frac{AZ(s)}{de(s)}$$

These were then compared with those in reference [1] and were found to be in good agreement.

3. THE DECOUPLED LINEAR LATERAL-DIRECTIONAL MODEL

3.1 Equations of motion

Again the small perturbation equations of motion for the linear lateral directional model were obtained directly from reference [1] as follows ,

$$\begin{bmatrix} s - Y_v & -\dfrac{(W_0 s + g*\cos\theta_0)}{V_{T_0}} & \dfrac{U_0 s - g*\sin\theta_0}{V_{T_0} s} \\ -L'_\beta & s(s - L'_p) & -L'_r \\ -N'_\beta & -N'_p s & s - N'_r \end{bmatrix} \begin{bmatrix} \beta \\ p/s \\ r \end{bmatrix} = \begin{bmatrix} Y^*_{\delta_a} & Y^*_{\delta_r} \\ L'_{\delta_a} & L'_{\delta_r} \\ N'_{\delta_a} & N'_{\delta_r} \end{bmatrix} \begin{bmatrix} \delta_a \\ \delta_r \end{bmatrix} \quad (5)$$

$$\begin{aligned} \phi &= (p / s) + (r / s) * tg\,\theta_0 \\ \psi &= r / (s * \cos\theta_0) \end{aligned} \quad (6)$$

Here s is the Laplace operator. The equivalent time domain equations may be expressed in state space form as follows ,

$$\begin{bmatrix} \dot\beta \\ \dot p \\ \dot r \\ \dot\phi \end{bmatrix} = \begin{bmatrix} a51 & a52 & a53 & a54 \\ a61 & a62 & a63 & a64 \\ a71 & a72 & a73 & a74 \\ a81 & a82 & a83 & a84 \end{bmatrix} \begin{bmatrix} \beta \\ p \\ r \\ \phi \end{bmatrix} + \begin{bmatrix} b51 & b52 \\ b61 & b62 \\ b71 & b72 \\ b81 & b82 \end{bmatrix} \begin{bmatrix} da \\ dr \end{bmatrix} \quad (7)$$

$$\dot\psi = r / \cos(\theta_0) \quad (8)$$

As before these equations are referred to a generalized body axis system.

3.2 Aerodynamic coefficients

The constant coeficients in equations (7) are defined in terms of aerodynamic and control derivatives as follows ,

a51	=	YV	a61	=	LBL
a52	=	W0 / VT0	a62	=	LPL
a53	=	- U0 / VT0	a63	=	LRL
a54	=	grav * cos(θ_0) / VT0	a64	=	0.0
a71	=	NBL	a81	=	0.0
a72	=	NPL	a82	=	1.0
a73	=	NRL	a83	=	tan(θ_0)
a74	=	0.0	a84	=	0.0
b51	=	YDAST	b52	=	YDRST
b61	=	LDAL	b62	=	LDRL
b71	=	NDAL	b72	=	NDRL
b81	=	0.0	b82	=	0.0

The aerodynamic stability and control derivatives are referred to stability axis in reference [1] and were transformed to body axis using the transformation relations given in appendix B of reference [1]

3.3 Auxiliary equations

The auxiliary equations required to complete the lateral-directional computer model are as follows :

$$
\begin{aligned}
ay &= \dot{v} - W0 * p + U0 * r - grav * \sin(\phi) * \cos(\theta_0) \\
\dot{ye} &= U0 * \cos(\theta_0) * \sin(\psi) + \\
&\quad VT * (\sin(\phi)*\sin(\theta_0)*\sin(\psi)+\cos(\phi)*\cos(\psi)) + \\
&\quad W0 * (\cos(\phi)*\sin(\theta_0)*\sin(\psi)-\sin(\phi)*\cos(\psi)) \\
v &= VT0 * \sin(\beta) \\
\dot{v} &= VT0 * \dot{\beta} \\
ny &= ay / grav \\
VT &= V0 + V
\end{aligned}
\qquad (9)
$$

3.4 Computer simulation

The equations (7) (8) and (9) were coded in the ACSL language and a full listing is contained in appendix 3. The simulation was tested by obtaining the lateral and directional response transfer functions ,

$$\frac{\beta(s)}{da(s)}, \frac{P(s)}{da(s)}, \frac{R(s)}{da(s)}, \frac{\phi(s)}{da(s)}, \frac{AY(s)}{da(s)}$$

$$\frac{\beta(s)}{dr(s)}, \frac{P(s)}{dr(s)}, \frac{R(s)}{dr(s)}, \frac{\phi(s)}{dr(s)}, \frac{AY(s)}{dr(s)}$$

These were then compared with those in reference [1] and were found to be in good agreement.

4. THE FULLY COUPLED NON-LINEAR MODEL

4.1 Description of the model

A full six-degrees of freedom non-linear model has also been developed and is based on reference [1] and reference [2]. This model includes coefficients which vary during the simulation as functions of mach number , altitude and angle of attack. The coefficient data is assembled in tabular format and the same tables as used for the previously described linear models are utilized again in this model. At each integration step the aerodynamic coefficients are obtained from the tables and are then used to update the aerodynamic derivatives.

To obtain the non-linear equations of motion the description developed in chapter 2 of reference [2] was used, the coupling coefficients were thus defined and then included in the linearised equations described in sections 2 and 3 of this report.

4.2 Equations of motion

The equations obtained as described in (4.1) above are as follows ,

(i) Force equations :

$$\dot{U} = R * VT - Q * WT - grav * \sin(\theta_T) + X0 / mass + XUST * U + XW * W + XQ * Q + XDE * de$$

$$\dot{V} = P * WT - R * UT + grav * \cos(\theta_T) * \sin(\phi) + Y0 / mass + YV * V + YR * R + YP * P + YDAST * da + YDRST * dr$$

$$\dot{W} = (Q * UT - P * VT) / (1 - ZWP) + Z0 / (1 - ZWP) + (grav * \cos(\theta_T) * \sin(\phi)) / (1 - ZWP) + (ZUST * U + ZW * W + ZQ * Q + ZDE * de) * 1 / (1 - ZWP)$$

(10)

(ii) Moment equations :

$$\dot{P} = (LBL / U1) * V + LRL * R + LPL * P + K5 * P * Q - K6 * Q * R + LDAL * da + LDRL * dr$$

$$\dot{Q} = MUST * U + MW * W + MWP * WP + MQ * Q + MDE * de - IXZ * (P * P - R * R) / IY + (IX - IZ) * P * R / IY$$

$$\dot{R} = NBL * V / U1 + NRL * R + NPL * P - K3 * Q * R + K4 * P * Q + NDAL * da + NDRL * dr$$

(11)

(iii) Euler equations :

$$\dot{\Phi} = P + (Q * \sin(\Phi) + R * \cos(\Phi)) * tg(\theta_T)$$
$$\dot{\Psi} = (Q * \sin(\Phi) + R * \cos(\Phi)) / \cos(\theta_T)$$
$$\dot{\theta} = Q * \cos(\Phi) - R * \sin(\Phi)$$

(12)

4.3 Auxiliary equations

The following auxiliary equations complete the description of the model :

$$ax = \dot{U} - VT * R + WT * Q + grav * \sin(\theta_T)$$
$$ay = \dot{V} - WT * P + UT * R - grav * \sin(\Phi) * \cos(\theta_T)$$
$$az = \dot{W} + P * VT - Q * UT - grav * \cos(\Phi) * \cos(\theta_T)$$
$$\dot{h} = UT * \sin(\theta_T) - VT * \sin(\Phi) * \cos(\theta_T) - WT * \cos(\Phi) * \cos(\theta_T)$$
$$\dot{xe} = UT * \cos(\theta_T) * \cos(\Psi) + VT * (\sin(\Phi) * \sin(\theta_T) * \cos(\Psi) - \cos(\Phi) * \sin(\Psi)) + WT * (\cos(\Phi) * \sin(\theta_T) * \cos(\Psi) + \sin(\Phi) * \sin(\Psi))$$
$$\dot{ye} = UT * \cos(\theta_T) * \sin(\Psi) + VT * (\sin(\Phi) * \sin(\theta_T) * \sin(\Psi) + \cos(\Phi) * \cos(\Psi)) + WT * (\cos(\Phi) * \sin(\theta_T) * \sin(\Psi) - \sin(\Phi) * \cos(\Psi))$$

(13)

$$\dot{ze} = - UT * \sin(\theta_T) + VT * \sin(\Phi) * \cos(\theta_T) + WT * \cos(\Phi) * \cos(\theta_T)$$

$$UT = U0 + U$$

$$VT = V0 + V$$

$$WT = W0 + W$$

$$\alpha_T = \text{arctg}(WT / UT)$$

$$\theta_T = \theta + \theta_0$$

$$U1 = \sqrt{UT * UT + VT * VT + WT * WT}$$

$$\gamma_T = \theta_T - \alpha_T$$

$$\dot{\alpha} = \dot{W} / UT$$

$$\beta = \arcsin (VT / U1)$$

$$\dot{\beta} = \dot{V} / U1$$

(13)

The constants listed below are used in the various equations described above :

$$KLAT = 1 / (1 - (IXZ * IXZ / (IX * IZ)))$$

$$K1 = IXZ / IZ$$

$$K2 = IXZ / IX$$

$$K3 = KLAT * K1 * (1 + (IZ - IY) / IX)$$

$$K4 = KLAT * (K7 - (IY - IX) / IZ)$$

$$K5 = KLAT * K2 * (1 - (IY - IX) / IZ)$$

$$K6 = KLAT * (K7 + (IZ - IY) / IX)$$

$$K7 = (IXZ * IXZ) / (IX * IZ)$$

4.4 Computer simulation

The equations (10) , (11) , (12) and (13) were coded in the ACSL language and a full listing is contained in appendix 4. The simulation was tested by obtaining responses to inputs of elevator , aileron and rudder for comparison with the linear model responses and for comparison with response data contained in reference [1].

5. AERODYNAMIC DATA

The aerodynamic and control data used in the models was obtained directly from reference [1] and is in American coefficient notation. Each coefficient is quoted as a function of both altitude and mach number and is expressed in tabular form. For example , the tabular format for each coefficient is as follows ,

```
TABLE XCOEF,2,4,3 ...
/ 0.4  ,  0.5  ,  0.6  ,  0.7
, 0.0  ,  10000  ,  20000
, m1   ,  m2   ,  m3  ,  m4
, n1   ,  n2   ,  n3  ,  n4
, s1   ,  s2   ,  s3  ,  s4
```

where ,

XCOEF is the name of the coefficient,

2 means that XCOEF is a function of two variables, mach number and altitude,

4 is the number of mach number values (0.4 ; 0.5 ; 0.6 and 0.7) for which the coefficient is listed,

3 is the number of altitude values (0 ; 10000 and 20000) for which the coefficient is listed,

m1 , m2 , m3 and m4 are the values of the coefficient corresponding with the four Mach number values at the first altitude,

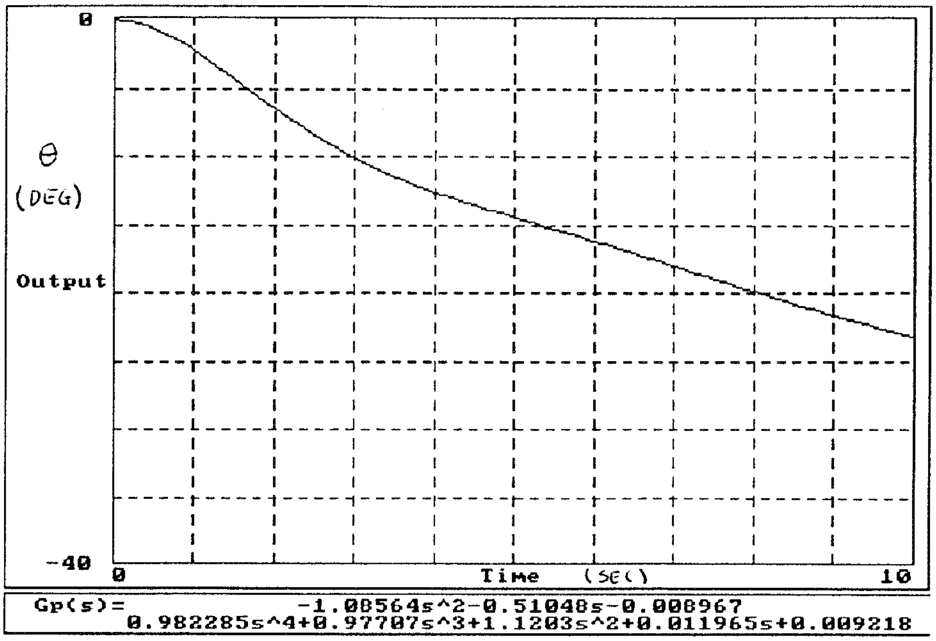
(n) and (s) , (i= 1 to 4) are the values of the coefficient for the next two altitudes respectively and corresponding with the four Mach number values.

The tabulated values for all of the coefficients used in the simulation model are listed in appendix 1.

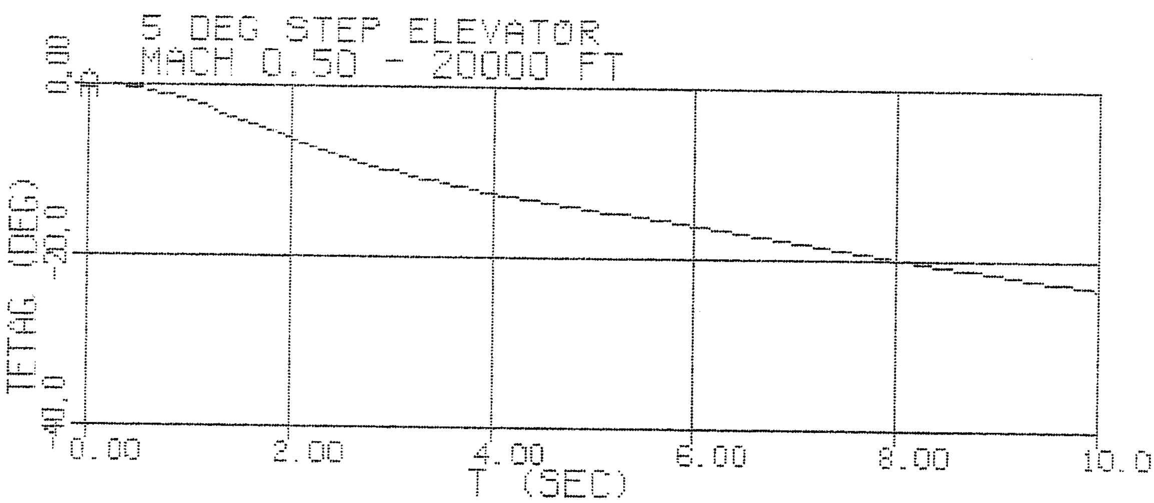
6. COMPARISON OF MODEL RESPONSES WITH TRANSFER FUNCTION RESPONSES

6.1 Longitudinal response to elevator

In order to verify the linear longitudinal model, the simulation was stimulated with an input of 5 deg. step in elevator and the response time histories obtained were compared with those obtained by applying the same input to the appropriate transfer functions obtained from reference [1] The CODAS software (ref [4]) package was used for this comparison. The comparative response time histories are shown in figures (6.1.a) to (6.1.e) inclusive below. Referring to these figures , it is seen that the simulation model responses and the transfer function responses are in very good agreement thus validating the simulation model.

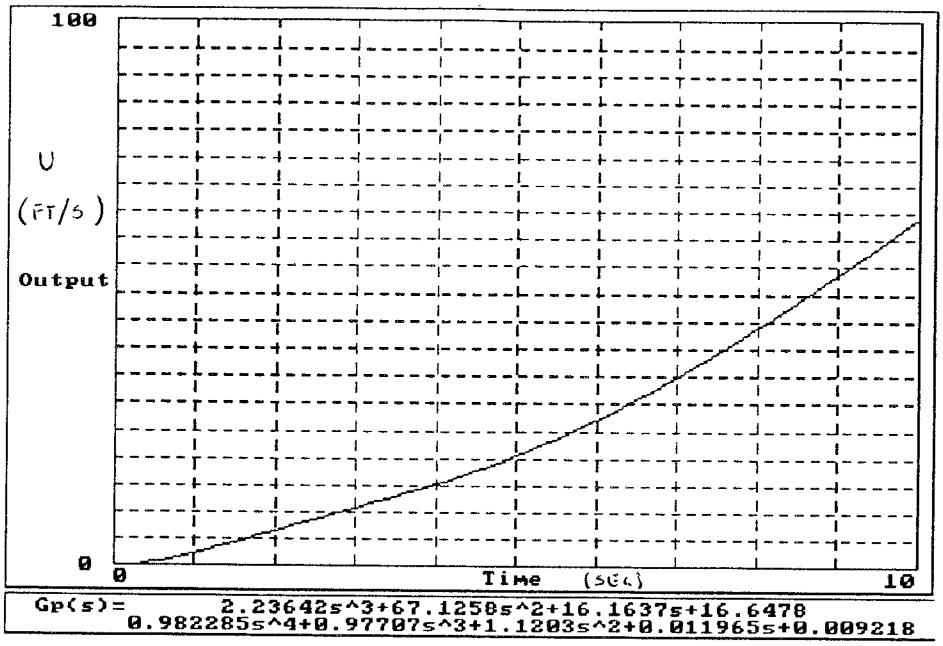


Transfer Function Response

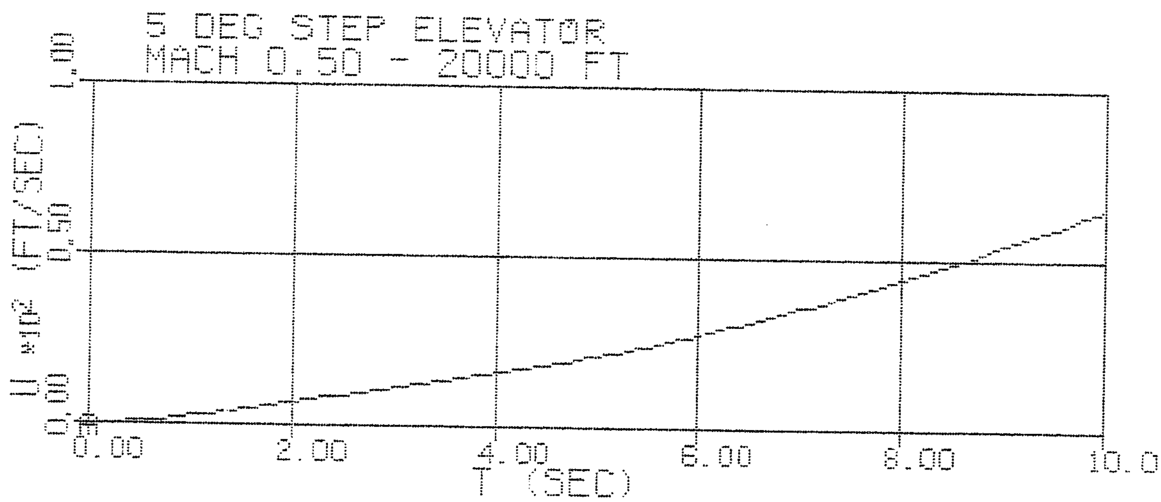


Model Response

Figure 6.1.a θ response comparison between the model and the transfer function

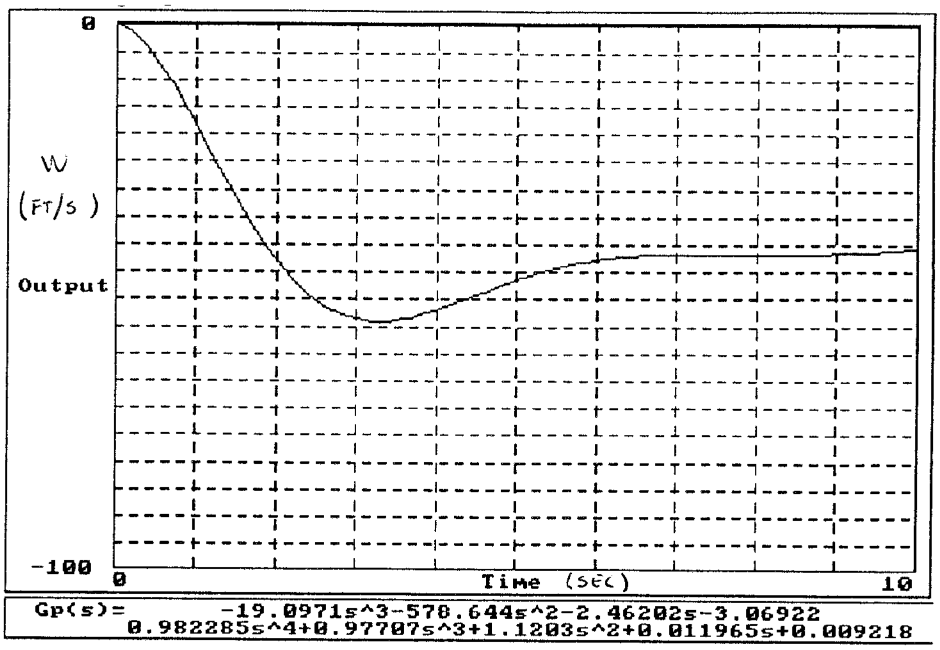


Transfer Function Response

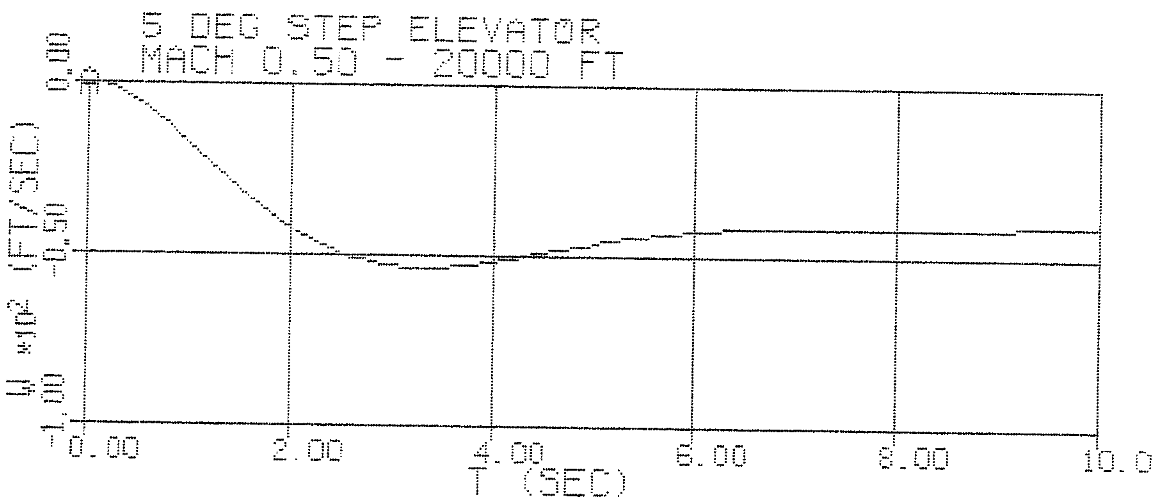


Model Response

Figure 6.1.b U response comparison between the model and the transfer function

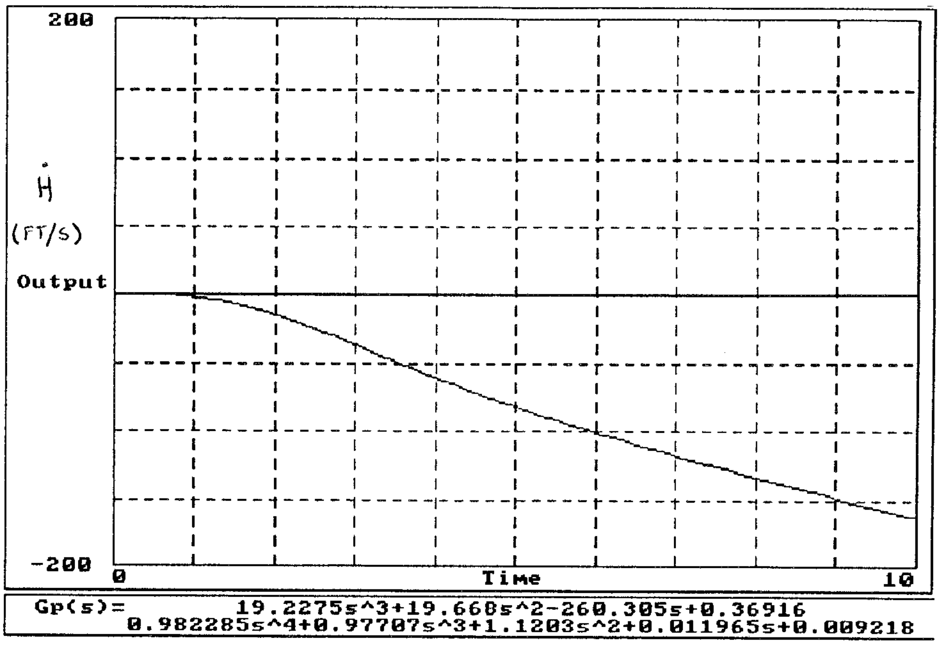


Transfer Function Response

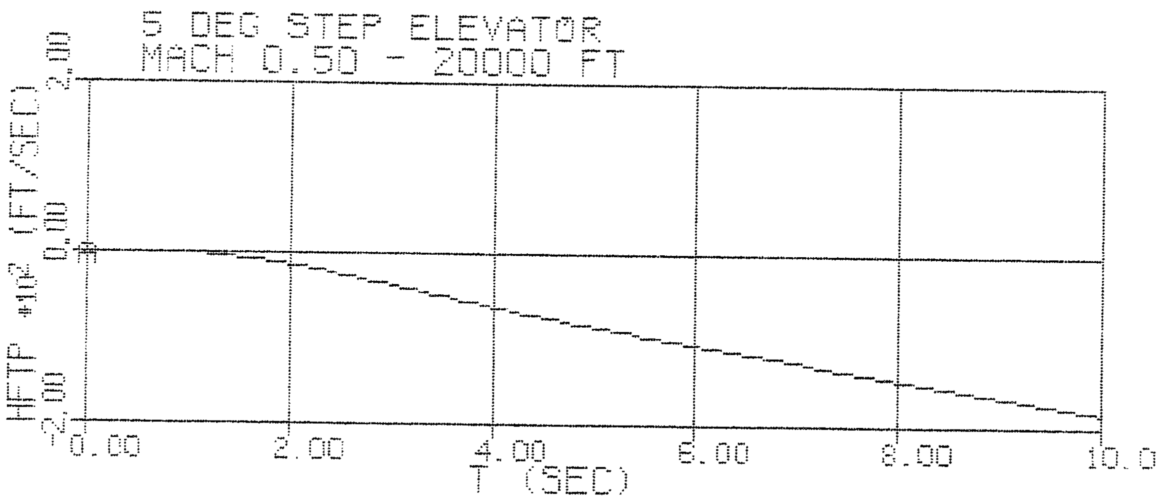


Model Response

Figure 6.1.c W response comparison between the model and the transfer function

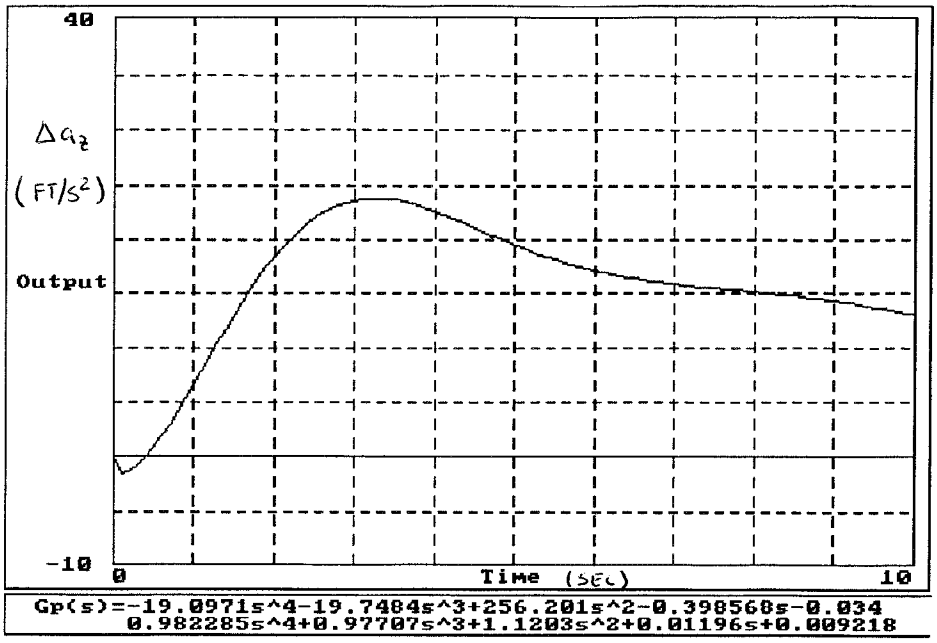


Transfer Function Response

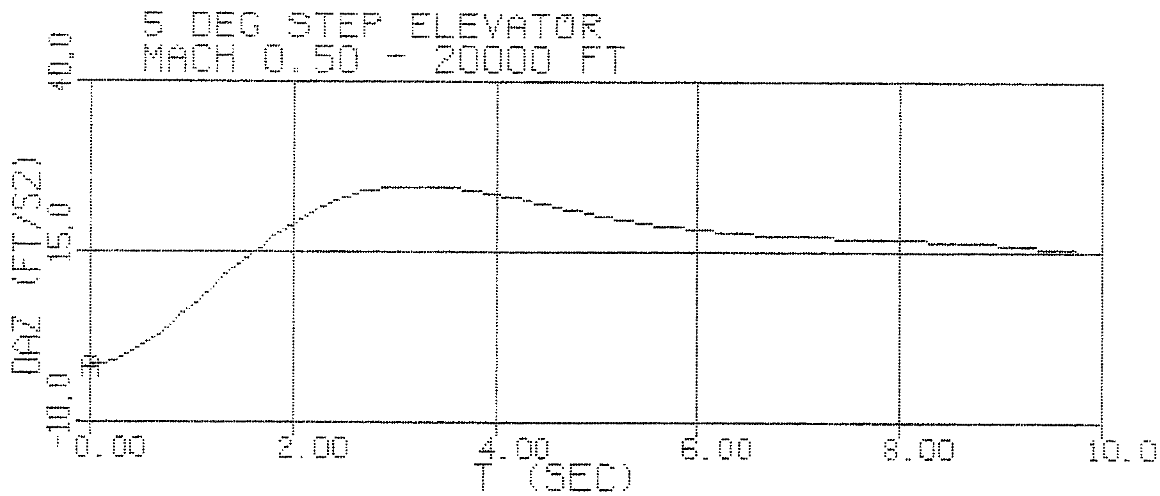


Model Response

Figure 6.1.d $\dot{H}$ response comparison between the model and the transfer function



Transfer Function Response

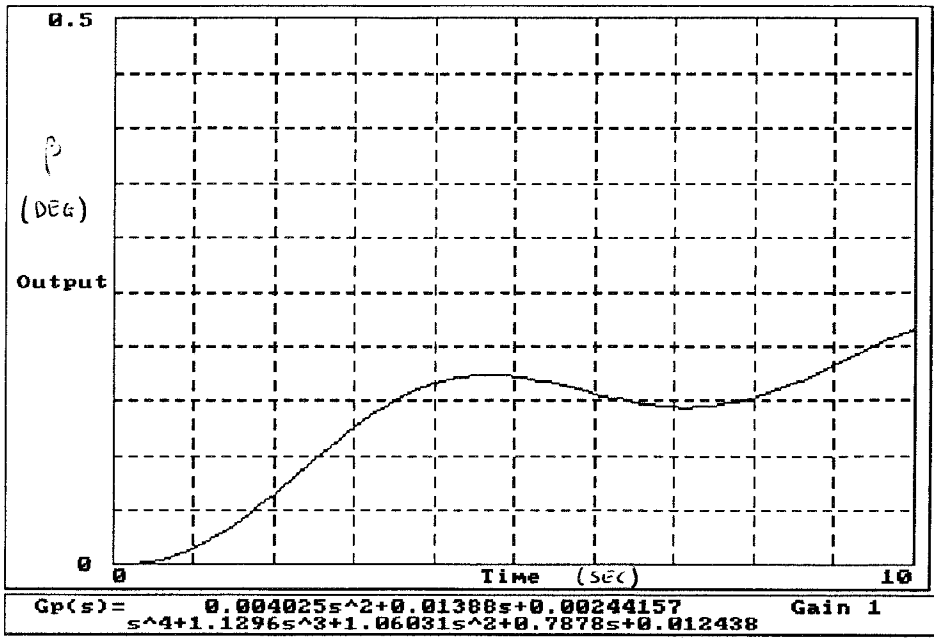


Model Response

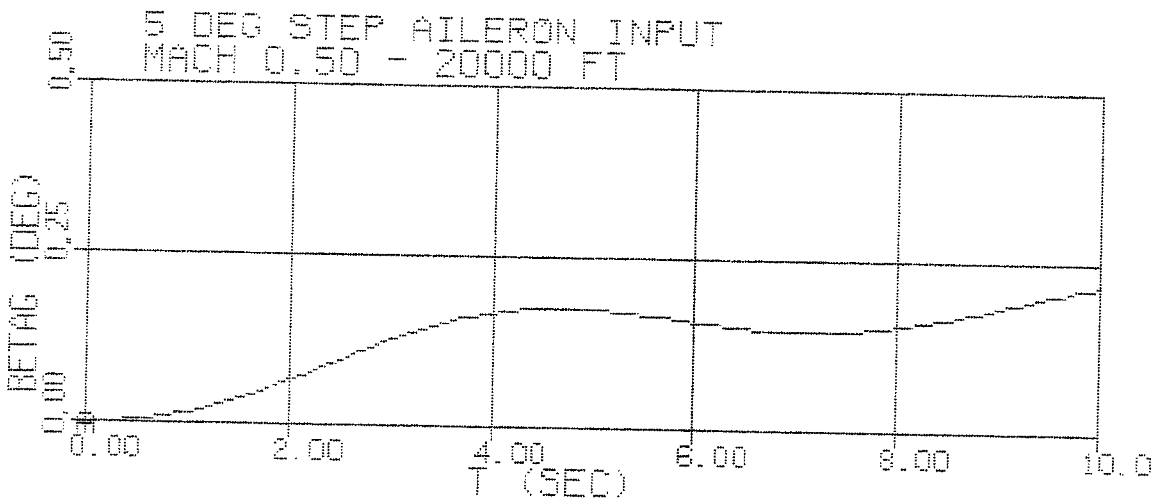
Figure 6.1.e DAZ response comparison between the model and the transfer function

6.2 Lateral-directional response to aileron

In order to verify the linear lateral-directional model the simulation was stimulated with an input of 5 deg. step in aileron and the response time histories were compared with those obtained by applying the same input to the transfer functions obtained from reference [1] .
The comparative response time histories are shown in figures (6.2.a) to (6.2.c) inclusive below.
Referring to these figures , it is again seen that the simulation model responses are in good agreement with the transfer function responses thus validating the simulation model.

