NASA CR–114601

V/STOL TILT ROTOR AIRCRAFT STUDY MATHEMATICAL MODEL FOR A REAL TIME SIMULATION OF A TILT ROTOR AIRCRAFT (BOEING VERTOL MODEL 222)

VOLUME VIII

By: H. Rosenstein
M. A. McVeigh
P. A. Mollenkof

APRIL 1973

Prepared Under Contract No. NAS2-6598 by

BOEING VERTOL COMPANY
A DIVISION OF THE BOEING COMPANY
P.O. BOX 16858
PHILADELPHIA, PENNSYLVANIA 19142

for

AMES RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

and

UNITED STATES ARMY AIR MOBILITY RESEARCH & DEVELOPMENT LABORATORY
AMES DIRECTORATE

Boeing Document D222-10061-1

FOREWORD

This report is one of a series prepared by The Boeing Vertol Company, Philadelphia, Pennsylvania for the National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California under contract NAS2-6598. The studies reported under Volumes I through IV and VIII through X were jointly funded by NASA and the U.S. Army Air Mobility Research and Development Laboratory, Ames Directorate. Volumes V through VII were funded by the U. S. Air Force Flight Dynamics Laboratory, Wright Patterson Air Force Base, Ohio.

This contract was administered by the National Aeronautics and Space Administration. Mr. Richard J. Abbott was the Contract Administrator, Mr. Gary B. Churchill, Tilt Rotor Research Aircraft Project Office, was the Technical Monitor, and coordination and liaison with the U. S. Air Force Flight Dynamics Laboratory was through Mr. D. Fraga. The Boeing Vertol Company Project Engineer for the work presented in this report was Mr. H. Rosenstein.

The complete list of reports published under this contract is as follows:

Volume I -- Conceptual Design of Useful Military and/or Commercial Aircraft, NASA CR-114437

Volume II -- Preliminary Design of Research Aircraft, NASA CR-114438

Volume III -- Overall Research Aircraft Project Plan, Schedules, and Estimated Cost, NASA CR-114439

Volume IV -- Wind Tunnel Investigation Plan for a Full Scale Tilt Rotor Research Aircraft, CR-114440

Volume V -- Definition of Stowed Rotor Research Aircraft, NASA CR-114598

Volume VI -- Preliminary Design of a Composite Wing for Tilt Rotor Aircraft, NASA CR-114599

Volume VII -- Tilt Rotor Flight Control Program Feedback Studies, NASA CR-114600

Volume VIII -- Mathematical Model for a Real Time Simulation of a Tilt Rotor Aircraft (Boeing Vertol Model 222), NASA CR-114601

Volume IX -- Piloted Simulator Evaluation of the Boeing Vertol Model 222 Tilt Rotor Aircraft, NASA CR-114602

Volume X -- Performance and Stability Test of a 1/4.622 Froude Scaled Boeing Vertol Model 222 Tilt Rotor Aircraft (Phase I), NASA CR-114603

SUMMARY

This report documents the development of a real time mathematical model of a tilt rotor aircraft. This mathematical model is to be used in conjunction with the NASA Flight Simulator for Advanced Aircraft (FSAA) at Ames Research Center for evaluation of aircraft performance and handling qualities. In addition to developing the mathematical model, a parallel programming effort was conducted utilizing Boeing-Vertol's Hybrid Simulation Laboratory for the purpose of developing and evaluating model simplification.

The mathematical model is an eleven degree of freedom total force model. This model includes the basic six degree of freedom rigid body outer loop equations written about the instantaneous center of gravity with the inertial and aerodynamic terms included. The rotor is treated as a point source of forces and moments with appropriate response time lags and actuator dynamics. The wing has one vertical bending and one wing torsion degree of freedom. These structural degrees of freedom are treated on a "quasistatic"basis; i.e., the natural frequencies of vibration of the structure are much higher than the frequencies of the rigid body motion, and the coupling is in the aerodynamic terms. Each nacelle has an independent pitch degree of freedom about the wing pivot. The aerodynamics of the wing, tail, rotors, landing gear and fuselage are included. Wing and tail mutual interference effects and turbine engine performance and dynamic responses are represented.

The control system elements represented include pilot command (longitudinal and lateral stick, pedals, nacelle position and rate, power), three-axis stability augmentation systems (SAS), thrust management system (includes rotor constant speed govenor) and a load alleviation system (LAS). The LAS system incorporates feedback to rotor cyclic and collective pitch for purposes of improving stability, blade load reduction, gust alleviation and increased damping of aeroelastic modes. Control system actuator dynamics are represented by appropriate second order systems.

The mathematical model was programmed on Boeing's hybrid computer. This program was real time and was used to evaluate model simplification and also to develop and optimize stability augmentation, control, and load alleviation systems.

The mathematical model was written to make it as flexible and as general as possible while still retaining the real time execution capability. This program is a valuable design tool for control system design, SAS optimization, and flying qualities evaluations and improvements. The model is capable of operating in all modes of V/STOL flight (forwards, backwards, and sidewards) with no restrictions. This mathematical model represents the Model 222 tilt rotor configuration as proposed in Boeing's "Study of V/STOL Tilt Rotor Research Aircraft Program (Phase II)", dated January 1973.

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

LIST OF TABLES

NOMENCLATURE

Symbol	Definition	Units
A	Rotor disc area (per rotor)	ft^2
AR	Aspect ratio	N.D.
$A_{D\,(u+5v)}$	Coefficients of curve fit equation for wing drag coefficient as a function of angle of attack and surface deflection	--
$A_{NF\,(u+4v)}$	Coefficients of curve fit equation for normal force coefficient with zero cyclic pitch	--
$A_{P\,(u+4v)}$	Coefficients of curve fit equation for rotor power coefficient with zero cyclic pitch	--
$A_{PM\,(u+4v)}$	Coefficients of curve fit equation for rotor pitching moment coefficient with zero cyclic pitch	--
$A_{SF\,(u+4v)}$	Coefficients of curve fit equation for rotor side force coefficient with zero cyclic pitch	--
$A_{T\,(u+4v)}$	Coefficients of curve fit equation for rotor thrust coefficient with zero cyclic pitch	--
$A_{YM\,(u+4v)}$	Coefficients of curve fit equation for rotor yawing coefficient with zero cyclic pitch	--
A_{1c}	Lateral cyclic angle in rotor wind axes	deg
A'_{1c}	Lateral cyclic angle in swashplate axes	deg
A''_{1c}	Lateral cyclic angle in swashplate axes resolved through swashplate phase angle	deg
$\bar{a}$	Speed of sound or acceleration	ft/sec or ft/sec^2
a	Acceleration	ft/sec^2
(a_g/a)	Ratio of lift curve slope in ground effect to lift curve slope out of ground effect	ND

NOMENCLATURE

Symbol	Definition	Units
B_G	Percent brake pedal deflection	N.D.
B.L.	Aircraft butt line	inches
B_{1c}	Longitudinal cyclic angle in rotor wind axes	deg
B'_{1c}	Longitudinal cyclic angle in swashplate axes	deg
B''_{1c}	Longitudinal cyclic angle in swashplate axes resolved through swashplate phase angle	deg
b	Span of lifting surface (wing, tail,etc.)	feet
C	Chord	ft.
C_D	Drag coefficient = $\frac{D}{qS}$	ND
C_{D_O}	Drag coefficient at zero lift	ND
ΔC_D	Drag coefficient increment	ND
C_{DS}	Drag coefficient referred to rotor slipstream dynamic pressure = $D/q_S S$	ND
C_L	Lift coefficient = L/qS	ND
C_{L_O}	Average lift coefficient	ND
ΔC_L	Lift coefficient increment	ND
C_{L_S}	Lift coefficient referred to rotor slipstream dynamic pressure = $L/q_S S$	ND
C_{L_α}	Lift curve slope	1/rad
$C_{L\delta}$	Lift increment due to flap deflection	1/deg
C_L	Rolling moment coefficient = $L/q\ bS$	ND
C_{L_S}	Rolling moment coefficient referred to rotor slipstream dynamic pressure = $L/q_S bS$	ND

NOMENCLATURE

Symbol	Definition	Units
C_M	Pitching moment coefficient = M/qSC	ND
C_{M_O}	Wing pitching moment coefficient as a function of flap deflection; pitching moment coefficient of fuselage or nacelles at zero angle of attack	ND
$\triangle C_M$	Pitching moment coefficient increment	ND
C_{M_S}	Pitching moment coefficient referred to rotor slipstream dynamic pressure = $M/q_S SC$	
C_{M_δ}	Change in wing/body pitching moment coefficient as a function of flaperon deflection	ND
C_N	Yawing moment coefficient = N/qSb	ND
C_{N_O}	Yawing moment coefficient of fuselage or nacelles at zero angle of attack	ND
C_{n_S}	Yawing moment coefficient referred to rotor slipstream dynamic pressure = $N/q_S Sb$	ND
C_{NF}	Rotor normal force coefficient = $NF/\rho\pi\Omega^2R^4$	ND
C_{NF_O}	Rotor normal force coefficient with zero cyclic pitch	ND
C_P	Rotor power coefficient = $\dfrac{550RHP}{\rho\pi\Omega^3R^5}$	ND
C_{P_O}	Rotor power coefficient with zero cyclic pitch	ND
C_{PM}	Rotor hub pitching moment coefficient = $PM/\rho\pi\Omega^2R^5$	ND
C_{PM_O}	Rotor hub pitching moment coefficient with zero cyclic pitch	ND
C_{SF}	Rotor side force coefficient = $SF/\rho\pi\Omega^2R^4$	ND

NOMENCLATURE

Symbol	Definition	Units
C_{SF_o}	Rotor side force coefficient with zero cyclic pitch	ND
C_T	Rotor thrust coefficient = $T/\rho\pi\Omega^2R^4$	ND
C_{T_o}	Rotor thrust coefficient with zero cyclic pitch	ND
C_{T_s}	Rotor thrust coefficient referred to rotor slipstream dynamic pressure = T/q_sA	ND
C_Y	Side force coefficient = Y/qS	ND
C_{YM}	Rotor yawing moment coefficient $\eta/\rho\pi\Omega^2R^5$	ND
C_{YM_o}	Rotor yawing moment coefficient with zero cyclic pitch	ND
C_{Y_α}	Lift curve slope of vertical tail	1/rad
C_o	Coefficient of equation that defines pitching moment coefficient as a function of flap deflection	ND
C_1	Coefficient of equation that defines pitching moment coefficient as a function of flap deflection	1/rad
C_2	Coefficient of equation that defines pitching moment coefficient as a function of flap deflection	$1/rad^2$
D	Rotor diameter	ft.
(D/T)	Aircraft download to thrust ratio	ND
$D_{NF_{1\to4}}$	Coefficients in the equation for the change in normal force coefficient with lateral cyclic angle	1/deg
$D_{PM_{1\to7}}$	Coefficients in the equation for the change in hub pitching moment coefficient with lateral cyclic angle	1/deg
$D_{SF_{1\to4}}$	Coefficients in the equation for the change in side force coefficient with lateral cyclic angle	1/deg

NOMENCLATURE

Symbol	Definition	Units
D_{ST_n}	Damping coefficients of the landing gear oleo struts	lb/ft/sec
$D_{YM_{1\to7}}$	Coefficients in the equation for the change in hub yawing moment coefficient with lateral cyclic angle	1/deg
dC_{NF}/dA_{1c}	Change in normal force coefficient with lateral cyclic angle	1/deg
dC_{NF}/dB_{1c}	Change in normal force coefficient with longitudinal cyclic angle	1/deg
dC_{PM}/dA_{1c}	Change in hub pitching moment coefficient with lateral cyclic angle	1/deg
dC_{PM}/dB_{1c}	Change in hub pitching moment coefficient with longitudinal cyclic angle	1/deg
dC_{PM}/dQ	Change in hub pitching moment coefficient with pitch rate	1/rad/sec
dC_{SF}/dA_{1c}	Change in side force coefficient with lateral cyclic angle	1/deg
dC_{SF}/dB_{1c}	Change in side force coefficient with longitudinal cyclic angle	1/deg
dC_{YM}/dA_{1c}	Change in hub yawing moment coefficient with lateral cyclic angle	1/deg
dC_{YM}/dB_{1c}	Change in hub yawing moment coefficient with longitudinal cyclic angle	1/deg
dC_{YM}/dR	Change in hub yawing moment coefficient with yaw rate	1/rad/sec
$dC_{M}\ /dC_{L}$	Change in wing pitching moment with lift coefficient	ND
$d\sigma/d\beta$	Change in fuselage sidewash angle with sideslip angle	ND
EI	Product of modulus of elasticity and moment of inertia	$lb\text{-}in^2$
EI_o	Product of modulus of elasticity and moment of inertia at wing root	$lb\text{-}in^2$

NOMENCLATURE

Symbol	Definition	Units
$E_{NF_{1\to 4}}$	Coefficients in the equation for the change in normal force coefficient with longitudinal cyclic angle	1/deg
$E_{PM_{1\to 7}}$	Coefficients in the equation for the change in hub pitching moment coefficient with longitudinal cyclic angle	1/deg
$E_{SF_{1\to 4}}$	Coefficients in the equation for the change in side force coefficient with longitudinal cyclic angle	1/deg
$E_{YM_{1\to 7}}$	Coefficients in the equation for the change in hub yawing moment coefficient with longitudinal cyclic angle	1/deg
e	Oswald efficiency of wing or tail	ND
F	Generalized force or force on nacelle	lb
FPR	Lateral-directional SAS function	--
FR1	Lateral-directional SAS function	--
$F\phi$	Lateral-directional SAS function	--
$F\phi 1$	Lateral-directional SAS function	--
$F\phi 2$	Lateral-directional SAS function	--
$F\psi 1$	Lateral-directional SAS function	--
$F\psi 2$	Lateral-directional SAS function	--
F_a	Aerodynamic force on nacelle	lb
F_{qzn}	Landing gear oleo strut vertical force	lb
F_{sn}	Landing gear oleo strut lateral force	lb
F_x	Longitudinal generalized force	lb
F_y	Lateral generalized force	lb
F_z	Vertical generalized force	lb
$F_{\mu n}$	Landing gear oleo strut longitudinal force	lb

NOMENCLATURE

Symbol	Definition	Units
f_{e_u}	Leading edge umbrella drag	ft^2
f_{NF}	Multiplier on rotor normal force	ND
f_p	Multiplier on rotor power	ND
f_{PM}	Multiplier on rotor hub pitching moment	ND
f_Q	Multiplier on rotor torque	ND
f_{SF}	Multiplier on rotor side force	ND
f_T	Multiplier on rotor thrust	ND
f_{YM}	Multiplier on rotor hub yawing moment	ND
G	Generalized moment	ft-lb
GEF	Ground effect factor $= \left[1 - \frac{(\Delta\varepsilon)_g}{\varepsilon}\right]$	ND
G_{A1_α}	Load alleviation system gain - change in lateral cyclic with angle of attack	deg/deg
G_{A1_β}	Load alleviation system gain - change in lateral cyclic with angle of sideslip	deg/deg
G_{B1_α}	Load alleviation system gain - change in longitudinal cyclic with angle of attack	deg/deg
G_{G1}	Governor gain	deg/sec/rad/sec
G_{G2}	Governor gain	deg/sec/ rad/sec
G_{G3}	Governor gain	deg/sec/deg
G_p	Lateral directional SAS gain	inches/rad/sec
G_{pr1}	Lateral directional SAS gain	inches/rad/sec
$G_{p\delta_s}$	Lateral directional SAS gain	inches/inch
G_q	Longitudinal SAS gain	deg/rad/sec
G_r	Lateral directional SAS gain	inches/rad/sec

NOMENCLATURE

Symbol	Definition	Units
G_{r2}	Lateral directonal SAS gain	inches/rad/sec
$G_{r_{\delta r}}$	Lateral directional SAS gain	inches/rad/sec
$G_{\beta p}$	Lateral directional SAS gain	inches/rad
$G_{\beta r}$	Lateral directional SAS gain	inches/rad
$G_{\beta \delta r}$	Lateral directional SAS gain	inches/inch
$G_{\delta B1}$	Longitudinal SAS gain	deg/inch
$G_{\delta B2}$	Longitudinal SAS gain	deg/inch
$G_{\delta TH}$	Governor throttle gain	deg/inch
G_{θ}	Longitudinal SAS gain	deg/rad/sec
G_{ϕ}	Lateral-directional SAS gain	inches/rad/sec
G_{ψ}	Lateral directional SAS gain	inch/inch
$G_{\psi \delta r}$	Lateral directional SAS gain	inch/inch
g	Gravitational constant	ft/sec^2
H	Height	ft
HP	Horsepower	--
$H_{PM(u+4v)}$	Coefficients in the equation for the change in hub pitching moment with pitch rate	--
$H'_{w'FUEL}$	Horizontal distance between wing mass element center of gravity and fuel center of gravity	ft
$H'_{w'NF}$	Horizontal distance between wing mass element center of gravity and fixed nacelle center of gravity	ft
$H'_{w'w}$	Horizontal distance between wing mass element center of gravity and fixed nacelle center of gravity	ft

NOMENCLATURE

Symbol	Definition	Units
h	Height or angular momentum	ft or lb-ft-sec
h_{CG}^{N}	Angular momentum of nacelle about aircraft center of gravity	lb-ft-sec
h_F	Distance from wing pivot plane to fuselage mass element center of gravity	ft
h_P	Height of pivot above wing chord line or angular momentum of nacelle about the pivot	
h_T	Landing gear oleo strut deflection during ground contact	ft
h_W	Distance from wing pivot plane to wing mass element center of gravity	ft
h_O	Angular momentum of an element of mass about its own center of gravity	lb-ft-sec
h_1	Wing vertical bending deflection	ft
h/D	Rotor hub height to rotor diameter ratio	ND
h_θ	Distance from aircraft center of gravity bottom of right main gear following a positive pitch rotation	ft
h_ϕ	Distance from aircraft center of gravity to bottom of right main gear following a positive roll	ft
I	Mass moment of inertia	slug-ft^2
I_{xx}	Vehicle mass roll moment of inertia about center of gravity	slug-ft^2
I_{xx_O}	Mass roll moment of inertia of aircraft components about their own center of gravity	slug-ft^2
$I_{xx}^{(F)}$	Mass roll moment of inertia of fuselage mass element about its center of gravity	slug-ft^2

NOMENCLATURE

Symbol	Definition	Units
$I_{xx}^{(W)}$	Mass roll moment of inertia of wing mass element about its center of gravity	slug-ft^2
I'_{xx}	Mass roll moment of inertia of the tilting portion of each nacelle about its center of gravity	slug-ft^2
I_{yy}	Vehicle mass pitch moment of inertia about center of gravity	slug-ft^2
I_{yy_o}	Mass pitch moment of inertia of aircraft components about their own center of gravity	slug-ft^2
$I_{yy}^{(F)}$	Mass pitch moment of inertia of fuselage mass element about its center of gravity	slug-ft^2
$I_{yy}^{(W)}$	Mass pitch moment of inertia of wing mass element about its center of gravity	slug-ft^2
I'_{yy}	Mass pitch moment of inertia of the tilting portion of each nacelle about its center of gravity	slug-ft^2
I_{xz}	Vehicle mass product of inertia about center of gravity	slug-ft^2
I_{xz_o}	Mass product of inertia of aircraft components about their own center of gravity	slug-ft^2
$I_{xz}^{(F)}$	Mass product of inertia of fuselage mass element about its center of gravity	slug-ft^2
$I_{xz}^{(W)}$	Mass product of inertia of wing mass element about its center of gravity	slug-ft^2
I'_{xz}	Mass product of inertia of the tilting portion of each nacelle about its center of gravity	slug-ft^2

NOMENCLATURE

Symbol	Definition	Units
I_{zz}	Vehicle mass yaw moment of inertia about center of gravity	slug-ft^2
I_{zz_O}	Mass yaw moment of inertia of aircraft components about their own center of gravity	slug-ft^2
$I_{zz}^{(F)}$	Mass yaw moment of inertia of fuselage mass element about its center of gravity	slug-ft^2
$I_{zz}^{(W)}$	Mass yaw moment of inertia of wing mass element about its center of gravity	slug-ft^2
I'_{zz}	Mass yaw moment of inertia of the tilting portion of <u>each</u> nacelle about its center of gravity	slug-ft^2
i	Incidence angle	deg or rad
$\underline{\hat{i}}$	Unit vector in i direction	--
J_{xx}	Dummy inertia = $(I_{zz}-I_{yy})$	slug-ft^2
$J_{YM(u+4v)}$	Coefficients of curve fit equation for rotor hub moment with hub yaw rate	--
J_{yy}	Dummy inertia = $(I_{xx}-I_{zz})$	slug-ft^2
J_{zz}	Dummy inertia = $(I_{yy}-I_{xx})$	slug-ft^2
$\underline{\hat{j}}$	Unit vector in j direction	--
K'_A	Wing slipstream correction factor	ND
$K_{\frac{D1}{T}} \rightarrow K_{\frac{D4}{T}}$	Coefficients of curve fit equation for wing download as a function of rotor height/diameter ratio	ND
$K_{\frac{M1}{T}} \rightarrow K_{\frac{M4}{T}}$	Coefficients of curve fit equation for wing pitching moment as a function of rotor height/diameter ratio	ND
$K_{\mathcal{L}}$	Multiplier on slipstream rolling moment coefficient	ND
K_{η}	Multiplier on slipstream yawing moment coefficient	ND

NOMENCLATURE

Symbol	Definition	Units
K_{ST_η}	Landing gear spring constants	lb/ft
$K_{WI} \rightarrow K_{W10}$	Coefficients for wing bending equations	--
K_{δ_B}	Multiplier on longitudinal cyclic pitch available from longitudinal stick	inch/inch
K_{δ_e}	Ratio between longitudinal stick motion and elevator deflection	deg/inch
K_{δ_R}	Multiplier on longitudinal cyclic pitch available from pedal displacement	inch/inch
$K\delta_{RUD}$	Ratio between pedal and rudder deflection	deg/inch
K_{δ_s}	Multiplier on longitudinal cyclic pitch and differential collective available from lateral stick	inch/inch
$K_{\delta's}$	Provision for lateral cyclic pitch on lateral stick	deg/deg
K_θ	Wing stiffness	ft-lb/rad
K_o	Coefficient of fuselage drag coefficient equation to account for drag due to sideslip	$1/rad^3$
K_1	Coefficient of fuselage drag coefficient equation	$1/rad^2$
K_2	Coefficient of fuselage drag coefficient equation	1/rad
K_3	Coefficient of fuselage lift coefficient equation	1/rad
K_4	Coefficient of fuselage lift coefficient equation	$1/rad^2$
K_5	Coefficient of fuselage pitching moment coefficient equation	1/rad

NOMENCLATURE

Symbol	Definition	Units
K_6	Coefficient of fuselage pitching moment coefficient equation	$1/rad^2$
K_7	Coefficient of fuselage side force coefficient equation	1/rad
K_8	Coefficient of fuselage side force coefficient equation	1/rad
K_9	Coefficient of fuselage yawing moment coefficient equation	1/rad
K_{10}	Coefficient of fuselage yawing moment coefficient equation	$1/rad^2$
K_{20}	Wing/body interference effects on $C_{L\beta}$	1/rad
K_{21}	Wing planform effects on $C_{L\beta}$	1/rad
K_{22}	Wing planform and lift effects on $C_{\eta\beta}$	1/rad
K_{30}	Coefficient of nacelle drag coefficient equation	1/rad
K_{31}	Coefficient of nacelle drag coefficient equation	$1/rad^2$
K_{32}	Coefficient of nacelle lift coefficient equation	1/rad
K_{34}	Coefficient of nacelle pitching moment coefficient equation	1/rad
K_{35}	Coefficient of nacelle pitching moment coefficient equation	$1/rad^2$
K_{36}	Coefficient of nacelle side force coefficient equation	1/rad
K_{37}	Coefficient of nacelle side force coefficient equation	$1/rad^2$
K_{38}	Coefficient of nacelle yawing moment coefficient equation	1/rad
K_{39}	Coefficient of nacelle yawing moment coefficient equation	$1/rad^2$

NOMENCLATURE

Symbol	Definition	Units
K_{40}	Coefficient of nacelle yawing moment coefficient equation	1/rad
K_{41}	Coefficient of nacelle yawing moment coefficient equation	$1/rad^2$
K_{42}	Coefficient of fuselage lift coefficient equation	ND
$\hat{k}$	Unit vector in k direction	--
L	Rolling moment or nacelle shaft length	ft-lb ,ft
L	Rolling Moment	ft-lb
ℓ	Distance from nacelle pivot to nacelle center of gravity	ft
ℓ'	Horizontal distance from nacelle pivot to noted aircraft component center of gravity position - positive forward from pivot	ft
ℓ_{AC}	Horizontal distance from horizontal tail quarter chord to wing aerodynamic center	ft
ℓ_F	Horizontal distance from pivot to center of gravity of fuselage mass element	ft
ℓ_0	Wing root lift/foot	lb/ft
ℓ_{PA}	Horizontal distance from pivot to center of gravity of pilots station - positive forward from pivot	ft
ℓ_W	Horizontal distance from pivot to wing mass element center of gravity	
M	Pitching moment	ft-lb
$\mathfrak{m}$	Pitching moment	ft-lb
M/T	Pitching moment/rotor thrust	ft-lb/lb
m	Aircraft total mass	slugs

NOMENCLATURE

Symbol	Definition	Units
$\dot{m}_f$	Mass of fuselage mass element	slugs
m_N	Mass of one nacelle	slugs
m_W	Mass of wing mass element	slugs
N	Yawing moment	ft-lb
η	Yawing moment	ft-lb
NF	Rotor normal force	lb
N_I	Engine gas generator speed	rev/min
$N_{1\ IND}$	Engine gas generator indicator	--
N_I^*	Engine gas generator speed at sea level standard, static conditions	rev/min
$N_{1\theta\ IND}$	Referred engine gas generator speed indicator	--
N_{II}	Engine power turbine speed	
N_{II}^*	Engine power turbine speed at sea level standard static conditions	
P	Body axes roll rate	rad/sec
PC	Horizontal distance from wing leading edge to pivot location	ft.
P^N	Nacelle axes roll rate	rad/sec
PR	Nacelle wind axes roll rate	rad/sec
p	Body axes roll rate	rad/sec
Q	Body axes pitch rate or rotor torque	rad/sec or lb-ft
Q_{IND}	Torque indicator	ND
Q_{MAX}	Maximum engine torque available	lb-ft
Q^N	Nacelle axes pitch rate	rad/sec
Q^R	Nacelle wind axes pitch rate	rad/sec

NOMENCLATURE

Symbol	Definition	Units
Q^*	Engine torque at sea level standard static condition	lb-ft
q	Body axes pitch rate or freestream dynamic pressure	rad/sec or lb/ft^2
q_s	Dynamic pressure based on rotor slipstream = $(q + T/A)$	lb/ft^2
R	Body axes yaw rate or rotor resultant force or rotor radius	rad/sec or lb or ft
RHP	Rotor horsepower	--
R^N	Nacelle axes yaw rate	rad/sec
R^R	Nacelle wind axes yaw rate	rad/sec
r	Body axes yaw rate	rad/sec
$\underline{r}$	Radius vector	--
r_n	Landing gear tire radius	ft.
S	Surface area	ft^2
SF	Rotor side force	lb
SHP	Shaft horsepower	--
SHP*	Engine shaft horsepower at sea level standard static conditions	
T	Rotor thrust	lb
TEA	Engine referred turbine inlet temperature	degrees
(T_{IGE}/T_{OGE})	Ratio of the rotor thrust in ground effect to the thrust out of ground effect	--
$T_1 \rightarrow T_3$	Coefficients of curve fit equations for rotor/rotor interference	ND
t	Time	sec

NOMENCLATURE

Symbol	Definition	Units
u	Body axes longitudinal component of velocity at aircraft center of gravity or rotor hub, wing, horizontal and vertical tail velocities referred to rotor shaft and local surface chord axes respectively.	ft/sec
u'	Body axes longitudinal component of velocity at rotor hub and wing aerodynamic center	ft/sec
u_{PA}	Body axes longitudinal component of velocity at pilots station	ft/sec
V	Total velocity	ft/sec
V_t	Rotor tip speed	ft/sec
V'	Resultant flow through rotor disc	ft/sec
V_*	Non-dimensional rotor forward velocity	N.D.
$\underline{V}$	Total Velocity Vector	——
v	Body axes lateral component of velocity at aircraft center of gravity or rotor hub wing, horizontal and vertical tail velocities referred to rotor shaft and local surface chord axes respectively	ft/sec
v'	Body axes lateral component of velocity at rotor hub and wing aerodynamic center	ft/sec
v_i	Rotor induced velocity	ft/sec
v_{PA}	Body axes lateral component of velocity at pilots station.	ft/sec
v_*	Non-dimensional rotor induced velocity	N.D.
W.L.	Fuselage water line position	inches
W'	Weight of aircraft components	lb.
WDTIND	Fuel flow indicator	——
w	Body axes vertical component of velocity at aircraft center of gravity or rotor	ft/sec

NOMENCLATURE

Symbol	Definition	Units
	hub, wing, horizontal and vertical tail velocities referred to rotor shaft and local surface chord axes respectively	
w'	Body axes vertical component of velocity at rotor hub and wing aerodynamic center	ft/sec
w_{PA}	Body axes vertical component of velocity at pilots station.	
$X_{subscript}$	Longitudinal distance, measured positive forward from nacelle pivot along body axes	ft.
$\Delta X_{subscript}$	Longitudinal force, measured positive forward along body axes	lb.
X_{aero}	Total longitudinal aerodynamic force at center of gravity measured positive forward along body axes.	lb.
$X^{sprscript}_{subscript}$	Longitudinal force, measured positive forward along body axes.	lb.
$\dot{X}_{North}$	Longitudinal ground track velocity	ft/sec
$Y_{subscript}$	Lateral distance, measured positive along right wing along body axes	ft.
$\Delta Y_{subscript}$	Lateral force, measured positive along right wing in body axes	lb.
Y_{aero}	Total lateral aerodynamic force at center of gravity measured positive along right wing in body axes	lb.
$Y^{sprscript}_{subscript}$	Lateral force, measured positive along right wing in body axes	lb.
$\dot{Y}_{East}$	Lateral ground track velocity	ft/sec
$Z_{subscript}$	Vertical distance, measured positive down nacelle pivot along body axes	ft.
$\Delta Z_{subscript}$	Vertical force, measured positive down along body axes	lb.
Z_{aero}	Total vertical aerodynamic force at center	lb.

NOMENCLATURE

Symbol	Definition	Units
	of gravity, measured positive down along body axes.	
$Z^{\text{sprscript}}_{\text{subscript}}$	Vertical force, measured positive down along body axes	lb.
$\dot{Z}_{\text{down}}$	Vertical ground track velocity	ft/sec
z	Vertical distance from nacelle pivot to center of gravity of aircraft component, positive down from nacelle pivot along body axes.	ft.
α	Angle of attack	rad
β	Angle of sideslip	rad
$\Delta'_{w'fuel}$	Vertical distance between wing fuel center of gravity and wing mass element center of gravity	ft.
$\Delta'_{w'NF}$	Vertical distance between fixed nacelle center of gravity and wing mass element center of gravity.	ft.
$\Delta'_{w'w}$	Vertical distance between wing center of gravity and wing mass element center of gravity.	ft.
δ	Control element (surface or stick) angular or linear displacement	deg. or in.
δ'_{C}	Vertical distance between cargo center of gravity and fuselage mass element center of gravity	ft.
δ'_{CR}	Vertical distance between crew center of gravity and fuselage mass element center of gravity	ft.
$\delta'_{F'}$	Vertical distance between fuselage center of gravity and fuselage mass element center of gravity	ft.
δ'_{HT}	Vertical distance between horizontal tail center of gravity and fuselage mass element center of gravity	ft.

Symbol	NOMENCLATURE Definition	UNITS
δ'_{VT}	Vertical distance between vertical tail center of gravity and fuselage mass element center of gravity	ft.
ε	Wing or rotor downwash angle	rad
ε_o	Wing downwash angle at zero wing angle of attach	rad
ε_{iLR}	Rotor/rotor interference angle, left rotor on right rotor	rad
ε_{iRL}	Rotor/rotor interference angle, right rotor on left rotor	rad
ε_w	Wing on rotor interference	rad
ζ	Rotor sideslip angle or damping ratio	rad orN.D.
$\zeta_{w1} \rightarrow \zeta_{w4}$	Wing damping ratio	N.D.
$H'_{w'fuel}$	Horizontal distance between wing fuel center of gravity and wing mass element center of gravity	ft.
$H'_{w'NF}$	Horizontal distance between fixed nacelle center of gravity and wing mass element center of gravity	ft.
$H'_{w'w}$	Horizontal distance between wing center of gravity and wing mass element center of gravity	ft.
η'_c	Horizontal distance between cargo center of gravity and fuselage mass element center of gravity	ft.
η'_{CR}	Horizontal distance between crew center of gravity and fuselage mass element center of gravity	ft.
η'_F	Horizontal distance between fuselage center of gravity and fuselage mass	ft

Symbol	NOMENCLATURE Definition	Units
	element center of gravity	
η_{HT}	Horizontal tail efficiency	N.D.
η'_{HT}	Horizontal distance between horizontal tail center of gravity and fuselage mass element center of gravity.	lb.
η_{VT}	Vertical tail efficiency factor	N.D.
η'_{VT}	Horizontal distance between vertical tail center of gravity and fuselage mass element center of gravity	ft.
η_{TR}	Transmission efficiency	N.D.
θ	Aircraft pitch or Euler angle or temperature ratio	rad or N.D.
θ_t	Wing twist angle	rad
$\theta_{0.75}$	Rotor collective pitch angle at three quarter radius	deg.
λ	Angle between the rotor shaft and a line drawn through the nacelle center of gravity from the pivot.	rad
μ	Rotor advance ratio = $V/\Omega R$	N.D.
μ_S	Tire sliding coefficient of friction when sliding sidewards (for concrete)	N.D.
μ_o	Tire rolling coefficient of friction (for concrete)	N.D.
μ_1	Coefficient of rolling friction for brakes	N.D.
$\xi_{R1} \rightarrow \xi_{R4}$	Terms of wing immersed area calculation	——
π	3.14159	——
ρ	Ambient air density	$slug/ft^3$
σ	Fuselage sidewash angle	rad

NOMENCLATURE

Symbol	Definition	Units
σ_h	Ambient density ratio	N.D.
τ	Angle between freestream velocity and rotor resultant force	rad
τ_D	Engine response time constant	sec.
τ_E	Engine response time constant	sec.
τ_{HT}	Horizontal tail effectiveness	rad/rad
τ_{LAS}	Load alleviation system time constant	sec
τ_{VT}	Vertical tail effectiviness	rad/rad
τ_p	Lateral directional SAS time constant	sec
τ_r	Lateral directional SAS time constant	sec
τ_ϕ	Lateral directional SAS time constant	sec
$\tau_{\phi_{\delta s}}$	Lateral directional SAS time constant	sec
τ_ψ	Lateral directional SAS time constant	sec
$\tau_{\psi_{\delta r}}$	Lateral directional SAS time constant	sec
τ_1	Rotor thrust response time constant	sec
τ_2	Rotor thrust response time constant	sec
ϕ	Aircraft roll angle or Euler angle	rad
ϕ_P	Rotor swashplate phase angle	rad
$\phi_1 \rightarrow \phi_5$	Functions in wing vertical bending equations	——
χ	Rotor wake skew angle	rad
ψ	Aircraft yaw angle or Euler angle	rad
Ω	Rotor or engine rotational speed	rad/sec
$\underline{\Omega}$	Rotational speed vector	rad/sec
ω	Natural frequency	rad/sec
$\omega_{w1} \rightarrow \omega_{w3}$	Wing natural frequency	rad/sec

Subscripts

A	Available
AC	Aerodynamic center
ACT	Actuator
AERO	Aerodynamic force
a	Aileron
B	Longitudinal stick
c	Cargo
CG	Center of gravity
CR	Crew
C/4	Quarter chord
DUM	Dummy variable
E	Engine
EFF	Effective
e	Elevator or effective
F	Fuselage
FAC	Fuselage aerodynamic center
FUEL	Fuel in wing
$FUEL_{CG}$	Fuel center of gravity
FUS	Fuselage
F'	Fuselage less landing gear
f	Flap
GLAS	Load alleviation system
GYRO	Gyroscopic
g	Ground or gust
HL	Left rotor hub

Subscripts

HR	Right rotor hub
HT	Horizontal tail
HTCG	Horizontal tail center of gravity
IGE	In ground effect
i	Immersed
L	Left wing or rotor
LAS	Load alleviation system
LE	Left engine
LG	Landing gear
L-L	Rotor lead-lag
LN	Left nacelle
LR	Left rotor
LRH	Left rotor hub
LT	Left wing tip
LW	Left wing
LW_o	Left wing referred to freestream
MAX	Maximum
N	Nacelle or natural frequency
NF	Fixed portion of nacelle
NFCG	Fixed portion of nacelle center of gravity
NL	Left nacelle
NR	Right nacelle
NT	Tilting portion of nacelle
n	Landing gear index, n=1 left gear, n=2 right gear, n=3 nose gear

Subscripts

OGE	Out of ground effect
P	Power, nacelle pivot, or rotor polar moment of inertia
POWER	Power
PA	Pilot station
R	Right wing, rotor or rudder pedal
RE	Right engine
REQ	Required
RIGID	Rigid
RN	Right nacelle
RR	Right rotor
RRH	Right rotor hub
RT	Right wing tip
RUD	Rudder
RW	Right wing
RW_o	Right wing referred to freestream
S	Rotor shaft, side, or lateral stick
SP	Spoiler
STALL	Stall
T	Tail, total or wing tip
TH	Throttle
VT	Vertical tail
VTCG	Vertical tail center of gravity
W	Wing
WAC	Wing aerodynamic center
WCG	Wing center of gravity

Subscripts

x	Along the lonitudinal body axes, positive forward
y	Along the lateral body axes, positive out right wing
z	Along the vertical body axes, positive down
——	Denotes a vector quantity

Superscripts

(c)	Referes to cargo or payload weight
(CR)	Refers to aircraft crew weight
F	Fuselage
F'	Fuselage less landing gear
HT	Horizontal tail
(HT)	Refers to horizontal tail weight component
IGE	In ground effect
LW	Left wing
N	Nacelle
NL	Left wing tip at pivot
NR	Right wing tip at pivot
(p)	Roll axes
(q)	Pitch axes
RW	Right wing
(r)	Yaw axes
T	Total of horizontal and vertical tail
VT	Vertical tail
(VT)	Referes to vertical tail weight component
W	Wing

Superscripts

(W'_{FUEL})	Refers to wing fuel weight
(W_f')	Refers to fuselage weight component
(W'_{NF})	Refers to weight of fixed portion of nacelle
(W'_W)	Refers to wing weight component
$\dot{}$	First derivative with respect to time; represents velocity
$\ddot{}$	Second derivative with respect to time; represents acceleration
"	Denotes an interim calculation or coeffiecient in local wind axes
'''	Denotes an interim calculation
$\bar{}$	Denotes average value
*	Denotes interim calculation or calculation in freestream wind axes
'	Denotes an interim calculation
+	Denotes an interim calculation
$\wedge$	Denotes an interim calculation
$\lvert\ \rvert$	Absolute values

NOTES

1. Some symbols not defined in this section, but used in this report, are defined in the section of the report they are used.

2. Alternate definitions, where applicable, for each symbol are given. Select the appropiate definition for each particular section

3. All distances are measured with respect to the nacelle pivot. Distances are positive forward, down and to the right of the pivot. Forces are positive forward, down, and to the right.

4. Δ or δ preceeding a symbol generally denotes an incremental change.

1.0 INTRODUCTION

Piloted simulation is a useful and important tool in the design, development and test of new flight vehicles. Figure 1.1 shows a summary of some of these uses as they could be applied to the Model 222 tilt rotor aircraft.

As part of Contract NAS2-6598 Boeing Vertol developed a complex mathematical model of the Model 222 tilt rotor, intended primarily for use with the NASA Flight Simulator for Advanced Aircraft (FSAA) at Ames Research Center. The purpose of this report is to document the development of that mathematical model and to substantiate the methods which were uniquely developed for this purpose.

- Evaluation of Tilt Rotor Handling Qualities
    - Stability and Control
    - Control System Optimization
    - Evaluation of Man-in-the-Loop System Compatibility
    - Evaluation of Malfunction Effects
- Evaluation of Tilt Rotor Performance
    - Maneuver Capability
    - VTOL and STOL Takeoff and Landing Capability
- As a Tool to Evaluate Configuration Changes
    - Changes in Cockpit Layout
    - Changes in Tail Size
    - Changes in Geometry
    - Changes in SAS Configuration
    - Changes in Elastic Characteristics
- As a Flight Test Support Tool
    - Development of Emergency Techniques
    - Familiarization of Flight Crews with Aircraft Characteristics Prior to Flight
    - Correlation Studies
    - Exploration of Flight-Discovered Phenomena

Figure No. 1.1. Summary of Uses for Piloted Simulation

2.0 GENERAL DESCRIPTION OF SIMULATION

The objective of this program was to develop a real time simulation program for a tilt rotor aircraft to be used at the NASA-Ames simulation facility in conjunction with the Flight Simulator for Advanced Aircraft (FSAA) for evaluation of tilt rotor aircraft performance and handling characteristics throughout the flight envelope and identifying problem areas within the envelope.

The mathematical model developed under this contract includes the basic 6 degree of rigid body freedom outer loop equations written about the instantaneous center of gravity with all inertial and aerodynamic coupling terms included. Euler angles are used to properly orient the aircraft in space.

Rotor forces and moments are input to the equations from curve-fit data. The rotor data bank applies to the Boeing Model 222 tilt rotor. Calculation of the rotor forces and moments on-line for real time simulation is not practical because of the complexity of the programs required to represent the lag-flap coupling effects of the soft-in-plane hingless rotor. Analytical studies show that the lag-flap coupling has a large effect upon the phasing of the hub forces and moments of the rotor thereby altering the direct rotor effects on aircraft stability significantly. The rotor rotational degree of freedom is included to represent the effects of rotor inertia which are included in the representation of the thrust management system.

The effects of rotor-on-wing, wing-on-rotor, and rotor-on-horizontal tail are included in this program. The effects of rotor-on-wing are represented by calculation of the slipstream angle of attack of the portions of the aircraft operating in the rotor slipstream by momentum methods and resolving the associated forces and moments to body axes. Correlation with test data are shown in Section 6.5.2 to verify these interference effects. The effects of the rotor slipstream on the horizontal tail downwash are also calculated by momentum methods. The angle through which the flow through the rotor is turned is assumed to represent the change in tail downwash. Provisions are made to incorporate the upwash effects of the wing on the rotor. Lifting line theory should be used to compute these effects.

The effects on lateral/directional parameters caused by rotor wake skew on the wing are included by computing the change in immersed wing area during sidewards flight and sideslips.

Structural dynamics effects included consist of the first mode wing vertical bending and the first wing torsion mode. These wing structural modes have been included on a "quasistatic" basis; i.e. the natural frequencies of vibration of the structure are much higher than the frequencies of the rigid body motion, and the coupling is in the aerodynamic terms.

The aerodynamics of the fuselage, empennage, nacelles, wings and rotors are included in detail. The aerodynamics of the wing and rotors are written separately for the left and right sides. The effects of the wing leading edge umbrellas are included, with provisions for the direct effects of wing download and pitching moment with the umbrellas open in slow flight. Ground effects are considered on the rotors, wing and horizontal tail. The effects of Mach number on the airplane are treated by application of the Prandtl-Glauert rule. The effects of Mach number on the rotor data have been included in the curve fit equations.

The control system elements represented include pilot command, three axis stability augmentation systems, a load alleviation system (LAS) and a thrust management system. Control system actuator dynamics are represented by appropriate first order and second order lags. The systems are assumed to be "tight" in that thresholds, biases and hysteresis loops are neglected.

Turbine engine performance with appropriate dynamic responses are included. Engine power is computed for the range of flight condition necessary to cover the flight envelope. A relatively simple engine dynamic response model modulates the power output in response to pilot control of throttle position.

Landing gear is represented by a spring-damper system without complex calculation of oleo strut response.

The effects of rotor tilt angle on the aircraft center of gravity and inertia are included. Forces and moments resulting from acceleration of the nacelles during tilting maneuvers are calculated in the program.

An airframe representation/preprocessor calculation is included that enables the user to input the location of major structural elements of the aircraft in terms of water line, butt line and station line location. All lengths and inertias required by the equation are then calculated. This feature enables the user to quickly change the location of major elements to assess their impact on vehicle response. The rest of the input data required has been kept to a minimum to augment the programs' usefulness. Provisions have been included to provide a very flexible design tool which enables the astute user to perform a wide variety of studies. Figure 2.1 summarizes the salient features of the mathematical model described in this document. It should be emphasized that this model has full flight envelope capability.

- Full Flight Envelope Capability with Total Force Representation
- 6 Rigid Body Degrees of Freedom
- Independent Nacelle Pitch Degree of Freedom
- 2 Elastic Degrees of Freedom
- 1 Rotor Rotational Degree of Freedom
- Includes the Aerodynamics of:
  - Rotors
  - Wings
  - Rotor/Wing & Wing/Rotor Interference
  - Fuselage
  - Landing Gear
  - Tail Surfaces
  - Engines
- Control System Elements:
  - Pilot Command
  - SAS
  - Load Alleviation System (LAS)
  - Thrust and Power Management System
- Aeroelastic Representation
  - Wing Vertical Bending
  - Wing Torsion

Figure 2.1. Salient Features of Math Model

3.0 SIGN CONVENTIONS

Standard aircraft sign conventions have been used throughout this report. Sign conventions are as follows:

Positive X axis forward

Positive Y axis outward along the right wing.

Positive Z axis downward perpendicular to the XY plane.

Lift is positive along the negative Z axis.

Pitching moment is positive nose-up about the Y axis.

Sideforce is positive outward in the direction of the positive Y axis.

Yawing moment is positive nose-right.

Rolling moment is positive right wing down.

Positive elevator deflection is trailing edge down

Positive rudder deflection is rudder-trailing-edge-left.

Positive aileron deflection is right-flaperon-trailing-edge-down.

Positive spoiler deflection is left-hand-spoiler-deflected-upward.

Positive deflection of the pilot's stick and rudder pedals yields positive aircraft pitch, roll, and yaw moments from negative control deflections.

Rotor sign conventions are illustrated in Section 7.0

Special sign convention used in the derivations are noted in the appropriate section.

4.0 MODEL 222 TILT ROTOR AIRCRAFT DESCRIPTION

The Boeing Model 222 Tilt Rotor Research Aircraft, shown in Figure 4.1 uses two 26-foot diameter soft in-plane hingeless rotors of the same design that has already been demonstrated in the NASA/Ames 40 by 80-foot tunnel. The soft in-plane rotor is mechanically simple and provides excellent flying qualities characteristics as well as freedom from aeroelastic problems. It is service proven on the FAA certified BO-105 helicopter. For transition, the rotors tilt from hover position (rotor disk horizontal) to cruise position (rotor disk vertical). Intermediate nacelle positions provide optimum performance capability for climb, descent and for STOL operations.

The Model 222 is powered by two modified Lycoming T53-L-13B turboshaft engines mounted in fixed (nontilting) nacelles at each wing tip. The rotors are interconnected by a cross shaft for single engine operation. The engine power available yields excellent single engine and temperature-altitude performance.

Fuselage and empennage are production (MU-2J) components, modified to accept the Model 222 wing and two production (OV-10) ejection seats. The retractable tricycle landing gear is also the existing MU-2J gear modified to provide increased energy absorption.

Collective and cyclic pitch of the rotors, together with nacelle tilt, provide high control power in hover. In the cruise mode, control is by conventional airplane elevators, rudder, flaperons and spoilers. Leading-edge "umbrella" flaps and large deflection trailing-edge flaps reduce download and ground effect turbulences in hover. Operation of flaps, umbrellas and elevator as well as phasing out of the rotor controls is mechanically programmed with nacelle tilt to relieve pilot workload.

A limited-authority stability augmentation system includes feedback from angle-of-attack, yaw angle, and dynamic pressure. In cruise flight it feeds back two axes of cyclic pitch to the rotor control. This provides increased static stability and reduces blade loads to increase fatigue margins. The feedback system is not required for either stability or structural integrity. This system permits easy variation of the stability characteristics of the aircraft.

WING	SPAN	33 FT 5 IN.
	CHORD	71.8 IN.
	AREA	200 FT^2
	ASPECT RATIO	5.61
	TAPER RATIO	1.0
	THICKNESS – CHORD RATIO	.21
	WING LOADING	67.7 LB/FT^2 (DESIGN GROSS WT)
HORIZONTAL TAIL	SPAN	15 FT 9 IN.
	AREA	58.3 FT^2
VERTICAL TAIL	SPAN	8 FT 9 IN.
	AREA	43.3 FT^2
ROTOR	DIAMETER	26 FT 0 IN.
	SOLIDITY	.115
	DISC LOADING	12.75 LB/FT^2 (DESIGN GROSS WT)
	NO. OF BLADES	3
WEIGHTS	DESIGN GROSS WT	13,541 LB
	ALTERNATE GROSS WT	15,500 LB
	NORMAL GROSS WT	12,321 LB

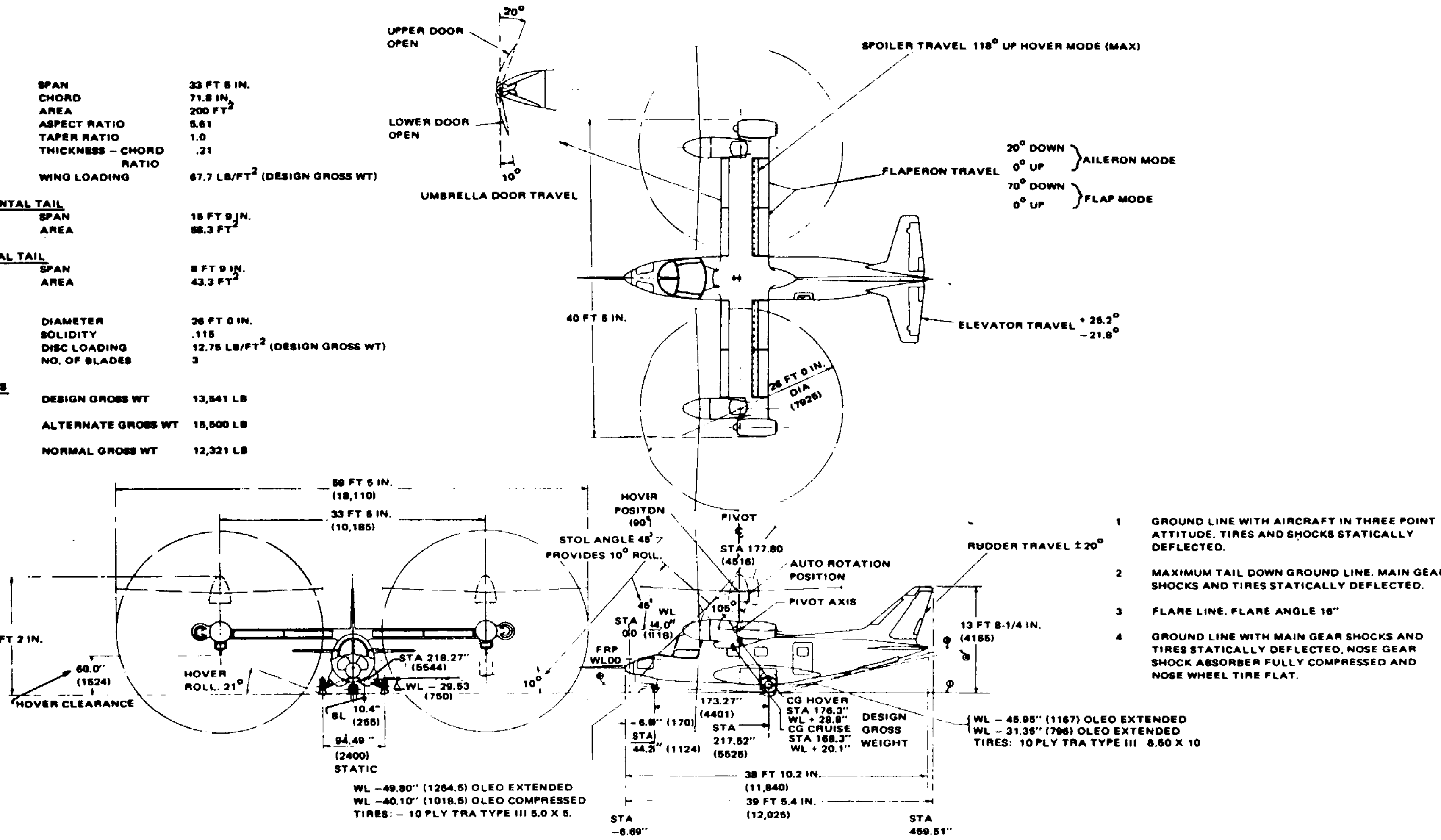


Figure No. 4.1. Model 222 Tilt Rotor Research Aircraft

FOLDOUT FRAME 1

FOLDOUT FRAME 2

5.0 EQUATIONS OF MOTION

This section presents the derivation of the airframe equations of motion and the simplifications that were made in order to obtain the final equations as presented in Appendix E. The treatment accounts for all six rigid-body degrees-of-freedom including the effects of the tilting nacelles and rotors. The principal features of the derivation are:

- Assumption of X-Z plane of symmetry
- The basic equations are derived about the instantaneous center of gravity of the aircraft since the center of gravity is strongly dependent on nacelle incidence.
- Rotor and engine gyroscopic terms are included
- The wing elastic degrees of freedom do not couple inertially. The coupling occurs through the aerodynamic terms in the equations as discussed in Section 12.
- Wing aeroelastic effects are not included in the center of gravity calculations.

5.1 AXES SYSTEM

A set of right-handed orthogonal axes OXYZ is placed at the center of mass of the aircraft and is fixed in the aircraft such that OX lies in the lateral plane of symmetry and is positive forward parallel to the fuselage water line zero. The remaining axes are placed as shown in Figure 5.1.

The orientation of the aircraft is defined with respect to a

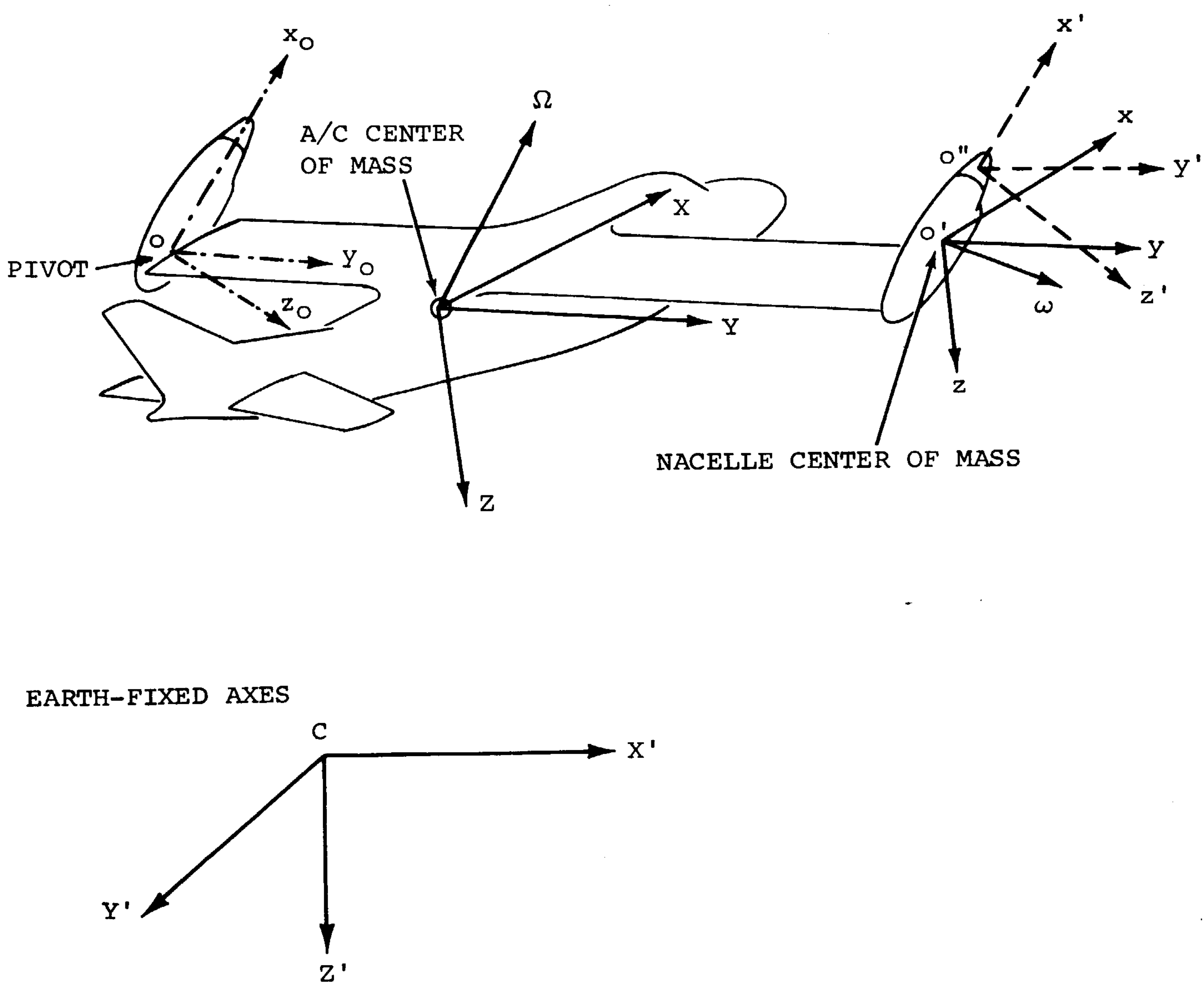


Figure 5.1. Axes Systems

set of earth-fixed axes C X'Y'Z'. With the axes OXYZ initially parallel to C X'Y'Z', the aircraft is yawed to the right about O through an angle ψ, then pitched up about OZ through the angle θ and finally rolled right about OX through the angle ϕ.

If $\underline{V}$ and $\underline{\Omega}$ are the aircraft velocity and angular velocity vectors relative to the earth-fixed axes, the projections of these vectors on the moving axes are U, V, and W, for the components along OX, OY and OZ, and P, Q and R for the angular velocity components.

Thus

$$\underline{V} = U\hat{\underline{i}} + V\hat{\underline{j}} + W\hat{\underline{k}} \tag{5.1}$$

$$\underline{\Omega} = P\hat{\underline{i}} + Q\hat{\underline{j}} + R\hat{\underline{k}} \tag{5.2}$$

where the unit vectors $\hat{\underline{i}}$, $\hat{\underline{j}}$ and $\hat{\underline{k}}$ lie along OX, OY and OZ.

5.2 AIRCRAFT GROUND TRACK

The components of $\underline{V}$ relative to the earth-fixed axes are obtained in terms of U, V, W and ψ,θ,ϕ as, (See Reference 10),

$$\begin{aligned}
\frac{dX'}{dt} &= U \cos\theta \cos\psi + V(\sin\phi \sin\theta \cos\psi - \cos\phi \sin\psi) \\
&\quad + W(\cos\phi \sin\theta \cos\psi + \sin\theta \sin\psi) \\
\frac{dY'}{dt} &= U \cos\theta \sin\psi + V(\sin\phi \sin\theta \sin\psi + \cos\phi \cos\psi) \\
&\quad + W(\cos\phi \sin\theta \sin\psi - \sin\phi \cos\psi) \\
\frac{dZ'}{dt} &= -U \sin\theta + V\sin\phi \cos\theta + W\cos\phi \cos\theta
\end{aligned} \tag{5.3}$$

Integration of these equations gives the aircraft ground track. A further relationship may be obtained between the rate of change of the Euler angles (ψ, θ, ϕ) and the components of the angular velocity in the moving axes system, viz,

$$\begin{aligned}
\dot{\psi} &= (R\cos\phi + Q\sin\phi)\sec\theta \\
\dot{\theta} &= Q\cos\phi - R\sin\phi \\
\dot{\phi} &= P + \dot{\psi}\sin\theta
\end{aligned} \tag{5.4}$$

5.3 FORCE EQUATION

The total external force, $\underline{F}$, acting at the aircraft center of mass is given by

$$F = \frac{d}{dt}(m\underline{V}) = m\left[\frac{\delta \underline{V}}{\delta t} + \underline{\Omega} \times \underline{V}\right] \tag{5.5}$$

where m is the mass of the aircraft and $\frac{\delta \underline{V}}{\delta t}$ is the rate of change of $\underline{V}$ with respect to the moving reference frame OXYZ i.e.

$$\frac{\delta \underline{V}}{\delta t} = U\,\hat{\underline{i}} + V\hat{\underline{j}} + W\hat{\underline{k}} \tag{5.6}$$

If $\underline{F}$ has components F_x, F_y and F_z along the respective axes then

$$\underline{F} = F_x\,\hat{\underline{i}} + F_y\hat{\underline{j}} + F_z\,\hat{\underline{k}} = m\left\{U\,\hat{\underline{i}} + V\hat{\underline{j}} + W\hat{\underline{k}} + \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ P & Q & R \\ U & V & W \end{vmatrix}\right\}$$

thus

$$\begin{aligned}
F_x &= m\,(\dot{U} + QW - RV) \\
F_y &= m\,(\dot{V} + RU - PW) \\
F_z &= m\,(\dot{W} + PV - QU)
\end{aligned} \tag{5.7}$$

The forces F_x, F_y and F_z are given by

$$F_x = X_{AERO} - mg \sin\theta$$
$$F_y = Y_{AERO} + mg \sin\phi \cos\theta \qquad (5.8)$$
$$F_z = Z_{AERO} + mg \cos\phi \cos\theta$$

where X_{AERO}, etc., are the components of the total aerodynamic force acting at the aircraft center of mass.

Substituting equations (5.8) in equations (5.7), the following equations are obtained for the aircraft accelerations,

$$\dot{U} = \frac{X_{AERO}}{m} - g \sin\theta - QW + RV$$
$$\dot{V} = \frac{Y_{AERO}}{m} + g \cos\theta \sin\phi - RU + PW \qquad (5.9)$$
$$\dot{W} = \frac{Z_{AERO}}{m} + g \cos\theta \cos\phi + QU - PV$$

5.4 MOMENT EQUATION

The derivation of the equations for the total moment acting about the aircraft center of mass is complicated by the fact that the center of mass changes position due to the tilting nacelles. Thus the centers of gravity of the principal aircraft component masses of the wings (m_w), fuselage (including tails) (m_f), and nacelles (m_N), move with respect to the reference axes OXYZ placed at the instantaneous overall center of gravity of the aircraft. The equation of motion for such a mass element will first be obtained and the total moment found by adding the contributions of all the elements.

5.5 EQUATION OF MOTION FOR A MASS ELEMENT

With reference to Figure (5.1) O'xyz is a right-handed set of axes placed at the center of gravity of the representative mass. The axes are parallel to the set OXYZ. The mass, m, rotates about its own center of gravity with angular velocity $\underline{\omega}$ which, in general, differs from $\underline{\Omega}$ the angular velocity of the aircraft. If $\underline{r}$ is the radius vector from O to O' then the velocity of the center of mass of the element is

$$V = \frac{\delta \underline{r}}{\delta t} + \underline{\Omega} \times \underline{r} \tag{5.10}$$

The angular momentum of this mass about O is

$$\underline{h} = m\ (\underline{r} \times \underline{V}) + \underline{ho} \tag{5.11}$$

where $\underline{ho}$ is the angular momentum of m about its own center of mass and is given by

$$\underline{ho} = \bar{I}\ \underline{\omega} \tag{5.12}$$

where

$$\bar{I} = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix} \tag{5.13}$$

and I_{xx}, etc., are the moments and products of inertia of the mass about O'xyz.