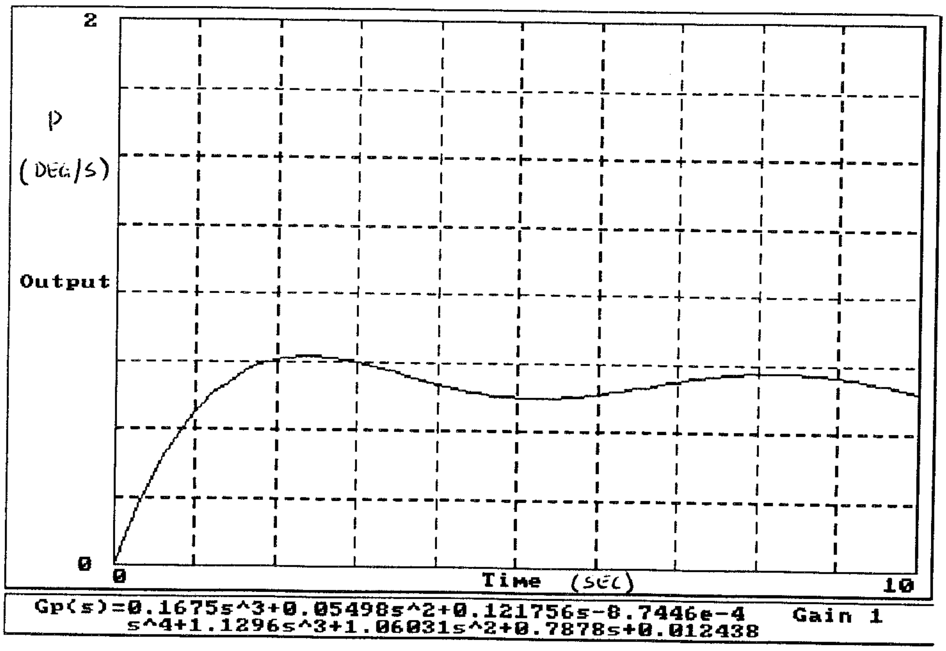


Transfer Function Response

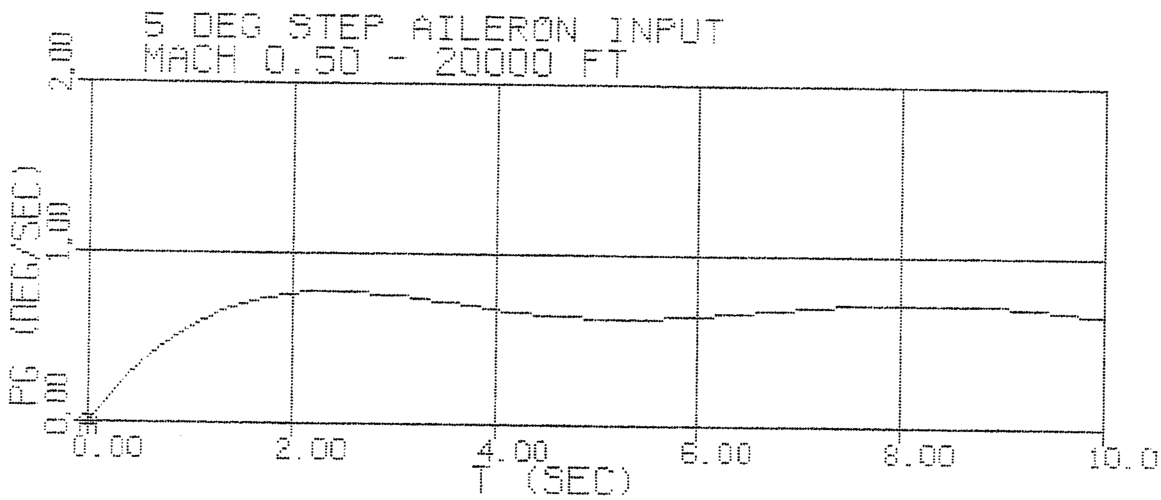


Model Response

Figure 6.2.a β response comparison between the model and the transfer function

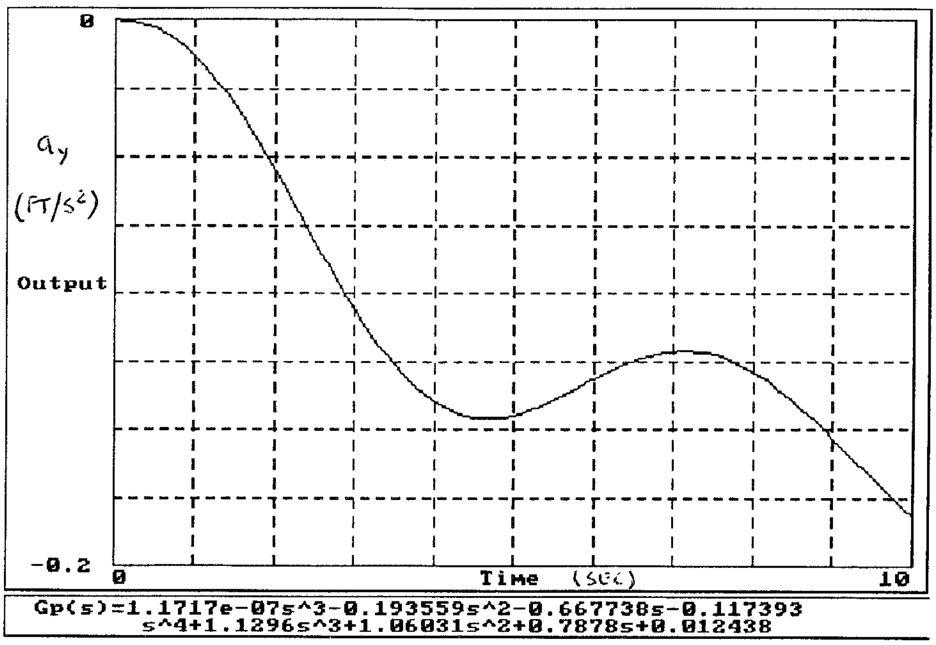


Transfer Function Response

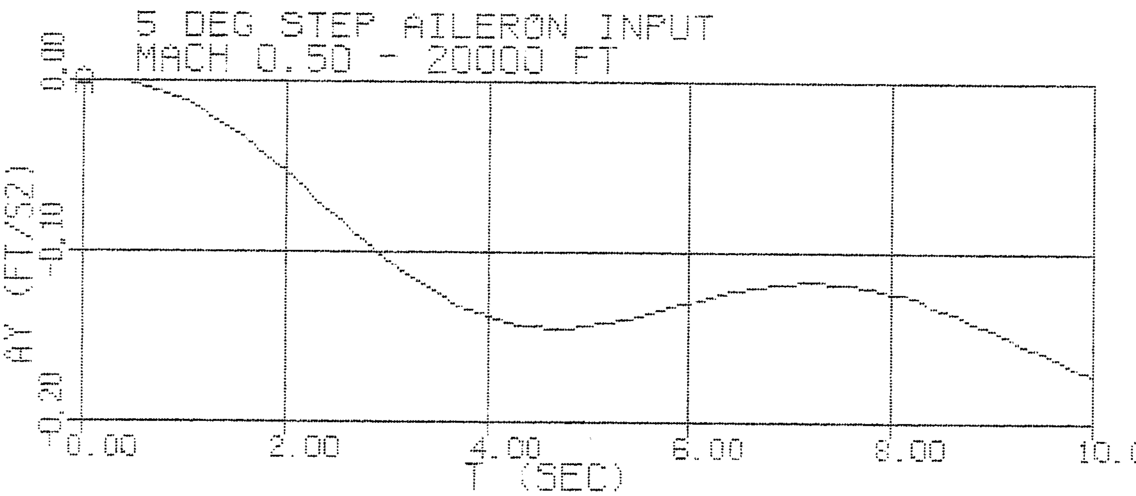


Model Response

Figure 6.2.b P response comparison between the model and the transfer function



Transfer Function Response

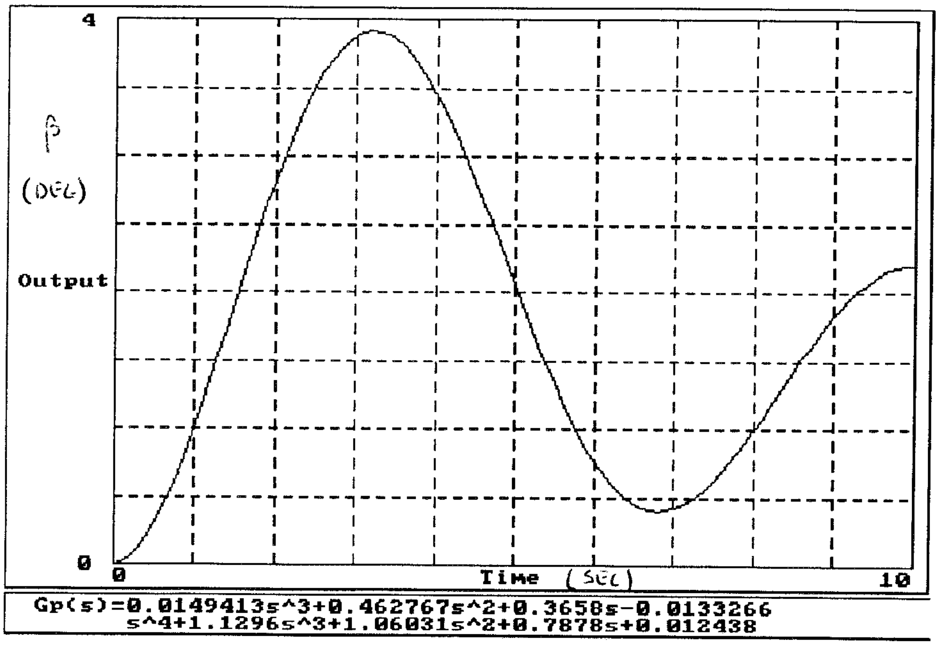


Model Response

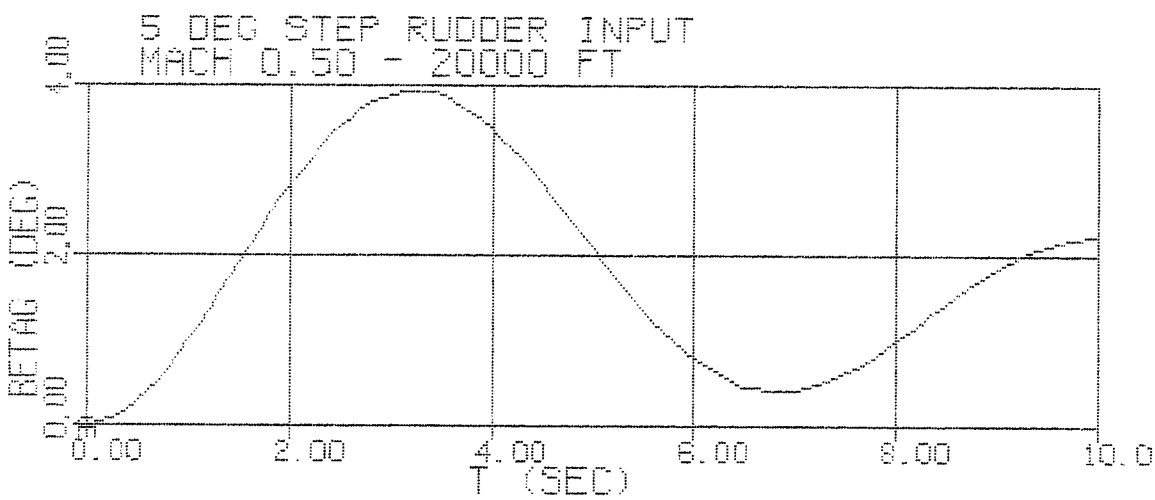
Figure 6.2.c ay response comparison between the model and the transfer function

6.3 Lateral-directional response to rudder

In order to verify the directional aspects of the linear lateral-directional model , the process described in (6.2) was repeated for a 5 deg. step input to rudder The comparative time histories obtained are included in figures (6.3.a) to (6.3.c) inclusive below and again it is seen that good agreement was obtained.

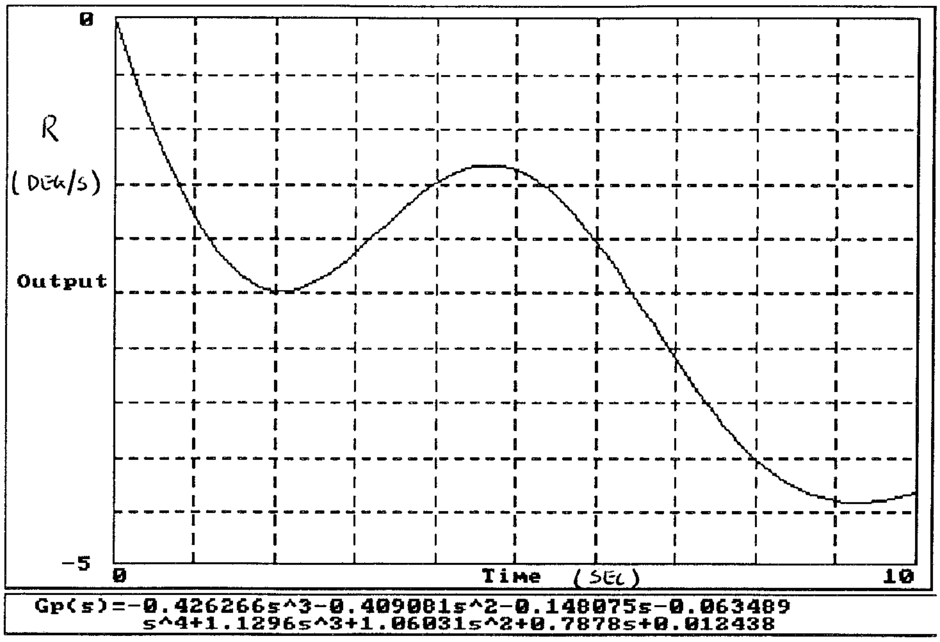


Transfer Function Response

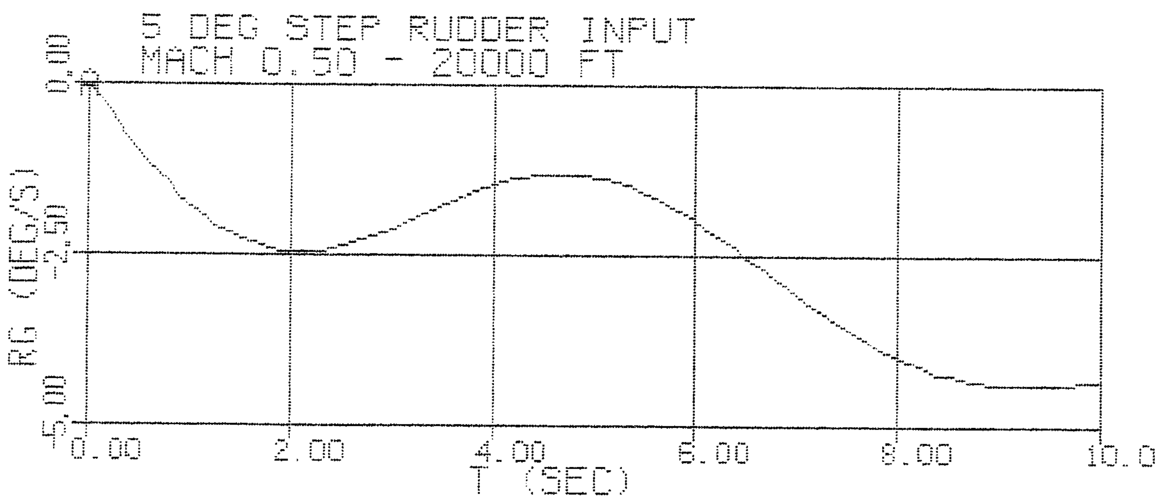


Model Response

Figure 6.3.a β response comparison between the model and the transfer function



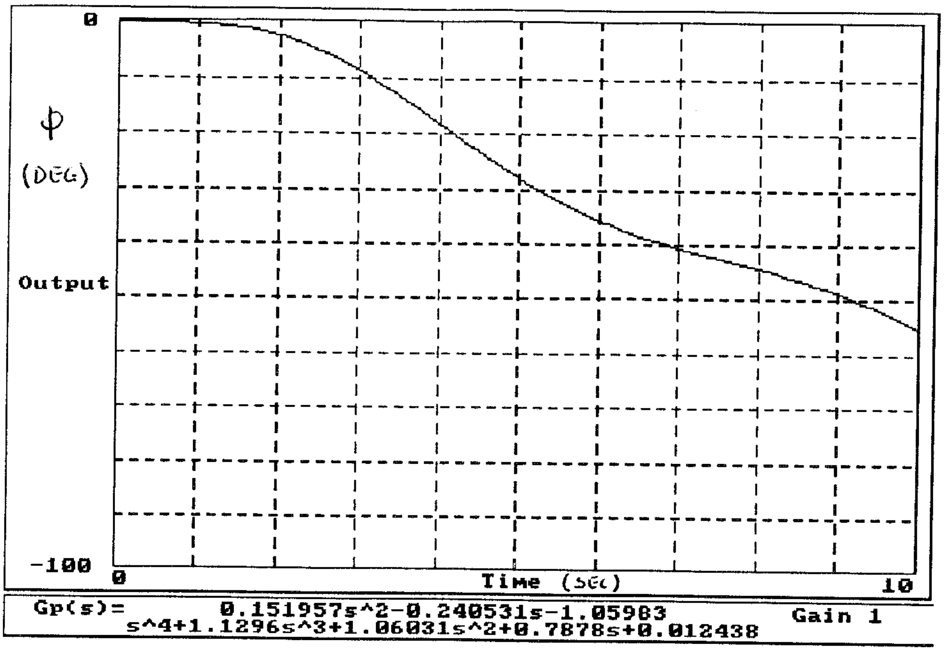
Transfer Function Response



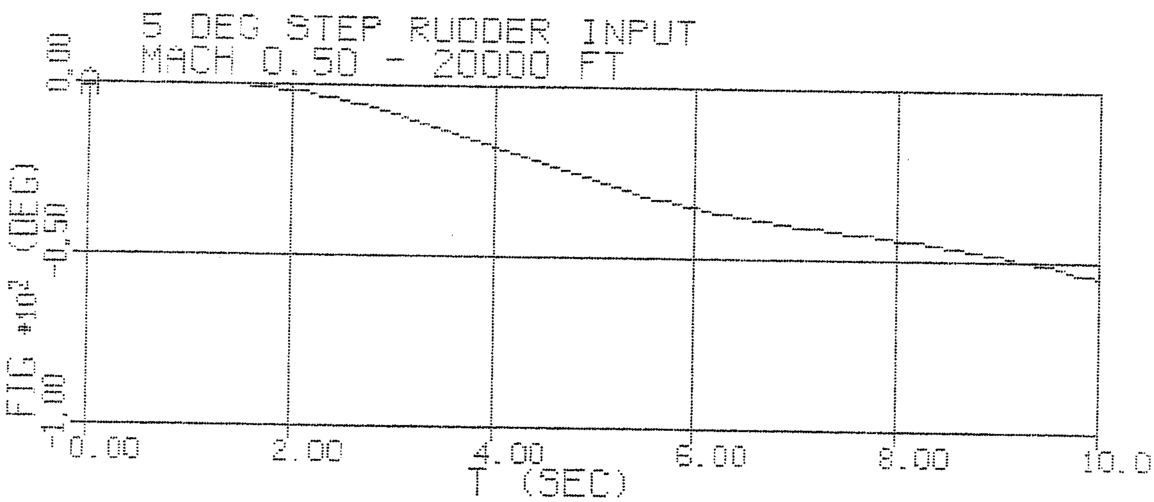
Model Response

Figure 6.3.b R response comparison

between the model and the transfer function



Transfer Function Response



Model Response

Figure 6.3.c ϕ response comparison between the model and the transfer function

7. COMPARISON BETWEEN THE NON-LINEAR SIMULATION MODEL AND THE LINEAR MODELS

For comparative purposes typical examples of responses were obtained with both the non-linear model and with the linear model for the flight condition ,

MACH = 0.50 H = 20000 ft

Weight = 636636 lbs

IX = 0.182e+8 slug-ft2

IY = 0.331e+8 slug-ft2

IZ = 0.497e+8 slug-ft2

IXZ = 970056 slug-ft2

TU = 0.0 GAMA0 = 0.0

7.1 Longitudinal response to elevator

For a representative elevator maneuver input at the above flight condition the following response time histories were obtained α , q , Nz and UT . Responses obtained with the non-linear model are plotted in figures (7.1.a) and (7.1.b) and the responses obtained with the linear longitudinal model are shown in figure (7.1.c) and (7.1.d). From these figures the only disparities that can be observed are small diferences in UT, forward velocity, between the two models. This confirm the validity of the linear model for handling qualities studies involving only relatively short term response.

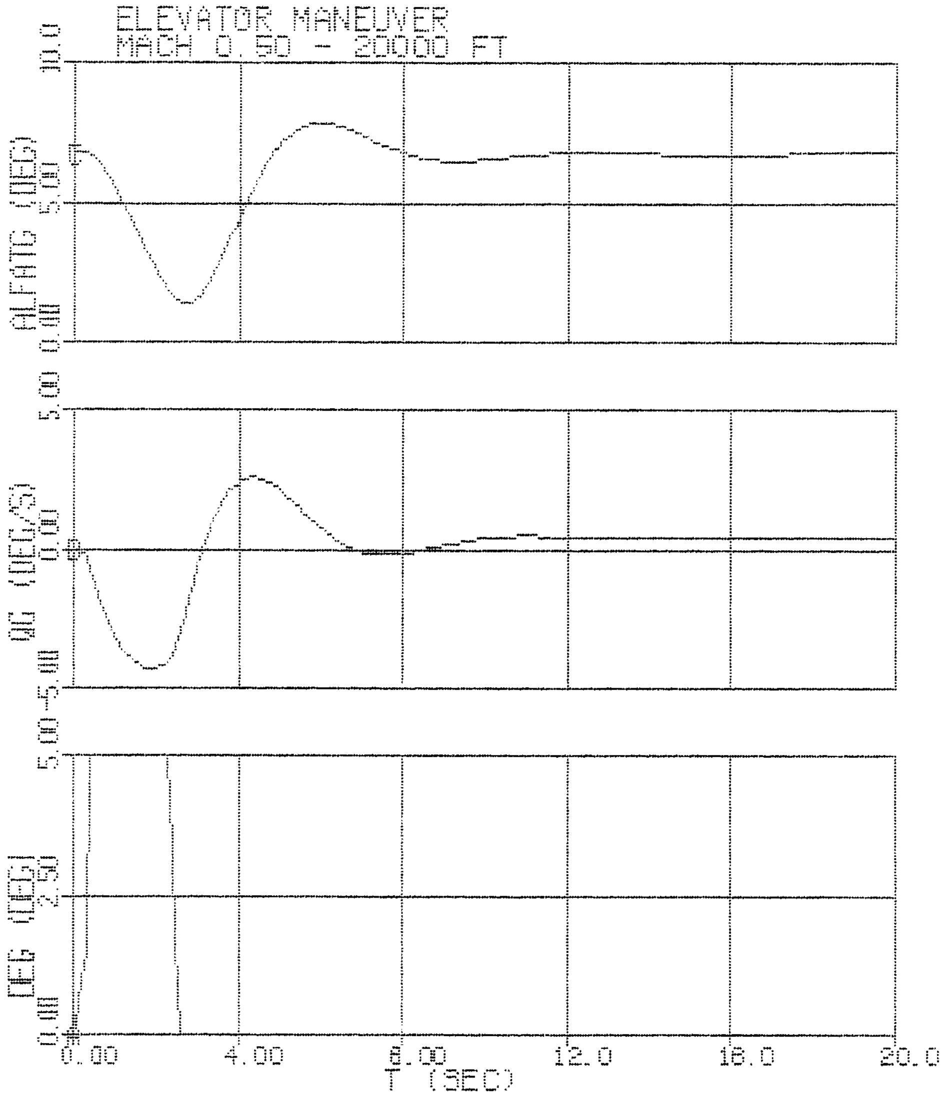


Figure 7.1.a α and Q responses to an elevator maneuver obtained with the non-linear model.

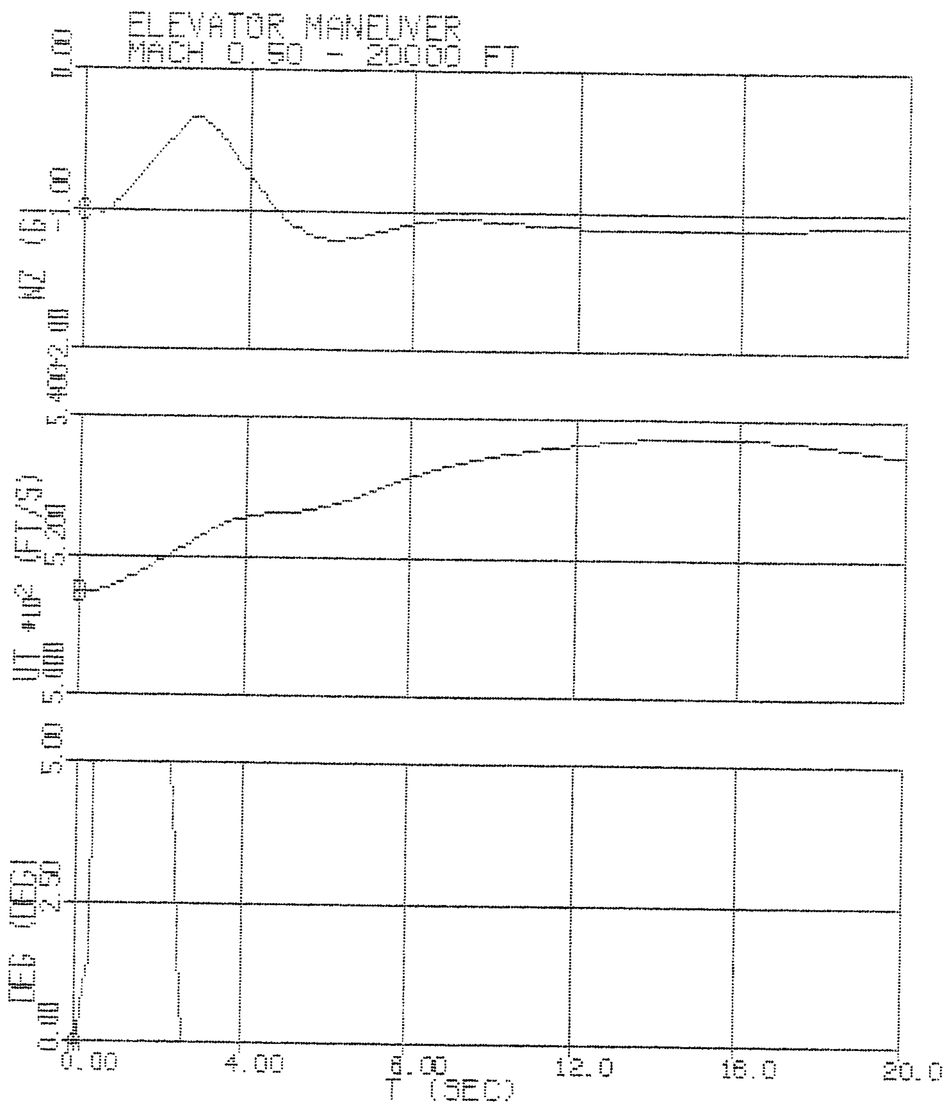


Figure 7.1.b Nz and UT responses to an elevator maneuver obtained with the non-linear model.

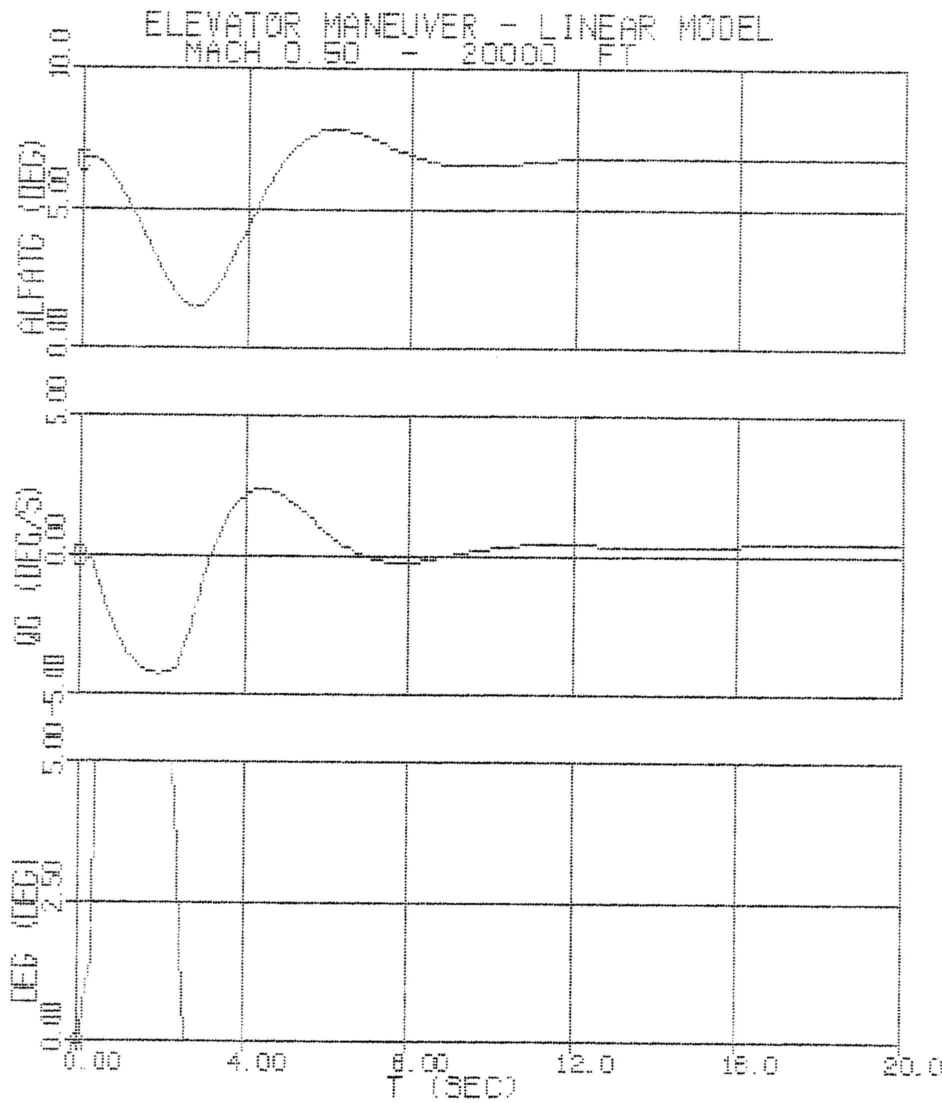


Figure 7.1.c α and Q responses to an elevator maneuver obtained with the longitudinal linear model.

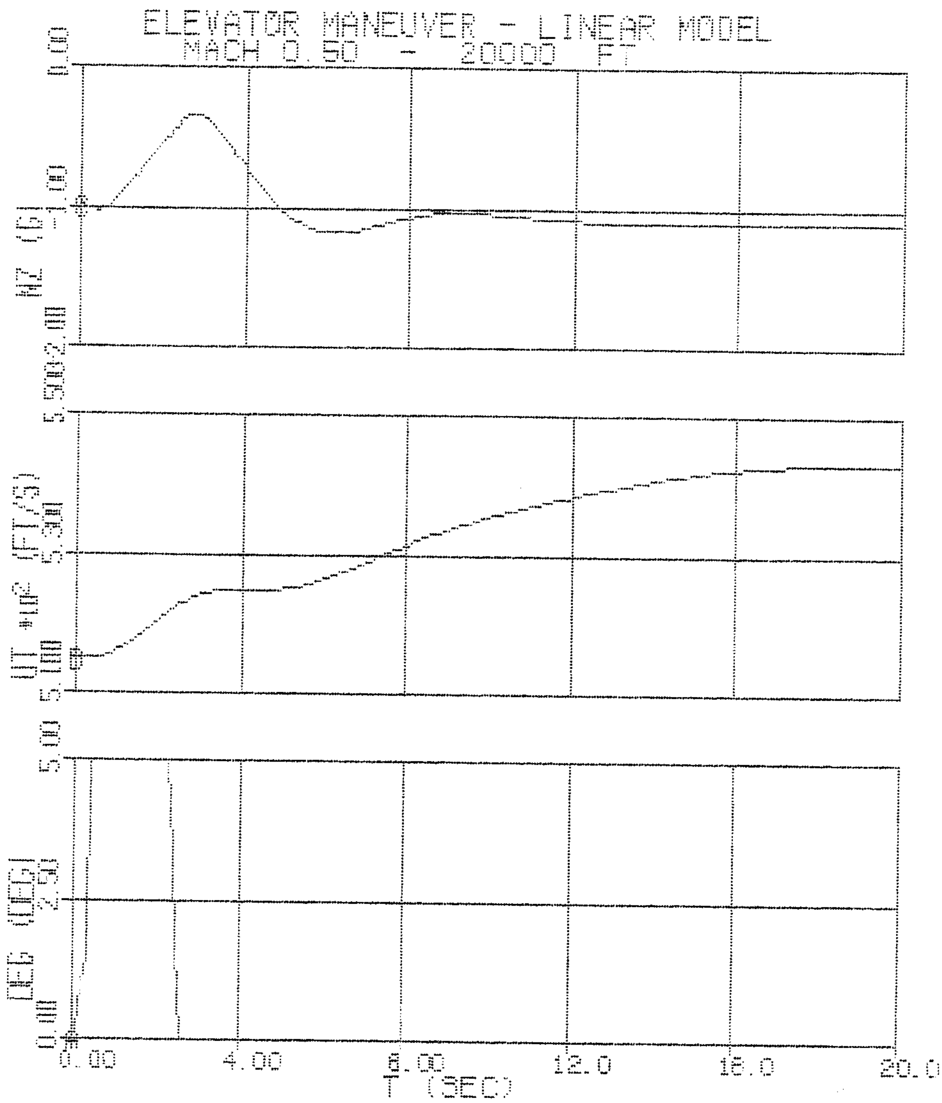


Figure 7.1.d Nz and UT responses to an elevator maneuver obtained with the longitudinal linear model.

7.2 Lateral-directional response to aileron

Using an aileron maneuvre input similar to that applied to the elevator, lateral-directional response time histories were obtained. The response time histories comprise ϕ , p , r and β which are shown on figures (7.2.a) and (7.2.b) for the non-linear simulation model and on figures (7.2.c) and (7.2.d) for the linear simulation model. Small differences may be observed between these two sets of responses and these are due to the effect of the coupling terms in the non-linear model.

7.3 Lateral-directional response to rudder

The exercise described in 7.2 was repeated for a similar maneuvre input to rudder. Again , the response time histories comprise ϕ , p , r and β which are shown on figures (7.3.a) and (7.3.b) for the non-linear simulation model and on figures (7.3.c) and (7.3.d) for the linear simulation model. As in the response to aileron case small differences between the two sets of responses are evident.

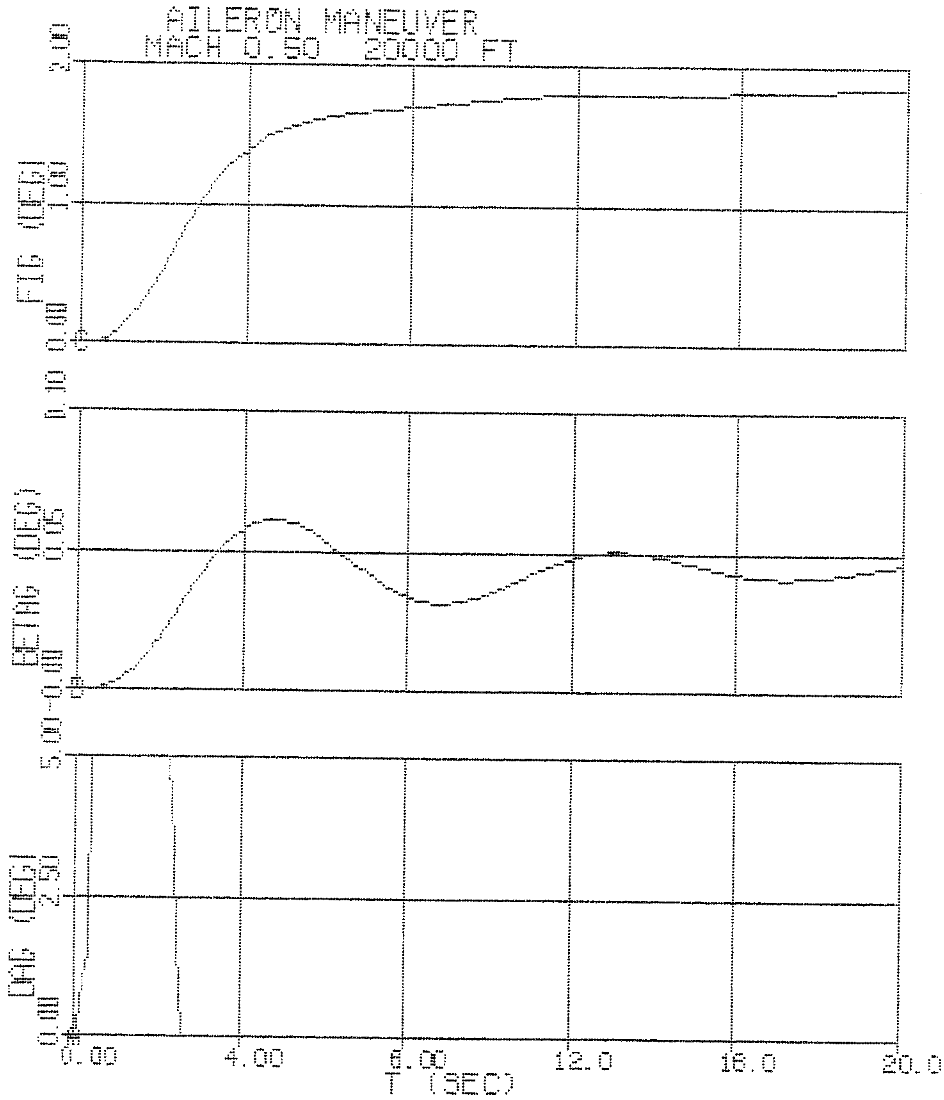


Figure 7.2.a ϕ and β responses to an aileron maneuver obtained with the non-linear model.

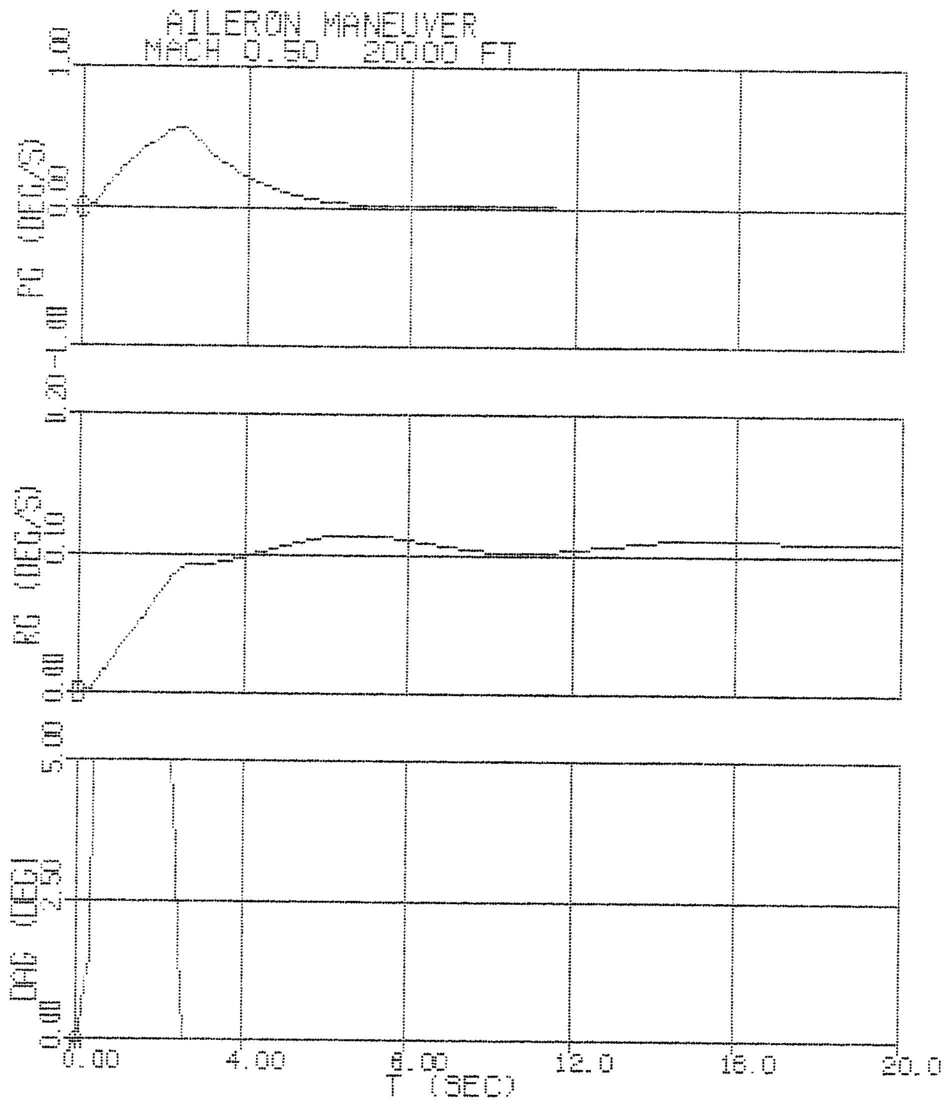


Figure 7.2.b P and R responses to an aileron maneuver obtained with the non-linear model.

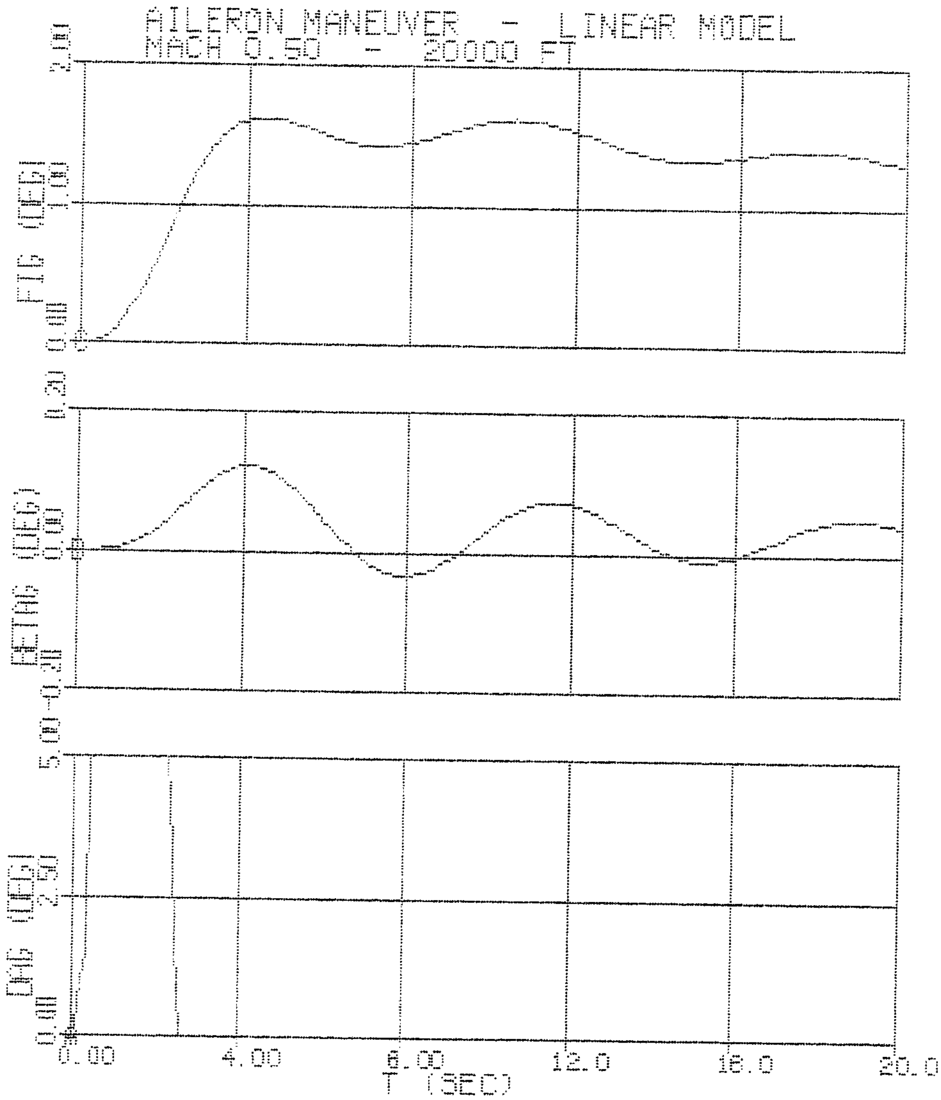


Figure 7.2.c ϕ and β responses to an aileron maneuver obtained with the linear lateral-directional model.

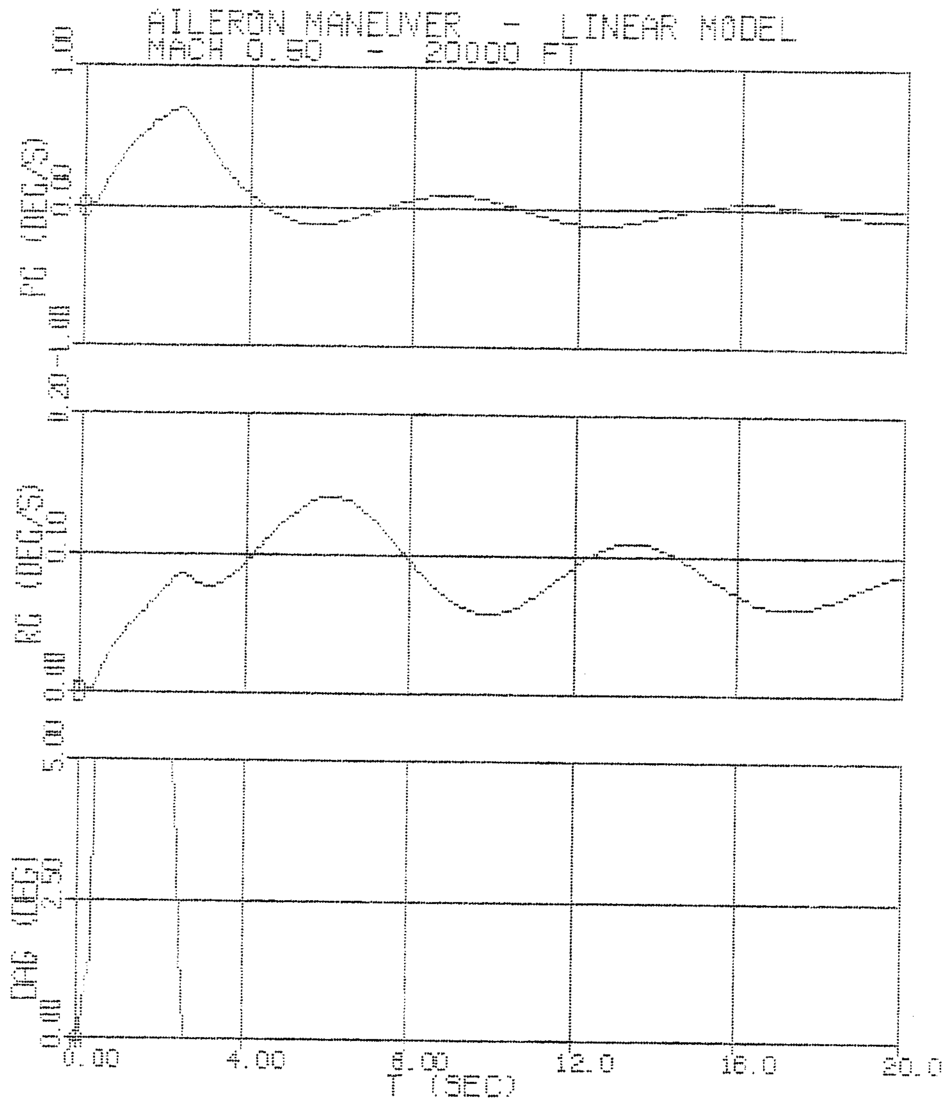


Figure 7.2.d P and R responses to an aileron maneuver obtained with the linear lateral-directional model.

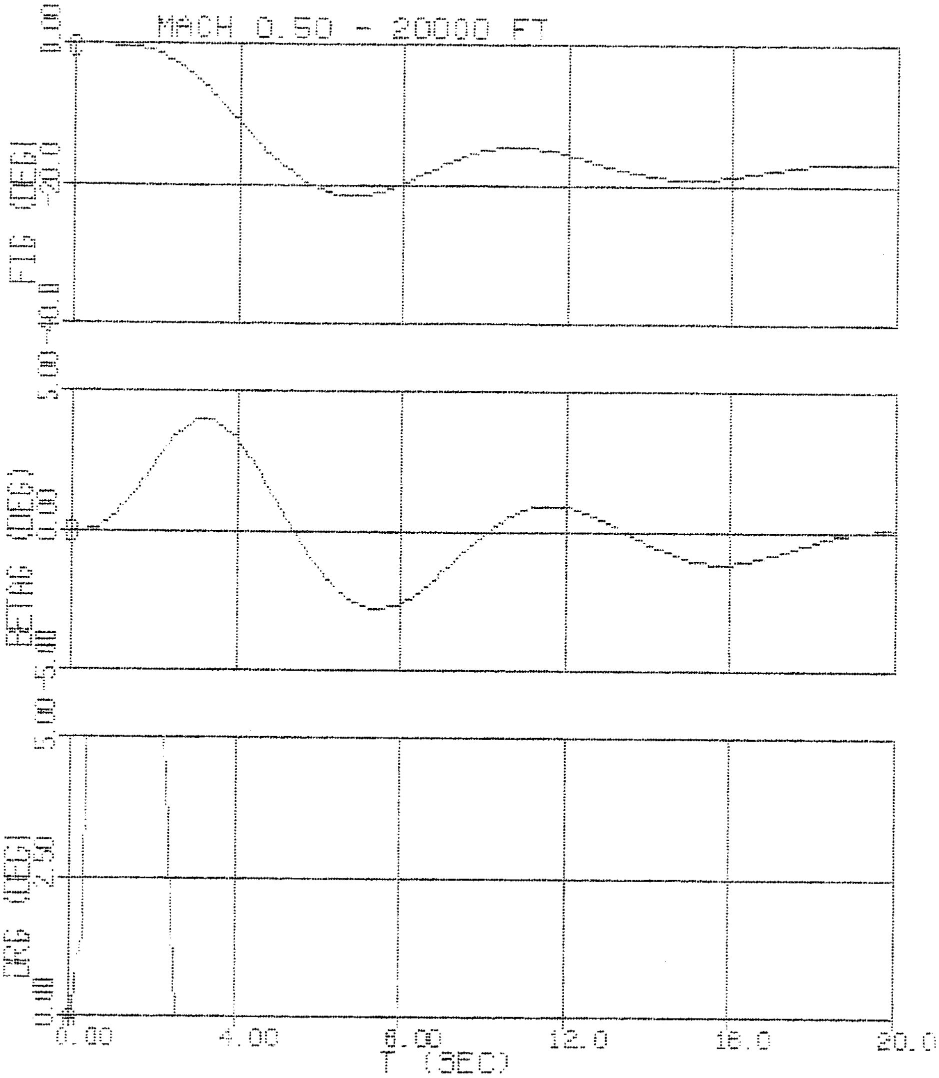


Figure 7.3.a Φ and β responses to an rudder maneuver obtained with the non-linear model.

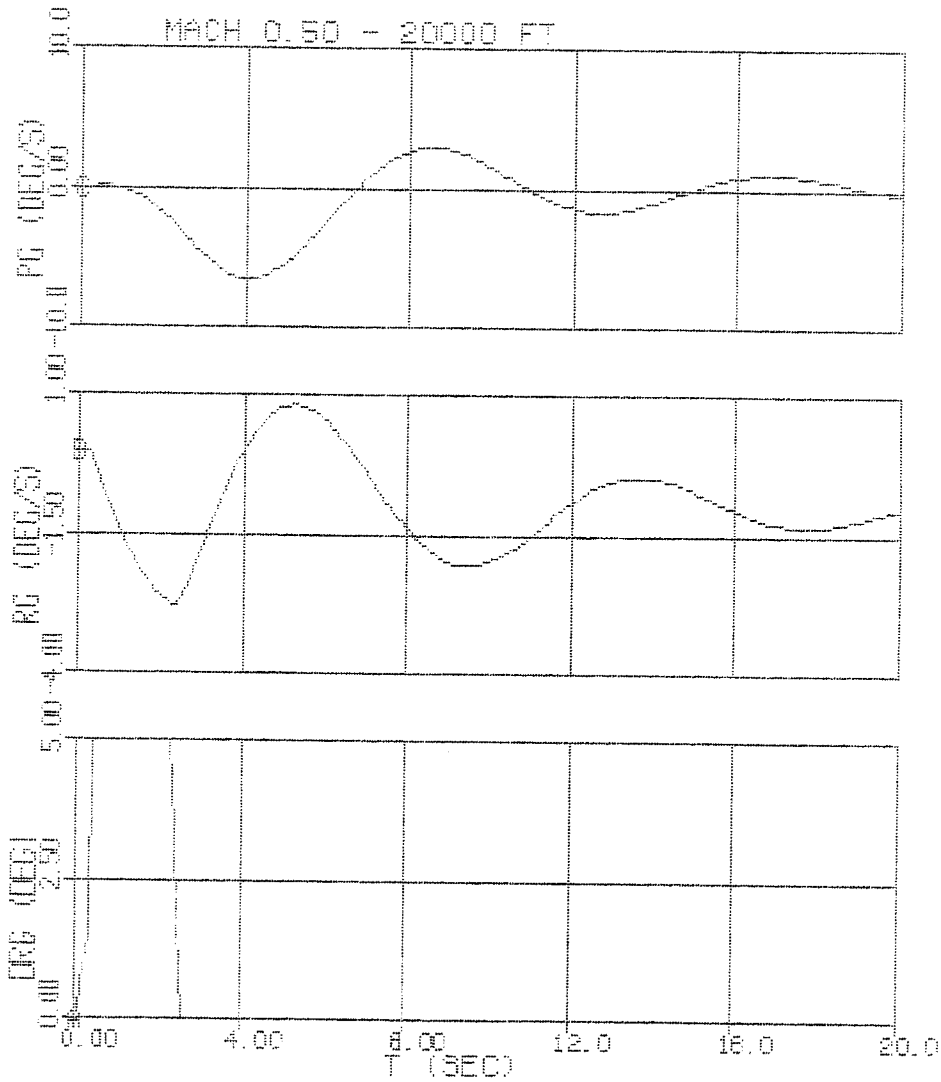


Figure 7.3.b P and R responses to an rudder maneuver obtained with the non-linear model.

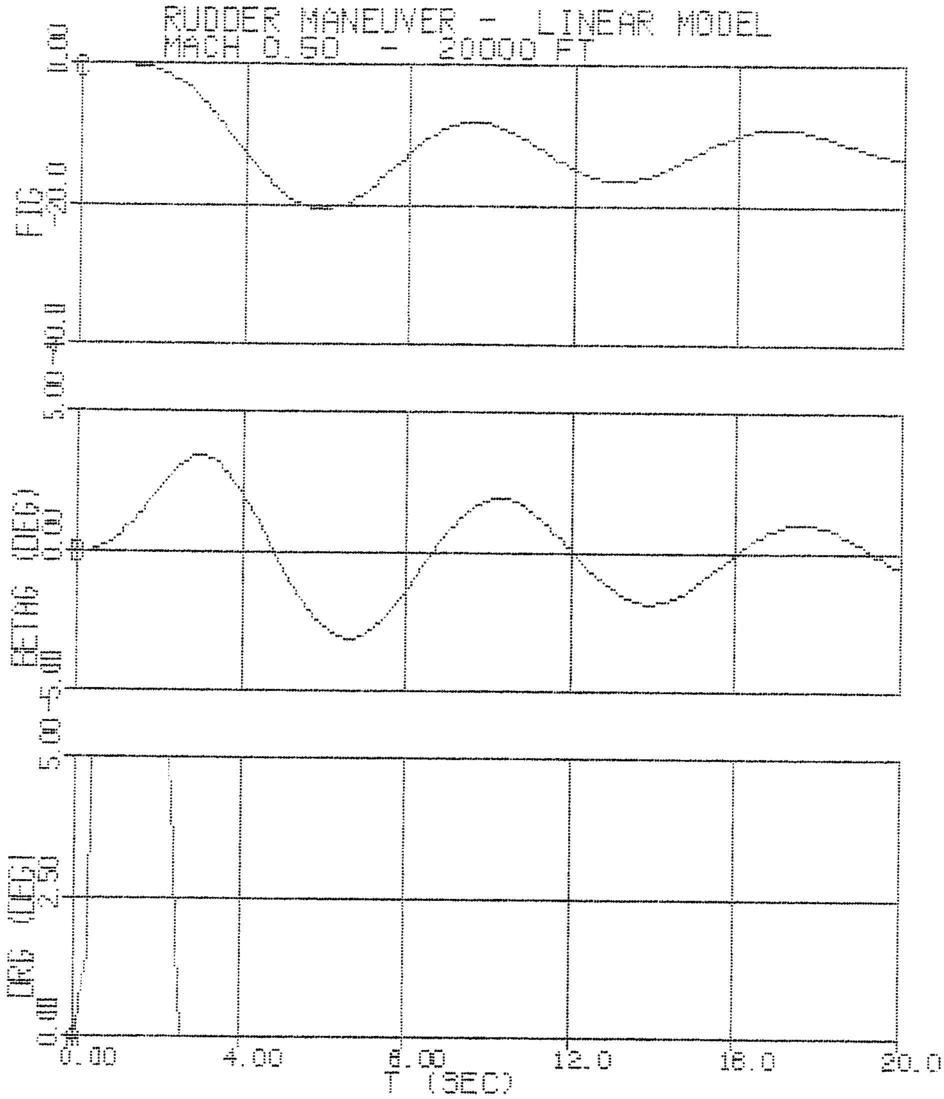


Figure 7.3.c Φ and β responses to an rudder maneuver obtained with the linear lateral-directional model.