The total moment, $\underline{G}$, about the aircraft center of mass is given by

$$G = \frac{dh}{dt} = \frac{\delta h}{\delta t} + \underline{\Omega} \times \underline{h} \tag{5.14}$$

Using equations (5.10), (5.11) and (5.12) in (5.14) the moment becomes

$$\underline{G} = m\left[\frac{\delta \underline{r}}{\delta t} \times \left(\frac{\delta \underline{r}}{\delta t} + \underline{\Omega} \times \underline{r}\right) + \underline{r} \times \frac{\delta}{\delta t}\left(\frac{\delta \underline{r}}{\delta t} + \underline{\Omega} \times \underline{r}\right)\right] + \frac{\delta}{\delta t}(\bar{I}\underline{\omega})$$
$$+ m\ \underline{\Omega} \times \left[\underline{r} \times \left(\frac{\delta \underline{r}}{\delta t} + \underline{\Omega} \times \underline{r}\right)\right] + \underline{\Omega} \times \left(\bar{I}\underline{\omega}\right) \tag{5.15}$$

which reduces to

$$\underline{G} = 2m\underline{\Omega}\left(\underline{r}\cdot \frac{\delta \underline{r}}{\delta t}\right) + m\underline{r} \times \frac{\delta^2 \underline{r}}{\delta t^2} + m \frac{\delta \underline{\Omega}}{\delta t} (\underline{r}\cdot\underline{r}) - m\underline{r}\left(\underline{r}\cdot \frac{\delta \underline{\Omega}}{\delta t}\right) \qquad (5.16)$$

$$-2m \frac{\delta \underline{r}}{\delta t} (\underline{\Omega}\cdot\underline{r}) - m(\underline{r}\cdot\underline{\Omega})(\underline{\Omega}\times\underline{r}) + \mathrm{I} \frac{\delta \underline{\omega}}{\delta t} + \underline{\Omega} \times\left(\bar{\mathrm{I}}\ \underline{\omega}\right)$$

The only masses that possess angular velocities different from that of the aircraft are the nacelles, which are free to pitch about O' with angular rate $\dot{i} = \frac{di_N}{dt}$. Thus $\underline{\omega}$ may be written generally as

$$\underline{\omega} = P\underline{\hat{i}} + (Q + \dot{i}_N)\ \underline{\hat{j}} + R\ \underline{\hat{k}} \qquad (5.17)$$

Now, with $\underline{r} = X\underline{\hat{i}} + Y\underline{\hat{j}} + Z\underline{\hat{k}}$, where X, Y, and Z are the instantaneous coordinates of the individual mass center relative to the aircraft mass center, the various terms of equation (5.16) are, in component form,

$$\underline{r}\cdot \frac{\delta \underline{r}}{\delta t} = XX + YY + ZZ$$

$$\underline{r} \times \frac{\delta^2 \underline{r}}{\delta t^2} = (YZ-ZY)\underline{\hat{i}} - (XZ-ZX)\underline{\hat{j}} + (XY-YX)\underline{\hat{k}}$$

$$\frac{\delta \underline{\Omega}}{\delta t} (\underline{r}\cdot\underline{r}) = (X^2 + Y^2 + Z^2)(\dot{P}\underline{\hat{i}} + \dot{Q}\underline{\hat{j}} + \dot{R}\underline{\hat{k}})$$

$$r\cdot \frac{\delta \underline{\Omega}}{\delta t} = X\dot{P} + Y\dot{Q} + Z\dot{R}$$

$$\underline{\Omega}\cdot\underline{r} = XP + YQ + ZR$$

$$(\underline{r}\cdot\underline{\Omega})(\underline{\Omega}\times\underline{r}) = (XP+YQ+XR)\left[(QZ-RY)\underline{\hat{i}} - (PZ-RX)\underline{\hat{j}} + (PY-XQ)\underline{\hat{k}}\right]$$

$$\bar{\mathrm{I}}\ \frac{\delta \underline{\omega}}{\delta t} = (I_{xx}\dot{P} - I_{xz}R)\underline{\hat{i}} + I_{yy}(\dot{Q} + \ddot{i}_N)\underline{\hat{j}} + (I_{zz}\dot{R} - I_{xz}\dot{P})\underline{\hat{k}}$$

$$\underline{\Omega} \times (\bar{\mathrm{I}}\underline{\omega}) = (QR\ I_{zz} - QPI_{xz} - RQI_{yy} - R\dot{i}_N I_{yy})\underline{\hat{i}}$$

$$-(PR\ I_{zz} - P^2 I_{xz} - PR\ I_{xx} + R^2 I_{xz})\underline{\hat{j}}$$

$$+(QR\ I_{xz} + PQI_{yy} + P\dot{i}_N I_{yy} - PQ\ I_{xx})\underline{\hat{k}}$$

where, in the last two terms, the products of inertia I_{xy} and I_{yz} are zero from symmetry considerations.

Substituting the above relations into equation (5.16) and noting that $\dot{Y}$ and $\ddot{Y}$ are always zero (no lateral motion of the individual masses) the following expressions are obtained for the components of the moment $\underline{G} = \Delta L\hat{\underline{i}} + \Delta M\hat{\underline{j}} + \Delta N\hat{\underline{k}}$:

$$\Delta L = \dot{P}[I_{xx} + m(Y^2 + Z^2)] - (\dot{R}+PQ)[I_{xz} + m\ XZ]$$
$$+ RQ[I_{zz}-I_{yy}+m(Y^2-Z^2)] + m\ YZ(R^2-Q^2) - I_{yy}R\ \dot{i}_N$$
$$+ m\ (Y\ddot{Z}-2\dot{X}YR - 2\dot{X}ZR + 2Z\dot{Z}P - XY\ (\dot{Q} - PR))$$

$$\Delta M = \dot{Q}\ [I_{yy}+m(X^2+Z^2)] - (R^2-P^2)[I_{xz} + mXZ]$$
$$+ PR\ [I_{xx}-I_{zz} + m(Z^2-X^2)] + I_{yy}\ddot{i}_N \qquad (5.19)$$
$$+ m\ [\ddot{X}Z-X\ddot{Z} + 2Q(Z\dot{Z}+X\dot{X})-XY\ (\dot{P}+RQ)+YZ(PQ-\dot{R})]$$

$$\Delta N = \dot{R}\ [I_{zz}+m(X^2+Y^2)] - (\dot{P}-RQ)\ [I_{xz}+m\ XZ] \qquad (5.20)$$
$$+ PQ\ [I_{yy}-I_{xx} + m(X^2-Y^2)] + I_{yy}P\ \dot{i}_N$$
$$+ m\ [2X\dot{X}R - Y\ddot{X} - 2XZP - 2Y\dot{Z}Q - YZ\ (\dot{Q}+PR)+XY(Q^2-P^2)]$$

Summing the rolling moment equation:

$$L = I_{XX}\ \dot{P}-I_{XZ}\ (\dot{R}+PQ) + (I_{ZZ}-I_{YY})RQ \qquad (5.21)$$
$$+ m_N(R^2-Q^2)(Z_{NR}-Z_{NL})Y_N + m_N\Big\{Y_N(\ddot{Z}_{NR}-\ddot{Z}_{NL})$$
$$-2Q(\dot{X}_{NR}-\dot{X}_{NL})Y_N-2R(\dot{X}_{NR}Z_{NR} + \dot{X}_{NL}Z_{NL}) + 2P(\dot{Z}_{NR}Z_{NR} +$$
$$\dot{Z}_{NL}Z_{NL})-(\dot{Q}-PR)(X_{NR}-X_{NL})\ Y_N\Big\}+ 2m_f Z_f(P\dot{Z}_f -$$
$$R\dot{X}_f) + 2m_w Z_w(P\dot{Z}_w - R\dot{X}_w)-R\ I_{yy}^{N}\ (\dot{i}_{NL} + \dot{i}_{NR})$$

where I_{XX}, I_{XZ}, I_{ZZ} and I_{YY} are the inertias of the aircraft about its center of gravity, and the subscripts f, w, NL and NR stand for fuselage, wing, left nacelle and right nacelle. The remaining symbols are defined in the List of Symbols. Similar expressions are obtained for the pitching moment and yawing moment. In the interests of brevity the remainder of the discussion will be limited to equation (5.21).

Evaluation of the terms of the rolling moment equation indicate that this equation may be simplified considerably without a significant change in accuracy. For example, terms containing $(\dot{X}_{NR}-\dot{X}_{NL})$ may be dropped because $\dot{X}_{NR}$ is normally identical to $\dot{X}_{NL}$, i.e. the nacelles are raised or lowered together at the same rate. Equation (5.21) may thus be written

$$L=I_{XX}\dot{P}-I_{XZ}(\dot{R}+PQ) + (I_{ZZ}-I_{YY})RQ + m_N Y_N(\ddot{X}_{NR}-\ddot{Z}_{NL}) \qquad (5.22)$$

where the last term has been retained in consideration of the high differential nacelle accelerations encountered during hover maneuvers.

From the relationships presented in Appendix C the last term of equation (5.22) may be rewritten as

$$-\ell m_N Y_N \,[\ddot{i}_{NR} \cos\,(i_{NR}-\lambda) + \dot{i}_{NL}^2 \sin\,(i_{NL}-\lambda)$$
$$-\dot{i}_{NR}^2 \sin\,(i_{NR}-\lambda) - \ddot{i}_{NL} \cos\,(i_{NL}-\lambda)] \qquad (5.23)$$

which may be approximated to

$$-\ell m_N Y_N \,[\ddot{i}_{NR} \cos\,(i_{NR}-\lambda) - \ddot{i}_{NL} \cos\,(i_{NL}-\lambda)] \qquad (5.24)$$

since the nacelle rates appear as squared terms.

Similar treatment of the pitching moment and yawing moment equations results in the following final form of the moment equations.

$$L_{AERO} = I_{XX}\dot{P} - I_{XZ}(\dot{R}+PQ) + (I_{ZZ}-I_{YY})RQ$$
$$-\ell m_N Y_N\,[\ddot{i}_{NR}\cos(i_{NR}-\lambda) - \ddot{i}_{NL}\cos(i_{NL}-\lambda)]$$

$$M_{AERO} = I_{YY}\dot{Q} - I_{XZ}(R^2-P^2) + (I_{XX}-I_{ZZ})PR$$
$$+ \ddot{i}_{NR}\left\{I^N_{YY_O} + \ell m_N\,[X_R\cos(i_{NR}-\lambda) - Z_R\sin(i_{NR}-\lambda)]\right\} \tag{5.25}$$
$$+ \ddot{i}_{NL}\left\{I^N_{YY_O} + \ell m_N\,[X_L\cos(i_{NL}-\lambda) - Z_L\sin(i_{NL}-\lambda)]\right\}$$

$$N_{AERO} = I_{ZZ}\dot{R} - I_{XZ}(\dot{P}-RQ) + (I_{YY}-I_{XX})PQ$$
$$+ \ell m_N Y_N\,[\ddot{i}_{NR}\sin(i_{NR}-\lambda) - \ddot{i}_{NL}\sin(i_{NL}-\lambda)]$$

where the moments L_{AERO}, M_{AERO} and N_{AERO} represent the sum of the aerodynamic moments and rotor/engine gyroscopic moments about the aircraft center of mass. $I^N_{YY_O}$ is the nacelle pitch inertia referred to the nacelle-fixed axes system described in Appendix C. Equations for the aircraft inertias are also presented in that Appendix.

5.6 EQUATIONS OF MOTION FOR NACELLES

The equation of motion for a nacelle is required in order to obtain the moment exerted by the nacelle on the wing tip at the pivot. This moment is then used in the equations for wing twist.

The angular momentum of a nacelle about its pivot point is given by

$$\begin{aligned} \underline{h}_p &= (\underline{r}-\underline{r}_p) \times m_N\underline{V} + \underline{h}_{o_N} \\ &= m_n\,(\underline{r}\times\underline{V}) + \underline{h}_o - m_n\underline{r}_p \times \underline{V} \end{aligned} \tag{5.26}$$

where $\underline{r}$ is the radius vector from aircraft c.g. to nacelle c.g.

$\underline{V}$ is the velocity of the nacelle c.g.

$\underline{h}_{oN}$ is the angular momentum of the nacelle about its own c.g.

m_N is the nacelle mass

and $\underline{r}_p$ is the radius vector from aircraft c.g. to nacelle pivot

The term $m_n\ (\underline{r}x\underline{V}) + \underline{h}_{oN}$ is the angular momentum of the nacelle about the aircraft c.g. $(= \underline{h}^N_{CG})$

$$\text{i.e.} \quad \underline{h}_p = \underline{h}^N_{CG} - m_N(\underline{r}_p \times \underline{V})$$

The moment about the pivot is

$$G_p = \frac{d\underline{h}_p}{dt} = \frac{d\underline{h}_N}{dt} - m_n \frac{d}{dt}(\underline{r}_p \times \underline{V}) = \underline{G}^N_{CG} - \Delta\underline{G} \tag{5.27}$$

Since the quantity $\underline{G}^N_{cg}$ has already been obtained (equations (5.18), (5.19) and (5.20)), only the remaining term needs to be evaluated.

$$\Delta\underline{G} = m_N \frac{d}{dt}(\underline{r}_p x \underline{V}) = m_N\left\{\frac{\delta\underline{r}_p}{\delta t} \times \underline{V} + \underline{r}_p \times \frac{\delta\underline{V}}{\delta t} + \underline{\Omega}(\underline{r}_p \times \underline{V})\right\}$$

$$= m_N\left\{\frac{\delta\underline{r}_p}{\delta t} \times \left(\frac{\delta\underline{r}}{\delta t} + \underline{\Omega}x\underline{r}\right) + \underline{r}_p \times \frac{\delta}{\delta t}\left(\frac{\delta\underline{r}}{\delta t} + \underline{\Omega}x\underline{r}\right)\right. \tag{5.28}$$
$$\left. + \underline{\Omega} \times \left[\underline{r}_p \times \left(\frac{\delta\underline{r}}{\delta t} + \underline{\Omega} \times \underline{r}\right)\right]\right\}$$

Expansion of these terms results in the following expression

$$\Delta\underline{G} = m_N\left\{\frac{\delta\underline{r}_p}{\delta t} \times \frac{\delta\underline{r}}{\delta t} + \underline{\Omega}\left(\underline{r}\cdot\frac{\delta\underline{r}_p}{\delta t}\right) - \underline{r}\left(\frac{\delta\underline{r}_p}{\delta t}\cdot\underline{\Omega}\right) + \underline{r}_p \times \frac{\delta^2\underline{r}}{\delta t^2} + \frac{\delta\underline{\Omega}}{\delta t}(\underline{r}\cdot\underline{r}_p)\right.$$
$$- \underline{r}\left(\underline{r}_p\cdot\frac{\delta\underline{\Omega}}{\delta t}\right) + \underline{\Omega}\left(\frac{\delta\underline{r}}{\delta t}\cdot\underline{r}_p\right) - 2\frac{\delta\underline{r}}{\delta t}(\underline{r}_p\cdot\underline{\Omega})$$
$$\left. + \underline{r}_p\left(\frac{\delta\underline{r}}{\delta t}\cdot\underline{\Omega}\right) - (\underline{r}_p\cdot\underline{\Omega})(\underline{\Omega}x\underline{r})\right\}$$

We require only the $\underline{\hat{j}}$ component of this vector in order to obtain the nacelle pivot pitching moment.

The components of the vectors $\underline{r}_p$, $\underline{r}$ and $\underline{\Omega}$ are

$$\underline{r}_p = X_p\hat{\underline{i}} + Y_N\hat{\underline{j}} + Z_p\hat{\underline{k}} = -X_{CG}\hat{\underline{i}} + Y_N\hat{\underline{j}} - Z_{CG}\hat{\underline{k}}$$

$$\underline{r} = X_N\hat{\underline{i}} + Y_N\hat{\underline{j}} + Z_N\hat{\underline{k}}$$

$$\underline{\Omega} = P\hat{\underline{i}} + Q\hat{\underline{j}} + R\hat{\underline{k}}$$

Noting that the $\hat{\underline{j}}$ components of $\frac{\delta \underline{r}_p}{\delta t}$, $\frac{\delta \underline{r}}{\delta t}$ are zero (since Y_N is a constant), the above expression yields

$$\Delta M = m_N\Big\{\ddot{X}_N Z_{CG} - \ddot{Z}_N X_{CG} + \dot{Z}_{CG}\dot{X}_N + \dot{Z}_N\dot{X}_{CG} + PQ\ Y_N Z_N - RQ\ X_N Y_N\Big\} \tag{5.30}$$

Combining this equation with Equation (5.19) and using the transformations given in Appendix C, the final equation for the right-hand nacelle pivot actuator pitching moment becomes, after some simplification,

$$\begin{aligned} M_{NR} = &-\ddot{i}_{NR}\left[I_{YY_o}^{N} + \ell^2 m_N\left(1-\frac{m_N}{m}\right)\right] - \ell^2 m_N\left(1-\frac{m_N}{m}\right)\Big[\dot{Q} - PR\cos 2(i_{NR}-\lambda) \\ &+ (R^2-P^2)\sin(i_{NR}-\lambda)\ \mathrm{Cos}\ (i_{NR}-\lambda)\Big] - (R^2-P^2)\ I_{zz_o}^{N}\sin i_{NR}\cos i_{NR} \\ &- I_{YY_o}\dot{Q} + \ell\frac{m_N}{m}\Big[X_{AERO}\sin(i_{NR}-\lambda) + Z_{AERO}\cos(i_{NR}-\lambda)\Big] \\ &- \ell m_N Y_N\Big\{(\dot{R}-PQ)\sin(i_{NR}-\lambda) - (\dot{P}+RQ)\cos(i_{NR}-\lambda)\Big\} \\ &+ M_{NR_{AERO}} \end{aligned} \tag{5.31}$$

where $M_{NR_{AERO}}$ includes the moment resulting from nacelle aerodynamic loads and the rotor gyroscopic moments. The terms X_{AERO} and Z_{AERO} are, respectively, the total aircraft aerodynamic X and Z forces.

The corresponding equation for the left nacelle actuator moment is obtained by substituting $-Y_N = Y_N$ and changing the R subscript to L.

5.7 DETERMINATION OF ROTOR GYROSCOPIC MOMENTS

The gyroscopic moments are most readily obtained as follows. A set of axes O"x'y'z' is taken at the rotor hub (rotor c.g.) parallel to the nacelle-fixed set of axes $Ox_oy_oz_o$. Associated with each axis are the corresponding unit vectors $\hat{\underline{i}}'$ $\hat{\underline{j}}'$ and $\hat{\underline{k}}'$. The angular velocity of the rotor with respect to these axes is the vector

$$\underline{\omega} = \Omega_R \hat{\underline{i}}' \tag{5.32}$$

where Ω_R is the rotor rotational speed.

The angular momentum of the rotor with respect to its c.g. is

$$\underline{h}_o = \bar{I}_R \underline{\omega} \tag{5.33}$$

where $\bar{I}_R$ is the inertia matrix $\begin{bmatrix} I_{R_{x'}} & & \\ & I_{R_{y'}} & \\ & & I_{R_{z'}} \end{bmatrix}$

the off-diagonal terms being zero since the axes O"x'y'z' are principal axes of inertia of the rotor and hub.

In component form the angular momentum of the rotor is

$$\underline{h}_o = I_{R_{y'}} \Omega_R \hat{\underline{i}}' = I_R \Omega_R \hat{\underline{i}}' \tag{5.34}$$

With respect to the inertial axes OXYZ, the components of $\underline{h}_o$ are

$$\underline{h}_o = I_R \Omega_R \cos i_N \hat{\underline{i}} - I_R \Omega_R \sin i_N \hat{\underline{k}} \tag{5.35}$$

The hub moment is therefore given by

$$\underline{G}_{HUB} = \frac{d\underline{h}_o}{\delta t} = \frac{\delta \underline{h}_o}{\delta t} + \underline{\Omega} \times \underline{h}_o \tag{5.36}$$

where $\underline{\Omega} = P\hat{\underline{i}} + Q\hat{\underline{j}} + R\hat{\underline{k}}$ (5.37)

Substitution of equations (5.35) and (5.37) into equation (5.36) results in the following equations for the rotor gyroscopic moments.

$$L_{gyro} = I_R\dot{\Omega}_R \cos i_N - I_R\Omega_R (\dot{i}_N+Q) \sin i_N \tag{5.38}$$

$$M_{gyro} = I_R P\Omega_R \sin i_N + I_R R\Omega_R \cos i_N \tag{5.39}$$

$$N_{gyro} = -I_R\dot{\Omega}_R \sin i_N - I_R\Omega_R (\dot{i}_N+Q) \cos i_N \tag{5.40}$$

The above terms appear in the Computer Representation (Appendix E) as additions to the rotor aerodynamic forces and moments.

6.0 AIRFRAME AERODYNAMICS

This section presents the mathematical equations and representations of the aerodynamic data for the aircraft without rotors. The contribution of the rotors is described in Section 7. The overall airframe aerodynamics are obtained from the following components:

(a) Fuselage

(b) Wings

(c) Horizontal Tail

(d) Vertical Tail

(e) Nacelles

The data and equations for each of the aerodynamic components are discussed below, together with the substantiating methods. The aerodynamic data are presented in local wind axes. Resolution to aircraft body axes is accomplished as described in the mathematical model (Appendix E). Where required, the equations have been written so as to be applicable over the entire range of angle of attack $\pm$ 180 degrees.

6.1 FUSELAGE

The aerodynamic lift, drag and pitching moment coefficients of the fuselage were estimated using the methods of Reference 1 . The forces and moments are referred to the point on the fuselage corresponding to the wing quarter chord position. This reference point was selected in order to minimize the number of force and moment transfer equations in the mathematical model. Wing-to-body carryover effects have been included in fuselage loads.

The equations for the fuselage forces and moments are:

Lift: $C_{L_F} = K_{42} + K_3 \sin\alpha_F \cos\alpha_F + K_4 \sin\alpha_F \cos\alpha_F | \sin\alpha_F \cos\alpha_F |$

Drag: $C_{D_F} = C_{D_{O_F}}(1 + K_o|\beta_F|^3) + K_2(\sin\alpha_F \cos\alpha_F)^2 + K_1 |\sin\alpha_F \cos\alpha_F| + \Delta C_{D_{LG}}$

Side Force: $C_{Y_F} = K_7 \sin\beta_F \cos\beta_F + K_8 \sin\beta_F \cos\beta_F |\sin\beta_F \cos\beta_F|$

Pitching Moment: $C_{M_F} = C_{M_{O_F}} + K_5 \sin\alpha_F \cos\alpha_F + K_6 \sin\alpha_F \cos\alpha_F | \sin\alpha_F \cos\alpha_F | + \Delta C_{M_{LG}}$

Yawing Moment: $C_{N_F} = C_{N_{OF}} + K_9 \sin\beta_F \cos\beta_F + K_{10} \sin\beta_F \cos\beta_F |\sin\beta_F \cos\beta_F|$

Rolling Moment: $C_{\ell_F} = 0$

$$\text{where } \alpha_F = \operatorname{Tan}^{-1}\left(\frac{W}{U}\right), \quad C_{L_F} = \frac{L_F}{\frac{1}{2}\rho V_{FUS}^2 S_W} \quad \text{etc.}$$

$$\beta_F = \operatorname{Tan}^{-1}\left[\frac{V}{\sqrt{U^2 + W^2}}\right], \quad C_{M_F} = \frac{M_F}{\frac{1}{2}\rho V_{FUS}^2 S_W C_W} \quad \text{etc.}$$

and $\Delta C_{D_{LG}}$, $\Delta C_{M_{LG}}$, are the landing gear contributions to fuselage drag and pitching moment coefficients, when the landing gear is extended.

The fuselage forces and moments are then resolved into body axes at the aircraft C.G.

6.2 NACELLES

The forces and moments acting on the nacelles were estimated using the cross-flow methods of Reference 12 . For convenience the resulting forces and moments are referred to the rotor hub, so that they may be added directly to the rotor forces and moments. The following equations are for the forces and moments on two nacelles:

$$C_{L_N} = K_{32} \sin \alpha_N \cos \alpha_N$$

$$C_{D_N} = C_{D_{O_N}} + K_{30} |\alpha_N| + K_{31} \alpha_N^2$$

$$C_{M_N} = C_{M_{O_N}} + K_{34} \sin \alpha_N \cos \alpha_N + K_{35} \sin \alpha_N \cos \alpha_N |\sin \alpha_N \cos \alpha_N|$$

$$C_{Y_N} = K_{36} \sin \beta_N \cos \beta_N + K_{37} \sin \beta_N \cos \beta_N |\sin \beta_N \cos \beta_N|$$

$$C_{N_N} = C_{N_{O_N}} + K_{38} \sin\beta_N \cos\beta_N + K_{39} \sin\beta_N \cos \beta_N |\sin\beta_N \cos \beta_N|$$

$$C_{\ell_N} = 0$$

The nacelle forces and moments in nacelle axes are:

$$\Delta X'_N = q_N S_W [-C_{D_N} \cos \alpha_N + C_{L_N} \sin \alpha_N - C_{Y_N} \sin \beta_N \cos \alpha_N] \frac{1}{2}$$

$$\Delta Y'_N = q_N S_W [C_{Y_N} \cos \beta_N - C_{D_N} \sin \beta_N] \frac{1}{2}$$

$$\Delta Z'_N = q_N S_W [-C_{L_N} \cos \alpha_N - C_{D_N} \cos \beta_N \sin \alpha_N - C_{Y_N} \sin \beta_N \sin \alpha_N] \frac{1}{2}$$

$$\Delta \ell'_N = q_N S_W b_W [-\left(\frac{C_W}{b_W}\right) C_{M_N} \sin \beta_N \cos \alpha_N - C_{N_N} \sin \alpha_N] \frac{1}{2}$$

$$\Delta M'_N = q_N S_W C_W [C_{M_N} \cos \beta_N] \frac{1}{2}$$

$$\Delta N'_N = q_N S_W b_W [C_{N_N} \cos \alpha_N - \left(\frac{C_W}{b_W}\right) C_{M_N} \sin \beta_N \cos \alpha_N] \frac{1}{2}$$

6.3 HORIZONTAL TAIL

Aerodynamics of the horizontal tail were obtained using the methods of Reference 1 in combination with test data. The horizontal tail includes a plain elevator.

The angle of attack of the horizontal tail, including interference effects, for zero elevator deflection, is

$$\alpha_{HT} = \mathrm{Tan}^{-1}\left[\frac{w_{HT}}{u_{HT}}\right] - \varepsilon + i_{HT}$$

where ε is the total downwash at the tail due to wing, rotor and ground effects and i_{HT} is the tail incidence angle.

The effect of elevator deflection on the effective tail angle of attack is introduced through the elevator effectiveness parameter, τ_{HT}, which is a function of the elevator and horizontal tail areas. Thus the effective horizontal tail angle of attack is

$$\alpha_{e_{HT}} = \alpha_{HT} + \tau_{HT}\delta_e$$

where δ_e is the elevator deflection.

The tail downwash angle, ε, depends on wing angle of attack and on rotor slipstream deflection. At a given rotor angle of attack, the slipstream deflection is a function of rotor thrust coefficient, C_{T_S}, where the coefficient is based on the slipstream dynamic pressure. Figure 6.1 presents data on downwash angles measured during tests on a tilt rotor wind tunnel model (Reference 7). As can be seen, the downwash at low values of thrust coefficient is the same as the value of the power-off wing

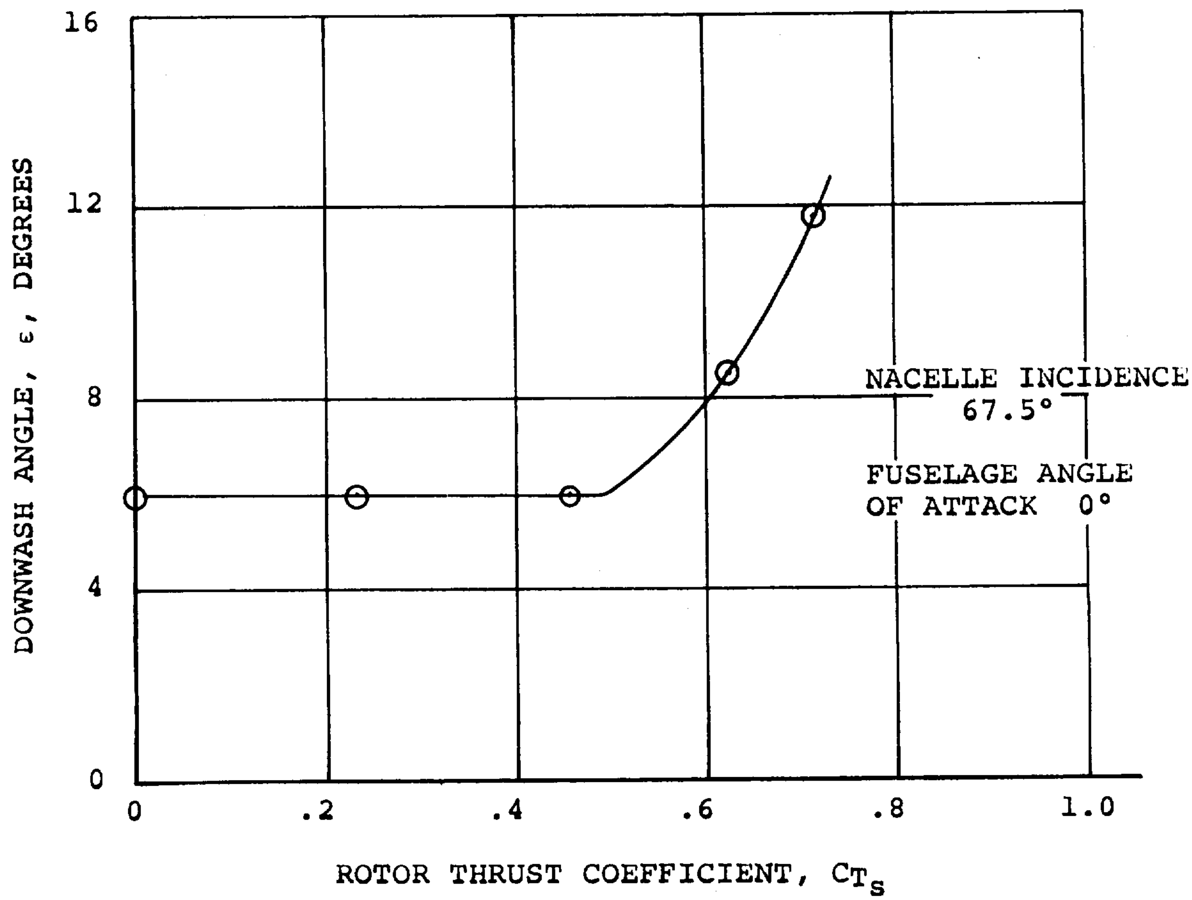


Figure 6.1. Variation of Horizontal Tail Downwash Angle with Thrust Coefficient

downwash (C_{T_S}=0). Above values of C_{T_S} in the neighborhood of C_{T_S}=.5 the downwash increases with increasing thrust coefficient. The values in the increasing portion of ε vs C_{T_S} were found to correspond approximately to the slipstream deflection angle ε_p. Therefore, the approach adopted in the mathematical model was to test if the rotor slipstream downwash ($\bar{\varepsilon}_p$) exceeded the wing downwash and, if so, to use the computed slipstream downwash value as the tail downwash angle. Otherwise the wing downwash value was used.

Thus if

$$\bar{\varepsilon}_p \geq \varepsilon_o + \frac{d\varepsilon}{d\alpha}\left(\bar{\alpha}_w - \ell_{AC}\frac{\dot{W}}{U^2}\right)$$

then $$\varepsilon = \frac{\bar{\varepsilon}_p(1-GEF)}{\sqrt{1-M^2}}$$

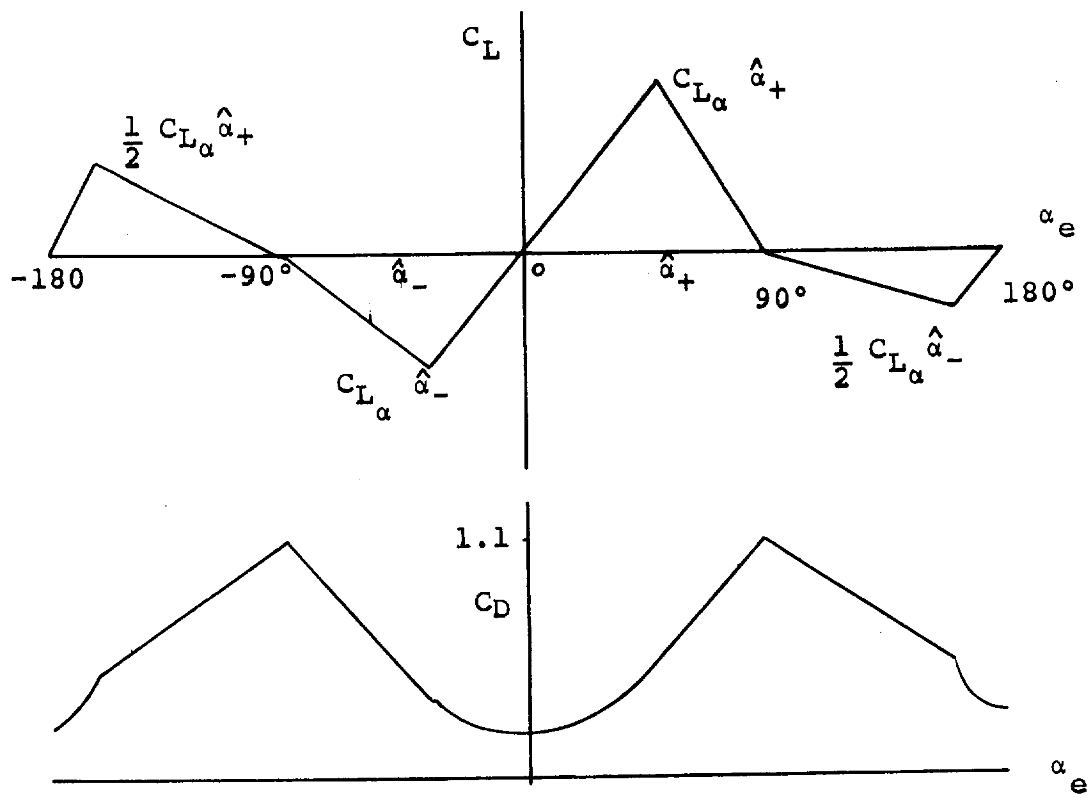
otherwise

$$\varepsilon = \left[\varepsilon_o + \frac{d\varepsilon}{d\alpha}\left(\bar{\alpha}_w - \ell_{AC}\frac{\dot{W}}{U^2}\right)\right]\frac{(1-GEF)}{\sqrt{1-M^2}}$$

In these expressions ε_o is the wing downwash angle at zero wing angle-of-attack, $\frac{d\varepsilon}{d\alpha}$ is the downwash derivative, ℓ_{AC} is the distance from the wing to the tail aerodynamic centers, and $\ell_{AC}\frac{\dot{W}}{U^2}$ is the familiar downwash lag term. In general, the quantities ε_o and $\frac{d\varepsilon}{d\alpha}$ depend on the average of the left and right flaperon deflections. The effect of differential deflection of aileron/spoiler in producing an asymmetrical downwash field at the horizontal tail was not included because of the small contribution this makes to total aircraft rolling moment.

The term (1-GEF) in the above equations is the ground effect factor. This quantity was obtained from Reference 10 and is a function of the wing span and height of the horizontal tail above the ground. This factor, when multiplied by the downwash which would be found out of ground effect, yields the downwash in ground effect. Ground effect is discussed in more detail in Section 10.

The lift and drag forces acting on the horizontal tail are required over the complete range of angle of attack -180° to +180°, since the tilt rotor can fly backwards. The following sketch shows the schematic variation of lift and drag coefficients over this range plotted as a function of the effective horizontal tail angle of attack, $\alpha_{e_{HT}}$.



The angle of attack for $C_{L_{HT_{MAX}}}$ is denoted by $\hat{\alpha}_{HT_+}$ and is the value of the effective angle of attack at the stall less 2 degrees i.e.

$$\hat{\alpha}_{HT_+} = (\alpha_{HT_{STALL}} - 2°) + \tau_{HT} \delta_e$$

Similarly the angle of attack for stall at negative angles of attack is

$$\hat{\alpha}_{HT_-} = -(\alpha_{HT_{STALL}} - 2°) + \tau_{HT}\delta_e$$

The slope of the lift curve within this range of positive and negative angles of attack is given by

$$C_{L_\alpha} = \frac{C_{L_{\alpha HT}}\left(\frac{a_g}{a}\right)}{\sqrt{1-M^2}}$$

where a_g/a is the ratio of tail lift-curve slopes in and out of ground effect, and $\sqrt{1-M^2}$ is the Prandtl-Glauert correction factor for the effect of Mach number on lift-curve slope.

Within this region on the lift curve the value of lift coefficient is given by $C_{L_{HT}} = C_{L_\alpha}\,\alpha_{e_{HT}}$ and the corresponding drag coefficient by

$$C_{D_{HT}} = C_{D_{O_{HT}}} + \frac{2C^2_{L_{HT}}}{\pi AR_{HT}}$$

After stall angle of attack is passed the lift is assumed to fall linearly to zero at $\alpha_e = \pm 90°$.

In these regions the lift is given by

$$C_{L_\alpha} = C_{L_\alpha}\,\hat{\alpha}_{\pm}\,\frac{(\pm 90 - \alpha_{e_{HT}})}{(\pm 90 - \hat{\alpha}_{HT_\pm})}$$

where the appropriate signs are taken depending on the sign of $\alpha_{e_{HT}}$.

The corresponding drag is obtained by assuming a linear variation of drag from the value at $C_{L_{MAX}}$ to a value of $C_D = 1.1$ (flat plate normal to stream) at $\alpha_{e_{HT}} = 90°$. Thus

$$C_{L_{HT_{STALL}}} = C_{L_\alpha} \hat{\alpha}_{HT_\pm}$$

$$C_{D_{HT_{STALL}}} = C_{D_{O_{HT}}} + \frac{2C^2_{L_{HT_{STALL}}}}{\pi AR_{HT}}$$

and

$$C_{D_{HT}} = C_{D_{HT_{STALL}}} + \frac{(\alpha_{e_{HT}} - \hat{\alpha}_{HT_\pm})(1.1 - C_{D_{HT_{STALL}}})}{(\pm 90 - \hat{\alpha}_{HT_\pm})}$$

If the effective angle of attack of the horizontal tail exceeds $\pm 90°$ the tail will point trailing-edge first into the relative wind. Under this condition early stalling is precipitated because of the sharp "leading edge" and blunt "trailing edge". In order to represent this, it was assumed that the attainable $C_{L_{MAX}}$ of the tail under these conditions is half that occurring in normal flight.

Thus if $\quad 90° < \alpha_{e_{HT}} \leq (180 - \frac{1}{2} \hat{\alpha}_{HT_-})$

or $(-180 + \frac{1}{2} \hat{\alpha}_{HT_+}) \leq \alpha_{e_{HT}} < -90°$

then

$$C_{L_{HT}} = .5 C_{L_\alpha} \hat{\alpha}_{HT_-} \quad \frac{(\alpha_{e_{HT}} - 90°)}{(90° - \frac{1}{2}\hat{\alpha}_{HT_-})}$$

or

$$C_{L_{HT}} = .5 C_{L_\alpha} \hat{\alpha}_{HT_+} \quad \frac{(\alpha_{e_{HT}} + 90°)}{(-90 + \frac{1}{2} \hat{\alpha}_{HT_+})}$$

The corresponding drag coefficients are:

for $90° < \alpha_{e_{HT}} \leq (180 - \frac{1}{2} \hat{\alpha}_{HT_-})$;

$$C_{L_{HT_{STALL}}} = 0.5 \, C_{L_\alpha} \hat{\alpha}_{HT_-}$$

$$C_{D_{HT_{STALL}}} = \frac{2C^2_{L_{HT_{STALL}}}}{\pi AR_{HT}} + C_{D_{O_{HT}}}$$

which gives $C_{D_{HT}} = C_{D_{HT_{STALL}}} + \dfrac{(\alpha_{e_{HT}} + 0.5\ \hat{\alpha}_{HT_-} - 180°)(1.1 - C_{D_{HT_{STALL}}})}{(0.5\ \hat{\alpha}_{HT_-} - 90°)}$

and for $(-180 + \frac{1}{2}\hat{\alpha}_{HT_+}) \leq \alpha_{e_{HT}} < -90°$;

$$C_{L_{HT_{STALL}}} = 0.5\ C_{L_\alpha}\ \hat{\alpha}_{HT_+}$$

$$C_{D_{HT_{STALL}}} = \frac{2C^2_{L_{HT_{STALL}}}}{\pi AR_{HT}} + C_{D_{O_{HT}}}$$

which gives $C_{D_{HT}} = C_{D_{HT_{STALL}}} - \dfrac{(\alpha_{e_{HT}} + 180° - .5\hat{\alpha}_{HT_+})(1.1 - C_{D_{HT_{STALL}}})}{(.5\hat{\alpha}_{HT_+} - 90°)}$

In the range $(180 - .5\hat{\alpha}_{HT_-}) \leq \alpha_{e_{HT}} \leq 180°$ when the tail has unstalled

$$C_{L_{HT}} = C_{L_\alpha}\ (\alpha_{e_{HT}} - 180°)$$

$$C_{D_{HT}} = C_{D_{O_{HT}}} + \frac{2C^2_{L_{HT}}}{\pi\ AR_{HT}}$$

and similarly for the range $-180° \leq \alpha_{e_{HT}} < (-180 + .5\ \hat{\alpha}_{HT_+})$

$$C_{L_{HT}} = C_{L_\alpha}\ (\alpha_{e_{HT}} + 180°)$$

$$C_{D_{HT}} = C_{D_{O_{HT}}} + \frac{2C^2_{L_{HT}}}{\pi AR_{HT}}$$

The above equations define the variation of tail lift and drag over the entire range of angle of attack. The tail pitching moment is not computed since it makes only a small contribution to the total aircraft pitching moment.

6.4 VERTICAL TAIL

The aerodynamic forces and moments acting on the vertical tail were estimated using the methods of Reference 1. The angle of attack of the vertical tail is given by

$$\alpha_{VT} = -\,\mathrm{Tan}^{-1}\left[\frac{v_{VT}}{\sqrt{u^2_{VT}+w^2_{VT}}}\right] + \beta_F\left(\frac{d\sigma}{d\beta}\right)$$

where u_{VT}, v_{VT} and w_{VT} are the components of velocity at the vertical tail aerodynamic center as given in Appendix C. The term $\beta_F\left(\frac{d\sigma}{d\beta}\right)$ is the sidewash correction for the presence of the fuselage.

As in the treatment of the horizontal tail, the effect of rudder deflection is obtained using a rudder effectiveness parameter τ_{VT}. Thus the effective angle of attack of the vertical tail when the rudder is deflected is

$$\alpha_{e_{VT}} = \alpha_{VT} + \tau_{VT}\,\delta_{RUD}$$

The treatment of the vertical tail aerodynamics through the complete angle of attack range -180° to +180° then follows the same lines as that for the horizontal tail aerodynamics previously described.

The vertical tail forces and moments in body axes are then obtained from:

$$X^{VT}_{AERO} = \bar{q}S_{VT}\eta_{VT}\left[-C_{D_{V_T}}\cos(\beta_{VT}-\sigma)\cos(\alpha_{HT}-i_{HT}) - C_{Y_{VT}}\sin(\beta_{VT}-\sigma)\cos(\alpha_{HT}-i_{HT})\right]$$

$$Y^{VT}_{AERO} = \bar{q}S_{VT}\eta_{VT}\left[C_{Y_{VT}}\cos(\beta_{VT}-\sigma) - C_{D_{VT}}\sin(\beta_{VT}-\sigma)\right]$$

$$Z^{VT}_{AERO} = \bar{q}S_{VT}\eta_{VT}\left[-C_{D_{VT}}\cos(\beta_{VT}-\sigma)\sin(\alpha_{HT}-i_{HT}) - C_{Y_{VT}}\sin(\beta_{VT}-\sigma)\sin(\alpha_{HT}-i_{HT})\right]$$

$$M_{AERO}^{VT} = Z_{AERO}^{VT}\,(X_{CG}-X_{VT}) + X_{AERO}^{VT}\,(Z_{VT}-Z_{CG})$$

$$N_{AERO}^{VT} = -Y_{AERO}^{VT}\,(X_{CG}-X_{VT})$$

$$L_{AERO}^{VT} = -\,Y_{AERO}^{VT}\,(Z_{VT}-Z_{CG})$$

6.5 WING AERODYNAMICS

The treatment of the wing aerodynamics is the most complex of all the components. Because wing flexibility must be represented, each wing panel required a separate treatment. The approach adopted for simulation purposes was first to obtain the aerodynamic forces and moments on the complete wing considered as rigid and uninfluenced by slipstream interference effects. With this data as a basis the effects of elastic deflection were introduced as an increment in the effective angle of attack of each wing panel and the rotor slipstream interference was then calculated. This approach is described in detail below.

6.5.1 BASIC WING AERODYNAMICS

The basic wing lift, drag and pitching moment coefficients for the wing in the presence of the fuselage rotors-off, were calculated using the methods of Reference 1 . This data is applicable to low speed flight. Corrections for Mach number effects are introduced through the Prandtl-Glauert factor $\sqrt{1-M^2}$. Beyond stall angle of attack, the lift, drag and pitching moment curves are extended linearly to $\pm 90°$

angle of attack in order to provide a representation of wing behavior at low transition speeds when wing angles of attack approach 90°. The data was calculated for the complete range of flaperon settings.

The complete wing basic lift, drag and pitching moment data also applies to each individual wing panel provided the data is obtained at the appropriate panel angle of attack. This approximation is acceptable if the angles of attack of each wing panel are not substantially different. This condition is normally fulfilled.

In addition to the above data, the effects of spoiler deflection on panel lift, drag and pitching moment are required. These were estimated using the data of Reference 1 . As can be seen from the equations presented in Appendix E the spoiler effectiveness is strongly dependent upon flaperon deflection, a result of the spoilers being slot-lip spoilers.

6.5.2 ROTOR SLIPSTREAM INTERFERENCE

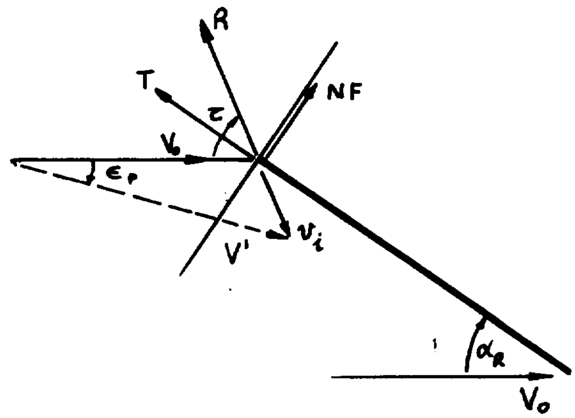
Before the basic wing aerodynamic data can be utilized in the calculation of the wing forces, the effects of the rotor slipstream must be calculated. The calculation procedure presented here has been developed and used at Boeing for some years, and gives acceptable agreement with wind tunnel test data on a wide variety of both tilt rotor and tilt wing configurations.

The method uses momentum theory to obtain the direction and speed of the rotor slipstream in the neighborhood of the wing. From this the effective angle of attack of that part of the wing that is immersed in the slipstream is calculated. The lift, drag and pitching moment on the wing are then calculated for this angle of attack as if the entire wing were immersed. The area of the wing immersed in the slipstream is now computed and, using the ratio of the immersed to total wing area, the forces acting on the immersed portion are approximated.

At the angle of attack of the wing outside the slipstream, the wing forces and moments are obtained from the basic wing data as if no slipstream effects were present. These forces are then scaled by the ratio of unimmersed to total wing areas to obtain approximately the forces acting on the unimmersed wing. The sum of the approximations to immersed and unimmersed wing forces is now formed. This sum is then multiplied by a correction factor to obtain the final forces.

This correction factor is obtained from a consideration of the mass flows associated with the rotor-wing combination. In the following outline of the method only one rotor is considered.

From the following sketch, which shows the forces acting on the rotor, the inclination of



the resultant force on the rotor to the freestream direction is given by

$$\tau_R = \alpha_R + \mathrm{Tan}^{-1}\left(\frac{NF}{T}\right)$$

The resultant force on the rotor is

$$R = \sqrt{T^2 + NF^2 + SF^2}$$

where T, NF and SF are the thrust, normal force and sideforce, respectively.

The mass flow through the disc is

$$m = \rho\ A\ V'$$

where A is the disc area and V' is obtained from the induced velocity triangle at the disc plane.

$$V' = \sqrt{(V_o + v_i \cos\tau)^2 + (v_i \sin\tau)^2}$$

The resultant force on the rotor is related to the mass flow by (Glauert's assumption)

$$R = 2\dot{m}\, v_i = 2\rho A\, V'\, v_i$$

From these equations the following quartic equation is obtained for the induced velocity at the disc.

$$v_*^4 + 2V_* v_*^3 \cos\tau + v_*^2 V_*^2 = 1$$

where the nondimensional notations

$$v_* = \frac{v_i}{\sqrt{\dfrac{R}{2\rho A}}} \qquad V_* = \frac{V_o}{\sqrt{\dfrac{R}{2\rho A}}}$$

have been introduced.

This equation is then solved for v_* and the direction of the slipstream just behind the rotor disc is calculated from

$$\varepsilon_p = \operatorname{Tan}^{-1}\left[\frac{v_* \sin\tau}{v_* \cos\tau + V_*}\right]$$

The rotor thrust coefficient C_{T_S} is defined as

$$C_{T_S} = \frac{T}{(q + \frac{T}{A})A}$$

NOTE: Because the rotor diameter to wing chord is large the slipstream is considered to be uncontracted in the vicinity of the wing.

with $T = R\cos(\tau - \alpha_R)$

and $q = \frac{1}{2}\rho V^2 = \frac{1}{4} V_*^2 R$

then $$C_{T_S} = \frac{\cos(\tau-\alpha_R)}{\cos(\tau-\alpha_R) + \frac{V_*^2}{4}}$$

The aspect ratio of the slipstream-immersed wing area is given by

$$AR_i = \frac{S_i}{c^2}$$

where S_i is the immersed area calculated by the method described in Appendix D, and c is the wing chord.

The lift on the wing, if the slipstream were absent, is obtained by calculating the effective angle of attack of the wing outside the slipstream from

$$\alpha_o = \sin^{-1}\left[\frac{w_W}{\sqrt{u_W^2+w_W^2}}\right] + \theta_t$$

where w_W, u_w are the velocites at the wing aerodynamic center and θ_t is the elastic twist at the point. The lift coefficient (C_L^*) for this angle of attack is obtained from the aerodynamic data for the appropriate flaperon/spoiler deflection.

Similarly the lift (C_L'') and drag (C_D'') coefficients of the wing in the slipstream (assuming wing is completely immersed) are obtained from the aerodynamic data at the angle of attack

$$\alpha_s = \alpha_o - \varepsilon$$

The total lift coefficient of the wing with slipstream is therefore

$$C_{L_s} = K_A'\left[\frac{S_i}{S}\,(C_L'' \cos\varepsilon - C_D'' \sin\varepsilon) + C_L^*\,(1-C_{T_s})(1-\frac{S_i}{S})\right]$$

where

$$C_{L_s} = \frac{L}{q_s S_W}$$

in which q_s is the nominal slipstream dynamic pressure, defined by $q_s = q + \frac{T}{A}$

The factor K_A' is a correction factor to account for the fact that the lift-sharing between the immersed and unimmersed portions of the wing is not simply proportional to the respective areas.

From considerations of the mass flows associated with the wing-rotor combination the factor K'_A was obtained in the form

$$K'_A = \frac{V_* + \dfrac{C_{L_{\alpha i}}}{C_{L_\alpha}} v_*}{V_* + v_*}$$

where, from wing theory,

$$\frac{C_{L_{\alpha i}}}{C_{L_\alpha}} = \frac{1}{1 + \dfrac{C_{L_\alpha}}{\pi}\left[\dfrac{1}{AR_i} - \dfrac{1}{AR}\right]}$$

The drag and pitching moments for the wing with slipstream are obtained similarly and are given by:

$$C_{D_S} = K'_A \left\{ \frac{S_i}{S} \left(C''_L \sin \varepsilon + C''_D \cos \varepsilon\right) + C^*_D \left(1-C_{T_S}\right)\left(1-\frac{S_i}{S}\right) \right\}$$

$$C_{M_S} = K'_A \left\{ \frac{S_i}{S} C''_M + C^*_M \left(1-C_{T_S}\right)\left(1-\frac{S_i}{S}\right) \right\}$$

The rolling moment and yawing moment coefficients for the wing are given by

$$C_{\ell_S} = \left(K_{20} + K_{21} \bar{C}_L\right)\left(1-\bar{C}_{T_S}\right)\beta_F + \bar{Y}_{AC}\left(\frac{1-C_{T_S}}{2b_W}\right)\left(C^*_{L_{LW}} - C^*_{L_{RW}}\right) + \Delta C_{\ell_{S_{POWER}}}$$

$$C_{n_S} = K_{22} \bar{C}_L^{\,2}\left(1-C_{T_S}\right)\beta_F + \bar{Y}_{AC}\frac{\left(1-C_{T_S}\right)}{2b_W}\left(C^*_{D_{RW}} - C^*_{D_{LW}}\right) + \Delta C_{n_{S_{POWER}}}$$

where the increment in rolling moment due to power is

$$\Delta C_{\ell_{S_{POWER}}} = \frac{1}{4}\left\{\left[C_{L_{S_{LW}}} - \left(1-\bar{C}_{T_S}\right)C^*_{L_{LW}}\right]\left[1-\frac{1}{2}\left(\frac{S_i}{S}\right)_{LW}\right] - \left[C_{L_{S_{RW}}} - \left(1-\bar{C}_{T_S}\right)C^*_{L_{RW}}\right]\left[1-\frac{1}{2}\left(\frac{S_i}{S}\right)_{RW}\right]\right\}$$

and the increment in yawing moment is

$$\Delta C_{n_{S_{POWER}}} = \frac{1}{4}\left\{\left[C_{D_{S_{RW}}} - (1-\bar{C}_{T_S})C^*_{D_{RW}}\right]\left[1-\frac{1}{2}\left(\frac{S_i}{S}\right)_{RW}\right]\right.$$

$$\left. - \left[C_{D_{S_{LW}}} - (1-\bar{C}_{T_S})C^*_{D_{LW}}\right]\left[1-\frac{1}{2}\left(\frac{S_i}{S}\right)_{LW}\right]\right\}$$

Figure 6.2 shows a correlation between the wing-in-slipstream method described above and experimental results for the Boeing Model 160 tilt rotor aircraft. As may be seen the simple treatment gives acceptable predictions of wing forces and moments.

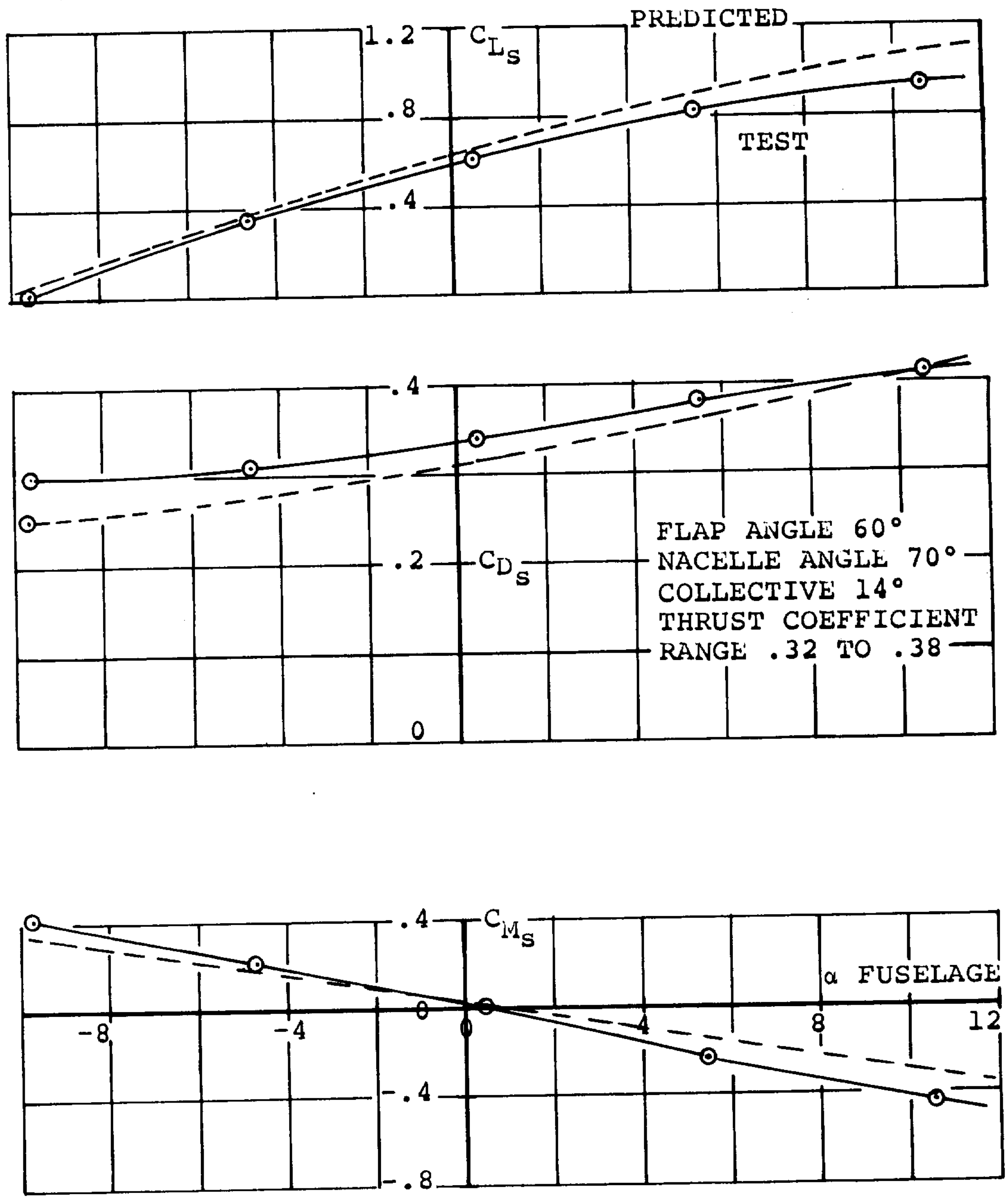


Figure 6.2. Correlation of Theory with Test for Predictions of Slipstream Forces and Moments

7.0 ROTOR AERODYNAMICS

The rotor aerodynamics as used in the mathematical model are described in this section. Also presented are the methods used to compute the rotor aerodynamics, a discussion on wing upwash as it effects the rotor, and a description of the technique used to account for rotor on rotor interference in skewed flight. In addition, correlation of the methods described in this section with test data for soft-in-plane hingeless rotors are presented. Calculation of the Model 222 rotor forces and moments was not practicable because of the complexity and size of the programs required to represent the lag-flap coupling effects of the rotor. In this mathematical model, the rotor forces and moments are input from a series of curve plot fit equations. These equations were generated by computing rotor data using the computer programs discussed in Section 7.2, and then a least squares curve fit program was used to obtain the curve fit equations. The rotor forces and moments used in the mathematical model include the six basic forces and moments (thrust, power, normal force, side force, pitching moment, yawing moment), hub pitching and yawing moments due to aircraft pitch and yaw rate, and changes to the six basic forces and moments due to cyclic pitch application.

7.1 FORMAT AND RANGE OF DATA

Rotor forces and moments are functions of thirteen variables. In order to reduce the size of the data bank, these variables were combined and non-dimensionalized. Each rotor force and moment can be written as:

$$F = f(V,\ V_t,\ \theta_{0.75} \text{ or } T,\ \alpha,\ \beta,\ P,\ Q,\ R,\ A_1,\ B_1,\ P_N^R,\ Q_N^R,\ R_N^R) \tag{7-1}$$

where V = Forward speed

V_t = Rotor tip speed

$\theta_{0.75}$ = Collective pitch at the .75 radius

T = Rotor thrust

α = Rotor angle of attack

β = Rotor sideslip angle

P = Body axis roll rate

Q = Body axis pitch rate

R = Body axis yaw rate

A_1 = Longitudinal cyclic pitch

B_1 = Lateral cyclic pitch

P_N^R = Rotor wind axis roll rate

Q_N^R = Rotor wind axis pitch rate

R_N^R = Rotor wind axis yaw rate

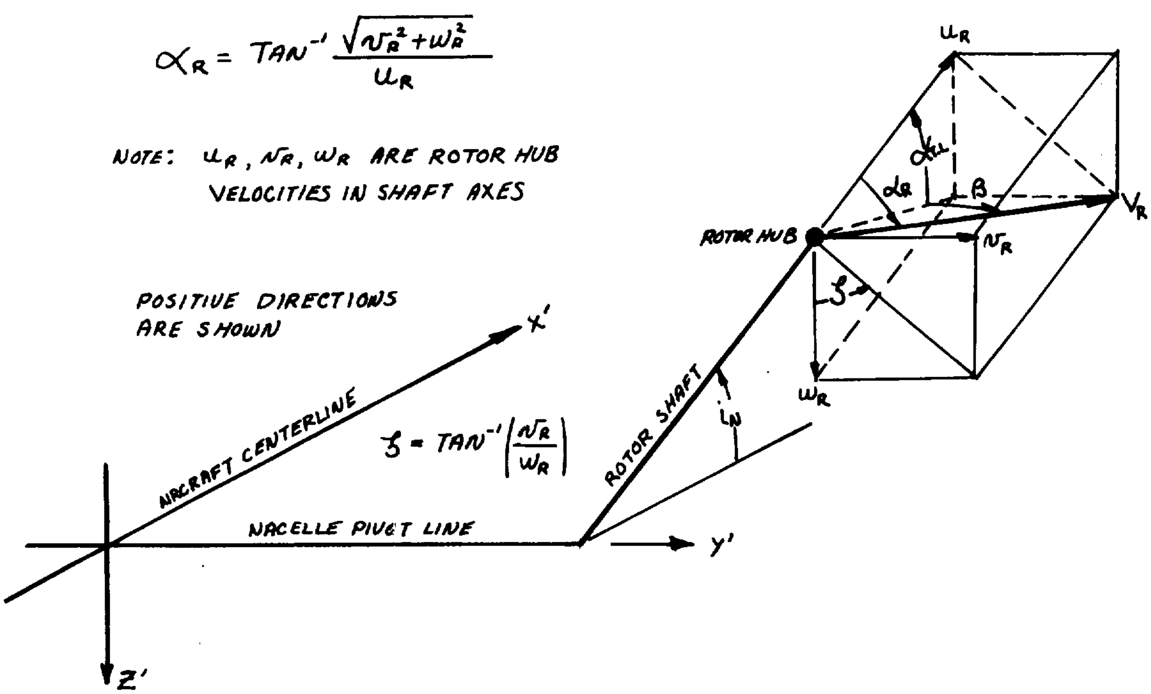
Forward speed and tip speed were combined to form rotor advance ratio and collective pitch or thrust were retained. Rotor angles of attack and sideslip and body axis roll, pitch and yaw rates were combined into a resultant angle of attack. Longitudinal and lateral cyclic pitch angles are retained. By combining the thirteen variables in this manner, Equation 7-1 can be expressed as:

$$F = f(\mu,\ \theta_{.75} \text{ or } C_T,\ \alpha_R) + [\Delta F = f(A_1, B_1)] + [\Delta F = f(P_N^R, Q_N^R, R_N^R)] \tag{7-2}$$

where μ = rotor advance ratio

α_R = rotor resultant angle of attack

By using this functional relationship, basic rotor forces and moments can be written as functions of three variables plus increments due to cyclic pitch control application and wind axis pitch roll and yaw rates at the rotor hub. This is the format used in the mathematical model. In addition, the rotor forces and moments are non-dimensionalized by dividing forces by $(\rho \pi R^2 V_t^2)$, moments by $(\rho \pi R^2 V_t^2 R)$, and power by $(\rho \pi R^2 V_t^3)$.



The above sketch shows a rotor under condition of combined angle of attack ($\alpha_{T.L.}$) and sideslip (β). The resultant angle of attack (α_R) is the angle between the "u_R" component of velocity at the rotor hub and the total velocity (V_R) at the hub. The velocity components that define this resultant angle are the rotor hub velocities resolved to shaft axes and derived in Appendix C. They include body axes pitch, roll and yaw rates. Other functional relationships that define the rotor resultant angle of attack are shown in Appendix D. Also shown on the sketch is the rotor sideslip angle (ζ). This angle represents the inclination of the plane containing the resultant velocity. Rotor wind axis forces and moments are defined relative to this plane. Since the resultant angle is defined from 0 through 180° the inclination of the rotor sideslip angle (ζ) determines the signs of the rotor forces and moments when they are resolved back to body axes.

After the functional format for the rotor data was established, the ranges of the variables were established. Discrete speeds and rotor rpm conditions were selected. A range of rotor resolved angles of attack and thrust levels were selected at each combination. These conditions were carefully selected to cover the total operating envelope of the Model 222. The ranges of the rotor data are shown in Table 7.1.

7.2 PROGRAMS USED TO COMPUTE ROTOR DATA

Rotor data used in the mathematical model were predicted from Boeing-developed computer programs. Hover and cruise performance (thrust-power) were obtained from a propeller performance analysis computer program (B-92). This analysis establishes a radial distribution of induced velocity based on a prescribed wake contraction schedule to calculate rotor induced and total power coefficients at specified thrust or

TABLE 7.1 RANGE OF ROTOR DATA

Total Velocity (V) ~ KTS	Rotor Speed (rpm)	Resultant Angle of Attack Range (α_R) ~ deg	Rotor Thrust (T) ~ Lb
0	551	0 → 180°	500 → 7000
45	551	0 → 180°	500 → 7000
60	551	0 → 180°	2000 → 6500
90	551	0 → 180°	2000 → 6500
120	400	0 → 45°	500 → 2600
142	386	0 → 20°	-700 → 3500
160	386	0 → 20°	-500 → 4750
200	386	0 → 20°	-500 → 6000
240	386	0 → 20°	0 → 3700
280	386	0 → 20°	0 → 3800
320	386	0 → 20°	0 → 4800
360	386	0 → 20°	0 → 3500

thrust coefficients. The radial airload distribution is also defined. A detailed description of this program is given in Reference 4.

Transition performance data, in-plane forces and moments and cyclic pitch effectiveness throughout the flight envelope were estimated using computer program D88 (Reference 5).

The D-88 computer program is an aeroelastic analysis for the study of aerodynamic, dynamic, and structural characteristics of current and advanced rotor and prop/rotor concepts. Airloads are calculated considering the effects of section geometry, compressibility and non-uniform inflow. An iterative process between the airloads and coupled flap-pitch dynamic response establishes blade accelerations which in turn are used to compute hub loads and rotor aerodynamic performance.

The rotor analysis is based on the idealization of a continuous, elastic, non-uniform beam into one composed of lumped discrete masses connected by weightless elastic sections. Associated with each mass is a flat rigid airfoil segment, with the mass center located at the midpoint. The aerodynamic loads generated by each segment are assumed to act at the mass center.

The effects of non-uniform inflow are included by considering a discontinuous constant circulation along part of the rotor blade, of sufficient strength to maintain the desired thrust. A vortex is assumed to trail from the inboard and outboard circulation discontinuities, of equal and opposite strength. By summing the effects of all the vortices on a given blade around the azimuth the non-uniform induced flow for each blade at every dynamic bay is determined. Total velocity at each point in the blade is computed by vector addition of the velocity components.

The local angle of attack of each blade element is then computed at every blade station for specified azimuth angles and the aerodynamic coefficients (C_L, C_D, C_M) are looked up from tables of coefficients as a function of Mach number. From these coefficients the airloads are computed. The vertical, tangential and pitching aerodynamic loads are then harmonically analyzed into 10 harmonics and act as the forcing functions for each blade section.

To obtain a thrust match, an iteration process is performed on the airloads until a steady collective pitch angle is obtained which corresponds to the desired thrust. To perform the dynamic analysis, the lumped mass and elastic bay elements of the idealized rotor blade are transformed into a sequence of transfer matrix products, by means of the Associated Matrix Method. This method replaces each blade element by an equivalent "transfer matrix" that transfers the dynamic system variables, shear, moment, deflection and slope, inboard across the element. Therefore, multiplying the system variables outboard of the element by the transfer matrix gives the variables inboard of the element. The whole mass, elastic blade idealization is then reduced to a sequence of transfer matrix products.