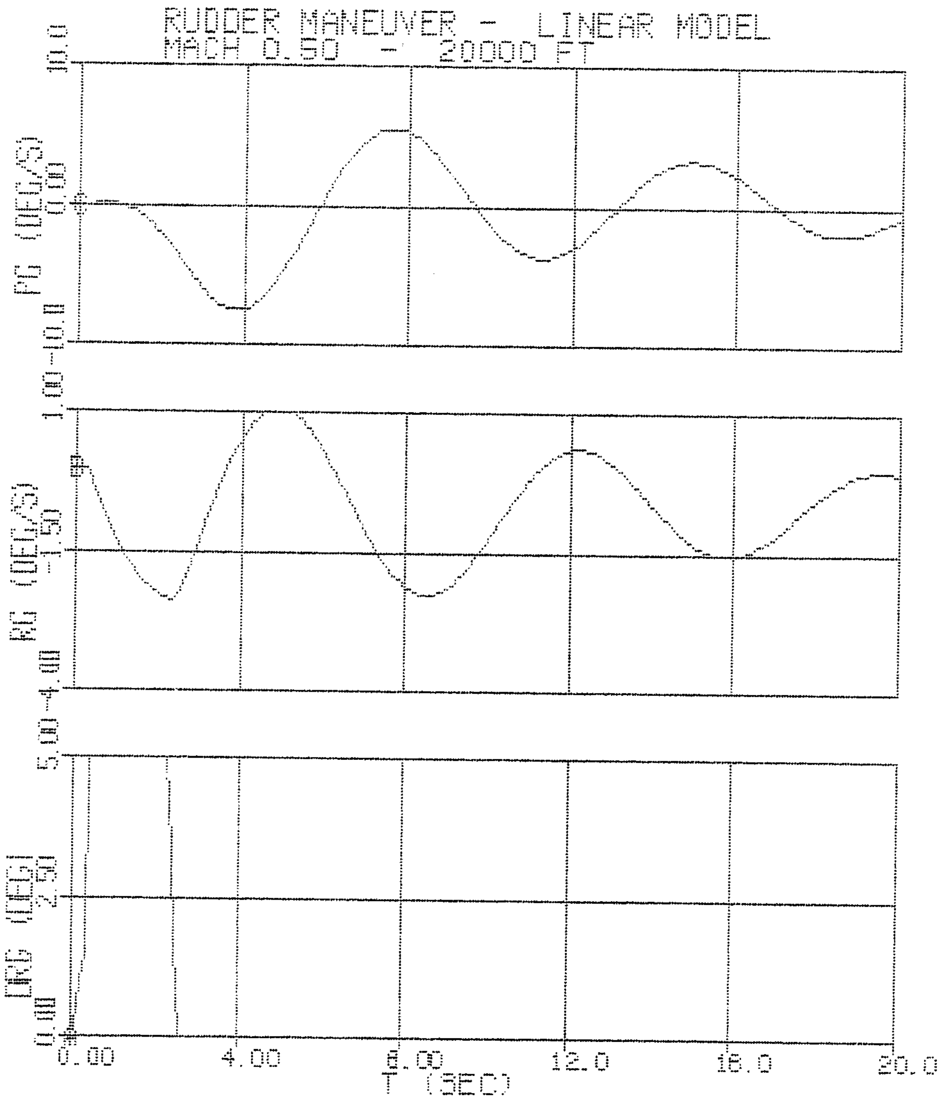


Figure 7.3.d P and R responses to an rudder maneuver obtained with the linear lateral-directional model.

8. THE DYNAMIC STABILITY AND CONTROL CHARACTERISTICS OF THE AIRCRAFT

In order to gain an appreciation of the basic flying qualities of the Boeing B-747 aircraft and the way in which they vary over the flight envelope, the stability modes characteristics were obtained from the simulation models for all of the flight conditions available. The modes were characterised by their natural frequencies, damping ratios and time constants as appropriate. These characteristics were then assessed against the requirements for a large class IV transport aeroplane in the American military specification MIL-F-8785C , reference [3] .

8.1 Longitudinal characteristics

The natural frequency ω_n and damping ratio ζ for the short period pitching mode and the phugoid mode are recorded in the following table for all flight conditions.

ALTITUDE (FT)	MACH NUMBER	SHORT PERIOD		PHUGOID	
		ω_n (rad/s)	ζ	ω_n (rad/s)	ζ
1000	0.30	1.019	0.580	0.137	0.046
1000	0.40	1.278	0.584	0.105	0.039
1000	0.50	1.478	0.602	0.076	0.039
1000	0.60	1.621	0.630	0.058	0.084
1000	0.70	1.692	0.680	0.053	0.109
20000	0.50	1.062	0.466	0.091	0.018
20000	0.60	1.225	0.480	0.079	0.032
20000	0.70	1.341	0.511	0.070	0.039
20000	0.80	1.320	0.588	0.029	0.156
40000	0.70	0.905	0.380	0.068	0.036
40000	0.80	0.992	0.409	0.052	0.062
40000	0.90	1.370	0.368	0.042	0.284

8.2 Lateral-directional characteristics

The natural frequency ω_n and damping ratio ζ for the dutch-roll mode and the time constants for the non-oscillatory roll subsidence mode and the spiral mode are recorded in the following table for all flight conditions.

ALTITUDE (FT)	MACH NUMBER	DUTCH-ROLL ω_n (rad/s)	DUTCH-ROLL ζ	ROLL MODE TIME CTE (sec)	SPIRAL TIME CTE (sec)
1000	0.30	0.789	0.159	1.079	17.8
1000	0.40	1.014	0.168	0.775	38.3
1000	0.50	1.197	0.174	0.630	35.9
1000	0.60	1.370	0.186	0.548	37.7
1000	0.70	1.553	0.192	0.490	39.5
20000	0.50	0.923	0.113	1.106	62.1
20000	0.60	1.058	0.116	0.945	59.5
20000	0.70	1.207	0.127	0.844	63.3
20000	0.80	1.373	0.125	0.730	68.0
40000	0.70	0.847	0.090	1.780	625
40000	0.80	1.026	0.060	1.450	83.3
40000	0.90	1.074	0.114	1.620	*

8.3 Flying qualities evaluation

To evaluate the flying qualities of the B-747 against the requirements of MIL-F-8785C , it was assumed that since the B-747 is a very large transport aircraft it is a class III type and that flight phase category B , cruising flight , was applicable. The natural frequency , damping ratio and time constant for each mode are plotted as functions of altitude and mach number as appropriate, the data being taken from tables I and II. Each plot also shows the level 1, 2 and 3 minima as determined from MIL-F-8785C. The plots are shown on figures : 8.3.a ; 8.3.b ; 8.3.c and 8.3.d and include all modes with the exception of the spiral mode. The spiral mode was not plotted in this way since it meets the level 1 flying qualities requirement for all flight conditions investigated including the case where the mode is unstable. A review of the plots indicates, as would be expected, that the aircraft characteristics are fairly benign and broadly meet the requirements with the exception of the dutch roll mode.

The deficiencies in the dutch-roll mode are augmented to an acceptable level in this aircraft with an artificial yaw damper system, a solution which is very commonly applied to large transport aircraft.

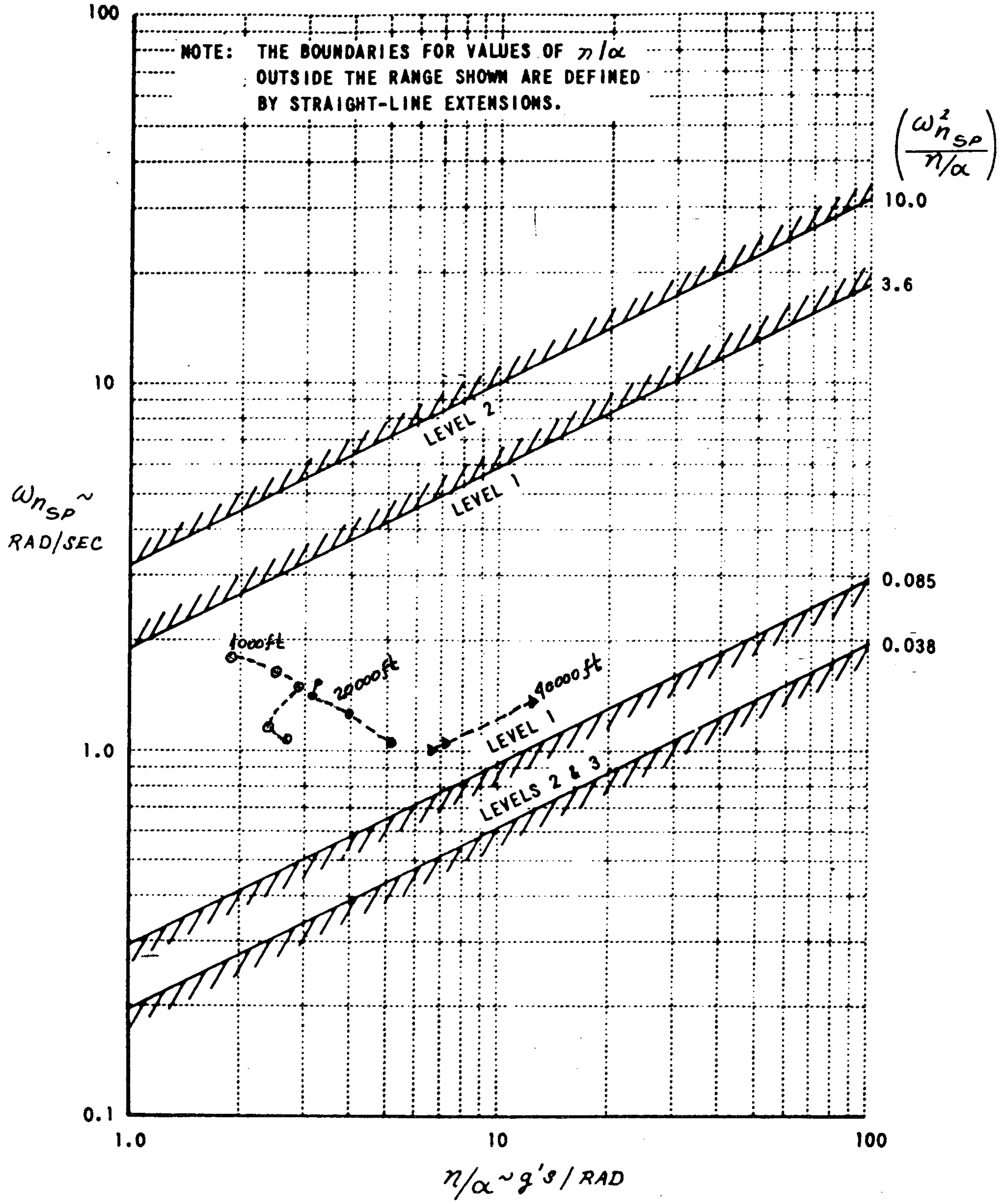


Figure 8.3.a short period frequency plot with respect to MIL-F-8785C requeriments.

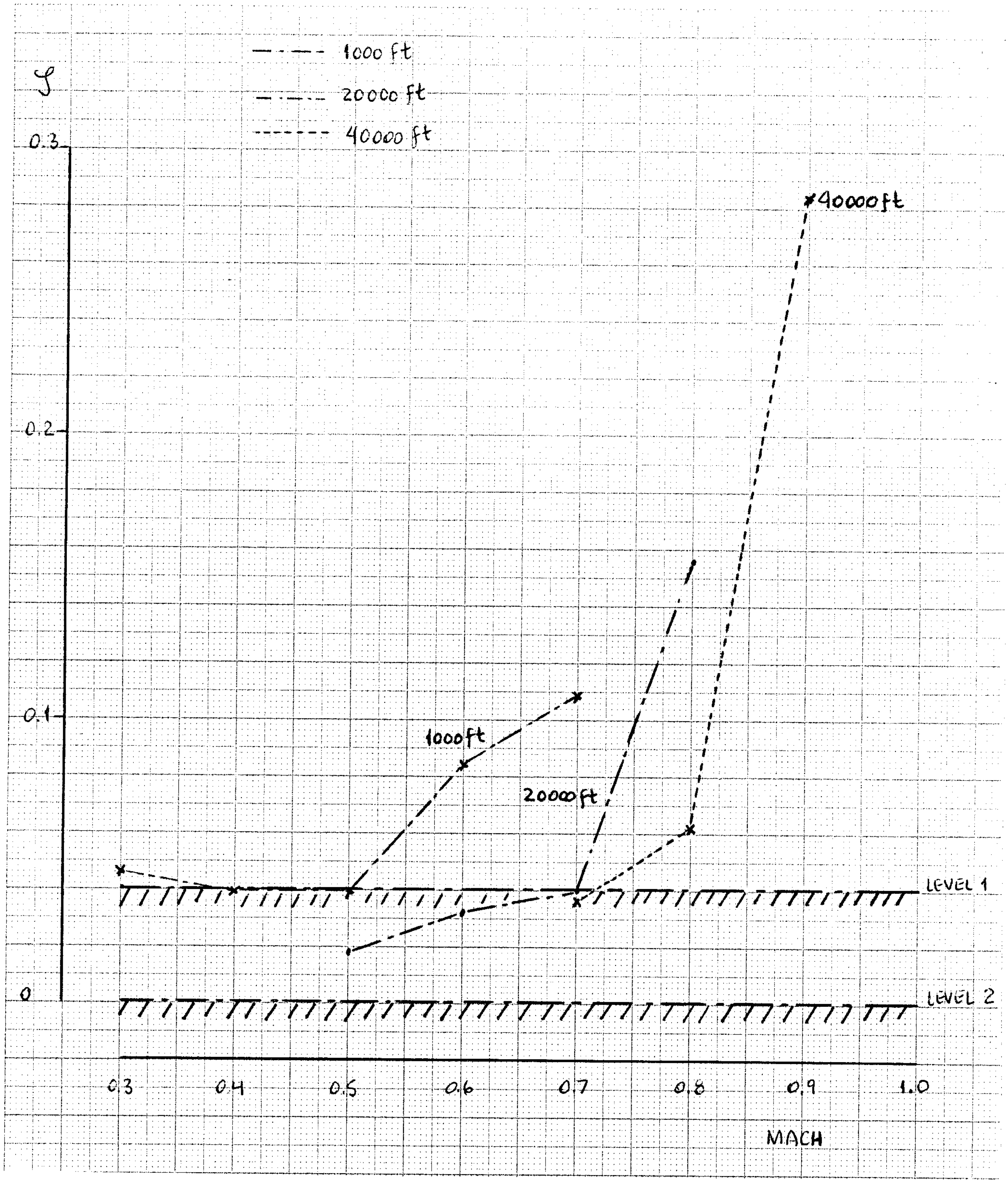


Figure 8.3.b Phugoid damping ratio plots with respect to MIL-F-8785C requirements.

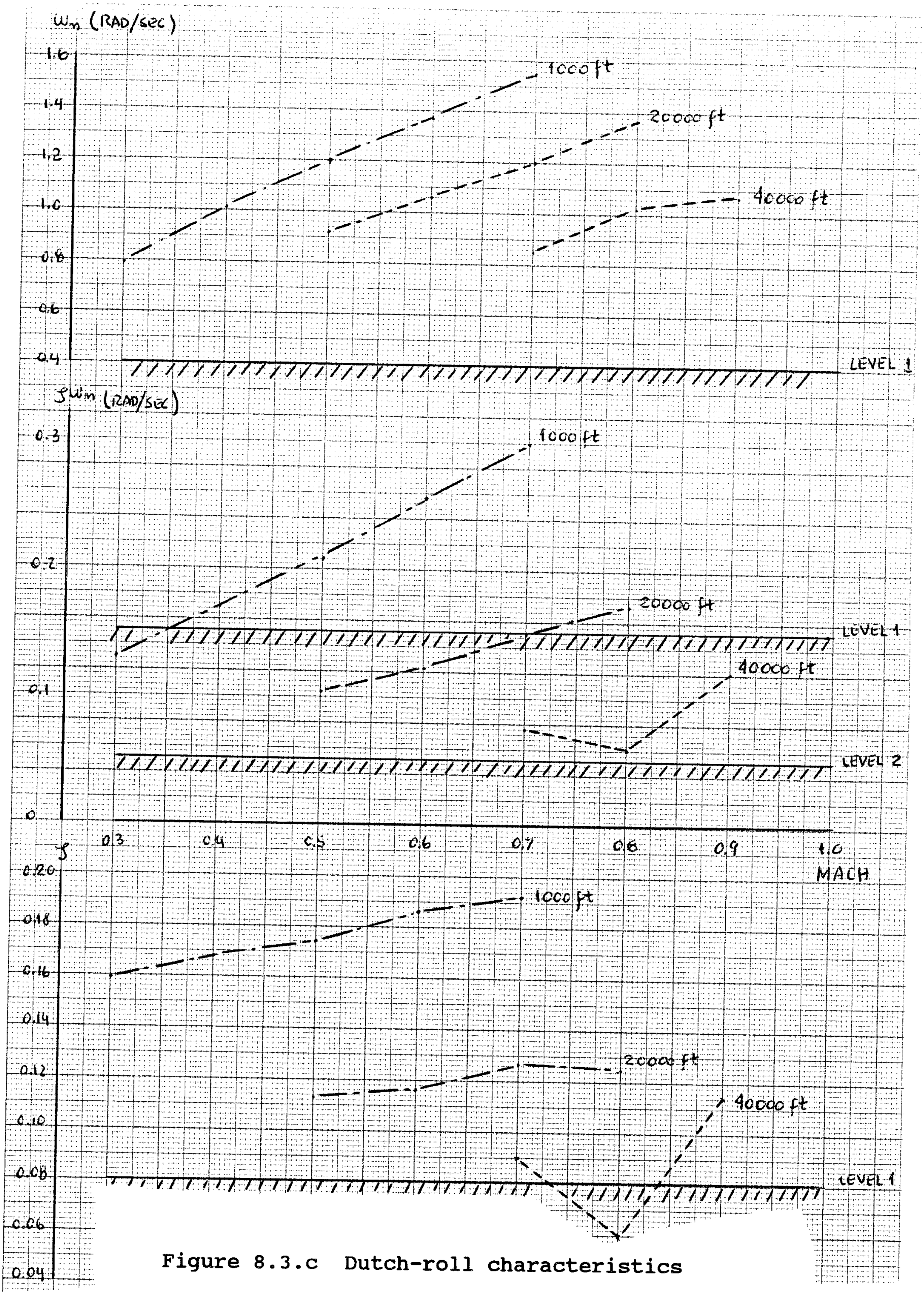


Figure 8.3.c Dutch-roll characteristics with respect to MIL-F-8785C.

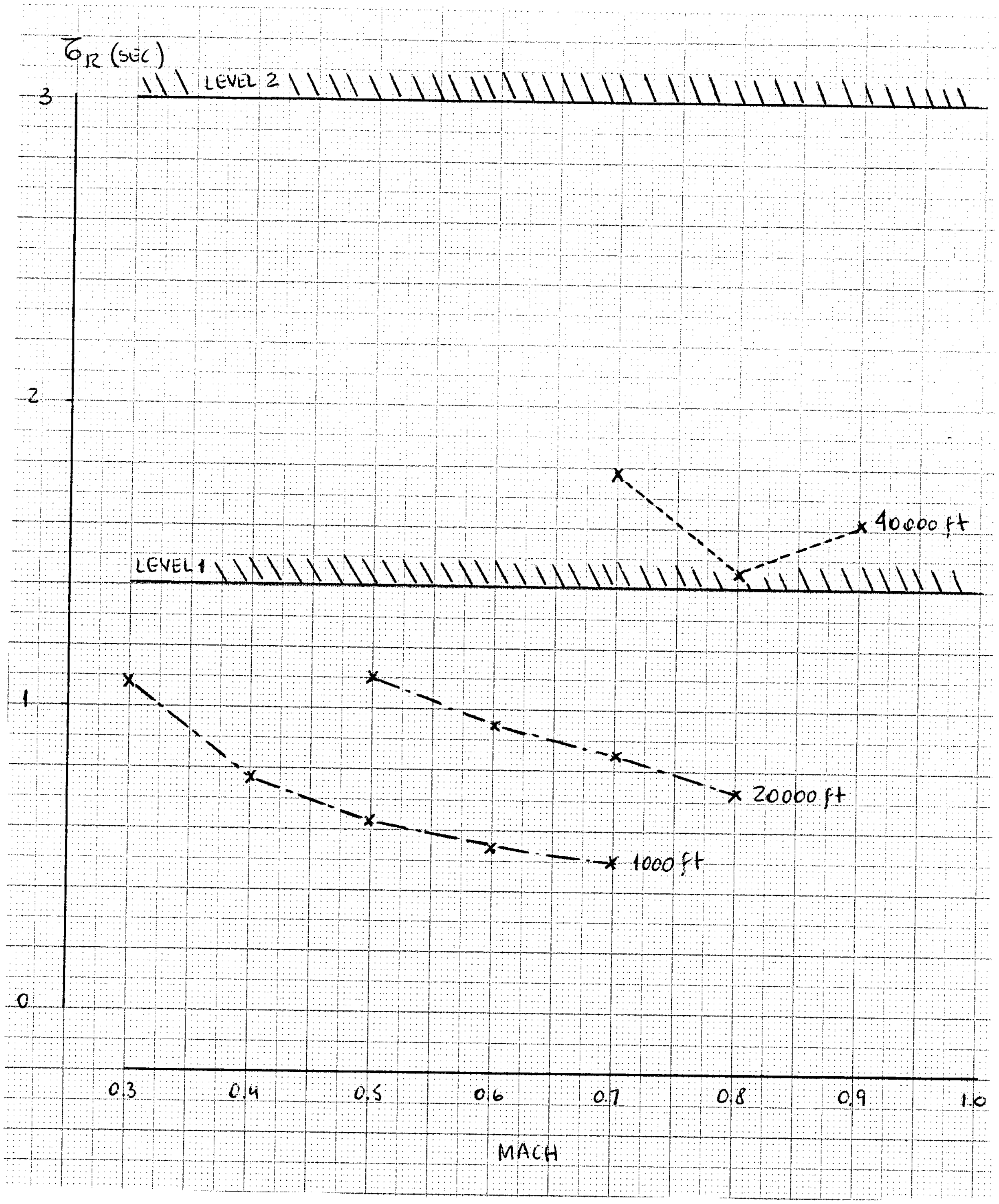


Figure 8.3.d Roll-mode time constant plots relative to MIL-F-8785C.

9. CONCLUSIONS

A decoupled linear model and a fully coupled non-linear model of the B-747 have been developed from a small perturbation aerodynamic description of the aircraft. Two corresponding computer simulations have been programmed and evaluated for use as tools in flight control system development studies. Both the linear and non-linear models produce response time histories which correlate very well and which both agree with similar responses taken from the source publication. It is concluded that the simulation models provide a reasonable dynamic representation of the B-747 aircraft over its flight envelope. However, it should be noted that the simulation models do not include detailed description of engine dynamics.

10. REFERENCES

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[3] MIL-F-8785C. " Flying qualities of piloted airplanes." November 1980 . DOD, United States Government.

[4] Mitchell , E. and Gauthier.
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Mitchell and Gauthier Associates
Concord, Mass. 01742.

[5] CODAS - II
" Control system design and simulation ".
Golten and Verwer Partners 1989.