In-plane elastic rotor derivatives (both static and rate) in axial flow were calculated using computer program C-41 (Reference 2).

Dynamic derivatives for a rotor system are defined taking account of the modal behavior of the blades in two general flap-lag modes. These derivatives are given as matrix arrays of the partial derivatives of rotor forces with respect to unit amounts of elementary linear and angular motions of the hub and unit displacements in the blade modes. These effects are separated into inertial, damping and gyroscopic, and stiffness effects. Thus an element m_{ij} in the inertia derivative matrix is $\partial F_i/\partial g_j$, i.e., the force in the i direction due to unit acceleration in the j direction, all other quantities being held constant.

Similarly element d_{ij} of the damping derivative matrix will represent $\partial F_i/\partial g_j$ which might for appropriate (ij) be the aggregate gyroscopic and aerodynamic pitching moment due to unit velocity of yaw.

Similarly the elements of the stiffness derivative matrix represent such quantities as the normal force due to unit amount of shaft angle of attack, and generalized forces in the blade freedoms due to unit displacements in each of the other freedoms.

The matrices are of order 15 x 15 maximum. The first 6 rows and columns refer to forces in the vertical, lateral and axial directions and moments in the yaw pitch and roll directions due to unit acceleration, rates and displacements in each of the directions. These are the only numbers present if the rotor blades are assumed rigid. Three additional rows and columns are added for each blade mode considered. A limit of two blade modes is currently applied. The final three rows are for cyclic and collective pitch.

These derivative matrices provide a ready means for evaluating the contribution of the rotor to the coefficients of the aircraft dynamic equations. This program also provides the in-plane elastic rotor derivatives.

Elastic rotor rate derivatives in transition were estimated using computer program C-49 (Reference 3). This program evaluates hub force and moment derivatives for shaft angles varying from cruise to hover conditions. Dynamic derivatives suitable for transient analysis are computed. The dynamic derivatives are the partial differentials of hub forces and moments with respect to hub positions rates and accelerations and include inertial and gyroscopic effects as well as aerodynamic effects. For the static derivatives a constant shaft angle to the relative wind is assumed and the resulting blade motion computed. The effects of blade aerodynamic and inertia and gyroscopic forces are combined to give the hub derivatives due to constant shaft angle and constant rate of change of shaft angle.

The output rotor forces and moments of these programs are in rotor wind axis.

7.3 ROTOR SIGN CONVENTION

The rotor sign conventions as used in this mathematical model are shown in Figure 7.1 . Positive directions of all rotor forces, moments and cyclic pitch angles are noted.

7.4 CURVE FIT FORMAT

The rotor data generated for the Model 222 mathematical model was curve fit at each advance ratio. A curve fit which is third order in angle of attack and second order in thrust coefficient or collective pitch was found to yield the most accurate results. The curve fits have the following general form.

$$C_F = \sum_{v=0}^{2} \sum_{u=0}^{3} \left[A_{(u+4v)} \alpha^{u} C_T^{v} \right]$$

The double summation is expanded starting with the inner quantity i.e. set v and expand u from 0 to 3. Repeat until the summations are satisfied. The expansion of the generalized form is

$$\begin{aligned} C_F &= A_0 + A_1\alpha + A_2\alpha^2 + A_3\alpha^3 \\ &+ (A_4 + A_5\alpha + A_6\alpha^2 + A_7\alpha^3)C_T \\ &+ (A_8 + A_9\alpha + A_{10}\alpha^2 + A_{11}\alpha^3)C_T^2 \end{aligned}$$

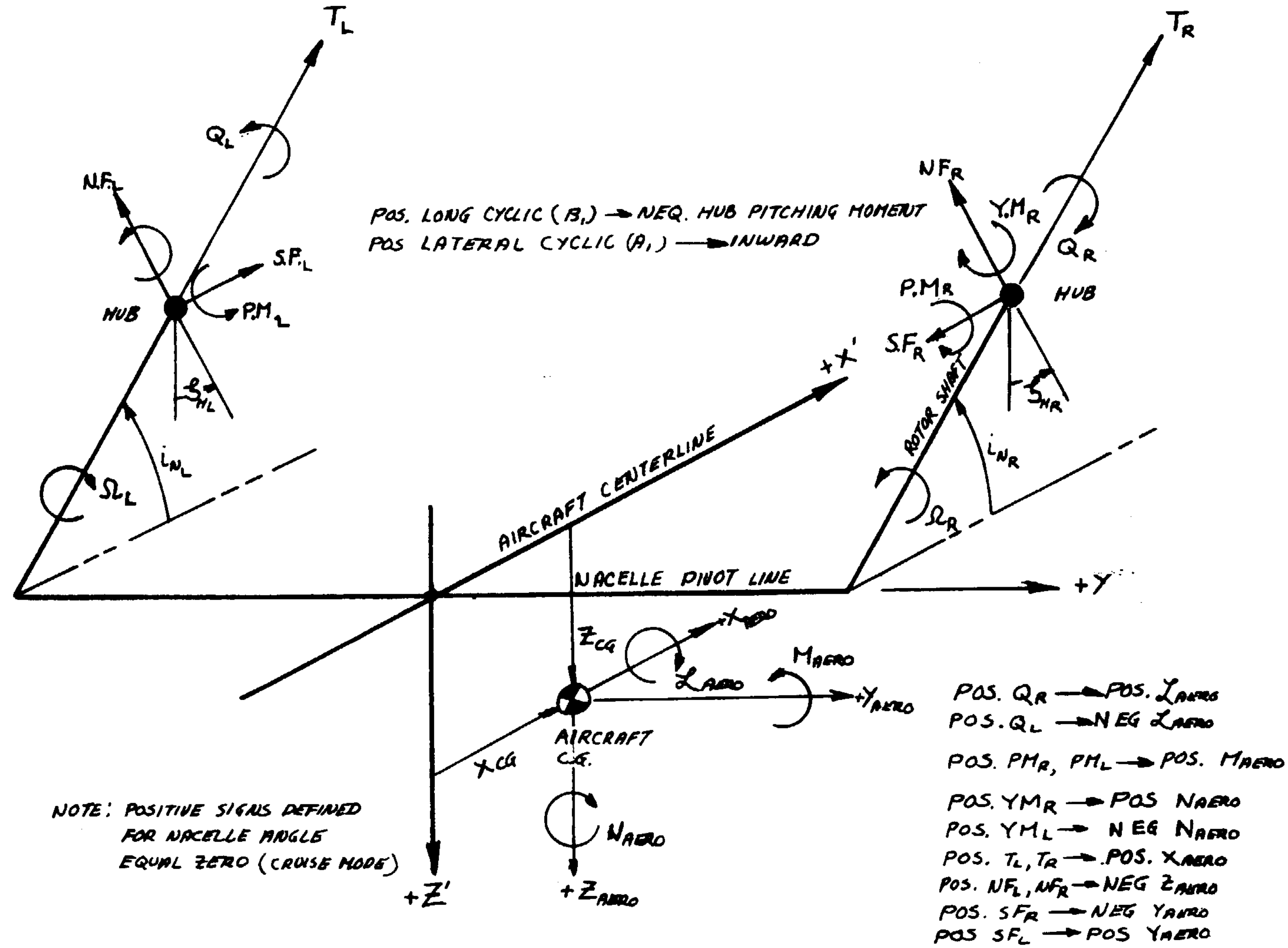


Figure 7.1. Rotor Sign Conventions

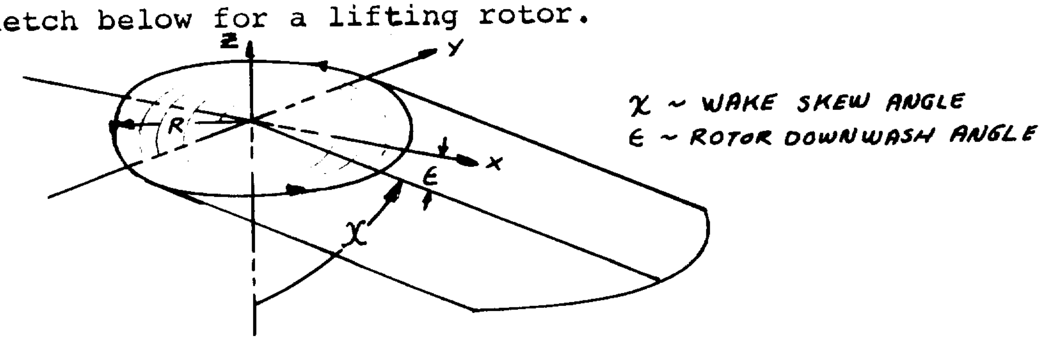
All of the rotor forces and moments are curve fit in this format. The coefficients of the equation were obtained from a least squares fit of the computed rotor data. The criteria used to determine the final coefficients was to have not more than a 5% difference between the curve fit equations and the computed rotor data at the nominal aircraft trim condition. In general this criteria was met.

7.5 EFFECT OF WING UPWASH ON ROTOR PERFORMANCE

The rotor operates in the upwash field associated with the lifting wing. Thus, the rotor behaves as if it were operating at an increased angle of attack. The effective upwash angles were calculated using lifting line theory. In the mathematical model the upwash angles are input in the form of a table of upwash angles as a function of wing lift coefficient, and nacelle incidence angle.

7.6 ROTOR/ROTOR INTERFERENCE

In order to obtain the correct lateral stick gradient when flying sidewards or at large sideslip angles, a calculation for rotor-on-rotor interference is included in the mathematical model. In Reference 11, the wake skew angle is defined as in the sketch below for a lifting rotor.



Also presented in this reference are contour charts of the normal component of induced velocity near a rotor with a triangular disc loading for six different skew angles in the range from 0° to 90°. For the Model 222 geometry, a curve of normal induced velocity/average induced velocity as a function of skew angle was obtained. For the case of the Model 222 flying sidewards, the downwind rotor is assumed to be operating at a lower angle of attack than the upwind rotor, and will therefore generate different forces and moments. The downwash angle is calculated from the normal component of induced velocity. The rotor/rotor interference is washed out as a function of nacelle angle and sideslip angle such that there is no interference in the high transition speed and cruise modes. The equations derived are shown in Appendix E , under the rotor/rotor interference section.

7.7 ISOLATED ROTOR AERODYNAMICS

The equations utilized to represent the isolated rotor aerodynamics are presented below. These equations are then resolved into body axis forces and moments to be used in the equation of motion.

7.7.1 Thrust [(1)]

$$C'_{T_R} = [C_{T_{ORR}} \cos A_{1C_R} \cos B_{1C_R}]$$

where $C_{T_{ORR}} = \sum_{v=0}^{2} \sum_{u=0}^{3} [A_{T(u+4v)} \alpha^{u}_{RR} \theta^{v}_{0.75}]$

(1) In the equations that follow, subscript RR denotes right rotor. The left rotor is identical provided due regard is paid to sign convention and azimuth reference.

$A_{T(u+4v)}$ = function of μ $\left(\mu = \frac{V}{V_t}\right)$ and is obtained from Appendix F

A_{1C_R} = Lateral cyclic pitch

B_{1C_R} = Longitudinal cyclic pitch

$\theta_{0.75}$ = Blade pitch angle at 75% blade radius

$$\alpha_{RR} = \tan^{-1}\left\{\frac{\sqrt{v_{RR}^2 + (w_{RR}+u_{RR}\varepsilon_{wRR})^2}}{u_{RR}}\right\} + \varepsilon_{i_{LR}}$$

u_{RR}, v_{RR}, w_{RR} = rotor shaft axis velocity components

$\varepsilon_{w_{RR}}$ = Wing upwash angle

$\varepsilon_{i_{LR}}$ = Rotor/rotor interference angle

The effect of close proximity to the ground is accounted for by use of the following relationships

$$C_{T_{RR}} = C'_{T_{RR}} \left(\frac{T_{IGE}}{T_{OGE}}\right)_{RR}$$

where $\left(\frac{T_{IGE}}{T_{OGE}}\right)$ is defined in Section 10 under the discussion of ground effect.

7.7.2 Power

$$C_{P_{RR}} = C_{P_{O_{RR}}} = \sum_{v=0}^{2} \sum_{u=0}^{3} \left[A_p(u+4v)\,\alpha_{RR}^u\, C'^{v}_{T_{RR}}\right]$$

where: $A_p(u+4v)$ may be obtained from Appendix F as a function of μ_{RR}

7.7.3 Normal Force

$$C_{NF_{RR}} = C_{NF_{ORR}} + \frac{dC_{NF_{RR}}}{dA_{1C_R}} A_{1C_R} + \frac{dC_{NF_{RR}}}{dB_{1C_R}} B_{1C_R}$$

where: $$C_{NF_{O_{RR}}} = \sum_{v=0}^{2} \sum_{u=0}^{3} \left[A_{NF}(u+4v)\,\alpha_{RR}^{u}\, C'^{v}_{T_{RR}}\right]$$

$A_{NF}(u+4v)$ = Function of μ_{RR} and may be obtained from Appendix F.

$$\frac{dC_{NF_{RR}}}{dA_{1C_R}} = D_{NF_1} C_{T_{RR}} + D_{NF_2} \mu_{RR}^2 + D_{NF_3} \mu_{RR} + D_{NF_4}$$

$$\frac{dC_{NF_{RR}}}{dB_{1C_R}} = E_{NF_1} C_{T_{RR}} + E_{NF_2} \mu_{RR}^2 + E_{NF_3} \mu_{RR} + E_{NF_4}$$

The coefficients in the above 2 equations may be obtained from Appendix F.

7.7.4 Side Force

$$C_{SF_{RR}} = C_{SF_{ORR}} + \frac{dC_{SF_{RR}}}{dA_{1C_R}} A_{1C_R} + \frac{dC_{SF_{RR}}}{dB_{1C_R}} B_{1C_R}$$

where: $$C_{SF_{O_{RR}}} = \sum_{v=0}^{2} \sum_{u=0}^{3} \left[A_{SF}(u+4v)\, \alpha_{RR}^{u}\, C_{T_{RR}}^{\prime v} \right]$$

$A_{SF}(u+4v)$=function of μ_{RR} and may be obtained from Appendix F.

$$\frac{dC_{SF_{RR}}}{dA_{1C_R}} = D_{SF_1} C_{T_{RR}} + D_{SF_2} \mu_{RR}^2 + D_{SF_3} \mu_{RR} + D_{SF_4}$$

$$\frac{dC_{SF_{RR}}}{dB_{1C_R}} = E_{SF_1} C_{T_{RR}} + E_{SF_2} \mu_{RR}^2 + E_{SF_3} \mu_{RR} + E_{SF_4}$$

The coefficients in the above 2 equations may be obtained from Appendix F.

7.7.5 Hub Pitching Moment

$$C_{PM_{RR}} = C_{PM_{O_{RR}}} + \frac{dC_{PM_{RR}}}{dA_{1C_R}} A_{1C_R} + \frac{dC_{PM_{RR}}}{dB_{1C_R}} B_{1C_R} + \frac{dC_{PM_{RR}}}{dQ} Q_{NR}^{R}$$

where: $$C_{PM_{O_{RR}}} = \sum_{v=0}^{2} \sum_{u=0}^{3} \left[A_{PM}(u+4v)\, \alpha_{RR}^{u}\, C_{T_{RR}}^{\prime v} \right]$$

$A_{PM}(u+4v)$ = function of μ_{RR} and may be obtained from Appendix F.

$$\frac{dC_{PM_{RR}}}{dQ} = \sum_{v=0}^{2} \sum_{u=0}^{3} \left[H_{PM}(u+4v)\, \alpha_{RR}^{u}\, C_{T_{RR}}'^{v} \right]$$

$H_{PM}(u+4v)$ = function of μ_{RR} and may be obtained from Appendix F

$$\overset{R}{Q}_{NR} = \overset{N}{Q}_{NR} \cos \zeta_{HR} + \overset{N}{R}_{NR} \sin \zeta_{HR}$$

$$\overset{N}{Q}_{NR} = Q + \dot{i}_{N_R}$$

$$\overset{N}{R}_{NR} = -R \cos i_{N_R} - P \sin i_{N_R}$$

ζ_{HR} = right rotor sideslip angle

$\dot{i}_{NR}$ = right nacelle velocity

i_{NR} = right nacelle angle

$$\frac{dC_{PM_{RR}}}{dA_{1C_R}} = D_{PM_1} C_{T_{RR}} + D_{PM_2}\mu^2{}_{RR} + D_{PM_3}\mu_{RR} + D_{PM_4} \quad (\mu_{RR} \le .35)$$

$$= D_{PM_1} C_{T_{RR}} + D_{PM_5}\mu^2{}_{RR} + D_{PM_6}\mu_{RR} + D_{PM_7} \quad (\mu_{RR} > .35)$$

$$\frac{dC_{PM_{RR}}}{dB_{1C_R}} = E_{PM_1} C_{T_{RR}} + E_{PM_2}\mu^2{}_{RR} + E_{PM_3}\mu_{RR} + E_{PM_4} \quad (\mu_{RR} \le .35)$$

$$= E_{PM_1} C_{T_{RR}} + E_{PM_5}\mu^2{}_{RR} + E_{PM_6}\mu_{RR} + E_{PM_7} \quad (\mu_{RR} > .35)$$

Values for the coefficients in the above 2 sets of equations may be found in Appendix F.

7.7.6 Hub Yawing Moment

$$C_{YM_{RR}} = C_{YM_{O_{RR}}} + \frac{dC_{YM_{RR}}}{dA_{1C_R}} A_{1C_R} + \frac{dC_{YM_{RR}}}{dB_{1C_R}} B_{1C_R} + \frac{dC_{YM_{RR}}}{dR} \overset{R}{R}_{NR}$$

where: $$C_{YM_{O_{RR}}} = \sum_{v=0}^{2} \sum_{u=0}^{3} \left[A_{YM(u+4v)}\, \alpha_{RR}^{u}\, C_{T_{RR}}'^{v} \right]$$

$A_{YM}(u+4v)$ is a function of μ_{RR} and may be obtained from Appendix F.

$$\frac{dC_{YM_{RR}}}{dR} = \sum_{v=0}^{2} \sum_{u=0}^{3} \left[J_{YM\,(u+4v)} \alpha_{RR}^{u} C'^{\,v}_{T_{RR}} \right]$$

$J_{YM}(u+4v)$ is a function of μ_{RR} and may be obtained from Appendix F.

$$R_{NR}^{R} = R_{NR}^{N} \cos \zeta_{HR} - Q_{NR}^{N} \sin \zeta_{HR}$$

$$R_{NR}^{N} = -R \cos i_{NR} - P \sin i_{NR}$$

$$Q_{NR}^{N} = Q + \dot{i}_{NR}$$

ζ_{HR} = Right rotor sideslip angle

$\dot{i}_{NR}$ = Right nacelle velocity

i_{NR} = Right nacelle angle

$$\frac{dC_{YM_{RR}}}{dA_{1C_R}} = D_{YM1} C_{T_{RR}} + D_{YM2} \mu^2{}_{RR} + D_{YM3} \mu_{RR} + D_{YM4} \; (\mu_{RR} \leq .35)$$

$$= D_{YM1} C_T + D_{YM5} \mu^2_{RR} + D_{YM6} \mu_{RR} + D_{YM7} \; (\mu_{RR} > .35)$$

$$\frac{dC_{YM_{RR}}}{dB_{1C_R}} = E_{YM1} C_T + E_{YM2} \mu^2{}_{RR} + E_{YM3} \mu_{RR} + E_{YM4} \; (\mu_{RR} \leq .35)$$

$$= E_{YM1} C_{T_{RR}} + E_{YM5} \mu^2{}_{RR} + E_{YM6} \mu_{RR} + E_{EM7} \; (\mu_{RR} > .35)$$

Values for the coefficients in the above 2 sets of equations may be found in Appendix F.

Notes: (1) Application of rotor equations for left rotor follow similar format with subscript "RR" changed to "LR".

(2) When solving equations with double summations for values of μ not given in tables, solve equations for the two values of μ closest to the value desired and then interpolate linearly for exact value of μ.

7.8 CORRELATIONS OF ROTOR PREDICTION METHODS WITH TEST DATA

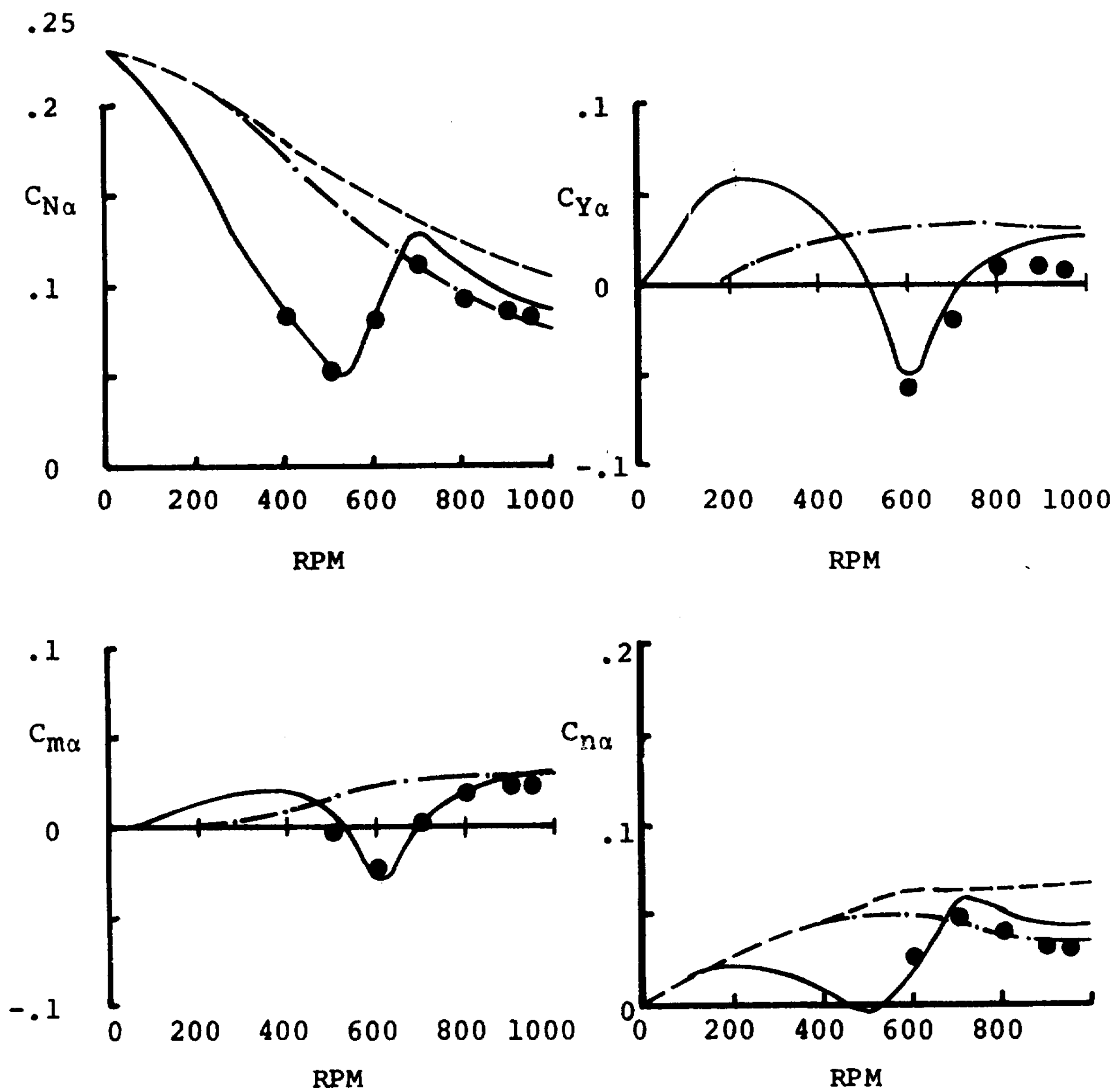
This section presents the results of correlation studies that were conducted to verify the adequacy of the rotor prediction methods used for the Model 222 tilt rotor. In general, prediction of trends is excellent with quite good agreement in absolute magnitudes.

7.8.1 Model 213 Four Blade Hingeless Rotor Correlation

Figure 7.2 presents correlation with rotor derivatives measured on a 1/9 scale dynamically similar model of a tilt/stowed rotor conversion model. In this test the rotor hub forces and moments were carefully measured over a range of RPM in which the lead-lag modal frequency progressed from less than 1 per rev at 900 RPM to values significantly greater than 1 per rev as the rotor was feathered. The measured values confirm the predicted behavior trend and the quantitative correlation is also excellent.

7.8.2 Correlation with Model 222 26-Foot Diameter Rotor Test in NASA-Ames 40 x 80-Foot Tunnel

Figure 7.3 shows the schematic of the windmilling test stand and its instrumentation. Test data were obtained from strain gages mounted on the outer portion of the wing as shown, and calibrated to measure normal force, pitching moment and yawing moment. Comparison with test data was made by calculating the moments about the wing strain gage locations using forces and moments predicted by the C-41 program. The results of this



Test Points ●

Theoretical Predictions
— — — — Rigid Blades
—·— Flap Only
——— Flap & Lead Lag

$\frac{dC_L}{d\alpha} = 5.7$

Definitions

Normal Force = $1/2\rho\pi R^2 V^2 C_{N\alpha}\cdot\alpha$
Side Force = $1/2\rho\pi R^2 V^2 C_{Y\alpha}\cdot\alpha$
Pitching Moment = $\rho\pi R^3 V^2 C_{m\alpha}\cdot\alpha$
Yawing Moment = $\rho\pi R^3 V^2 C_{n\alpha}\cdot\alpha$

Figure 7.2. Model 213 1/9 Scale Conversion Model — 85 Ft/Sec Derivative Variation with RPM

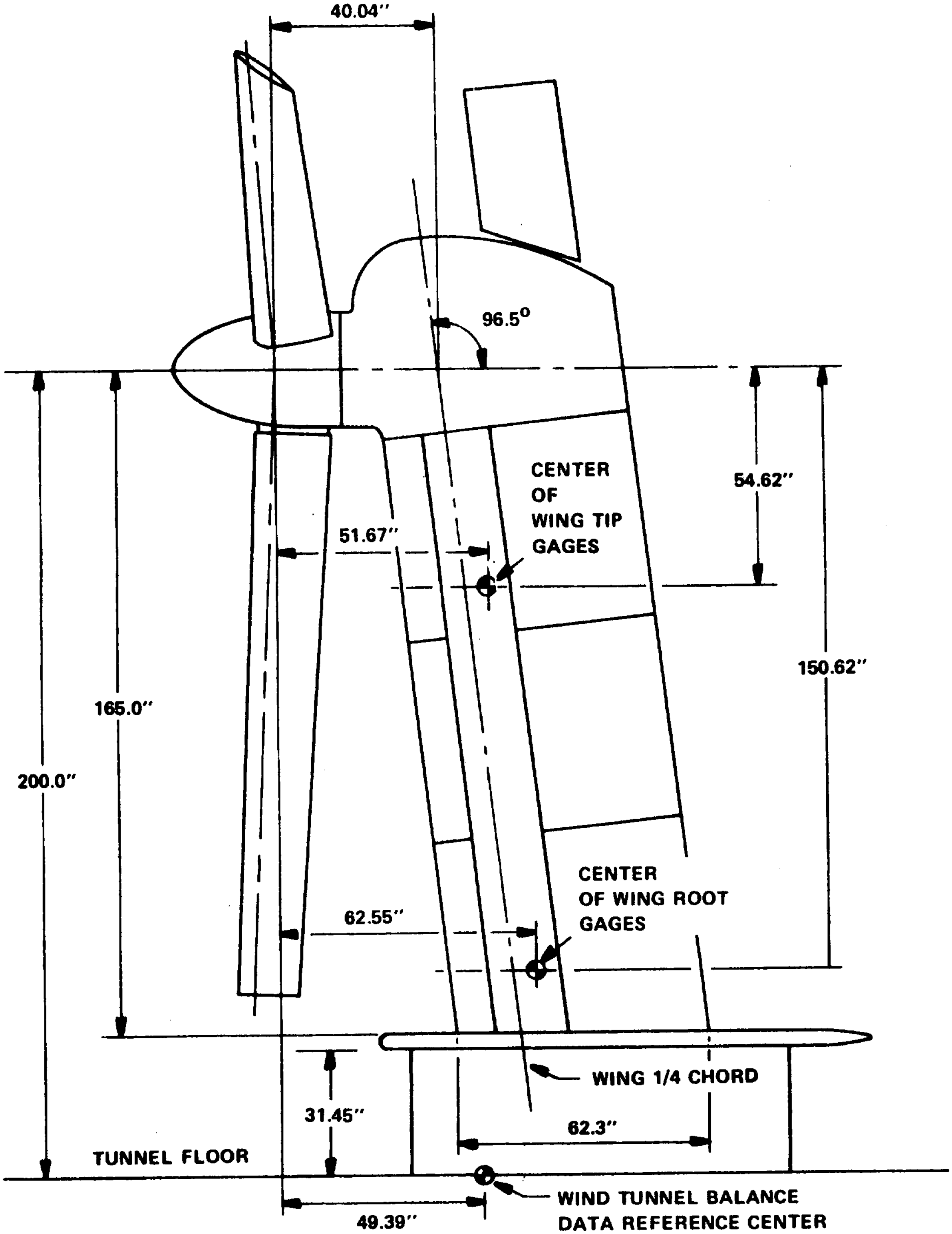


Figure 7.3. 26 Ft. Rotor Test Stand in NASA's 40' x 80' Tunnel

comparison for alpha derivatives are given in Figure 7.4 and for cyclic pitch derivatives in Figures 7.5 and 7.6 .

The analysis did not attempt to account for force and moment contributions from nacelle and wing aerodynamic interference. Nevertheless, quite good correlation is observed. These plots also show the values of derivatives predicted by several other programs. These include D-88 program which accounts for compressible non-linear downwash and L-22 which uses linear airfoil theory and uncoupled flap-lag freedoms. C-49 accounts for unsteady aerodynamics while C-41 uses a linear representation. C-41 and C-49 use a modal representation of blade freedoms (2 coupled flap-lag modes) while D-88 and L-22 make use of a finite element discrete mass representation.

The rotor derivative data was also compared with C-41 using a total unresolved moment approach. Total moments about the center of the wing tip gages and the reference azimuth position (orientation of the moment vector in the rotor disc plane) were calculated from the C-41 hub forces and moments and compared with test results (Figure 7.7). The interesting conclusion which is not apparent from the resolved forces and moments is that the total moment is predicted well but there are slight differences in the reference azimuth position.

7.8.3 Correlation with Model 222 1/4.622 Scale Model Data

The subject model is a dynamically similar version of the M222. The test data presented in Figures 7.8 and 7.9 were taken

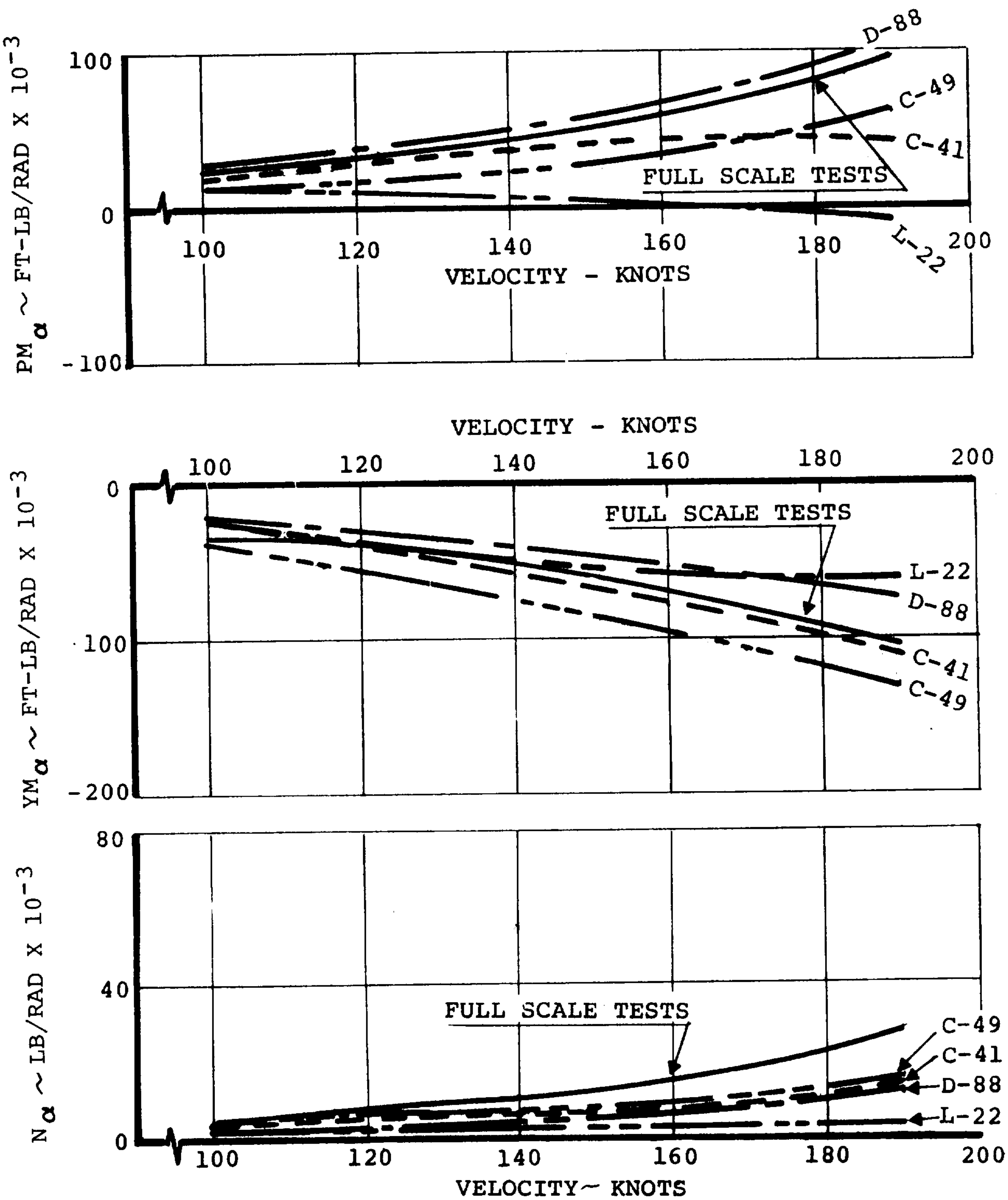


Figure 7.4. Correlation of 26 Ft Rotor Test Data with Various Rotor Derivative Programs

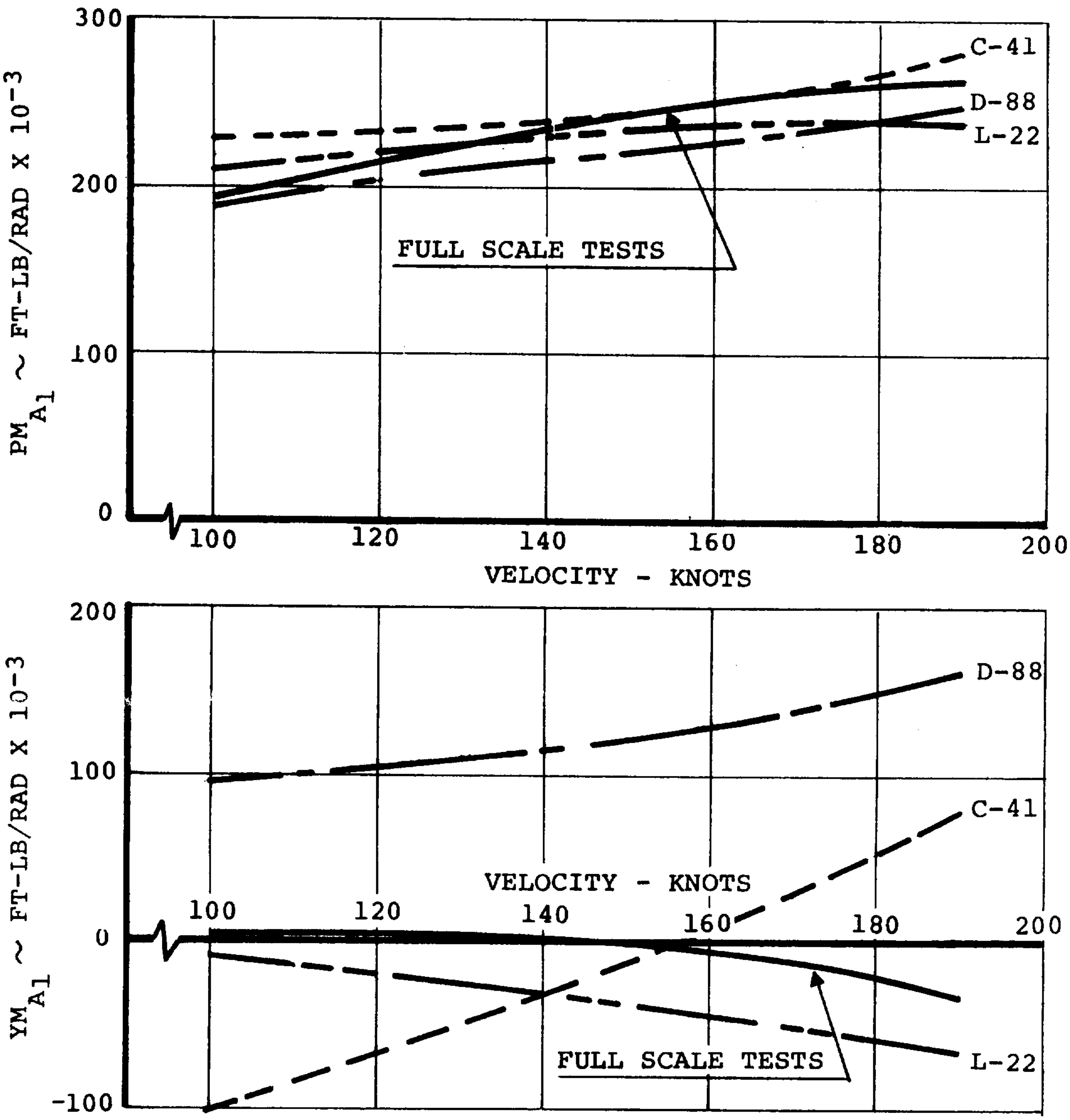


Figure 7.5. Correlation of 26 Ft Rotor Test Data with Various Rotor Derivative Programs — Cyclic Moment Derivatives

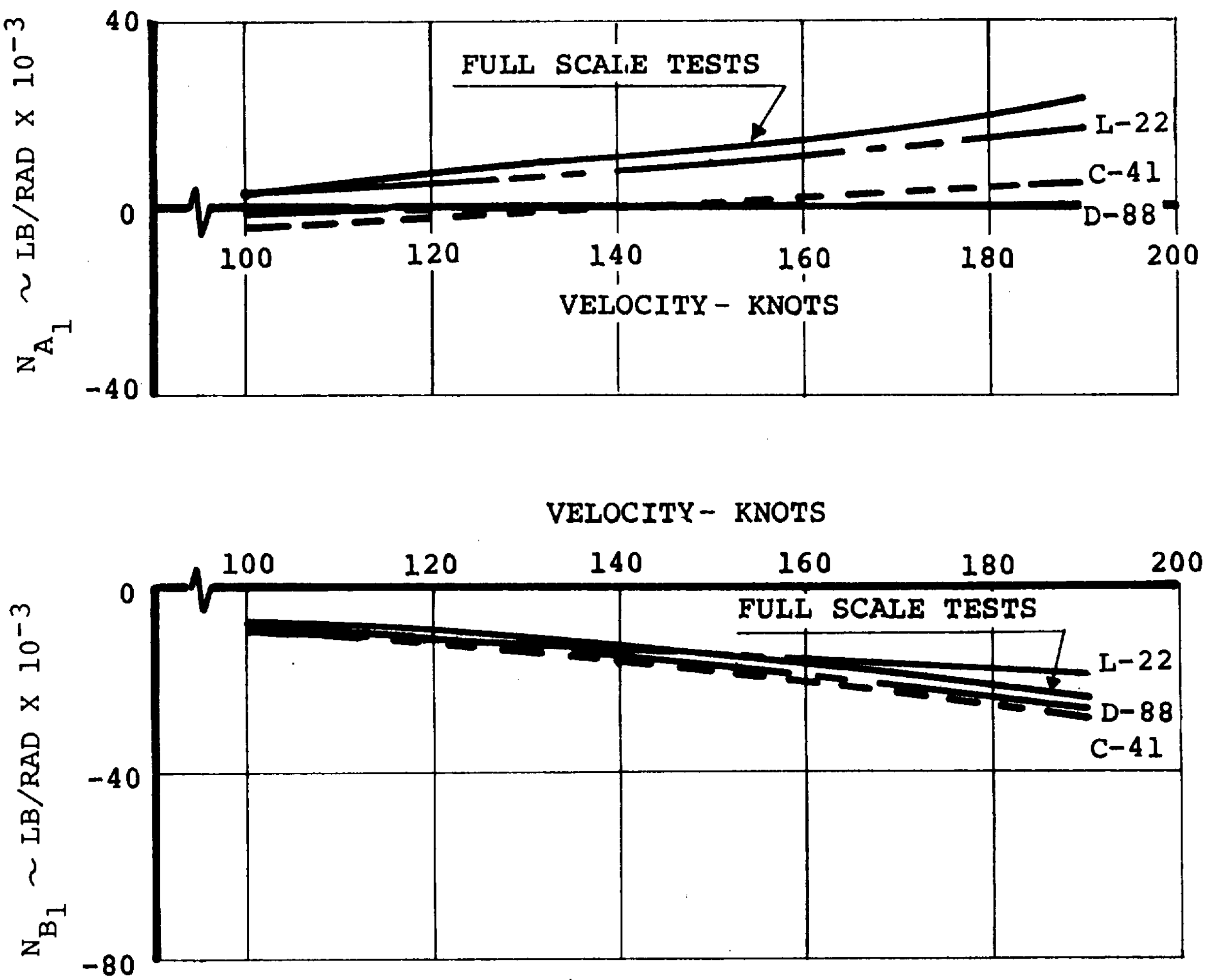


Figure 7.6. Correlation of 26 Ft Rotor Test Data with Various Rotor Derivative Programs — Cyclic Force Derivatives

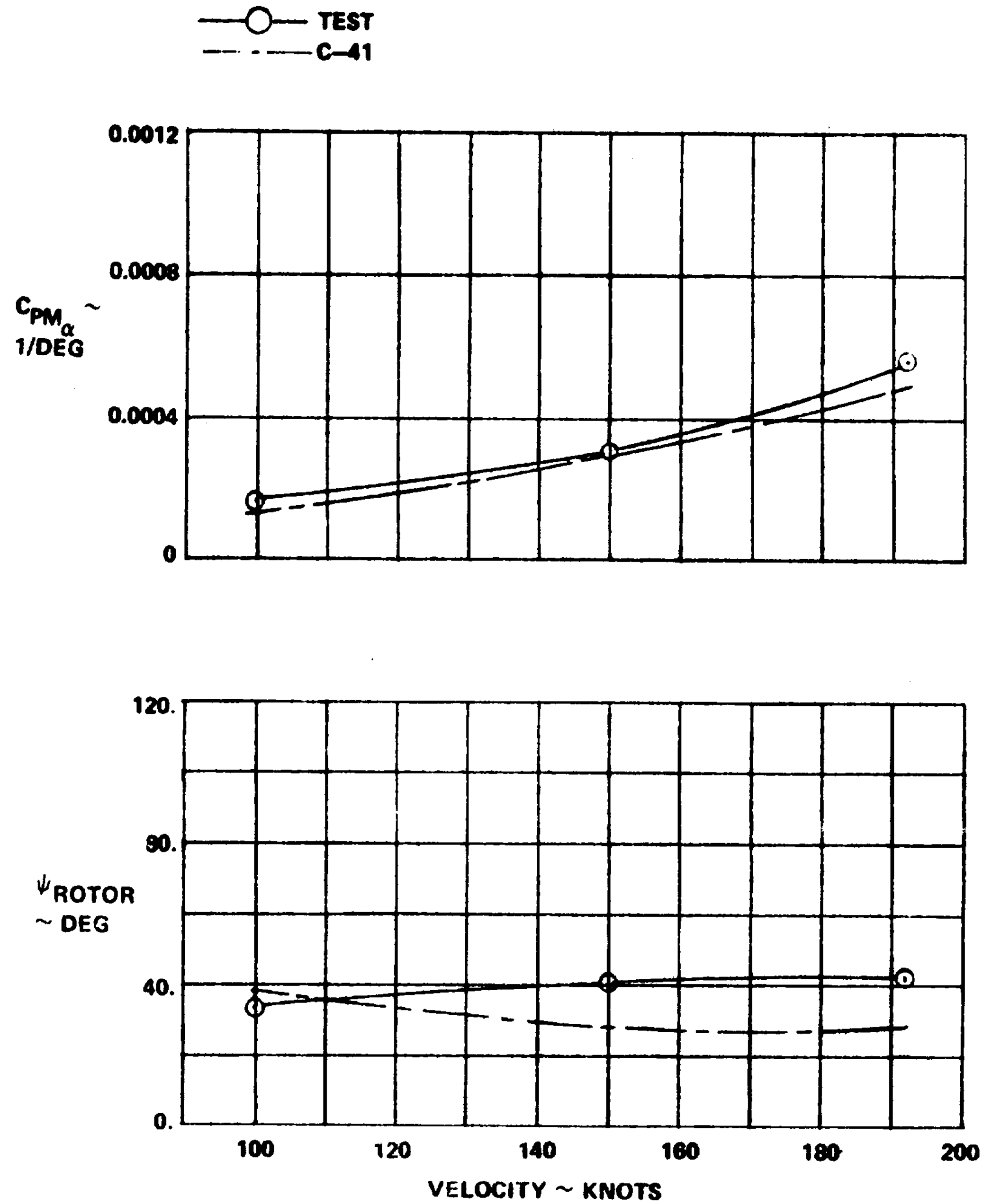


Figure 7.7. Rotor Moment and Azimuth Angle Due to Angle of Attack – Correlation with 26 Ft Rotor Data

with the model mounted on a pedestal in the tunnel. The rotors were given angles of attack to the free stream by pitching the complete model with zero sideslip angle and yawing the model at zero angle of attack. The yawing data contains minimal wing induced flow effects and comparison with the pitch data indicates the importance of induced flow on the rotor forces and moments. Forces and moments were computed for the isolated rotor and it is seen from Figure 7.8 that correlation with test data is excellent when wing induced effects are small; in Figure 7.9 wing effects introduce perceptible shifts which increase with dynamic pressure.

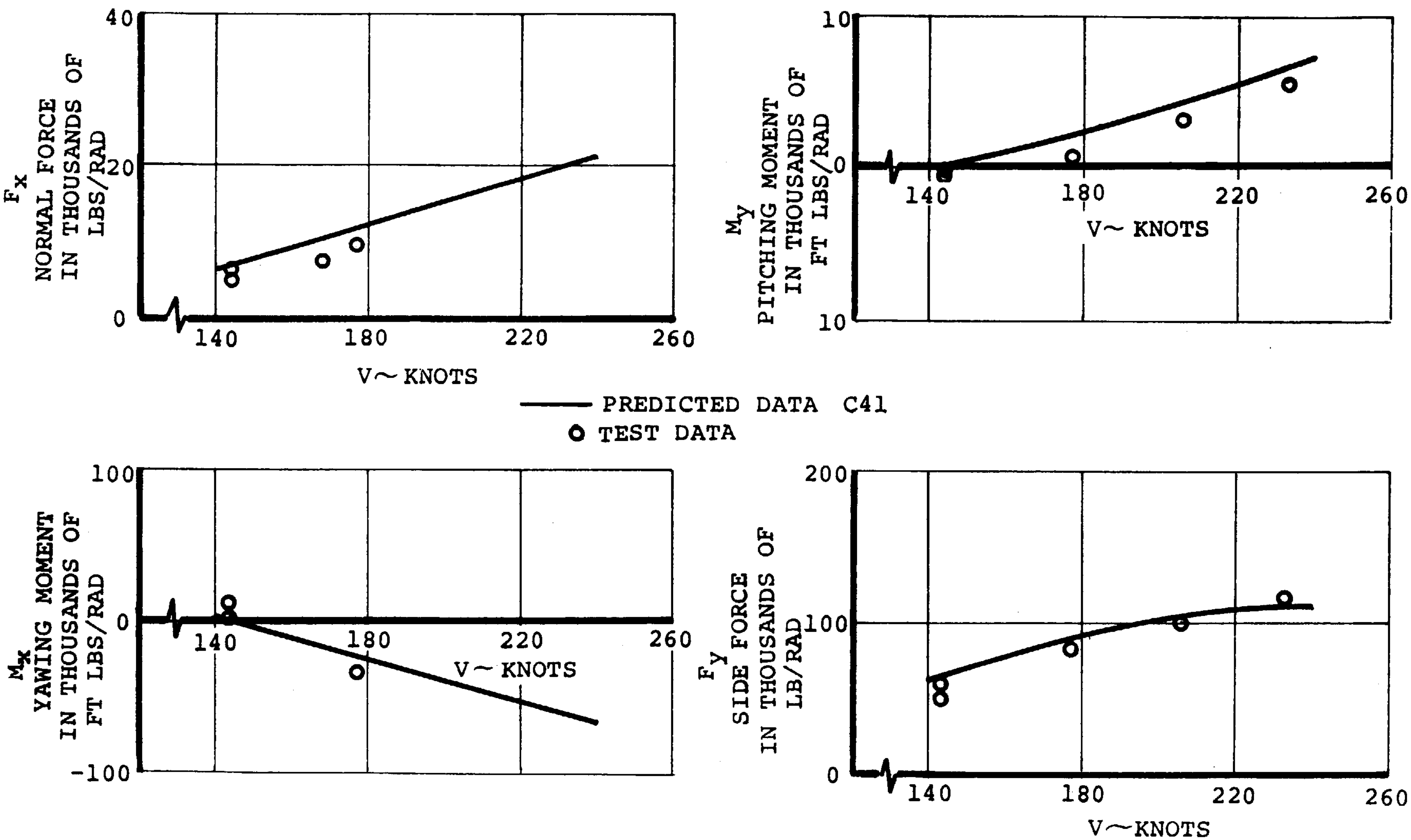


Figure 7.8. Comparison of Calculated and Test Rotor Hub Force and Moment Derivatives for M222 1/4.622 Scale Model (Yaw Sweep) Ω = 386 RPM

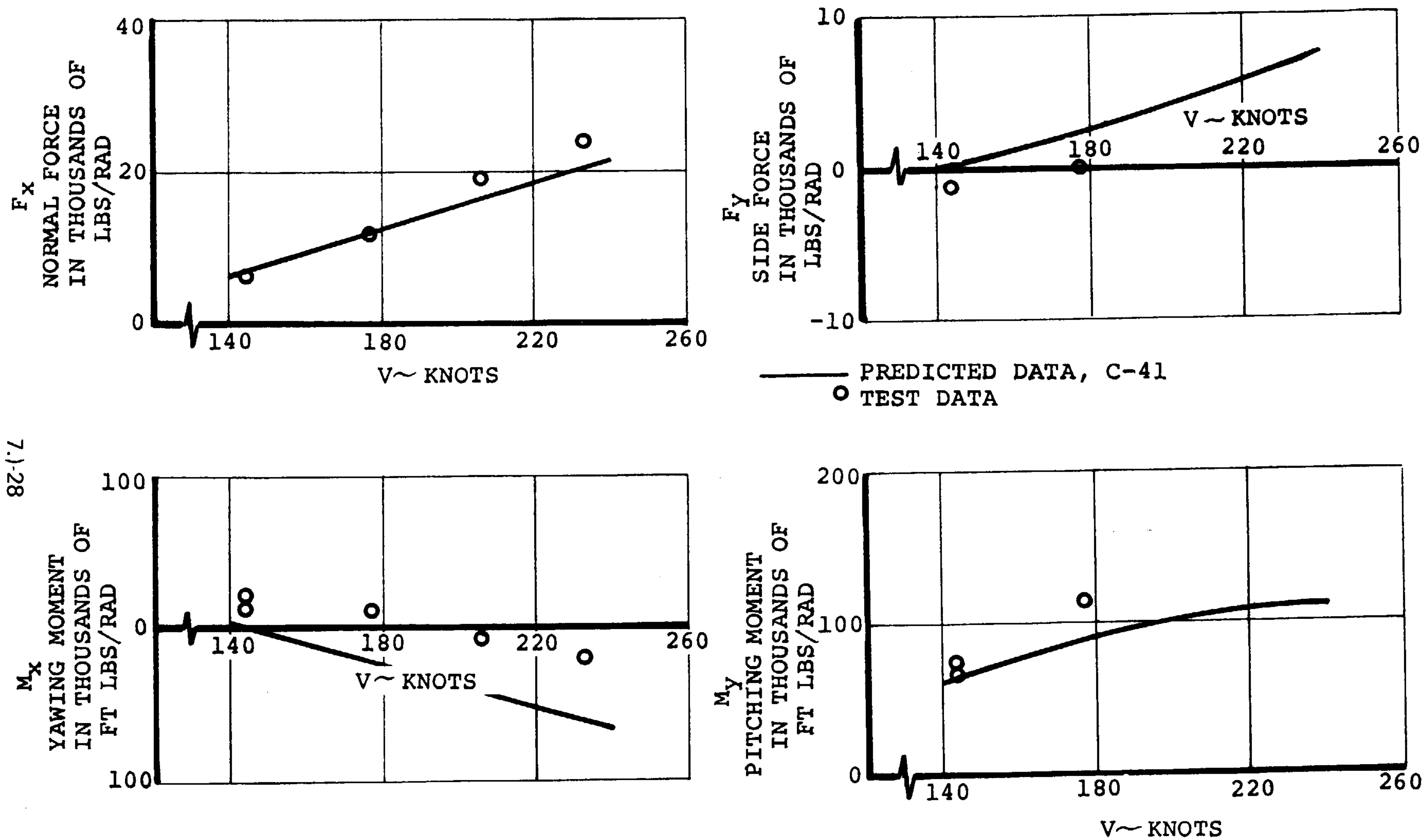


Figure 7.9. Comparison of Calculated and Test Rotor Hub Force and Moment Derivatives for M222 1/4.622 Scale Model (Pitch Sweep) $\Omega = 386$ RPM

8.0 CONTROL SYSTEM DESCRIPTION

This section describes the control system, stability augmentation systems, load alleviation system and thrust management system utilized in the mathematical model. A more complete description is given in Reference 8. .

8.1 CONTROL AERODYNAMIC CONFIGURATION

Control of the Model 222 aircraft is accomplished by utilization of longitudinal cyclic, differential longitudinal cyclic, collective and differential collective pitch, and differential nacelle tilt control in conjunction with the airplane control surfaces. The airplane control surfaces consist of conventional elevator and rudder and a flaperon and spoiler arrangement. The primary controls in each axis for each regime of flight are shown in Table 8.1.

The rotor controls provide a major portion of the control capability from hover through the low transition speed range, but airplane surface controls are operative in all regimes of flight, including hover. The rotor controls are phased out during transition as nacelle incidence decreases, speed increases, and the surface controls become more effective.

8.2 LONGITUDINAL CONTROL

Longitudinal control in hover is provided by longitudinal cyclic pitch. This is phased out through transition as the elevator becomes more effective. The elevator provides longitudinal control in the cruise mode.

TABLE 8.1 FLIGHT CONTROL MIXING

FLIGHT MODE	PRIMARY CONTROLS
<u>Helicopter (Hover)</u>	
Pitch	Longitudinal Cyclic
Roll	Differential Collective
Yaw	Differential Longitudinal Cyclic and Differential Nacelle Tilt
*Height Control	Collective/Engine Power
<u>Transition</u>	
Pitch	Longitudinal Cyclic and Elevator
Roll	Differential Collective, Differential Longitudincal Cyclic, Differential Nacelle Tilt, Aileron and Spoiler
Yaw	Differential Longitudinal Cyclic, Differential Nacelle Tilt, and Rudder
<u>Airplane</u>	
Pitch	Elevator
Roll	Aileron and Spoiler
Yaw	Rudder

8.3 LATERAL CONTROL

Lateral control in hover is provided by differential collective pitch, together with differential engine fuel flow (power). The differential engine power is provided to ensure maintaining roll control in the event of a cross shaft failure. It also serves to minimize the cross shaft torque. In transition, differential collective and differential cyclic are scheduled as a function of nacelle tilt.

When differential cyclic pitch is commanded the nacelles are also actuated to tilt differentially, thereby increasing the thrust vectoring effect of the cyclic pitch. Differential deflection of the nacelles is ± 1.55 degrees per degree of cyclic plus approximately ± 0.20 degrees of differential nacelle tilt due to elasticity of wing and nacelles. This results in a large increase in control power as compared to the control power available from cyclic alone. The control power requirements may, therefore, be met with modest amounts of cyclic control resulting in low blade stresses and long rotor fatigue life. Collective pitch is also scheduled with nacelle tilt so that when the nacelles are tilted differentially, pitch is increased on the rotor whose disc is tilted down, and decreased on the rotor which is tilted up. This maintains the thrust approximately equal on the two rotors, ensuring that thrust vectoring rather than differential thrust is achieved by the differential cyclic pitch and differential nacelle tilt.

The wing has full span flaps and spoilers mounted on the trailing edge. The flaps are single slotted of 30 percent chord with a fixed hinge point 14.6 percent below the wing chord line. The flaps act as flaperons for roll control and deflect downward only by a maximum of 20 degrees from the nominal flap setting. Maximum incremental lift from the flaps is attained at approximately 35 degrees deflection and the maximum rolling moment occurs at the same time, so the flaperon deflection for roll control is limited to a maximum total flap deflection of 35 degrees. If, for example, the flaps are symmetrically deflected 30 degrees, only 5 degrees additional deflection is utilized for roll control. Full span spoilers of 12.7 percent chord are located forward of the flaps and hinged to the rear spar. The spoilers are "slot-lipped", i.e., they open up the slot forward of the flap with the flaps extended resulting in a large increase in roll control as compared to the control power with flaps closed. Maximum deflection of the spoilers for roll control is 45 degrees from the closed position.

Maximum spoiler rolling moment coefficient is also attained with flaps deflected approximately 35 degrees. Spoiler effectiveness with the flaps retracted is approximately one-third that attainable with the flaps extended. Spoiler rolling moment is further reduced at high speed by limiting the spoiler actuator force capability, thereby restricting the spoiler extension at speeds above 175 knots.

The spoilers and flaps are also used in conjunction with download alleviation devices referred to as umbrellas mounted on the leading edge of the wing for download relief in the hover and low-speed range. The umbrellas are 18.6 percent chord on the upper and lower wing surfaces. Maximum deflections of the surfaces for download alleviation are: flaps 70 degrees, spoilers 110 degrees from closed, and umbrellas aft-edge-of-the-upper surface up to 20 degrees from vertical and aft-edge-of-lower-surface down to 10 degrees from vertical. The umbrellas and spoilers retract at 50 knots automatically.

8.4 DIRECTIONAL CONTROL

Directional control in hover is provided by differential longitudinal cyclic pitch, which, as discussed above under lateral control, also actuates differential nacelle tilt to amplify the thrust vectoring effect of the cyclic pitch.

In transition, the differential cyclic and its associated nacelle tilt are phased out as the rudder becomes more effective. This results in near zero initial roll acceleration in response to a yaw input.

8.5 THRUST/COLLECTIVE CONTROL

In hover, forward motion of the thrust/collective lever mechanically commands both increased collective pitch and increased power. The governor provides a fine adjustment to the collective pitch to maintain rpm. Over travel of the pilot's lever, beyond the normal max power position, provides a collective pitch landing flare capability. The over travel is entered by going through a "gate",which shuts down the rotor governor and leaves the pilot's lever directly connected to collective pitch, just like a helicopter collective pitch lever.

The collective pitch is also scheduled through transition as a function of nacelle incidence, minimizing the adjustment needed from the governor and also providing the pitch variation with differential nacelle tilt required for roll and yaw control.

In cruise the mechanical interconnection of the thrust/collective lever with collective pitch is phased out completely so that a pure power demand system with governed pitch, like a conventional fixed wing airplane, is provided. The control system block diagrams are shown in Appendix E.

8.6 CONTROL FEEL

Control force gradient variation with dynamic pressure prevents excessive sensitivity of control at high speed. In the model 222, the force gradients of the primary controls (longitudinal and lateral stick, and pedals) are varied linearly with dynamic pressure. The rudder and elevator deflections vary linearly with pilot's rudder pedal and longitudinal stick travel. Aileron deflection is programmed linearly and spoiler deflection nonlinearly with lateral stick deflection, to provide near-linear rolling moment effectiveness to near cruise speed. As mentioned earlier, spoiler deflection is limited at high speed by limiting the actuator capacity. The control force breakout forces and gradients are shown in Appendix F.

8.7 STABILITY AUGMENTATION SYSTEMS

Stability augmentation systems are provided to enhance aircraft flying qualities. The system consists of longitudinal, lateral and direction SAS. The longitudinal stability augmentation system incorporates a pitch rate feedback and a longitudinal stick pickoff. In addition, a lagged pitch rate signal is incorporated to provide some degree of attitude stabilization without the autopilot. (An autopilot is not represented in this simulation.) These signals are shaped and put through an authority limit. The longitudinal SAS commands longitudinal cyclic ptich to provide the required damping in hover and transition. It is not required in the cruise mode and is phased out at 175 knots. The block diagram of the longitudinal SAS is given in Appendix E.

The lateral stability augmentation system is operative in all flight modes. It consists of roll rate feedback for increased damping in roll, lagged roll rate feedback to provide roll attitude stability, and a lateral stick pickoff. In addition a sideslip feedback is incorporated to decrease the strong dihedral effect. These feedback loops are shaped and phased to yield good aircraft dynamic characteristics. A lateral SAS authority limit is incorporated in the circuit. The output of the lateral stability augmentation system is input to the control system in terms of equivalent lateral stick, since the drive actuator is in series with, and commands the same control as, the pilots lateral stick control linkage. The lateral SAS never opposes the pilots' command. The block diagram of this system is shown in Appendix E.

A directional stability augmentation system is provided and operates in all flight regimes. The yaw channel consists of yaw rate feedback for increased directional damping in hover and low speed flight modes, lagged yaw rate feedback to provide yaw attitude stability, and a rudder pedal pickoff for quickening. Directional damping provided by the rotors is quite high in the higher transition and cruise speed ranges. No additional yaw rate damping is therefore needed in cruise. A feedback is provided to modify the effective yawing moment due to roll rate which exists in the basic unaugmented aircraft configuration in the cruise speed range. The feedback gains, and the relative phasing of these gains have been optimized to provide good directional dynamic response. A directional SAS authority limit is incorporated. The SAS command is input to the control system in terms of equivalent inches of rudder pedal. The block diagram for the directional stability augmentation system is shown in Appendix E.

The stability augmentation systems used for the simulation are not set up to investigate individual component failures. Modifications are required in order to do malfunction type studies with this simulation.

8.8 LOAD ALLEVIATION SYSTEM (LAS)

Propeller type aircraft experience significant blade loads during exposure to skewed flow due to steady state or transient conditions (climb, sideslip, gusts, etc). The tilt rotor configuration can have similar problems. However, since cyclic pitch is a basic part of the tilt rotor control system it provides the means to significantly reduce the sensitivities to these effects. It also can be used to reduce the destabilizing moments which come from the rotors and thus improve static stability.

An automatic load alleviation system is provided and operates via the swashplate to reduce both transient and steady state hub forces and moments and the destabilizing moments at the nacelle pivot. It is not a required system for the Model 222, but will significantly enhance the static stability and the fatigue margins of the aircraft.

The overall objectives to be achieved through the use of cyclic feedback control are:

- Reduce rotor hub forces and moments for both steady state operation and gust encounter

- Improve flying qualities of the aircraft by using the cyclic control system to reduce pilot workload and improve short period response by reducing destabilizing forces and moments of the rotors

- Reduce aircraft structural loads resulting from gust turbulence

- Improve ride qualities by damping the response to gust turbulence

The load alleviation system, as mechanized in this simulation consists of angle of attack, angle of sideslip, and dynamic pressure sensors which drive through appropriate gains and filters to reduce the longitudinal and lateral moments at the nacelle pivot. The lateral cyclic pitch used for load alleviation is authority limited and drives separate actuators in each hub. The longitudinal cyclic pitch is summed in with the longitudinal SAS. The block diagram for this system as mechanized is shown in Appendix . This system is operative from low transition speed (approx. 50 knots) through dive speed and reduces the pivot moments from 50% in the 150 to 200 knot range to 100% in all other modes of flight.

8.9 THRUST MANAGEMENT SYSTEM

The thrust and power management system for a tilt rotor aircraft must be compatible with both the helicopter and airplane configurations. Thrust control for the hover task, rpm control, gust response (especially in the cruise flight regime), and effect on aircraft flying qualities must all be considered. Classically, helicopters have used collective pitch demand to control thrust and fuel governing to control rpm while fixed-wing aircraft have used fuel flow demand to control thrust and collective pitch governing to control rpm. Each system has its advantages. For a tilt rotor aircraft it is desirable from a practical viewpoint to have one type of governing for both the helicopter and fixed-wing flight regimes. Collective pitch governing was chosen for Model 222 for several reasons:

- It is more readily adapted to the hover flight regime than the fuel governor is to cruise
- It has better gust response characteristics
- It is fast acting and has high accuracy
- Thrust response to pilot control can be easily shaped with feed forward loops
- It has been demonstrated successfully in hover, transition and cruise in the CL-84 aircraft

With collective pitch governing there are two areas in the thrust management system to be considered: (1) style of the collective pitch governor; and (2) the feed forward loops for shaping pilot thrust control. The block diagram for this system as mechanized in this simulation is shown in Appendix E.