APPENDIX 1

TABLES OF THE AERODYNAMIC DATA

```
TABLE XCL,2,16,3  ...

/  0.250  ,  0.300  ,   0.350  ,  0.400  ,  0.450  ...
,  0.500  ,  0.550  ,   0.600  ,  0.650  ,  0.700  ...
,  0.750  ,  0.800  ,   0.850  ,  0.900  ,  0.950  ...
,  1.000                                           ...
,  0.000  , 20000.0 , 40000.0                      ...
,  1.500  ,  1.000  ,   0.780  ,  0.590  ,  0.465  ...
,  0.340  ,  0.300  ,   0.260  ,  0.2225 ,  0.185  ...
,  0.165  ,  0.145  ,   0.125  ,  0.105  ,  0.085  ...
,  0.065                                           ...
,  2.450  ,  2.050  ,  1.650   ,  1.250  ,  0.975  ...
,  0.700  ,  0.600  ,  0.500   ,  0.460  ,  0.420  ...
,  0.3725 ,  0.325  ,  0.275   ,  0.225  ,  0.200  ...
,  0.175                                           ...
,  4.200  ,  3.700  ,  3.200   ,  2.700  ,  2.200  ...
,  1.700  ,  1.525  ,  1.350   ,  1.150  ,  0.950  ...
,  0.850  ,  0.750  ,  0.655   ,  0.560  ,  0.510  ...
,  0.460  /

TABLE XCD,2,16,3  ...

/  0.250   ,  0.300   ,  0.350  ,  0.400   ,  0.450   ...
,  0.500   ,  0.550   ,  0.600  ,  0.650   ,  0.700   ...
,  0.750   ,  0.800   ,  0.850  ,  0.900   ,  0.950   ...
,  1.000                                              ...
,  0.000   , 20000.0  , 40000.0                       ...
,  0.135   ,  0.095   ,  0.055  ,  0.0375  ,  0.0262  ...
,  0.0195  ,  0.01875 ,  0.0180 ,  0.0175  ,  0.0170  ...
,  0.0165  ,  0.0160  ,  0.0155 ,  0.0150  ,  0.0145  ...
,  0.0140                                             ...
,  0.355   ,  0.285   ,  0.215  ,  0.145   ,  0.075   ...
,  0.042   ,  0.03675 ,  0.0315 ,  0.02825 ,  0.0250  ...
,  0.020   ,  0.019   ,  0.0185 ,  0.020   ,  0.0325  ...
,  0.045                                              ...
,  0.500   ,  0.455   ,  0.410  ,  0.365   ,  0.320   ...
,  0.275   ,  0.230   ,  0.185  ,  0.140   ,  0.095   ...
,  0.07375 ,  0.0525  ,  0.0458 ,  0.045   ,  0.050   ...
,  0.055   /
```

```
TABLE XCLDE,2,16,3 ...

/    0.250   ,   0.300   ,   0.350   ,   0.400   ,   0.450   ...
,    0.500   ,   0.550   ,   0.600   ,   0.650   ,   0.700   ...
,    0.750   ,   0.800   ,   0.850   ,   0.900   ,   0.950   ...
,    1.000                                                   ...
,    0.000   , 20000.0   , 40000.0                           ...
,    0.3375  ,   0.320   ,   0.3025  ,   0.285   ,   0.265   ...
,    0.245   ,   0.225   ,   0.205   ,   0.1875  ,   0.170   ...
,    0.1525  ,   0.135   ,   0.1175  ,   0.100   ,   0.0825  ...
,    0.065                                                   ...
,    0.385   ,   0.380   ,   0.375   ,   0.370   ,   0.365   ...
,    0.360   ,   0.350   ,   0.340   ,   0.3275  ,   0.315   ...
,    0.295   ,   0.275   ,   0.2375  ,   0.200   ,   0.150   ...
,    0.100                                                   ...
,    0.535   ,   0.520   ,   0.505   ,   0.490   ,   0.475   ...
,    0.460   ,   0.445   ,   0.430   ,   0.415   ,   0.400   ...
,    0.385   ,   0.370   ,   0.340   ,   0.300   ,   0.250   ...
,    0.200   /


TABLE XCMDE,2,16,3 ...

/    0.250   ,   0.300   ,   0.350   ,   0.400   ,   0.450   ...
,    0.500   ,   0.550   ,   0.600   ,   0.650   ,   0.700   ...
,    0.750   ,   0.800   ,   0.850   ,   0.900   ,   0.950   ...
,    1.000                                                   ...
,    0.000   , 20000.0   , 40000.0                           ...
,  -1.3325   ,  -1.260   ,  -1.1875  ,  -1.115   ,  -1.0425  ...
,  -0.970    ,  -0.890   ,  -0.810   ,  -0.730   ,  -0.650   ...
,  -0.570    ,  -0.490   ,  -0.410   ,  -0.330   ,  -0.250   ...
,  -0.170                                                    ...
,  -1.550    ,  -1.520   ,  -1.490   ,  -1.460   ,  -1.430   ...
,  -1.400    ,  -1.365   ,  -1.330   ,  -1.285   ,  -1.240   ...
,  -1.170    ,  -1.080   ,  -0.940   ,  -0.800   ,  -0.600   ...
,  -0.400                                                    ...
,  -2.275    ,  -2.200   ,  -2.125   ,  -2.050   ,  -1.975   ...
,  -1.900    ,  -1.825   ,  -1.750   ,  -1.675   ,  -1.600   ...
,  -1.525    ,  -1.450   ,  -1.325   ,  -1.200   ,  -1.000   ...
,  -0.800    /
```

```
TABLE XCLM,2,16,3 ...

/   0.250   ,   0.300   ,   0.350   ,   0.400   ,   0.450   ...
,   0.500   ,   0.550   ,   0.600   ,   0.650   ,   0.700   ...
,   0.750   ,   0.800   ,   0.850   ,   0.900   ,   0.950   ...
,   1.000                                                   ...
,   0.000   , 20000.0   , 40000.0                           ...
,  -0.375   ,  -0.300   ,  -0.225   ,  -0.150   ,  -0.075   ...
,   0.000   ,   0.075   ,   0.150   ,   0.225   ,   0.300   ...
,   0.375   ,   0.450   ,   0.525   ,   0.600   ,   0.675   ...
,   0.750                                                   ...
,  -0.600   ,  -0.500   ,  -0.400   ,  -0.300   ,  -0.200   ...
,  -0.100   ,   0.000   ,   0.100   ,   0.150   ,   0.200   ...
,   0.150   ,   0.100   ,   0.025   ,  -0.050   ,  -0.500   ...
,  -0.950                                                   ...
,   1.200   ,   1.100   ,   1.000   ,   0.900   ,   0.800   ...
,   0.700   ,   0.600   ,   0.500   ,   0.400   ,   0.300   ...
,   0.200   ,   0.100   ,  -0.100   ,  -0.300   ,  -0.500   ...
,  -0.700   /


TABLE XCDM,2,16,3 ...

/   0.250   ,   0.300   ,   0.350   ,   0.400   ,   0.450   ...
,   0.500   ,   0.550   ,   0.600   ,   0.650   ,   0.700   ...
,   0.750   ,   0.800   ,   0.850   ,   0.900   ,   0.950   ...
,   1.000                                                   ...
,   0.000   , 20000.0   , 40000.0                           ...
,   0.000   ,   0.000   ,   0.000   ,   0.000   ,   0.000   ...
,   0.000   ,   0.000   ,   0.000   ,   0.000   ,   0.000   ...
,   0.000   ,   0.000   ,   0.000   ,   0.000   ,   0.000   ...
,   0.000                                                   ...
,  -0.045   ,  -0.040   ,  -0.035   ,  -0.030   ,  -0.025   ...
,  -0.020   ,  -0.0150  ,  -0.010   ,  -0.005   ,   0.000   ...
,   0.005   ,   0.010   ,   0.045   ,   0.1825  ,   0.320   ...
,   0.4575                                                  ...
,  -0.1125  ,  -0.100   ,  -0.0875  ,  -0.075   ,  -0.0625  ...
,  -0.050   ,  -0.0375  ,  -0.0250  ,  -0.0125  ,   0.000   ...
,   0.0125  ,   0.025   ,   0.1375  ,   0.250   ,   0.3625  ...
,   0.475   /
```

```
TABLE XCMM,2,16,3 ...

/   0.250   ,   0.300   ,   0.350   ,   0.400   ,   0.450   ...
,   0.500   ,   0.550   ,   0.600   ,   0.650   ,   0.700   ...
,   0.750   ,   0.800   ,   0.850   ,   0.900   ,   0.950   ...
,   1.000                                                   ...
,   0.000   , 20000.0   , 40000.0                           ...
,   0.255   ,   0.200   ,   0.145   ,   0.090   ,   0.045   ...
,   0.000   ,  -0.030   ,  -0.060   ,  -0.050   ,  -0.040   ...
,  -0.030   ,  -0.020   ,  -0.010   ,   0.000   ,   0.010   ...
,   0.020                                                   ...
,   0.270   ,   0.240   ,   0.210   ,   0.180   ,   0.150   ...
,   0.120   ,   0.090   ,   0.060   ,   0.030   ,   0.000   ...
,  -0.050   ,  -0.100   ,  -0.253   ,  -0.200   ,   0.100   ...
,   0.040                                                   ...
,  -0.0202  ,  -0.0320  ,  -0.0440  ,  -0.0550  ,  -0.0670  ...
,  -0.0790  ,  -0.0910  ,  -0.1030  ,  -0.1150  ,  -0.1260  ...
,  -0.1380  ,  -0.1500  ,  -0.1700  ,  -0.0660  ,   0.4800  ...
,   1.0800  /


TABLE XCMA,2,16,3 ...

/   0.250   ,   0.300   ,   0.350   ,   0.400   ,   0.450   ...
,   0.500   ,   0.550   ,   0.600   ,   0.650   ,   0.700   ...
,   0.750   ,   0.800   ,   0.850   ,   0.900   ,   0.950   ...
,   1.000                                                   ...
,   0.000   , 20000.0   , 40000.0                           ...
,  -1.275   ,  -1.200   ,  -1.125   ,  -1.050   ,  -0.960   ...
,  -0.870   ,  -0.780   ,  -0.690   ,  -0.595   ,  -0.500   ...
,  -0.405   ,  -0.310   ,  -0.215   ,  -0.120   ,  -0.025   ...
,   0.070                                                   ...
,  -1.335   ,  -1.300   ,  -1.265   ,  -1.230   ,  -1.185   ...
,  -1.140   ,  -1.095   ,  -1.050   ,  -0.975   ,  -0.900   ...
,  -0.760   ,  -0.620   ,  -0.800   ,  -1.200   ,  -1.600   ...
,  -2.000                                                   ...
,  -1.625   ,  -1.570   ,  -1.515   ,  -1.460   ,  -1.405   ...
,  -1.350   ,  -1.295   ,  -1.240   ,  -1.185   ,  -1.130   ...
,  -1.075   ,  -1.020   ,  -1.200   ,  -1.600   ,  -2.000   ...
,  -2.400   /
```

```
TABLE XCMAP,2,16,3 ...

/    0.250    ,   0.300    ,   0.350    ,   0.400    ,   0.450    ...
,    0.500    ,   0.550    ,   0.600    ,   0.650    ,   0.700    ...
,    0.750    ,   0.800    ,   0.850    ,   0.900    ,   0.950    ...
,    1.000                                                       ...
,    0.000    , 20000.0    , 40000.0                             ...
,   -3.000    ,  -3.000    ,  -3.000    ,  -3.000    ,  -3.000    ...
,   -3.000    ,  -3.000    ,  -3.000    ,  -3.1000   ,  -3.200    ...
,   -3.400    ,  -3.600    ,  -3.800    ,  -4.000    ,  -4.200    ...
,   -4.400                                                       ...
,   -2.200    ,  -2.400    ,  -2.600    ,  -2.800    ,  -3.000    ...
,   -3.200    ,  -3.400    ,  -3.600    ,  -3.900    ,  -4.200    ...
,   -4.700    ,  -5.200    ,  -5.900    ,  -6.600    ,  -4.500    ...
,   -2.400                                                       ...
,   -3.500    ,  -3.600    ,  -3.700    ,  -3.800    ,  -3.900    ...
,   -4.000    ,  -4.100    ,  -4.200    ,  -4.500    ,  -4.800    ...
,   -5.400    ,  -6.000    ,  -7.300    ,  -8.600    ,  -5.800    ...
,   -3.000    /


TABLE XCMQ,2,16,3 ...

/    0.250    ,   0.300    ,   0.350    ,   0.400    ,   0.450    ...
,    0.500    ,   0.550    ,   0.600    ,   0.650    ,   0.700    ...
,    0.750    ,   0.800    ,   0.850    ,   0.900    ,   0.950    ...
,    1.000                                                       ...
,    0.000    , 20000.0    , 40000.0                             ...
, -20.70      , -20.20     , -19.70     , -19.20     , -18.75     ...
, -18.30      , -17.85     , -17.40     , -17.10     , -16.80     ...
, -16.30      , -15.80     , -15.30     , -14.80     , -14.30     ...
, -13.80                                                         ...
, -21.86      , -21.60     , -21.33     , -21.06     , -20.80     ...
, -20.53      , -20.26     , -20.00     , -20.00     , -20.00     ...
, -20.10      , -20.20     , -20.70     , -20.00     , -18.00     ...
, -16.00                                                         ...
, -22.05      , -22.10     , -22.15     , -22.20     , -22.25     ...
, -22.30      , -22.35     , -22.40     , -22.50     , -22.60     ...
, -23.30      , -24.00     , -24.85     , -24.00     , -22.00     ...
, -20.00      /
```

```
TABLE XCLA,2,16,3 ...

/    0.250     ,   0.300    ,   0.350    ,   0.400    ,   0.450     ...
,    0.500     ,   0.550    ,   0.600    ,   0.650    ,   0.700     ...
,    0.750     ,   0.800    ,   0.850    ,   0.900    ,   0.950     ...
,    1.000                                                          ...
,    0.000     , 20000.0    , 40000.0                               ...
,    4.800     ,   4.70     ,   4.60     ,   4.50     ,   4.40      ...
,    4.300     ,   4.20     ,   4.10     ,   4.00     ,   3.90      ...
,    3.85      ,   3.60     ,   3.35     ,   3.10     ,   2.85      ...
,    2.60                                                           ...
,    4.90      ,   4.85     ,   4.80     ,   4.75     ,   4.70      ...
,    4.65      ,   4.625    ,   4.60     ,   4.55     ,   4.50      ...
,    4.35      ,   4.20     ,   4.50     ,   4.80     ,   3.70      ...
,    1.95                                                           ...
,    5.90      ,   5.80     ,   5.70     ,   5.60     ,   5.50      ...
,    5.40      ,   5.30     ,   5.20     ,   5.10     ,   5.00      ...
,    4.95      ,   4.90     ,   5.20     ,   5.55     ,   4.30      ...
,    3.425     /


TABLE XCDA,2,16,3 ...

/    0.250     ,   0.300    ,   0.350    ,   0.400    ,   0.450     ...
,    0.500     ,   0.550    ,   0.600    ,   0.650    ,   0.700     ...
,    0.750     ,   0.800    ,   0.850    ,   0.900    ,   0.950     ...
,    1.000                                                          ...
,    0.000     , 20000.0    , 40000.0                               ...
,    0.700     ,   0.530    ,   0.360    ,   0.250    ,   0.160     ...
,    0.120     ,   0.085    ,   0.050    ,   0.025    ,   0.000     ...
,   -0.025     ,  -0.050    ,  -0.075    ,  -0.100    ,  -0.1250    ...
,   -0.150                                                          ...
,    2.880     ,   2.320    ,   1.760    ,   1.200    ,   0.640     ...
,    0.380     ,   0.300    ,   0.250    ,   0.200    ,   0.140     ...
,    0.110     ,   0.090    ,   0.090    ,   0.090    ,   0.090     ...
,    0.090                                                          ...
,    8.190     ,   7.390    ,   6.590    ,   5.790    ,   4.990     ...
,    4.190     ,   3.400    ,   2.600    ,   1.800    ,   1.000     ...
,    0.500     ,   0.430    ,   0.470    ,   0.520    ,   0.530     ...
,    0.540     /
```

```
TABLE XCLAP,2,9,3 ...

/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600     ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                  ...
,   0.000    , 20000.0    , 40000.0                               ...
,  -6.69     ,  -6.67     ,  -6.61     ,  -6.56     ,  -6.51      ...
,  -6.46     ,  -6.41     ,  -6.36     ,  -6.31                   ...
,  -6.82     ,  -6.78     ,  -6.70     ,  -6.62     ,  -6.54      ...
,  -6.32     ,  -5.98     ,  -5.63     ,  -5.28                   ...
,  -7.98     ,  -7.79     ,  -7.40     ,  -7.01     ,  -6.62      ...
,  -6.23     ,  -5.84     ,  -5.36     ,  -4.88     /

TABLE XCYB,2,16,3 ...

/   0.250    ,   0.300    ,   0.350    ,   0.400    ,   0.450     ...
,   0.500    ,   0.550    ,   0.600    ,   0.650    ,   0.700     ...
,   0.750    ,   0.800    ,   0.850    ,   0.900    ,   0.950     ...
,   1.000                                                         ...
,   0.000    , 20000.0    , 40000.0                               ...
,  -0.850    ,  -0.850    ,  -0.850    ,  -0.850    ,  -0.850     ...
,  -0.850    ,  -0.845    ,  -0.840    ,  -0.820    ,  -0.800     ...
,  -0.780    ,  -0.760    ,  -0.740    ,  -0.720    ,  -0.700     ...
,  -0.680                                                         ...
,  -0.9625   ,  -0.950    ,  -0.9375   ,  -0.925    ,  -0.9125    ...
,  -0.900    ,  -0.8875   ,  -0.875    ,  -0.8625   ,  -0.850     ...
,  -0.825    ,  -0.800    ,  -0.800    ,  -0.800    ,  -0.800     ...
,  -0.800                                                         ...
,  -0.925    ,  -0.920    ,  -0.915    ,  -0.910    ,  -0.905     ...
,  -0.900    ,  -0.895    ,  -0.890    ,  -0.885    ,  -0.880     ...
,  -0.875    ,  -0.870    ,  -0.855    ,  -0.840    ,  -0.840     ...
,  -0.840    /

TABLE XCNB,2,16,3 ...

/   0.250    ,   0.300    ,   0.350    ,   0.400    ,   0.450     ...
,   0.500    ,   0.550    ,   0.600    ,   0.650    ,   0.700     ...
,   0.750    ,   0.800    ,   0.850    ,   0.900    ,   0.950     ...
,   1.000                                                         ...
,   0.000    , 20000.0    , 40000.0                               ...
,   0.1375   ,   0.1400   ,   0.1425   ,   0.1450   ,   0.1450    ...
,   0.1450   ,   0.1435   ,   0.1420   ,   0.1420   ,   0.1420    ...
,   0.1420   ,   0.1420   ,   0.1420   ,   0.1420   ,   0.1420    ...
,   0.1420                                                        ...
,   0.100    ,   0.110    ,   0.120    ,   0.130    ,   0.140     ...
,   0.150    ,   0.155    ,   0.160    ,   0.165    ,   0.170     ...
,   0.175    ,   0.180    ,   0.190    ,   0.180    ,   0.160     ...
,   0.140                                                         ...
,   0.035    ,   0.050    ,   0.065    ,   0.080    ,   0.095     ...
,   0.110    ,   0.125    ,   0.140    ,   0.155    ,   0.170     ...
,   0.185    ,   0.200    ,   0.210    ,   0.2083   ,   0.195     ...
,   0.1816   /
```

```
TABLE XCRB,2,16,3 ...

/   0.250    ,   0.300    ,   0.350    ,   0.400    ,   0.450    ...
,   0.500    ,   0.550    ,   0.600    ,   0.650    ,   0.700    ...
,   0.750    ,   0.800    ,   0.850    ,   0.900    ,   0.950    ...
,   1.000                                                       ...
,   0.000    , 20000.0    , 40000.0                             ...
,  -0.1725   ,  -0.1750   ,  -0.1775   ,  -0.180    ,  -0.1725   ...
,  -0.1650   ,  -0.1575   ,  -0.1500   ,  -0.1475   ,  -0.1450   ...
,  -0.1425   ,  -0.1400   ,  -0.1375   ,  -0.1350   ,  -0.1325   ...
,  -0.1300                                                      ...
,   0.1825   ,   0.0950   ,   0.0075   ,  -0.080    ,  -0.1675   ...
,  -0.190    ,  -0.1840   ,  -0.1750   ,  -0.1675   ,  -0.160    ...
,  -0.160    ,  -0.160    ,  -0.1625   ,  -0.1650   ,  -0.030    ...
,   0.1050                                                      ...
,   0.560    ,   0.480    ,   0.400    ,   0.320    ,   0.240    ...
,   0.160    ,   0.080    ,   0.000    ,  -0.080    ,  -0.160    ...
,  -0.240    ,  -0.275    ,  -0.230    ,  -0.1000   ,  -0.030    ...
,  -0.0014   /

TABLE XCRP,2,16,3 ...

/   0.250    ,   0.300    ,   0.350    ,   0.400    ,   0.450    ...
,   0.500    ,   0.550    ,   0.600    ,   0.650    ,   0.700    ...
,   0.750    ,   0.800    ,   0.850    ,   0.900    ,   0.950    ...
,   1.000                                                       ...
,   0.000    , 20000.0    , 40000.0                             ...
,  -0.3225   ,  -0.320    ,  -0.3175   ,  -0.3150   ,  -0.3125   ...
,  -0.310    ,  -0.305    ,  -0.300    ,  -0.295    ,  -0.290    ...
,  -0.285    ,  -0.280    ,  -0.275    ,  -0.270    ,  -0.265    ...
,  -0.260                                                       ...
,  -0.100    ,  -0.155    ,  -0.210    ,  -0.265    ,  -0.320    ...
,  -0.330    ,  -0.3275   ,  -0.325    ,  -0.3225   ,  -0.320    ...
,  -0.325    ,  -0.330    ,  -0.315    ,  -0.300    ,  -0.275    ...
,  -0.250                                                       ...
,  -0.275    ,  -0.280    ,  -0.285    ,  -0.290    ,  -0.295    ...
,  -0.300    ,  -0.305    ,  -0.310    ,  -0.315    ,  -0.320    ...
,  -0.325    ,  -0.330    ,  -0.315    ,  -0.300    ,  -0.270    ...
,  -0.240    /
```

```
TABLE XCNP,2,16,3 ...

/    0.250    ,   0.300    ,   0.350    ,   0.400    ,   0.450    ...
,    0.500    ,   0.550    ,   0.600    ,   0.650    ,   0.700    ...
,    0.750    ,   0.800    ,   0.850    ,   0.900    ,   0.950    ...
,    1.000                                                        ...
,    0.000    , 20000.0    , 40000.0                              ...
,   -0.0540   ,  -0.066    ,  -0.064    ,  -0.048    ,  -0.032    ...
,   -0.020    ,  -0.012    ,  -0.004    ,   0.0036   ,   0.011    ...
,    0.019    ,   0.026    ,   0.034    ,   0.042    ,   0.049    ...
,    0.057                                                        ...
,    0.478    ,   0.338    ,   0.198    ,   0.058    ,  -0.066    ...
,   -0.0665   ,  -0.054    ,  -0.041    ,  -0.028    ,  -0.0157   ...
,   -0.0052   ,   0.0033   ,   0.010    ,   0.013    ,   0.016    ...
,    0.019                                                        ...
,   -0.106    ,  -0.100    ,  -0.095    ,  -0.090    ,  -0.084    ...
,   -0.079    ,  -0.074    ,  -0.0686   ,  -0.063    ,  -0.058    ...
,   -0.052    ,  -0.043    ,  -0.0155   ,   0.022    ,   0.0595   ...
,    0.097    /


TABLE XCRR,2,16,3 ...

/    0.250    ,   0.300    ,   0.350    ,   0.400    ,   0.450    ...
,    0.500    ,   0.550    ,   0.600    ,   0.650    ,   0.700    ...
,    0.750    ,   0.800    ,   0.850    ,   0.900    ,   0.950    ...
,    1.000                                                        ...
,    0.000    , 20000.0    , 40000.0                              ...
,    0.028    ,   0.023    ,   0.180    ,   0.150    ,   0.120    ...
,    0.095    ,   0.080    ,   0.065    ,   0.055    ,   0.0475   ...
,    0.040    ,   0.0325   ,   0.025    ,   0.0175   ,   0.010    ...
,    0.0025                                                       ...
,    0.3775   ,   0.345    ,   0.3125   ,   0.280    ,   0.2475   ...
,    0.215    ,   0.1875   ,   0.160    ,   0.140    ,   0.125    ...
,    0.110    ,   0.100    ,   0.080    ,   0.050    ,   0.020    ...
,   -0.010                                                        ...
,    0.195    ,   0.205    ,   0.215    ,   0.225    ,   0.235    ...
,    0.245    ,   0.255    ,   0.265    ,   0.275    ,   0.285    ...
,    0.295    ,   0.305    ,   0.285    ,   0.200    ,   0.115    ...
,    0.030    /
```

```
TABLE XCNR,2,16,3 ...

/   0.250     ,  0.300     ,  0.350     ,  0.400     ,  0.450     ...
,   0.500     ,  0.550     ,  0.600     ,  0.650     ,  0.700     ...
,   0.750     ,  0.800     ,  0.850     ,  0.900     ,  0.950     ...
,   1.000                                                        ...
,   0.000     , 20000.0    , 40000.0                             ...
,  -0.275     , -0.270     , -0.265     , -0.260     , -0.255     ...
,  -0.250     , -0.24625   , -0.2425    , -0.23875   , -0.235     ...
,  -0.23125   , -0.2275    , -0.22375   , -0.220     , -0.21625   ...
,  -0.2125                                                       ...
,  -0.325     , -0.315     , -0.305     , -0.295     , -0.285     ...
,  -0.277     , -0.276     , -0.275     , -0.275     , -0.275     ...
,  -0.270     , -0.265     , -0.256     , -0.248     , -0.240     ...
,  -0.231                                                        ...
,  -0.2975    , -0.300     , -0.3025    , -0.305     , -0.3075    ...
,  -0.310     , -0.3125    , -0.3150    , -0.3175    , -0.320     ...
,  -0.3225    , -0.325     , -0.3275    , -0.330     , -0.322     ...
,  -0.314     /


TABLE XCRDA,2,16,3 ...

/   0.250     ,  0.300     ,  0.350     ,  0.400     ,  0.450     ...
,   0.500     ,  0.550     ,  0.600     ,  0.650     ,  0.700     ...
,   0.750     ,  0.800     ,  0.850     ,  0.900     ,  0.950     ...
,   1.000                                                        ...
,   0.000     , 20000.0    , 40000.0                             ...
,   0.012     ,  0.0126    ,  0.0132    ,  0.935     ,  0.473     ...
,   0.0123    ,  0.0115    ,  0.0108    ,  0.0101    ,  0.0094    ...
,   0.0087    ,  0.0080    ,  0.0073    ,  0.0066    ,  0.0059    ...
,   0.0052                                                       ...
,  -0.0040    ,  0.000     ,  0.0040    ,  0.0080    ,  0.0120    ...
,   0.0132    ,  0.01295   ,  0.0127    ,  0.01235   ,  0.0120    ...
,   0.0120    ,  0.0120    ,  0.0115    ,  0.010     ,  0.0074    ...
,   0.0048                                                       ...
,   0.00655   ,  0.0072    ,  0.00785   ,  0.0085    ,  0.00915   ...
,   0.0098    ,  0.01045   ,  0.0111    ,  0.01175   ,  0.0124    ...
,   0.01305   ,  0.0137    ,  0.0140    ,  0.0140    ,  0.0118    ...
,   0.0096    /
```

```
TABLE XCNDA,2,16,3 ...

/   0.250    ,  0.300    ,  0.350    ,  0.400    ,  0.450    ...
,   0.500    ,  0.550    ,  0.600    ,  0.650    ,  0.700    ...
,   0.750    ,  0.800    ,  0.850    ,  0.900    ,  0.950    ...
,   1.000                                                    ...
,   0.000    , 20000.0   , 40000.0                           ...
,   0.000    ,  0.0012   ,  0.0024   ,  0.0028   ,  0.0031   ...
,   0.0030   ,  0.00275  ,  0.0025   ,  0.00225  ,  0.0020   ...
,   0.00175  ,  0.00150  ,  0.00125  ,  0.0010   ,  0.00075  ...
,   0.0005                                                   ...
,  -0.00115  , -0.0006   , -0.0005   ,  0.0005   ,  0.00105  ...
,   0.0016   ,  0.00185  ,  0.0021   ,  0.0021   ,  0.0018   ...
,   0.00125  ,  0.0007   , -0.0006   , -0.0026   , -0.0046   ...
,  -0.0066                                                   ...
,  -0.0010   , -0.0008   , -0.0006   , -0.0004   , -0.0002   ...
,   0.000    ,  0.0002   ,  0.0004   ,  0.0006   ,  0.0008   ...
,   0.0005   ,  0.0002   , -0.0008   , -0.0027   , -0.0037   ...
,  -0.0047   /


TABLE XCYDR,2,16,3 ...

/   0.250    ,  0.300    ,  0.350    ,  0.400    ,  0.450    ...
,   0.500    ,  0.550    ,  0.600    ,  0.650    ,  0.700    ...
,   0.750    ,  0.800    ,  0.850    ,  0.900    ,  0.950    ...
,   1.000                                                    ...
,   0.000    , 20000.0   , 40000.0                           ...
,   0.175    ,  0.165    ,  0.155    ,  0.145    ,  0.135    ...
,   0.125    ,  0.1125   ,  0.100    ,  0.0875   ,  0.075    ...
,   0.0625   ,  0.050    ,  0.0375   ,  0.0250   ,  0.0125   ...
,   0.000                                                    ...
,   0.18875  ,  0.180    ,  0.17125  ,  0.1625   ,  0.15375  ...
,   0.145    ,  0.13625  ,  0.1275   ,  0.11875  ,  0.110    ...
,   0.0975   ,  0.085    ,  0.0725   ,  0.060    ,  0.0475   ...
,   0.035                                                    ...
,   0.2075   ,  0.200    ,  0.1925   ,  0.1850   ,  0.1775   ...
,   0.170    ,  0.1625   ,  0.1550   ,  0.1475   ,  0.140    ...
,   0.1325   ,  0.1250   ,  0.095    ,  0.065    ,  0.030    ...
,  -0.005    /
```

```
TABLE XCNDR,2,16,3 ...

/   0.250    ,   0.300    ,   0.350    ,   0.400    ,   0.450    ...
,   0.500    ,   0.550    ,   0.600    ,   0.650    ,   0.700    ...
,   0.750    ,   0.800    ,   0.850    ,   0.900    ,   0.950    ...
,   1.000                                                        ...
,   0.000    , 20000.0    , 40000.0                              ...
,  -0.108    ,  -0.105    ,  -0.102    ,  -0.099    ,  -0.0955   ...
,  -0.092    ,  -0.086    ,  -0.080    ,  -0.073    ,  -0.066    ...
,  -0.059    ,  -0.052    ,  -0.045    ,  -0.038    ,  -0.031    ...
,  -0.024                                                        ...
,  -0.138    ,  -0.132    ,  -0.126    ,  -0.120    ,  -0.114    ...
,  -0.108    ,  -0.109    ,  -0.110    ,  -0.105    ,  -0.100    ...
,  -0.0995   ,  -0.099    ,  -0.090    ,  -0.081    ,  -0.072    ...
,  -0.063                                                        ...
,  -0.0555   ,  -0.062    ,  -0.0685   ,  -0.0750   ,  -0.0815   ...
,  -0.088    ,  -0.0945   ,  -0.101    ,  -0.1075   ,  -0.114    ...
,  -0.1205   ,  -0.1270   ,  -0.1160   ,  -0.098    ,  -0.064    ...
,  -0.030    /


TABLE XCRDR,2,16,3 ...

/   0.250    ,   0.300    ,   0.350    ,   0.400    ,   0.450    ...
,   0.500    ,   0.550    ,   0.600    ,   0.650    ,   0.700    ...
,   0.750    ,   0.800    ,   0.850    ,   0.900    ,   0.950    ...
,   1.000                                                        ...
,   0.000    , 20000.0    , 40000.0                              ...
,  -0.007    ,   0.000    ,   0.007    ,   0.010    ,   0.012    ...
,   0.0115   ,   0.01075  ,   0.010    ,   0.00925  ,   0.0085   ...
,   0.00775  ,   0.0070   ,   0.00625  ,   0.0055   ,   0.00475  ...
,   0.0040                                                       ...
,  -0.020    ,  -0.0150   ,  -0.010    ,  -0.005    ,   0.000    ...
,   0.005    ,   0.00675  ,   0.0085   ,   0.00925  ,   0.010    ...
,   0.00925  ,   0.0085   ,   0.0060   ,   0.0035   ,   0.0010   ...
,  -0.0015                                                       ...
,  -0.01775  ,  -0.0155   ,  -0.01325  ,  -0.011    ,  -0.00875  ...
,  -0.0065   ,  -0.00425  ,  -0.0020   ,   0.00025  ,   0.0025   ...
,   0.00475  ,   0.0070   ,   0.0070   ,   0.0055   ,  -0.0036   ...
,  -0.0128   /
```