Several different governor configurations were considered for The M222 in order to determine the governor system best suited to meet the following objectives: (1) 0.3 percent steady state error in 2.5 to 3 seconds; (2) 2 percent rpm overshoot; and (3), satisfactory effect on aircraft flying qualities in the all-operational mode (i.e., all aircraft components operational and performing as designed) and various failure modes. A single governor reference which used the rpm signal from each rotor and averaged them was chosen as the configuration that best satisfied the design criteria. To achieve the required accuracy and transient response goals, integral as well as proportional feedback of rpm was necessary in both the hover and cruise regimes. Governor gain is scheduled with nacelle incidence to maintain a near optimum level of governing throughout the flight envelope. Gains are varied linearly as the rotor rpm is changed from 551 in hover to 386 in cruise. The second requirement of the governor system is shaping the rotor thrust output for a pilot throttle input. Considerations in determining the proper shaping include:

(1) throttle sensitivity;

(2) time constant to reach 63% of steady-state thrust; and

(3) allowable thrust overshoot

Variable pilot's control sensitivity is employed to give the optimum sensitivity in the hover power range yet maintain full power control within a reasonable throttle throw (8 inches). Shaping of the pilot command with collective quickening is done to improve the thrust time constant and thrust response transient shaping so that the pilot may perform the precision hover task with a minimum of difficulty. In the cruise regime, shaping of the thrust output is unnecessary and is phased out during transition.

The thrust/collective pitch control system is designed in such a manner that, during hover, when the pilot moves his control, he commands both a change in engine fuel setting and, mechanically, a change in collective setting. The governor then operates with a time lag to trim the collective to the value required to maintain rpm. The mechanical collective change feature is washed out as a function of nacelle incidence so that when nacelle incidence is decreased to zero, the pilot commands only engine fuel. In addition, the reference setting schedule for collective has been established to maintain equal thrust output from both rotors during application of differential nacelle tilt.

As was mentioned previously, additional details on the Model 222 control system may be obtained from Reference 8.

9.0 ENGINE REPRESENTATION

This section describes the engine performance and dynamic model representation that is used in the mathematical model. The basic engine cycle performance data consists of tabulated values of four variables: power, fuel flow, gas generator shaft rpm, and power turbine shaft rpm. These parameters are a function of Mach number and turbine inlet temperature. All data are in referred, normalized format as shown in Table 9.1. Because of the normalized, referred format, all data are valid for any ambient conditions. The effects on engine performance of operating at non-optimum power turbine speed are included in this model. The referred format also facilitates including engine thermodynamic and mechanical limits. Limitations on engine cycle operation may be input on any combination of the following: fuel flow, torque, gas generator speed, gas generator referred rpm or output shaft speed. A detailed description of this routine is in Reference 9. The flow charts which describe this routine mathematically are shown in Appendix E.

A simplified dynamic model of the Lycoming T53-L-13 engine was formulated for use in the tilt rotor mathematical model. This model was coupled to the output of the engine performance program described above. The model consists basically of 2 first order lags in series with variable time constants and gains. The output of the model is rate limited to reflect actual engine performance. This simplified model gives satisfactory results for both large and small power transients. The block diagram for this system is shown as part of the thrust management system block diagram shown in Appendix E.

TABLE 9.1 ENGINE CYCLE DATA FORMAT

VARIABLE	SYMBOL	REFERRED, NORMALIZED FORM
Thrust	F_N	$F_N/\delta F^*_N$
Power	SHP	$SHP/\delta\sqrt{\theta}SHP^*$
Gas Generator rpm	N_I	$N_I/\sqrt{\theta}N^*_I$
Power Turbine rpm	N_{II}	$N_{II}/\sqrt{\theta}N^*_{II}$
Fuel Flow	W_f	$W_f/\delta\sqrt{\theta}F^*_N$
		$W_f/\delta\sqrt{\theta}SHP^*$
Turbine Inlet Temperature	T	T/θ
Where:	*	= Max. Power Setting, Static, Sea Level, Standard Day
	θ	= Ambient Temperature (°R) Divided by 518.69°R
	δ	= Ambient Pressure (psia) Divided by 14.696 psia

10.0 GROUND EFFECTS

The effects of operating near the ground on the rotors and airframe are included in this model. The presence of the ground on the airframe imposes a boundary condition which inhibits the downward flow of air normally associated with the lifting action of the wing and tail. The reduced downwash has three main effects;

- A reduction in the downwash angle at the tail
- An increase in the wing lift curve slope
- An increase in the tail lift curve slope

These have been accounted for by the methods given in Reference 10 Appendix B-7. The data given in the reference for the change in wing and tail lift curve slope has been used directly. The equation specified for the change in downwash angle at the tail due to ground proximity was modified for convenience. The equation as stated is:

$$\frac{(\Delta\varepsilon)_g}{\varepsilon} = \frac{b_1^2 + 4(h-H)^2}{b_1^2 + 4(h+H)^2}$$

where $(\Delta\varepsilon)_g$ = the change in tail downwash angle due to ground proximity

ε = the downwash remote from ground

h = the height of the tail root quarter chord point above the ground

H = the height of the wing root quarter chord point above the ground

b_1 = a function of wing lift and wing flap geometry

For this mathematical model, the b_1 in the above equation was taken to be equal to the wing span, b_w. This results in a small error in the change in horizontal tail downwash. It is, however, sufficiently accurate for this simulation.

Ground effects on the rotor are difficult to predict analytically, especially in forward flight. Wind tunnel test data for the Model 160 powered model, Reference 6 was plotted as a thrust ratio versus effective rotor height/diameter ratio, for two rotor advance ratios. This data, shown in Figure 10.1 was curve fit and linearly interpolated for advance ratio. The resulting equation is as follows: - (for the right rotor. The left rotor is identical except for subscripts)

$$\left(\frac{T_{IGE}}{T_{OGE}}\right)_{RR} = \left[\left(\frac{h}{D}\right)^2_{EFF_{RR}} (.1741 - .6216\ \mu_{RR}) + \left(\frac{h}{D}\right)_{EFF_{RR}} (1.4779\ \mu_{RR} - .4143) + 1.2479 - .8806\ \mu_{RR}\right]$$

where $$\left(\frac{h}{D}\right)_{EFF_{RR}} = \frac{h_{RR}}{2R[\,|\sin(\theta + i_{N_R})\cos\phi| + .0174]}$$

$$h_{RR} = -Z_{DOWN} + (L_S \cos i_{N_R} - X_{CG}) \sin\theta + [(L_S \sin i_{N_R} + Z_{CG}) \cos\phi - Y_N \sin\phi] \cos\theta$$

= Rotor hub height above the ground

L_S = Distance from the nacelle pivot to the rotor hub

X_{CG} = Longitudinal distance from the pivot to the CG

Z_{CG} = Vertical distance from the pivot to the CG

θ = Aircraft pitch attitude

ϕ = Aircraft roll attitude

i_{N_R} = Right rotor nacelle angle

Y_N = Wing semispan

$$\left(\frac{T_{IGE}}{T_{OGE}}\right) = \left[\left(\frac{h}{D}\right)^2_{EFF} (.1741-.6216\mu) + \left(\frac{h}{D}\right)_{EFF} (1.4779\mu-.4143) + 1.2479 - .8806\mu\right]$$

<u>NOTE</u>: <u>If</u> $\mu > 0.283$; $\left(\frac{T_{IGE}}{T_{OGE}}\right) = 1.0$

<u>or</u>

<u>If</u> $\left(\frac{h}{D}\right)_{EFF} > 1.3$; $\left(\frac{T_{IGE}}{T_{OGE}}\right) = 1.0$

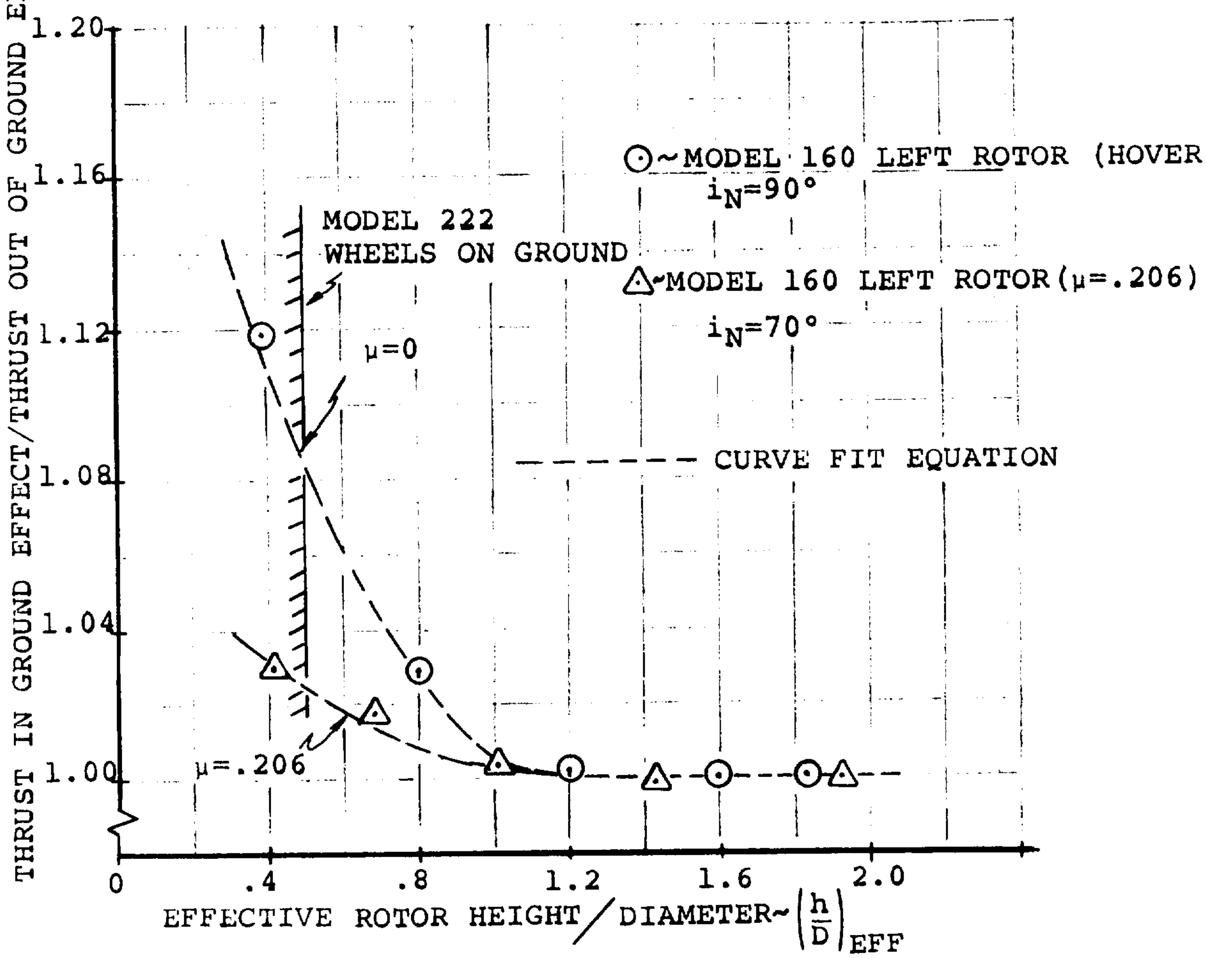


Figure 10.1. Effect of Rotor Height on Thrust Augmentation Ratio

The equation for the effective rotor height to diameter ratio $(h/D)_{EFF}$ was derived by dividing the rotor hub height by $[\sin(\theta+i_N)\cos\phi]$. This yields the rotor height along the shaft. For the cruise condition the hub height is infinite, $(h/D)_{EFF}$ is infinite and the augmentation ratio due to ground effect is unity. Some special conditions which must be observed when using these equations are noted in Figure 10.1.

11.0 AIRFRAME REPRESENTATION (PREPROCESSOR)

An airframe representation/preprocessor calculation is included in the mathematical model that enables the user to input the location of major structural elements of the aircraft in terms of water line, butt line and station line location. All lengths, center of gravity distances and inertias used in the equations are then calculated. This feature enables the user to quickly change the location of major structural elements to assess their impact on vehicle response.

In the derivation of the basic equations of motion, the aircraft was divided into three principal mass elements. The fuselage mass element (m_f), the wing mass element (m_W) and the tilting nacelle mass element (m_N). The components of the three mass elements are shown below and are available from a standard mass properties buildup of the Model 222.

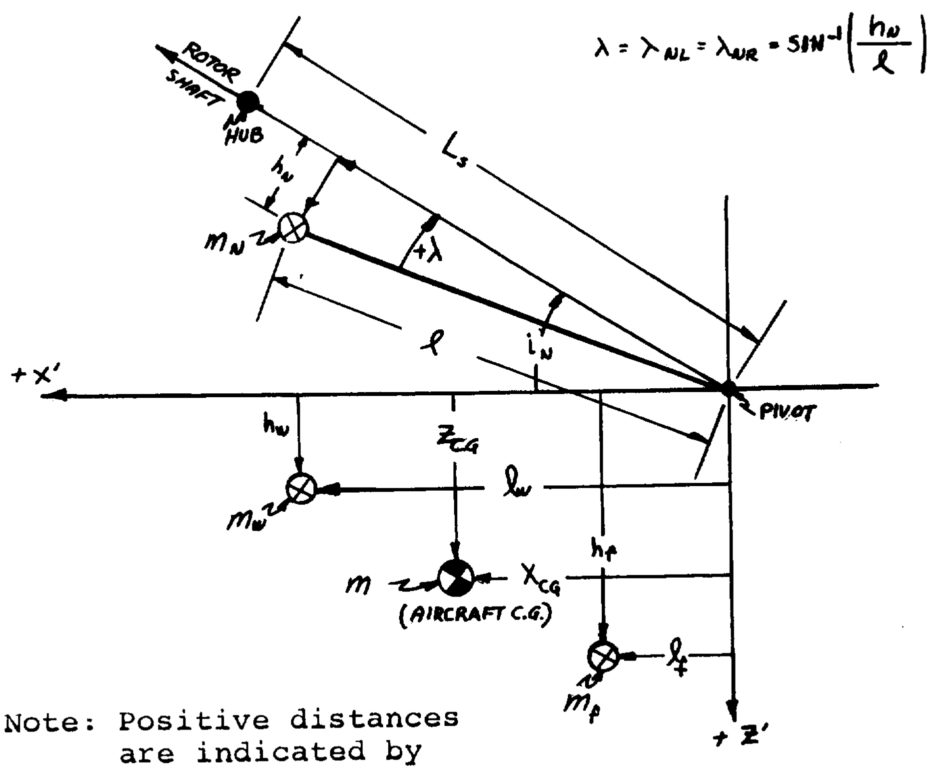
- fuselage mass element (m_f)
  - Fuselage and contents
  - Horizontal tail and contents
  - Vertical tail and contents
  - Crew and trapped liquids
  - Cargo
- wing mass element (m_W)
  - Wing and contents
  - Fuel carried in wing
  - Fixed nacelles and/or engines
- tilting nacelle mass element (m_N)
  - Tilting nacelle (including rotors)

These three mass elements along with their respective distances from the nacelle pivot to the center of each mass element are used to compute the aircraft center of gravity distances with respect to the nacelle pivot. The equations for these center of gravity distances, derived in Appendix C, and including the effects of nacelle tilt are:

$$x_{CG} = \frac{m_f \ell_f + m_w \ell_w}{m} + \ell \left(\frac{m_N}{m}\right) \left[\cos(i_{NL} - \lambda) + \cos(i_{NR} - \lambda)\right]$$

$$z_{CG} = \frac{m_f h_f + m_w h_w}{m} - \ell \left(\frac{m_N}{m}\right) \left[\sin(i_{NL} - \lambda) + \sin(i_{NR} - \lambda)\right]$$

The masses and distances used in these equations are defined on the sketch below.



Note: Positive distances are indicated by the direction of the arrows

The quantities required to compute m_f, ℓ_f, m_w, ℓ_w, m, ℓ, m_N, λ, h_f, h_w are available from an aircraft three-view drawing and a standard mass properties buildup. The quantities ℓ and λ (defined in the sketch) are easily obtainable from a drawing. The mass quantities (m, m_N, m_f, m_w) are computed from a mass properties buildup by adding up the components of each mass element as described in the previous paragraph. The lengths ℓ_f, ℓ_w, h_f and h_w are computed by summing the weight moments of the components of each mass element about the nacelle pivot. The equations for these operations have been derived and are presented in Appendix E under the preprocessor equations. The input data to these equations include the weight of each component, and its location in terms of water line, fuselage station line, and butt line.

When the center of gravity distance of each mass element has been determined, the component and total aircraft mass moments of inertia can be computed. The equations for the total aircraft mass moments of inertia are presented in Appendix C. The moments of inertia of each mass element are computed by application of the parallel axis theorem. The moments of inertia of each component about its own center of gravity must be known. The parallel axis theorem states:

$$I_{xx} = \sum_{i=1}^{N} \left[I_{xx_{o_i}} + m_i (y_i^2 + z_i^2) \right]$$

$$I_{yy} = \sum_{i=1}^{N} \left[I_{yy_{o_i}} + m_i (z_i^2 + x_i^2) \right]$$

$$I_{zz} = \sum_{i=1}^{N} \left[I_{zz_{o_i}} + m_i (x_i^2 + y_i^2) \right]$$

$$I_{xz} = \sum_{i=1}^{N} \left[I_{xz_{o_i}} + m_i (x_i z_i) \right]$$

where N represents the number of component masses.

These equations have been expanded to compute the moments of inertia of each mass element and are shown in Appendix E under the preprocessor section. The only additional input data required are the inertias of each component about their own centers of gravity. These are readily available from the mass properties buildup of the Model 222.

Other lengths required for the mathematical model are computed in this section. The input data for these computations are in terms of the water line, butt line and fuselage station line locations of the elements in question.

12.0 AERO-ELASTIC REPRESENTATION

Two aero-elastic degrees of freedom are included in the tilt rotor mathematical model. These are first mode wing vertical bending and first mode wing torsion. The stability and control characteristics of flexible airplanes may be significantly influenced by distortions of the structure under transient loading conditions. When the separation in frequency between the elastic degrees of freedom and the rigid body motions is not large, then significant aerodynamic and inertial coupling can occur between the two. Many of the important effects of elastic distortion, however, can be accounted for simply by modifying the aerodynamic equations. The assumption is made that the changes in aerodynamic loading take place so slowly that the structure is at all times in static equilibrium. This is equivalent to assuming that the natural frequencies of vibration of the structure are much higher than the frequencies of the rigid body motions. Thus a change in load produces a proportional change in the shape of the airplane, which in turn influences the load. This is known as the method of "quasistatic" deflections where all the coupling occurs in the aerodynamic equations.

The wing uncoupled natural frequencies were investigated to determine which method would be used. Table 12.1 shows the

TABLE 12.1 WING UNCOUPLED FREQUENCIES (BLADES OFF) CRUISE CONFIGURATION

Symmetric Mode	Frequency
Vertical Bending	3.6 cps
Chordwise Bending	5.4 cps
Torsion	6.1 cps
Antisymmetric Mode	**Frequency**
Vertical Bending	11.2 cps
Chordwise Bending	9.1 cps
Torsion	5.7 cps

Model 222 wing uncoupled frequencies for the cruise condition for both the symmetric and anti-symmetric modes. As can be noted in the table, the lowest vertical bending frequency is 3.6 cps and the lowest wing torsional frequency is 5.7 cps. The rigid body short period mode varies from approximately 0.40 cps to 1.35 cps. Since the rigid body short period modes are separated from the elastic modes by a substantial margin, the method of "quasistatic" deflection is used to represent the wing bending and torsion modes, with the only coupling in the aerodynamic terms (through angle of attack). The wing twists and bends instantaneously when subjected to an applied load. The assumptions made in deriving the wing bending and torsion relationships are as follows:

- No coupling between bending and torsion modes
- Wings are cantilevered from the fuselage
- Elliptical loading assumed for the rigid untwisted wing
- Aerodynamic loads act at the wing quarter chord
- Wing elastic axis coincident with cross shaft
- Wing center of mass assumed to lie on the elastic axis
- First wing torsional mode assumed linear from tip to root

In the mathematical model, wing twist at the tip is calculated using the following equation:

$$K_{\theta_t}\theta_t = M_{ACT} - I_E\Omega_E R + q\,\frac{c_w^2\,b_w}{2}\,Cm_o + qc_w^2\left(\frac{dCm_{c/4}}{dC_\ell} + \frac{x_{WAC}}{c_w}\right)\left(\frac{C_{L_\alpha}\,b_w}{6\pi}\right)\left(4\theta_t + 3\pi\alpha_{RIGID}\right)$$

where:

K_{θ_t} = Wing torsional spring constant

θ_t = Wing twist angle in degrees

MACT = Nacelle actuator pitching moment

I_E = Engine inertia

Ω_E = Engine speed

R = Body yaw rate

q = Dynamic pressure

c_w = Wing reference chord

b_w = Wing reference span

C_{m_o} = Wing zero lift pitching moment coefficient

$\frac{dCm_{c/4}}{dC_\ell}$ = Wing pitching moment slope with lift coefficient

C_{L_α} = Wing lift curve slope

α_{RIGID} = Wing angle of attack without twist

Assuming a linear mode shape from the wing tip to the root and a cantilevered wing (zero twist at root), the wing twist at the aerodynamic center location of the wing is obtained by linear interpolation. The wing twist represents the change in angle of attack of the wing tip and aerodynamic center and are used in the aerodynamic equations.

Wing vertical bending deflection is also treated on a "quasi-static" basis. The form of the equation used in the mathematical model for the wing tip deflection is as follows:

$$h_1 = K_{W_1} Z^N_{AERO} + K_{W_2} Z^W_{AERO} - K_{W_3} L^N_{AERO} - K_{W_4} \bar{a}_T - K_{W_5} \bar{a}_{WAC}$$

where: h_1 = Wing tip deflection

Z^W_{AERO} = Wing lift

Z^N_{AERO} = Total wing lift

L^N_{AERO} = Nacelle rolling moment

$\bar{a}_T$ = Vertical acceleration of the nacelle

$\bar{a}_{WAC}$ = Vertical acceleration of the wing aerodynamic center

$K_{W_1} \rightarrow K_{W_5}$ = Constants for Model 222 wing

The form of the equation for the wing deflection at the aerodynamic center is written similarly:

$$h_{1_{WAC}} = K_{W_6} Z^N_{AERO} + K_{W_7} Z^W_{AERO} - K_{W_8} L^N_{AERO} - K_{W_9} \bar{a}_T - K_{W_{10}} \bar{a}_{WAC}$$

The symbols represent the same quantities as the tip deflections except the quantities K_{W_6} to $K_{W_{10}}$ are different from K_1 to K_5.

These equations are derived in Appendix A. Since the wings are assumed cantilevered, these equations may be written for the left and right sides. The equations as used in the mathematical model are written in Appendix E.

The wing tip and aerodynamic center vertical bending velocities are computed by dividing the change in vertical bending deflection by the simulation time frame. The vertical bending deflections and velocities are then added to the velocity components at the wing tip and aerodynamic center. These velocity components are then used in the calculation of the aerodynamic angle of attack.

In addition to the aerodynamic coupling via angle of attack, as discussed above, the wing tip vertical forces and moments act as the driving functions to a set of second order equations that are forced at the wing vertical bending frequency. This results in giving the pilot a "seat of the pants" feel for the vibratory aspects of the wing vertical bending mode. The equations were written in this manner to see if the pilot could induce a P.I.O. (pilot induced oscillation) during the piloted simulations due to wing vertical bending.

13.0 CONCLUSIONS AND RECOMMENDATIONS

1. Formulation of an eleven degree of freedom tilt rotor mathematical model and setting up an in-house hybrid simulation program using this model have been successfully completed.

2. The simulation model has been successfully checked out and validated at the Ames Research Center.

3. The in-house simulation model is "real time" and executes in 40 milliseconds. The Ames simulation is also real time with a 50 millisecond time frame. This increased time is due to the all digital nature of the Ames simulation.

4. It is desirable to shorten the frame time of the simulation. This may be accomplished by streamlining the following elements of the mathematical model:
   - Slipstream aerodynamics
   - Input aerodynamic data in body axes rather than wind axes to eliminate axes transforms

5. The simulation could be improved by incorporating advances in methodology in such areas as:
   - Rotor Representation - Formulate a simplified analytical model to adequately represent the dynamics and aerodynamics of soft-in-plane hingeless

rotors for all flight regimes. This would avoid the necessity for complex time-consuming table look ups of rotor data.

- Slipstream Aerodynamics - Simplify the analytical representation based on wind tunnel test data.
- Interference Effects - Improve the prediction of the tail downwash environment at low transition speeds.

14.0 REFERENCES

1. USAF Stability and Control DATCOM, Air Force Flight Dynamics Laboratory, October 1960, (Revised September 1970).
2. Reed, T. J., "User Report" Prop/Rotor Dynamic Derivative Program C41 J.N.", Boeing Document D210-10116-1, Vertol Division, The Boeing Company, Philadelphia, Pa., June 1970.
3. Amos, A. K.; Miao, W., "Program C-49: Rotor Stability Derivatives", Boeing Interoffice Memorandum, 8-7453-1-2483, Vertol Division, The Boeing Company, Philadelphia, Pa., July 1971.
4. Davenport, F. J., "Analysis of Propeller and Rotor Performance in Static and Axial Flight by an Explicit Vortex Influence Technique", Boeing Document R-372, Boeing Company, Vertol Division, Philadelphia, Pa., February 1965.
5. Tarzanin, F. and Thomas, E., "Aeroelastic Rotor Analysis", Boeing Document D8-0614, Boeing Company, Vertol Division, Philadelphia, Pa., May 1967.
6. Magee, J. P., et al, "Test Program II, Wind Tunnel Test of a Powered Tilt Rotor Performance Model, Volume VI, Results and Analysis", Boeing Document D213-10000-6, Boeing Company, Vertol Division, Philadelphia, Pa., August 1970.
7. Smith, M. C., "University of Maryland Wind Tunnel Test 489, Force, Moment and Downwash Measurements on a Rigid Rotor

and Semispan Wing", (4 volumes), Boeing Document D8-1062-1, The Boeing Company, Vertol Division, Philadelphia, Pa., March 1968.

8. "Study of V/STOL Tilt Rotor Research Aircraft Program (Phase I)", Volumes II and III, Prepared under contract NAS2-7259 for NASA, Ames Research Center, Boeing Vertol Company, Philadelphia, Pa., January 1973.

9. Schoen, A. H., "User's Manual for VASCOMP II, The V/STOL Aircraft Sizing and Performance Computer Program", Boeing Document D8-0375, Volume VI, Boeing Company, Vertol Division, Philadelphia, Pa., March 1968.

10. Etkin, Bernard, "Dynamics of Flight", John Wiley and Sons, Inc., 1959.

11. Heyson, Harry H. and Katzoff, S.; "Induced Velocities Near a Lifting Rotor with Non-uniform Disk Loading", NACA Report 1319, December 7, 1956.

12. Allen, H.J. and Perkins, E.W., "A Study of Effects of Viscosity on Flow Over Slender Inclined Bodies of Revolution", NACA TR 1048, 1951.

APPENDIX A - TREATMENT OF WING FLEXIBILITY

As described in Section 12 the large separation which exists between the natural frequencies of vibration of the wing structure and the aircraft rigid body motions, enables the elastic deformations of the wing structure to be calculated on a quasi-static basis.

In the simple treatment presented below, the bending and torsion modes are considered to be uncoupled. The wing is treated as a cantilever with a built-in root end. The wing is free to twist about the elastic axis which is assumed to coincide with the nacelle pivot line. The center of mass of each chordwise strip is also taken to lie on the pivot line. The unloaded wing has neither geometric nor aerodynamic twist.

WING TWIST

Spanwise twisting of the wing takes place under the action of the nacelle aerodynamic and inertial moments, the wing lift distribution, and the spanwise distribution of aerodynamic pitching moment. The nacelle aerodynamic moments consist of rotor hub loads, transferred to the pivot, together with the aerodynamic loads on the nacelle itself. Nacelle inertial moments include the gyroscopic effects of the rotor drive system.

With reference to Figure A.1, M_N is the moment supplied or absorbed by the nacelle tilt actuator. If K_θ is the wing stiffness as seen by the wing tip, then

$$M_N = K_\theta \, \theta_T \tag{A-1}$$

The total moment about the elastic axis due to wing aerodynamics, nacelle loads and engine gyroscopic torque is

$$T = \int_0^{b/2} m \, dy + M_N + M_{gyro} \tag{A-2}$$

The aerodynamic moment about the elastic axis at any station y is given by

$$m = m_{c/4} + \ell x \tag{A-3}$$

where ℓ is the section lift and x is the distance from the quarter chord to the elastic axis. In terms of the section aerodynamic coefficients,

$$m(y) = \frac{1}{2}\rho V^2 c^2 \, C_{m_{c/4}} + \frac{1}{2}\rho V^2 c^2 C_\ell \, \frac{x}{c} \tag{A-4}$$

The section lift coefficient, C_ℓ, is given by

$$c_\ell = k \, \frac{dC_\ell}{d\alpha} (\alpha - \alpha_o) \sqrt{1 - \left(\frac{2y}{b}\right)^2}$$

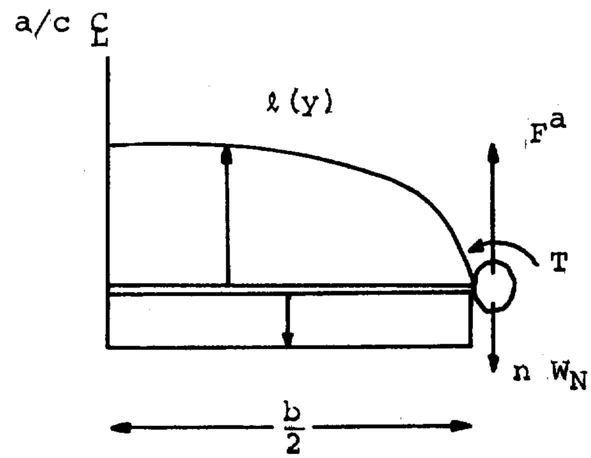
$$= k \, a_o \, (\alpha_R - \varepsilon_p - \alpha_o + \theta_t(y)) \sqrt{1 - \left(\frac{2y}{b}\right)^2} \tag{A-5}$$

where α_R is the wing root section angle of attack

ε_p is the rotor induced downwash, assumed constant spanwise

α_o is the section zero-lift angle

θ_t is the structural twist at station y



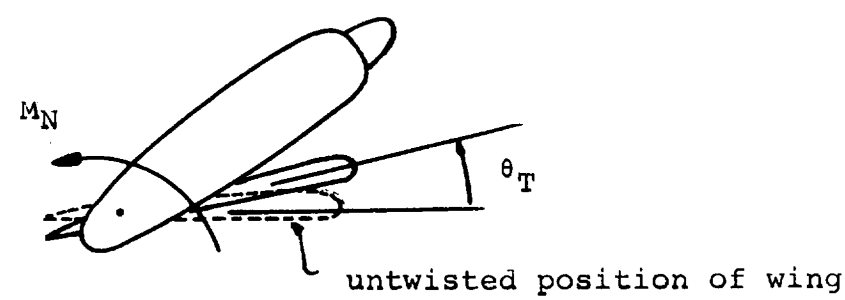


Figure A.1. Wing Geometry for Derivation of Flexibility

The factor $k\sqrt{1-\left(\frac{2y}{b}\right)^2}$ is introduced so that, for the untwisted wing, the lift distribution is elliptical. The value of k is obtained from the rigid wing elliptical loading as

$$k = \frac{4}{\pi}\,\frac{C_{L_\alpha}}{a_o} \qquad \text{(A-6)}$$

Thus the equation for C_ℓ becomes, with $\alpha_{RIGID} = \alpha_R - \varepsilon_{\bar{p}}\alpha_o$,

$$C_\ell = \frac{4}{\pi}\,C_{L_\alpha}\left[\alpha_{RIGID}\sqrt{1-\left(\frac{2y}{b}\right)^2} + \theta_t\sqrt{1-\left(\frac{2y}{b}\right)^2}\right] \qquad \text{(A-7)}$$

In equation (A-4) we can write, for low angles of attack,

$$C_{m_{c/4}} = C_{m_o} + \frac{dC_{m_{c/4}}}{dC_\ell}\,C_\ell \qquad \text{(A-8)}$$

and therefore

$$m(y) = \frac{1}{2}\rho V^2c^2\left\{C_{m_o} + \left(\frac{dC_{m_{c/4}}}{dC_\ell} + \frac{x}{c}\right)C_\ell\right\} \qquad \text{(A-9)}$$

The equation for the total wing twisting moment, equation (A-2),can now be written as,

$$T = M_{actuator} + M_{GYRO} + \frac{1}{4}\rho V^2c^2C_{m_o}\,b + \frac{1}{2}\rho V^2c^2$$

$$\left(\frac{dC_{m_{c/4}}}{dC_\ell} + \frac{x}{c}\right)\int_0^{b/2} C_\ell dy \qquad \text{(A-10)}$$

Using equation (A-7), assuming a linear structural twist from root to tip and performing the indicated integrations, the equation for total wing twisting moment becomes

$$T=K_\theta\theta_T=M_{actuator}+M_{gyro}+\frac{1}{4}\rho V^2bc^2C_{m_o}+\frac{1}{2}\rho V^2c^2\left(\frac{dC_{m_{c/4}}}{dC_\ell}+\frac{x}{c}\right)$$

$$\times\,\frac{C_{L_\alpha}b}{6\pi}\left(3\pi\alpha_{RIGID} + 4\theta_T\right) \qquad \text{(A-11)}$$

The equation for the actuator moment is given in the equations of motion, Section 5.0.

Rearranging, and writing $q = q_s\ (1-C_{T_s}) = \frac{1}{2}\rho V^2$

$$\theta_T = \frac{M_N + M_{gyro} + \frac{1}{2} q_s (1-C_{T_s}) c_w^2 \left[6\pi\alpha_{rigid}\left(\frac{dC_m}{dC_L} + \frac{x}{c}\right) + b_w C_{m_o}\right]}{K_\theta - \frac{2}{3\pi} q_s b_w c_w^2\ C_{L_\alpha} (1-C_{T_s}) \left(\frac{dC_m}{dC_L} + \frac{x}{c}\right)} \qquad \text{(A-12)}$$

where C_{m_o}, the zero-lift wing section pitching moment coefficient, is a function of flap deflection:

$$C_{m_o} = C_1 + C_2\delta_f + C_3\delta_f^2 \qquad \text{(A-13)}$$

Knowing the tip value of twist, the twist at any other spanwise station is obtained by assuming a linear variation of twist from zero at the root to the tip value.

WING VERTICAL BENDING

The spanwise bending moment at any spanwise station y, on the wing is the sum of the bending moments due to wing aerodynamic lift, wing weight, nacelle lift, nacelle weight and net torque on the nacelle. The expressions for each contribution to the bending moments are derived below.

- Bending moment due to wing loading.

  Assuming an elliptical distribution of lift the bending moment is given by

$$M^a(y_1) = \int_{y_1}^{b/2} \ell(y)(y-y_1)dy \qquad \text{(A-14)}$$

$$= \frac{\ell_o b^2}{4} \int_{y_1}^{b/2} \sqrt{1-\left(\frac{2y}{b}\right)^2} \left(\frac{2y}{b} - \frac{2y_1}{b}\right) d\left(\frac{2y}{b}\right)$$

where ℓ_0 is the lift per unit length at the wing root. Introducing the spanwise variable $\theta=\cos^{-1}\left(\frac{2y}{b}\right)$ making the required substitutions and integrating, the bending moment at any point y is:

$$M^a(y) = \frac{\ell_o b^2}{4}\left[\frac{1}{2}(\sin\theta-\theta\cos\theta)-\frac{1}{6}\sin^3\theta\right] \qquad \text{(A-15)}$$

- <u>Bending due to nacelle net vertical load.</u>

  The net vertical force on nacelle is

  $$F=F^a - nW_N$$

  where F^a is the aerodynamic force and nW_N is the inertial load on the nacelle. The bending moment due to nacelle force is

  $$M^N(y) = \frac{Fb}{2}(1-\cos\theta) \qquad \text{(A-16)}$$

- <u>Bending due to wing weight.</u>

  Assuming a uniform distribution of wing weight

  $$M^w(y_1) = -n\int_{y_1}^{b/2} w(y)(y-y_1)dy$$

  and $w(y) = 2W/b$ where W is the weight of one wing panel

  $$\therefore M^w(y_1) = \frac{2nW}{b}\int_{y_1}^{b/2}(y-y_1)dy \qquad \text{(A-17)}$$

  i.e. $$M^w(y) = -\frac{nWb}{2}\left(1-\cos\theta-\frac{1}{2}\sin^2\theta\right)$$

- <u>Bending due to nacelle torque (rolling moment)</u>

  $$T(y) = \text{constant} = T \qquad \text{(A-18)}$$

Total bending moment at station y is therefore

$$M(y) = M^a(y) + M^N(y) + M^W(y) + T \tag{A-19}$$

Assuming a linear variation of EI from root to tip given by

$$EI(y) = EI_o\left[1-a\left(\frac{2y}{b}\right)\right] = EI_o\ (1-a\cos\theta), \tag{A-20}$$

the curvature of the wing due to bending is

$$\frac{M(y)}{EI(y)} = \frac{d^2z}{dy^2} = \frac{\ell_o b^2}{8EI_o}\left[\frac{(\sin\theta-\theta\cos\theta)-1/3\sin^3\theta}{1-a\cos\theta}\right] + \frac{F_a b}{2EI_o}\left[\frac{1-\cos\theta}{1-a\cos\theta}\right]$$

$$-\frac{nW_N b}{2EI_o}\left[\frac{1-\cos\theta}{1-a\cos\theta}\right] - \frac{nW_w b}{2EI_o}\left[\frac{1-\cos\theta-\frac{1}{2}\sin^2\theta}{1-a\cos\theta}\right]$$

$$+\frac{T}{EI_o}\left[\frac{1}{(1-a\cos\theta)}\right] \tag{A-21}$$

Double integration of this equation yields the following expression for the bending deflection of the wing at any point y on the span:-

$$z(y) = \frac{Lb^3}{8\pi EI_o}\phi_1 + \frac{b^3F^a}{8EI_o}\phi_2 - \frac{nW_N b^3}{8EI_o}\phi_3$$

$$-\frac{nW_W b^3}{8EI_o}\phi_4 + \frac{Tb^3}{4EI_o}\phi_5 \tag{A-22}$$

where $\phi_1 = \int_0^y \left\{ \int_0^y \frac{(\sin\theta - \theta\cos\theta) - \frac{1}{3}\sin^3\theta}{1-a\cos\theta}\,dy \right\} dy$

$$\phi_2 = \phi_3 = \int_0^y \left\{ \int_0^y \frac{1-\cos\theta}{1-a\cos\theta}\,dy \right\} dy$$

$$\phi_4 = \int_0^y \left\{ \int_0^y \frac{1-\cos\theta-\frac{1}{2}\sin^2\theta}{1-a\cos\theta}\,dy \right\} dy$$

$$\phi_5 = \int_0^y \left\{ \int_0^y \frac{dy}{1-a\cos\theta} \right\} dy$$

and where the wing lift (2 wing panels) $L = \frac{\pi}{4} \ell_o b$. The function ϕ_1 through ϕ_5 were obtained numerically and are presented in Figure A.2 .

Since $L = -2\, Z^W_{AERO}$

$$F^a = -\; Z^N_{AERO}$$

$$T = -\; L^N_{AERO}$$

$$nW_W = \frac{1}{2}\, m_W\, \frac{Z_{AERO}}{m} = \frac{1}{2}\, m_W\, \bar{a}_{WAC}$$

$$nW_N = m_N\, \bar{a}_T$$

where m_W is the mass of two wing panels

m is the total aircraft mass

$\bar{a}_{WAC}$ is the acceleration of the wing aerodynamic center

$\bar{a}_T$ is the acceleration of the wing tip

and since the values of ϕ_1 through ϕ_5 are constant for any given station y on the wing we can write the final equation for wing bending in the form

$$h_1 = K_{W_1}\, Z^N_{AERO} + K_{W_2}\, Z^W_{AERO} - K_{W_3} L^N_{AERO} - K_{W_4}\, \bar{a}_T - K_{W_5}\, \bar{a}_{WAC}$$

where $h_1 = -z$

$$K_{W_1} = \frac{b^3 \phi_2}{8EI_o}$$

$$K_{W_2} = \frac{b^3 \phi_1}{4\pi EI_o}$$

$$K_{W_3} = \frac{b^3 \phi_5}{4EI_o}$$

$$K_{W_4} = \frac{m_N b^3 \phi_2}{8EI_o}$$

$$K_{W_5} = \frac{m_W b^3 \phi_4}{8EI_o}$$

This is the form given in the computer representation. The bending deflection at the aerodynamic center and at the wing tip are obtained using the values of $\phi_1 \rightarrow \phi_5$ appropriate to these stations.

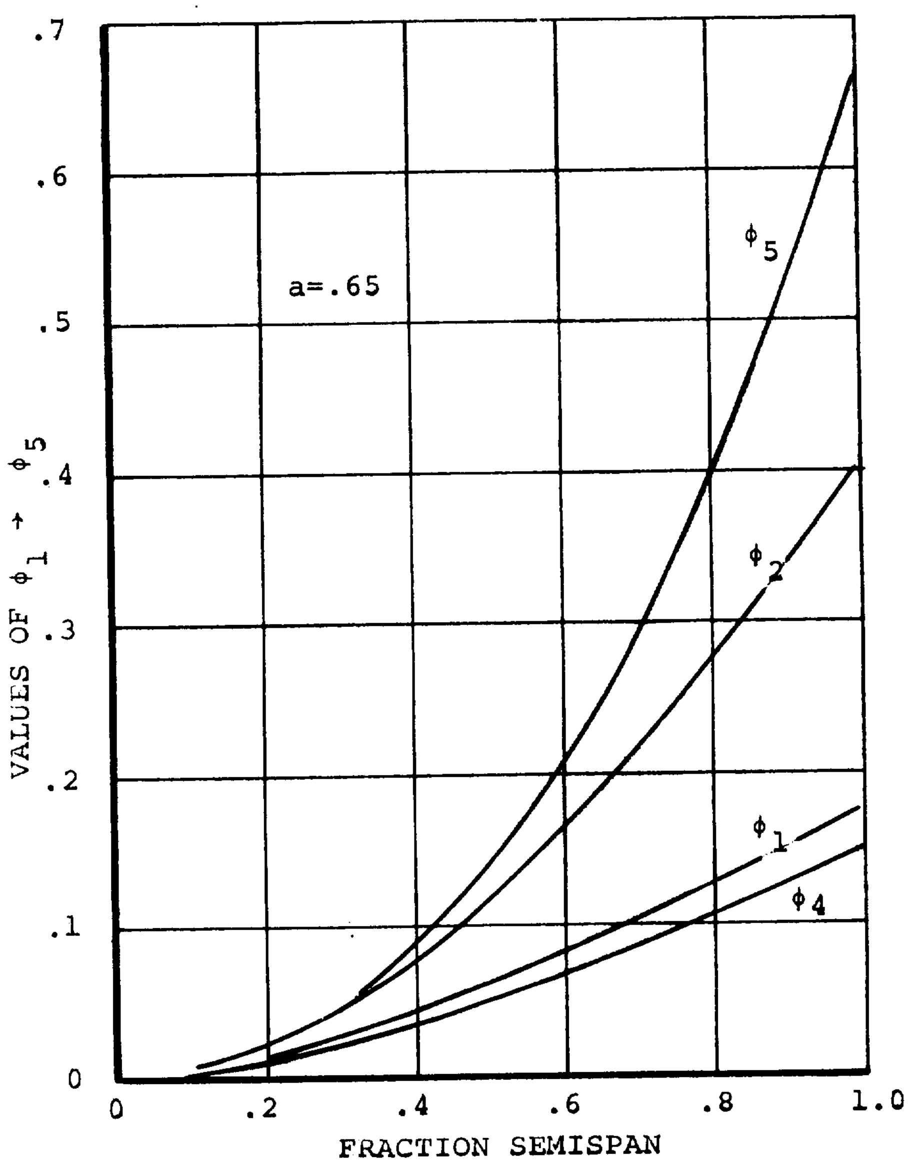


Figure A.2. Wing Bending Functions

APPENDIX B - DERIVATION OF LANDING GEAR EQUATIONS

Presented below are the equations for landing gear forces and moments arising from ground contact. The derivation accounts for brake and friction forces together with a simplified representation of the oleo dynamics. Nose wheel steering is not included.

With reference to Figure B-1 the distance from the center of gravity to the bottom of the right main wheel following a positive pitch rotation is

$$h_\theta = X \sin\theta - Z\cos\theta - r \tag{B-1}$$

where X and Z are the coordinates of the hub of the wheel relative to the C.G. and r is the tire radius. If the aircraft is now rolled right, through the angle ϕ, the bottom of the right gear moves through a distance

$$h_\phi = \left[Y \sin\phi + (Z+r)(\cos\phi - 1)\right]\cos\theta \tag{B-2}$$

The height of the bottom of the wheel above the ground is therefore

$$h = H_{CG} + h_\theta - h_\phi \tag{B-3}$$

and the oleo deflection during ground contact is given by

$$h_T = \frac{H_{CG} + h_\theta - h_\phi}{\cos\phi\cos\theta} \tag{B-4}$$

By differentiation of equation B-4 and making small angle assumptions regarding the aircraft pitch and roll angles during touchdown, the rate of change of oleo strut deflection is

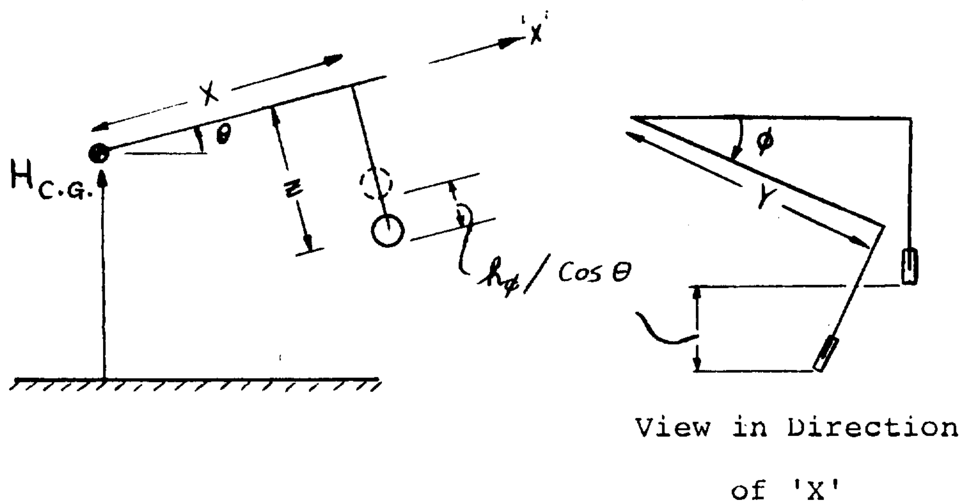


Figure B.1. Geometry of Landing Gear

obtained as

$$\dot{h}_T = \frac{\dot{H}_{CG}}{\cos\phi \cos\theta} + XQ - YP \qquad \text{(B-5)}$$

Assuming that the oleo response is that of a second order system, the equation of motion for the landing gear is

$$F_G = K_{ST}\, h_T + D_{ST}\, \dot{h}_T \qquad \text{(B-6)}$$

where K_{ST} and D_{ST} are the equivalent spring rates and damping for the oleo, and F_G is the force on the landing gear strut.

Tire Friction and Side Force

The friction force acting on each tire during ground contact is resolved into a force F_μ along the line of intersection of the plane of the wheel and the ground plane, positive forward, and a side force F_μ at right angles to F_μ lying in the ground plane and positive to starboard. The friction force F_s is assumed to be proportional to oleo force and the amount of braking exerted by the pilot. The side force is proportional to the oleo force.

The components of tire friction are:

$$F_\mu = (\mu_0 + \mu_1\, B_G)\, F_{GZ} \frac{u}{|u|} \qquad \text{(B-7)}$$

$$F_s = \mu_s\, F_{GZ}\, \frac{v}{|v|} \qquad \text{(B-8)}$$

where μ_s, μ_1 and μ_s are the coefficients for rolling friction, brake friction and sliding friction. B_G is expressed as a percentage of full brake pedal deflection. The signs of the forward and sidewards velocity are introduced to properly orient the tire forces.

The force and moment contributions of each landing gear to the aircraft total forces and moments are, assuming small angles;

$$\Delta X_n = F_{\mu_n} - F_{GZ_n}\theta \quad \text{(B-9)}$$

$$\Delta Y_n = F_{s_n} + F_{GZ_n}\phi \quad \text{(B-10)}$$

$$\Delta Z_n = F_{\mu_n}\theta - F_{s_n}\phi + F_{GZ_n} \quad \text{(B-11)}$$

$$\Delta M_n = -\Delta Z_n X_n + \Delta X_n (Z_n + r_n + h_{T_n}) \quad \text{(B-12)}$$

$$\Delta L_n = \Delta Z_n Y_n - \Delta Y_n (Z_n + r_n + h_T) \quad \text{(B-13)}$$

$$\Delta N_n = -\Delta X_n Y_n + X_n \Delta Y_n \quad \text{(B-14)}$$

where n=1,2 and 3 denote the left main gear, right main gear and nose gear, respectively.

The total contribution of the landing gear forces to the forces and moments at the center of gravity of the aircraft are:

$$\Delta X_{LG} = \sum_{n=1}^{3} \Delta X_n$$

$$\Delta Y_{LG} = \sum_{n=1}^{3} \Delta Y_n$$

$$\Delta Z_{LG} = \sum_{n=1}^{3} \Delta Z_n$$

$$\Delta L_{LG} = \sum_{n=1}^{3} \Delta L_n$$

$$\Delta M_{LG} = \sum_{n=1}^{3} \Delta M_n$$

$$\Delta N_{LG} = \sum_{n=1}^{3} \Delta N_n$$

APPENDIX C - VELOCITY AND ACCELERATION TRANSFORMATIONS AND CENTER OF GRAVITY/INERTIA EQUATIONS

C.1 Velocity Transformations

The calculation of aerodynamic forces on wings, fuselage, nacelles and tail surfaces requires that the angle of attack and relative wind velocity at these surfaces be known. These velocities are obtained most conveniently in terms of the velocity of the pivot reference point.

With reference to Figure C.1 , the velocity of a general point in the aircraft relative to the airplane center of gravity is

$$V = \frac{\delta r}{\delta t} + \underline{\Omega} \times \underline{r} \tag{C-1}$$

where $\underline{r}$ is the radius vector from the c.g. to the point and $\underline{\Omega}$ is the angular velocity of the aircraft. Thus, expanding equation C-1, the velocity of the pivot relative to the c.g. is

$$\begin{aligned} u_p' &= \dot{X}_p + QZ_p - Y_pR \\ v_p' &= \dot{Y}_p - PZ_p + X_pR \\ w_p' &= \dot{Z}_p + PY_p - QX_p \end{aligned} \tag{C-2}$$

where X_p, Y_p and Z_p are the distances of the pivot from the c.g., measured positively forward, to the right and downwards, respectively. If we measure all distances from the pivot location then $X_P = -X_{CG}$, $Y_P = -Y_{CG} = 0$, $Z_P = -Z_{CG}$ and the velocity of the pivot relative to inertial space can be written,

$$\begin{aligned} u_p &= U + u_p' = U - \dot{X}_{CG} - QZ_{CG} \\ v_p &= V + v_p' = V + PZ_{CG} - X_{CG}R \\ w_p &= W + w_p' = W + QX_{CG} - \dot{Z}_{CG} \end{aligned} \tag{C-3}$$

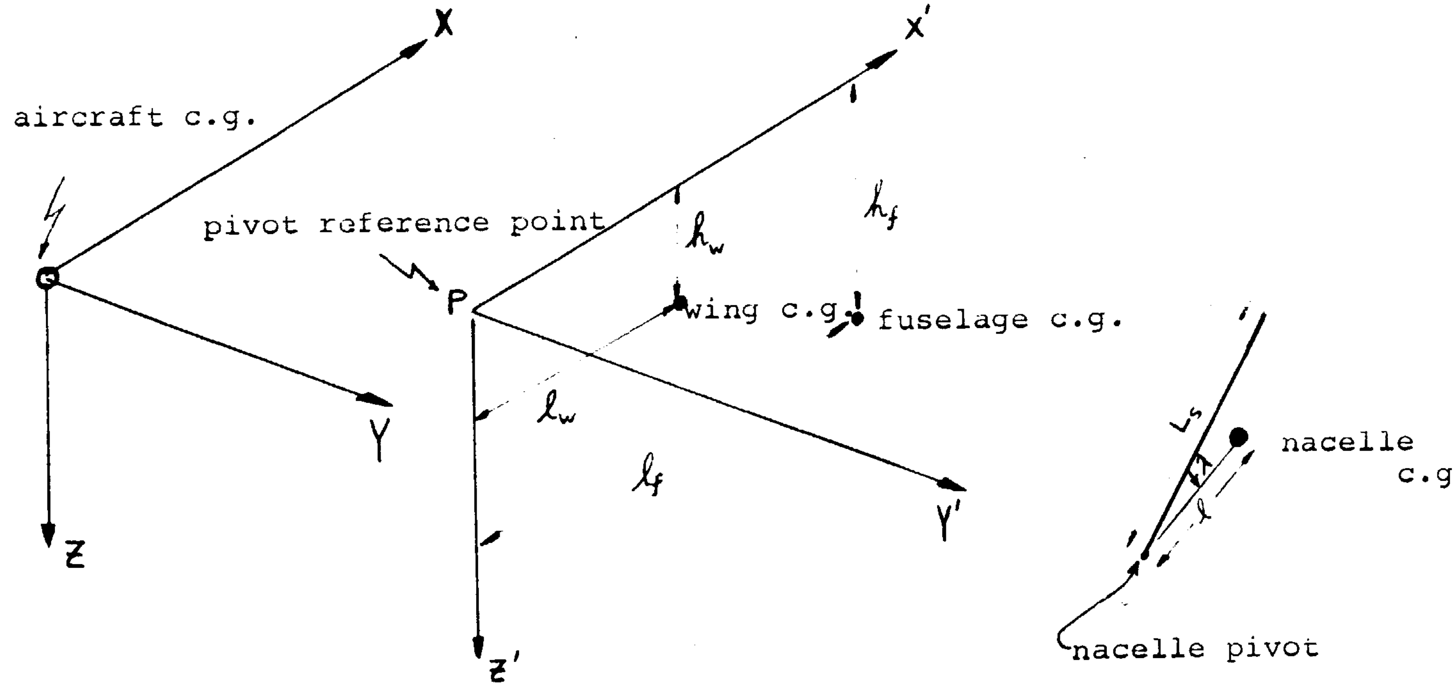


Figure C.1. Reference Axes Systems

where U, V and W are the components of the velocity of the airplane center of gravity.

The velocity of a point in the aircraft relative to the pivot is

$$\begin{aligned} u &= \dot{X} + QZ - YR \\ v &= \dot{Y} + RX - PZ \\ w &= \dot{Z} + PY - QX \end{aligned} \qquad \text{(C-4)}$$

where X, Y, and Z are measured from the pivot to the point. By adding equations (C-3) and (C-4) the velocities of the following components are obtained relative to inertial space. The indicated distances are measured relative to the pivot.

<u>Velocity of Horizontal Tail Aerodynamic Center</u>

$$\begin{aligned} u_{HT} &= u_P + Z_{HT}Q \\ v_{HT} &= v_P + X_{HT}R - Z_{HT}P \\ w_{HT} &= w_P - X_{HT}Q \end{aligned} \qquad \text{(C-5)}$$

<u>Velocity of Vertical Tail Aerodynamic Center</u>

$$\begin{aligned} u_{VT} &= u_P + Z_{VT}Q \\ v_{VT} &= u_P + X_{VT}R - Z_{VT}P \\ w_{VT} &= w_P + X_{VT}Q \end{aligned} \qquad \text{(C-6)}$$

<u>Velocity of Left Wing Aerodynamic Center - Body Axes</u>

$$\begin{aligned} u'_{LW} &= u_P + Q\ (Z_{WAC} + h_{1_{L_{WAC}}}) + Y_{WAC}R \\ v'_{LW} &= u_P + X_{WAC}R - P(Z_{WAC} + h_{1_{L_{WAC}}}) \\ w'_{LW} &= w_P - Y_{WAC}P - X_{WAC}Q + \dot{h}_{1_{L_{WAC}}} \end{aligned} \qquad \text{(C-7)}$$

where $h_{1_{L_{WAC}}}$ is the elastic deflection of the left wing aerodynamic center. The equations for the right wing are obtained by substituting

$$Y_{R_{WAC}} = -Y_{L_{WAC}}$$

and $$h_{1_{R_{WAC}}} = h_{1_{L_{WAC}}}$$

Velocity of Left Wing Aerodynamic Center-Chord Axes

In order to compute wing angle-of-attack the velocity components are required relative to the wing chord line. If the wing chord makes an angle i_W with the body centerline then

$$\begin{aligned} u_{LW} &= u'_{LW} \cos i_W - w'_{LW} \sin i_W \\ v_{LW} &= v'_{LW} \\ w_{LW} &= w'_{LW} \cos i_W + w'_{LW} \sin i_W \end{aligned} \tag{C-8}$$

The equations for the right wing are obtained by changing the subscript.

Velocity of Left Rotor Hub - Body Axes

$$\begin{aligned} u'_{RL} &= u_P + RY_N - L_s (\dot{i}_{NL} + Q) \sin i_{NL} + Qh_{1_L} \\ v'_{RL} &= v_P + L_s (R \cos i_{NL} + P \sin i_{NL}) - Ph_{1_L} \\ w'_{RL} &= w_P - PY_N - L_s (\dot{i}_{NL} + Q) \cos i_{NL} + \dot{h}_{1_L} \end{aligned} \tag{C-9}$$

where L_s is the distance from the rotor pivot point to the rotor hub and h_{1_L} is the deflection of the wing tip. The equations for the right hub are obtained by changing subscripts and substituting $Y_N = - Y_N$.

Velocity of Left Rotor Hub - Shaft Axes

Since the rotor aerodynamic forces and moments are functions of the shaft angle of attack and sideslip, the velocity components are required relative to shaft axes.

$$
\begin{aligned}
u_{RL} &= u'_{RL} \cos i_{NL} - w'_{RL} \sin i_{NL} \\
v_{RL} &= v'_{RL} \qquad\qquad\qquad\qquad\qquad\qquad\qquad \text{(C-10)} \\
w_{RL} &= w'_{RL} \sin i_{NL} + w'_{RL} \cos i_{NL}
\end{aligned}
$$

The corresponding equations for the right hub are obtained by changing the subscript.

C.2 Center of Gravity and Inertia Equations

Equations are required that express the overall aircraft center of gravity position and inertias in terms of the centers of gravity and inertias of the individual mass components. In order to do this a fixed reference point is chosen in the aircraft defined by the intersection of the line joining the nacelle pivots and the vertical plane of symmetry of the aircraft, see Figure C.1. A set of axes $Px^py^pz^p$ is taken at this pivot reference point, parallel to the axes OXYZ at the aircraft center of gravity. If the location of the aircraft center of gravity with respect to the pivot reference axes is $(X'_{CG}, Y'_{CG}, Z'_{CG})$ and if (ℓ_f, h_f) and (ℓ_w, h_w) are the x and z coordinates of the fuselage and wing masses measured from the pivot, then the following relationships are obtained between the centers of mass of the components and the aircraft center of gravity.

Fuselage CG Relative to Aircraft CG

$$X_f = \ell_f - X'_{CG}$$
$$X_f = h_f - Z_{CG} \tag{C-11}$$

Wing CG Relative to Aircraft CG

$$X_w = \ell_w - X'_{CG} \tag{C-12}$$
$$Z_w = h_w - Z'_{CG}$$

Nacelle CG Relative to Aircraft CG

$$X_{NR} = \ell \cos (i_{NR} - \lambda) - X'_{CG}$$
$$X_{NL} = \ell \cos (i_{NL} - \lambda) - X'_{CG} \tag{C-13}$$
$$Z_{NR} = \ell \sin (i_{NR} - \lambda) - Z'_{CG}$$
$$Z_{NL} = \ell \sin (i_{NL} - \lambda) - Z'_{CG}$$

where ℓ is the distance from the nacelle pivot point to the nacelle c.g., and λ is the angular depression of the nacelle center of mass below the nacelle pivot, when the nacelle is in the down position, see Figure C.1.

Aircraft Center of Gravity Position

By taking moments about the pivot, the aircraft center of gravity is given by

$$x'_{CG} = \frac{m_f \ \ell_f + m_w \ \ell_w}{m} + \ell \left(\frac{m_N}{m}\right) \left[\cos(i_{NL}-\lambda) + \cos(i_{NR}-\lambda)\right]$$

$$z'_{CG} = \frac{m_f \ h_f + m_w \ h_w}{m} - \ell \left(\frac{m_N}{m}\right) \left[\sin(i_{NL}-\lambda) + \sin(i_{NR}-\lambda)\right] \tag{C-14}$$

The equations of motion (Section 5) require the first and second time derivatives of the center of gravity position. They are as follows:

Center of Gravity Velocity Relative to Pivot Point

$$\dot{x}'_{CG} = -\ell \left(\frac{m_N}{m}\right) \left[i_{NR}\sin(i_{NR}-\lambda) + i_{NL}\sin(i_{NL}-\lambda)\right]$$

$$\dot{z}'_{CG} = -\ell \left(\frac{m_N}{m}\right) \left[i_{NR}\cos(i_{NR}-\lambda) + i_{NL}\cos(i_{NL}-\lambda)\right] \tag{C-15}$$

Center of Gravity Acceleration Relative to Pivot Point

$$\ddot{x}'_{CG} = -\ell \left(\frac{m_N}{m}\right) \left[\ddot{i}_{NR}\sin(i_{NR}-\lambda) + \ddot{i}_{NL}\sin(i_{NL}-\lambda) + \dot{i}_{NL}^2 \cos (i_{NL}-\lambda) + i_{NR}^2 \cos (i_{NR}-\lambda)\right] \tag{C-16}$$

$$\ddot{z}'_{CG} = -\ell \left(\frac{m_N}{m}\right) \left[\ddot{i}_{NR}\cos(i_{NR}-\lambda) + \ddot{i}_{NL}\cos(i_{NL}-\lambda) - \dot{i}_{NL}^2\sin (i_{NL}-\lambda) - \dot{i}_{NR}^2\sin (i_{NR}-\lambda)\right]$$

Pilot Station Velocities - Body Axes

The velocities at the pilot's station are required in order to drive the visual display. From equations (C-3) and (C-4) the components of velocity of the pilot's station in body axes are:

$$u_{PA} = u_P + QZ_{PA} - RY_{PA}$$

$$v_{PA} = v_P + R\ell_{PA} - PZ_{PA}$$

$$w_{PA} = w_P + PY_{PA} - Q\ell_{PA}$$

C-3 Pilot Station Acceleration - Body Axes

The pilot station acceleration is also required to drive the visual display. These accelerations are derived here.

The velocity at the pilot's station is

$$\underline{V}_{PA} = \underline{V}_{CG} + \underline{\Omega} \times \underline{r}_{PA} + \frac{\delta \underline{r}_{PA}}{\delta t}$$

where $\underline{r}_{PA}$ is the vector from the aircraft CG to the pilot's station and $\frac{\delta \underline{r}_{PA}}{\delta t}$ is the rate of change of the pilot's station with respect to the aircraft CG.

The pilot's station acceleration is

$$\underline{a}_{PA} = \frac{d\underline{V}_{PA}}{dt} = \frac{d\underline{V}_{CG}}{dt} + \frac{d}{dt}(\underline{\Omega} \times \underline{r}_{PA}) + \frac{d}{dt}\left(\frac{\delta \underline{r}_{PA}}{\delta t}\right)$$

$$= \underline{a}_{CG} + \frac{\delta}{\delta t}(\underline{\Omega} \times \underline{r}_{PA}) + \underline{\Omega} \times (\underline{\Omega} \times \underline{r}_{PA}) + \frac{\delta^2 \underline{r}_{PA}}{\delta t^2} + \underline{\Omega} \times \frac{\delta \underline{r}_{PA}}{\delta t}$$

$$= \underline{a}_{CG} + \frac{\delta \underline{\Omega}}{\delta t} \times \underline{r}_{PA} + 2\Omega \times \frac{\delta \underline{r}_{PA}}{\delta t} + \underline{\Omega}\,(\underline{r}_{PA} \cdot \underline{\Omega}) - \Omega^2 \underline{r}_{PA} + \frac{\delta^2 \underline{r}_{PA}}{\delta t^2}$$

with $\underline{\Omega} = P\hat{\underline{i}} + Q\hat{\underline{j}} + R\hat{\underline{k}}$

$$\frac{\delta \Omega}{\delta t} = \dot{P}\hat{\underline{i}} + \dot{Q}\hat{\underline{j}} + \dot{R}\hat{\underline{k}}$$

$$\underline{r}_{PA} = (X_{PA} - X_{CG})\,\hat{\underline{i}} + (Y_{PA} - Y_{CG})\,\hat{\underline{j}} + (Z_{PA} - Z_{CG})\,\hat{\underline{k}}$$

$$\frac{\delta \underline{r}_{PA}}{\delta t} = (\dot{X}_{PA} - \dot{X}_{CG})\,\hat{\underline{i}} + (\dot{Y}_{PA} - \dot{Y}_{CG})\,\hat{\underline{j}} + (\dot{Z}_{PA} - \dot{Z}_{CG})\,\hat{\underline{k}}$$

and noting that Y_{CG} and the time derivatives of X_{PA}, Y_{PA}, Z_{PA} are always zero, the above equation yields the pilot's station accelerations as: -

$$a_{x_{PA}} = \frac{X_{AERO}}{m} + (\dot{Q} + PR)(Z_{PA} - Z_{CG}) + (Q^2 + R^2)(X_{CG} - \ell_{PA})$$

$$+ Y_{PA}(PQ - \dot{R}) - 2Q\dot{Z}_{CG} - \ddot{X}_{CG}$$

$$a_{y_{PA}} = \frac{Y_{AERO}}{m} + (\dot{P} - QR)(Z_{CG} - Z_{PA}) + (\dot{R} + PQ)(\ell_{PA} - X_{CG})$$

$$- Y_{PA}(R^2 + P^2) + 2(P\dot{Z}_{CG} - R\dot{X}_{CG})$$

$$a_{z_{PA}} = \frac{Z_{AERO}}{m} + (\dot{Q} - PR)(X_{CG} - \ell_{PA}) + (P^2 + Q^2)(Z_{CG} - Z_{PA})$$

$$+ Y_{PA}(\dot{P} + QR) + 2Q\dot{X}_{CG} - \ddot{Z}_{CG}$$

where $a_{x_{CG}} = \dfrac{Z_{AERO}}{m}$ etc.

$X_{PA} = \ell_{PA}$, the distance from the pivot to the pilot's station

C.4 Aircraft Inertias

The aircraft roll inertia about the aircraft center of gravity is, from the parallel axis theorem,

$$I_{xx} = I^{f}_{xx} + I^{w}_{xx} + I^{NL}_{xx} + I^{NR}_{xx} + m_f Z_f^2 + m_w Z_w^2 + 2m_N Y_N^2 + m_N Z_{NL}^2 + m_N Z_{NR}^2 \quad \text{(C-17)}$$

where I^{f}_{xx}, etc., are the inertias of the various components about their individual centers of gravity.

In the case of the nacelles the inertias I_{xx}^{NL}, I_{xx}^{NR} are dependent on the nacelle tilt angle, i_N. These inertias are **related** to the inertias of the nacelle with respect to a set of nacelle-fixed axes O"xyz placed as shown in Figure 5.1. The relationships are

$$
\begin{aligned}
I_{xx}^{N} &= I_{xx_o}^{N} + (I_{zz_o}^{N} - I_{xx_o}^{N}) \sin^2 i_N - I_{xz_o} \sin 2i_N \\
I_{yy}^{N} &= I_{yy_o}^{N} \\
I_{zz}^{N} &= I_{zz_o}^{N} + (I_{xx_o}^{N} - I_{zz_o}^{N}) \sin^2 i_N + I_{xz_o} \sin 2i_N \\
I_{xz}^{N} &= I_{xz_o}^{N} \cos 2i_N + \frac{1}{2} (I_{xx_o} - I_{zz_o}) \sin 2i_N
\end{aligned}
\tag{C-18}
$$

Using equations (C-18) together with (C-13), (C-11) and (C-12), in equation (C-17), the roll inertia becomes

$$
\begin{aligned}
I_{xx} = {} & I_{xx}^{f} + I_{xx}^{W} + 2I_{xx_o}^{N} + (I_{zz_o}^{N} - I_{xx_o}^{N}) (\sin^2 i_{NL} + \sin^2 i_{NR}) \\
& - I_{xz_o}^{N} (\sin 2i_{NL} + \sin 2i_{NR}) + 2\, m_N Y_N^2 + m_f h_f Z_f \\
& + m_w h_w z_w - m_f Z_f Z'_{CG} - m_w Z_w Z'_{CG} \\
& - m_N Z_{NL} Z'_{CG} - m_N Z_{NR} Z'_{CG} \\
& - \ell m_N \left[Z_{NR} \sin(i_{NR} - \lambda) + Z_{NL} \sin(i_{NL} - \lambda) \right]
\end{aligned}
$$

$$= I^f_{xx} + I^w_{xx} + 2I^N_{xx_o} + (I^N_{zz_o} - I^N_{xx_o})\ (\sin^2 i_{NL} + \sin^2 i_{NR})$$

$$- I^N_{xz_o}\ (\sin 2i_{NL} + \sin 2i_{NR}) + 2\ m_N Y_N^2 + m_f h_f Z_f$$

$$+ m_w h_w Z_w - \ell m_N \left[Z_{NR} \sin\ (i_{NR} - \lambda) + Z_{NL} \sin\ (i_{NL} - \lambda) \right]$$

since the terms containing Z'_{CG} sum to zero.

Similarly

$$I_{xz} = I^f_{xz} + I^w_{xz} + I^N_{xz}\ (\cos 2i_{NL} + \cos 2i_{NR})$$

$$+ \frac{1}{2}\ (I^N_{xx_o} - I^N_{zz_o})\ (\sin 2i_{NL} + \sin 2i_{NR}) + m_f \ell_f Z_f$$

$$+ m_w Z_w \ell_w + \ell m_N \left[Z_{NR} \cos\ (i_{NR} - \lambda) + Z_{NL}\ \cos\ (i_{NL} - \lambda) \right]$$

$$(I_{zz} - I_{yy}) = I^f_{zz} - I^f_{yy} + I^w_{zz} - I^w_{yy} + 2(I^N_{zz_o} - I^N_{yy_o})$$

$$+ (I^N_{xx_o} - I^N_{zz_o})(\sin^2 i_{NL} + \sin^2 i_{NR}) + I^N_{xz_o}(\sin 2i_{NL} + \sin 2i_{NR})$$

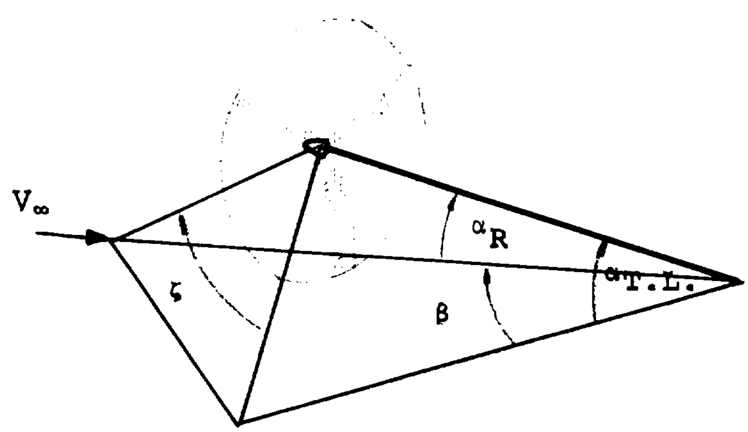
$$-(m_f h_f Z_f + m_w h_w Z_w) + m_N \ell \left[Z_{NL} \sin\ (i_{NL} - \lambda) \right.$$

$$\left. + Z_{NR} \sin\ (i_{NR} - \lambda) \right] + 2m_N Y_N^2$$

Similar expressions are obtained for I_{yy} and I_{zz} and these are presented in Appendix E.

APPENDIX D - CALCULATION OF SLIPSTREAM-IMMERSED WING AREAS

The wing areas washed by the rotor slipstreams are required in the calculation of wing lift and drag. These immersed areas depend on rotor shaft inclination, wing angle of attack and sideslip, and rotor thrust. The equations presented in Appendix E for the immersed areas S_{i_L} and S_{i_R} were obtained as follows.



The above sketch shows a rotor under conditions of combined angle of attack ($\alpha_{T.L.}$) and sideslip (β). The resultant angle of attack of the shaft is given by

$$\alpha_R = \cos^{-1} (\cos \alpha_{T.L.} \cos \beta) \tag{D-1}$$

If the rotor shaft is inclined to the fuselage centerline at angle i_N and the fuselage is at angle of attack α_f then

$$\alpha_{T.L.} = \alpha_f + i_N \tag{D-2}$$

The rotor "sideslip" angle, ζ, is defined by

$$\zeta = \mathrm{Tan}^{-1}\left[\frac{\mathrm{Tan}\ \beta}{\mathrm{Sin}\ \alpha_{T.L.}}\right] \tag{D-3}$$

and is the angle shown in the sketch.

Figure D.1 presents four views of the geometry of rotor slipstream/wing planform interaction.

Figure D.1[a] is a view of the plane taken through the rotor shaft parallel to the aircraft vertical plane of symmetry. The line PT is the wing chord, the distances PC and h_P are the horizontal and vertical coordinates of the pivot measured from the wing leading edge, and ℓ is the spinner-to-pivot shaft length.

Figure D.1[b] is a view taken normal to the rotor disc plane. In this view, the traces of the slipstream on planes taken through the wing leading and trailing edges parallel to the disc plane appear as circles. This assumes that the slipstream is a sheared circular cylinder.

Figure D.1[c] is a section taken in the plane containing the rotor shaft and the freestream velocity vector V_∞. The angle ε is the deflection of the slipstream relative to the freestream direction. Planes are taken through the wing leading and trailing edges parallel to the rotor disc. These intersect the rotor shaftline at the points O and T, and intersect the slipstream centerline at the points O' and O". These points enable the slipstream traces shown in (b) to be constructed.

Figure (D.1[d]) is a view taken perpendicular to the wing surface showing the areas washed by the slipstream. For convenience this view combines the immersed areas of both left and right wings. In general, the imprint of the slipstream on the wing will be bounded in the chordwise direction by curved lines; however, the approximation is made that these lines are straight.

The immersed area of the right wing panel is (assuming that the tip is immersed),

$$S_{i_R} = \frac{1}{2}(PM + TN)c$$

$$= \frac{1}{2}(PR + RM + TS + SN)c \qquad \text{(D-4)}$$

From Figure D.1[b] $\quad PR = OO' \sin \zeta \qquad$ (D-5)

From Figure D.1[c] $\quad OO' = (\ell - OD)\ \mathrm{Tan}\ (\alpha_R - \varepsilon) \qquad$ (D-6)

From Figure D.1[a] $\quad OD = PC \cos (i_N - i_W) - h_p \sin(i_N - i_W) \qquad$ (D-7)

From Figure D.1[b] $\quad RM = R'M' = \sqrt{\frac{D_s^2}{4} - O'R'^2} \qquad$ (D-8)

From Figure D.1[b] $\quad O'R' = OO' \cos \zeta + OP \qquad$ (D-9)

From Figure D.1[a] $\quad OP = PC \sin (i_N - i_W) + h_p \cos (i_N - i_W) \qquad$ (D-10)

These equations define the leading edge intersection PM. If RM is zero or negative, the slipstream does not intersect the leading edge and the wing is considered to be unaffected by the slipstream.

For the trailing edge intersection, TN:

$$TS = OO'' \sin \zeta \qquad \text{(D-11)}$$

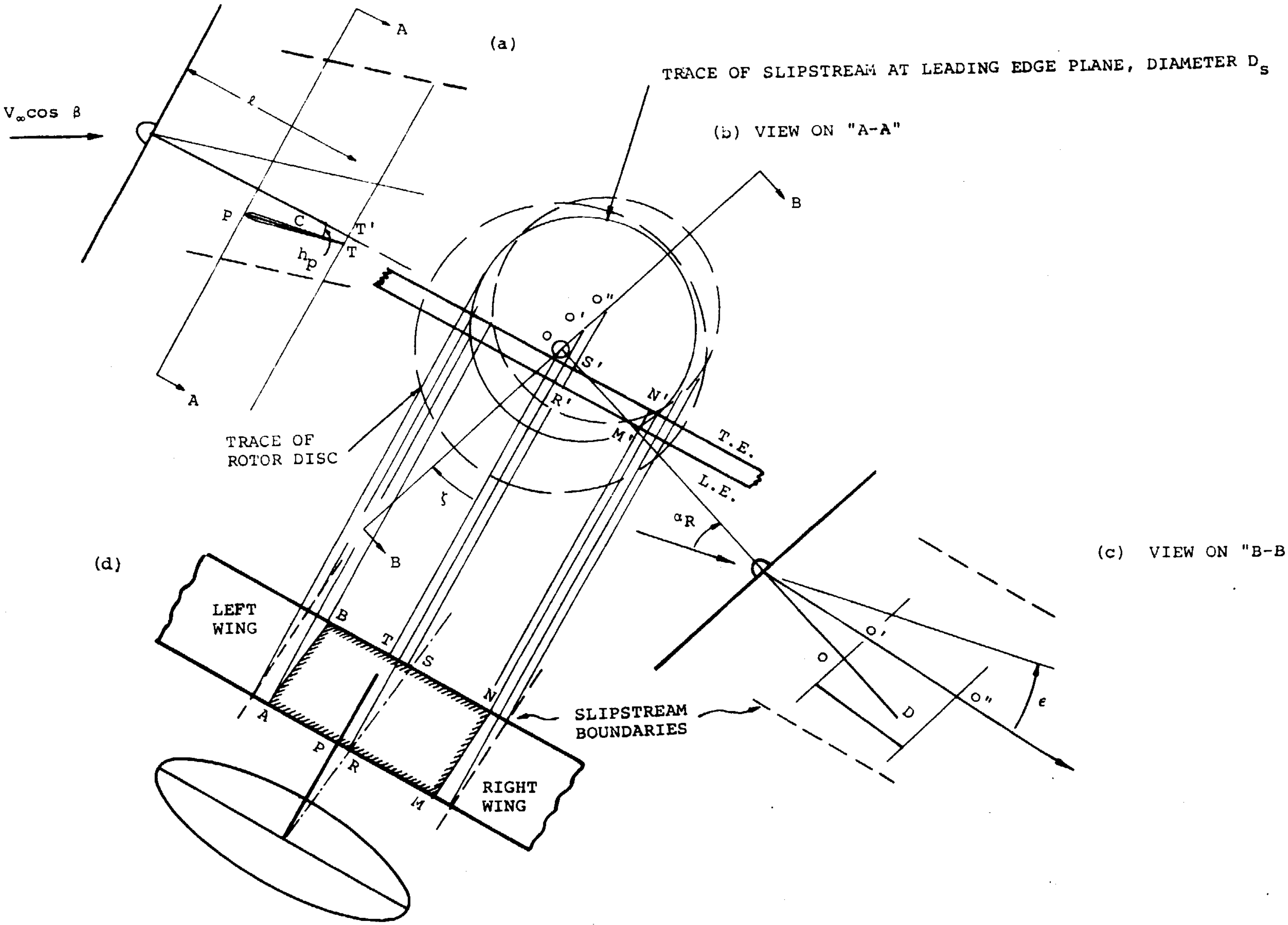


Figure D.1. Geometry of Rotor Slipstream/Wing Planform Interaction

$$OO'' = (\ell + c\cos(i_N - i_W) - OD)\,\mathrm{Tan}\,(\alpha_R - \varepsilon) \quad \text{(D-12)}$$

$$SN = S'N' = \frac{D_s^2}{4} - O''S'^2 \quad \text{(D-13)}$$

$$O''S' = OO''\cos\zeta + TT' \quad \text{(D-14)}$$

$$TT' = OP - c\sin(i_N - i_W) \quad \text{(D-15)}$$

If we write

$\xi_1 = PR$, $\xi_2 = RM$, $\xi_3 = TS$, and $\xi_4 = SN$

then, using the above equations,

$$\xi_1 = [\ell - PC\cos(i_N - i_W) + h_p\sin(i_N - i_W)]\,\mathrm{Tan}(\alpha_R - \varepsilon)\sin\xi \quad \text{(D-16)}$$

and

$$\xi_2 = \sqrt{\frac{D_s^2}{4} - \{[\ell - PC\cos(i_N - i_W) + h_p\sin(i_N - i_W)]\,\mathrm{Tan}(\alpha_R - \varepsilon)\cos\zeta + PC\sin(i_N - i_W) + h_p\cos(i_N - i_W)\}} \quad \text{(D-17)}$$

The corresponding equations for ξ_3 and ξ_4 are obtained by replacing PC in (D-16) and (D-17) with (PC-c)

Thus the immersed area of the right wing panel is given by $S_{i_R} = \frac{1}{2}c\,(\xi_1 + \xi_2 + \xi_3 + \xi_4)$ (D-18)

From the symmetry of Figure D.1(d), SN=BS and RM=AR. The total immersed area of both wing panels is

$$S_{i_T} = \frac{1}{2}\,c\,(AM + BN) = \frac{1}{2}\,c\,(2\xi_2 + 2\xi_4) = C(\xi_2 + \xi_4) \quad \text{(D-19)}$$

and therefore the immersed area of the left wing is obtained from

$$S_{i_L} = S_{i_T} - S_{i_R} \quad \text{(D-20)}$$

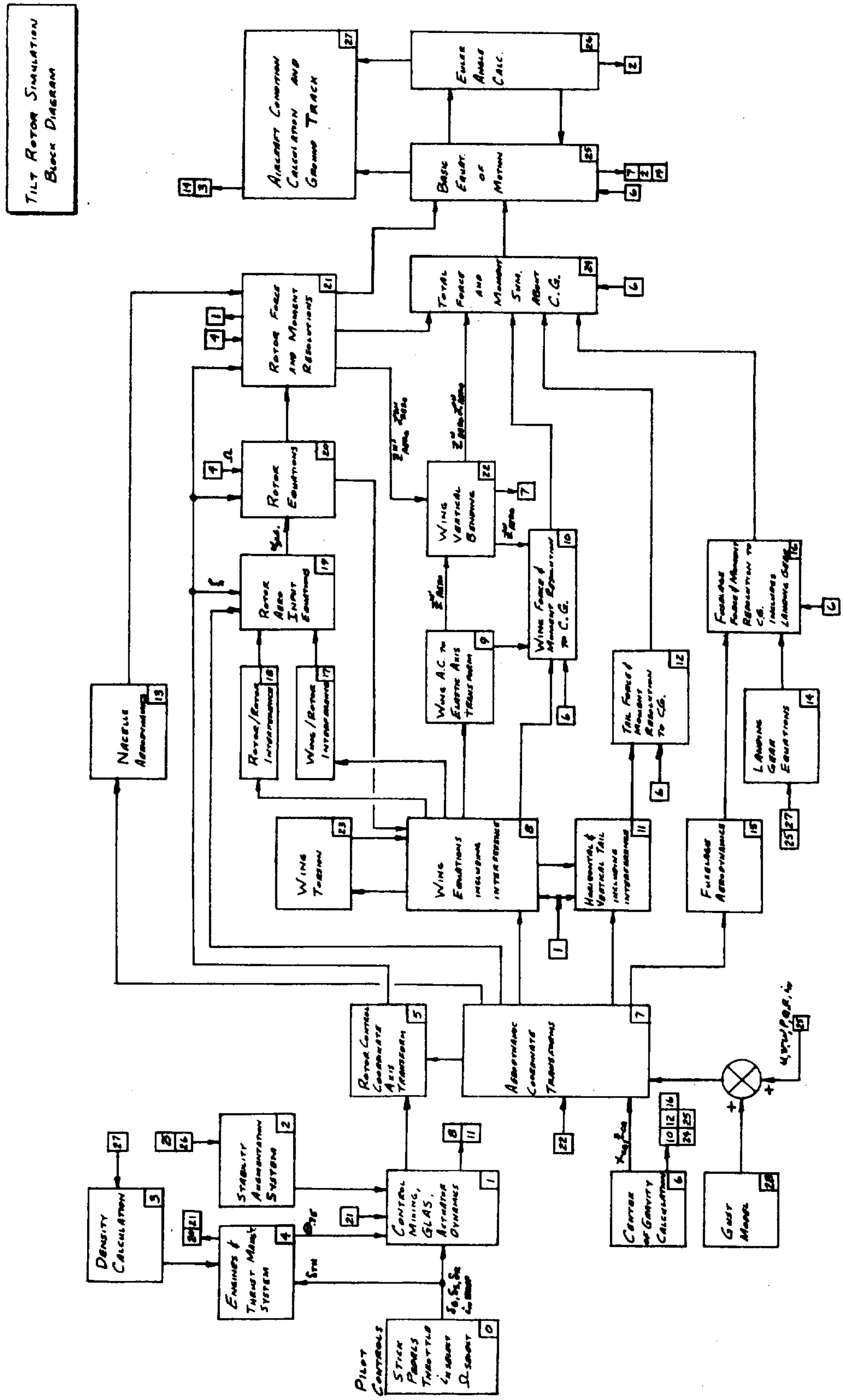
The above equations correspond to those presented in Appendix E for calculating immersed wing area.

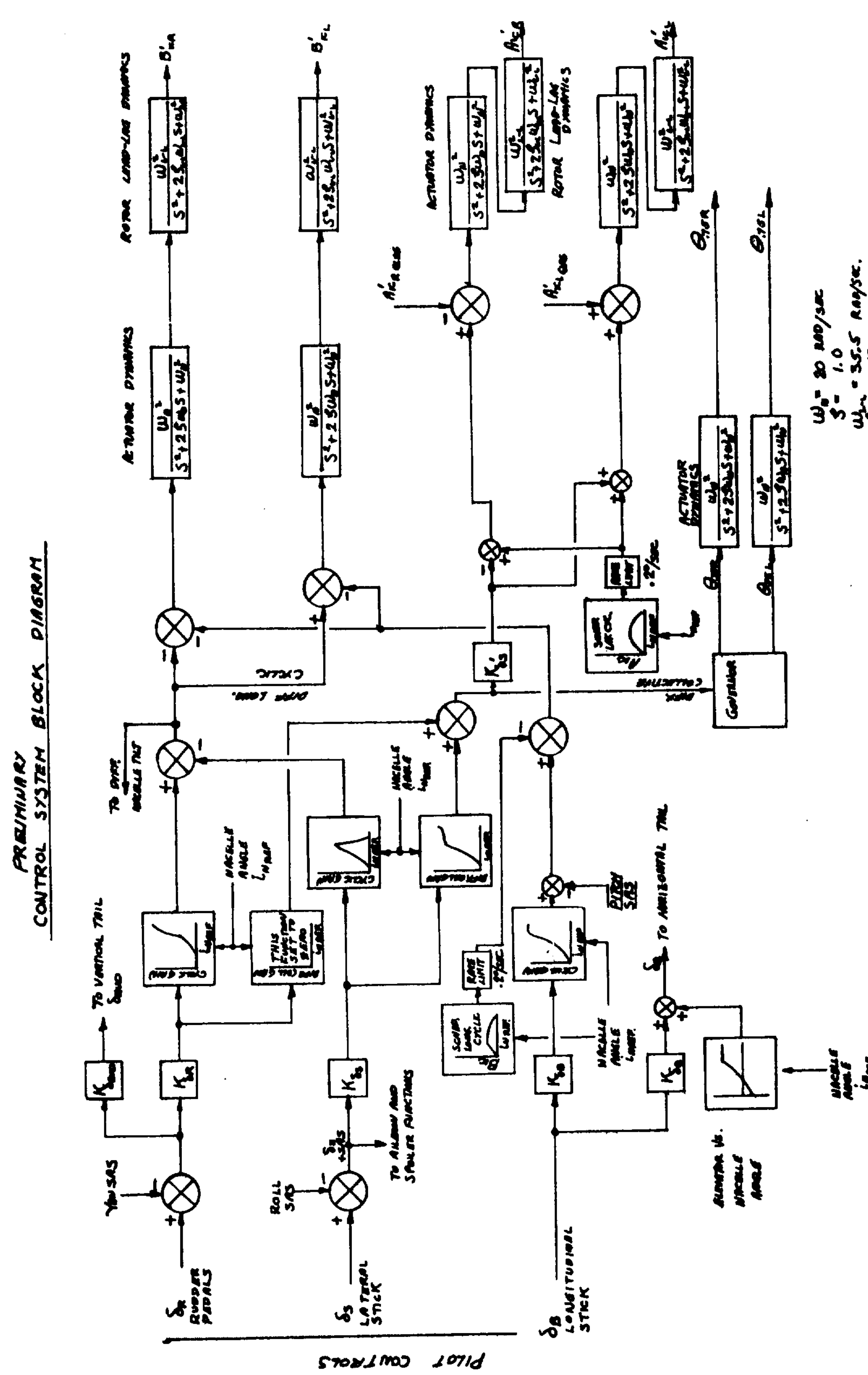
APPENDIX E COMPUTER REPRESENTATION

The equations derived in previous sections of this report have been collected and written in a format to facilitate computer programming. The complete set of equations which define the Model 222 simulation mathematical model are contained in this section. The computer block diagram for the simulation is also included. Each element of this block diagram contains an index number. Figure E.1 lists the index number, the name of the element, and its page number in this appendix. In addition the input and output, where appropriate, to each element are identified by their index numbers.

INDEX NUMBER	BLOCK DIAGRAM ELEMENT NAMES	PAGE NUMBER
1.	Control Mixing, Load Alleviation System and Actuator Dynamics	E-4
2.	Stability Augmentation System	E-7
3.	Density Calculation	E-9
4.	Engines and Thrust Management System	E-10
5.	Rotor Control Coordinate Axis Transforms	E-14
6.	Center of Gravity Calculation	E-15
7.	Aerodynamic Coordinate Transforms	E-16
8.	Wing Equations (Including Interference)	E-19
9.	Wing A.C. to Elastic Axis Transform	E-33
10.	Wing Force and Moment Resolution to Center of Gravity	E-34
11.	Horizontal and Vertical Tail Aerodynamics (Including Interference)	E-35
12.	Tail Force and Moment Resolution to Center of Gravity	E-43
13.	Nacelle Aerodynamics	E-44
14.	Landing Gear Equations	E-46
15.	Fuselage Aerodynamics	E-49
16.	Fuselage Force and Moment Resolution to Center of Gravity (Includes Landing Gear)	E-50
17.	Wing/Rotor Interference	E-51
18.	Rotor/Rotor Interference	E-52
19.	Rotor Aero Input Equations	E-53
20.	Rotor Equations	E-54
21.	Rotor Force and Moment Resolution	E-61
22.	Wing Vertical Bending	E-64
23.	Wing Torsion	E-66
24.	Total Force and Moment Summation About Center of Gravity	E-67
25.	Basic Equations of Motion	E-68
26.	Euler Angle Calculation	E-77
27.	Aircraft Condition Calculation and Ground Track	E-78
28.	Gust Model	E-80
29.	Preliminary Calculation (Preprocess)	E-81
30.	Trim Loops	E-87

Figure E.1. Block Diagram Element Index Numbers

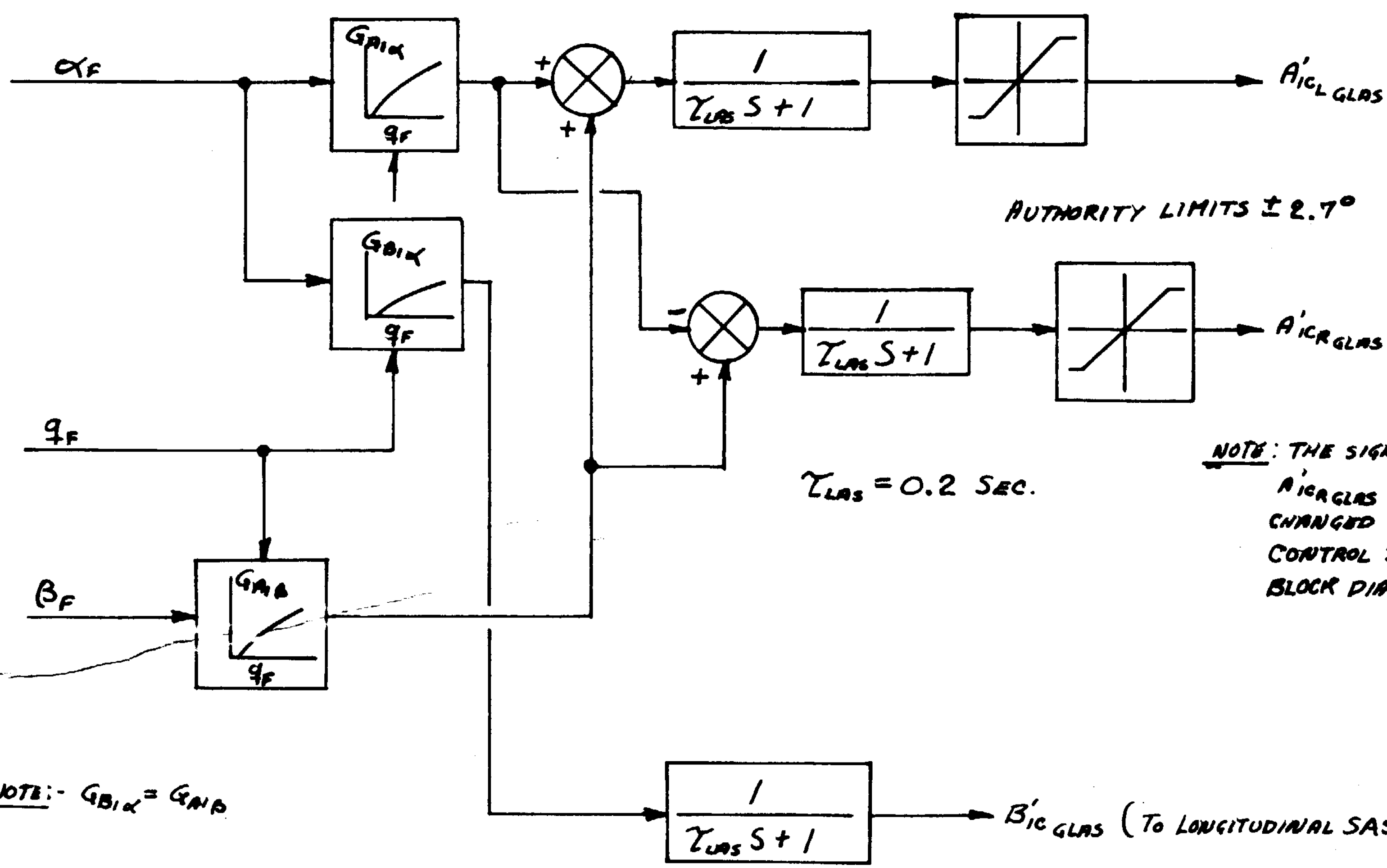

TILT ROTOR SIMULATION BLOCK DIAGRAM
AIRCRAFT CONDITION CALCULATION AND GROUND TRACK
EULER ANGLE CALC.
BASIC EQUAT. OF MOTION
ROTOR FORCE AND MOMENT RESOLUTIONS
TOTAL FORCE AND MOMENT SUM. ABOUT C.G.
ROTOR EQUATIONS
WING VERTICAL BENDING
ROTOR AERO INPUT EQUATIONS
WING FORCE & MOMENT RESOLUTION TO C.G.
WING A.C. TO ELASTIC AXIS TRANSFORM
FUSELAGE FORCE & MOMENT RESOLUTION TO C.G. INCLUDING LANDING GEAR
NACELLE AERODYNAMICS
ROTOR/ROTOR INTERFERENCE
WING/ROTOR INTERFERENCE
TAIL FORCE & MOMENT RESOLUTION TO C.G.
LANDING GEAR EQUATIONS
WING TORSION
WING EQUATIONS INCLUDING INTERFERENCE
HORIZONTAL & VERTICAL TAIL INCLUDING INTERFERENCE
FUSELAGE AERODYNAMICS
ROTOR CONTROL COORDINATE AXIS TRANSFORM
AERODYNAMIC COORDINATE TRANSFORMS
DENSITY CALCULATION
STABILITY AUGMENTATION SYSTEM
CONTROL MIXING, GLAS, ACTUATOR DYNAMICS
ENGINES & THRUST MANAG. SYSTEM
CENTER OF GRAVITY CALCULATION
GUST MODEL
PILOT CONTROLS
STICK
PEDALS
THROTTLE



PRELIMINARY
CONTROL SYSTEM BLOCK DIAGRAM
PILOT CONTROLS
RUDDER PEDALS
LATERAL STICK
LONGITUDINAL STICK
YAW SAS
ROLL SAS
PITCH SAS
TO VERTICAL TAIL
TO AILERON AND SPOILER FUNCTIONS
TO HORIZONTAL TAIL
NACELLE ANGLE
ELEVATOR VS. NACELLE ANGLE
CYCLIC
DIFF. COLL.
COLLECTIVE
GOVERNOR
RATE LIMIT
ACTUATOR DYNAMICS
ROTOR LEAD-LAG DYNAMICS

MODEL 222 LOAD ALLEVIATION SYSTEM (LAS.)

(FOR PIVOT MOMENTS - SINGLE COMMON LONG. ACTUATOR)



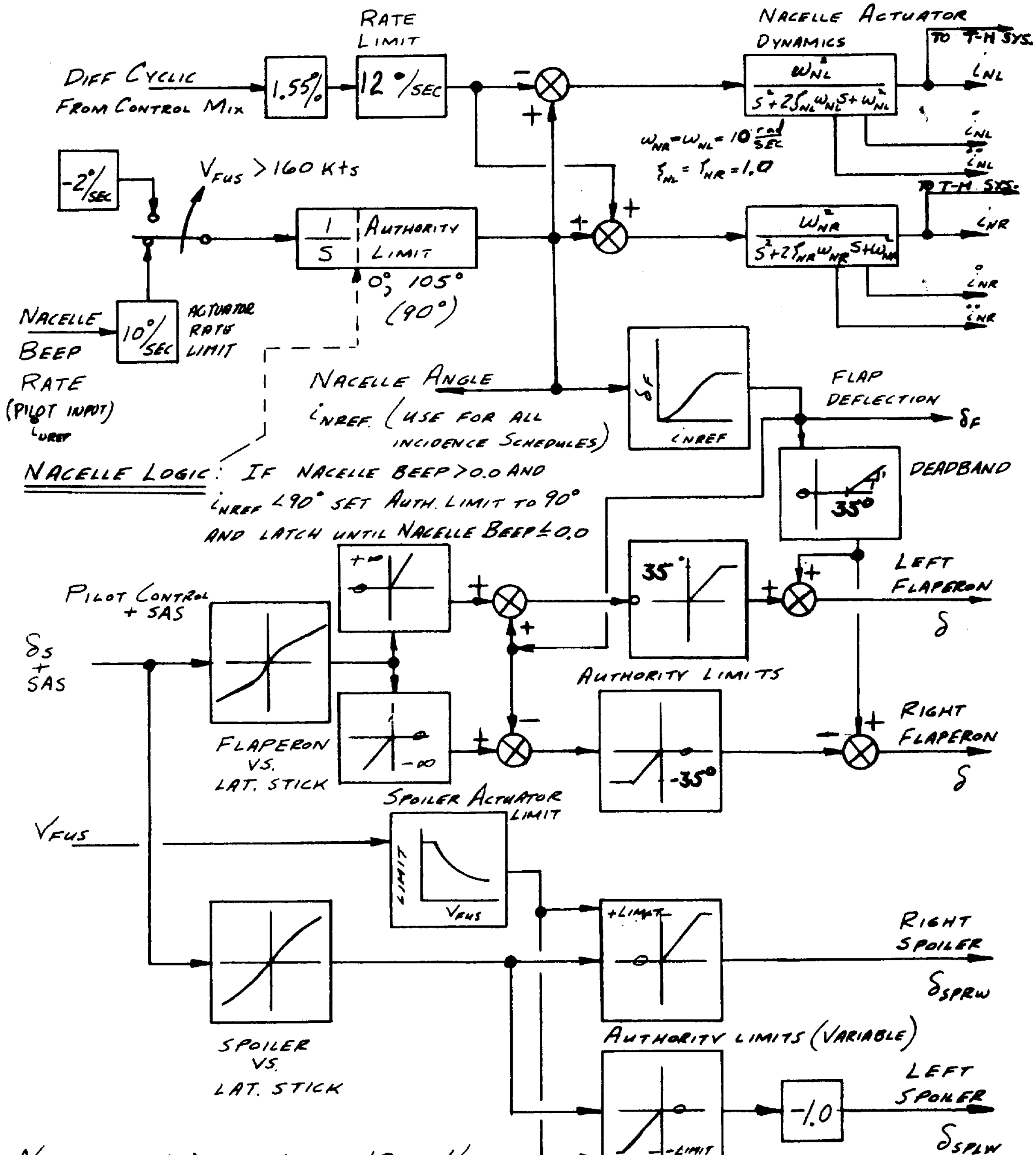
NOTE: THE SIGN OF $A'_{IC_R GLAS}$ IS CHANGED IN THE CONTROL SYSTEM BLOCK DIAGRAM

NOTE:- $G_{BI\alpha} = G_{AI\beta}$

GOVERNING EQUATIONS

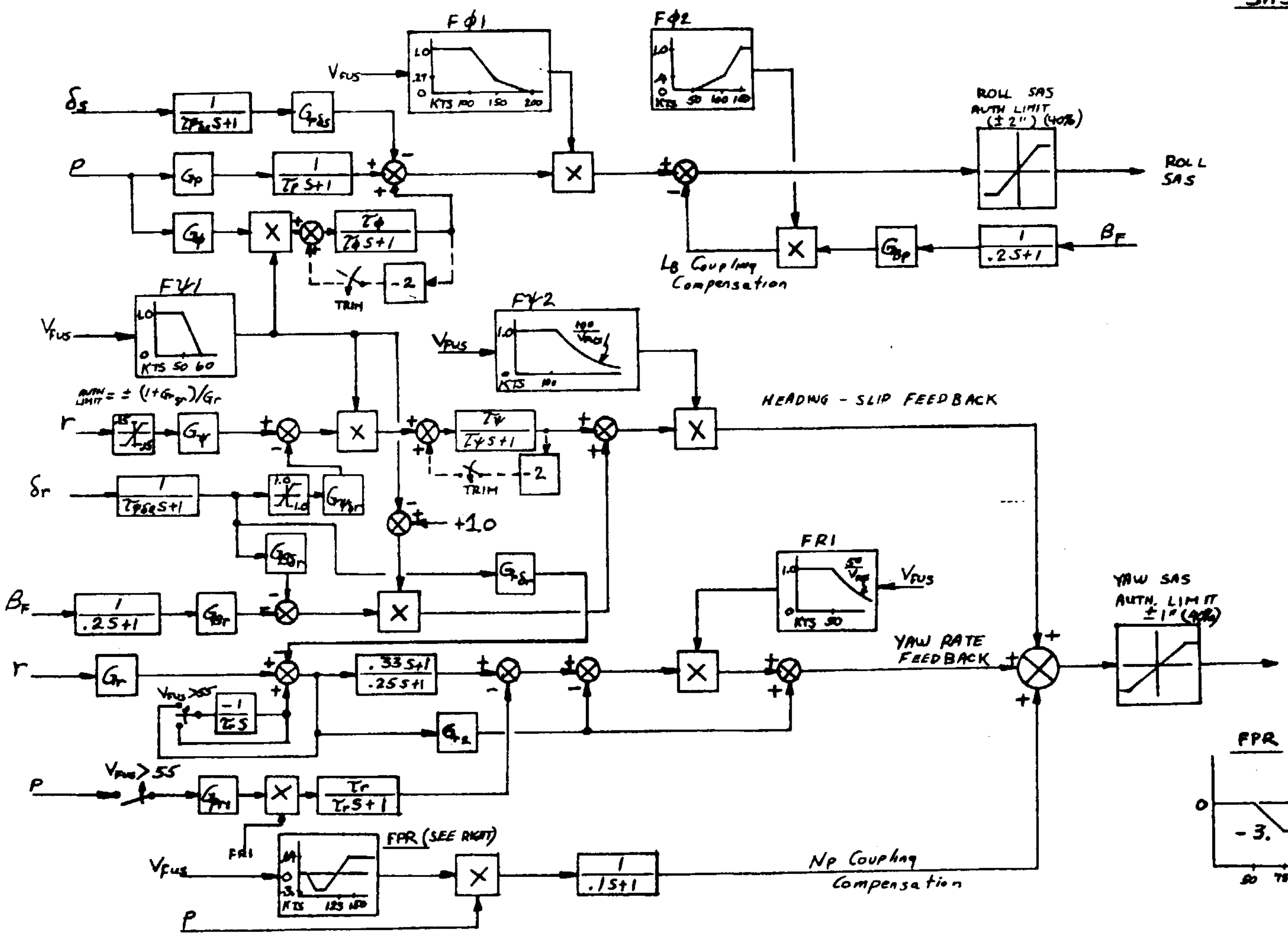
$$A'_{IC_L GLAS} = G_{AI\alpha}\,\alpha + G_{AI\beta}\,\beta$$
$$A'_{IC_R GLAS} = G_{AI\alpha}\,\alpha - G_{AI\beta}\,\beta$$
$$B'_{IC GLAS} = G_{BI\alpha}\,\alpha$$

MODEL 222
NACELLE, FLAP, FLAPERON, & SPOILER CONTROLS



NOTE: $\omega_{NL} = \omega_{NR} = 10$ rad/sec
$\zeta_{NL} = \zeta_{NR} = 1.0$ (critical)

LATERAL - DIRECTIONAL SAS

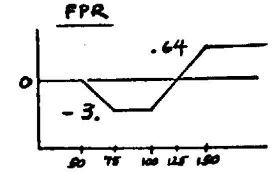


$G_{\psi\delta_r} = \frac{G_\psi(1+G_{r\delta r})}{G_r} = 1.125\%$

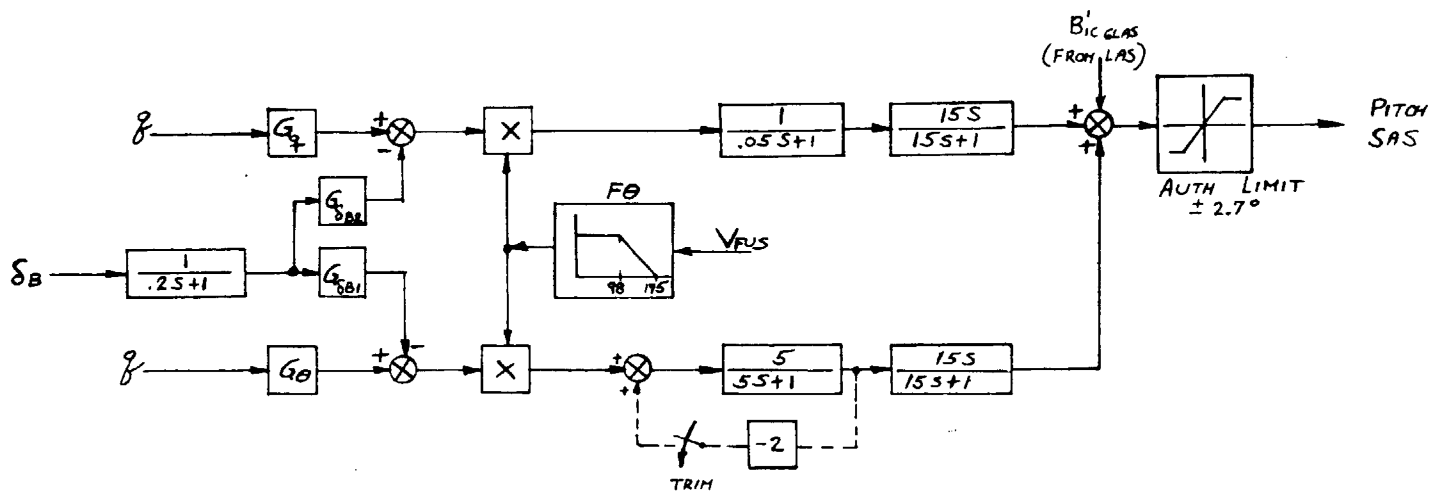
$G_{\beta\delta_r} = .5''$/INCH
$G_\psi = 7.5''$/INCH
$\tau_{\psi\delta r} = 1.0$ SEC
$\tau_\psi = 10$ SEC.
$G_{\beta r} = 10''$/RAD
$G_r = 10''$/RAD/SEC
$G_{r_2} = 0$
$\tau_r = 2.5$ SEC.
$G_{pr1} = 3.64''$/RAD/SEC
$G_{r\delta r} = 0.5$

$G_{p\delta s} = .5''$/INCH
$G_p = 5''$/RAD/SEC
$G_\phi = 5''$/RAD/SEC.
$\tau_{\phi\delta s} = .1$ SEC
$\tau_p = .1$ SEC.
$\tau_\phi = 5$ SEC.
$G_{Bp} = 10''$/RAD.

FPR



LONGITUDINAL SAS



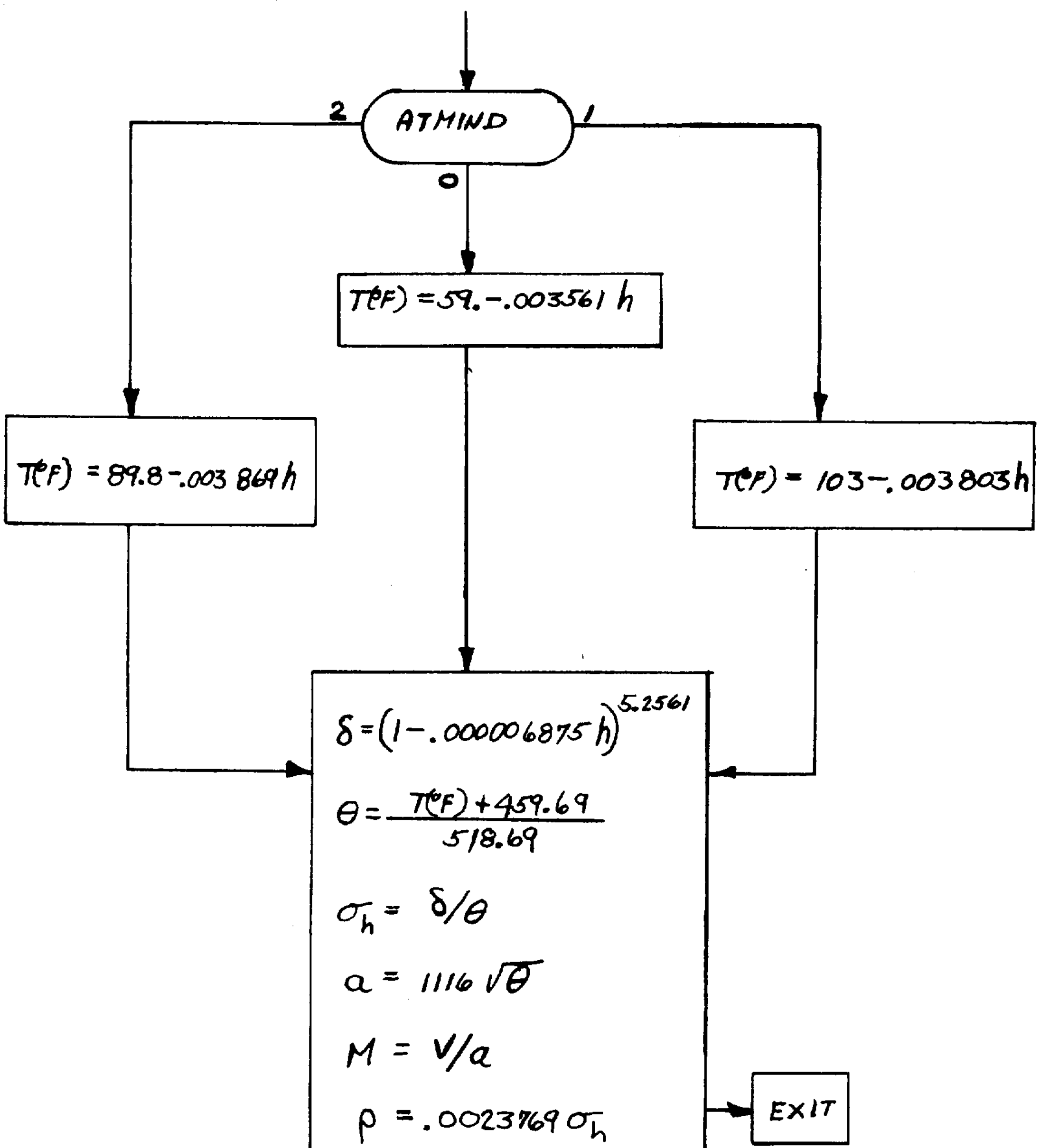
$G_q = 0.50$ DEG/RAD/SEC

$G_\theta = 2.0625$ DEG/RAD/SEC

$G_{\delta B_1} = .17$ DEG/INCH

$G_{\delta B_2} = 0$ DEG/INCH

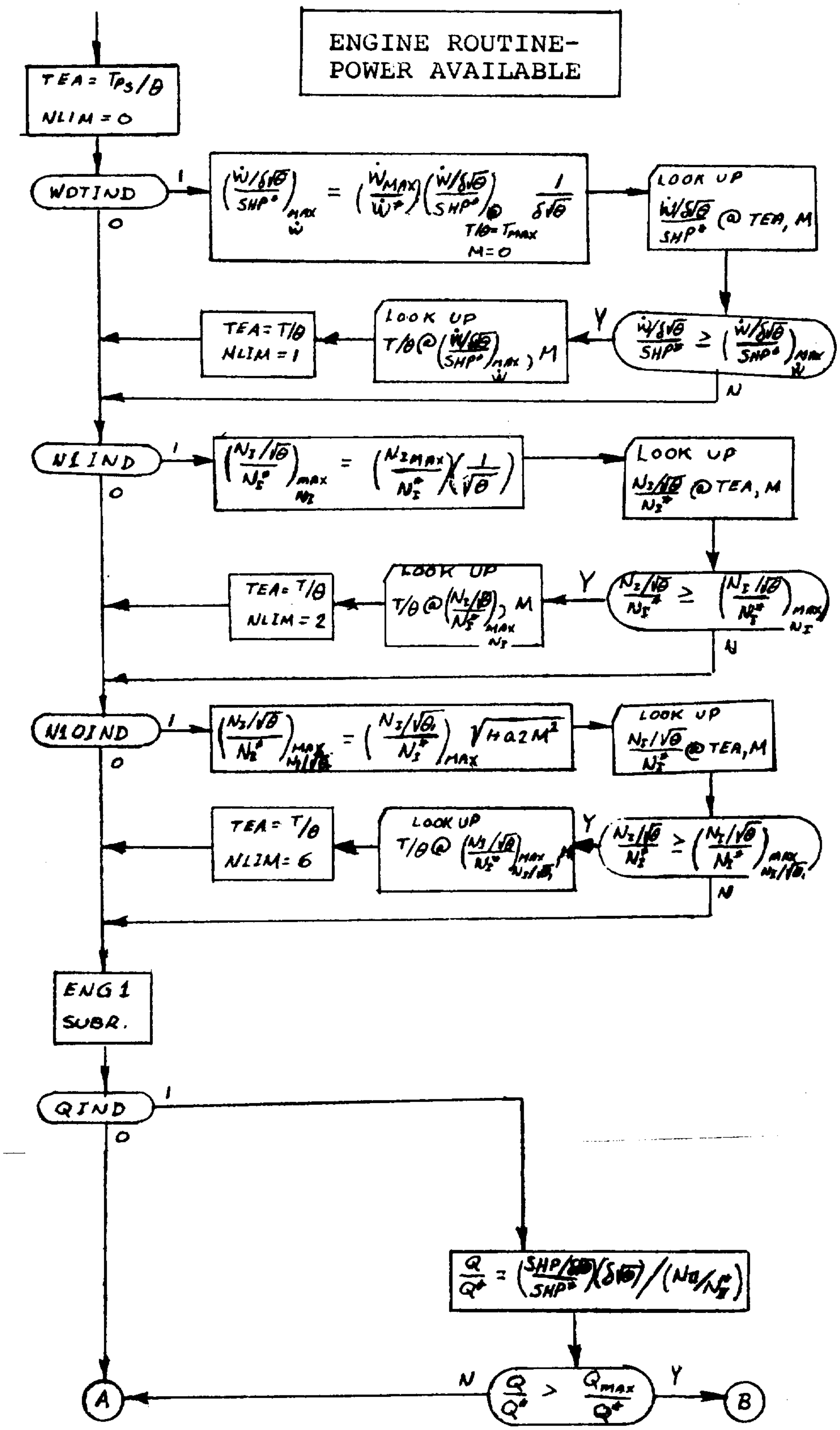
DENSITY CALCULATIONS

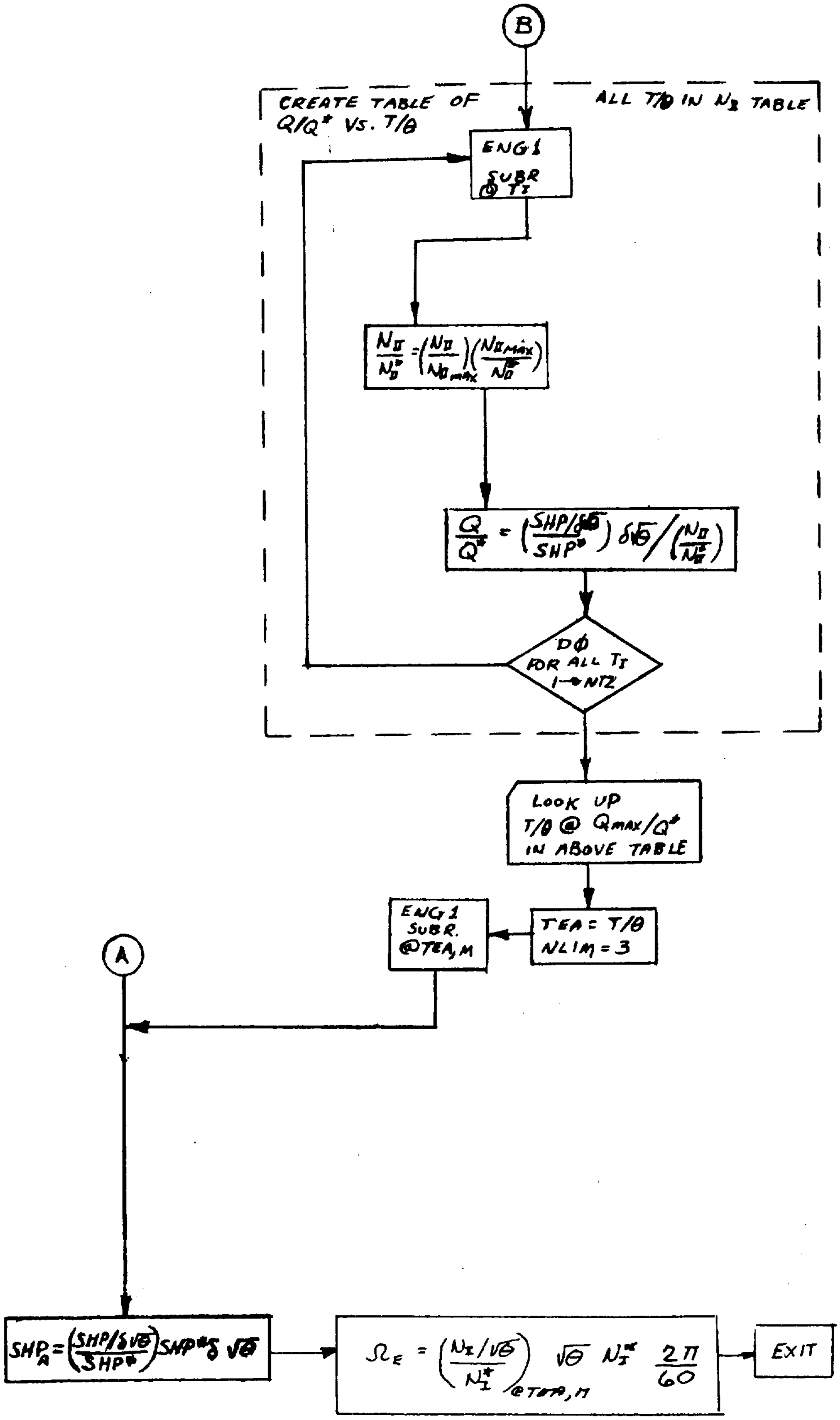


INPUT: h

ATMIND: 0 ~ STD ATMOS
1 ~ HOT ATMOS
2 ~ TROPICAL ATMOS

OUTPUT: δ, θ, σ_h, a, M, ρ


ENGINE ROUTINE-
POWER AVAILABLE
TEA = TPS/θ
NLIM = 0
WDTIND
LOOK UP
TEA = T/θ
NLIM = 1
N1IND
LOOK UP
TEA = T/θ
NLIM = 2
N1OIND
LOOK UP
TEA = T/θ
NLIM = 6
ENG1
SUBR.
QIND
A
B


B
CREATE TABLE OF Q/Q* VS. T/θ
ALL T/θ IN N_I TABLE
ENG 1 SUBR @ T_I
$\frac{N_{II}}{N_{II}^*} = \left(\frac{N_{II}}{N_{II\,max}}\right)\left(\frac{N_{II\,max}}{N_{II}^*}\right)$
$\frac{Q}{Q^*} = \left(\frac{SHP/\delta\sqrt{\theta}}{SHP^*}\right)\delta\sqrt{\theta}\Big/\left(\frac{N_{II}}{N_{II}^*}\right)$
DØ FOR ALL T_I 1→NT2
LOOK UP T/θ @ Q_{MAX}/Q^* IN ABOVE TABLE
TEA = T/θ
NLIM = 3
ENG 1 SUBR. @TEA, M
A
$SHP_A = \left(\frac{SHP/\delta\sqrt{\theta}}{SHP^*}\right) SHP^*\delta\sqrt{\theta}$
$\Omega_E = \left(\frac{N_I/\sqrt{\theta}}{N_I^*}\right)_{@TEA,M} \sqrt{\theta}\; N_I^* \;\frac{2\pi}{60}$
EXIT

$$\frac{N_{II}}{N_{II}^*} = \left(\frac{N_{II}}{N_{II\,MAX}}\right)\left(\frac{N_{II\,MAX}}{N_{II}^*}\right)$$

LOOK UP

$\frac{N_{II}/\sqrt{\theta}}{N_{II}^*}$ @ T/θ, M

$$\frac{N_{II}}{N_{II\,OPT}} = \frac{N_{II}/N_{II}^*}{N_{II}/\sqrt{\theta}/N_{II}^*} \quad \frac{1}{\sqrt{\theta}}$$

$$K_{PN} = 1 - \left(1 - \frac{N_{II}}{N_{II\,OPT}}\right)^2$$

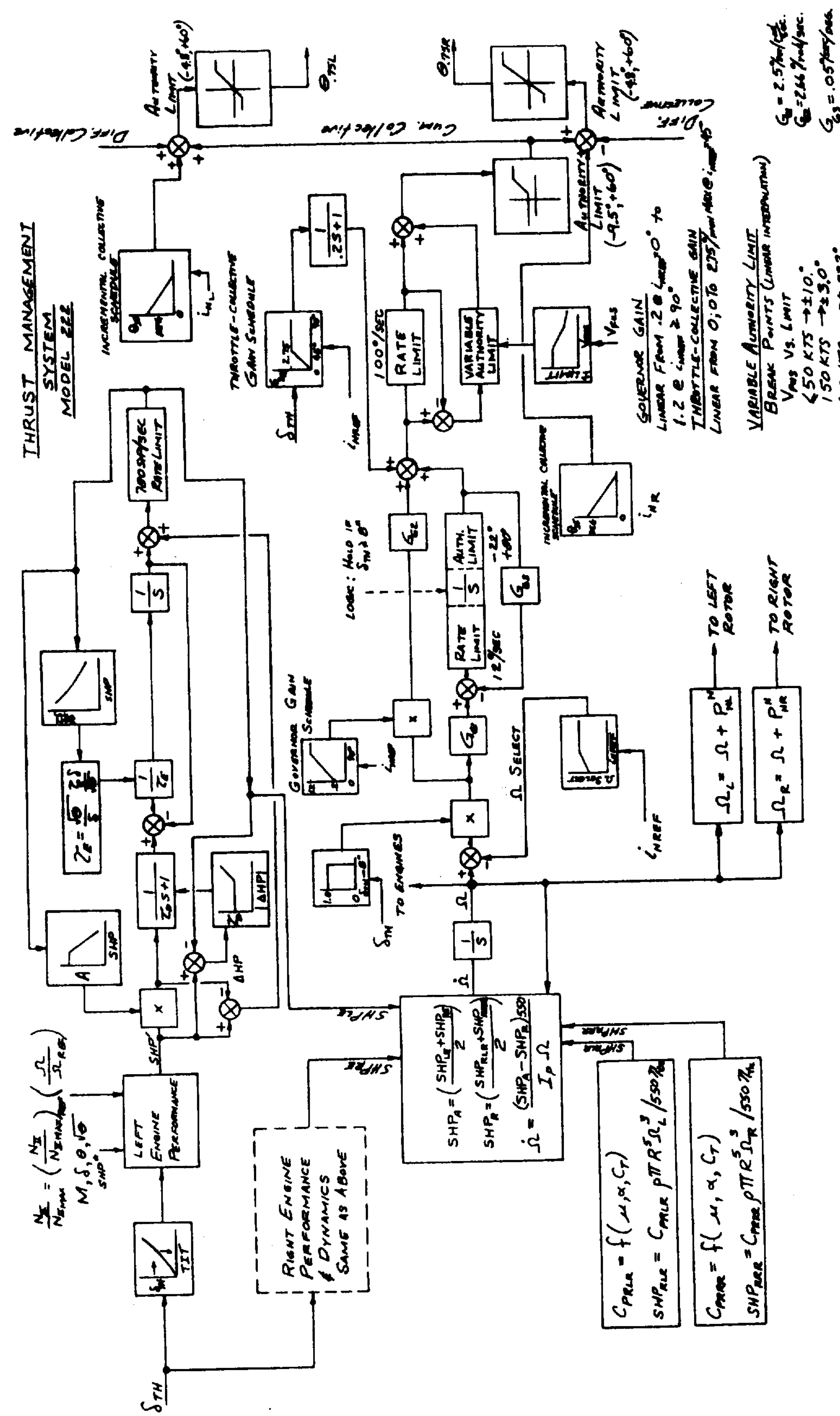
LOOK UP

$\frac{SHP/\delta\sqrt{\theta}}{SHP^*}$ @ T/θ, M

$$\frac{SHP/\delta\sqrt{\theta}}{SHP^*} = \left(K_{PN}\right)\left(\frac{SHP/\delta\sqrt{\theta}}{SHP^*}\right)$$

EXIT

ENG 1 SUBROUTINE, FLOW CHART


THRUST MANAGEMENT SYSTEM MODEL 222
LEFT ENGINE PERFORMANCE
RIGHT ENGINE PERFORMANCE & DYNAMICS SAME AS ABOVE
RATE LIMIT
VARIABLE AUTHORITY LIMIT
GOVERNOR GAIN SCHEDULE
THROTTLE-COLLECTIVE GAIN SCHEDULE
INCREMENTAL COLLECTIVE SCHEDULE
Ω SELECT
TO ENGINES
TO LEFT ROTOR
TO RIGHT ROTOR
Cum. Collective
Diff. Collective
AUTHORITY LIMIT
GOVERNOR GAIN
THROTTLE-COLLECTIVE GAIN
VARIABLE AUTHORITY LIMIT

ROTOR CONTROL COORDINATE AXIS TRANSFORM

LEFT

$$A''_{ICL} = A'_{ICL} \cos\phi_P + B'_{ICL} \sin\phi_P$$

$$B''_{ICL} = -A'_{ICL} \sin\phi_P + B'_{ICL} \cos\phi_P$$

$$A_{ICL} = A''_{ICL} \cos\zeta_{HL} - B''_{ICL} \sin\zeta_{HL}$$

$$B_{ICL} = A''_{ICL} \sin\zeta_{HL} + B''_{ICL} \cos\zeta_{HL}$$

RIGHT

$$A''_{ICR} = A'_{ICR} \cos\phi_P + B'_{ICR} \sin\phi_P$$

$$B''_{ICR} = -A'_{ICR} \sin\phi_P + B'_{ICR} \cos\phi_P$$

$$A_{ICR} = +A''_{ICR} \cos\zeta_{HR} + B''_{ICR} \sin\zeta_{HR}$$

$$B_{ICR} = -A''_{ICR} \sin\zeta_{HR} + B''_{ICR} \cos\zeta_{HR}$$

ROTOR SIDESLIP ANGLE

$$\zeta_{HR} = \tan^{-1} \frac{V_{RR}}{W_{RR} + \epsilon_{WRR} U_{RR}}$$

$$\zeta_{HL} = \tan^{-1} \frac{V_{RL}}{W_{RL} + \epsilon_{WRL} U_{RL}}$$

FORM THE sin & cos OF ζ_{HR} & ζ_{HL}

NOTE: ϕ_P IS THE CONTROL PHASE ANGLE. ϕ_P IS POSITIVE FOR THE CONTROL AXIS MOVED OPPOSITE TO ROTOR ROTATION.

CENTER OF GRAVITY CALCULATION

C.G. LOCATION w.r.t. PIVOT

$$X_{CG} = \frac{m_f l_f + m_w l_w}{m} + l\left(\frac{m_N}{m}\right)\left[\cos(i_{NL}-\lambda)+\cos(i_{NR}-\lambda)\right]$$

$$Z_{CG} = \frac{m_f h_f + m_w h_w}{m} - l\left(\frac{m_N}{m}\right)\left[\sin(i_{NL}-\lambda)+\sin(i_{NR}-\lambda)\right]$$

C.G. VELOCITY w.r.t. PIVOT

$$\dot{X}_{CG} = -l\,\frac{m_N}{m}\left[\dot{i}_{NL}\sin(i_{NL}-\lambda) + \dot{i}_{NR}\sin(i_{NR}-\lambda)\right]$$

$$\dot{Z}_{CG} = -l\,\frac{m_N}{m}\left[\dot{i}_{NL}\cos(i_{NL}-\lambda) + \dot{i}_{NR}\cos(i_{NR}-\lambda)\right]$$

C.G. ACCELERATION w.r.t. PIVOT

$$\ddot{X}_{CG} = -l\,\frac{m_N}{m}\Big[\ddot{i}_{NL}\sin(i_{NL}-\lambda) + \dot{i}_{NL}^{2}\cos(i_{NL}-\lambda) + \ddot{i}_{NR}\sin(i_{NR}-\lambda) + \dot{i}_{NR}^{2}\cos(i_{NR}-\lambda)\Big]$$

$$\ddot{Z}_{CG} = -l\,\frac{m_N}{m}\Big[\ddot{i}_{NL}\cos(i_{NL}-\lambda) - \dot{i}_{NL}^{2}\sin(i_{NL}-\lambda) + \ddot{i}_{NR}\cos(i_{NR}-\lambda) - \dot{i}_{NR}^{2}\sin(i_{NR}-\lambda)\Big]$$

FUSELAGE PIVOT VELOCITY

$$U_P = U - Z_{CG}\,q - \dot{X}_{CG}$$

$$V_P = V + Z_{CG}\,p - X_{CG}\,r$$

$$W_P = W + X_{CG}\,q - \dot{Z}_{CG}$$

AERODYNAMIC COORDINATE TRANSFORM

LEFT WING A.C. VELOCITY – BODY AXES

$$u'_{LW} = u_P + Z_{WAC}\, q + Y_{WAC}\, r + q\, h_{1LWAC}$$

$$v'_{LW} = v_P + X_{WAC}\, r - Z_{WAC}\, p - p\, h_{1LWAC}$$

$$w'_{LW} = w_P - Y_{WAC}\, p - X_{WAC}\, q + \dot{h}_{1LWAC}$$

RIGHT WING A.C. VELOCITY – BODY AXES

$$u'_{RW} = u_P + Z_{WAC}\, q - Y_{WAC}\, r + q\, h_{1RWAC}$$

$$v'_{RW} = v_P + X_{WAC}\, r - Z_{WAC}\, p - p\, h_{1RWAC}$$

$$w'_{RW} = w_P + Y_{WAC}\, p - X_{WAC}\, q + \dot{h}_{1RWAC}$$

LEFT ROTOR HUB VELOCITY – BODY AXES

$$u'_{RL} = u_P + r\, Y_N - L_S \sin i_{NL} \left(\dot{i}_{NL} + q\right) + q\, h_{1L}$$

$$v'_{RL} = v_P + L_S \left(r \cos i_{NL} + p \sin i_{NL} \right) - p\, h_{1L}$$

$$w'_{RL} = w_P - p\, Y_N - L_S \left(\dot{i}_{NL} + q\right) \cos i_{NL} + \dot{h}_{1L}$$

RIGHT ROTOR HUB VELOCITY – BODY AXES

$$u'_{RR} = u_P - r\, Y_N - L_S \sin i_{NR} \left(\dot{i}_{NR} + q\right) + q\, h_{1R}$$

$$v'_{RR} = v_P + L_S \left(r \cos i_{NR} + p \sin i_{NR} \right) - p\, h_{1R}$$

$$w'_{RR} = w_P + p\, Y_N - L_S \left(\dot{i}_{NR} + q\right) \cos i_{NR} + \dot{h}_{1R}$$

Aerodynamic Coordinate Transform (Cont'd.)