APPENDIX 2

ACSL SIMULATION PROGRAM OF THE LONGITUDINAL MODEL

```
PROGRAM              LONGITUDINAL SIMULATION

INITIAL

 "  -------   FLIGHT CONDITION   -----------------  "

   CONSTANT  HFT0    = 20000.0   ,  MACH   =  0.50
   CONSTANT  GAMA0   = 0.0       ,  weight  =  564032.0
   CONSTANT  IY      = .323e+8   ,  ITH     =  0.043630
   CONSTANT  TU      =  0.0

 "  ---------------  AERODYNAMIC DATA  ----------  "

   CONSTANT  CM      =   0.0     ,  CDDE   =  0.0

 "  ------------  GENERAL PARAMETERS  ------------ "

   CONSTANT  grav    =  32.2  ,  ROSL  =  1.225
   CONSTANT  S       =  5500. ,  MAC   =  27.31
   CONSTANT  LT14    =  103.0 ,  LTH   =  10.0

 "  -------   INITIALIZATION OF VARIABLES  ------  "

   CONSTANT  U       =  0.0   ,  W     =   0.0    ,  de  = 0.0
   CONSTANT  Q       =  0.0   ,  zei   =  -40000.0
   CONSTANT  ui      =  0.0   ,  wi    =   0.0
   CONSTANT  qi      =  0.0   ,  tetai =   0.0
   CONSTANT  xei     =  0.0

 "  -----  TIME TO FINISH THE SIMULATION  -------------- "

   CONSTANT  TFIM    =  10.0

 "  -----  PARAMETERS TO PERFORM THE PILOT MANEUVER ------- "

   CONSTANT  T0      =  0.0    , T1    =   0.3    ,  T2      =   2.3
   CONSTANT  T3      =  2.6    , DPOSG =   5.0


      "  -----  PRELIMINARIES CALCULATIONS  --------     "

     "  -----  TABLE OF TRIM ANGLE OF ATTACK   ------- "

   TABLE ALFTR,2,14,3 ...
    /  0.30    ,   0.35    ,   0.40    ,   0.45    ,   0.50    ...
    ,  0.55    ,   0.60    ,   0.65    ,   0.70    ,   0.75    ...
    ,  0.80    ,   0.85    ,   0.90    ,   0.95                ...
    ,  0.00    , 20000.0   , 40000.0                           ...
    ,  8.8     ,   6.6     ,   4.3     ,   3.1     ,   2.0     ...
    ,  1.2     ,   0.5     ,   0.0     ,  -0.6     ,  -1.2     ...
    , -1.8     ,  -2.4     ,  -3.0     ,  -3.6                 ...
    , 21.0     ,  17.0     ,  13.0     ,   9.0     ,   6.8     ...
    ,  5.0     ,   3.7     ,   2.5     ,   1.7     ,   0.7     ...
    ,  0.0     ,  -0.7     ,  -1.4     ,  -2.1                 ...
    , 18.6     ,  17.2     ,  15.8     ,  14.4     ,  13.0     ...
    , 11.6     ,  10.2     ,   8.8     ,   7.4     ,   6.0     ...
    ,  4.5     ,   3.4     ,   2.2     ,   1.0     /
```

```
"   --------  altitude in meters  -------------  "

     H0       =  0.3048 * HFT0

"  ------    PARAMETERS OF PILOT MANEUVER   ----------------  "

     DPOS     =  0.01745 * DPOSG
     AUXMA1   =  DPOS/(T2-T3)


"  -------  SPEED OF SOUND IN AIR   ------------------------  "

     if(HFT0-36089.0.ge.0.0)go to 97
     VSOM    =  SQRT(115800.05-(0.79615*HFT0))
     go to 96
 97..VSOM    =  293.91
 96..A       =  3.281 * VSOM

"  -----  AIR MASS DENSITY   -------------------------------  "

     ROSI    =  ROSL * (   ( 1.0 - ( 2.2567e-05 ) * H0 ) ** 4.25532 )
     RO      =  1.94 * 0.001 * ROSI

"  --------  INITIAL PARAMETERS ----------------------------   "

   "  --------  steady state linear velocity   ------------  "
     VT0     =  A * MACH
   "  --------  steady state angle of attack   ------------  "
     ALFA0   =  0.01745 * ALFTR(MACH,HFT0)
   "  --------  thrust angle    ---------------------------  "
     KSI0    =  ITH + ALFA0
   "  --------  steady state pitch angle  -----------------  "
     TETA0   =  GAMA0 + ALFA0
   "  --------  inverse of IY  ----------------------------  "
     IYIN    =  1./IY
   "  --------  mass of the aircraft  ---------------------  "
     mass    =  weight/grav
   "  --------  inverse of mass    ------------------------  "
     MIN     =  1./mass
   "  --------  sines and cosines of alfa0 and teta0  -----  "
     COA0    =  COS(ALFA0)
     SEA0    =  SIN(ALFA0)
     SEA02   =  SEA0 * SEA0
     COA02   =  COA0 * COA0
     SECOA0  =  SEA0 * COA0
     COT0    =  COS(TETA0)
     ICOT0   =  1./COT0
     SET0    =  SIN(TETA0)
     TANT0   =  TAN(TETA0)
   "  -------   initial velocities    ---------------------  "
     U0      =  VT0 * COA0
     W0      =  VT0 * SEA0
     U1      =  VT0
```

```
  "  -------  inverse of the velocities    ------------------ "
     U0IN    =  1./U0
     VT0IN   =  1./VT0
  "  -------  total variables    --------------------------- "
     UT      =  U0    +  ui
     WT      =  W0    +  wi
     QT      =  Q0    +  qi
     TETAT   =  TETA0 +  tetai

"    ---------    TABLES OF AERODYNAMIC DATA   ---------------- "

  TABLE XCL,2,9,3  ...
   /  0.250  ,   0.300  ,   0.400  ,   0.500  ,   0.600  ...
   ,  0.700  ,   0.800  ,   0.900  ,   1.0               ...
   ,  0.000  , 20000.0  , 40000.0                        ...
   ,  1.500  ,   1.000  ,   0.590  ,   0.340  ,   0.260  ...
   ,  0.185  ,   0.145  ,   0.105  ,   0.065             ...
   ,  2.450  ,   2.050  ,   1.250  ,   0.70   ,   0.50   ...
   ,  0.420  ,   0.325  ,   0.225  ,   0.175             ...
   ,  4.200  ,   3.700  ,   2.700  ,   1.700  ,   1.350  ...
   ,  0.950  ,   0.75   ,   0.560  ,   0.460  /

  TABLE XCD,2,9,3  ...
   /  0.250   ,   0.300   ,   0.40    ,   0.500   ,   0.650   ...
   ,  0.700   ,   0.80    ,   0.900   ,   1.00                ...
   ,  0.000   , 20000.0   , 40000.0                           ...
   ,  0.135   ,   0.095   ,   0.0375  ,   0.0195  ,   0.0180  ...
   ,  0.0170  ,   0.0160  ,   0.0150  ,   0.0140              ...
   ,  0.355   ,   0.285   ,   0.145   ,   0.042   ,   0.0315  ...
   ,  0.025   ,   0.019   ,   0.020   ,   0.045               ...
   ,  0.500   ,   0.455   ,   0.365   ,   0.275   ,   0.185   ...
   ,  0.095   ,   0.0525  ,   0.045   ,   0.055   /

  TABLE XCLDE,2,9,3 ...
   /  0.250   ,   0.300   ,   0.40    ,   0.500   ,   0.60    ...
   ,  0.700   ,   0.80    ,   0.900   ,   1.00                ...
   ,  0.000   , 20000.0   , 40000.0                           ...
   ,  0.3375  ,   0.320   ,   0.285   ,   0.245   ,   0.205   ...
   ,  0.170   ,   0.135   ,   0.100   ,   0.065               ...
   ,  0.385   ,   0.380   ,   0.370   ,   0.360   ,   0.340   ...
   ,  0.315   ,   0.275   ,   0.200   ,   0.100               ...
   ,  0.535   ,   0.520   ,   0.490   ,   0.460   ,   0.430   ...
   ,  0.400   ,   0.370   ,   0.300   ,   0.200   /

  TABLE XCMDE,2,9,3 ...
   /  0.250   ,   0.300   ,   0.40    ,   0.500   ,   0.600   ...
   ,  0.700   ,   0.80    ,   0.900   ,   1.000               ...
   ,  0.000   , 20000.0   , 40000.0                           ...
   , -1.3325  ,  -1.260   ,  -1.115   ,  -0.970   ,  -0.810   ...
   , -0.650   ,  -0.490   ,  -0.330   ,  -0.170               ...
   , -1.550   ,  -1.520   ,  -1.460   ,  -1.400   ,  -1.330   ...
   , -1.240   ,  -1.080   ,  -0.800   ,  -0.400               ...
   , -2.275   ,  -2.200   ,  -2.050   ,  -1.900   ,  -1.750   ...
   , -1.600   ,  -1.450   ,  -1.200   ,  -0.800   /
```

```
TABLE XCLM,2,9,3 ...
/    0.250    ,    0.300    ,    0.40     ,    0.500    ,    0.60     ...
,    0.700    ,    0.800    ,    0.900    ,    1.0                   ...
,    0.000    ,  20000.0    ,  40000.0                              ...
,   -0.375    ,   -0.300    ,   -0.150    ,    0.000    ,    0.150    ...
,    0.300    ,    0.450    ,    0.600    ,    0.750                 ...
,   -0.600    ,   -0.500    ,   -0.300    ,   -0.100    ,    0.100    ...
,    0.200    ,    0.100    ,   -0.050    ,   -0.950                 ...
,    1.200    ,    1.100    ,    0.900    ,    0.700    ,    0.500    ...
,    0.300    ,    0.100    ,   -0.300    ,   -0.700    /

TABLE XCDM,2,9,3 ...
/    0.250    ,    0.300    ,    0.40     ,    0.500    ,    0.60     ...
,    0.700    ,    0.80     ,    0.900    ,    1.00                  ...
,    0.000    ,  20000.0    ,  40000.0                              ...
,    0.000    ,    0.000    ,    0.000    ,    0.000    ,    0.000    ...
,    0.000    ,    0.000    ,    0.000    ,    0.000                 ...
,   -0.045    ,   -0.040    ,   -0.030    ,   -0.020    ,   -0.010    ...
,    0.000    ,    0.010    ,    0.1825   ,    0.4575                ...
,   -0.1125   ,   -0.100    ,   -0.075    ,   -0.050    ,   -0.025    ...
,    0.000    ,    0.025    ,    0.250    ,    0.475    /

TABLE XCMM,2,9,3 ...
/    0.250    ,    0.300    ,    0.40     ,    0.500    ,    0.60     ...
,    0.700    ,    0.80     ,    0.900    ,    1.00                  ...
,    0.000    ,  20000.0    ,  40000.0                              ...
,    0.255    ,    0.200    ,    0.090    ,    0.000    ,   -0.060    ...
,   -0.040    ,   -0.020    ,    0.000    ,    0.020                 ...
,    0.270    ,    0.240    ,    0.180    ,    0.120    ,    0.060    ...
,    0.000    ,   -0.100    ,   -0.200    ,    0.040                 ...
,   -0.0202   ,   -0.032    ,   -0.055    ,   -0.079    ,   -0.103    ...
,   -0.126    ,   -0.150    ,   -0.066    ,    1.080    /

TABLE XCMA,2,9,3 ...
/    0.250    ,    0.300    ,    0.40     ,    0.500    ,    0.600    ...
,    0.700    ,    0.800    ,    0.900    ,    1.000                 ...
,    0.000    ,  20000.0    ,  40000.0                              ...
,   -1.275    ,   -1.200    ,   -1.050    ,   -0.870    ,   -0.690    ...
,   -0.500    ,   -0.310    ,   -0.120    ,    0.070                 ...
,   -1.335    ,   -1.300    ,   -1.230    ,   -1.140    ,   -1.050    ...
,   -0.900    ,   -0.620    ,   -1.200    ,   -2.000                 ...
,   -1.625    ,   -1.570    ,   -1.460    ,   -1.350    ,   -1.240    ...
,   -1.130    ,   -1.020    ,   -1.600    ,   -2.400    /

TABLE XCMAP,2,9,3 ...
/    0.250    ,    0.300    ,    0.400    ,    0.500    ,    0.600    ...
,    0.700    ,    0.800    ,    0.900    ,    1.000                 ...
,    0.000    ,  20000.0    ,  40000.0                              ...
,   -3.00     ,   -3.00     ,   -3.00     ,   -3.00     ,   -3.00     ...
,   -3.20     ,   -3.60     ,   -4.00     ,   -4.40                  ...
,   -2.20     ,   -2.40     ,   -2.80     ,   -3.20     ,   -3.60     ...
,   -4.20     ,   -5.20     ,   -6.60     ,   -2.40                  ...
,   -3.50     ,   -3.60     ,   -3.80     ,   -4.00     ,   -4.20     ...
,   -4.80     ,   -6.00     ,   -8.60     ,   -3.00     /
```

```
TABLE XCMQ,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
, -20.70     , -20.20     , -19.20     , -18.30     , -17.40     ...
, -16.80     , -15.80     , -14.80     , -13.80                  ...
, -21.86     , -21.60     , -21.06     , -20.53     , -20.00     ...
, -20.00     , -20.20     , -20.00     , -16.00                  ...
, -22.05     , -22.10     , -22.20     , -22.30     , -22.40     ...
, -22.60     , -24.00     , -24.00     , -20.00     /

TABLE XCLA,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
,   4.80     ,   4.70     ,   4.50     ,   4.30     ,   4.10     ...
,   3.90     ,   3.60     ,   3.10     ,   2.60                  ...
,   4.90     ,   4.85     ,   4.75     ,   4.65     ,   4.60     ...
,   4.50     ,   4.20     ,   4.80     ,   1.95                  ...
,   5.90     ,   5.80     ,   5.60     ,   5.40     ,   5.20     ...
,   5.00     ,   4.90     ,   5.55     ,   3.425    /

TABLE XCDA,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
,   0.70     ,   0.53     ,   0.25     ,   0.120    ,   0.050    ...
,   0.00     ,  -0.050    ,  -0.10     ,  -0.15                  ...
,   2.88     ,   2.320    ,   1.20     ,   0.38     ,   0.25     ...
,   0.14     ,   0.090    ,   0.090    ,   0.090                 ...
,   8.19     ,   7.39     ,   5.79     ,   4.19     ,   2.60     ...
,   1.00     ,   0.43     ,   0.52     ,   0.54     /

TABLE XCLAP,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
,  -6.69     ,  -6.67     ,  -6.61     ,  -6.56     ,  -6.51     ...
,  -6.46     ,  -6.41     ,  -6.36     ,  -6.31                  ...
,  -6.82     ,  -6.78     ,  -6.70     ,  -6.62     ,  -6.54     ...
,  -6.32     ,  -5.98     ,  -5.63     ,  -5.28                  ...
,  -7.98     ,  -7.79     ,  -7.40     ,  -7.01     ,  -6.62     ...
,  -6.23     ,  -5.84     ,  -5.36     ,  -4.88     /
```

```
"  ------                 NONDIMENSIONAL                 ------------- "
"  ------  COEFICIENTS AND AERODYNAMIC DERIVATIVES     ----------- "
"  --------                 STABILITY AXIS             ----------------- "

          CL     =   XCL(MACH,HFT0)
          CD     =   XCD(MACH,HFT0)
          CLDE   =   XCLDE(MACH,HFT0)
          CMDE   =   XCMDE(MACH,HFT0)
          CLM    =   XCLM(MACH,HFT0)
          CDM    =   XCDM(MACH,HFT0)
          CMM    =   XCMM(MACH,HFT0)
          CMA    =   XCMA(MACH,HFT0)
          CMAP   =   XCMAP(MACH,HFT0)
          CMQ    =   XCMQ(MACH,HFT0)
          CLA    =   XCLA(MACH,HFT0)
          CDA    =   XCDA(MACH,HFT0)
          CLAP   =   XCLAP(MACH,HFT0)
          CLQ    =  -(MAC*CMQ)/LT14

"  -------     AUXILIARY FACTORS     ------------------------------   "

     FAT1  =  RO*S*U0*MIN
     FAT2  = -0.5*RO*S*VT0*VT0*MIN
     FAT3  =  RO*S*MAC
     FAT4  =  FAT3*U0*IYIN

"  ----                   NONDIMENSIONAL                ------------- "
"  ----   LONGITUDINAL COEFICIENTS AND DERIVATIVES IN   -------  "
"  ----                    BODY AXIS                    ------------- "

     CN     =  CL * COA0 + CD * SEA0
     CX     =  CD * COA0 - CL * SEA0
     CNA    =  (CLA+CD) * COA0 + (CDA-CL) * SEA0
     CNAP   =  CLAP * COA0
     CNQ    =  CLQ * COA0
     CNM    =  CLM * COA0 + CDM * SEA0
     CNDE   =  CLDE * COA0 + CDDE * SEA0
     CXA    =  (CDA-CL) * COA0 - (CLA+CD) * SEA0
     CXAP   =  -CLAP * SEA0
     CXQ    =  -CLQ * SEA0
     CXM    =  CDM * COA0 - CLM * SEA0
     CXDE   =  CDDE * COA0 - CLDE * SEA0

"  -------          DIMENSIONAL      ---------------------------- "
"  ------     LONGITUDINAL DERIVATIVES     --------------------   "
"  --------         IN BODY AXIS      ---------------------------  "

  XU   =  FAT1 * (-0.5*MACH*CXM - CX + 0.5*W0*CXA*U0IN )
  XW   =  FAT1 * 0.5 *(-CXA -2.*W0*(CX+0.5*MACH*CXM)*U0IN)
  XDE  =  FAT2 * CXDE
  XUST =  XU + TU * COS(KSI0)
  XQ   =  0.0
```

```
ZU   =  FAT1 * (-0.5*MACH*CNM - CN + (0.5*W0*CNA) * U0IN)
ZW   =  FAT1 * 0.5 *(-CNA -2.* W0 * (CN+MACH*0.5*CNM) * U0IN)
ZWP  =  -0.25 * MIN * FAT3 * U0 * CNAP * VT0IN
ZDE  =  FAT2 * CNDE
ZUST =  ZU - TU * SIN(KSI0)
ZQ   =  -CLQ

MU   =  FAT4 * ( 0.5*MACH*CMM + CM - 0.5*W0*CMA*U0IN )
MUST =  MU + LTH * TU * IYIN
MW   =  FAT4 * 0.5 * ( CMA + 2.*W0*U0IN * ( CM+0.5*MACH*CMM ) )
MWP  =  FAT4 * 0.25 * MAC * VT0IN * CMAP
MA   =  U0 * MW
MAP  =  U0 * MWP
MQ   =  FAT3 * MAC * VT0 * CMQ * 0.25 * IYIN
MDE  =  FAT3 * VT0 * VT0 * CMDE * 0.5 * IYIN


" -----  COEFICIENTS OF THE LINEAR LONGITUDINAL MODEL  ----- "

   FAW   =  1./(1.-ZWP)

   a11   =  XUST
   a12   =  XW
   a13   =  XQ - W0
   a14   =  -grav * COT0

   a21   =  ZUST * FAW
   a22   =  ZW * FAW
   a23   =  (ZQ + U0 ) * FAW
   a24   =  -grav * SET0 * FAW

   a31   =  MUST + MWP * ZUST * FAW
   a32   =  MW + ZW * MWP * FAW
   a33   =  MQ + MWP * ( ZQ + U0 ) * FAW
   a34   =  -MWP * grav * SET0 * FAW

   a41   =  0.0
   a42   =  0.0
   a43   =  1.0
   a44   =  0.0

   b11   =  XDE
   b21   =  ZDE * FAW
   b31   =  MDE + MWP * ZDE * FAW
   b41   =  0.0

END $  " of initial "
```

```
DYNAMIC

DERIVATIVE

  "   ---------      PILOT MANEUVER      ----------------------------  "

      PROCEDURAL ( DE = T1,T2,T3,AUXMA1,DPOS )

       IF(T.LE.T1) DE = DPOS * T
       IF(T.LE.T2.AND.T.GT.T1) DE = DPOS
       IF(T.LE.T3.AND.T.GT.T2) DE = AUXMA1 * ( T - T3 )
       IF(T.GT.T3) DE = 0.0

      END $ " of procedural "


"   -----------       EQUATIONS OF MOTION     ----------------------  "

       up   = a11 * u + a12 * w + a13 * q + a14 * teta + b11 * de
       wp   = a21 * u + a22 * w + a23 * q + a24 * teta + b21 * de
       qp   = a31 * u + a32 * w + a33 * q + a34 * teta + b31 * de
    tetap   = a41 * u + a42 * w + a43 * q + a44 * teta + b41 * de

"   -----------     AUXILIARY EQUATIONS       ----------------------  "

     "  -------   acceleration equations   --------------- "
       ax     =  up + WT * q + grav * sin(TETAT)
       az     =  wp - q * UT - grav * cos(TETAT)
       daz    =  wp - q * UT + grav * TETA * SETO
     "  -------  load factor equations   ----------------- "
       nx     =  ax/grav
       nz     =  az/grav
       nlf    = -nz
     "  -------- aircraft displacement relative to earth --------  "
       xep    =  UT * cos(TETAT) + WT * sin(TETAT)
       zep    = -UT * sin(TETAT) + WT * cos(TETAT)
     "  -----------    altitude rate equation    ----------------- "
       hftp   =  UT * sin(TETAT) - WT * cos(TETAT)

 "  -----      INTEGRATION OF THE EQUATIONS      -------------------  "

       U    =    INTEG(up    ,  ui)
       W    =    INTEG(wp    ,  wi)
       Q    =    INTEG(qp    ,  qi)
    TETA    =    INTEG(tetap , tetai)
     HFT    =    INTEG(HFTP  ,  HFTO)
      XE    =    INTEG(XEP   ,  xei)
      ZE    =    INTEG(ZEP   ,  zei)
```

```
"  ----------------     TOTAL VARIABLES      --------------------  "

     H    =     0.3048 * HFT
   UT     =     U0   +  U
   WT     =     W0   +  W
   QT     =     Q0   +  Q
   ALFAT  =     ATAN( WT/UT )
   ALFA   =     ALFAT   - ALFA0
   TETAT  =     TETA0   + TETA

   U1     =    sqrt(ut*ut+wt*wt)

   GAMAT  =     TETAT - ALFAT
   ALFAP  =     WP/UT
   GAMA   =     GAMAT - GAMA0

"  --------------    TRANSFORMATION TO DEGRES   ------------------  "

         QG          =  57.296 * Q
         QPG         =  57.296 * QP
         TETAG       =  57.296 * TETA
         TETAPG      =  57.296 * TETAP
         TETATG      =  57.296 * TETAT
         TETA0G      =  57.296 * TETA0
         ALFAPG      =  57.296 * ALFAP
         ALFATG      =  57.296 * ALFAT
         ALFA0G      =  57.296 * ALFA0
         ALFAG       =  57.296 * ALFA
         GAMATG      =  57.296 * GAMAT
         GAMA0G      =  57.296 * GAMA0
         GAMAG       =  57.296 * GAMA
         DEG         =  57.296 * DE

END $ " of derivative "

      TERMT(T.GE.TFIM)

END $ " of dynamic "


END $ " of Program "
```