Left Rotor Hub Velocity – Shaft Axes

$$u_{RL} = u'_{RL} \cos i_{NL} - w'_{RL} \sin i_{NL}$$

$$v_{RL} = v'_{RL}$$

$$w_{RL} = u'_{RL} \sin i_{NL} + w'_{RL} \cos i_{NL}$$

Right Rotor Hub Velocity – Shaft Axes

$$u_{RR} = u'_{RR} \cos i_{NR} - w'_{RR} \sin i_{NR}$$

$$v_{RR} = v'_{RR}$$

$$w_{RR} = u'_{RR} \sin i_{NR} + w'_{RR} \cos i_{NR}$$

Left Wing A.C. Velocity – Chord Axes

$$u_{LW} = u'_{LW} \cos i_{W} - w'_{LW} \sin i_{W}$$

$$v_{LW} = v'_{LW}$$

$$w_{LW} = u'_{LW} \sin i_{W} + w'_{LW} \cos i_{W}$$

Right Wing A.C. Velocity – Chord Axes

$$u_{RW} = u'_{RW} \cos i_{W} - w'_{RW} \sin i_{W}$$

$$v_{RW} = v'_{RW}$$

$$w_{RW} = u'_{RW} \sin i_{W} + w'_{RW} \cos i_{W}$$

AERODYNAMIC COORDINATE TRANSFORM (Cont'd.)

HORIZONTAL STABILIZER A.C. VELOCITY

$$u_{HT} = u_p + Z_{HT} q$$

$$v_{HT} = v_p + X_{HT} r - Z_{HT} p$$

$$w_{HT} = w_p - X_{HT} q$$

VERTICAL FIN A.C. VELOCITY

$$u_{VT} = u_p + Z_{VT} q$$

$$v_{VT} = v_p + X_{VT} r - Z_{VT} p$$

$$w_{VT} = w_p - X_{VT} q$$

WING EQUATIONS

$$\tau_{RR} = \alpha_{RR} + \tan^{-1}\left(\frac{NF_R}{T_R}\right)$$

$$R_{RR} = \sqrt{T_R^2 + NF_R^2 + SF_R^2}$$

$$V_{*_R} = \frac{V_{RR}}{\sqrt{\dfrac{|R_{RR}|+10}{2\rho A}}}$$

$$v_{*_R}^4 + 2V_{*_R}v_{*_R}^3 \cos\tau_{RR} + v_{*_R}^2 V_{*_R}^2 = 1 \quad (\text{Solve for } v_{*_R})$$

$$\epsilon_{P_{RR}} = \tan^{-1}\frac{v_{*_R}\sin\tau_{RR}}{V_{*_R} + v_{*_R}\cos\tau_{RR}}$$

$$C_{TS_{RR}} = \frac{\cos(\tau_{RR} - \alpha_{RR})}{\cos(\tau_{RR} - \alpha_{RR}) + \dfrac{V_{*R}^2}{4}}$$

$$\tau_{LR} = \alpha_{LR} + \tan^{-1}\left(\frac{NF_L}{T_L}\right)$$

$$R_{LR} = \sqrt{T_L^2 + NF_L^2 + SF_L^2}$$

$$V_{*_L} = \frac{V_{LR}}{\sqrt{\dfrac{|R_{LR}|+10}{2\rho A}}}$$

$$v_{*L}^4 + 2V_{*L}v_{*L}^3 \cos\tau_{LR} + v_{*L}^2 V_{*L}^2 = 1 \quad (\text{solve for } v_{*L})$$

$$\epsilon_{PLR} = \tan^{-1}\frac{v_{*L}\sin\tau_{LR}}{V_{*L} + v_{*L}\cos\tau_{LR}}$$

$$C_{TSLR} = \frac{\cos(\tau_{LR} - \alpha_{LR})}{\cos(\tau_{LR} - \alpha_{LR}) + \dfrac{V_{*L}^2}{4}}$$

WING EQUATIONS (Cont'd.)

$$\bar{\xi} = (\xi_{HR} + \xi_{HL}).5$$

$$\bar{\alpha}_R = (\alpha_{RR} + \alpha_{LR}).5$$

$$\left.\begin{array}{l}\bar{\epsilon}_P = (\epsilon_{PRR} + \epsilon_{PLR}).5 \\ \bar{C}_{TS} = (C_{TSRR} + C_{TSLR}).5\end{array}\right\} \text{Used in Tail Aerodynamics}$$

$$\left.\begin{array}{l}\bar{i}_N = (i_{NL} + i_{NR}).5 \\ C_{LW} = \dfrac{(C_{LSRW} + C_{LSLW})}{(1-\bar{C}_{TS})}.5\end{array}\right\} \text{Used in Wing/Rotor Interfer.}$$

$$\xi_{R1} = \left[L_S - PC\cos(\bar{i}_N - i_W) + h_P\sin(\bar{i}_N - i_W)\right]\tan(\bar{\alpha}_R - \bar{\epsilon}_P)\sin\bar{\xi}$$

$$\xi_{R2} = \sqrt{\frac{D^2}{4} - \left\{\left[L_S - PC\cos(\bar{i}_N - i_W) + h_P\sin(\bar{i}_N - i_W)\right]\tan(\bar{\alpha}_R - \bar{\epsilon}_P)\cos\bar{\xi} + PC\sin(\bar{i}_N - i_W) + h_P\cos(\bar{i}_N - i_W)\right\}^2}$$

IF: $\xi_{R2} = 0$ OR Imaginary, $S_{iRW} = 0$ and $S_{iLW} = 0$,
also $\left(\frac{C_{L\alpha i}}{C_{L\alpha}}\right)_{RW} = 0$ and $\left(\frac{C_{L\alpha i}}{C_{L\alpha}}\right)_{LW} = 0.0$

FORM ξ_{R3} BY REPLACING PC IN ξ_{R1} EQUATION WITH $(PC - C_W)$

FORM ξ_{R4} BY REPLACING PC IN ξ_{R2} EQUATION WITH $(PC - C_W)$

IF: $\xi_{R4} = 0$ OR Imaginary; $S_{iRW} = 0$ and $S_{iLW} = 0$,
also $\left(\frac{C_{L\alpha i}}{C_{L\alpha}}\right)_{RW} = 0.0$ and $\left(\frac{C_{L\alpha i}}{C_{L\alpha}}\right)_{LW} = 0.0$

IF: UMBRELLAS OPEN; SET $C_{LW} = 0.0$

UMBRELLA LOGIC:

IF: $i_{NREF} < F_{iN}$ OR $q_F > 8.479$ LB/FT²,
SET UMBRELLAS CLOSED (Hysteresis $F_{iN} \pm 1°$; $q_F \pm .1 \frac{LB}{FT^2}$)

WING EQUATIONS (CONT'D)

$$S_{i_{RW}} = \frac{C_W}{2}\left[\xi_{R1} + \xi_{R2} + \xi_{R3} + \xi_{R4}\right]$$

$$\left(\frac{S_i}{S}\right)_{RW} = 2\left(\frac{S_{i_R}}{S_W}\right)$$

$$S_{i_T} = C_W\left[\xi_{R2} + \xi_{R4}\right]$$

$$S_{i_{LW}} = S_{i_T} - S_{i_R}$$

$$\left(\frac{S_i}{S}\right)_{LW} = 2\left(\frac{S_{i_L}}{S_W}\right)$$

$$(\mathcal{R}_i)_{LW} = \left(\frac{S_{i_L}}{C_W^2}\right)$$

$$(\mathcal{R}_i)_{RW} = \left(\frac{S_{i_R}}{C_W^2}\right)$$

$$\mathcal{R}_W = \frac{S_W}{C_W^2} \quad \text{(PRELIMINARY)}$$

$$\left(\frac{C_{L\alpha i}}{C_{L\alpha}}\right)_{LW} = \frac{1}{1 + \frac{C_{L\alpha_W}}{\pi}\left[\frac{1}{(\mathcal{R}_i)_{LW}} - \frac{1}{\mathcal{R}_W}\right]}$$

$$\left(\frac{C_{L\alpha i}}{C_{L\alpha}}\right)_{RW} = \frac{1}{1 + \frac{C_{L\alpha}}{\pi}\left[\frac{1}{(\mathcal{R}_i)_{RW}} - \frac{1}{\mathcal{R}_W}\right]}$$

$$K'_{AL} = \frac{V_{\phi_L} + \left(\frac{C_{L\alpha i}}{C_{L\alpha}}\right)_{LW} \nu_{\phi_L}}{V_{\phi_L} + \nu_{\phi_L}}$$

$$K'_{AR} = \frac{V_{\phi_R} + \left(\frac{C_{L\alpha i}}{C_{L\alpha}}\right)_{RW} \nu_{\phi_R}}{V_{\phi_R} + \nu_{\phi_R}}$$

WING EQUATIONS (CONTINUED)

$$\bar{q}_S = \left[\frac{1}{2}\rho\left(u^2+v^2+w^2\right) + \frac{(T_L + T_R).5}{A} \right]$$

$$q_{S_{RW}} = \left[\frac{1}{2}\rho\left(u^2_{RW}+v^2_{RW}+w^2_{RW}\right) + \frac{T_R}{A} \right]$$

$$q_{S_{LW}} = \left[\frac{1}{2}\rho\left(u^2_{LW}+v^2_{LW}+w^2_{LW}\right) + \frac{T_L}{A} \right]$$

WING EQUATIONS (Cont'd.)

WING ANGLE OF ATTACK AND SIDESLIP

$$\alpha_{LWo} = \sin^{-1}\left[\frac{w_{LW}}{\sqrt{u_{LW}^2 + w_{LW}^2}}\right] + \theta_{tLWAC}$$

$$\alpha_{RWo} = \sin^{-1}\left[\frac{w_{RW}}{\sqrt{u_{RW}^2 + w_{RW}^2}}\right] + \theta_{tRWAC}$$

$$\beta_{LWo} = \sin^{-1}\left[\frac{v_{LW}}{\sqrt{u_{LW}^2 + v_{LW}^2 + w_{LW}^2}}\right]$$

$$\beta_{RWo} = \sin^{-1}\left[\frac{v_{RW}}{\sqrt{u_{RW}^2 + v_{RW}^2 + w_{RW}^2}}\right]$$

$$\alpha_{LWSS_o} = \alpha_{LWo} - \epsilon_{PLR}$$

$$\alpha_{RWSSo} = \alpha_{RWo} - \epsilon_{PRR}$$

$$\bar{\alpha}_{w} = (\alpha_{LWo} + \alpha_{RWo})\,.5$$

$$\alpha_{LW rigid} = \sin^{-1}\left[\frac{w_{LW}}{\sqrt{u_{LW}^2 + w_{LW}^2}}\right] - \epsilon_{PLR}$$

$$\alpha_{RW rigid} = \sin^{-1}\left[\frac{w_{RW}}{\sqrt{u_{RW}^2 + w_{RW}^2}}\right] - \epsilon_{PRR}$$

$$\alpha'_{LWo} = \alpha_{LWo} - i_{w} - \theta_{tLWAC}$$

$$\alpha'_{RWo} = \alpha_{RWo} - i_{w} - \theta_{tRWAC}$$

NOTE: IF α_{LWSS_o} OR α_{RWSSO} $\geq$ α_{MAX} ; PRINT OUT STALL WARNING

WING EQUATIONS (CONT'D)

CALCULATION OF INCREMENTAL LIFT, DRAG AND MOMENT COEFFICIENTS

CALCULATE:

$$C_{L_{LW_0}} = C_L \text{ @ } \alpha = \alpha_{LWSS_0} \;,\quad \delta = \delta_{a_{LW}} + \delta_f \;,\quad \delta_{SP} = \delta_{SP_L}$$

$$C_{L_{RW_0}} = C_L \text{ @ } \alpha = \alpha_{RWSS_0} \;,\quad \delta = \delta_{a_{RW}} + \delta_f \;,\quad \delta_{SP} = \delta_{SP_R}$$

$$C^{*}_{L_{LW_0}} = C_L \text{ @ } \alpha = \alpha_{LW_0} \;,\quad \delta = \delta_{a_{LW}} + \delta_f \;,\quad \delta_{SP} = \delta_{SP_L}$$

$$C^{*}_{L_{RW_0}} = C_L \text{ @ } \alpha = \alpha_{RW_0} \;,\quad \delta = \delta_{a_{RW}} + \delta_f \;,\quad \delta_{SP} = \delta_{SP_R}$$

$$C_{L_0} = C_L \text{ @ } \alpha_F + i_w \;,\quad \delta = \delta_f$$

CALCULATE:

$$\alpha^{+}_{N.L} = 14.6^\circ - 0.12\,\delta \qquad (0^\circ \le \delta \le 40^\circ)$$

$$= 9.8^\circ \qquad (\delta > 40^\circ)$$

$$\alpha^{-}_{N.L} = -16.7^\circ - .1138\,\delta \qquad (0^\circ \le \delta \le 40^\circ)$$

$$= -21.25^\circ \qquad (\delta > 40^\circ)$$

IF: $\alpha^{-}_{N.L} \le \alpha \le \alpha^{+}_{N.L}$

$$C_L = 0.134 + C_{L_{\alpha_W}}\alpha + \Delta C_{L_\delta} + F\,\Delta C_{L_{SP}}$$

WHERE:

$$\Delta C_{L_\delta} = .0269\,\delta \qquad (0^\circ \le \delta \le 22.22906^\circ)$$

$$= -2.437137 + .20607\,\delta - .003128\,\delta^2 \qquad (22.22906^\circ < \delta \le 29.786^\circ)$$

$$= .442188 + .0263\,\delta - .000338\,\delta^2 \qquad (\delta > 29.786^\circ)$$

$$\Delta C_{L_{SP}} = -0.01132\,\delta_{SP} \qquad (0^\circ \le \delta_{SP} \le 30^\circ)$$

$$= .076 - .018666\,\delta_{SP} + .00016\,\delta_{SP}^2 \qquad (\delta_{SP} > 30^\circ)$$

$$F = 1.003412 + .011163\,\delta + .002168\,\delta^2 \qquad (0^\circ \le \delta \le 20.1665^\circ)$$

$$F = -.756323 + .185684\,\delta - .002159\,\delta^2 \qquad (\delta > 20.1665^\circ)$$

WING EQUATIONS (CONT'D)

IF: $\alpha^{+}_{N.L} < \alpha \leq \alpha^{+}_{N.L} + 8.534^{\circ}$

CALCULATE: $C'_{L_{N.L}} = 0.134 + C_{L\alpha_w}\alpha^{+}_{N.L} + \Delta C_{L_\delta} + F\Delta C_{L_{SP}}$

$$\alpha_{DUM} = \alpha - \alpha^{+}_{N.L} + 14.6^{\circ}$$

$$\Delta C_{L_{N.L}} = -.00547619\ \alpha^2_{DUM} + .18254762\ \alpha_{DUM} - 1.421571513$$

$C_L = C'_{L_{N.L}} + \Delta C_{L_{N.L}}$ AND PRINT STALL WARNING

IF:- $(\alpha^{+}_{N.L} + 8.534^{\circ}) < \alpha < 90^{\circ}$

CALCULATE: $C'_{L_{N.L}} = 0.134 + C_{L\alpha_w}\alpha^{+}_{N.L} + \Delta C_{L_\delta} + F\Delta C_{L_{SP}}$

$C_L = \dfrac{C'_{L_{N.L}}(90^{\circ} - \alpha)}{90^{\circ} - (\alpha^{+}_{N.L} + 8.534^{\circ})}$ AND PRINT STALL WARNING.

IF: $(\alpha^{-}_{N.L} - 8.534^{\circ}) \leq \alpha < \alpha^{-}_{N.L}$

CALCULATE:

$$C'_{L_{N.L}} = 0.134 + C_{L\alpha_w}\alpha^{-}_{N.L} + \Delta C_{L_\delta} + F\Delta C_{L_{SP}}$$

$$\alpha_{DUM} = \alpha^{-}_{N.L} - \alpha + 14.6^{\circ}$$

$$\Delta C_{L_{N.L}} = -.00547619\ \alpha^2_{DUM} + 0.18254762\ \alpha_{DUM} - 1.421571513$$

$C_L = C'_{L_{N.L}} - \Delta C_{L_{N.L}}$ AND PRINT STALL WARNING

IF: $-90^{\circ} \leq \alpha < (\alpha^{-}_{N.L} - 8.534^{\circ})$

CALCULATE:-

$$C'_{L_{N.L}} = 0.134 + C_{L\alpha_w}\alpha^{-}_{N.L} + \Delta C_{L_\delta} + F\Delta C_{L_{SP}}$$

$C_L = \dfrac{C'_{L_{N.L}}(90^{\circ} + \alpha)}{90^{\circ} + \alpha^{-}_{N.L} - 8.534^{\circ}}$ AND PRINT STALL WARNING

NOTE:- α, α_{DUM}, δ, δ_{a_w}, $\delta_{a_{RW}}$, δ_F, $\alpha^{-}_{N.L}$, $\alpha^{+}_{N.L}$, δ_{SPL}, δ_{SPR}, IN DEGREES ; $C_{L\alpha_w} \sim$ 1/DEGREES

WING EQUATIONS (CONT'D)

CALCULATE:-

$$C_{D_{LW}} = C_D \text{ @ } \alpha = \alpha_{LWSS0}, \quad \delta = \delta_f + \delta a_{LW}, \quad \delta_{SP} = \delta_{SP_L}$$

$$C_{D_{RW}} = C_D \text{ @ } \alpha = \alpha_{RWSS0}, \quad \delta = \delta_f + \delta a_{RW}, \quad \delta_{SP} = \delta_{SP_R}$$

$$C^{*\prime}_{D_{LW_0}} = C_D \text{ @ } \alpha = \alpha_{LW_0}, \quad \delta = \delta_f + \delta a_{LW}, \quad \delta_{SP} = \delta_{SP_L}$$

$$C^{*\prime}_{D_{RW_0}} = C_D \text{ @ } \alpha = \alpha_{RW_0}, \quad \delta = \delta_f + \delta a_{RW}, \quad \delta_{SP} = \delta_{SP_R}$$

AS FOLLOWS:

IF:- $-20° \le \alpha \le 20°$

CALCULATE: $$C_D = .00059250\,\alpha^2 + .002109993\,\alpha + .01765 + \sum_{v=0}^{4}\sum_{u=0}^{4}\left[A_{D(u+5v)}\,\delta^u\,\alpha^v\right] + \Delta C_{D_{SP}}$$

WHERE: $$\Delta C_{D_{SP}} = -.000098784\,\delta_{SP} + .000009622\,\delta_{SP}^2$$

IF: $20° < \alpha \le 90°$, $\alpha_{DUM} = 20°$

CALCULATE: $$C_D^+ = 0.31105749 + \sum_{v=0}^{4}\sum_{u=0}^{4}\left[A_{D(u+5v)}\,\delta^u\,\alpha_{DUM}^v\right] + \Delta C_{D_{SP}}$$

$$C_D = C_D^+ + \frac{(1 - C_D^+)}{70°}(\alpha - 20°)$$

IF: $-90° \le \alpha < -20°$, $\alpha_{DUM} = -20°$

CALCULATE: $$C_D^- = 0.19124389 + \sum_{v=0}^{4}\sum_{u=0}^{4}\left[A_{D(u+5v)}\,\delta^u\,\alpha_{DUM}^v\right] + \Delta C_{D_{SP}}$$

$$C_D = C_D^- - \frac{(1 - C_D^-)}{70°}(\alpha + 20°)$$

NOTE: α, α_{DUM}, δ, δa_{RW}, δa_{LW}, δ_{SP_R}, δ_{SP_L} IN DEGREES

WING EQUATIONS (CONT'D)

CALCULATE:

$$C_{M_{LW}} = C_M \text{ @ } \alpha = \alpha_{LW_{SSO}} \quad , \quad \delta = \delta_f + \delta_{a_{LW}}$$

$$C_{M_{RW}} = C_M \text{ @ } \alpha = \alpha_{RW_{SSO}} \quad , \quad \delta = \delta_f + \delta_{a_{RW}}$$

$$C^{*\prime}_{M_{LW_0}} = C_M \text{ @ } \alpha = \alpha_{LW_0} \quad , \quad \delta = \delta_f + \delta_{a_{LW}}$$

$$C^{*\prime}_{M_{RW_0}} = C_M \text{ @ } \alpha = \alpha_{RW_0} \quad , \quad \delta = \delta_f + \delta_{a_{RW}}$$

AS FOLLOWS:

IF:- $-20^\circ \leq \alpha \leq 20^\circ$

CALCULATE:- $C_M' = -.030117 - .0003162\,\alpha$

$$\Delta C_{M_\delta} = .0000778\,\delta^2 - .010033\,\delta \qquad (0^\circ \leq \delta \leq 45^\circ)$$

$$\Delta C_{M_\delta} = .0000322\,\delta^2 - .0049045\,\delta - .1384272 \qquad (\delta > 45^\circ)$$

$$C_M = C_M' + \Delta C_{M_\delta}$$

IF: $\alpha > 20^\circ$

CALCULATE: $C_M' = -.036441 + \Delta C_{M_\delta}$

$$C_M = C_M' \frac{(90^\circ - \alpha)}{70^\circ}$$

IF $\alpha < -20^\circ$

CALCULATE $C_M' = -.023793 + \Delta C_{M_\delta}$

$$C_M = C_M' \frac{(90^\circ + \alpha)}{70^\circ}$$

NOTE: α, α_{DVM}, δ, $\delta_{a_{RW}}$, $\delta_{a_{LW}}$, δ_{SP_R}, δ_{SP_L} IN DEGREES

WING EQUATIONS (CONT'D)

CALCULATE :-

$$C''''_{L_{LW}} = C_{L_{LWO}} \quad ; \quad C'''_{D_{LW}} = C_{D_{LW}} \quad ; \quad C''_{M_{LW}} = C_{M_{LW}}$$

$$C'''_{L_{RW}} = C_{L_{RWO}} \quad ; \quad C''_{D_{RW}} = C_{D_{RW}} \quad ; \quad C''_{M_{RW}} = C_{M_{RW}}$$

$$C''_{L_{LWMAX}} = C_{L_{MAX}} + \Delta C_{L_\delta} + \Delta C_{L_{SP}}$$

$$C''_{L_{RWMAX}} = C_{L_{MAX}} + \Delta C_{L_\delta} + \Delta C_{L_{SP}}$$

$$C^{*\prime}_{L_{RW}} = C^{*}_{L_{RWO}} \quad ; \quad C^{*\prime}_{D_{RW}} = C^{*\prime}_{D_{RWO}} \quad ; \quad C^{*}_{M_{RW}} = C^{*\prime}_{M_{RWO}}$$

$$C^{*\prime}_{L_{LW}} = C^{*}_{L_{LWO}} \quad ; \quad C^{*\prime}_{D_{LW}} = C^{*\prime}_{D_{LWO}} \quad ; \quad C^{*}_{M_{LW}} = C^{*\prime}_{M_{LWO}}$$

$$C^{*}_{L_{LWMAX}} = C''_{L_{LWMAX}}$$

$$C^{*}_{L_{RWMAX}} = C''_{L_{RWMAX}}$$

$$\overline{C_L} = \frac{C_{L_O}\left(\frac{a_g}{a}\right)_w}{\sqrt{1-M^2}}$$

$$C''^{\,IGE}_{L_{LW}} = C'''_{L_{LW}}\frac{\left(\frac{a_g}{a}\right)_w}{\sqrt{1-M^2}} \quad ; \quad C''^{\,IGE}_{L_{RW}} = C'''_{L_{RW}}\frac{\left(\frac{a_g}{a}\right)_w}{\sqrt{1-M^2}} \quad ;$$

$$C^{*\,IGE}_{L_{LW}} = C^{*\prime}_{L_{LW}}\frac{\left(\frac{a_g}{a}\right)_w}{\sqrt{1-M^2}} \quad ; \quad C^{*\,IGE}_{L_{RW}} = C^{*\prime}_{L_{RW}}\frac{\left(\frac{a_g}{a}\right)}{\sqrt{1-M^2}}$$

WING EQUATIONS (CONT'D)

$$\Delta C_{DLW}^{''IGE} = K_{99}\frac{\left(C_{LLW}^{''IGE} - C_{LLW}^{'''}\right)^2}{\pi AR_w};\ \Delta C_{DRW}^{''IGE} = K_{99}\frac{\left(C_{LRW}^{''IGE} - C_{LRW}^{'''}\right)^2}{\pi AR_w};$$

$$\Delta C_{DLW}^{\star IGE} = K_{99}\frac{\left(C_{LLW}^{\star IGE} - C_{LLW}^{\star\prime}\right)^2}{\pi AR_w};\ \Delta C_{DRW}^{\star IGE} = K_{99}\frac{\left(C_{LRW}^{\star IGE} - C_{LRW}^{\star\prime}\right)^2}{\pi AR_w}$$

$$\text{IF: } C_{LLW}^{''IGE} \geq C_{LLWMAX}^{''};\ \text{SET } \Delta C_{DLW}^{''IGE} = 0.0\ \&\ C_{LLW}^{''IGE} = C_{LLWMAX}^{''}$$

$$\text{IF: } C_{LRW}^{''IGE} \geq C_{LRWMAX}^{''};\ \text{SET } \Delta C_{DRW}^{''IGE} = 0.0\ \&\ C_{LRW}^{''IGE} = C_{LRWMAX}^{''}$$

$$\text{IF: } C_{LLW}^{\star IGE} \geq C_{LLWMAX}^{\star};\ \text{SET } \Delta C_{DLW}^{\star IGE} = 0.0\ \&\ C_{LLW}^{\star IGE} = C_{LLWMAX}^{\star}$$

$$\text{IF: } C_{LRW}^{\star IGE} \geq C_{LRWMAX}^{\star};\ \text{SET } \Delta C_{DRW}^{\star IGE} = 0.0\ \&\ C_{LRW}^{\star IGE} = C_{LRWMAX}^{\star}$$

$$\text{IF: } \left(a_g/a\right) > 1.0;\ \text{SET } K_{99} = -1.0$$

$$\left(a_g/a\right) \leq 1.0;\ \text{SET } K_{99} = +1.0$$

CALCULATE

$$C_{LLW}^{''} = C_{LLW}^{''IGE}$$

$$C_{DLW}^{''} = C_{DLW}^{'''} + \Delta C_{DLW}^{''IGE}$$

$$C_{LRW}^{''} = C_{LRW}^{''IGE}$$

$$C_{DRW}^{''} = C_{DRW}^{'''} + \Delta C_{DRW}^{''IGE}$$

$$C_{LLW}^{\star} = C_{LLW}^{\star IGE}$$

$$C_{DLW}^{\star} = C_{DLW}^{\star\prime} + \Delta C_{DLW}^{\star IGE}$$

$$C_{LRW}^{\star} = C_{LRW}^{\star IGE}$$

$$C_{DRW}^{\star} = C_{DRW}^{\star\prime} + \Delta C_{DRW}^{\star IGE}$$

WING EQUATIONS (cont'd.)

$$C_{LSLW} = K'_{A_L}\left\{\left(\frac{S_i}{S}\right)_{LW}\left(C''_{LLW}\cos\epsilon_{PLR} - C''_{DLW}\sin\epsilon_{PLR}\right) + C^{\star}_{LLW}\left(1 - C_{TSLR}\right)\left[1 - \left(\frac{S_i}{S}\right)_{LW}\right]\right\}$$

$$C_{LSRW} = K'_{A_R}\left\{\left(\frac{S_i}{S}\right)_{RW}\left(C''_{LRW}\cos\epsilon_{PRR} - C''_{DRW}\sin\epsilon_{PRR}\right) + C^{\star}_{LRW}\left(1 - C_{TSRR}\right)\left[1 - \left(\frac{S_i}{S}\right)_{RW}\right]\right\}$$

$$C_{DSLW} = K'_{A_L}\left\{\left(\frac{S_i}{S}\right)_{LW}\left(C''_{LLW}\sin\epsilon_{PLR} + C''_{DLW}\cos\epsilon_{PLR}\right) + C^{\star}_{DLW}\left(1 - C_{TSLR}\right)\left[1 - \left(\frac{S_i}{S}\right)_{LW}\right]\right\}$$

$$C_{DSRW} = K'_{A_R}\left\{\left(\frac{S_i}{S}\right)_{RW}\left(C''_{LRW}\sin\epsilon_{PRR} + C''_{DRW}\cos\epsilon_{PRR}\right) + C^{\star}_{DRW}\left(1 - C_{TSRR}\right)\left[1 - \left(\frac{S_i}{S}\right)_{RW}\right]\right\}$$

$$C_{MSLW} = K'_{A_L}\left\{\left(\frac{S_i}{S}\right)_{LW}\left(C''_{MLW}\right) + C^{\star}_{MLW}\left(1 - C_{TSLR}\right)\left[1 - \left(\frac{S_i}{S}\right)_{LW}\right]\right\}$$

$$C_{MSRW} = K'_{A_R}\left\{\left(\frac{S_i}{S}\right)_{RW}\left(C''_{MRW}\right) + C^{\star}_{MRW}\left(1 - C_{TSRR}\right)\left[1 - \left(\frac{S_i}{S}\right)_{RW}\right]\right\}$$

WING EQUATIONS (cont'd.)

$$\Delta C_{\ell S_{POWER}} = \frac{1}{4}\left\{\left[C_{LSLW} - (1-\bar{C}_{TS})\,C^{\star}_{LLW}\right]\left[1-\frac{1}{2}\left(\frac{S_i}{S}\right)_{LW}\right] - \left[C_{LSRW} - (1-\bar{C}_{TS})\,C^{\star}_{LRW}\right]\left[1-\frac{1}{2}\left(\frac{S_i}{S}\right)_{RW}\right]\right\}$$

$$\Delta C_{\eta S_{POWER}} = \frac{1}{4}\left\{\left[C_{DSRW} - (1-\bar{C}_{TS})\,C^{\star}_{DRW}\right]\left[1-\frac{1}{2}\left(\frac{S_i}{S}\right)_{RW}\right] - \left[C_{DSLW} - (1-\bar{C}_{TS})\,C^{\star}_{DLW}\right]\left[1-\frac{1}{2}\left(\frac{S_i}{S}\right)_{LW}\right]\right\}$$

$$C_{\ell SW} = (K_{20} + K_{21}\bar{C}_L)(1-\bar{C}_{TS})\beta_f + \left(\frac{1-\bar{C}_{TS}}{2b_w}\right)(K_\ell)(C^{\star}_{LLW} - C^{\star}_{LRW})\,\bar{Y}_{AC}$$

$$+\Delta C_{\ell S_{POWER}}$$

$$C_{\eta SW} = (K_{22}\bar{C}_L^2)(1-\bar{C}_{TS})\beta_f + \left(\frac{1-\bar{C}_{TS}}{2b_w}\right)(K_\eta)\left\{(C^{\star}_{DRW} - C^{\star}_{DLW}) - \left[C^{\star}_{LRW}\,\mathrm{SIN}(\alpha_{RW_0} - i_w) + C^{\star}_{LLW}\,\mathrm{SIN}(i_w - \alpha_{LW_0})\right]\right\}\bar{Y}_{AC}$$

$$+\Delta C_{\eta S_{POWER}}$$

WING EQUATIONS

SPECIAL CONDITIONS (FOR UMBRELLAS OPEN)

IF : UMBRELLAS CLOSED; GO THROUGH WING EQUATIONS

IF : UMBRELLAS OPEN ; CALCULATE THE WING FORCES AND MOMENTS AS FOLLOWS:

$$X^{LW}_{AERO} = fe_u \, q_{SLW}(1 - C_{TSLR})\left[\frac{-U_{LW}}{|U_{LW}|+.1}\right]$$

$$X^{RW}_{AERO} = fe_u \, q_{SRW}(1 - C_{TSRR})\left[\frac{-U_{RW}}{|U_{RW}|+.1}\right]$$

$$Y^{LW}_{AERO} = 0.0$$

$$Y^{RW}_{AERO} = 0.0$$

$$\left.\begin{aligned} Z^{LWP}_{AERO} &= T_L \left(\tfrac{D}{T}\right)_L \\ Z^{RWP}_{AERO} &= T_R \left(\tfrac{D}{T}\right)_R \end{aligned}\right\} \text{GO TO WING BENDING}$$

$$\left.\begin{aligned} \mathcal{M}^{LW}_{AERO} &= -X_{\frac{c}{2}} Z^{LW}_{AERO} + \left(\tfrac{M}{T}\right)_L T_L \\ \mathcal{M}^{RW}_{AERO} &= -X_{\frac{c}{2}} Z^{RW}_{AERO} + \left(\tfrac{M}{T}\right)_R T_R \end{aligned}\right\} Z^{LW}_{AERO} \,\&\, Z^{RW}_{AERO} \text{ FROM WING BENDING}$$

$$\mathcal{L}^{W}_{AERO} = \left(\frac{b_w}{2}\right)\left\{ Z^{RW}_{AERO}\left[1 - \frac{\left(\frac{S_i}{S}\right)_{RW}}{2}\right] - Z^{LW}_{AERO}\left[1 - \frac{\left(\frac{S_i}{S}\right)_{LW}}{2}\right]\right\}$$

$$\mathcal{N}^{W}_{AERO} = 0.0$$

IF: $\left[\frac{h}{D}\right]_{EFF_{LR}} \le 1.3$; $\left(\frac{D}{T}\right)_L = K_{\frac{D}{T}1}\left[\frac{h}{D}\right]^2_{EFF_{LR}} + K_{\frac{D}{T}2}\left[\frac{h}{D}\right]_{EFF_{LR}} + K_{\frac{D}{T}3}$;

$\&$ $\left(\frac{M}{T}\right)_R = K_{\frac{M}{T}1}\left[\frac{h}{D}\right]^2_{EFF_{LR}} + K_{\frac{M}{T}2}\left[\frac{h}{D}\right]_{EFF_{LR}} + K_{\frac{M}{T}3}$

IF: $\left[\frac{h}{D}\right]_{EFF_{LR}} > 1.3$; $\left(\frac{D}{T}\right)_L = K_{\frac{D}{T}4}$; $\&$ $\left(\frac{M}{T}\right)_L = K_{\frac{M}{T}4}$

IF: $\left[\frac{h}{D}\right]_{EFF_{RR}} \le 1.3$; $\left(\frac{D}{T}\right)_R = K_{\frac{D}{T}1}\left[\frac{h}{D}\right]^2_{EFF_{RR}} + K_{\frac{D}{T}2}\left[\frac{h}{D}\right]_{EFF_{RR}} + K_{\frac{D}{T}3}$

$\&$ $\left(\frac{M}{T}\right)_R = K_{\frac{M}{T}1}\left[\frac{h}{D}\right]^2_{EFF_{RR}} + K_{\frac{M}{T}2}\left[\frac{h}{D}\right]_{EFF_{RR}} + K_{\frac{M}{T}3}$

IF: $\left[\frac{h}{D}\right]_{EFF_{RR}} > 1.3$; $\left(\frac{D}{T}\right)_R = K_{\frac{D}{T}4}$; $\&$ $\left(\frac{M}{T}\right)_R = K_{\frac{M}{T}4}$

WING A.C. TO ELASTIC AXIS TRANSFORM

PITCHING MOMENT

$$M^{RW}_{AERO} = C_{MSRW}\ q_{SRW}\ \frac{S_W}{2}\ c_W - X_{WAC}\ Z^{RW}_{AERO} + Z_{WAC}\ X^{RW}_{AERO}$$

$$M^{LW}_{AERO} = C_{MSLW}\ q_{SLW}\ \frac{S_W}{2}\ c_W - X_{WAC}\ Z^{LW}_{AERO} + Z_{WAC}\ X^{LW}_{AERO}$$

VERTICAL FORCES

$$Z^{RW'}_{AERO} = \left[-C_{LSRW} - C_{DSRW}\ \alpha'_{RWO} \right] q_{SRW}\ \frac{S_W}{2}$$

$$Z^{LW'}_{AERO} = \left[-C_{LSLW} - C_{DSLW}\ \alpha'_{LWO} \right] q_{SLW}\ \frac{S_W}{2}$$

NOTE: $Z^{RW'}_{AERO}$ & $Z^{LW'}_{AERO}$ ARE USED IN VERTICAL BENDING EQ.'S

Wing Force & Moment Resolution - Body Axes @ C.G.

$$X^{LW}_{AERO} = \left[-C_{DSLW} + C_{LSLW}\,\alpha'_{LWO} \right] q_{SLW} \frac{S_W}{2}$$

$$X^{RW}_{AERO} = \left[-C_{DSRW} + C_{LSRW}\,\alpha'_{RWO} \right] q_{SRW} \frac{S_W}{2}$$

$$Y^{LW}_{AERO} = \left[-C_{DSLW}\,\beta_{LWO} \right] q_{SLW} \frac{S_W}{2}$$

$$Y^{RW}_{AERO} = \left[-C_{DSRW}\,\beta_{RWO} \right] q_{SRW} \frac{S_W}{2}$$

$$\left.\begin{matrix} Z^{LW}_{AERO} \\ Z^{RW}_{AERO} \end{matrix}\right\} \text{From Vertical Bending}$$

$$\mathcal{L}^{W}_{AERO} = C_{\mathcal{L}SW}\,\bar{q}_S\,S_W\,b_W$$

$$\mathcal{M}^{W}_{AERO} = M^{LW}_{AERO} + M^{RW}_{AERO} + X_{CG}\left(Z^{LW}_{AERO} + Z^{RW}_{AERO}\right) - Z_{CG}\left(X^{LW}_{AERO} + X^{RW}_{AERO}\right)$$

$$\mathcal{N}^{W}_{AERO} = C_{\mathcal{N}SW}\,\bar{q}_S\,S_W\,b_W$$

Note: Observe Wing Equation Special Conditions

HORIZONTAL AND VERTICAL TAIL AERODYNAMICS

WING AND TAIL ALTITUDE ~ GROUND EFFECT

$$h_{w_{c/4}} = -Z_{DOWN} + (X_{wAC} - X_{CG})\,\text{SIN}\,\theta + (Z_{CG} - Z_{wAC})\,\text{COS}\,\theta$$

$$h_{T_{c/4}} = -Z_{DOWN} + (X_{HT} - X_{CG})\,\text{SIN}\,\theta + (Z_{CG} - Z_{HT})\,\text{COS}\,\theta$$

HORIZONTAL TAIL ANGLE OF ATTACK

$$\ell_{AC} = X_{wAC} - X_{HT} \qquad \text{(PRELIMINARY)}$$

$$GEF = \left[b_w^2 + 4(h_{T_{c/4}} - h_{w_{c/4}})^2\right] \Big/ \left[b_w^2 + 4(h_{T_{c/4}} + h_{w_{c/4}})^2\right]$$

IF: $\bar{\epsilon}_P \dfrac{(1-GEF)}{\sqrt{1-M^2}} \geq \left[\epsilon_0 + \dfrac{d\epsilon}{d\alpha}\left(\bar{\alpha}_w - \ell_{AC}\dfrac{\dot{w}}{u^2}\right)\right]\dfrac{(1-GEF)}{\sqrt{1-M^2}}$

$$\epsilon = \frac{\bar{\epsilon}_P (1-GEF)}{\sqrt{1-M^2}}$$

IF: $\dfrac{\bar{\epsilon}_P (1-GEF)}{\sqrt{1-M^2}} < \left[\epsilon_0 + \dfrac{d\epsilon}{d\alpha}\left(\bar{\alpha}_w - \ell_{AC}\dfrac{\dot{w}}{u^2}\right)\right]\dfrac{(1-GEF)}{\sqrt{1-M^2}}$

$$\epsilon = \left[\epsilon_0 + \frac{d\epsilon}{d\alpha}\left(\bar{\alpha}_w - \ell_{AC}\frac{\dot{w}}{u^2}\right)\right]\frac{(1-GEF)}{\sqrt{1-M^2}}$$

USE FOR RESOLUTION OF FORCES: $\alpha_{HT} = \text{TAN}^{-1}\left[\dfrac{w_{HT}}{u_{HT}}\right] - \epsilon + i_{HT}$;

NOTE:- IF $u < 0$: $\alpha_{HT} = \text{TAN}^{-1}\left[\dfrac{w_{HT}}{u_{HT}}\right] + i_{HT}$

WHERE $\epsilon_0 = f(\delta_L + \delta_R).5$ AND $\dfrac{d\epsilon}{d\alpha} = f(\delta_L + \delta_R).5$

IF: $|\alpha_{HT}| > 180°$; $\underbrace{\alpha_{HT} = -(\text{SIGN}\,\alpha_{HT})360° + \alpha_{HT}}_{\text{USE ONLY IN EQ. FOR FORCE AND MOMENT COEFF.}}$

HORIZONTAL TAIL LIFT AND DRAG.

$$\alpha_{e_{HT}} = \alpha_{HT} + \tau_{HT}\,\delta e$$

$$\hat{\alpha}_{HT_+} = (\alpha_{HT_{STALL}} - 2^\circ) + \tau_{HT}\,\delta e$$

$$\hat{\alpha}_{HT_-} = -(\alpha_{HT_{STALL}} - 2^\circ) + \tau_{HT}\,\delta e$$

$$C_{L\alpha} = C_{L\alpha_{HT}} \left(\frac{a_q}{a}\right)_{HT} \Big/ \sqrt{1-M^2}$$

WHERE $\left(\frac{a_q}{a}\right)_{HT} = f(h_{TC/4})$; $\tau_{HT} = f(S_e/S_T)$

IF:- $\hat{\alpha}_{HT_-} \le \alpha_{e_{HT}} \le \hat{\alpha}_{HT_+}$

$$C_{L_{HT}} = C_{L\alpha}\,\alpha_{e_{HT}}$$

$$C_{D_{HT}} = C_{D_{O_{HT}}} + \frac{2C_{L_{HT}}^2}{\pi\, A\!R_{HT}}$$

IF:- $\hat{\alpha}_{HT_+} < \alpha_{e_{HT}} \le 90^\circ$

$$C_{L_{HT}} = C_{L\alpha}\,\hat{\alpha}_{HT_+} \left[\frac{90^\circ - \alpha_{e_{HT}}}{90^\circ - \hat{\alpha}_{HT_+}}\right]$$

$$C_{L_{HT_{STALL}}} = C_{L\alpha}\,\hat{\alpha}_{HT_+}$$

$$C_{D_{HT_{STALL}}} = C_{D_{O_{HT}}} + \frac{2C_{L_{HT_{STALL}}}^2}{\pi\, A\!R_{HT}}$$

$$C_{D_{HT}} = C_{D_{HT_{STALL}}} + \frac{(\alpha_{e_{HT}} - \hat{\alpha}_{HT_+})(1.1 - C_{D_{HT_{STALL}}})}{90^\circ - \hat{\alpha}_{HT_+}}$$

HORIZONTAL AND VERTICAL TAIL AERODYNAMICS (CONT'D)

HORIZONTAL TAIL LIFT AND DRAG (CONT'D)

IF:- $90° < \alpha_{eHT} \leq (180° - .5\,\hat{\alpha}_{HT-})$

$$C_{L_{HT}} = .5\, C_{L\alpha}\, \hat{\alpha}_{HT-}\, \frac{(\alpha_{eHT} - 90°)}{(90° - .5\,\hat{\alpha}_{HT-})}$$

$$C_{L_{HTSTALL}} = .5\, C_{L\alpha}\, \hat{\alpha}_{HT-}$$

$$C_{D_{HTSTALL}} = \frac{2\, C_{L_{HTSTALL}}^2}{\pi\, AR_{HT}} + C_{D_{0HT}}$$

$$C_{D_{HT}} = C_{D_{HTSTALL}} + \frac{(\alpha_{eHT} + .5\,\hat{\alpha}_{HT-} - 180°)(1.1 - C_{D_{HTSTALL}})}{(.5\,\hat{\alpha}_{HT-} - 90°)}$$

IF:- $(180° - .5\hat{\alpha}_{HT-}) \leq \alpha_{eHT} \leq 180°$

$$C_{L_{HT}} = C_{L\alpha}\,(\alpha_{eHT} - 180°)$$

$$C_{D_{HT}} = C_{D_{0HT}} + \frac{2\, C_{L_{HT}}^2}{\pi\, AR_{HT}}$$

IF:- $-90° \leq \alpha_{eHT} < \hat{\alpha}_{HT-}$

$$C_{L_{HT}} = C_{L\alpha}\, \hat{\alpha}_{HT-}\, \frac{(-90° - \alpha_{eHT})}{(-90° - \hat{\alpha}_{HT-})}$$

$$C_{L_{HTSTALL}} = C_{L\alpha}\, \hat{\alpha}_{HT-}$$

$$C_{D_{HTSTALL}} = C_{D_{0HT}} + \frac{2\, C_{L_{HTSTALL}}^2}{\pi\, AR_{HT}}$$

$$C_{D_{HT}} = C_{D_{HTSTALL}} + \frac{(\alpha_{eHT} - \hat{\alpha}_{HT-})(1.1 - C_{D_{HTSTALL}})}{(-90° - \hat{\alpha}_{HT-})}$$

HORIZONTAL TAIL LIFT AND DRAG (CONT'D)

IF:- $(-180° + .5\hat{\alpha}_{HT_+}) < \alpha_{e_{HT}} < -90°$

$$C_{L_{HT}} = .5\, C_{L_\alpha}\, \hat{\alpha}_{HT_+} \frac{(\alpha_{e_{HT}} + 90°)}{(-90° + .5\hat{\alpha}_{HT_+})}$$

$$C_{L_{HT STALL}} = .5\, C_{L_\alpha}\, \hat{\alpha}_{HT_+}$$

$$C_{D_{HT STALL}} = C_{D_{0_{HT}}} + \frac{2\, C^2_{L_{HT STALL}}}{\pi A\!\!R_{HT}}$$

$$C_{D_{HT}} = C_{D_{HT STALL}} - \frac{(\alpha_{e_{HT}} + 180° - .5\hat{\alpha}_{HT_+})(1.1 - C_{D_{HT STALL}})}{(.5\hat{\alpha}_{HT_+} - 90°)}$$

IF:- $-180° \le \alpha_{e_{HT}} < (-180° + .5\hat{\alpha}_{HT_+})$

$$C_{L_{HT}} = C_{L_\alpha}(\alpha_{e_{HT}} + 180°)$$

$$C_{D_{HT}} = C_{D_{0_{HT}}} + \frac{2\, C^2_{L_{HT}}}{\pi A\!\!R_{HT}}$$

HORIZONTAL AND VERTICAL TAIL AERODYNAMICS (CONT'D)

VERTICAL TAIL AERODYNAMICS

VERTICAL TAIL ANGLE OF ATTACK AND SIDESLIP

$$\beta_{VT} = TAN^{-1} \frac{v_{VT}}{\sqrt{u_{VT}^2 + w_{VT}^2}}$$

$$\alpha_{VT} = -\beta_{VT} + \beta_F \left(\frac{d\sigma}{d\beta}\right)$$ {NOTE: THIS VALUE OF α_{VT} IS USED IN RESOLUTION OF FORCES AND MOMENTS}

IF: $|\alpha_{VT}| > 180°$; $\alpha_{VT} = \alpha_{VT} - (SIGN\ \alpha_{VT})(360°)$ {NOTE: THIS VALUE OF α_{VT} ONLY USED IN CALC. OF FORCE AND MOMENT COEFFICIENTS}

$$\alpha_{e_{VT}} = (\alpha_{VT} + I_{VT}\,\delta_{RUD})$$

$$\hat{\alpha}_{VT_+} = (\alpha_{VT_{STALL}} - 2°) + I_{VT}\,\delta_{RUD}$$

$$\hat{\alpha}_{VT_-} = -(\alpha_{VT_{STALL}} - 2°) + I_{VT}\,\delta_{RUD}$$

$$C_{Y_\alpha} = C_{Y_{\alpha VT}} / \sqrt{1-M^2}$$

TAIL DYNAMIC PRESSURE AND SIDEWASH

$$\bar{q} = \frac{\rho}{2}(u^2 + v^2 + w^2)$$

$$\sigma = \frac{d\sigma}{d\beta}\,\beta_F$$

VERTICAL TAIL LIFT AND DRAG

IF:- $\hat{\alpha}_{VT_-} \le \alpha_{e_{VT}} \le \hat{\alpha}_{VT_+}$

$$C_{Y_{VT}} = C_{Y_\alpha}\,\alpha_{e_{VT}}$$

$$C_{D_{VT}} = C_{D_{0_{VT}}} + \frac{2\,C_{Y_{VT}}^2}{\pi\, AR_{VT}}$$

HORIZONTAL AND VERTICAL TAIL AERODYNAMICS (CONT'D)

VERTICAL TAIL LIFT AND DRAG (CONT'D)

IF:- $\hat{\alpha}_{VT_+} < \alpha_{e_{VT}} \leq 90°$

$$C_{Y_{VT}} = C_{Y_\alpha} \hat{\alpha}_{VT_+} \left[\frac{90° - \alpha_{e_{VT}}}{90° - \hat{\alpha}_{VT_+}} \right]$$

$$C_{Y_{VT_{STALL}}} = C_{Y_\alpha} \hat{\alpha}_{VT_+}$$

$$C_{D_{VT_{STALL}}} = C_{D_{0_{VT}}} + \frac{2\, C^2_{Y_{VT_{STALL}}}}{\pi\, AR_{VT}}$$

$$C_{D_{VT}} = C_{D_{VT_{STALL}}} + \frac{(\alpha_{e_{VT}} - \hat{\alpha}_{VT_+})(1.1 - C_{D_{VT_{STALL}}})}{90° - \hat{\alpha}_{VT_+}}$$

IF:- $90° < \alpha_{e_{VT}} \leq (180° - .5\, \hat{\alpha}_{VT_-})$

$$C_{Y_{VT}} = .5\, C_{Y_\alpha} \hat{\alpha}_{VT_-} \left(\frac{\alpha_{e_{VT}} - 90°}{90° - .5\, \hat{\alpha}_{VT_-}} \right)$$

$$C_{Y_{VT_{STALL}}} = .5\, C_{Y_\alpha} \hat{\alpha}_{VT_-}$$

$$C_{D_{VT_{STALL}}} = C_{D_{0_{VT}}} + \frac{2\, C^2_{Y_{VT_{STALL}}}}{\pi\, AR_{VT}}$$

$$C_{D_{VT}} = C_{D_{VT_{STALL}}} + \frac{(\alpha_{e_{VT}} + .5\, \hat{\alpha}_{VT_-} - 180°)(1.1 - C_{D_{VT_{STALL}}})}{(.5\, \hat{\alpha}_{VT_-} - 90°)}$$

IF:- $(180° - .5\, \hat{\alpha}_{VT_-}) \leq \alpha_{e_{VT}} \leq 180°$

$$C_{Y_{VT}} = C_{Y_\alpha} (\alpha_{e_{VT}} - 180°)$$

$$C_{D_{VT}} = C_{D_{0_{VT}}} + \frac{2\, C^2_{Y_{VT}}}{\pi\, AR_{VT}}$$

VERTICAL TAIL LIFT AND DRAG (CONT'D)

IF:- $-90° \le \alpha_{e_{VT}} < \hat{\alpha}_{VT_-}$

$$C_{Y_{VT}} = C_{Y_\alpha} \hat{\alpha}_{VT_-} \frac{(-90° - \alpha_{e_{VT}})}{(-90° - \hat{\alpha}_{VT_-})}$$

$$C_{Y_{VT_{STALL}}} = C_{Y_\alpha} \hat{\alpha}_{VT_-}$$

$$C_{D_{VT_{STALL}}} = C_{D_{0_{VT}}} + \frac{2\, C^2_{Y_{VT_{STALL}}}}{\pi \, AR_{VT}}$$

$$C_{D_{VT}} = C_{D_{VT_{STALL}}} + \frac{(\alpha_{e_{VT}} - \hat{\alpha}_{VT_-})(1.1 - C_{D_{VT_{STALL}}})}{(-90° - \hat{\alpha}_{VT_-})}$$

IF:- $(-180° + .5\,\hat{\alpha}_{VT_+}) < \alpha_{e_{VT}} < -90°$

$$C_{Y_{VT}} = .5\, C_{Y_\alpha} \hat{\alpha}_{VT_+} \frac{(\alpha_{e_{VT}} + 90°)}{(-90° + .5\,\hat{\alpha}_{VT_+})}$$

$$C_{Y_{VT_{STALL}}} = .5\, C_{Y_\alpha} \hat{\alpha}_{VT_+}$$

$$C_{D_{VT_{STALL}}} = C_{D_{0_{VT}}} + \frac{2\, C^2_{Y_{VT_{STALL}}}}{\pi \, AR_{VT}}$$

$$C_{D_{VT}} = C_{D_{VT_{STALL}}} - \frac{(\alpha_{e_{VT}} + 180° - .5\,\hat{\alpha}_{VT_+})(1.1 - C_{D_{VT_{STALL}}})}{(.5\,\hat{\alpha}_{VT_+} - 90°)}$$

IF:- $-180° \le \alpha_{e_{VT}} < (-180° + .5\,\hat{\alpha}_{VT_+})$

$$C_{Y_{VT}} = C_{Y_\alpha} (\alpha_{e_{VT}} + 180°)$$

$$C_{D_{VT}} = C_{D_{0_{VT}}} + \frac{2\, C^2_{Y_{VT}}}{\pi \, AR_{VT}}$$

HORIZONTAL AND VERTICAL TAIL AERODYNAMICS (CONT'D)

TAIL EQUATIONS LOGIC

HORIZONTAL TAIL

1. IF $h_{w_{c/4}} > 100$ FT., SET GEF = 0.0

2. IF THE UMBRELLAS OPEN; SET $\epsilon = \dfrac{\bar{\epsilon}_p (1 - GEP)}{\sqrt{1 - M^2}}$

3. IF $\alpha_{e_{HT}} > \hat{\alpha}_{HT_+}$ PRINT STALL WARNING.

4. IF $\alpha_{e_{HT}} < \hat{\alpha}_{HT_-}$ PRINT STALL WARNING

VERTICAL TAIL

1. IF $\alpha_{e_{VT}} > \hat{\alpha}_{VT_+}$ PRINT STALL WARNING

2. IF $\alpha_{e_{VT}} < \hat{\alpha}_{VT_-}$ PRINT STALL WARNING

TAIL FORCE AND MOMENT RESOLUTION TO C.G.

HORIZONTAL TAIL NOTE:- IF UMBRELLAS OPEN AND $\mu > 0$; SET $\eta_{HT} = .5\,\eta_{HT}$

$$X_{AERO}^{HT} = \left[-C_{DHT} \cos(\alpha_{HT} - i_{HT}) \cos(\beta_{VT} - \sigma) + C_{LHT} \sin(\alpha_{HT} - i_{HT}) \right] \bar{q}\, S_{HT}\, \eta_{HT}$$

$$Y_{AERO}^{HT} = \left[-C_{DHT} \sin(\beta_{VT} - \sigma) \right] \bar{q}\, S_{HT}\, \eta_{HT}$$

$$Z_{AERO}^{HT} = \left[-C_{LHT} \cos(\alpha_{HT} - i_{HT}) - C_{DHT} \cos(\beta_{VT} - \sigma) \sin(\alpha_{HT} - i_{HT}) \right] \bar{q}\, S_{HT}\, \eta_{HT}$$

$$\mathcal{L}_{AERO}^{HT} = -Y_{AERO}^{HT} (Z_{HT} - Z_{CG})$$

$$\mathcal{M}_{AERO}^{HT} = Z_{AERO}^{HT} (X_{CG} - X_{HT}) + X_{AERO}^{HT} (Z_{HT} - Z_{CG})$$

$$\mathcal{N}_{AERO}^{HT} = -Y_{AERO}^{HT} (X_{CG} - X_{HT})$$

VERTICAL TAIL

$$X_{AERO}^{VT} = \left[-C_{DVT} \cos(\beta_{VT} - \sigma) \cos(\alpha_{HT} - i_{HT}) - C_{yVT} \sin(\beta_{VT} - \sigma) \cos(\alpha_{HT} - i_{HT}) \right] \times \bar{q}\, S_{VT}\, \eta_{VT}$$

$$Y_{AERO}^{VT} = \left[C_{yVT} \cos(\beta_{VT} - \sigma) - C_{DVT} \sin(\beta_{VT} - \sigma) \right] \bar{q}\, S_{VT}\, \eta_{VT}$$

$$Z_{AERO}^{VT} = \left[-C_{DVT} \cos(\beta_{VT} - \sigma) \sin(\alpha_{HT} - i_{HT}) - C_{yVT} \sin(\beta_{VT} - \sigma) \sin(\alpha_{HT} - i_{HT}) \right] \bar{q}\, S_{VT}\, \eta_{VT}$$

$$\mathcal{L}_{AERO}^{VT} = -Y_{AERO}^{VT} (Z_{VT} - Z_{CG})$$

$$\mathcal{M}_{AERO}^{VT} = Z_{AERO}^{VT} (X_{CG} - X_{VT}) + X_{AERO}^{VT} (Z_{VT} - Z_{CG})$$

$$\mathcal{N}_{AERO}^{VT} = -Y_{AERO}^{VT} (X_{CG} - X_{VT})$$

TOTAL TAIL CONTRIBUTION

$$X_{AERO}^{T} = X_{AERO}^{VT} + X_{AERO}^{HT} \;;\; Z_{AERO}^{T} = Z_{AERO}^{VT} + Z_{AERO}^{HT} \qquad \mathcal{M}_{AERO}^{T} = \mathcal{M}_{AERO}^{VT} + \mathcal{M}_{AERO}^{HT}$$

$$Y_{AERO}^{T} = Y_{AERO}^{VT} + Y_{AERO}^{HT} \;;\; \mathcal{L}_{AERO}^{T} = \mathcal{L}_{AERO}^{VT} + \mathcal{L}_{AERO}^{HT} \qquad \mathcal{N}_{AERO}^{T} = \mathcal{N}_{AERO}^{VT} + \mathcal{N}_{AERO}^{HT}$$

NACELLE AERODYNAMICS

NACELLE ANGLE OF ATTACK AND SIDESLIP

$$\alpha_{RN} = \tan^{-1} \frac{w_{RR}}{u_{RR}} \quad ; \quad q_{RN} = \frac{1}{2}\rho V_{RR}^2$$

$$\alpha_{LN} = \tan^{-1} \frac{w_{RL}}{u_{RL}} \quad ; \quad q_{LN} = \frac{1}{2}\rho V_{LR}^2$$

$$\beta_{RN} = \tan^{-1} \frac{v_{RR}}{\sqrt{u_{RR}^2 + w_{RR}^2}}$$

$$\beta_{LN} = \tan^{-1} \frac{v_{RL}}{\sqrt{u_{RL}^2 + w_{RL}^2}}$$

NACELLE WIND AXIS FORCE & MOMENT COEF.'S

$$C_{DRN} = C_{DORN} + K_{30} \left| \alpha_{RN} \right| + K_{31} \left| \alpha_{RN}^2 \right|$$

$$C_{DLN} = C_{DOLN} + K_{30} \left| \alpha_{LN} \right| + K_{31} \left| \alpha_{LN}^2 \right|$$

NOTE: CHECK RANGE OF α_{RN} & α_{LN} TO DETERMINE VALUES FOR CONSTANTS.

WHERE: $C_{DORN} = C_{DON}$

$C_{DOLN} = C_{DON}$

$$C_{LRN} = K_{32} \sin\alpha_{RN} \cos\alpha_{RN}$$

$$C_{LLN} = K_{32} \sin\alpha_{LN} \cos\alpha_{LN}$$

$$C_{MRN} = C_{MON} + K_{34} \sin\alpha_{RN} \cos\alpha_{RN} + K_{35} (\sin\alpha_{RN} \cos\alpha_{RN}) \left| \sin\alpha_{RN} \cos\alpha_{RN} \right|$$

$$C_{MLN} = C_{MON} + K_{34} \sin\alpha_{LN} \cos\alpha_{LN} + K_{35} (\sin\alpha_{LN} \cos\alpha_{LN}) \left| \sin\alpha_{LN} \cos\alpha_{LN} \right|$$

SPECIAL CONDITIONS

1. IF: $V_{RR}^2 \leq 1 (ft/sec)^2$; RIGHT NACELLE AERO $\equiv 0.0$ & HOLD VALUE OF α_{RN} & β_{RN}
2. IF: $V_{LR}^2 \leq 1 (ft/sec)^2$; LEFT NACELLE AERO $\equiv 0.0$ & HOLD VALUE OF α_{LN} & β_{LN}

Nacelle Aerodynamics (Cont'd.)

$$C_{YRN} = K_{36} \sin\beta_{RN} \cos\beta_{RN} + K_{37}(\sin\beta_{RN} \cos\beta_{RN}) \left| \sin\beta_{RN} \cos\beta_{RN} \right|$$

$$C_{YLN} = K'_{36} \sin\beta_{LN} \cos\beta_{LN} + K'_{37}(\sin\beta_{LN} \cos\beta_{LN}) \left| \sin\beta_{LN} \cos\beta_{LN} \right|$$

$$C_{NRN} = C_{N0RN} + K_{38} \sin\beta_{RN} \cos\beta_{RN} + K_{39}(\sin\beta_{RN} \cos\beta_{RN}) \left| \sin\beta_{RN} \cos\beta_{RN} \right|$$

$$C_{NLN} = C_{N0LN} + K_{40} \sin\beta_{LN} \cos\beta_{LN} + K_{41}(\sin\beta_{LN} \cos\beta_{LN}) \left| \sin\beta_{LN} \cos\beta_{LN} \right|$$

$$C_{ZRN} = C_{ZLN} \equiv 0.0$$

Nacelle Forces & Moments – Nacelle Axes

RIGHT

$$\Delta X'_{RN} = q_{RN} S_w \left[-C_{DRN} \cos\alpha_{RN} + C_{LRN} \sin\alpha_{RN} - C_{YRN} \sin\beta_{RN} \cos\alpha_{RN} \right] \frac{1}{2}$$

$$\Delta Y'_{RN} = q_{RN} S_w \left[C_{YRN} \cos\beta_{RN} - C_{DRN} \sin\beta_{RN} \right] \frac{1}{2}$$

$$\Delta Z'_{RN} = q_{RN} S_w \left[-C_{LRN} \cos\alpha_{RN} - C_{DRN} \cos\beta_{RN} \sin\alpha_{RN} - C_{YRN} \sin\beta_{RN} \sin\alpha_{RN} \right] \frac{1}{2}$$

$$\Delta \mathcal{L}'_{RN} = q_{RN} S_w b_w \left[-\left(\frac{c_w}{b_w}\right) C_{MRN} \sin\beta_{RN} \cos\alpha_{RN} - C_{NRN} \sin\alpha_{RN} \right] \frac{1}{2}$$

$$\Delta \mathcal{M}'_{RN} = q_{RN} S_w c_w \left[C_{MRN} \cos\beta_{RN} \right] \frac{1}{2}$$

$$\Delta \mathcal{N}'_{RN} = q_{RN} S_w b_w \left[C_{NRN} \cos\alpha_{RN} - \left(\frac{c_w}{b_w}\right) C_{MRN} \sin\beta_{RN} \cos\alpha_{RN} \right] \frac{1}{2}$$

LEFT

$$\Delta X'_{LN} = q_{LN} S_w \left[-C_{DLN} \cos\alpha_{LN} + C_{LLN} \sin\alpha_{LN} - C_{YLN} \sin\beta_{LN} \cos\alpha_{LN} \right] \frac{1}{2}$$

$$\Delta Y'_{LN} = q_{LN} S_w \left[C_{YLN} \cos\beta_{LN} - C_{DLN} \sin\beta_{LN} \right] \frac{1}{2}$$

$$\Delta Z'_{LN} = q_{LN} S_w \left[-C_{LLN} \cos\alpha_{LN} - C_{DLN} \cos\beta_{LN} \sin\alpha_{LN} - C_{YLN} \sin\beta_{LN} \sin\alpha_{LN} \right] \frac{1}{2}$$

$$\Delta \mathcal{L}'_{LN} = q_{LN} S_w b_w \left[-\left(\frac{c_w}{b_w}\right) C_{MLN} \sin\beta_{LN} \cos\alpha_{LN} - C_{NLN} \sin\alpha_{LN} \right] \frac{1}{2}$$

$$\Delta \mathcal{M}'_{LN} = q_{LN} S_w c_w \left[C_{MLN} \cos\beta_{LN} \right] \frac{1}{2}$$

$$\Delta \mathcal{N}'_{LN} = q_{LN} S_w b_w \left[C_{NLN} \cos\alpha_{LN} - \left(\frac{c_w}{b_w}\right) C_{MLN} \sin\beta_{LN} \cos\alpha_{LN} \right] \frac{1}{2}$$

LANDING GEAR EQUATIONS

PERFORM THE FOLLOWING CALCULATIONS FOR EACH OF THREE LANDING GEAR i.e. $n = 1, 2 \& 3$.

LANDING GEAR - A/C LOCATION

$n = 1$ LEFT MAIN GEAR
$n = 2$ RIGHT MAIN GEAR
$n = 3$ NOSE GEAR

$$X_n = -X_{CG} + X_{Gn}$$

$$Y_n = Y_{Gn}$$

$$Z_n = -Z_{CG} + Z_{Gn}$$

Strut Deflection

$$h_{G\theta n} = X_n \sin\theta - Z_n \cos\theta - r_n$$

$$h_{G\phi n} = \left[Y_n \sin\phi + (Z_n + r_n)(\cos\phi - 1) \right] \cos\theta$$

$$h_{Tn} = \left(-Z_{Down} + h_{G\theta n} - h_{G\phi n} \right) / (\cos\phi \cos\theta)$$

Rate of Strut Deflection

$$\dot{h}_{Tn} = -\dot{Z}_{Down} \left(\frac{1}{\cos\phi\cos\theta} \right) + X_n q - Y_n p$$

Vertical force

$$F_{GZn} = K_{STn} h_{Tn} + D_{STn} \dot{h}_{Tn}$$

NOTE: COMPUTE F_{GZn} ONLY IF $h_{Tn} < 0$;

IF $h_{Tn} > 0$; $F_{GZn} = 0.0 \phi$

REMAINING CALCULATIONS MAY BE SET

TO ZERO.

LANDING GEAR EQUATIONS (Cont'd.)

Longitudinal force:

$$F_{\mu n} = +(\mu_o + \mu_1 B_{Gn}) F_{GZn} \frac{+u}{|u|}$$

i.e. IF $u > 0$ $F_{\mu n}$ is negative
IF $u < 0$ $F_{\mu n}$ is positive
IF $u = 0$ $F_{\mu n} \equiv 0.0$

NOTE: B_{Gn} is percent brake pedal deflection

Side force:

$$F_{Sn} = \mu_S F_{GZn} \frac{+v}{|v|}$$

i.e. IF $v > 0$ F_{Sn} is negative
IF $v < 0$ F_{Sn} is positive
IF $v \equiv 0$ $F_{Sn} = 0.0$

FORCE & MOMENT CONTRIBUTION OF EACH GEAR

$$\Delta X_n = F_{\mu n} - F_{GZn}\theta$$

$$\Delta Y_n = F_{Sn} + F_{GZn}\phi$$

$$\Delta Z_n = F_{\mu n}\theta - F_{Sn}\phi + F_{GZn}$$

$$\Delta \mathcal{M}_n = -\Delta Z_n X_n + \Delta X_n (Z_n + r_n + h_{Tn})$$

$$\Delta \mathcal{L}_n = \Delta Z_n Y_n - \Delta Y_n (Z_n + r_n + h_{Tn})$$

$$\Delta \mathcal{N}_n = -\Delta X_n Y_n + X_n \Delta Y_n$$

LANDING GEAR EQUATIONS (Cont'd.)

$$\Delta X_{LG} = \sum_{1}^{3} \Delta X_n$$

$$\Delta Y_{LG} = \sum_{1}^{3} \Delta Y_n$$

$$\Delta Z_{LG} = \sum_{1}^{3} \Delta Z_n$$

$$\Delta \mathcal{L}_{LG} = \sum_{1}^{3} \Delta \mathcal{L}_n$$

$$\Delta \mathcal{M}_{LG} = \sum_{1}^{3} \Delta \mathcal{M}_n$$

$$\Delta \mathcal{N}_{LG} = \sum_{1}^{3} \Delta \mathcal{N}_n$$

FUSELAGE AERODYNAMICS

FUSELAGE INPUT EQUATIONS

$$\alpha_F = \tan^{-1}\frac{w}{u} \qquad \beta_F = \tan^{-1}\frac{v}{\sqrt{u^2+w^2}}$$

$$\alpha'_P = \sin\alpha_F \cos\alpha_F \qquad \beta'_F = \sin\beta_F \cos\beta_F$$

$$V_F = \sqrt{u^2+v^2+w^2}$$

$$q_F = \frac{1}{2}\rho V_F^2$$ (q) SAME AS TAIL DYNAMIC PRESSURE

$$V_{FUS} = V_F\sqrt{\sigma_h}$$

FUSELAGE WIND AXIS COEF'S.

$$C_{DF} = C_{DOF}\left(1+K_0|\beta_F|^3\right) + K_2\alpha_F^2 + K_1|\alpha_F| + \Delta C_{DLG}$$

$$C_{LF} = K_3\alpha'_F + K_4\alpha'_F|\alpha'_F| + K42$$

$$C_{YF} = K_7\beta'_F + K_8\beta'_F|\beta'_F|$$

$$C_{MF} = C_{MOF} + K_5\alpha'_F + K_6\alpha'_F|\alpha'_F| + \Delta C_{MLG}$$

$$C_{NF} = C_{NOF} + K_9\beta'_F + K_{10}\beta'_F|\beta'_F|$$

NOTE: IF GEAR IS UP; ΔC_{DLG} & $\Delta C_{MLG} \equiv 0.0$

SPECIAL CONDITIONS

1. IF $V_F^2 \le 1\ (ft/sec)^2$ FUSELAGE AERO $= 0.0$ & HOLD VALUE OF α_F & β_F

FUSELAGE FORCES & MOMENT ABOUT A/C C.G.

$$X^{F'}_{AERO} = \left[-C_{DF} \cos\alpha_F + C_{LF} \sin\alpha_F - C_{YF} \sin\beta_F \cos\alpha_F \right] q_F S_W$$

$$Y^{F'}_{AERO} = \left[C_{YF} \cos\beta_F - C_{DF} \sin\beta_F \right] q_F S_W$$

$$Z^{F'}_{AERO} = \left[-C_{LF} \cos\alpha_F - C_{DF} \cos\beta_F \sin\alpha_F - C_{YF} \sin\beta_F \sin\alpha_F \right] q_F S_W$$

$$\mathcal{L}^{F'}_{AERO} = \left[-\left(\frac{C_W}{b_W}\right) C_{MF} \sin\beta_F \cos\alpha_F - C_{NF} \sin\alpha_F \right] q_F S_W b_W + \\ + Y^{F'}_{AERO} \left[Z_{CG} - Z_{FAC} \right]$$

$$\mathcal{M}^{F'}_{AERO} = \left[C_{MF} \cos\beta_F \right] q_F S_W C_W + Z^{F'}_{AERO} \left[X_{CG} - X_{FAC} \right] \\ - X^{F'}_{AERO} \left[Z_{CG} - Z_{FAC} \right] +$$

$$\mathcal{N}^{F'}_{AERO} = \left[C_{NF} \cos\alpha_F - \left(\frac{C_W}{b_W}\right) C_{MF} \sin\beta_F \sin\alpha_F \right] q_F S_W b_W \\ - Y^{F'}_{AERO} \left[X_{CG} - X_{FAC} \right] +$$

$$X^{F}_{AERO} = X^{F'}_{AERO} + \Delta X_{LG}$$

$$Y^{F}_{AERO} = Y^{F'}_{AERO} + \Delta Y_{LG}$$

$$Z^{F}_{AERO} = Z^{F'}_{AERO} + \Delta Z_{LG}$$

$$\mathcal{L}^{F}_{AERO} = \mathcal{L}^{F'}_{AERO} + \Delta \mathcal{L}_{LG}$$

$$\mathcal{M}^{F}_{AERO} = \mathcal{M}^{F'}_{AERO} + \Delta \mathcal{M}_{LG}$$

$$\mathcal{N}^{F}_{AERO} = \mathcal{N}^{F'}_{AERO} + \Delta \mathcal{N}_{LG}$$

WING ON ROTOR INTERFERENCE

AVERAGE NACELLE INCIDENCE

$$\bar{i}_N = 0.5\,(i_{NL} + i_{NR})$$

AVERAGE LIFT COEF.

$$C_{LW} = 0.5\,\frac{(C_{LSRW} + C_{LSLW})}{(1 - \bar{C}_{TS})}$$

LOOK-UP: ϵ_{WRR} & ϵ_{WRL} @ $\bar{i}_N$ & C_{LW}

WING INTERFERENCE LOGIC

1. IF: UMBRELLAS OPEN, SET $C_{LW} = 0.0$ & $\epsilon = \dfrac{\epsilon_P(1 - G_{EP})}{\sqrt{1-M^2}}$

ROTOR / ROTOR INTERFERENCE

POSITIVE SIDESLIP i.e., $v > 0.0$ (LOGIC REQUIRED)

$$\chi = 1.5708 - \epsilon_{PRR}$$

$$\left(\frac{\delta v_{RL}^*}{v_{RR}^*}\right) = T_1 + T_2(\chi) + T_3(\chi)^2$$

$$\delta v_{RL} = \left(\frac{\delta v_{RL}^*}{v_{RR}^*}\right) v_{xR} \sqrt{\frac{R_{RR}}{2\rho \pi R^2}}$$

$$\epsilon_{iRL}' = -\tan^{-1}\left[\frac{\delta v_{RL}}{V_{LR} + 1.0}\right]$$

$$\epsilon_{iRL} = (|\beta_F|)(.40528\, i_{NL})\, \epsilon_{iRL}'$$

$$\epsilon_{iLR} = 0.0$$

NEGATIVE SIDESLIP i.e. $v < 0.0$

$$\chi = 1.5708 - \epsilon_{PLR}$$

$$\left(\frac{\delta v_{LR}^*}{v_{LR}^*}\right) = T_1 + T_2(\chi) + T_3(\chi)^2$$

$$\delta v_{LR} = \left(\frac{\delta v_{LR}^*}{v_{RR}^*}\right) v_{xL} \sqrt{\frac{R_{LR}}{2\rho \pi R^2}}$$

$$\epsilon_{iLR}' = -\tan^{-1}\left[\frac{\delta v_{LR}}{V_{RR} + 1.0}\right]$$

$$\epsilon_{iLR} = (|\beta_F|)(.40528\, i_{NR})\, \epsilon_{iLR}'$$

$$\epsilon_{iRL} = 0.0$$

NOTE: v_{xR} & v_{xL} FROM WING EQUATIONS.

Rotor Aero Input Equations

Right Rotor

$$\alpha_{RR} = \tan^{-1}\left\{ \frac{\sqrt{V_{RR}^2 + (W_{RR} + U_{RR}\epsilon_{WRR})^2}}{U_{RR}} \right\} + \epsilon_{iLR}$$

$$V_{RR} = \sqrt{U_{RR}^2 + V_{RR}^2 + W_{RR}^2} \quad ; \quad \mu_{RR} = \frac{V_{RR}}{\Omega_R R}$$

Left Rotor

$$\alpha_{LR} = \tan^{-1}\left\{ \frac{\sqrt{V_{RL}^2 + (W_{RL} + U_{RL}\epsilon_{WRL})^2}}{U_{RL}} \right\} + \epsilon_{iRL}$$

$$V_{LR} = \sqrt{U_{RL}^2 + V_{RL}^2 + W_{RL}^2} \quad ; \quad \mu_{LR} = \frac{V_{LR}}{\Omega_L R}$$

Rotor Angular Rate Transforms

Right - Nacelle Axes

$$P_{NR}^N = -p\cos i_{NR} + r\sin i_{NR}$$

$$Q_{NR}^N = q + \dot{i}_{NR}$$

$$R_{NR}^N = -r\cos i_{NR} - p\sin i_{NR}$$

Left - Nacelle Axes

$$P_{NL}^N = p\cos i_{NL} - r\sin i_{NL}$$

$$Q_{NL}^N = q + \dot{i}_{NL}$$

$$R_{NL}^N = r\cos i_{NL} + p\sin i_{NL}$$

Right Wind Axes

$$P_{NR}^R = P_{NR}^N$$

$$Q_{NR}^R = Q_{NR}^N \cos \zeta_{HR} + R_{NR}^N \sin \zeta_{HR}$$

$$R_{NR}^R = R_{NR}^N \cos \zeta_{NR} - Q_{NR}^N \sin \zeta_{HR}$$

Left Wind Axes

$$P_{NL}^R = P_{NL}^N$$

$$Q_{NL}^R = Q_{NL}^N \cos \zeta_{HL} - R_{NL}^N \sin \zeta_{HL}$$

$$R_{NL}^R = R_{NL}^N \cos \zeta_{HL} + Q_{NL}^N \sin \zeta_{HL}$$

Note: Use Wind Axis Rates in Rotor Routine

ROTOR EQUATIONS

RIGHT ROTOR

THRUST

$$C'_{T_{RR}} = \left[\frac{\tau_1 s + 1}{\tau_2 s + 1}\right]\left[C_{T_{0RR}} \cos A_{1C_R} \cos B_{1C_R}\right]$$

WHERE:-

$$C_{T_{0RR}} = \sum_{v=0}^{2} \sum_{u=0}^{3} \left[A_{T(u+4v)} \; \alpha_{RR}^{u} \; \theta_{.75_R}^{v} \right]$$

$$A_{T(u+4v)} = f\,(\mu_{RR})$$

INTERPOLATE $C_{T_{0RR}}$ LINEARLY BETWEEN μ's

GROUND EFFECT

$$h_{RR} = -Z_{DOWN} + (L_s \cos i_{NR} - X_{CG}) \sin\theta + \left[(L_s \sin i_{NR} + Z_{CG})\cos\phi - Y_N \sin\phi\right]\cos\theta$$

$$\left(\frac{h}{D}\right)_{EFF_{RR}} = \frac{h_{RR}}{2R\left[\,|\sin(\theta + i_{NR})\cos\phi| + .0174\right]}$$

$$\left(\frac{T_{IGE}}{T_{OGE}}\right)_{RR} = \left[\left(\frac{h}{D}\right)^2_{EFF_{RR}}(.1741 - .6216\,\mu_{RR}) + \left(\frac{h}{D}\right)_{EFF_{RR}}(1.4779\,\mu_{RR} - .4143) + 1.2479 - .8806\,\mu_{RR}\right]$$

$$C_{T_{RR}} = C'_{T_{RR}}\left(\frac{T_{IGE}}{T_{OGE}}\right)_{RR}$$

SPECIAL CONDITIONS: IF $\mu_{RR} \geq 0.283$; $\left(\frac{T_{IGE}}{T_{OGE}}\right)_{RR} = 1.0$

OR IF $\left(\frac{h}{D}\right)_{EFF_{RR}} \geq 1.3$; $\left(\frac{T_{IGE}}{T_{OGE}}\right)_{RR} = 1.0$

ROTOR EQUATIONS (CONTINUED)

POWER

$$C_{P_{RR}} = C_{P_{O_{RR}}}$$

WHERE :-

$$\left.\begin{aligned} C_{P_{O_{RR}}} &= \sum_{v=0}^{2} \sum_{u=0}^{3} \left[A_{P(u+4v)}\, \alpha_{RR}^{u}\, C_{T_{RR}}'^{\,v} \right] \\ A_{P(u+4v)} &= f(\mu_{RR}) \end{aligned}\right\}$$

INTERPOLATE $C_{P_{O_{RR}}}$ LINEARLY BETWEEN μ's

NORMAL FORCE

$$C_{NF_{RR}} = C_{NF_{O_{RR}}} + \frac{d\,C_{NF_{RR}}}{d\,A_{1CR}} A_{1CR} + \frac{d\,C_{NF_{RR}}}{d\,B_{1CR}} B_{1CR}$$

WHERE :-

$$\left.\begin{aligned} C_{NF_{O_{RR}}} &= \sum_{v=0}^{2} \sum_{u=0}^{3} \left[A_{NF(u+4v)}\, \alpha_{RR}^{u}\, C_{T_{RR}}'^{\,v} \right] \\ A_{NF(u+4v)} &= f(\mu_{RR}) \end{aligned}\right\}$$

INTERPOLATE $C_{NF_{O_{RR}}}$ LINEARLY BETWEEN μ's

$$\frac{d\,C_{NF_{RR}}}{d\,A_{1CR}} = D_{NF_1} C_{T_{RR}} + D_{NF_2} \mu_{RR}^2 + D_{NF_3} \mu_{RR} + D_{NF_4}$$

$$\frac{d\,C_{NF_{RR}}}{d\,B_{1CR}} = E_{NF_1} C_{T_{RR}} + E_{NF_2} \mu_{RR}^2 + E_{NF_3} \mu_{RR} + E_{NF_4}$$

ROTOR EQUATIONS (CONTINUED)

SIDE FORCE

$$C_{SF_{RR}} = C_{SF0_{RR}} + \frac{dC_{SF_{RR}}}{dA_{1CR}} A_{1CR} + \frac{dC_{SF_{RR}}}{dB_{1CR}} B_{1CR}$$

WHERE:-

$$C_{SF0_{RR}} = \sum_{v=0}^{2} \sum_{u=0}^{3} \left[A_{SF(u+4v)} \alpha_{RR}^{u} C_{T_{RR}}^{\prime v} \right]$$

$$A_{SF(u+4v)} = f(\mu_{RR})$$

INTERPOLATE $C_{SF0_{RR}}$ LINEARLY BETWEEN μ's

$$\frac{dC_{SF_{RR}}}{dA_{1CR}} = D_{SF_1} C_{T_{RR}} + D_{SF_2} \mu_{RR}^2 + D_{SF_3} \mu_{RR} + D_{SF_4}$$

$$\frac{dC_{SF_{RR}}}{dB_{1CR}} = E_{SF_1} C_{T_{RR}} + E_{SF_2} \mu_{RR}^2 + E_{SF_3} \mu_{RR} + E_{SF_4}$$

ROTOR EQUATIONS (CONTINUED)

HUB PITCHING MOMENT

$$C_{PM_{RR}} = C_{PMo_{RR}} + \frac{d\,C_{PM_{RR}}}{d\,A_{1CR}} A_{1CR} + \frac{d\,C_{PM_{RR}}}{d\,B_{1CR}} B_{1CR} + \frac{d\,C_{PM_{RR}}}{d\,Q} Q^{R}_{NR}$$

WHERE :-

$$C_{PMo_{RR}} = \sum_{v=0}^{2} \sum_{u=0}^{3} \left[A_{PM(u+4v)}\, \alpha^{u}_{RR}\, C'^{\,v}_{T_{RR}} \right]$$

$$A_{PM(u+4v)} = f(\mu_{RR})$$

$$\frac{d\,C_{PM_{RR}}}{d\,Q} = \sum_{v=0}^{2} \sum_{u=0}^{3} \left[H_{PM(u+4v)}\, \alpha^{u}_{RR}\, C'^{\,v}_{T_{RR}} \right]$$

$$H_{PM(u+4v)} = f(\mu_{RR})$$

INTERPOLATE $C_{PMo_{RR}}$ AND $\frac{d\,C_{PM_{RR}}}{d\,Q}$ LINEARLY BETWEEN μ's

NOTE:-

FOR $\mu_{RR} \leq 0.35$

$$\frac{d\,C_{PM_{RR}}}{d\,A_{1CR}} = D_{PM_1} C_{T_{RR}} + D_{PM_2}\, \mu^2_{RR} + D_{PM_3}\, \mu_{RR} + D_{PM_4}$$

FOR $\mu_{RR} > 0.35$, THE COEFF'S ABOVE CHANGE AS FOLLOWS

$$D_{PM_2} \equiv D_{PM_5}$$

$$D_{PM_3} = D_{PM_6}$$

$$D_{PM_4} \equiv D_{PM_7}$$

ROTOR EQUATIONS (CONTINUED)

HUB PITCHING MOMENT (CONTINUED)

$$\frac{d\,C_{PMRR}}{d\,B_{1CR}} = E_{PM_1} C_{TRR} + E_{PM_2} \mu_{RR}^2 + E_{PM_3} \mu + E_{PM_4}$$

NOTE:- USE THE ABOVE EQUATION FOR $\mu_{RR} \leq 0.35$

FOR $\mu_{RR} > 0.35$: $E_{PM_2} \equiv E_{PM_5}$

$E_{PM_3} \equiv E_{PM_6}$

$E_{PM_4} \equiv E_{PM_7}$

HUB YAWING MOMENT

$$C_{YMRR} = C_{YMORR} + \frac{d\,C_{YMRR}}{d\,A_{1CR}} A_{1CR} + \frac{d\,C_{YMRR}}{d\,B_{1CR}} B_{1CR} + \frac{d\,C_{YMRR}}{d\,R} R_{\nu R}^{R}$$

WHERE:-

$$C_{YMO\,RR} = \sum_{\nu=0}^{2} \sum_{u=0}^{3} \left[A_{YM(u+4\nu)}\, \alpha_{RR}^{u}\, C_{TRR}^{\prime\,\nu} \right]$$

$$A_{YM(u+4\nu)} = f(\mu_{RR})$$

$$\frac{d\,C_{YMRR}}{d\,R} = \sum_{\nu=0}^{2} \sum_{u=0}^{3} \left[J_{YM(u+4\nu)}\, \alpha_{RR}^{u}\, C_{TRR}^{\prime\,\nu} \right]$$

$$J_{YM(u+4\nu)} = f(\mu_{RR})$$

INTERPOLATE C_{YMRR} AND $\frac{d\,C_{YMRR}}{d\,R}$ LINEARLY BETWEEN μ's.

ROTOR EQUATIONS (CONTINUED)

HUB YAWING MOMENT (CONTINUED)

FOR $\mu_{RR} \leq 0.35$

$$\frac{d\,C_{YM\,RR}}{d\,A_{1CR}} = D_{YM_1} C_{TRR} + D_{YM_2} \mu_{RR}^2 + D_{YM_3} \mu_{RR} + D_{YM_4}$$

FOR $\mu_{RR} > 0.35$

$$D_{YM_2} \equiv D_{YM_5}$$

$$D_{YM_3} \equiv D_{YM_6}$$

$$D_{YM_4} \equiv D_{YM_7}$$

FOR $\mu_{RR} \leq 0.35$

$$\frac{d\,C_{YMRR}}{d\,B_{1CR}} = E_{YM_1} C_{TRR} + E_{YM_2} \mu_{RR}^2 + E_{YM_3} \mu_{RR} + E_{YM_4}$$

FOR $\mu_{RR} > 0.35$

$$E_{YM_2} \equiv E_{YM_5}$$

$$E_{YM_3} \equiv E_{YM_6}$$

$$E_{YM_4} \equiv E_{YM_7}$$

ROTOR EQUATIONS (Cont'd)

ROTOR FORCE & MOMENT CALCULATION

$$T_R = f_{T_R} C_{TRR} \rho \pi R^4 \Omega_R^2$$

$$N.F_R = f_{N.F_R} C_{NFRR} \rho \pi R^4 \Omega_R^2$$

$$S.F_R = f_{S.F_R} C_{SFRR} \rho \pi R^4 \Omega_R^2$$

$$\mathcal{M}_R = f_{PM_R} C_{PMRR} \rho \pi R^5 \Omega_R^2$$

$$\mathcal{N}_R = f_{Y.M_R} C_{YMRR} \rho \pi R^5 \Omega_R^2$$

$$Q_{RREQ} = f_{Q_R} C_{PRR} \rho \pi R^5 \Omega_R^2$$

$$RHP_{RR} = f_{P_R} C_{PRR} \rho \pi R^5 \Omega_R^3 / 550 \quad \text{OR} \quad RHP_{RR} = Q_{RREQ} \left(\frac{\Omega_R}{550}\right)$$

LEFT ROTOR FOLLOWS SIMILAR FORMAT

WITH SUBSCRIPTS CHANGED.

THE LEFT ROTOR ALTITUDE EQUATION IS AS FOLLOWS:

$$h_{LR} = -Z_{DOWN} + (L_s \cos i_{NL} - X_{CG}) \sin\theta + \left[(L_s \sin i_{NL} + Z_{CG}) \cos\phi + Y_N \sin\phi \right] \cos\theta$$

OR;

$$h_{LR} = h_{RR} + 2 Y_N \sin\phi \cos\theta$$

Rotor Force & Moment Resolution

Hub Moments – Nacelle Axes

Left

$$\mathcal{L}_{LRH} = -Q_{LREQ} - I_p \dot{\Omega}_L$$

$$\mathcal{M}_{LRH} = \mathcal{M}_L \cos \zeta_{HL} - \mathcal{N}_L \sin \zeta_{HL}$$
$$- I_p \Omega_L (p \sin i_{NL} + r \cos i_{NL})$$

$$\mathcal{N}_{LRH} = -\mathcal{N}_L \cos \zeta_{HL} - \mathcal{M}_L \sin \zeta_{HL} + I_p \Omega_L (\dot{i}_{NL} + q)$$

Right

$$\mathcal{L}_{RRH} = Q_{RREQ} + I_p \dot{\Omega}_R$$

$$\mathcal{M}_{RRH} = \mathcal{M}_R \cos \zeta_{HR} + \mathcal{N}_R \sin \zeta_{HR}$$
$$+ I_p \Omega_R (p \sin i_{NR} + r \cos i_{NR})$$

$$\mathcal{N}_{RRH} = \mathcal{N}_R \cos \zeta_{HR} - \mathcal{M}_R \sin \zeta_{HR} - I_p \Omega_R (\dot{i}_{NR} + q)$$

NOTE: NACELLE AXES ARE RIGHT HANDED SYSTEMS

Rotor Forces & Moment Resolution (Cont'd.)

Left Tip Pivot - Body Axes @ Tip (w/ Nacelle Aero)

$$X^{NL}_{AERO} = \left(T_L + \Delta X'_{LN}\right)\cos i_{NL} - \sin i_{NL}\left(N.F._L \cos \zeta_{HL} + S.F._L \sin \zeta_{HL} - \Delta Z'_{LN}\right)$$

$$Y^{NL}_{AERO} = S.F._L \cos \zeta_{HL} - N.F._L \sin \zeta_{HL} + \Delta Y'_{LN}$$

$$Z^{NL'}_{AERO} = -\left(T_L + \Delta X'_{LN}\right)\sin i_{NL} - \cos i_{NL}\left(N.F._L \cos \zeta_{HL} + S.F._L \sin \zeta_{HL} - \Delta Z'_{LN}\right)$$

$$\mathcal{L}^{NL'}_{AERO} = \left(\mathcal{L}_{LRH} + \Delta \mathcal{L}'_{LN}\right)\cos i_{NL} + \sin i_{NL}\left(\mathcal{N}_{LRH} + \Delta \mathcal{N}'_{LN} + L_s Y^{NL}_{AERO}\right)$$

$$\mathcal{M}^{NL}_{AERO} = \mathcal{M}_{LRH} + \Delta \mathcal{M}'_{LN} + N.F._L\, L_S \cos \zeta_{HL} + S.F._L L_S \sin \zeta_{HL} - L_S \Delta Z'_{LN} - I_E \Omega_{EL}\, r$$

$$\mathcal{N}^{NL}_{AERO} = \cos i_{NL}\left(\mathcal{N}_{LRH} + \Delta \mathcal{N}'_{LN} + L_S Y^{NL}_{AERO}\right) - \sin i_{NL}\left(\mathcal{L}_{LRH} + \Delta \mathcal{L}'_{LN}\right) + I_E \Omega_{EL}\, q$$

Nacelle Equation Input - Left

$$\mathcal{M}_{NL\,AERO} = \mathcal{M}_{LRH} + \Delta \mathcal{M}'_{LN} + \left(N.F._L \cos \zeta_{HL} + S.F._L \sin \zeta_{HL} - \Delta Z'_{LN}\right) L_S$$

GLAS Inputs - Left

$$\mathcal{M}_{NL\,AERO\,GLAS} = \mathcal{M}_{LRH} + L_S\left(N.F._L \cos \zeta_{HL} + S.F._L \sin \zeta_{HL}\right)$$

$$\mathcal{N}_{NL\,AERO\,GLAS} = \mathcal{N}_{LRH} + L_S\left(S.F._L \cos \zeta_{HL} - N.F._L \sin \zeta_{HL}\right)$$

ROTOR FORCE & MOMENT RESOLUTION (Con t'd.)

RIGHT TIP PIVOT - BODY AXES @ TIP (w/ NACELLE AERO)

$$X^{NR}_{AERO} = \left(T_R + \Delta X'_{RN}\right)\cos i_{NR} + \sin i_{NR}\left(-N.F_R \cos \zeta_{HR} + S.F_R \sin \zeta_{HR} + \Delta Z'_{RN}\right)$$

$$Y^{NR}_{AERO} = -S.F_R \cos \zeta_{HR} - N.F_R \sin \zeta_{HR} + \Delta Y'_{RN}$$

$$Z^{NRP}_{AERO} = -\left(T_R + \Delta X'_{RN}\right)\sin i_{NR} + \cos i_{NR}\left(-N.F_R \cos \zeta_{HR} + S.F_R \sin \zeta_{HR} + \Delta Z'_{RN}\right)$$

$$\mathcal{L}^{NRP}_{AERO} = \left(\mathcal{L}_{RRH} + \Delta \mathcal{L}'_{RN}\right)\cos i_{NR} + \sin i_{NR}\left(\mathcal{N}_{RRH} + L_S Y^{NR}_{AERO} + \Delta \mathcal{N}'_{RN}\right)$$

$$\mathcal{M}^{NR}_{AERO} = \mathcal{M}_{RRH} + \Delta \mathcal{M}'_{RN} + N.F_R L_S \cos \zeta_{HR} - S.F_R L_S \sin \zeta_{HR} - L_S \Delta Z'_{RN} - I_E \Omega_{ER} r$$

$$\mathcal{N}^{NR}_{AERO} = \cos i_{NR}\left(\mathcal{N}_{RRH} + \Delta \mathcal{N}'_{RN} + L_S Y^{NR}_{AERO}\right) - \sin i_{NR}\left(\mathcal{L}_{RRH} + \Delta \mathcal{L}'_{RN}\right) + I_E \Omega_{ER} q$$

NACELLE EQUATION INPUT - RIGHT

$$\mathcal{M}_{NR\,AERO} = \mathcal{M}_{RRH} + \Delta \mathcal{M}'_{RN} + \left(N.F_R \cos \zeta_{HR} - S.F_R \sin \zeta_{HR} - \Delta Z'_{NR}\right) L_S$$

GLAS INPUTS - RIGHT

$$\mathcal{M}_{NR\,AERO\,GLAS} = \mathcal{M}_{RRH} + L_S\left(N.F_R \cos \zeta_{NR} - S F_R \sin \zeta_{NR}\right)$$

$$\mathcal{N}_{NR\,AERO\,GLAS} = \mathcal{N}_{RRH} - L_S\left(S.F_R \cos \zeta_{NR} + N.F \sin \zeta_{NR}\right)$$

WING VERTICAL BENDING

RIGHT WING TIP DEFLECTION

$$\bar{a}_{RT} = \frac{Z_{AERO}}{m} + Y_N \dot{p}$$

$$\bar{a}_{RWAC} = \frac{Z_{AERO}}{m} + Y_{WAC} \dot{p}$$

$$h_{1R} = K_{w1} Z^{NR'}_{AERO} + K_{w2} Z^{RW'}_{AERO} + K_{w3} \mathcal{L}^{NR'}_{AERO} - K_{w4} \bar{a}_{RT} - K_{w5} \bar{a}_{RWAC}$$

$$\mathring{h}_{1R} = \Delta h_{1R} / \Delta t$$

WHERE; Δh_{1R} IS THE DIFFERENCE OF h_{1R} BETWEEN TIME FRAMES AND Δt IS THE TIME FRAME

RIGHT WING A.C. DEFLECTION

$$h_{1RWAC} = K_{w6} Z^{NR'}_{AERO} + K_{w7} Z^{RW'}_{AERO} + K_{w8} \mathcal{L}^{NR'}_{AERO} - K_{w9} \bar{a}_{RT} - K_{w10} \bar{a}_{RWAC}$$

$$\mathring{h}_{1RWAC} = \Delta h_{1RWAC} / \Delta t$$

WHERE: Δh_{1RWAC} IS THE DIFFERENCE OF h_{1RWAC} BETWEEN TIME FRAMES AND Δt IS THE TIME FRAME.

FORCE AND MOMENT EFFECTS

$$\ddot{Z}^{NR}_{AERO} = -2 \zeta_{w1} \omega_{w1} \dot{Z}^{NR}_{AERO} - \omega_{w1}^2 Z^{NR}_{AERO} + \omega_{w1}^2 Z^{NR'}_{AERO}$$

$$\ddot{Z}^{RW}_{AERO} = -2 \zeta_{w2} \omega_{w2} \dot{Z}^{RW}_{AERO} - \omega_{w2}^2 Z^{RW}_{AERO} + \omega_{w2}^2 Z^{RW'}_{AERO}$$

$$\ddot{\mathcal{L}}^{NR}_{AERO} = -2 \zeta_{w3} \omega_{w3} \dot{\mathcal{L}}^{NR}_{AERO} - \omega_{w3}^2 \mathcal{L}^{NR}_{AERO} + \omega_{w3}^2 \mathcal{L}^{NR'}_{AERO}$$

FORM Z^{NR}_{AERO}, Z^{RW}_{AERO}, & $\mathcal{L}^{NR}_{AERO}$

Wing Vertical Bending (Cont'd.)

Left Wing Tip Deflection

$$\bar{a}_{LT} = \frac{Z_{AERO}}{m} - Y_N \dot{p}$$

$$\bar{a}_{LWAC} = \frac{Z_{AERO}}{m} - Y_{WAC} \dot{p}$$

$$h_{1L} = K_{W1} Z_{AERO}^{NL'} + K_{W2} Z_{AERO}^{LW'} - K_{W3} \mathcal{L}_{AERO}^{NL'} - K_{W4} \bar{a}_{LT} - K_{W5} \bar{a}_{LWAC}$$

$$\overset{\circ}{h}_{1L} = \Delta h_{1L} / \Delta t$$

WHERE: Δh_{1L} IS THE DIFFERENCE OF h_{1L} BETWEEN TIME FRAMES AND Δt IS THE TIME FRAME

Left Wing A.C. Deflection

$$h_{1LWAC} = K_{W6} Z_{AERO}^{NL'} + K_{W7} Z_{AERO}^{LW'} - K_{W8} \mathcal{L}_{AERO}^{NL'} - K_{W9} \bar{a}_{LT} - K_{W10} \bar{a}_{LWAC}$$

$$\overset{\circ}{h}_{1LWAC} = \Delta h_{1LWAC} / \Delta t$$

WHERE: Δh_{1LWAC} IS THE DIFERENCE OF h_{1LWAC} BETWEEN TIME FRAMES AND Δt IS THE TIME FRAME

Force and Moment Effects

$$\overset{\circ\circ}{Z}{}_{AERO}^{NL} = -2 \zeta_{W1} \omega_{W1} \overset{\circ}{Z}{}_{AERO}^{NL} - \omega_{W1}^2 Z_{AERO}^{NL} + \omega_{W1}^2 Z_{AERO}^{NL'}$$

$$\overset{\circ\circ}{Z}{}_{AERO}^{LW} = -2 \zeta_{W2} \omega_{W2} \overset{\circ}{Z}{}_{AERO}^{LW} - \omega_{W2}^2 Z_{AERO}^{LW} + \omega_{W2}^2 Z_{AERO}^{LW'}$$

$$\overset{\circ\circ}{\mathcal{L}}{}_{AERO}^{NL} = -2 \zeta_{W3} \omega_{W3} \overset{\circ}{\mathcal{L}}{}_{AERO}^{NL} - \omega_{W3}^2 \mathcal{L}_{AERO}^{NL} + \omega_{W3}^2 \mathcal{L}_{AERO}^{NL'}$$

FORM Z_{AERO}^{NL}, Z_{AERO}^{LW}, & $\mathcal{L}_{AERO}^{NL}$

WING TORSION

LEFT WING TWIST @ TIP

$$K_{\theta t}\,\theta_{tLW} = M_{NLACT} - I_E\,\Omega_{EL}\,r$$
$$+\, q_{SLW}\,\frac{c_w^2\,b_w}{2}\,C_{Mo}\left(1 - C_{TSLR}\right)$$
$$+\left(1 - C_{TSLR}\right) q_{SLW}\,c_w^2\left(\frac{dC_{MWc/4}}{dC_L} + \frac{X_{WAC}}{C_w}\right)\left(\frac{C_{L\alpha}b_w}{6\pi}\right)\left(4\theta_{tLW} + 3\pi\alpha_{LW\,RIGID}\right)$$

RIGHT WING TWIST @ TIP

$$K_{\theta t}\,\theta_{tRW} = M_{NRACT} - I_E\,\Omega_{ER}\,r$$
$$+\, q_{SRW}\,\frac{c_w^2\,b_w}{2}\,C_{Mo}\left(1 - C_{TSRR}\right)$$
$$+\left(1 - C_{TSRR}\right) q_{SRW}\,c^2\left(\frac{dC_{MWc/4}}{dC_L} + \frac{X_{WAC}}{C_w}\right)\left(\frac{C_{L\alpha}b_w}{6\pi}\right)\left(4\theta_{tRW} + 3\pi\alpha_{RW\,RIGID}\right)$$

WHERE: $$C_{Mo} = C_1 + C_2\,\delta_F + C_3\,\delta_F^2$$

$$\theta_{tLWAC} = \frac{Y_{WAC}}{Y_N}\,\theta_{tLW}$$

$$\theta_{tRWAC} = \frac{Y_{WAC}}{Y_N}\,\theta_{tRW}$$

NOTE: IF UMBRELLAS ARE OPEN; SET TERMS CONTAINING $q_S\left(1 - C_{TS}\right)$ EQUAL TO ZERO

Total Force and Moment Summation About C.G.

$$X_{AERO} = X^{NL}_{AERO} + X^{NR}_{AERO} + X^{F}_{AERO} + X^{LW}_{AERO} + X^{RW}_{AERO} + X^{T}_{AERO}$$

$$Y_{AERO} = Y^{NL}_{AERO} + Y^{NR}_{AERO} + Y^{F}_{AERO} + Y^{LW}_{AERO} + Y^{RW}_{AERO} + Y^{T}_{AERO}$$

$$Z_{AERO} = Z^{NL}_{AERO} + Z^{NR}_{AERO} + Z^{F}_{AERO} + Z^{LW}_{AERO} + Z^{RW}_{AERO} + Z^{T}_{AERO}$$

$$\mathcal{L}_{AERO} = \mathcal{L}^{NL}_{AERO} + \mathcal{L}^{NR}_{AERO} + \mathcal{L}^{F}_{AERO} + \mathcal{L}^{W}_{AERO} + \mathcal{L}^{T}_{AERO} + Y_N \left(Z^{NR}_{AERO} - Z^{NL}_{AERO} \right) + Z_{CG} \left(Y^{NL}_{AERO} + Y^{NR}_{AERO} \right)$$

$$\mathcal{M}_{AERO} = \mathcal{M}^{NL}_{AERO} + \mathcal{M}^{NR}_{AERO} + \mathcal{M}^{F}_{AERO} + \mathcal{M}^{W}_{AERO} + \mathcal{M}^{T}_{AERO} + X_{CG} \left(Z^{NL}_{AERO} + Z^{NR}_{AERO} \right) - Z_{CG} \left(X^{NL}_{AERO} + X^{NR}_{AERO} \right)$$

$$\mathcal{N}_{AERO} = \mathcal{N}^{NL}_{AERO} + \mathcal{N}^{NR}_{AERO} + \mathcal{N}^{F}_{AERO} + \mathcal{N}^{W}_{AERO} + \mathcal{N}^{T}_{AERO} + Y_N \left(X^{NL}_{AERO} - X^{NR}_{AERO} \right) - X_{CG} \left(Y^{NL}_{AERO} + Y^{NR}_{AERO} \right)$$

NOMENCLATURE

l_f, h_f ~ FUSELAGE MASS CENTER w.r.t. PIVOT FUSE. CENTER, AXES.

l_w, h_w ~ WING " " " " " " "

l ~ NACELLE PIVOT TO NACELLE C.G. DISTANCE

λ ~ ANGLE BETWEEN NACELLE SHAFT AXIS AND ITS C.G. to PIVOT AXIS.

m_f ~ MASS OF FUSELAGE

m_w ~ MASS OF BOTH WINGS

m_N ~ MASS OF <u>ONE</u> NACELLE

i_N ~ NACELLE SHAFT TO FUSELAGE X-AXIS ANGLE

$I_{xx}^{(f)}, I_{yy}^{(f)}, I_{zz}^{(f)}, I_{xz}^{(f)}$ ~ FUSELAGE INERTIAS ABOUT ITS C.G.

$I_{xx}^{(w)}, I_{yy}^{(w)}, I_{zz}^{(w)}, I_{xz}^{(w)}$ ~ WING INERTIAS ABOUT <u>THEIR</u> C.G.

$I'_{xx}, I'_{yy}, I'_{zz}, I'_{xz}$ ~ MOMENTS OF INERTIA OF ONE NACELLE ABOUT ITS C.G.

p, q, r ~ FUSELAGE BODY AXIS ANGULAR RATES

u, v, w ~ FUSELAGE BODY AXIS LINEAR RATES

I_p ~ ROTOR POLAR MOMENT OF INERTIA

Ω ~ ROTOR SPEED, ANGULAR

X_{AERO}; Y_{AERO}; Z_{AERO} ~ TOTAL AERODYNAMIC FORCES IN THE BODY AXIS.

SUBSCRIPTS

R ~ RIGHT
L ~ LEFT
w ~ WING
f ~ FUSELAGE

Basic Equations of Motion

Preliminary Calculations

Fuselage C.G. w.r.t. A/C C.G.

$$x_f = l_f - x_{CG}$$

$$z_f = h_f - z_{CG}$$

Wing C.G w.r.t. A/C C.G.

$$x_w = l_w - x_{CG}$$

$$z_w = h_w - z_{CG}$$

Nacelle C.G.'s w.r.t. A/C C.G.

$$x_R = l\cos(i_{NR} - \lambda) - x_{CG}$$

$$z_R = -l\sin(i_{NR} - \lambda) - z_{CG}$$

$$x_L = l\cos(i_{NL} - \lambda) - x_{CG}$$

$$z_L = -l\sin(i_{NL} - \lambda) - z_{CG}$$

PRELIMINARY CALCULATIONS

INERTIA TERMS

$$\sum_k I_{ij}^{(k)} = I_{ij}^{(f)} + I_{ij}^{(\omega)} + 2I'_{ij}$$

$$I_{xx} = \sum_k I_{xx}^{(k)} + \left(I'_{zz} - I'_{xx}\right)\left(\sin^2 i_{NR} + \sin^2 i_{NL}\right)$$
$$- I'_{xz}\left(\sin 2i_{NR} + \sin 2i_{NL}\right) + 2m_N Y_N^2$$
$$+ m_f h_f Z_f + m_\omega h_\omega Z_\omega +$$
$$- \ell m_N \left[Z_R \sin\left(i_{NR} - \lambda\right) + Z_L \sin\left(i_{NL} - \lambda\right)\right]$$

$$J_{xx} = \sum_k \left(I_{zz}^{(k)} - I_{yy}^{(k)}\right) + \left(I'_{xx} - I'_{zz}\right)\left(\sin^2 i_{NR} + \sin^2 i_{NL}\right)$$
$$+ I'_{xz}\left(\sin 2i_{NR} + \sin 2i_{NL}\right) + 2m_N Y_N^2$$
$$- \left(m_f h_f Z_f + m_\omega h_\omega Z_\omega\right)$$
$$+ \ell m_N \left[Z_R \sin\left(i_{NR} - \lambda\right) + Z_L \sin\left(i_{NL} - \lambda\right)\right]$$

$$I_{xz}^{(P)} = I_{xz}^{(f)} + I_{xz}^{(\omega)} + \frac{1}{2}\left(I'_{xx} - I'_{zz}\right)\left(\sin 2i_{NR} + \sin 2i_{NL}\right)$$
$$+ I'_{xz}\left(\cos 2i_{NR} + \cos 2i_{NL}\right) + \left(m_f \ell_f Z_f + m_\omega \ell_\omega Z_\omega\right)$$
$$+ m_N \ell\left[Z_R \cos\left(i_{NR} - \lambda\right) + Z_L \cos\left(i_{NL} - \lambda\right)\right]$$

Inertia Terms

$$
\begin{aligned}
I_{yy} = {} & \sum_{k} I_{yy}^{(k)} + m_f\left(\ell_f X_f + h_f Z_f\right) + m_w\left(\ell_w X_w + h_w Z_w\right) \\
& + m_N \ell\left[X_R \cos\left(i_{NR}-\lambda\right) - Z_R \sin\left(i_{NR}-\lambda\right)\right] \\
& + m_N \ell\left[X_L \cos\left(i_{NL}-\lambda\right) - Z_L \sin\left(i_{NL}-\lambda\right)\right]
\end{aligned}
$$

$$
\begin{aligned}
J_{yy} = {} & \left(I_{xx}^{(f)} - I_{zz}^{(f)}\right) + \left(I_{xx}^{(w)} - I_{zz}^{(w)}\right) + \\
& + \left(I'_{xx} - I'_{zz}\right)\left(\cos 2 i_{NR} + \cos 2 i_{NL}\right) \\
& - 2 I'_{xz}\left(\sin 2 i_{NR} + \sin 2 i_{NL}\right) + m_f\left(-\ell_f X_f + h_f Z_f\right) \\
& + m_w\left(-\ell_w X_w + h_w Z_w\right) \\
& - m_N \ell\left[X_R \cos\left(i_{NR}-\lambda\right) + Z_R \sin\left(i_{NR}-\lambda\right) + X_L \cos\left(i_{NL}-\lambda\right)\right. \\
& \qquad \left. + Z_L \sin\left(i_{NL}-\lambda\right)\right]
\end{aligned}
$$

$$
\begin{aligned}
I_{xz}^{(g)} = {} & I_{xz}^{(f)} + I_{xz}^{(w)} + \frac{1}{2}\left(I'_{xx} - I'_{zz}\right)\left(\sin 2 i_{NR} + \sin 2 i_{NL}\right) \\
& + I'_{xz}\left(\cos 2 i_{NR} + \cos 2 i_{NL}\right) \\
& - m_N \ell\left[X_R \sin\left(i_{NR}-\lambda\right) + X_L \sin\left(i_{NL}-\lambda\right)\right] \\
& + m_f h_f X_f + m_w h_w X_w
\end{aligned}
$$

INERTIA TERMS

$$I_{zz} = \sum_{k} I_{zz}^{(k)} + (I'_{xx} - I'_{zz})(\sin^2 i_{NR} + \sin^2 i_{NL})$$
$$+ I'_{xz}(\sin 2i_{NR} + \sin 2i_{NL}) + 2m_N Y_N^2$$
$$+ m_f l_f X_f + m_w l_w X_w$$
$$+ m_N l\left[X_R \cos(i_{NR} - \lambda) + X_L \cos(i_{NL} - \lambda)\right]$$

$$J_{zz} = \sum_{k}\left(I_{yy}^{(k)} - I_{xx}^{(k)}\right) + (I'_{xx} - I'_{zz})(\sin^2 i_{NR} + \sin^2 i_{NL})$$
$$+ I'_{xz}(\sin 2i_{NR} + \sin 2i_{NL}) - 2m_N Y_N^2$$
$$+ m_f l_f X_f + m_w l_w X_w$$
$$+ m_N l\left[X_R \cos(i_{NR} - \lambda) + X_L \cos(i_{NL} - \lambda)\right]$$

$$I_{xz}^{(r)} = I_{xz}^{(f)} + I_{xz}^{(w)} + \frac{1}{2}(I'_{xx} - I'_{zz})(\sin 2i_{NR} + \sin 2i_{NL})$$
$$+ I'_{xz}(\cos 2i_{NR} + \cos 2i_{NL}) + m_f h_f X_f + m_w h_w X_w$$
$$- l m_N\left[X_R \sin(i_{NR} - \lambda) + X_L \sin(i_{NL} - \lambda)\right]$$

BASIC EQUATIONS — FINAL SIMPLIFICATION

ROLL EQUATION

$$I_{xx}\,\dot{p} = -J_{xx}\,rq + I_{xz}^{(p)}\left(\dot{r} + pq\right) + \ell m_N Y_N \left\{ \ddot{i}_{NR}\cos\left(i_{NR}-\lambda\right) - \ddot{i}_{NL}\cos\left(i_{NL}-\lambda\right) \right\} + \mathcal{L}_{AERO}$$

PITCH EQUATION

$$I_{yy}\,\dot{q} = -J_{yy}\,pr - I_{xz}^{(q)}\left(p^2 - r^2\right) - \ddot{i}_{NR}\left\{ I'_{yy} + \ell m_N\left[-Z_R \sin\left(i_{NR}-\lambda\right) + X_R\cos\left(i_{NR}-\lambda\right)\right]\right\} - \ddot{i}_{NL}\left\{ I'_{yy} + \ell m_N\left[-Z_L \sin\left(i_{NL}-\lambda\right) + X_L\cos\left(i_{NL}-\lambda\right)\right]\right\} + \mathcal{M}_{AERO}$$

YAW EQUATION

$$I_{zz}\,\dot{r} = -J_{zz}\,pq - \left(rq - \dot{p}\right) I_{xz}^{(r)} - \ell m_N Y_N \left\{ \ddot{i}_{NR}\sin\left(i_{NR}-\lambda\right) - \ddot{i}_{NL}\sin\left(i_{NL}-\lambda\right) \right\} + \mathcal{N}_{AERO}$$

Basic Equations

Right Nacelle Actuator Pitching Moment Equation

$$
\begin{aligned}
M_{NRACT} = &-\ddot{i}_{NR}\left[I'_{yy} + \ell^2 m_N \left(1 - \frac{m_N}{m}\right)\right] \\
&- \ell^2 m_N \left(1 - \frac{m_N}{m}\right)\Big[- pr \cos 2(i_{NR} - \lambda) + \dot{q} \\
&\quad + (r^2 - p^2)\sin(i_{NR} - \lambda)\cos(i_{NR} - \lambda)\Big] \\
&- (r^2 - p^2)\left[I'_{zz} \sin i_{NR} \cos i_{NR}\right] - I'_{yy}\dot{q} \\
&+ \ell \frac{m_N}{m}\left[X_{AERO} \sin(i_{NR} - \lambda) + Z_{AERO} \cos(i_{NR} - \lambda)\right] \\
&- \ell m_N Y_N \Big\{ (\dot{r} - pq)\left[\sin(i_{NR} - \lambda)\right] \\
&\qquad - (\dot{p} + rq)\left[\cos(i_{NR} - \lambda)\right]\Big\} \\
&+ \mathcal{M}_{NRAERO}
\end{aligned}
$$

Note: The above equation must be calculated for wing torsion calculation <u>only</u>

BASIC EQUATIONS

LEFT NACELLE ACTUATOR PITCHING MOMENT EQUATION

$$
\begin{aligned}
M_{NLACT} = &- \ddot{i}_{NL}\left[I'_{yy} + \ell^2 m_N \left(1 - \frac{m_N}{m}\right)\right] \\
&- \ell^2 m_N \left(1 - \frac{m_N}{m}\right)\left[- pr \cos 2 (i_{NL} - \lambda) + \dot{q} \right. \\
&\quad \left. + (r^2 - p^2) \sin (i_{NL} - \lambda) \cos (i_{NL} - \lambda)\right] \\
&\quad - (r^2 - p^2)\left[I'_{zz} \sin i_{NL} \cos i_{NL} \right] - I'_{yy} \dot{q} \\
&\quad + \ell \frac{m_N}{m}\left[X_{Aero} \sin (i_{NL} - \lambda) + Z_{AERO} \cos (i_{NL} - \lambda)\right] \\
&\quad + \ell m_N Y_N \left\{ (\dot{r} - pq)\left[\sin (i_{NL} - \lambda)\right] \right. \\
&\qquad \left. - (\dot{p} + rq)\left[\cos (i_{NL} - \lambda)\right]\right\} \\
&\quad + \mathcal{M}_{NL\,AERO}
\end{aligned}
$$

NOTE: The above equation must be calculated for wing torsion calculation ONLY.

AIRCRAFT CONDITION CALCULATIONS

LINEAR EQUATIONS OF MOTION (ψ, θ, ϕ-EULER SYSTEM)

$$\dot{u} = \frac{X_{AERO}}{m} - g\sin\theta - qw + rv$$

$$\dot{v} = \frac{Y_{AERO}}{m} + g\cos\theta\sin\phi - ru + pw$$

$$\dot{w} = \frac{Z_{AERO}}{m} + g\cos\theta\cos\phi + qu - pv$$

EULER ANGLE CALCULATION - ψ, θ, ϕ SYSTEM

$$\dot{\psi} = (r\cos\phi + q\sin\phi)/\cos\theta$$

$$\dot{\theta} = q\cos\phi - r\sin\phi$$

$$\dot{\phi} = p + \dot{\psi}\sin\theta$$

Aircraft Condition Calculations

Ground Track

Northward Velocity

$$\dot{X}_{NORTH} = U \cos\theta \cos\psi + V(\sin\phi \sin\theta \cos\psi - \cos\phi \sin\psi) + W(\cos\phi \sin\theta \cos\psi + \sin\phi \sin\psi)$$

Eastward Velocity

$$\dot{Y}_{EAST} = U \cos\theta \sin\psi + V(\sin\phi \sin\theta \sin\psi + \cos\phi \cos\psi) + W(\cos\phi \sin\theta \sin\psi - \sin\phi \cos\psi)$$

Downward Velocity

$$\dot{Z}_{DOWN} = -U \sin\theta + V \sin\phi \cos\theta + W \cos\phi \cos\theta$$

AIRCRAFT CONDITION CALCULATIONS (CONTINUED)

PILOT STATION ACCELERATIONS (BODY AXES)

$$a_{xPA} = \frac{X_{AERO}}{m} + (\dot{q} + pr)(Z_{PA} - Z_{CG}) + (q^2 + r^2)(X_{CG} - l_{PA}) + Y_{PA}(pq - \dot{r}) - 2q\dot{Z}_{CG} - \ddot{X}_{CG}$$

$$a_{YPA} = \frac{Y_{AERO}}{m} + (\dot{p} - qr)(Z_{CG} - Z_{PA}) + (\dot{r} + pq)(l_{PA} - X_{CG}) - Y_{PA}(r^2 + p^2) + 2(p\dot{Z}_{CG} - r\dot{X}_{CG})$$

$$a_{ZPA} = \frac{Z_{AERO}}{m} + (\dot{q} - pr)(X_{CG} - l_{PA}) + (p^2 + q^2)(Z_{CG} - Z_{PA}) + Y_{PA}(\dot{p} + qr) + 2q\dot{X}_{CG} - \ddot{Z}_{CG}$$

PILOT STATION VELOCITIES (BODY AXES)

$$u_{PA} = u_P + qZ_{PA} - rY_{PA}$$

$$v_{PA} = v_P + r l_{PA} - pZ_{PA}$$

$$w_{PA} = w_P + pY_{PA} - q l_{PA}$$

GUST MODEL

The Gust Model to be used with the simulation will consist of:

NASA-AMES program number NAPS-80.

The output of this program is in the form of gust components that will be added to the inertial components of the basic equations of motion. In practice, the following equations will be used in formulating the input to the aerodynamic coordinate transforms etc.,.

$$
\begin{aligned}
U &= U' + U_g & \qquad P &= P' + P_g \\
V &= V' + V_g & \qquad Q &= Q' + Q_g \\
W &= W' + W_g & \qquad R &= R' + R_g
\end{aligned}
$$

The primed terms above are derived from the basic equations.

Alterations to nomenclature in the Vertol equations has been resisted at this time for the sake of simplicity.

PRELIMINARY CALCULATIONS (PREPROCESS)

CENTER OF GRAVITY CALCULATIONS

$$m = \frac{1}{32.174}\left[W'_f + W'_{NT} + W'_{HT} + W'_{VT} + W'_w + W'_{NF} + W'_{CR} + W'_{FUEL} + W'_c\right]$$

$$m_N = \frac{1}{32.174}\left(\frac{W'_{NT}}{2}\right)$$

$$m_f = \frac{1}{32.174}\left[W'_f + W'_{HT} + W'_{VT} + W'_{CR} + W'_c\right]$$

$$m_w = \frac{1}{32.174}\left[W'_w + W'_{FUEL} + W'_{NF}\right]$$

$$\ell'_f = \left[(FS)_p - (FS)_{f'}\right]\frac{1}{12}$$

$$\ell'_{HT} = \left[(FS)_p - (FS)_{HTCG}\right]\frac{1}{12}$$

$$\ell'_{VT} = \left[(FS)_p - (FS)_{VTCG}\right]\frac{1}{12}$$

$$\ell'_{PA} = \left[(FS)_p - (FS)_{PA}\right]\frac{1}{12}$$

$$\ell'_c = \left[(FS)_p - (FS)_c\right]\frac{1}{12}$$

$$\ell_f = \frac{1}{m_f(32.174)}\left[W'_f\,\ell'_f + W'_{HT}\,\ell'_{HT} + W'_{VT}\,\ell'_{VT} + W'_{CR}\,\ell_{PA} + W'_c\,\ell'_c\right]$$

$$\ell'_w = \left[(FS)_p - (FS)_w\right]\frac{1}{12}$$

$$\ell'_{FUEL} = \left[(FS)_p - (FS)_{FUEL}\right]\frac{1}{12}$$

$$\ell'_{NF} = \left[(FS)_p - (FS)_{NF}\right]\frac{1}{12}$$

$$\ell_w = \frac{1}{m_w(32.174)}\left[W'_w\,\ell'_w + W'_{FUEL}\,\ell'_{FUEL} + W'_{NF}\,\ell'_{NF}\right]$$

PRELIMINARY CALCULATIONS (CONT'D.)

$$z'_f = \left[(WL)_P - (WL)_{f'} \right] \frac{1}{12}$$

$$z'_{HT} = \left[(WL)_P - (WL)_{HTCG} \right] \frac{1}{12}$$

$$z'_{VT} = \left[(WL)_P - (WL)_{VTCG} \right] \frac{1}{12}$$

$$Z_{PA} = \left[(WL)_P - (WL)_{PA} \right] \frac{1}{12}$$

$$z'_c = \left[(WL)_P - (WL)_c \right] \frac{1}{12}$$

$$h_f = \frac{1}{(32.174)(m_f)} \left[W'_f z'_f + W'_{HT} z'_{HT} + W'_{VT} z'_{VT} + W'_{CR} Z_{PA} + W'_c z'_c \right]$$

$$z'_w = \left[(WL)_P - (WL)_w \right] \frac{1}{12}$$

$$z'_{FUEL} = \left[(WL)_P - (WL)_{FUEL} \right] \frac{1}{12}$$

$$z'_{NF} = \left[(WL)_P - (WL)_{NF} \right] \frac{1}{12}$$

$$h_w = \frac{1}{(32.174)\, m_w} \left[W'_w z'_w + W'_{FUEL} z'_{FUEL} + W'_{NF} z'_{NF} \right]$$

$$X_{WAC} = \left[(FS)_P - (FS)_{WAC} \right] \frac{1}{12}$$

$$Y_{WAC} = \left[(BL)_{WAC} \right] \frac{1}{12}$$

$$Z_{WAC} = \left[(WL)_P - (WL)_{WAC} \right] \frac{1}{12}$$

$$Y_N = \left[(BL)_N \right] \frac{1}{12}$$

PRELIMINARY CALCULATIONS (CONT'D)

$$X_{HT} = \left[(FS)_P - (FS)_{HT}\right] \frac{1}{12}$$

$$Z_{HT} = \left[(WL)_P - (WL)_{HT}\right] \frac{1}{12}$$

$$X_{VT} = \left[(FS)_P - (FS)_{VT}\right] \frac{1}{12}$$

$$Z_{VT} = \left[(WL)_P - (WL)_{VT}\right] \frac{1}{12}$$

$$A = 3.14159\ R^2$$

$$\bar{Y}_{WAC} = \left[(\bar{BL})_{WAC}\right] \frac{1}{12}$$

$$X_{G2} = X_{G1} = \left[(FS)_P - (FS)_{G2}\right] \frac{1}{12}$$

$$Z_{G2} = Z_{G1} = \left[(WL)_P - (WL)_{G2}\right] \frac{1}{12}$$

$$Y_{G2} = \left[(BL)_{G2}\right] \frac{1}{12}$$

$$Y_{G1} = -Y_{G2}$$

$$Y_{G3} = 0.$$

$$Y_{PA} = \left[(BL)_{PA}\right] \frac{1}{12}$$; POSITIVE FOR PILOT IN RIGHT SEAT

$$X_{fAC} = \left[(FS)_P - (FS)_{fAC}\right] \frac{1}{12}$$

$$Z_{fAC} = \left[(WL)_P - (WL)_{fAC}\right] \frac{1}{12}$$

PRELIMINARY CALCULATIONS (CONT'D)

$$X_{c/2} = \left[(FS)_P - (FS)_{c/2}\right]\frac{1}{12}$$

$$Z_{G3} = \left[(WL)_P - (WL)_{G3}\right]\frac{1}{12}$$

$$X_{G3} = \left[(FS)_P - (FS)_{G3}\right]\frac{1}{12}$$

$$Y_{NF} = \left[(BL)_{NFCG}\right]\frac{1}{12}$$

$$Y_{HT} = \left[(BL)_{HTCG}\right]\frac{1}{12}$$

$$Y_w = \left[(BL)_{WCG}\right]\frac{1}{12}$$

$$Y_{FUEL} = \left[(BL)_{FUEL\,CG}\right]\frac{1}{12}$$

INERTIA CALCULATIONS

$$\eta'_{f'} = l_f - l'_f$$

$$\delta'_{f'} = h_f - z'_f$$

$$\eta'_{HT} = l_f - l'_{HT}$$

$$\delta'_{HT} = h_f - z'_{HT}$$

$$\eta'_{VT} = l_f - l'_{VT}$$

$$\delta'_{VT} = h_f - z'_{VT}$$

$$\eta'_{CA} = l_f - l_{PA}$$

$$\delta'_{CA} = h_f - z_{PA}$$

PRELIMINARY CALCULATIONS (CONT'D)

$$\eta'_c = l_f - l'_c$$

$$\delta'_c = h_f - z'_c$$

$$I_{yy}^{(f)} = I_{yy_o}^{(W_{f'})} + I_{yy_o}^{(HT)} + I_{yy_o}^{(VT)} + I_{yy_o}^{(CR)} + I_{yy_o}^{(c)} + \frac{W'_f}{32.174}\left(\eta'^2_{f'} + \delta'^2_{f'}\right)$$
$$+ \frac{W'_{HT}}{32.174}\left(\eta'^2_{HT} + \delta'^2_{HT}\right) + \frac{W'_{VT}}{32.174}\left(\eta'^2_{VT} + \delta'^2_{VT}\right)$$
$$+ \frac{W'_{CR}}{32.174}\left(\eta'^2_{CR} + \delta'^2_{CR}\right) + \frac{W'_c}{32.174}\left(\eta'^2_c + \delta'^2_c\right)$$

$$I_{xx}^{(f)} = I_{xx_o}^{(W_{f'})} + I_{xx_o}^{(HT)} + I_{xx_o}^{(VT)} + I_{xx_o}^{(CR)} + I_{xx_o}^{(c)} + \frac{W'_f}{32.174}\delta'^2_{f'} + \frac{W'_{HT}}{32.174}\left(\delta'^2_{HT} + Y^2_{HT}\right)$$
$$+ \frac{W'_{VT}}{32.174}\delta'^2_{VT} + \frac{W'_{CR}}{32.174}\delta'^2_{CR} + \frac{W'_c}{32.174}\delta'^2_c$$

$$I_{zz}^{(f)} = I_{zz_o}^{(W_{f'})} + I_{zz_o}^{(HT)} + I_{zz_o}^{(VT)} + I_{zz_o}^{(CR)} + I_{zz_o}^{(c)} + \frac{W'_f}{32.174}\eta'^2_{f'} + \frac{W'_{HT}}{32.174}\left(\eta'^2_{HT} + Y^2_{HT}\right)$$
$$+ \frac{W'_{VT}}{32.174}\eta'^2_{VT} + \frac{W'_{CR}}{32.174}\eta'^2_{CR} + \frac{W'_c}{32.174}\eta'^2_c$$

$$I_{xz}^{(f)} = I_{xz_o}^{(W_{f'})} + I_{xz_o}^{(HT)} + I_{xz_o}^{(VT)} + I_{xz_o}^{(CR)} + I_{xz_o}^{(c)} + \frac{W'_f}{32.174}\eta'_{f'}\delta'_{f'}$$
$$+ \frac{W'_{HT}}{32.174}\eta'_{HT}\delta'_{HT} + \frac{W'_{VT}}{32.174}\eta'_{VT}\delta'_{VT} + \frac{W'_{CR}}{32.174}\eta'_{CR}\delta'_{CR}$$
$$+ \frac{W'_c}{32.174}\eta'_c\delta'_c$$

$$H'_{w'_w} = l_w - l'_w$$

$$\Delta'_{w'_w} = h_w - z'_w$$

$$H'_{w'_{FUEL}} = l_w - l'_{FUEL}$$

$$\Delta'_{w'_{FUEL}} = h_w - z'_{FUEL}$$

PRELIMINARY CALCULATIONS (CONT'D)

$$H'_{w'NF} = l_w - l'_{NF}$$

$$\Delta'_{w'NF} = h_w - z'_{NF}$$

$$I_{YY}^{(w)} = I_{YY_o}^{(w'_w)} + I_{YY_o}^{(w'_{FUEL})} + I_{YY_o}^{(w'_{NF})} + \frac{W'_w}{32.174}\left(H'^{2}_{w'_w} + \Delta'^{2}_{w'_w}\right)$$

$$+ \frac{W'_{FUEL}}{32.174}\left(H'^{2}_{w'_{FUEL}} + \Delta'^{2}_{w'_{FUEL}}\right) + \frac{W'_{NF}}{32.174}\left(H'^{2}_{w'_{NF}} + \Delta'^{2}_{w'_{NF}}\right)$$

$$I_{XX}^{(w)} = I_{XX_o}^{(w'_w)} + I_{XX_o}^{(w'_{FUEL})} + I_{XX_o}^{(w'_{NF})} + \frac{W'_w}{32.174}\left(\Delta'^{2}_{w'_w} + Y_w^2\right)$$

$$+ \frac{W'_{FUEL}}{32.174}\left(\Delta'^{2}_{w'_{FUEL}} + Y^2_{FUEL}\right) + \frac{W'_{NF}}{32.174}\left(\Delta'^{2}_{w'_{NF}} + Y^2_{NF}\right)$$

$$I_{ZZ}^{(w)} = I_{ZZ_o}^{(w'_w)} + I_{ZZ_o}^{(w'_{FUEL})} + I_{ZZ_o}^{(w'_{NF})} + \frac{W'_w}{32.174}\left(H'^{2}_{w'_w} + Y_w^2\right)$$

$$+ \frac{W'_{FUEL}}{32.174}\left(H'^{2}_{w'_{FUEL}} + Y^2_{FUEL}\right) + \frac{W'_{NF}}{32.174}\left(H'^{2}_{w'_{NF}} + Y^2_{NF}\right)$$

$$I_{XZ}^{(w)} = I_{XZ_o}^{(w'_w)} + I_{XZ_o}^{(w'_{FUEL})} + I_{XZ_o}^{(w'_{NF})} + \frac{W'_w}{32.174} H'_{w'_w} \Delta_{w'_w}$$

$$+ \frac{W'_{FUEL}}{32.174} H'_{w'_{FUEL}} \Delta'_{w'_{FUEL}} + \frac{W'_{NF}}{32.174} H'_{w'_{NF}} \Delta'_{w'_{NF}}$$

MATH MODEL TRIM LOOPS - STEADY FLIGHT

INITIALIZE $u, v, \theta, h, \Omega, P, q, r$ AT DESIRED FLIGHT CONDITION.