APPENDIX 3

ACSL SIMULATION PROGRAM OF THE LATERAL-DIRECTIONAL MODEL

```
PROGRAM               LATERAL-DIRECTIONAL SIMULATION

INITIAL

 "  ------------     FLIGHT CONDITION    -------------------------  "

   CONSTANT  HFT0    = 20000.0 ,  MACH  =  0.50
   CONSTANT  weight   = 564032.0    ,  IXZ  =  870050.0
   CONSTANT  IX     =  .142e+8      ,  IZ   =  .454e+8
   CONSTANT  GAMA0   =  0.0         ,  ITH  =  0.0436330

 "  -----------------   ADITIONAL PARAMETERS   ------------------  "

   CONSTANT  grav    =  32.2  ,  ROSL  =  1.225
   CONSTANT  S       =  5500. ,  b     =  195.68

 "  -----------------   INITIAL VALUES    -----------------------  "

   CONSTANT  beta0 =   0.0   ,  V0    =   0.0
   CONSTANT  vi      =  0.0   ,  ri    =   0.0    ,  pi  =  0.0
   CONSTANT  fii     =  0.0   ,  psii  =   0.0    ,  betai  =  0.0
   CONSTANT  yei     =  0.0

 "  ----------------   MANEUVER PARAMETERS  -------------------  "

   CONSTANT  DA     =   0.0   ,  DR     =   0.0
   CONSTANT  IA     =   1.0   ,  IR     =   0.0

 "  --------------   AERODYNAMIC PARAMETERS  --------------------  "

   CONSTANT  CYR     =   0.0  ,  CYP    =   0.0    ,  CYDA    =   0.0

 "  -----------  TIME TO FINISH THE SIMULATION   ----------------  "

   CONSTANT  TFIM    =  10.0

 "  ------------ PARAMETERS OF THE PILOT MANEUVER   --------------  "

   CONSTANT  T0      =  0.0     , T1     =   0.3    ,  T2       =   2.3
   CONSTANT  T3      =  2.6     , DPOSG =   5.0
```

```
"  -----          PRELIMINARIES CALCULATIONS          ----------------    "

"  ------------  TRIM ANGLE OF ATTACK  --------------------------- "

  TABLE ALFTR,2,14,3 ...
   /    0.30    ,   0.35    ,   0.40    ,   0.45    ,   0.50     ...
   ,    0.55    ,   0.60    ,   0.65    ,   0.70    ,   0.75     ...
   ,    0.80    ,   0.85    ,   0.90    ,   0.95                 ...
   ,    0.00    , 20000.0   , 40000.0                            ...
   ,    8.8     ,   6.0     ,   4.3     ,   3.1     ,   2.0      ...
   ,    1.2     ,   0.5     ,   0.0     ,  -0.6     ,  -1.2      ...
   ,   -1.8     ,  -2.4     ,  -3.0     ,  -3.6                  ...
   ,   21.0     ,  17.0     ,  13.0     ,   9.0     ,   6.8      ...
   ,    5.0     ,   3.7     ,   2.5     ,   1.7     ,   0.7      ...
   ,    0.0     ,  -0.7     ,  -1.4     ,  -2.1                  ...
   ,   18.6     ,  17.2     ,  15.8     ,  14.4     ,  13.0      ...
   ,   11.6     ,  10.2     ,   8.8     ,   7.4     ,   6.0      ...
   ,    4.5     ,   3.4     ,   2.2     ,   1.0     /

"   --------   ALTITUDE IN METERS   ------------------------------   "

      H0       =  0.3048 * HFT0

"   -------   PARAMETERS OF THE MANEUVER   -------------------------- "

      DPOS     =  0.01745 * DPOSG
      AUXMA1   =  DPOS/(T2-T3)

"   --------   SPEED OF SOUND   ------------------------------------- "

      if(HFT0-36089.0.ge.0.0)go to 97
      VSOM     =  SQRT(115800.05-(0.79615*HFT0))
      go to 96
  97..VSOM     =  293.91
  96..A        =  3.281 * VSOM

"  -------  MASS AIR DENSITY   ------------------------------------- "

      ROSI     =  ROSL * (  ( 1.0 - ( 2.2567e-05 ) * H0 ) ** 4.25532 )
      RO       =  1.94 * 0.001 * ROSI
      VT0      =  MACH * A

"  ------------    INITIAL PARAMETERS    -------------------------- "

    "   -------  trim  angle of attack  ---------------  "
      ALFA0    =  0.01745 * ALFTR(MACH,HFT0)
    "   -------  steady state pitch angle  -------------  "
      TETA0    =  GAMA0 + ALFA0
```

```
"  -------  lateral-directional factors  ---------- "
   IXIN    =  1./IX
   IZIN    =  1./IZ
   KLAT    =  1./(1.-(IXZ**2/(IX*IZ)))
"  --------  mass of the aircraft  ------------------ "
   mass    =  weight/grav
"  --------  inverse of the mass  ------------------- "
   MIN     =  1./mass
"  ---  sines , cosines and tang's of alfa0 and teta0  ---- "
   COA0    =  COS(ALFA0)
   SEA0    =  SIN(ALFA0)
   SEA02   =  SEA0 * SEA0
   COA02   =  COA0 * COA0
   SECOA0  =  SEA0 * COA0
   COT0    =  COS(TETA0)
   ICOT0   =  1./COT0
   SET0    =  SIN(TETA0)
   TANT0   =  TAN(TETA0)
   COB0    =  COS(BETA0)
   SEB0    =  SIN(BETA0)
"  --------   initial velocities  ---------------- "
   U0      =  VT0 * COA0 * COB0
   V0      =  VT0 * SEB0
   W0      =  VT0 * SEA0 * COB0
"  --------  inverse of steady state velocity  ----------- "
   VT0IN   =  1./VT0
"  --------  total lateral velocity  ---------------- "
   VT      =  V0    +  vi

"  -------------   AERODYNAMIC TABLES  ------------------------------ "


TABLE XCYB,2,9,3 ...
/   0.250   ,   0.300   ,   0.400   ,   0.500   ,   0.600   ...
,   0.700   ,   0.800   ,   0.900   ,   1.000               ...
,   0.000   , 20000.0   , 40000.0                           ...
,  -0.85    ,  -0.85    ,  -0.85    ,  -0.85    ,  -0.84    ...
,  -0.80    ,  -0.76    ,  -0.72    ,  -0.68                ...
,  -0.9625  ,  -0.95    ,  -0.925   ,  -0.90    ,  -0.875   ...
,  -0.85    ,  -0.80    ,  -0.80    ,  -0.80                ...
,  -0.925   ,  -0.92    ,  -0.91    ,  -0.90    ,  -0.89    ...
,  -0.88    ,  -0.87    ,  -0.84    ,  -0.84    /

TABLE XCNB,2,9,3 ...
/   0.250   ,   0.300   ,   0.400   ,   0.500   ,   0.600   ...
,   0.700   ,   0.800   ,   0.900   ,   1.000               ...
,   0.000   , 20000.0   , 40000.0                           ...
,   0.1375  ,   0.140   ,   0.145   ,   0.145   ,   0.142   ...
,   0.142   ,   0.142   ,   0.142   ,   0.142               ...
,   0.100   ,   0.110   ,   0.130   ,   0.150   ,   0.160   ...
,   0.170   ,   0.18    ,   0.18    ,   0.14                ...
,   0.035   ,   0.050   ,   0.080   ,   0.11    ,   0.14    ...
,   0.17    ,   0.20    ,   0.2083  ,   0.1816  /
```

```
TABLE XCRB,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
,  -0.1725   ,  -0.175    ,  -0.180    ,  -0.165    ,  -0.150    ...
,  -0.145    ,  -0.140    ,  -0.135    ,  -0.130                 ...
,   0.1825   ,   0.095    ,  -0.080    ,  -0.190    ,  -0.175    ...
,  -0.160    ,  -0.160    ,  -0.165    ,   0.105                 ...
,   0.560    ,   0.480    ,   0.320    ,   0.160    ,   0.000    ...
,  -0.160    ,  -0.275    ,  -0.10     ,  -0.0014   /

TABLE XCRP,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
,  -0.3225   ,  -0.320    ,  -0.315    ,  -0.310    ,  -0.300    ...
,  -0.290    ,  -0.280    ,  -0.270    ,  -0.260                 ...
,  -0.10     ,  -0.155    ,  -0.265    ,  -0.33     ,  -0.325    ...
,  -0.32     ,  -0.33     ,  -0.30     ,  -0.25                  ...
,  -0.275    ,  -0.280    ,  -0.290    ,  -0.300    ,  -0.310    ...
,  -0.320    ,  -0.33     ,  -0.30     ,  -0.24     /

TABLE XCNP,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
,  -0.054    ,  -0.066    ,  -0.048    ,  -0.020    ,  -0.004    ...
,   0.011    ,   0.026    ,   0.042    ,   0.057                 ...
,   0.478    ,   0.338    ,   0.058    ,  -0.0665   ,  -0.041    ...
,  -0.0157   ,   0.0033   ,   0.013    ,   0.019                 ...
,  -0.106    ,  -0.100    ,  -0.090    ,  -0.079    ,  -0.0686   ...
,  -0.058    ,  -0.043    ,   0.022    ,   0.097    /

TABLE XCRR,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
,   0.028    ,   0.023    ,   0.150    ,   0.095    ,   0.065    ...
,   0.0475   ,   0.0325   ,   0.0175   ,   0.0025                ...
,   0.3775   ,   0.345    ,   0.280    ,   0.215    ,   0.160    ...
,   0.125    ,   0.100    ,   0.050    ,  -0.010                 ...
,   0.195    ,   0.205    ,   0.225    ,   0.245    ,   0.265    ...
,   0.285    ,   0.305    ,   0.200    ,   0.030    /

TABLE XCNR,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
,  -0.275    ,  -0.270    ,  -0.260    ,  -0.250    ,  -0.2425   ...
,  -0.235    ,  -0.2275   ,  -0.22     ,  -0.2125                ...
,  -0.325    ,  -0.315    ,  -0.295    ,  -0.277    ,  -0.275    ...
,  -0.275    ,  -0.265    ,  -0.248    ,  -0.231                 ...
,  -0.2975   ,  -0.30     ,  -0.305    ,  -0.310    ,  -0.315    ...
,  -0.320    ,  -0.325    ,  -0.33     ,  -0.314    /
```

```
TABLE XCRDA,2,9,3 ...
/    0.250   ,   0.300   ,   0.400   ,   0.500   ,   0.600   ...
,    0.700   ,   0.800   ,   0.900   ,   1.000               ...
,    0.000   , 20000.0   , 40000.0                           ...
,    0.012   ,   0.0126  ,   0.935   ,   0.0123  ,   0.0108  ...
,    0.0094  ,   0.0080  ,   0.0066  ,   0.0052              ...
,   -0.004   ,   0.000   ,   0.008   ,   0.0132  ,   0.0127  ...
,    0.0120  ,   0.0120  ,   0.010   ,   0.0048              ...
,    0.00655 ,   0.0072  ,   0.0085  ,   0.0098  ,   0.0111  ...
,    0.0124  ,   0.0137  ,   0.0140  ,   0.0096  /

TABLE XCNDA,2,9,3 ...
/    0.250   ,   0.300   ,   0.400   ,   0.500   ,   0.600   ...
,    0.700   ,   0.800   ,   0.900   ,   1.000               ...
,    0.000   , 20000.0   , 40000.0                           ...
,    0.000   ,   0.0012  ,   0.0028  ,   0.0030  ,   0.0025  ...
,    0.0020  ,   0.0015  ,   0.0010  ,   0.0005              ...
,   -0.00115 ,  -0.0006  ,   0.0005  ,   0.0016  ,   0.0021  ...
,    0.0018  ,   0.0007  ,  -0.0026  ,  -0.0066              ...
,   -0.001   ,  -0.0008  ,  -0.0004  ,   0.000   ,   0.0004  ...
,    0.0008  ,   0.0002  ,  -0.0027  ,  -0.0047  /

TABLE XCYDR,2,9,3 ...
/    0.250   ,   0.300   ,   0.400   ,   0.500   ,   0.600   ...
,    0.700   ,   0.800   ,   0.900   ,   1.000               ...
,    0.000   , 20000.0   , 40000.0                           ...
,    0.175   ,   0.165   ,   0.145   ,   0.125   ,   0.100   ...
,    0.075   ,   0.050   ,   0.025   ,   0.000               ...
,    0.1887  ,   0.180   ,   0.1625  ,   0.145   ,   0.1275  ...
,    0.11    ,   0.085   ,   0.060   ,   0.035               ...
,    0.2075  ,   0.20    ,   0.185   ,   0.17    ,   0.155   ...
,    0.14    ,   0.125   ,   0.065   ,  -0.005   /

TABLE XCNDR,2,9,3 ...
/    0.250   ,   0.300   ,   0.400   ,   0.500   ,   0.600   ...
,    0.700   ,   0.800   ,   0.900   ,   1.00                ...
,    0.000   , 20000.0   , 40000.0                           ...
,   -0.108   ,  -0.105   ,  -0.099   ,  -0.092   ,  -0.080   ...
,   -0.066   ,  -0.052   ,  -0.038   ,  -0.024               ...
,   -0.138   ,  -0.132   ,  -0.120   ,  -0.108   ,  -0.110   ...
,   -0.10    ,  -0.099   ,  -0.081   ,  -0.063               ...
,   -0.055   ,  -0.062   ,  -0.075   ,  -0.088   ,  -0.101   ...
,   -0.114   ,  -0.127   ,  -0.098   ,  -0.030   /

TABLE XCRDR,2,9,3 ...
/    0.250   ,   0.300   ,   0.400   ,   0.500   ,   0.600   ...
,    0.700   ,   0.800   ,   0.900   ,   1.000               ...
,    0.000   , 20000.0   , 40000.0                           ...
,   -0.007   ,   0.000   ,   0.010   ,   0.0115  ,   0.010   ...
,    0.0085  ,   0.0070  ,   0.0055  ,   0.0040              ...
,   -0.020   ,  -0.015   ,  -0.005   ,   0.005   ,   0.0085  ...
,    0.010   ,   0.0085  ,   0.0035  ,  -0.0015              ...
,   -0.0177  ,  -0.0155  ,  -0.011   ,  -0.0065  ,  -0.0020  ...
,    0.0025  ,   0.0070  ,   0.0055  ,  -0.0128  /
```

```
"  -----------          NONDIMENSIONAL              ---------------  "
"  -----------   AERODYNAMIC DERIVATIVES IN         ---------------  "
"  -----------          STABILITY AXIS              ---------------  "

           CYB    =   XCYB(MACH,HFT0)
           CNB    =   XCNB(MACH,HFT0)
           CRB    =   XCRB(MACH,HFT0)
           CRP    =   XCRP(MACH,HFT0)
           CNP    =   XCNP(MACH,HFT0)
           CRR    =   XCRR(MACH,HFT0)
           CNR    =   XCNR(MACH,HFT0)
           CRDA   =   XCRDA(MACH,HFT0)
           CNDA   =   XCNDA(MACH,HFT0)
           CYDR   =   XCYDR(MACH,HFT0)
           CNDR   =   XCNDR(MACH,HFT0)
           CRDR   =   XCRDR(MACH,HFT0)

"  -------    AUXILIARY FACTORS    ------------------------------  "

      RSV    =  RO * S * VT0
      RSVB   =  RSV * B

"  ----              NONDIMENSIONAL                        --------   "
"  ----     LATERAL AND DIRECTINAL COEFICIENTS             ---------  "
"  ----                BODY AXIS                           ---------  "

      CRBB   =  CRB * COA0 - CNB * SEA0
      CRPB   =  CRP * COA02 - ( CRR + CNP ) * SECOA0 + ...
                CNR * SEA02
      CRRB   =  CRR * COA02 - ( CNR - CRP ) * SECOA0 - ...
                CNP * SEA02
      CRDAB  =  CRDA * COA0 - CNDA * SEA0
      CRDRB  =  CRDR * COA0 - CNDR * SEA0

      CNBB   =  CNB * COA0 + CRB * SEA0
      CNPB   =  CNP * COA02 - ( CNR - CRP ) * SECOA0 - ...
                CRR * SEA02
      CNRB   =  CNR * COA02 + ( CRR + CNP ) * SECOA0 + ...
                CRP * SEA02
      CNDAB  =  CNDA * COA0 + CRDA * SEA0
      CNDRB  =  CNDR * COA0 + CRDR * SEA0

" ------              DIMENSIONAL                       -------------   "
" ------    LATERAL AND DIRECTIONAL DERIVATIVES         -------------   "

    YV      =  RSV * 0.5 * MIN * CYB
    YB      =  VT0 * YV
    YDA     =  RSV * VT0 * 0.5 * MIN * CYDA
    YDR     =  RSV * VT0 * 0.5 * MIN * CYDR
    YDRST   =  RSV * 0.5 * MIN * CYDR
    YDAST   =  RSV * 0.5 * MIN * CYDA
```

```
LB     =  RSVB * VT0 * 0.5 * IXIN * CRBB
LP     =  RSVB * B * 0.25 * IXIN * CRPB
LR     =  RSVB * B * 0.25 * IXIN * CRRB
LDA    =  RSVB * VT0 * 0.5 * IXIN * CRDAB
LDR    =  RSVB * VT0 * 0.5 * IXIN * CRDRB

NB     =  RSVB * VT0 * 0.5 * IZIN * CNBB
NP     =  RSVB * B * 0.25 * IZIN * CNPB
NR     =  RSVB * B * 0.25 * IZIN * CNRB
NDA    =  RSVB * VT0 * 0.5 * IZIN * CNDAB
NDR    =  RSVB * VT0 * 0.5 * IZIN * CNDRB

LBL    =  ( LB + IXZ * NB * IXIN ) * KLAT
LPL    =  ( LP + IXZ * NP * IXIN ) * KLAT
LRL    =  ( LR + IXZ * NR * IXIN ) * KLAT
LDRL   =  ( LDR + IXZ * NDR * IXIN ) * KLAT
LDAL   =  ( LDA + IXZ * NDA * IXIN ) * KLAT

NBL    =  ( NB + IXZ * LB * IZIN ) * KLAT
NPL    =  ( NP + IXZ * LP * IZIN ) * KLAT
NRL    =  ( NR + IXZ * LR * IZIN ) * KLAT
NDRL   =  ( NDR + IXZ * LDR * IZIN ) * KLAT
NDAL   =  ( NDA + IXZ * LDA * IZIN ) * KLAT

" -----   COEFICIENTS OF THE CHARACTERISTIC EQUATION   ------- "

  A   =  1.0
  B   = -(YV + LPL + NRL )
  C   =  (U0 * NBL) / VT0 + LPL*(YV+NRL) - NPL*LRL + ...
        YV*NRL - (W0*LBL)/VT0
  D   = (U0/VT0)*(NPL*LBL-LPL*NBL) + ...
         YV*(NPL*LRL-LPL*NRL) ...
       -(grav/VT0)*(LBL*COT0+NBL*SET0) + ...
        (W0/VT0)*(LBL*NRL-NBL*LRL)
  E   =  (grav/VT0)*((LBL*NRL-NBL*LRL)*COT0 - ...
          (NPL*LBL-LPL*NBL)*SET0)

 " --------  NUMERATOR OF BETA/DA  ---------------------------- "

ABDA  =  YDAST
BBDA  = -YDAST * (LPL + NRL) - (NDAL * U0)/VT0 + ...
          (W0 * LDAL)/VT0
CBDA  =  YDAST * (LPL * NRL - NPL * LRL) + ...
         (LDAL * grav * COT0) / VT0 + ...
         (NDAL * LPL - LDAL * NPL) * (U0/VT0) + ...
         (NDAL * LRL - LDAL * NRL) * (W0/VT0) + ...
         (NDAL * grav * SET0)/VT0
DBDA  =  (NDAL * LRL - LDAL * NRL ) * ((grav*COT0)/VT0) + ...
         (NPL * LDAL - NDAL * LPL) * ((grav*SET0)/VT0)
```

```
" -------- NUMERATOR OF P/DA --------------------------------- "

APDA  =  LDAL
BPDA  =  YDAST * LBL - LDAL * (NRL + YV) + NDAL * LRL
CPDA  =  YDAST * (LRL*NBL - LBL*NRL) + LDAL * YV * NRL ...
        -NDAL * YV * LRL + (LDAL*NBL - NDAL*LBL)*(U0/VT0)
DPDA  = -(grav*SET0/VT0) * (LDAL * NBL - NDAL * LBL)

" --------- NUMERATOR OF R/DA ------------------------------- "

ARDA  =  NDAL
BRDA  =  YDAST * NBL + LDAL * NPL - NDAL * (YV + LPL)
CRDA  =  YDAST * (LBL * NPL - NBL * LPL) - ...
         LDAL * YV * NPL + NDAL * YV * LPL + ...
         (W0/VT0) * (LDAL * NBL - NDAL * LBL)
DRDA  =  ((grav*COT0)/VT0) * (LDAL * NBL - NDAL * LBL)

" --------- NUMERATOR OF FI/DA ------------------------------ "

AFIDA =  APDA + ARDA * TANT0
BFIDA =  BPDA + BRDA * TANT0
CFIDA =  CPDA + CRDA * TANT0

" --------- NUMERATOR OF AY/DA ------------------------------ "

AAYDA  =  VT0 * ABDA
BAYDA  =  VT0 * BBDA + U0 * ARDA - W0 * APDA
CAYDA  =  VT0 * CBDA + U0 * BRDA - W0 * BPDA - ...
          grav * COT0 * AFIDA
DAYDA  =  VT0 * DBDA + U0 * CRDA - W0 * CPDA - ...
          grav * COT0 * BFIDA
EAYDA  =  U0 * DRDA - W0 * DPDA - grav * COT0 * CFIDA

" ---------- NUMERATOR OF BETA/DR ------------------------------ "

ABDR   =  YDRST
BBDR   = -YDRST * (LPL + NRL) - (NDRL * U0)/VT0 + ...
          (W0 * LDRL)/VT0
CBDR   =  YDRST * (LPL * NRL - NPL * LRL) + ...
          (LDRL * grav * COT0)/VT0 + ...
          (NDRL * LPL - LDRL * NPL) * (U0/VT0) + ...
          (W0/VT0) * (NDRL * LRL - LDRL * NRL) + ...
          (NDRL * grav * SET0)/VT0
DBDR   =  ((grav * COT0)/VT0) * (NDRL*LRL - LDRL*NRL) ...
        +((grav * SET0)/VT0) * (NPL * LDRL - NDRL * LPL)
```

```
"  --------   NUMERATOR OF P/DR    --------------------------------  "

     APDR   =   LDRL
     BPDR   =   YDRST*LBL - LDRL*(NRL+YV) + NDRL*LRL
     CPDR   =   YDRST*(LRL*NBL-LBL*NRL) + LDRL*YV*NRL - ...
                NDRL*YV*LRL + (U0/VT0)*(LDRL*NBL-NDRL*LBL)
     DPDR   =   -(grav/VT0)*(LDRL*NBL-NDRL*LBL)*SET0

"  ---------  NUMERATOR OF R/DR   ----------------------------------- "

      ARDR  =   NDRL
      BRDR  =   YDRST*NBL + LDRL*NPL - NDRL*(YV+LPL)
      CRDR  =   YDRST*(LBL*NPL-NBL*LPL) - LDRL*YV*NPL ...
               + NDRL*YV*LPL + (W0/VT0)*(LDRL*NBL-NDRL*LBL)
      DRDR  =    (grav/VT0)*(LDRL*NBL-NDRL*LBL)*COT0

" --------   NUMERATOR OF FI/DR    ------------------------------------  "

      AFIDR  =  APDR + ARDR * TANT0
      BFIDR  =  BPDR + BRDR * TANT0
      CFIDR  =  CPDR + CRDR * TANT0

"  -------   NUMERATOR OF AY/DR    ------------------------------------ "

     AAYDR  =  VT0 * ABDR
     BAYDR  =  VT0 * BBDR + U0 * ARDR - W0 * APDR
     CAYDR  =  VT0 * CBDR + U0 * BRDR - W0 * BPDR - ...
               grav * COT0 * AFIDR
     DAYDR  =  VT0 * DBDR + U0 * CRDR - W0 * CPDR - ...
               grav * COT0 * BFIDR
     EAYDR  =  U0 * DRDR - W0 * DPDR - grav * COT0 * CFIDR
```

```
 "  --------  COEFICIENTS OF THE LATERAL AND DIRECTIONAL       ---------- "
 "  --------                LINEAR MODEL                        ---------  "

        a51   =   YV
        a52   =   W0 * VT0IN
        a53   =  -U0 * VT0IN
        a54   =   grav * COT0 * VT0IN

        a61   =   LBL
        a62   =   LPL
        a63   =   LRL
        a64   =   0.0

        a71   =   NBL
        a72   =   NPL
        a73   =   NRL
        a74   =   0.0

        a81   =   0.0
        a82   =   1.0
        a83   =   TANT0
        a84   =   0.0

        b51   =   YDAST
        b52   =   YDRST

        b61   =   LDAL
        b62   =   LDRL

        b71   =   NDAL
        b72   =   NDRL

        b81   =   0.0
        b82   =   0.0

END $ " of initial "

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 "  ------   PILOT MANEUVER    ------------------------------------  "

          PROCEDURAL ( DCOM = T1,T2,T3,AUXMA1,DPOS )

            IF(T.LE.T1) DCOM = DPOS * T
            IF(T.LE.T2.AND.T.GT.T1) DCOM = DPOS
            IF(T.LE.T3.AND.T.GT.T2) DCOM = AUXMA1 * ( T - T3 )
            IF(T.GT.T3) DCOM = 0.0

          END $ " of procedural "

             DCOM    =  DPOS
             DA   =   IA * DCOM
             DR   =   IR * DCOM
```

```
"  -----     EQUATIONS OF MOTION    --------------------------------  "

      betap = a51 * beta + a52 * p + a53 * r + a54 * fi + ...
              b51 *   da + b52 * dr
      pp    = a61 * beta + a62 * p + a63 * r + a64 * fi + ...
              b61 *   da + b62 * dr
      rp    = a71 * beta + a72 * p + a73 * r + a74 * fi + ...
              b71 *   da + b72 * dr
      fip   = a81 * beta + a82 * p + a83 * r + a84 * fi + ...
              b81 *   da + b82 * dr
      psip  = r * ICOTO

"  ---------    AUXILIARY EQUATIONS     ---------------------------  "

    "  ------- lateral acceleration equation  ------- "
      ay    = vp - W0 * p + U0 * r - grav * sin(fi) * cos(TETA0)
    "  ------- lateral load factor   ---------------- "
      ny    = ay/grav
    " -------- lateral displacement of the aircraft  ----- "
      yep   = U0 * cos(TETA0) * sin(psi) + ...
       v * (sin(fi)*sin(TETA0)*sin(psi)+cos(fi)*cos(psi)) + ...
       W0 * (cos(fi)*sin(TETA0)*sin(psi)-sin(fi)*cos(psi))


 "  -----    INTEGRATION OF THE EQUATIONS    -----------------------  "


    BETA   =    INTEG(betap , betai)
       P   =    INTEG(pp    ,    pi)
       R   =    INTEG(rp    ,    ri)
      FI   =    INTEG(fip   ,   fii)
     PSI   =    INTEG(psip  ,  psii)
     YE    =    INTEG(YEP   ,   yei)
```

```
"   -------------    TOTAL VARIABLES     -------------------------------  "

      V     =    VT0 * SIN(BETA)
      vp    =    VT0 * betap
      VT    =    V0  +  V

"   --------   TRANSFORMATION TO DEGRES     --------------------------  "

            PG         =  57.296 * P
            RG         =  57.296 * R
            PPG        =  57.296 * PP
            RPG        =  57.296 * RP
            BETAG      =  57.296 * BETA
            BETAPG     =  57.296 * BETAP
            FIPG       =  57.296 * FIP
            PSIPG      =  57.296 * PSIP
            FIG        =  57.296 * FI
            PSIG       =  57.296 * PSI
            DAG        =  57.296 * DA
            DRG        =  57.296 * DR
            ALFA0G     =  57.296 * ALFA0

END $ " of derivative "

         TERMT(T.GE.TFIM)

END $ " of dynamic "


END $ " of Program "
```

APPENDIX 4

ACSL SIMULATION PROGRAM OF

THE NON LINEAR SIMULATION MODEL

```
PROGRAM          NON LINEAR SIMULATION

INITIAL

  "  ------------  FLIGHT CONDITION  ----------------------------  "

   CONSTANT  HFTO    =  20000.0   ,  MACH    =  0.50
   CONSTANT  weight  =  636636.0  ,  IXZ     = 970056.0
   CONSTANT  IX      =  .182e+8   ,  IZ      = .497e+8
   CONSTANT  IY      =  .331e+8
   CONSTANT  GAMA0   =   0.0      ,  ITH     = 0.0436330
   CONSTANT  TU      =   0.0

 "  --------------   CONSTANT PARAMETERS   ---------------------- "

   CONSTANT  grav    = 32.2       ,  ROSL    =  1.225

 "  ---------------   INITIAL CONDITIONS  ------------------------ "

   CONSTANT  xei    =  0.0   ,  yei   =  0.0     ,  zei   =   -100.0
   CONSTANT  DE     =  0.0   ,  DA    =  0.0     ,  DR    =    0.0
   CONSTANT  BETA0  =  0.0   ,  FI0   =  0.0     ,  PSI0 =    0.0

"  ------------------  AERODYNAMIC PARAMETERS  ------------------- "

   CONSTANT  CDDE   =  0.0   ,  CM    =   0.0    ,  CYP   =  0.0
   CONSTANT  CYR    =  0.0   ,  CYDA =   0.0

"  -----------------  AIRCRAFT GEOMETRIC DATA  ------------------  "

   CONSTANT  S      =  5500. ,  b     =  195.68 ,  MAC     =   27.31
   CONSTANT  LTH    =  10.0  ,  LT14  =  103.0

"  -------------  TIME TO FINISH THE SIMULATION  ----------------  "

   CONSTANT  TFIM  =  15.0

"  ---------------   PARAMETERS OF THE MANEUVER  ----------------  "

   CONSTANT  T0     =  0.0     , T1     =   0.3   ,  T2      =   2.3
   CONSTANT  T3     =  2.6     , DPOSG =   20.0

"  ---------------  FLAG TO CHOSE THE MANEUVER  ----------------  "

"  -----  IA = 1.0  =  AILERON  MANEUVER   ----------------------  "
"  -----  IR = 1.0  =  RUDDER   MANEUVER   ----------------------  "
"  -----  IE = 1.0  =  ELEVATOR MANEUVER   ----------------------  "
"  -----  IA = 0.0 or IR = 0.0 or IE = 0.0 = ZERO MANEUVER  -----  "

   CONSTANT  IE      =  1.0     , IA     =   0.0   ,  IR    =  0.0
```

```
        "  -----   PRELIMINARIES CALCULATIONS  --------    "

"  ---------------         TABLE OF         ----------------------  "
"  ---------------  TRIM ANGLE OF ATTACK  ----------------------  "

   TABLE ALFTR,2,14,3  ...
    /   0.30   ,   0.35   ,   0.40   ,   0.45   ,   0.50    ...
    ,   0.55   ,   0.60   ,   0.65   ,   0.70   ,   0.75    ...
    ,   0.80   ,   0.85   ,   0.90   ,   0.95               ...
    ,   0.00   , 20000.0  , 40000.0                         ...
    ,   8.8    ,   6.0    ,   4.3    ,   3.1    ,   2.0     ...
    ,   1.2    ,   0.5    ,   0.0    ,  -0.6    ,  -1.2     ...
    ,  -1.8    ,  -2.4    ,  -3.0    ,  -3.6                ...
    ,  21.0    ,  17.0    ,  13.0    ,   9.0    ,   6.8     ...
    ,   5.0    ,   3.7    ,   2.5    ,   1.7    ,   0.7     ...
    ,   0.0    ,  -0.7    ,  -1.4    ,  -2.1                ...
    ,  18.6    ,  17.2    ,  15.8    ,  14.4    ,  13.0     ...
    ,  11.6    ,  10.2    ,   8.8    ,   7.4    ,   6.0     ...
    ,   4.5    ,   3.4    ,   2.2    ,   1.0    /

 "  --------------  ALTITUDE IN METERS  ---------------------  "

        H0      =  0.3048 * HFT0

 "  ---------------  PARAMETERS OF THE MANEUVER  --------------- "

        DPOS    =  0.01745 * DPOSG
        AUXMA1  =  DPOS/(T2-T3)


 "  ------------  SPEED OF SOUND IN AIR   ---------------------- "

        if(HFT0-36089.0.ge.0.0)go to 97
        VSOM    =  SQRT(115800.05-(0.79615*HFT0))
        go to 96
    97..VSOM    =  293.91
    96..A       =  3.281 * VSOM

 "  -------------  MASS AIR DENSITY  ------------------------------  "

        ROSI    =  ROSL * (  ( 1.0 - ( 2.2567e-05 ) * H0 ) ** 4.25532 )
        RO      =  1.94 * 0.001 * ROSI

 "  --------------   INITIAL PARAMETERS  ----------------------------  "

    "   -------   steady state velocity  ------------ "
        VT0     =  MACH * A
    "   -------   steady state angle of attack  ----- "
        ALFA0   =  0.01745 * ALFTR(MACH,HFT0)
    "   -------   thrust angle  ------------------- "
        KSI     =  ITH + ALFA0
    "   -------   steady state pitch angle  --------- "
        TETA0   =  GAMA0 + ALFA0
```

```
"   -------   inverse of mass and moments of inertia  -----  "
    IXIN    =  1./IX
    IYIN    =  1./IY
    IZIN    =  1./IZ
    mass    =  weight/grav
    MIN     =  1./mass
"   -------   lateral factors   ----------------- "
    KLAT    =  1./(1.-(IXZ**2/(IX*IZ)))
    K1      =  IXZ * IZIN
    K2      =  IXZ * IXIN
    K7      =  IXZ * IXZ * IXIN * IZIN
    K3      =  KLAT * K1 * ( 1. + (IZ - IY) * IXIN )
    K4      =  KLAT * ( K7 - (IY - IX) * IZIN )
    K5      =  KLAT * K2 * ( 1. - (IY -IX) * IZIN )
    K6      =  KLAT * (K7 + (IZ - IY) * IXIN )
"   -------   steady state linear velocities  --- "
    U0      =  VT0 * COS(ALFA0) * COS(BETA0)
    V0      =  VT0 * SIN(BETA0)
    W0      =  VT0 * SIN(ALFA0) * COS(BETA0)
"   -------   steady state forces   ------------- "
    X0      =  weight * SIN(TETA0)
    Y0      = -weight * COS(TETA0) * SIN(FI0)
    Z0      = -weight * COS(TETA0) * COS(FI0)
"   -------   inverse of U0   ------------------- "
    UTIN    =  1./U0
"   -------   initial U1  ---------------------- "
    U1      =  VT0
"   -------   inverse of U1   ------------------- "
    U1IN    =  1./U1
"   -------   initial linear velocities   -------- "
    WT      =  W0
    UT      =  U0
    VT      =  V0

"  ----------    INITIAL CONDITIONS TO INTEGRATORS   ---------------   "

    ui      =  0.0
    vi      =  0.0
    wi      =  0.0
    pi      =  0.0
    qi      =  0.0
    ri      =  0.0
    fii     =  0.0
    psii    =  0.0
    tetai   =  0.0

END $ " of initial "
```

DYNAMIC

DERIVATIVE

```
 "  ------                  TABLES OF                       --------------  "
 "  ------   AERODYNAMIC COEFICIENTS AND DERIVATIVES        --------------  "
 "  ------               IN STABILITY AXIS                  --------------  "

    TABLE XCL,2,9,3  ...
     /  0.250   ,   0.300   ,   0.400   ,   0.500   ,   0.600   ...
     ,  0.700   ,   0.800   ,   0.900   ,   1.0                 ...
     ,  0.000   , 20000.0   , 40000.0                           ...
     ,  1.500   ,   1.000   ,   0.590   ,   0.340   ,   0.260   ...
     ,  0.185   ,   0.145   ,   0.105   ,   0.065               ...
     ,  2.450   ,   2.050   ,   1.250   ,   0.70    ,   0.50    ...
     ,  0.420   ,   0.325   ,   0.225   ,   0.175               ...
     ,  4.200   ,   3.700   ,   2.700   ,   1.700   ,   1.350   ...
     ,  0.950   ,   0.75    ,   0.560   ,   0.460   /

     TABLE XCD,2,9,3  ...
     /  0.250    ,   0.300    ,   0.40     ,   0.500    ,   0.650    ...
     ,  0.700    ,   0.80     ,   0.900    ,   1.00                 ...
     ,  0.000    , 20000.0    , 40000.0                             ...
     ,  0.135    ,   0.095    ,   0.0375   ,   0.0195   ,   0.0180   ...
     ,  0.0170   ,   0.0160   ,   0.0150   ,   0.0140               ...
     ,  0.355    ,   0.285    ,   0.145    ,   0.042    ,   0.0315   ...
     ,  0.025    ,   0.019    ,   0.020    ,   0.045                ...
     ,  0.500    ,   0.455    ,   0.365    ,   0.275    ,   0.185    ...
     ,  0.095    ,   0.0525   ,   0.045    ,   0.055    /

     TABLE XCLDE,2,9,3 ...
     /  0.250    ,   0.300    ,   0.40     ,   0.500    ,   0.60     ...
     ,  0.700    ,   0.80     ,   0.900    ,   1.00                 ...
     ,  0.000    , 20000.0    , 40000.0                             ...
     ,  0.3375   ,   0.320    ,   0.285    ,   0.245    ,   0.205    ...
     ,  0.170    ,   0.135    ,   0.100    ,   0.065                ...
     ,  0.385    ,   0.380    ,   0.370    ,   0.360    ,   0.340    ...
     ,  0.315    ,   0.275    ,   0.200    ,   0.100                ...
     ,  0.535    ,   0.520    ,   0.490    ,   0.460    ,   0.430    ...
     ,  0.400    ,   0.370    ,   0.300    ,   0.200    /

     TABLE XCMDE,2,9,3 ...
     /  0.250    ,   0.300    ,   0.40     ,   0.500    ,   0.600    ...
     ,  0.700    ,   0.80     ,   0.900    ,   1.000                ...
     ,  0.000    , 20000.0    , 40000.0                             ...
     , -1.3325   ,  -1.260    ,  -1.115    ,  -0.970    ,  -0.810    ...
     , -0.650    ,  -0.490    ,  -0.330    ,  -0.170                ...
     , -1.550    ,  -1.520    ,  -1.460    ,  -1.400    ,  -1.330    ...
     , -1.240    ,  -1.080    ,  -0.800    ,  -0.400                ...
     , -2.275    ,  -2.200    ,  -2.050    ,  -1.900    ,  -1.750    ...
     , -1.600    ,  -1.450    ,  -1.200    ,  -0.800    /
```

```
TABLE XCLM,2,9,3 ...
/   0.250    ,   0.300    ,   0.40     ,   0.500    ,   0.60     ...
,   0.700    ,   0.800    ,   0.900    ,   1.0                  ...
,   0.000    , 20000.0    , 40000.0                             ...
,  -0.375    ,  -0.300    ,  -0.150    ,   0.000    ,   0.150   ...
,   0.300    ,   0.450    ,   0.600    ,   0.750                ...
,  -0.600    ,  -0.500    ,  -0.300    ,  -0.100    ,   0.100   ...
,   0.200    ,   0.100    ,  -0.050    ,  -0.950                ...
,   1.200    ,   1.100    ,   0.900    ,   0.700    ,   0.500   ...
,   0.300    ,   0.100    ,  -0.300    ,  -0.700    /

TABLE XCDM,2,9,3 ...
/   0.250    ,   0.300    ,   0.40     ,   0.500    ,   0.60     ...
,   0.700    ,   0.80     ,   0.900    ,   1.00                 ...
,   0.000    , 20000.0    , 40000.0                             ...
,   0.000    ,   0.000    ,   0.000    ,   0.000    ,   0.000   ...
,   0.000    ,   0.000    ,   0.000    ,   0.000                ...
,  -0.045    ,  -0.040    ,  -0.030    ,  -0.020    ,  -0.010   ...
,   0.000    ,   0.010    ,   0.1825   ,   0.4575               ...
,  -0.1125   ,  -0.100    ,  -0.075    ,  -0.050    ,  -0.025   ...
,   0.000    ,   0.025    ,   0.250    ,   0.475    /

TABLE XCMM,2,9,3 ...
/   0.250    ,   0.300    ,   0.40     ,   0.500    ,   0.60     ...
,   0.700    ,   0.80     ,   0.900    ,   1.00                 ...
,   0.000    , 20000.0    , 40000.0                             ...
,   0.255    ,   0.200    ,   0.090    ,   0.000    ,  -0.060   ...
,  -0.040    ,  -0.020    ,   0.000    ,   0.020                ...
,   0.270    ,   0.240    ,   0.180    ,   0.120    ,   0.060   ...
,   0.000    ,  -0.100    ,  -0.200    ,   0.040                ...
,  -0.0202   ,  -0.032    ,  -0.055    ,  -0.079    ,  -0.103   ...
,  -0.126    ,  -0.150    ,  -0.066    ,   1.080    /

TABLE XCMA,2,9,3 ...
/   0.250    ,   0.300    ,   0.40     ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                ...
,   0.000    , 20000.0    , 40000.0                             ...
,  -1.275    ,  -1.200    ,  -1.050    ,  -0.870    ,  -0.690   ...
,  -0.500    ,  -0.310    ,  -0.120    ,   0.070                ...
,  -1.335    ,  -1.300    ,  -1.230    ,  -1.140    ,  -1.050   ...
,  -0.900    ,  -0.620    ,  -1.200    ,  -2.000                ...
,  -1.625    ,  -1.570    ,  -1.460    ,  -1.350    ,  -1.240   ...
,  -1.130    ,  -1.020    ,  -1.600    ,  -2.400    /

TABLE XCMAP,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                ...
,   0.000    , 20000.0    , 40000.0                             ...
,  -3.00     ,  -3.00     ,  -3.00     ,  -3.00     ,  -3.00    ...
,  -3.20     ,  -3.60     ,  -4.00     ,  -4.40                 ...
,  -2.20     ,  -2.40     ,  -2.80     ,  -3.20     ,  -3.60    ...
,  -4.20     ,  -5.20     ,  -6.60     ,  -2.40                 ...
,  -3.50     ,  -3.60     ,  -3.80     ,  -4.00     ,  -4.20    ...
,  -4.80     ,  -6.00     ,  -8.60     ,  -3.00     /
```

```
TABLE XCMQ,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
, -20.70     , -20.20     , -19.20     , -18.30     , -17.40     ...
, -16.80     , -15.80     , -14.80     , -13.80                  ...
, -21.86     , -21.60     , -21.06     , -20.53     , -20.00     ...
, -20.00     , -20.20     , -20.00     , -16.00                  ...
, -22.05     , -22.10     , -22.20     , -22.30     , -22.40     ...
, -22.60     , -24.00     , -24.00     , -20.00     /

TABLE XCLA,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
,   4.80     ,   4.70     ,   4.50     ,   4.30     ,   4.10     ...
,   3.90     ,   3.60     ,   3.10     ,   2.60                  ...
,   4.90     ,   4.85     ,   4.75     ,   4.65     ,   4.60     ...
,   4.50     ,   4.20     ,   4.80     ,   1.95                  ...
,   5.90     ,   5.80     ,   5.60     ,   5.40     ,   5.20     ...
,   5.00     ,   4.90     ,   5.55     ,   3.425    /

TABLE XCDA,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
,   0.70     ,   0.53     ,   0.25     ,   0.120    ,   0.050    ...
,   0.00     ,  -0.050    ,  -0.10     ,  -0.15                  ...
,   2.88     ,   2.320    ,   1.20     ,   0.38     ,   0.25     ...
,   0.14     ,   0.090    ,   0.090    ,   0.090                 ...
,   8.19     ,   7.39     ,   5.79     ,   4.19     ,   2.60     ...
,   1.00     ,   0.43     ,   0.52     ,   0.54     /

TABLE XCLAP,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
,  -6.69     ,  -6.67     ,  -6.61     ,  -6.56     ,  -6.51     ...
,  -6.46     ,  -6.41     ,  -6.36     ,  -6.31                  ...
,  -6.82     ,  -6.78     ,  -6.70     ,  -6.62     ,  -6.54     ...
,  -6.32     ,  -5.98     ,  -5.63     ,  -5.28                  ...
,  -7.98     ,  -7.79     ,  -7.40     ,  -7.01     ,  -6.62     ...
,  -6.23     ,  -5.84     ,  -5.36     ,  -4.88     /

TABLE XCYB,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
,  -0.85     ,  -0.85     ,  -0.85     ,  -0.85     ,  -0.84     ...
,  -0.80     ,  -0.76     ,  -0.72     ,  -0.68                  ...
,  -0.9625   ,  -0.95     ,  -0.925    ,  -0.90     ,  -0.875    ...
,  -0.85     ,  -0.80     ,  -0.80     ,  -0.80                  ...
,  -0.925    ,  -0.92     ,  -0.91     ,  -0.90     ,  -0.89     ...
,  -0.88     ,  -0.87     ,  -0.84     ,  -0.84     /
```

```
TABLE XCNB,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
,   0.1375   ,   0.140    ,   0.145    ,   0.145    ,   0.142    ...
,   0.142    ,   0.142    ,   0.142    ,   0.142                 ...
,   0.100    ,   0.110    ,   0.130    ,   0.150    ,   0.160    ...
,   0.170    ,   0.18     ,   0.18     ,   0.14                  ...
,   0.035    ,   0.050    ,   0.080    ,   0.11     ,   0.14     ...
,   0.17     ,   0.20     ,   0.2083   ,   0.1816   /

TABLE XCRB,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
,  -0.1725   ,  -0.175    ,  -0.180    ,  -0.165    ,  -0.150    ...
,  -0.145    ,  -0.140    ,  -0.135    ,  -0.130                 ...
,   0.1825   ,   0.095    ,  -0.080    ,  -0.190    ,  -0.175    ...
,  -0.160    ,  -0.160    ,  -0.165    ,   0.105                 ...
,   0.560    ,   0.480    ,   0.320    ,   0.160    ,   0.000    ...
,  -0.160    ,  -0.275    ,  -0.10     ,  -0.0014   /

TABLE XCRP,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
,  -0.3225   ,  -0.320    ,  -0.315    ,  -0.310    ,  -0.300    ...
,  -0.290    ,  -0.280    ,  -0.270    ,  -0.260                 ...
,  -0.10     ,  -0.155    ,  -0.265    ,  -0.33     ,  -0.325    ...
,  -0.32     ,  -0.33     ,  -0.30     ,  -0.25                  ...
,  -0.275    ,  -0.280    ,  -0.290    ,  -0.300    ,  -0.310    ...
,  -0.320    ,  -0.33     ,  -0.30     ,  -0.24     /

TABLE XCNP,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
,  -0.054    ,  -0.066    ,  -0.048    ,  -0.020    ,  -0.004    ...
,   0.011    ,   0.026    ,   0.042    ,   0.057                 ...
,   0.478    ,   0.338    ,   0.058    ,  -0.0665   ,  -0.041    ...
,  -0.0157   ,   0.0033   ,   0.013    ,   0.019                 ...
,  -0.106    ,  -0.100    ,  -0.090    ,  -0.079    ,  -0.0686   ...
,  -0.058    ,  -0.043    ,   0.022    ,   0.097    /

TABLE XCRR,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
,   0.028    ,   0.023    ,   0.150    ,   0.095    ,   0.065    ...
,   0.0475   ,   0.0325   ,   0.0175   ,   0.0025                ...
,   0.3775   ,   0.345    ,   0.280    ,   0.215    ,   0.160    ...
,   0.125    ,   0.100    ,   0.050    ,  -0.010                 ...
,   0.195    ,   0.205    ,   0.225    ,   0.245    ,   0.265    ...
,   0.285    ,   0.305    ,   0.200    ,   0.030    /
```

```
TABLE XCNR,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
,  -0.275    ,  -0.270    ,  -0.260    ,  -0.250    ,  -0.2425   ...
,  -0.235    ,  -0.2275   ,  -0.22     ,  -0.2125                ...
,  -0.325    ,  -0.315    ,  -0.295    ,  -0.277    ,  -0.275    ...
,  -0.275    ,  -0.265    ,  -0.248    ,  -0.231                 ...
,  -0.2975   ,  -0.30     ,  -0.305    ,  -0.310    ,  -0.315    ...
,  -0.320    ,  -0.325    ,  -0.33     ,  -0.314    /

TABLE XCRDA,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
,   0.012    ,   0.0126   ,   0.935    ,   0.0123   ,   0.0108   ...
,   0.0094   ,   0.0080   ,   0.0066   ,   0.0052                ...
,  -0.004    ,   0.000    ,   0.008    ,   0.0132   ,   0.0127   ...
,   0.0120   ,   0.0120   ,   0.010    ,   0.0048                ...
,   0.00655  ,   0.0072   ,   0.0085   ,   0.0098   ,   0.0111   ...
,   0.0124   ,   0.0137   ,   0.0140   ,   0.0096   /

TABLE XCNDA,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
,   0.000    ,   0.0012   ,   0.0028   ,   0.0030   ,   0.0025   ...
,   0.0020   ,   0.0015   ,   0.0010   ,   0.0005                ...
,  -0.00115  ,  -0.0006   ,   0.0005   ,   0.0016   ,   0.0021   ...
,   0.0018   ,   0.0007   ,  -0.0026   ,  -0.0066                ...
,  -0.001    ,  -0.0008   ,  -0.0004   ,   0.000    ,   0.0004   ...
,   0.0008   ,   0.0002   ,  -0.0027   ,  -0.0047   /

TABLE XCYDR,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
,   0.175    ,   0.165    ,   0.145    ,   0.125    ,   0.100    ...
,   0.075    ,   0.050    ,   0.025    ,   0.000                 ...
,   0.1887   ,   0.180    ,   0.1625   ,   0.145    ,   0.1275   ...
,   0.11     ,   0.085    ,   0.060    ,   0.035                 ...
,   0.2075   ,   0.20     ,   0.185    ,   0.17     ,   0.155    ...
,   0.14     ,   0.125    ,   0.065    ,  -0.005    /

TABLE XCNDR,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.00                  ...
,   0.000    , 20000.0    , 40000.0                              ...
,  -0.108    ,  -0.105    ,  -0.099    ,  -0.092    ,  -0.080    ...
,  -0.066    ,  -0.052    ,  -0.038    ,  -0.024                 ...
,  -0.138    ,  -0.132    ,  -0.120    ,  -0.108    ,  -0.110    ...
,  -0.10     ,  -0.099    ,  -0.081    ,  -0.063                 ...
,  -0.055    ,  -0.062    ,  -0.075    ,  -0.088    ,  -0.101    ...
,  -0.114    ,  -0.127    ,  -0.098    ,  -0.030    /
```

```
TABLE XCRDR,2,9,3 ...
/   0.250    ,   0.300    ,   0.400    ,   0.500    ,   0.600    ...
,   0.700    ,   0.800    ,   0.900    ,   1.000                 ...
,   0.000    , 20000.0    , 40000.0                              ...
,  -0.007    ,   0.000    ,   0.010    ,   0.0115   ,   0.010    ...
,   0.0085   ,   0.0070   ,   0.0055   ,   0.0040                ...
,  -0.020    ,  -0.015    ,  -0.005    ,   0.005    ,   0.0085   ...
,   0.010    ,   0.0085   ,   0.0035   ,  -0.0015                ...
,  -0.0177   ,  -0.0155   ,  -0.011    ,  -0.0065   ,  -0.0020   ...
,   0.0025   ,   0.0070   ,   0.0055   ,  -0.0128   /

"     -----    AERODYNAMIC COEFICIENTS AND DERIVATIVES   ----------- "
"     -----              IN STABILITY AXIS                ----------- "

         CL     =   XCL(MACH,HFT)
         CD     =   XCD(MACH,HFT)
         CLDE   =   XCLDE(MACH,HFT)
         CMDE   =   XCMDE(MACH,HFT)
         CLM    =   XCLM(MACH,HFT)
         CDM    =   XCDM(MACH,HFT)
         CMM    =   XCMM(MACH,HFT)
         CMA    =   XCMA(MACH,HFT)
         CMAP   =   XCMAP(MACH,HFT)
         CMQ    =   XCMQ(MACH,HFT)
         CLA    =   XCLA(MACH,HFT)
         CDA    =   XCDA(MACH,HFT)
         CLAP   =   XCLAP(MACH,HFT)
         CLQ    =  -(MAC*CMQ)/LT14

         CYB    =   XCYB(MACH,HFT)
         CNB    =   XCNB(MACH,HFT)
         CRB    =   XCRB(MACH,HFT)
         CRP    =   XCRP(MACH,HFT)
         CNP    =   XCNP(MACH,HFT)
         CRR    =   XCRR(MACH,HFT)
         CNR    =   XCNR(MACH,HFT)
         CRDA   =   XCRDA(MACH,HFT)
         CNDA   =   XCNDA(MACH,HFT)
         CYDR   =   XCYDR(MACH,HFT)
         CNDR   =   XCNDR(MACH,HFT)
         CRDR   =   XCRDR(MACH,HFT)

"  --------    AUXILIARY FACTORS    -----------------------------     "

     FAT1  =  RO*S*UT*MIN
     FAT2  = -0.5*RO*S*U1*U1*MIN
     FAT3  =  RO*S*MAC
     FAT4  =  FAT3*UT*IYIN

     RSV   =  RO * S * U1
     RSVB  =  RSV * B
```

```
"  ------      PILOT MANEUVER        ------------------------------  "

      PROCEDURAL ( DCOM = T1,T2,T3,AUXMA1,DPOS )

         IF(T.LE.T1) DCOM = DPOS * T
         IF(T.LE.T2.AND.T.GT.T1) DCOM = DPOS
         IF(T.LE.T3.AND.T.GT.T2) DCOM = AUXMA1 * (T-T3)
         IF(T.GT.T3) DCOM = 0.0

      END $ " of procedural "

          DE   =  IE * DCOM
          DA   =  IA * DCOM
          DR   =  IR * DCOM

"  --------    LONGITUDINAL COEFICIENTS      --------------------   "
"  --------          IN BODY AXIS            --------------------   "

     CN     =  CL * COS(ALFAT) + CD * SIN(ALFAT)
     CX     =  CD * COS(ALFAT) - CL * SIN(ALFAT)
     CNA    =  (CLA+CD) * COS(ALFAT) + (CDA-CL) * SIN(ALFAT)
     CNAP   =  CLAP * COS(ALFAT)
     CNQ    =  CLQ * COS(ALFAT)
     CNM    =  CLM * COS(ALFAT) + CDM * SIN(ALFAT)
     CNDE   =  CLDE * COS(ALFAT) + CDDE * SIN(ALFAT)
     CXA    =  (CDA-CL) * COS(ALFAT) - (CLA+CD) * SIN(ALFAT)
     CXAP   =  -CLAP * SIN(ALFAT)
     CXQ    =  -CLQ * SIN(ALFAT)
     CXM    =  CDM * COS(ALFAT) - CLM * SIN(ALFAT)
     CXDE   =  CDDE * COS(ALFAT) - CLDE * SIN(ALFAT)

 "  --------  LATERAL AND DIRECTINAL COEFICIENTS      ---------------- "
 "  --------             IN BODY AXIS                 ---------------- "

     CRBB   =  CRB * COS(ALFAT) - CNB * SIN(ALFAT)
     CRPB   =  CRP * COS(ALFAT)*COS(ALFAT)  ...
               - ( CRR + CNP ) * SIN(ALFAT)*COS(ALFAT) + ...
               CNR * SIN(ALFAT)*SIN(ALFAT)
     CRRB   =  CRR * COS(ALFAT)*COS(ALFAT)  ...
               - ( CNR - CRP ) * SIN(ALFAT)*COS(ALFAT) - ...
               CNP * SIN(ALFAT)*SIN(ALFAT)
     CRDAB =   CRDA * COS(ALFAT) - CNDA * SIN(ALFAT)
     CRDRB =   CRDR * COS(ALFAT) - CNDR * SIN(ALFAT)

     CNBB   =  CNB * COS(ALFAT) + CRB * SIN(ALFAT)
     CNPB   =  CNP * COS(ALFAT)*COS(ALFAT)  ...
               - ( CNR - CRP ) * SIN(ALFAT)*COS(ALFAT) - ...
               CRR * SIN(ALFAT)*SIN(ALFAT)
     CNRB   =  CNR * COS(ALFAT)*COS(ALFAT)  ...
               + ( CRR + CNP ) * SIN(ALFAT)*COS(ALFAT) + ...
               CRP * SIN(ALFAT)*SIN(ALFAT)
     CNDAB =   CNDA * COS(ALFAT) + CRDA * SIN(ALFAT)
     CNDRB =   CNDR * COS(ALFAT) + CRDR * SIN(ALFAT)
```

```
"  --------   LONGITUDINAL DERIVATIVES    -----------------------   "
"  --------             BODY AXIS         -----------------------   "

   XU    =  FAT1 * (-0.5*MACH*CXM - CX + 0.5*WT*CXA*UTIN )
   XW    =  FAT1 * 0.5 *(-CXA -2.*WT*(CX+0.5*MACH*CXM)*UTIN)
   XDE   =  FAT2 * CXDE
   XUST  =  XU + TU * COS(ITH+ALFAT)
   XQ    =  0.0

   ZU    =  FAT1 * (-0.5*MACH*CNM - CN + (0.5*WT*CNA) * UTIN)
   ZW    =  FAT1 * 0.5 *(-CNA -2.* WT * (CN+MACH*0.5*CNM) * UTIN)
   ZWP   =  -0.25 * MIN * FAT3 * UT * CNAP * U1IN
   ZDE   =  FAT2 * CNDE
   ZUST  =  ZU - TU * SIN(ITH+ALFAT)
   ZQ    =  -CLQ
   FAW   =  1./(1-ZWP)

   MU    =  FAT4 * ( 0.5*MACH*CMM + CM - 0.5*WT*CMA*UTIN )
   MUST  =  MU + LTH * TU * IYIN
   MW    =  FAT4 * 0.5 * ( CMA + 2.*WT*UTIN * ( CM+0.5*MACH*CMM ) )
   MWP   =  FAT4 * 0.25 * MAC * U1IN * CMAP
   MA    =  UT * MW
   MAP   =  UT * MWP
   MQ    =  FAT3 * MAC * U1 * CMQ * 0.25 * IYIN
   MDE   =  FAT3 * U1 * U1 * CMDE * 0.5 * IYIN


"  ---------   LATERAL AND DIRECTIONAL DERIVATIVES   ---------------   "
"  ---------                BODY AXIS                ---------------   "

   YV      =  RSV * 0.5 * MIN * CYB
   YB      =  U1 * YV
   YP      =  0.0
   YR      =  0.0
   YDA     =  RSV * U1 * 0.5 * MIN * CYDA
   YDR     =  RSV * U1 * 0.5 * MIN * CYDR
   YDRST   =  RSV * 0.5 * MIN * CYDR
   YDAST   =  RSV * 0.5 * MIN * CYDA

   LB      =  RSVB * U1 * 0.5 * IXIN * CRBB
   LP      =  RSVB * B * 0.25 * IXIN * CRPB
   LR      =  RSVB * B * 0.25 * IXIN * CRRB
   LDA     =  RSVB * U1 * 0.5 * IXIN * CRDAB
   LDR     =  RSVB * U1 * 0.5 * IXIN * CRDRB

   NB      =  RSVB * U1 * 0.5 * IZIN * CNBB
   NP      =  RSVB * B * 0.25 * IZIN * CNPB
   NR      =  RSVB * B * 0.25 * IZIN * CNRB
   NDA     =  RSVB * U1 * 0.5 * IZIN * CNDAB
   NDR     =  RSVB * U1 * 0.5 * IZIN * CNDRB
```

```
LBL    =  ( LB + IXZ * NB * IXIN ) * KLAT
LPL    =  ( LP + IXZ * NP * IXIN ) * KLAT
LRL    =  ( LR + IXZ * NR * IXIN ) * KLAT
LDRL   =  ( LDR + IXZ * NDR * IXIN ) * KLAT
LDAL   =  ( LDA + IXZ * NDA * IXIN ) * KLAT

NBL    =  ( NB + IXZ * LB * IZIN ) * KLAT
NPL    =  ( NP + IXZ * LP * IZIN ) * KLAT
NRL    =  ( NR + IXZ * LR * IZIN ) * KLAT
NDRL   =  ( NDR + IXZ * LDR * IZIN ) * KLAT
NDAL   =  ( NDA + IXZ * LDA * IZIN ) * KLAT

"  ------------   EQUATIONS OF MOTION   -------------------------  "

"  ---------------  FORCE EQUATIONS  ------------------------  "

UP  =  R * VT - Q * WT - grav * SIN(TETAT) + X0 * MIN + ...
       XUST * U + XW * W + XQ * Q + XDE * DE
VP  =  P * WT - R * UT + Y0 * MIN + ...
       grav * COS(TETAT)*SIN(FI) + ...
       YV * V + YR * R + YP * P + ...
       YDAST * DA + YDRST * DR
WP  =  FAW * Q * UT - FAW * P * VT + Z0 * MIN * FAW +  ...
       grav * FAW * COS(TETAT) * COS(FI) + ...
        FAW * ZUST * U + FAW * ZW * W +...
        FAW * ZQ * Q + FAW * ZDE * DE

"  ----------------  MOMENT EQUATIONS  ----------------------  "

PP  =  LBL * U1IN * V + LRL * R + LPL * P + K5 * P * Q ...
      - K6 * Q * R + LDAL * DA + LDRL * DR
QP  =  MUST * U + MW * W + ...
       MWP * WP + MQ * Q + MDE * DE ...
      - IXZ * IYIN * ( P * P - R * R ) - ...
        (IX - IZ) * IYIN * P * R
RP  =  NBL * U1IN * V + NRL * R + NPL * P - ...
       K3 * Q * R + K4 * P * Q + NDAL * DA + NDRL * DR

"  -----------------  EULER EQUATIONS  ------------------------ "

FIP =  P + (Q * SIN(FI) + R * COS(FI)) * TAN(TETAT)
PSIP = (Q * SIN(FI) + R * COS(FI)) / COS(TETAT)
TETAP  = Q * COS(FI) - R * SIN(FI)

"  -----------   AUXILIARY EQUATIONS   ---------------------------  "

"  ---------------  ACCELERATION EQUATIONS  -----------------  "

   AX    =  UP - VT * R + WT * Q + grav * sin(TETAT)
   AY    =  VP - WT * P + UT * R - grav * SIN(FI) * COS(TETAT)
   AZ    =  WP + P * VT - Q * UT - grav * cos(FI) * cos(TETAT)
```

```
"  ---------    LOAD FACTOR EQUATIONS  -----------------------  "

      NX     =  AX/grav
      NY     =  AY/grav
      NZ     =  AZ/grav
      NLF    = -NZ

"  ---------    ALTITUDE EQUATION    --------------------------  "

      HFTP   =  UT * sin(TETAT) - VT * sin(FI) * cos(TETAT) - ...
                WT * cos(FI) * cos(TETAT)

"  ---- EQUATIONS OF THE LINEAR DISPLACEMENT OF THE AIRCRAFT ---- "
"  ----                 RELATIVE TO EARTH                    ---- "

      XEP    =  UT * cos(TETAT) * cos(PSI) + ...
          VT *  (sin(FI)*sin(TETAT)*cos(PSI)-cos(FI)*sin(PSI)) ...
        + WT *  (cos(FI)*sin(TETAT)*cos(PSI)+sin(FI)*sin(PSI))
      YEP    =  UT * cos(TETAT) * sin(PSI) + ...
          VT *  (sin(FI)*sin(TETAT)*sin(PSI)+cos(FI)*cos(PSI)) ...
        + WT *  (cos(FI)*sin(TETAT)*sin(PSI)-sin(FI)*cos(PSI))
      ZEP    =  -UT * sin(TETAT) + VT * sin(FI) * cos(TETAT) ...
                + WT * cos(FI) * cos(TETAT)

"  ----------    INTEGRATION OF THE EQUATIONS    -----------------  "

      U    =    INTEG(UP    ,  ui)
      V    =    INTEG(VP    ,  vi)
      W    =    INTEG(WP    ,  wi)
      Q    =    INTEG(QP    ,  qi)
   TETA    =    INTEG(TETAP , tetai)
    HFT    =    INTEG(HFTP  ,  HFT0)
      P    =    INTEG(PP    ,    pi)
      R    =    INTEG(RP    ,    ri)
     FI    =    INTEG(FIP   ,   fii)
    PSI    =    INTEG(PSIP  ,  psii)
    XE     =    INTEG(XEP   ,   xei)
    YE     =    INTEG(YEP   ,   yei)
    ZE     =    INTEG(ZEP   ,   zei)
```

```
"  --------   TOTAL VALUES   ---------------------------------   "

   "  -------   altitude in meters   ---------- "
     H      =   0.3048 * HFT
   "  -------   total linear velocities  ------ "
     UT     =   U0 + U
     VT     =   V0 + V
     WT     =   W0 + W
   "  -------   inverse of UT  ---------------- "
     UTIN   =   1./UT
   "  -------   total angle of attack  -------- "
     ALFAT =    ATAN(WT*UTIN)
   "  -------   total pitch angle ------------- "
     TETAT =    TETA + TETA0
   " --------   total linear velocity  -------- "
     U1     =   sqrt(UT*UT+VT*VT+WT*WT)
   " --------   inverse of U1   --------------- "
     U1IN   =   1./U1
   " --------   total flight path angle  ------ "
     GAMAT =    TETAT - ALFAT
   " --------   angle of attack rate  --------- "
     ALFAP =    WP*UTIN
   " --------   sideslip angle   -------------- "
     BETA   =   ASIN(VT*U1IN)
   " --------   sideslip rate    --------------- "
     BETAP =    VP * U1IN

"  -----------   SPEED OF SOUND IN AIR   -------------------------   "

     PROCEDURAL ( SS = HFT )

             IF(HFT-36089.0.ge.0.0) go to 970
             ss = sqrt(115800.05-(0.79615-HFT))
             go to 960
        970..ss   =  293.91
        960..continue

     END $ " of procedural "

             A   =  3.281 * ss

"  -----------   MASS DENSITY OF AIR   ------------------------------   "

      PROCEDURAL ( ROP = H,ROSL,ROSI )

            ROSI = ROSL * ( ( 1.0 - ( 2.2567e-05 ) * H ) ** 4.25532 )
            ROP  = ROSI

      END $ " of procedural "

            RO   =  1.94 * 0.001 * ROP
```

```
"   ----------------   MACH NUMBER   -------------------------------  "

          MACH  =   U1 / A

"   ----------------   TRANSFORMATION TO DEGREES   ------------------  "

          PG        =  57.296 * P
          QG        =  57.296 * Q
          RG        =  57.296 * R
          PPG       =  57.296 * PP
          QPG       =  57.296 * QP
          RPG       =  57.296 * RP
          BETAG     =  57.296 * BETA
          BETAPG    =  57.296 * BETAP
          FIPG      =  57.296 * FIP
          PSIPG     =  57.296 * PSIP
          TETATG    =  57.296 * TETAT
          TETAPG    =  57.296 * TETAP
          ALFATG    =  57.296 * ALFAT
          ALFAPG    =  57.296 * ALFAP
          GAMATG    =  57.296 * GAMAT
          FIG       =  57.296 * FI
          PSIG      =  57.296 * PSI
          DEG       =  57.296 * DE
          DAG       =  57.296 * DA
          DRG       =  57.296 * DR

END $ " of derivative "

        TERMT(T.GE.TFIM)

END $ " of dynamic "

END $ " of Program "
```

APPENDIX 5

DERIVATION OF THE AERODYNAMIC COEFFICIENTS

APPENDIX 5

In this appendix we give the procedure to obtain the aerodynamic derivatives used in the simulations.

As a first step we get the aerodynamic coeficients from the tables contained in appendix 1 as function of mach number and altitude. The coeficients are in stability axis and are the following :

LONGITUDINAL	LATERAL-DIRECTIONAL
CL	CYB
CD	CNB
CLDE	CRB
CMDE	CRP
CLM	CNP
CDM	CRR
CMM	CNR
CMA	CRDA
CMAP	CNDA
CMQ	CYDR
CLA	CNDR
CDA	CRDR
CLAP	
CLQ	

After this we calculate the auxiliary factors :

```
FAT1  =  RO * S * UT / mass
FAT2  =  RO * S * U1 * U1 / ( 2 * mass )
FAT3  =  RO * S * MAC
FAT4  =  FAT3 * UT / IY
RSV   =  RO * S * V
RSVB  =  RSV * B
```

Then we obtain the longitudinal coeficients and derivatives in body-axis as in reference [1] :

```
CN    =  CL * COS(ALFAT) + CD * SIN(ALFAT)
CX    =  CD * COS(ALFAT) - CL * SIN(ALFAT)
CNA   =  ( CLA + CD ) * COS(ALFAT) +
         ( CDA - CL ) * SIN(ALFAT)
CNAP  =  CLAP * COS(ALFAT)
CNQ   =  CLQ * COS(ALFAT)
CNM   =  CLM * COS(ALFAT) + CDM * SIN(ALFAT)
CNDE  =  CLDE * COS(ALFAT) + CDDE * SIN(ALFAT)
CXA   =  ( CDA - CL ) * COS(ALFAT) -
         ( CLA + CD ) * SIN(ALFAT)
CXAP  =  - CLAP * SIN(ALFAT)
CXQ   =  - CLQ * SIN(ALFAT)
CXM   =  CDM * COS(ALFAT) - CLM * SIN(ALFAT)
CXDE  =  CDDE * COS(ALFAT) - CLDE * SIN(ALFAT)
```

To obtain the lateral and directional coeficients in body-axis we also follow reference [1] and the coeficients and derivatives are:

```
CRBB   =  CRB * COS(ALFAT) - CNB * SIN(ALFAT)
CRPB   =  CRP * COS(ALFAT) * COS(ALFAT) -
          ( CRR + CNP ) * SIN(ALFAT) * COS(ALFAT) +
          CNR * SIN(ALFAT) * SIN(ALFAT)
CRRB   =  CRR * COS(ALFAT) * COS(ALFAT) -
          ( CNR - CRP ) * SIN(ALFAT) * COS(ALFAT) -
          CNP * SIN(ALFAT) * SIN(ALFAT)
CRDAB  =  CRDA * COS(ALFAT) - CNDA * SIN(ALFAT)
CRDRB  =  CRDR * COS(ALFAT) - CNDR * SIN(ALFAT)
CNBB   =  CNB * COS(ALFAT) + CRB * SIN(ALFAT)
CNPB   =  CNP * COS(ALFAT) * COS(ALFAT) -
          ( CNR - CRP ) * COS(ALFAT) * SIN(ALFAT) -
          CRR * SIN(ALFAT) * SIN(ALFAT)
CNRB   =  CNR * COS(ALFAT) * COS(ALFAT) +
          ( CRR + CNP ) * SIN(ALFAT) * COS(ALFAT) +
          CRP * SIN(ALFAT) * SIN(ALFAT)
CNDAB  =  CNDA * COS(ALFAT) + CRDA * SIN(ALFAT)
CNDRB  =  CNDR * COS(ALFAT) + CRDR * SIN(ALFAT)
```

Then we obtain the dimensional derivatives again following reference [1]. The longitudinal dimensional derivatives are :

```
XU    =  FAT1 * ( MACH * CXM / 2  -  CX  +
                ( WT * CXA ) / ( 2 * UT )  )
XW    =  ( FAT1 / 2 ) * ( - CXA  - 2 * WT *
         ( CX + MACH * CXM / 2 ) / UT )
XDE   =  FAT2 * CXDE
XUST  =  XU  + TU * COS( ITH + ALFAT )
XQ    =  0


ZU    =  FAT1 * ( MACH * CNM / 2 - CN +
         ( WT * CNA ) / ( 2 * UT ) )
ZW    =  ( FAT1 / 2 ) * ( -CNA - 2 * WT *
         ( CN + MACH * CNM / 2 ) / UT )
ZWP   =  ( FAT3 * UT * CNAP ) / ( 4 * mass * U1 )
ZDE   =  FAT2 * CNDE
ZUST  =  ZU - TU * SIN ( ITH + ALFAT )
```

```
MU    =   FAT4 * ( MACH * CMM / 2 +  CM  -
           ( ( WT * CMA ) / ( 2 * UT ) )
MUST  =   MU + LTH * TU / IY
MW    =   ( FAT4 / 2 ) * ( CMA + ( 2 * WT / UT ) *
                               ( CM + MACH * CMM / 2 )  )
MWP   =   ( FAT4 * MAC * CMAP ) / ( 4 * U1 )
MA    =   UT * MW
MAP   =   UT * MWP
MQ    =   FAT3 * MAC * U1 * CMQ / ( 4 * IY )
MDE   =   FAT3 * U1 * U1 * CMDE / ( 2 * IY )
```

The lateral and directional dimensional derivatives in body-axis are the following :

```
YV     =  RSV * CYB /  ( 2 * mass )
YB     =  YV * U1
YP     =  0
YR     =  0
YDA    =  RSV * U1 * CYDA / ( 2 * mass )
YDR    =  RSV * U1 * CYDR / ( 2 * mass )
YDAST  =  RSV * CYDA / ( 2 * mass )
YDRST  =  RSV * CYDR / ( 2 * mass )

LB     =  RSVB * U1 * CRBB / ( 2 * IX )
LP     =  RSVB * B * CRPB  / ( 4 * IX )
LR     =  RSVB * B * CRRB  / ( 4 * IX )
LDA    =  RSVB * U1 * CRDAB  / ( 2 * IX )
LDR    =  RSVB * U1 * CRDRB  / ( 2 * IX )
```

```
NB    =   RSVB * U1 * CNBB / ( 2 * IZ )
NP    =   RSVB * B * CNPB / ( 4 * IZ )
NR    =   RSVB * CNRB / ( 4 * IZ )
NDA   =   RSVB * U1 * CNDAB / ( 2 * IZ )
NDR   =   RSVB * U1 * CNDRB / ( 2 * IZ )

LBL   =   ( LB + IXZ * NB / IX ) * KLAT
LPL   =   ( LP + IXZ * NP / IX ) * KLAT
LRL   =   ( LR + IXZ * NR / IX ) * KLAT
LDRL  =   ( LDR + IXZ * NDR / IX ) * KLAT
LDAL  =   ( LDA + IXZ * NDA / IX ) * KLAT

NBL   =   ( NB + IXZ * LB / IZ ) * KLAT
NPL   =   ( NP + IXZ * LP / IZ ) * KLAT
NRL   =   ( NR + IXZ * LR / IZ ) * KLAT
NDRL  =   ( NDR + IXZ * LDR / IZ ) * KLAT
NDAL  =   ( NDA + IXZ * LDA / IZ ) * KLAT
```

APPENDIX 6

SIGN CONVENTIONS USED IN THE MODELS

APPENDIX 6

The conventions used in the models are :

ax	positive forward
ay	positive out right wing
az	positive down
nx	positive forward
ny	positive out right wing
nz	positive down
nlf	positive up
lth	positive for nose up pitching moment due to thrust
M	pitching moment about y-axis positive for nose up
L	rolling moment about x-axis positive for right wing down
N	yawing moment about z-axis positive for nose right
p	roll rate about x axis positive right wing down
q	pitch rate about y-axis positive for nose up
r	yaw rate about z-axis positive for nose right
u	linear velocity along x-axis positive forward
v	linear velocity along y-axis positive ou right wing
w	linear velocity along z-axis positive down
X	aerodynamic force along x-axis positive forward
Y	aerodynamic force along y-axis positive out right wing
Z	aerodynamic force along z-axis positive down

N aerodynamic normal force along z axis positive up

da aileron deflection positive for positive rolling moment

de elevator deflection positive for nose-down pitching moment

dr rudder deflection positive for nose left yawing moment

teta pitch angle positive nose up

fi bank angle positive right wing down