CLOSE THE FOLLOWING TRIM FEEDBACK LOOPS TO TRIM MATH MODEL FOR FLIGHT.

$$i_{NREF} = K_{T1} \int \dot{u}\, dt + K_{T2} \dot{u}$$

$$\phi = -K_{T3} \int \dot{v}\, dt - K_{T4} \dot{v}$$

$$w = K_{T5} \int \dot{w}\, dt + K_{T6} \dot{w}$$

$$\delta_S = -K_{T7} \int \dot{p}\, dt - K_{T8} \dot{p}$$

$$\delta_R = -K_{T9} \int \dot{r}\, dt - K_{T10} \dot{r}$$

$$\delta_B = -K_{T11} \int \dot{q}\, dt - K_{T12} \dot{q}$$

$$i_{NR} = K_{T13} \iint \ddot{i}_{NR}\, dt\, dt + K_{T14} \int \ddot{i}_{NR}\, dt$$

$$i_{NL} = K_{T13} \iint \ddot{i}_{NL}\, dt\, dt + K_{T14} \int \ddot{i}_{NR}\, dt$$

$$\delta_{TH} = K_{T15} \int \dot{Z}_{DOWN_e}\, dt + K_{T16} \dot{Z}_{DOWN_e}$$

NOTE:
1.) HOLD INTEGRATED VALUE WHEN GOING TO FLIGHT.
2.) START SECOND TRIM FROM FIRST TRIM VALUES.
3.) DETERMINE K'S EXPERIMENTALLY TO MINIMIZE TRIM TIME.
4.) TRIM WITH ALL ACTUATOR DYNAMICS, SAS, AND GOVERNOR IN OPERATING CONDITION TO INSURE PROPER COCKPIT CONTROL AND COLLECTIVE POSITIONS.
5) $\dot{Z}_{DOWN_e} = \dot{Z}_{DOWN} - \dot{Z}_{DOWN_{TRIM}}$; set $\dot{Z}_{DOWN_{TRIM}}$ at desired R/C

MATH MODEL TRIM LOOP OPTIONS

1.) When specifying i_{NREF}, form:

$$\theta = K_{T17}\int \dot{u}\,dt + K_{T18}\dot{u}$$

Note: This option will be commonly used in cruise flight when the nacelles are down and locked.

APPENDIX F MATHEMATICAL MODEL INPUT DATA

Presented in this section is the input data for the mathematical model. A general description of the Model 222 tilt rotor was given in Section 4.0. Model 222 dimensional data and control surface deflections and travels are given on the following pages. Weight, balance and moment of inertia data for five nominal design operating conditions are defined in Figure F.1 . Center of gravity envelopes for the condition of nacelle incidence zero (cruise configuration) and nacelle incidence 90 degrees (hover configuration) are illustrated in Figure F.2. The mathematical model input data are given in Section F.1 to F.5 and are referenced by page number to the equations presented in Appendix E.

MODEL 222 DIMENSIONAL DATA

WING	
AREA (THEO.)	200 FT^2
ASPECT RATIO	5.61
SPAN (BETWEEN ROTOR ℄)	33.42 FT
TAPER RATIO	1.00
CHORDS:	
ROOT	71.8 IN
TIP	71.8 IN
MEAN AERODYNAMIC	71.8 IN
SWEEPBACK	0 DEGREES
DIHEDRAL	0 DEGREES
INCIDENCE	
ROOT	2.0 DEGREES
TIP	2.0 DEGREES
AIRFOIL SECTION	
ROOT	NACA 63_4221 (MODIFIED)
TIP	NACA 63_4221 (MODIFIED)
FUSELAGE	
LENGTH	38.83 FT
DEPTH (NOT INCLUDING SPONSONS)	5.45 FT
WIDTH (NOT INCLUDING SPONSONS)	5.45 FT
WETTED AREA (INCLUDING SPONSONS)	582 FT^2

MODEL 222 DIMENSIONAL DATA (Continued)

NACELLES	
ENGINE	
LENGTH	5.58 FT
DEPTH	2.37 FT
WIDTH	2.37 FT
WETTED AREA (PER NACELLE)	21 FT^2
TILTING	
LENGTH	3.70 FT
DEPTH	3.35 FT
WIDTH	2.37 FT
WETTED AREA (PER NACELLE)	22 FT^2
HORIZONTAL TAIL	
AREA (EXPOSED)	46.3 FT^2
AREA (THEO)	58.3 FT^2
SPAN	15.75 FT
ASPECT RATIO	4.26
TAPER RATIO	.379
DISTANCE $(\bar{c}/4)_W$ to $(\bar{c}/4)_{HT}$	20.29 FT
CHORDS	
ROOT	66.0 IN
TIP	25.0 IN
MEAN AERODYNAMIC	48.0 IN
SWEEPBACK AT 0 PERCENT CHORD	14° 51'
DIHEDRAL	0 DEGREES

MODEL 222 DIMENSIONAL DATA (Continued)

INCIDENCE	
ROOT	0 DEGREES
TIP	0 DEGREES
AIRFOIL SECTION	
ROOT	NACA 64A010 (MODIFIED
TIP	NACA 64A010 (MODIFIED)
VERTICAL TAIL	
AREA (EXPOSED, EXCLUDES DORSAL)	35.5 FT^2
AREA (REFERENCE)	43.3 FT^2
SPAN (REFERENCE)	8.14 FT
ASPECT RATIO	1.53
TAPER RATIO	.303
DISTANCE $(\bar{c}/4)_W$ to $(\bar{c}/4)_{VT}$	18.88 FT
CHORDS (REFERENCE)	
ROOT	8.17 FT
TIP	2.48 FT
MEAN AERODYNAMIC	5.83 FT
SWEEPBACK AT 0 PERCENT CHORD	46° 28'
AIRFOIL SECTION	NACA 64A008
CONTROL SURFACES	
FLAPERON	
AREA (AFT OF HINGE)	52.5 FT
SPAN (LENGTH EACH SIDE)	151.56 IN
CHORD (% OF WING CHORD)	30
SWEEPBACK OF HINGE LINE	0°
SPOILERS	
AREA	19.15 FT^2

CONTROL SURFACE DEFLECTIONS AND CONTROL TRAVELS

Control Surface Deflections (Positive deflection is trailing edge down unless indicated otherwise)

Elevator	±20° (Pilot Stick Command-Deflection From Scheduled Elevator Position)
Flaperon (Flap Mode)	+70°, -0°
(Aileron Mode)	+20°, -0° (Flaperon Used for Roll Control to a Maximum of 35° Combined Flap + Aileron Mode Deflection)
Rudder	±20°
Spoiler (Roll Control)	45° (T.E. Up)
(Max. Download Alleviation in Hover)	110° (T.E. Up)
Umbrella Upper Surface	Aft Edge 20° From Vertical
Lower Surface	Aft Edge 10° From Vertical

Rotor Control Authorities

Longitudinal Cyclic	±2.5° for Pitch Trim Plus Maneuver ±2.7° for Combined SAS + Load Alleviation
Differential Longitudinal Cyclic	±4.5° Maximum for Roll Command (Function of Nacelle Incidence)
Maximum Longitudinal Cyclic for Combined Inputs	±7°
Collective Pitch	0° to 56.5° (at .75R)
Differential Collective	±3.0° Maximum for Yaw Command & ±4.8° for Maximum Roll Command (Function of Nacelle Incidence)
Lateral Cyclic	±2.7° for Rotor Load Alleviation

Nacelle Deflection Authorities

Nacelle Tilt	0° to 105°
Differential Nacelle Tilt	1.55° Per Degree Differential Longitudinal Cyclic

Pilot Control Movements

Stick - Longitudinal	±6 Inches
- Lateral	±5 Inches
Rudder Pedals	±2.5 Inches

MASS PROPERTIES

(WEIGHT BALANCE AND MOMENTS OF INERTIA)

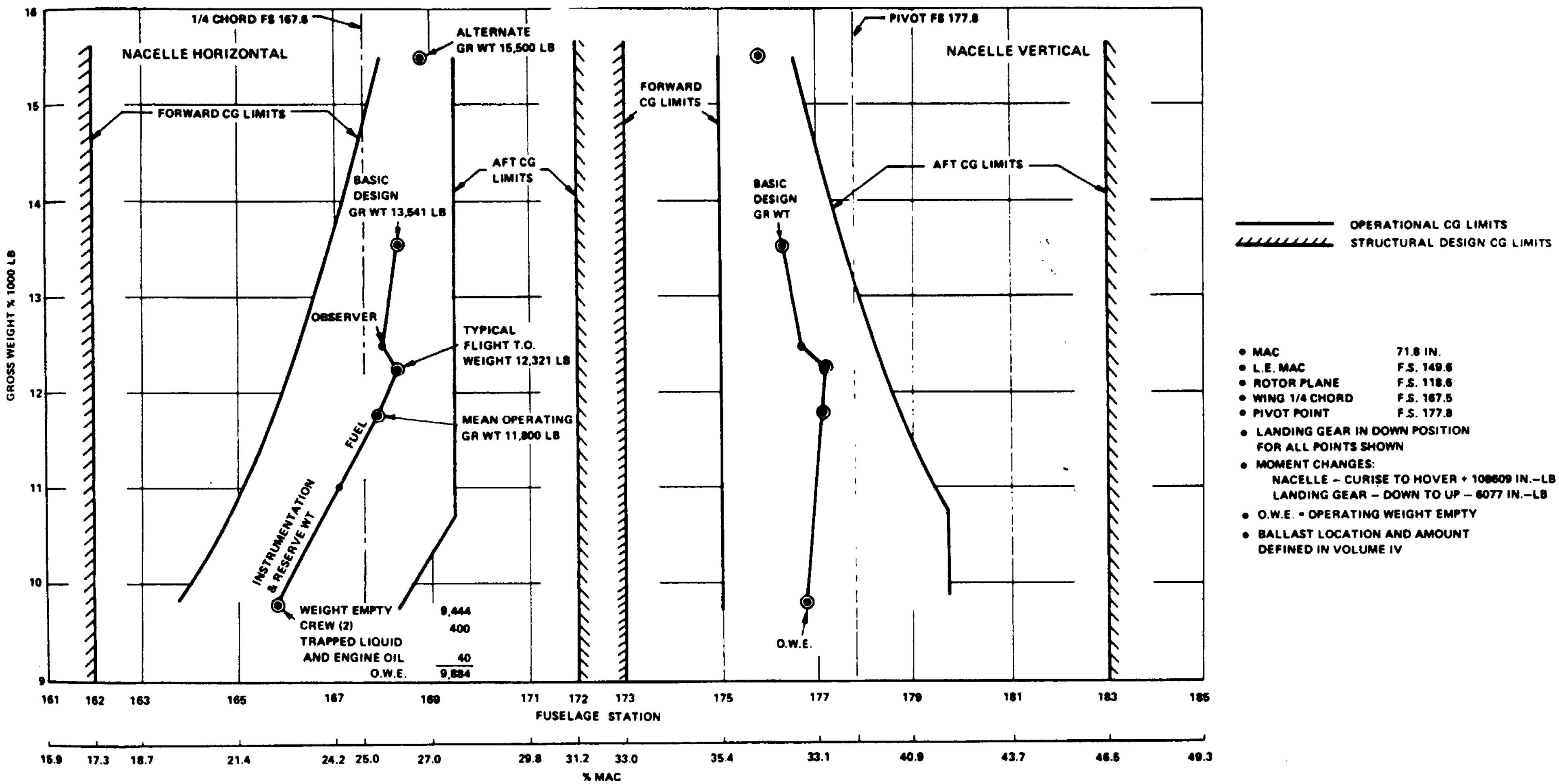
		NACELLE HORIZONTAL							NACELLE VERTICAL						
		BALANCE			INERTIA - SLUG FT^2				BALANCE			INERTIA - SLUG FT^2			
SUB-GROUPS	WEIGHT	X (F.S.)	Y (W.S.)	Z (W.L.)	I_{XX} (ROLL)	I_{YY} (PITCH)	I_{ZZ} (YAW)	I_{XZ}	X (F.S.)	Y (W.S.)	Z (W.L.)	I_{XX} (ROLL)	I_{YY} (PITCH)	I_{XX} (YAW)	I_{XZ}
• FUSELAGE & CONTENTS	3696	149.7		-9.0	903	6058	6152								
• HORIZONTAL TAIL	130	419.4	27.7	13.4	23	15	38								
• VERTICAL TAIL	96	406.7		63.8	15	22	7	SAME							
• WING & CONTENTS	1695	182.2	107.4	40.3	1266	200	1346								
• NACELLE & CONTENTS	(4267)	(160.0)	(210.1)	(42.4)	(224)	(1395)	(1507)								
FIXED	1475	202.7	227.8	43.1	43	115	61								
TILTING	2792	137.5	200.7	42.0	45	366	369		176.4	200.7	84.3	389	388	45	
OPER. WEIGHT EMPTY	9884	165.8		22.6	48674	12256	57263	490	176.8		34.6	50751	13308	56238	1141
• OBSERVER	200	150.0		1.0	6	7	4								
• FUEL	1280	178.6	109.0	37.0	380	32	416								
• INSTRU. & RES	1157	178.6		.5	110	275	300	SAME							
• OTHER	1020	171.5		.5	110	250	225								
BASIC DESIGN GROSS WEIGHT	13541	168.3		20.1	52843	13191	61576	474	176.3		28.8	55176	14482	50533	1197
• OBSERVER	200	150.0		1.0	6	7	4								
• FUEL	1375	178.6	109.0	37.0	380	32	416								
• INSTRU. & RES	1157	178.6		.5	110	275	300	SAME							
• OTHER	1020	171.5		.5	110	250	225								
• BALLAST	1864	171.5		.5	120	350	375								
ALTERNATE GROSS WEIGHT	15500	168.8		17.9	53308	13697	62254	412	175.7		25.5	55781	15120	61204	1182
• FUEL	1280	178.6	109.0	37.0	380	32	416								
• INSTRU. & RES	1157	178.6		.5	110	275	300	SAME							
TYPICAL FLIGHT TAKE-OFF WEIGHT	12321	168.3		22.0	52573	12787	61359	453	177.1		31.6	54826	13971	60290	1104
• FUEL	759	178.6	109.0	33.0	187	12	195								
• INSTRU. & RES	1157	178.6		.5	110	275	300	SAME							
MEAN OPERATING GROSS WEIGHT	11800	167.9		21.1	51053	12717	59743	425	177.1		31.1	53291	13856	58673	1101

NOTE: • ROTOR BLADE INERTIAS (I_O) ARE NOT INCLUDED IN THE ABOVE VALUES. THE ROTOR BLADE WEIGHT IS ASSUMED TO BE ACTING AT THE HUB ℄.

• ROTOR BLADE WEIGHT (COMPLETE AS REMOVED FROM HUB), BALANCE AND INERTIAS (I_O) ARE AS FOLLOWS:

BLADE WEIGHT 124 LBS., SPAN BALANCE 54.9" FROM HUB ℄, CHORD BALANCE FROM LEADING EDGE OF BLADE 4.7", INERTIAS (SLUG FT^2 AROUND BLADE C.G.) I_{XX} = 52, I_{YY} = 2, I_{ZZ} = 55.

Figure F.1. Mass Properties



- MAC 71.8 IN.
- L.E. MAC F.S. 149.6
- ROTOR PLANE F.S. 118.6
- WING 1/4 CHORD F.S. 167.5
- PIVOT POINT F.S. 177.8
- LANDING GEAR IN DOWN POSITION FOR ALL POINTS SHOWN
- MOMENT CHANGES:
  NACELLE – CURISE TO HOVER + 108609 IN.–LB
  LANDING GEAR – DOWN TO UP – 6077 IN.–LB
- O.W.E. = OPERATING WEIGHT EMPTY
- BALLAST LOCATION AND AMOUNT DEFINED IN VOLUME IV

Figure F.2. C.G. Limit Diagram

F.1 CONTROL SYSTEM INPUT DATA

The input data for the control system, SAS, thrust management, and load alleviation system are in this section, and are referenced by page number to the equations presented in Appendix E. Figures F.3 to F.14 present the scheduled function.

F.1.1 Control System Input Data(1)

Control Mixing (Page E.4)

$K_{\delta_{RUD}}$ = -8 deg/inch

K_{δ_R} = 1.0

K_{δ_s} = 1.0

K_{δ_B} = 1.0

K_{δ_e} = -3.33 deg/inch

$K_{\delta'_s}$ = 0

Actuator Dynamics

ω_N = 20 rad/sec

ζ = 1.0

Lead-lag Dynamics

ω_{L-L} = 35.5 rad/sec

ζ = .18

Scheduled Functions - Refer to Graphs

a) Scheduled Longitudinal Cyclic vs Nacelle Incidence

(1) Gains and time constants not shown on these pages are noted on the block diagrams.

b) Cyclic Gain vs Nacelle Incidence (Pedals)

c) Differential Collective Gain vs Nacelle Incidence (Pedals)

d) Differential Collective Gain vs Nacelle Incidence (Lateral Stick)

e) Longitudinal Cyclic Gain vs Nacelle Incidence (Long. Stick)

f) Lateral Cyclic Gain vs Nacelle Incidence

g) Elevator Deflection vs Nacelle Incidence

h) Scheduled Lateral Cyclic vs Nacelle Incidence

<u>Load Alleviation System (LAS) (Page E.5)</u>

$\tau_{LAS} = 0.2$ sec.

<u>LAS Functions</u>

$G_{B_{1_\alpha}}$, $G_{A_{1_\beta}}$, $G_{A_{1_\alpha}}$ vs Dynamic Pressure

<u>Nacelle and Airplane Controls (Page E.6)</u>

Nacelle Actuator Dynamics

$\omega_{NR} = \omega_{NL} = 10$ rad/sec

$\zeta_{NL} = \zeta_{NR} = 1.0$

<u>Scheduled Functions</u>

a) Scheduled Flap Angle vs Nacelle Incidence

b) Flaperon vs Lateral Stick

c) Spoiler Deflection vs Lateral Stick

d) Spoiler Actuator Limit

<u>Stability Augmentation System (Page E.7 and E.8)</u>

Gains, time constants and scheduled functions noted on block diagrams.

Roll SAS Authoritiy Limit = ± 2 inches

Yaw SAS Authority Limit = $\pm$ 1 inch

Pitch SAS Authority Limit = $\pm$ 2.7°

Thrust Management System (Page E.13)

$(N_{II}/N_{II_{MAX}})_{REF}$ = .8865

Ω_{REF} = 57.6923 rad/sec

η_{TR} = 1.0

I_P = 564 slug-ft^2

$\dot{G}_{G1}$ = 2.5 deg/sec / rad/sec

G_{G2} = 2.66 deg/rad/sec

G_{G3} = .05 deg/sec/deg

Scheduled Functions

a) Turbine Inlet Temperature vs Throttle Position

b) τ_D vs (ΔHP)

c) $\tau_e \delta/\sqrt{\theta}$ vs SHP

d) Output Gain Ratio vs Power Output

e) Governor Gain Schedule

f) RPM Select Schedule

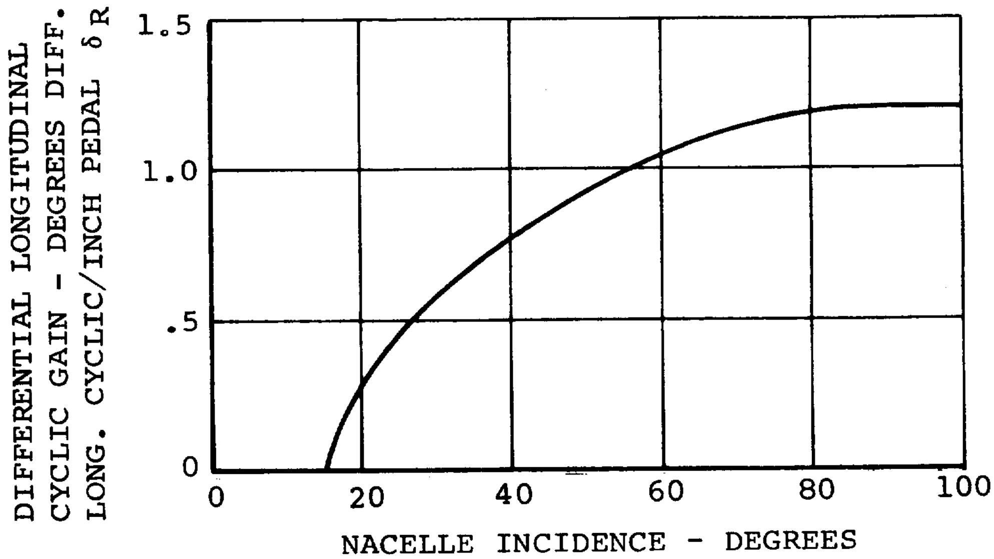
g) Throttle Collective Gain Schedule

h) Incremental Collective Schedule

i) Variable Authority Limit

Rotor Control Coordinate Axis Transforms (Page E.14)

ϕ_P = -12 degrees



NOTE: DIFFERENTIAL NACELLE TILT IS 1.55 DEGREES PER NACELLE PER DEGREE OF DIFF. CYCLIC

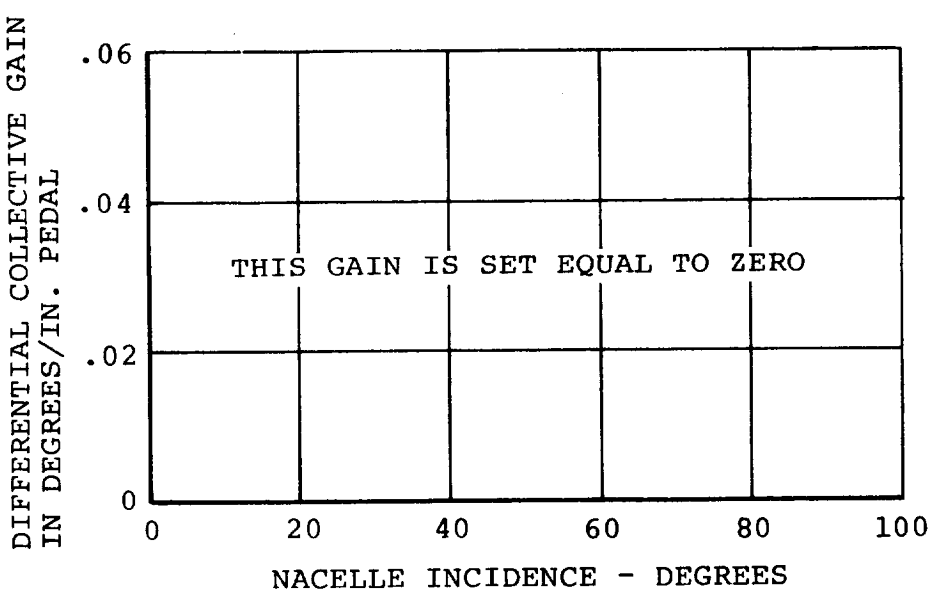
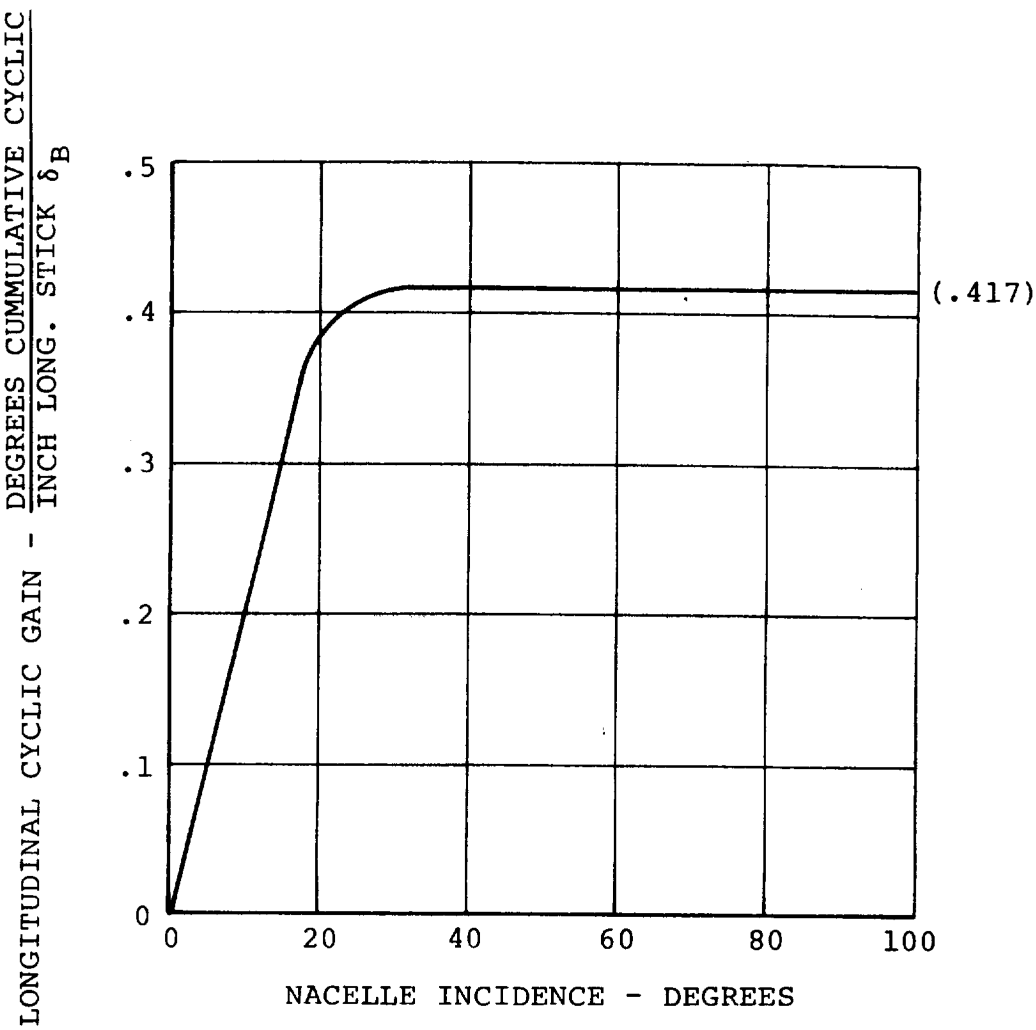


Figure F.3. Differential Long. Cyclic for Yaw Control vs Nacelle Incidence



NOTE: ELEVATOR DEFLECT 3.3333 DEGREES PER INCH OF LONGITUDINAL STICK

MAXIMUM LONG. STICK TRAVEL IS $\pm$ 6 INCHES

Figure F.5. Longitudinal Cyclic for Pitch Control Gain vs Nacelle Incidence

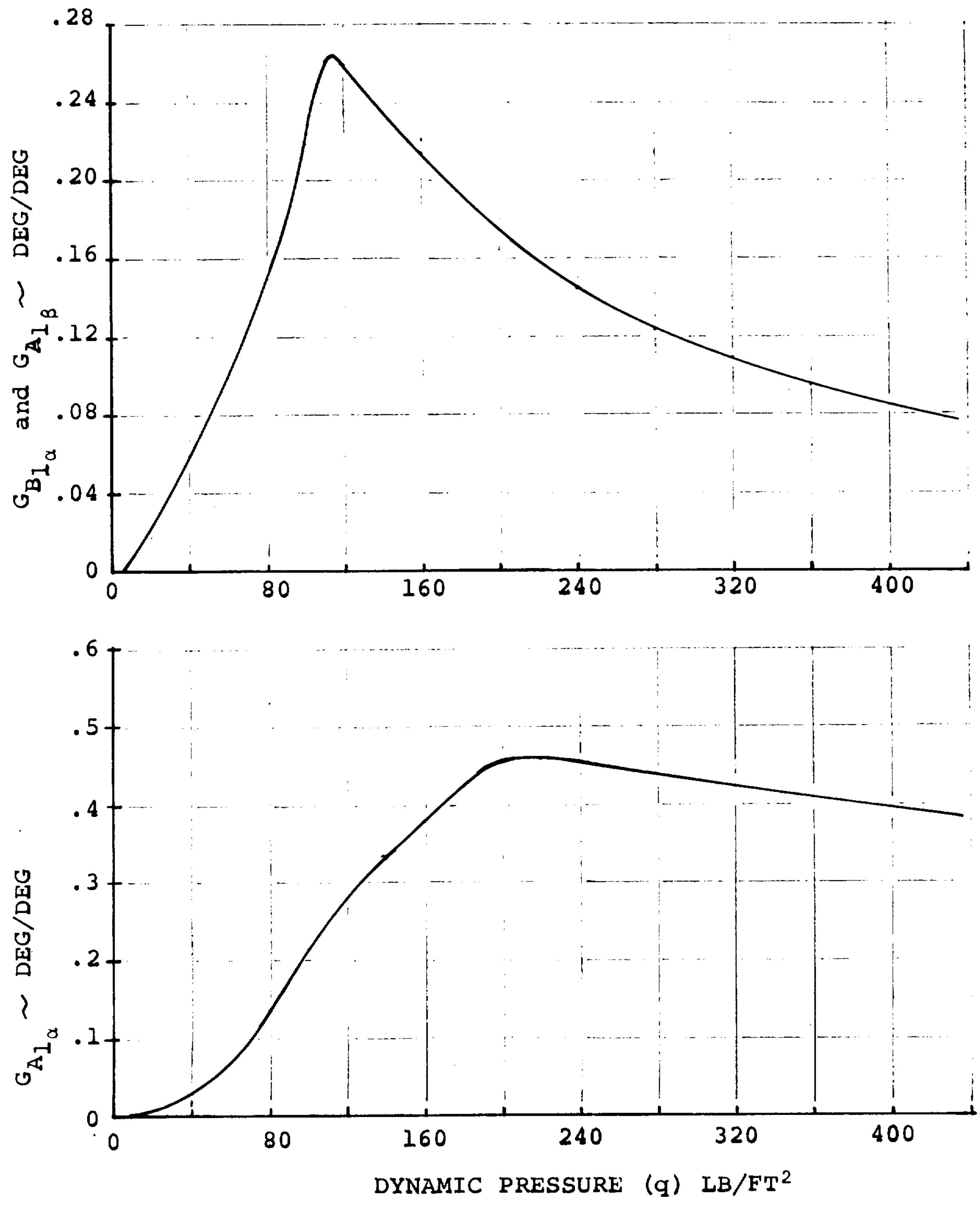


Figure F.6. Load Alleviation System Gain Schedule.

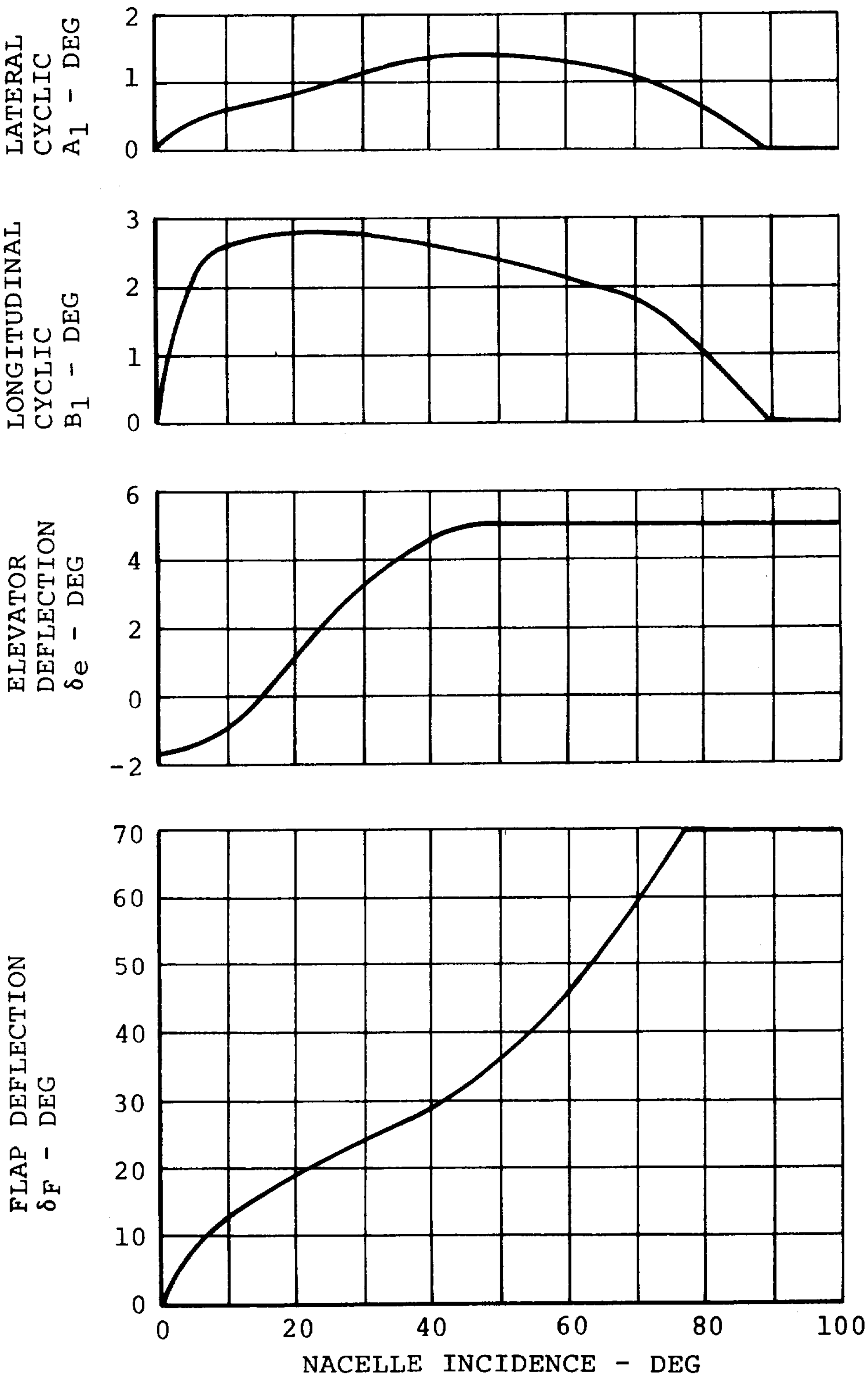


Figure F.7. Programmed Cyclic, Elevator, and Flap Deflection vs Nacelle Incidence

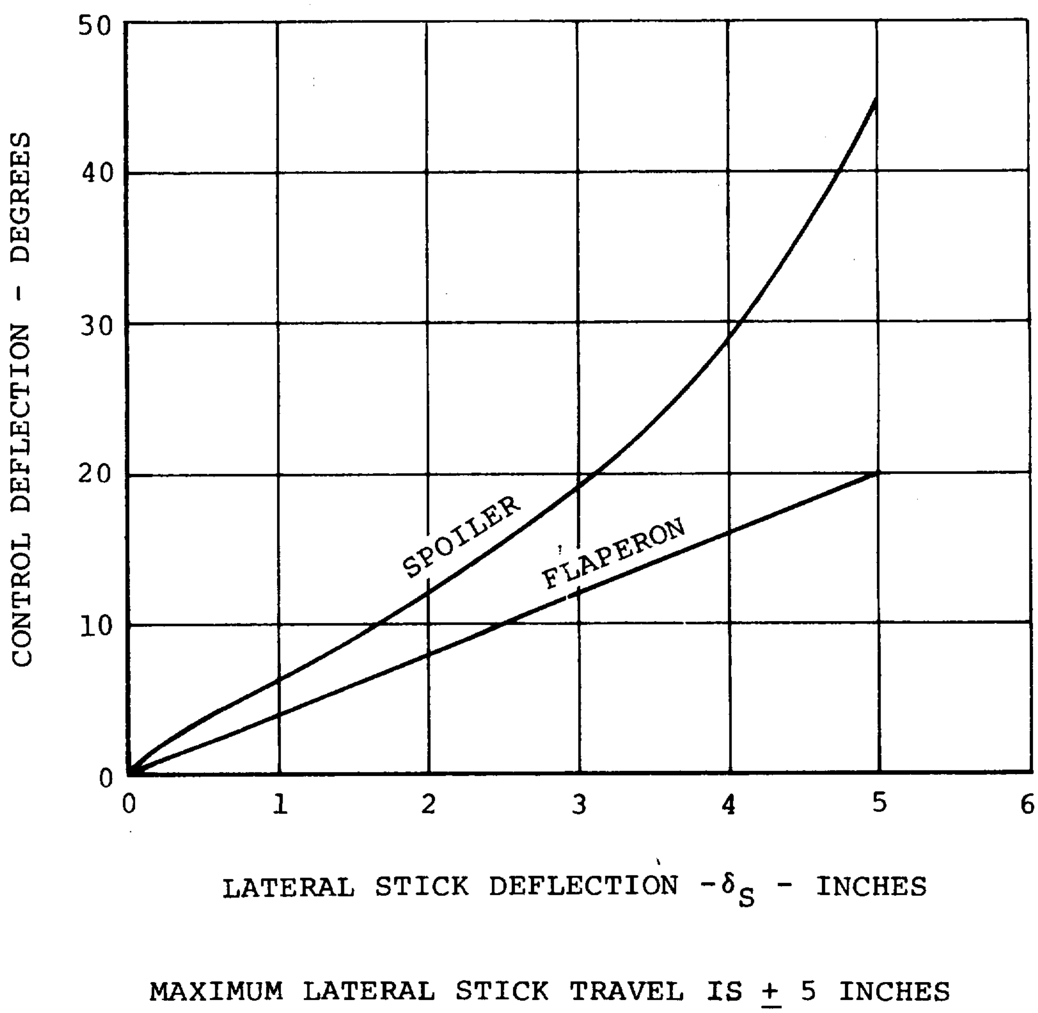


Figure F.8. Roll Control Deflection vs Stick Deflection

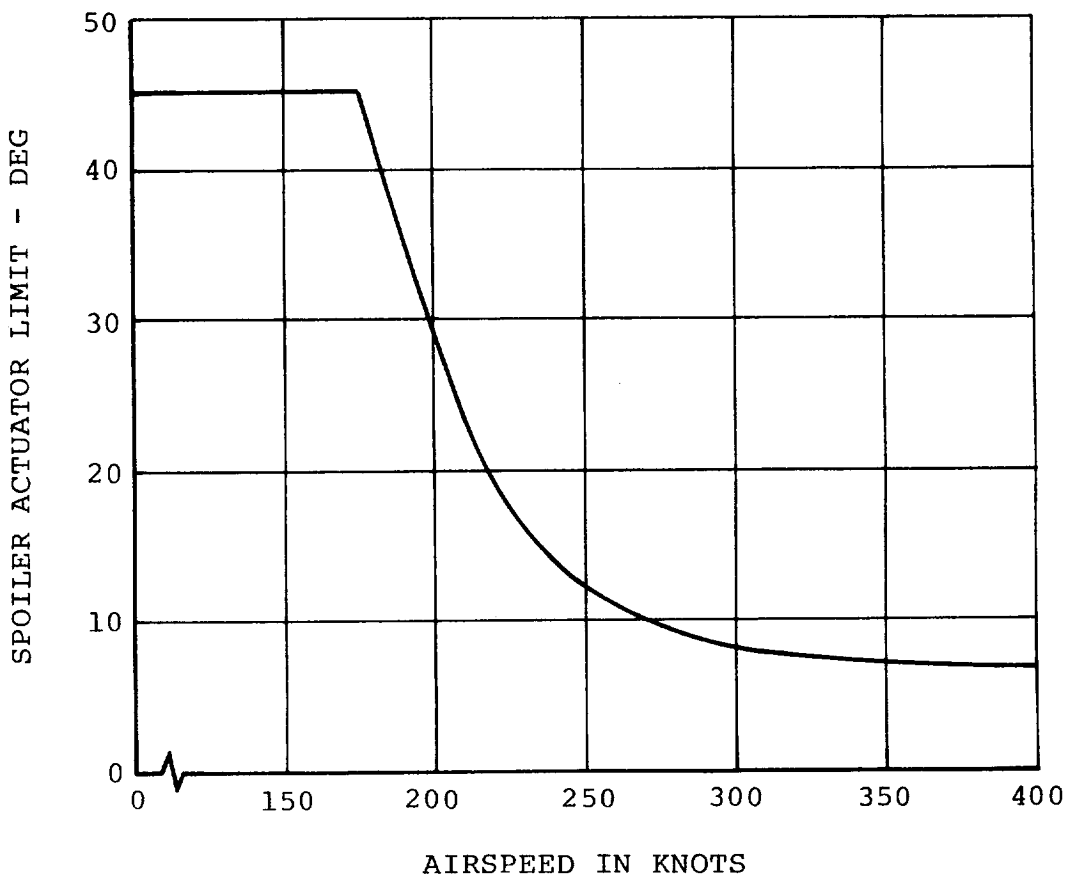


Figure F.9. Spoiler Actuator Limit vs Airspeed

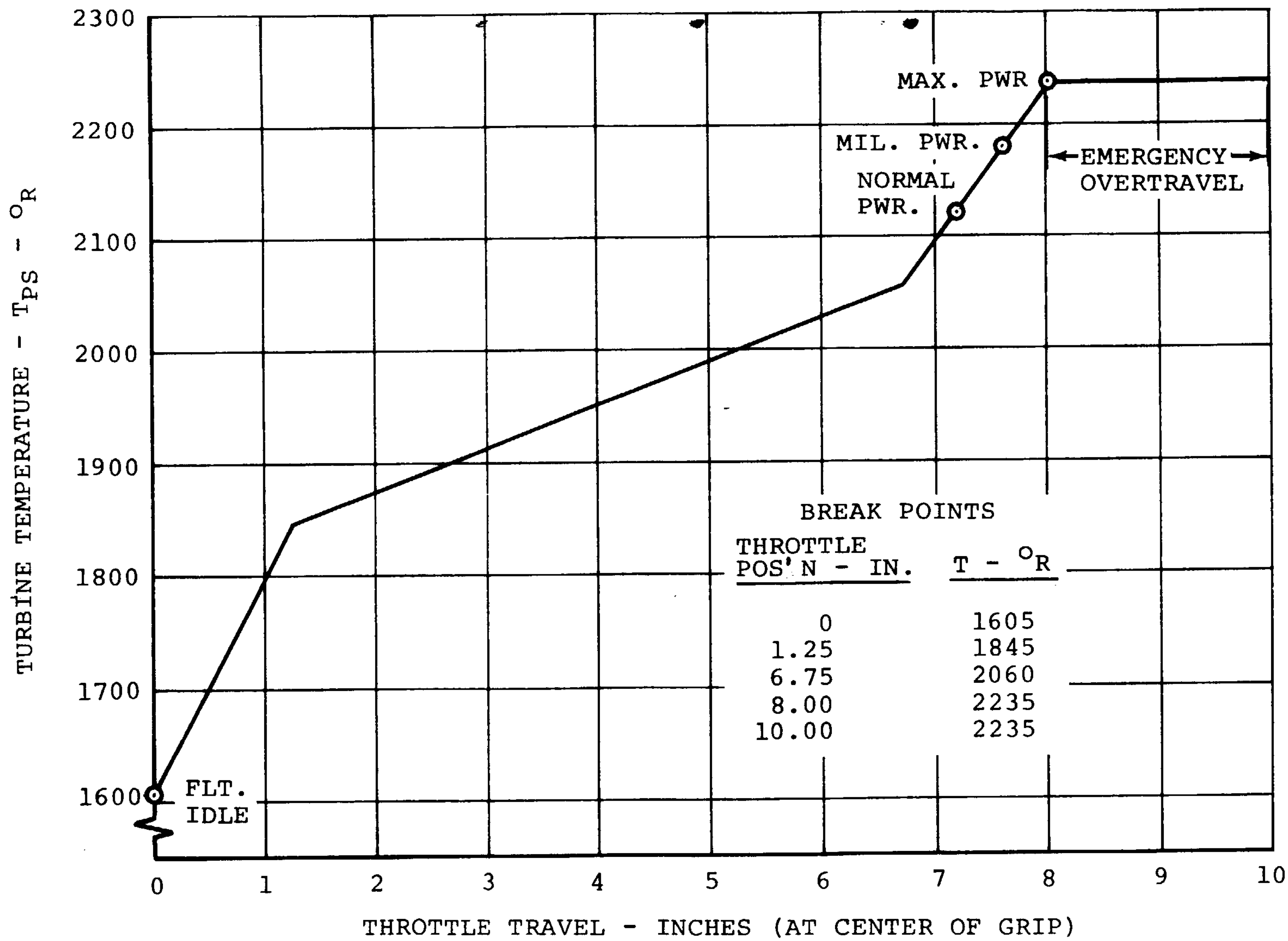


Figure F.10. Assumed Throttle Travel Model 222 Simulation Both Engines

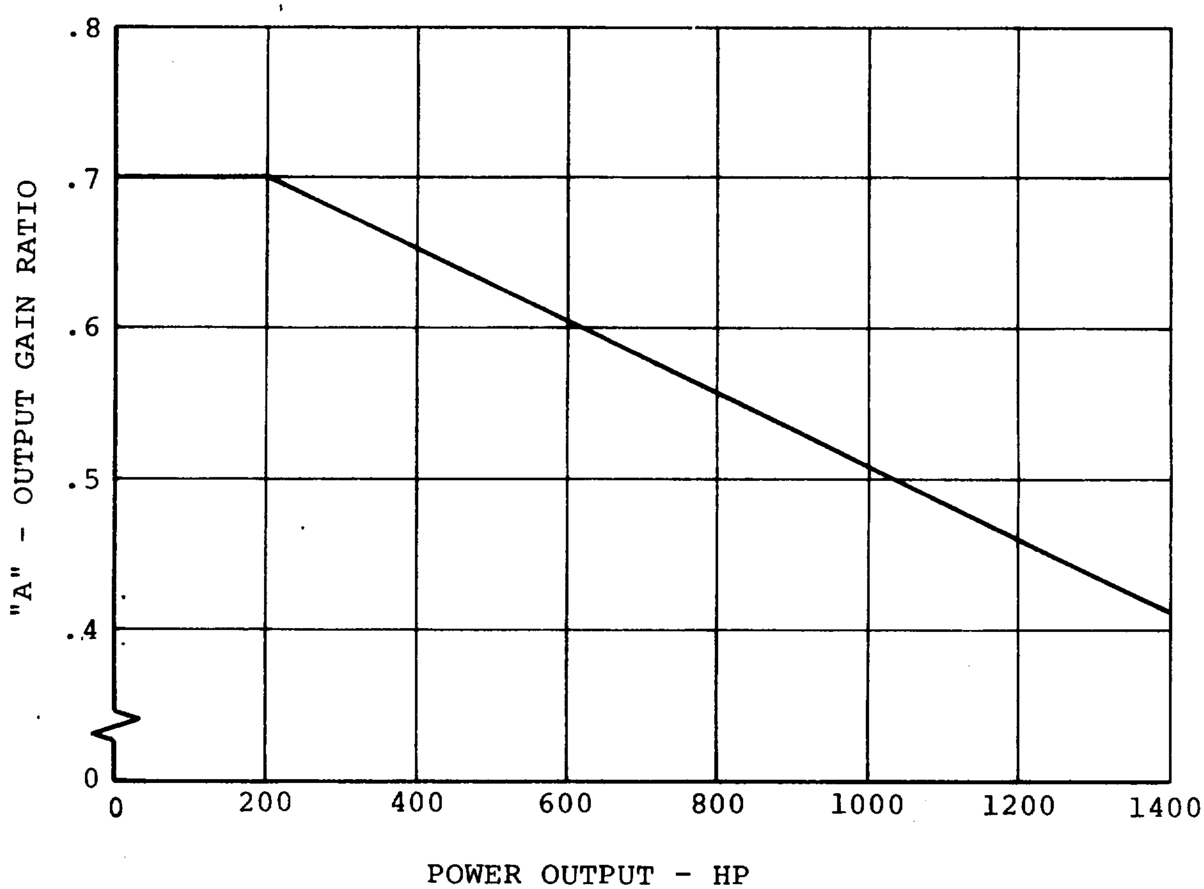


Figure F.12. Engine Characteristics Lycoming T53-L13 Engine

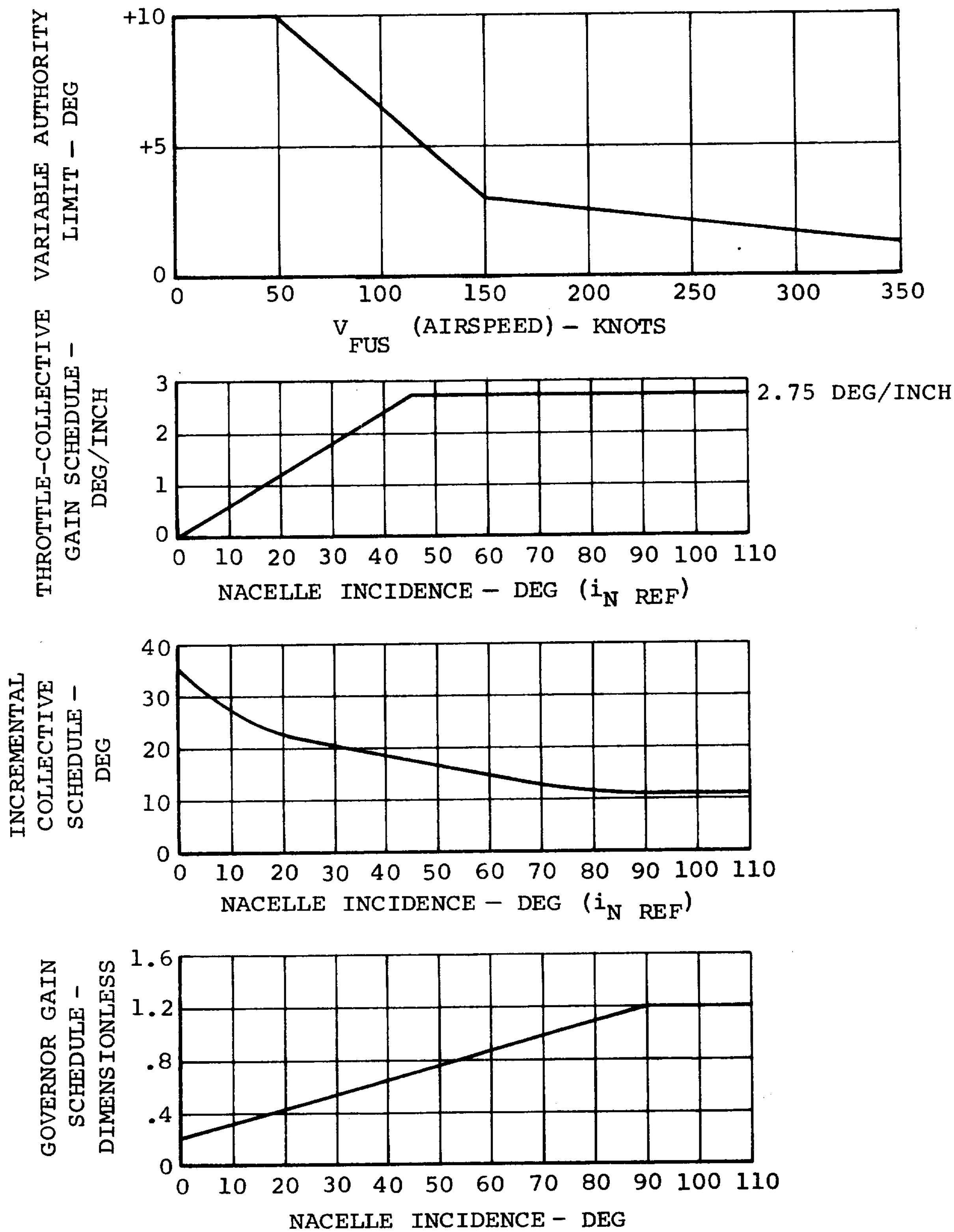


Figure F.13. Thrust Management System-Scheduled Parameters

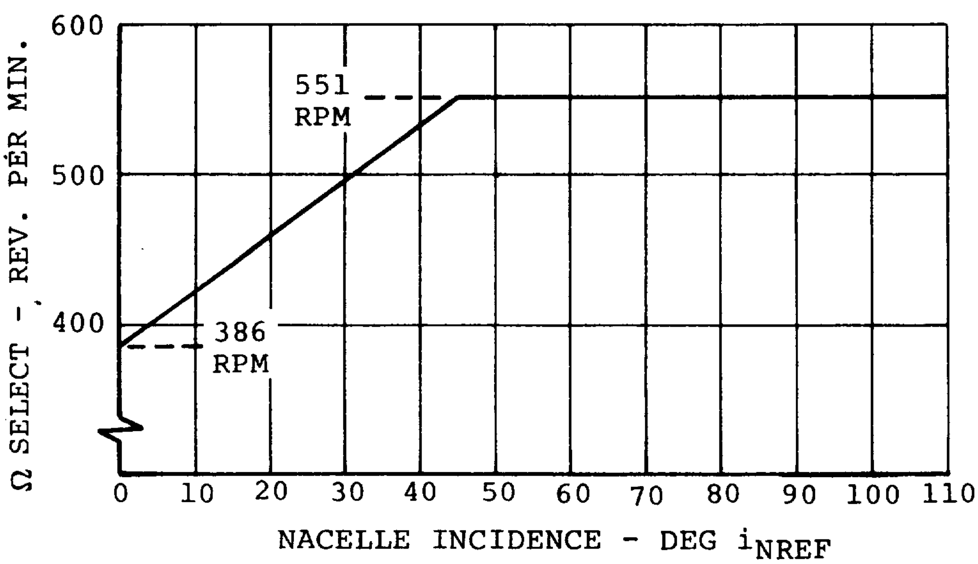


Figure F.14. Thrust Management System-Scheduled Parameters

F.2 ENGINE INPUT DATA

The input data for the engine performance subroutine is given in this section, and are referenced by page number to the equation presented in Appendix E. Plotted data are shown in Figures F.15 to F.18.

F.2.1 Turbine Engine Performance Input Data

Engine Performance Data (Pages E.10, E.11 and E.12)

SHP* = 1550

WDTIND = 1.0

N1IND = 1.0

N1θIND = 0

QIND = 1.0

$\dot{w}_{MAX}/\dot{w}^* = 1.11$

$N_{I_{MAX}}/N_I^* = 1.04$

$(N_I/\sqrt{\theta_1}/N_I^*)_{MAX} = 0$

$Q_{MAX}/Q^* = 1.446$

$N_{II_{MAX}}/N_{II}^* = 1.128$

$N_I^* = 25425$ RPM

$(N_{II}/N_{II_{MAX}})_{REF} = .8865$

$\Omega_{REF} = 57.6923$

Tabular Engine Cycle Input Data

a) Values of Referred Horsepower

b) Values of Referred Fuel Flow

c) Values of Referred Gas Generator Speed

d) Values of Referred Power Turbine Speed

1. VALUES OF REFERRED HORSEPOWER $SHP/\delta\sqrt{\theta}/SHP^*$

MACH NO.	$T/\theta=1600$	$T/\theta=1800$	$T/\theta=2000$	$T/\theta=2200$	$T/\theta=2400$	$T/\theta=2600$	$T/\theta=2800$
0	.035	.330	.630	.920	1.200	1.340	1.400
.2	.075	.375	.670	.960	1.245	1.390	1.450
.4	.125	.425	.720	1.010	1.295	1.440	1.500
.6	.180	.480	.775	1.065	1.350	1.495	1.550
.8	.240	.534	.835	1.125	1.410	1.550	1.600

2. VALUES OF REFERRED FUEL FLOW $W/\delta\sqrt{\theta}/SHP^*$

MACH NO.	$T/\theta=1600$	$T/\theta=1800$	$T/\theta=2000$	$T/\theta=2200$	$T/\theta=2400$	$T/\theta=2600$	$T/\theta=2800$
0	.150	.278	.407	.535	.662	.750	.802
.2	.150	.278	.407	.535	.662	.750	.802
.4	.150	.278	.407	.535	.662	.750	.802
.6	.150	.278	.407	.535	.662	.750	.802
.8	.150	.278	.407	.535	.662	.750	.802

3. VALUES OF REFERRED GAS GENERATOR SPEED $N_I/\sqrt{\theta}/N_I^*$

MACH NO.	T/θ=1600	T/θ=1800	T/θ=2000	T/θ=2200	T/θ=2400	T/θ=2600	T/θ=2800
0	.722	.840	.925	.990	1.045	1.097	1.150
.2	.735	.846	.927	.992	1.048	1.100	1.154
.4	.748	.853	.933	.997	1.052	1.105	1.158
.6	.766	.860	.939	1.004	1.059	1.111	1.162
.8	.789	.871	.950	1.015	1.068	1.119	1.170

4. VALUES OF REFERRED POWER TURBINE SPEED $N_{II}/\sqrt{\theta}/N_{II}^*$

MACH NO.	T/θ=1600	T/θ=1800	T/θ=2000	T/θ=2200	T/θ=2400	T/θ=2600	T/θ=2800
0	.445	.685	.856	.983	1.084	1.178	1.264
.2	.461	.699	.880	.997	1.088	1.169	1.246
.4	.500	.734	.908	1.009	1.089	1.158	1.224
.6	.557	.789	.940	1.023	1.086	1.145	1.197
.8	.640	.858	.973	1.029	1.076	1.123	1.161

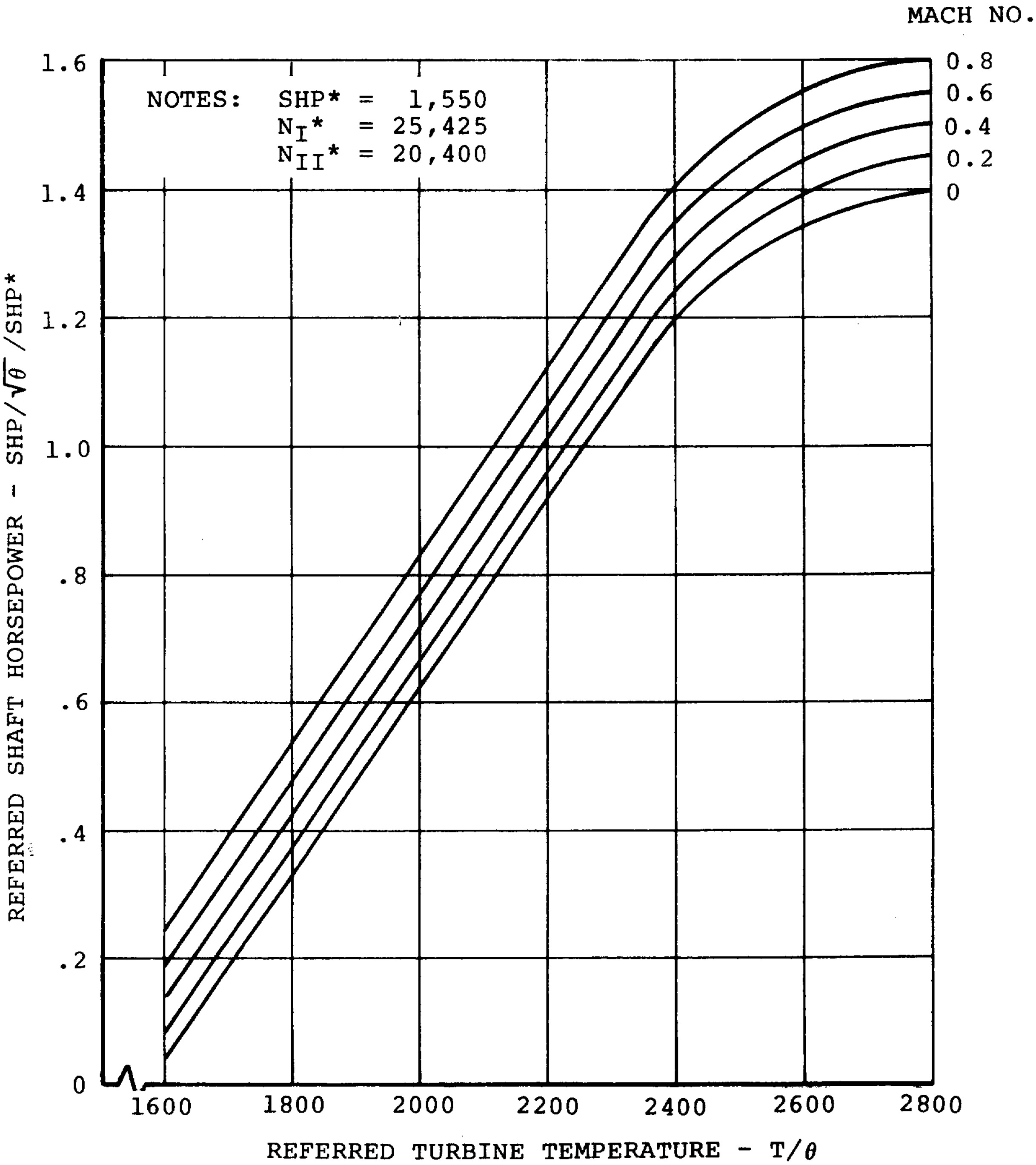


Figure F.15. Turbine Engine Performance - Engine Cycle 1.78

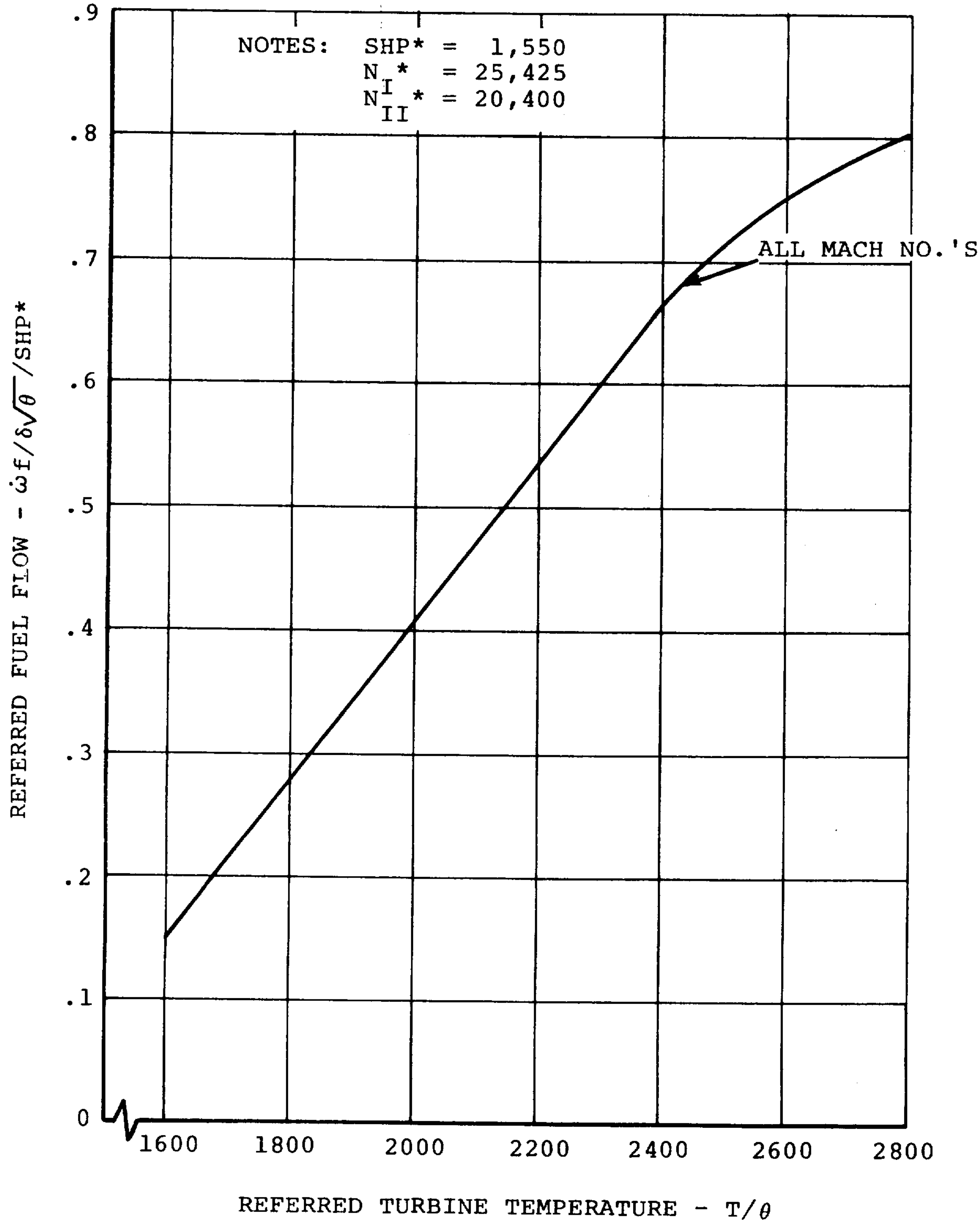


Figure F.16. Turbine Engine Performance - Engine Cycle 1.78

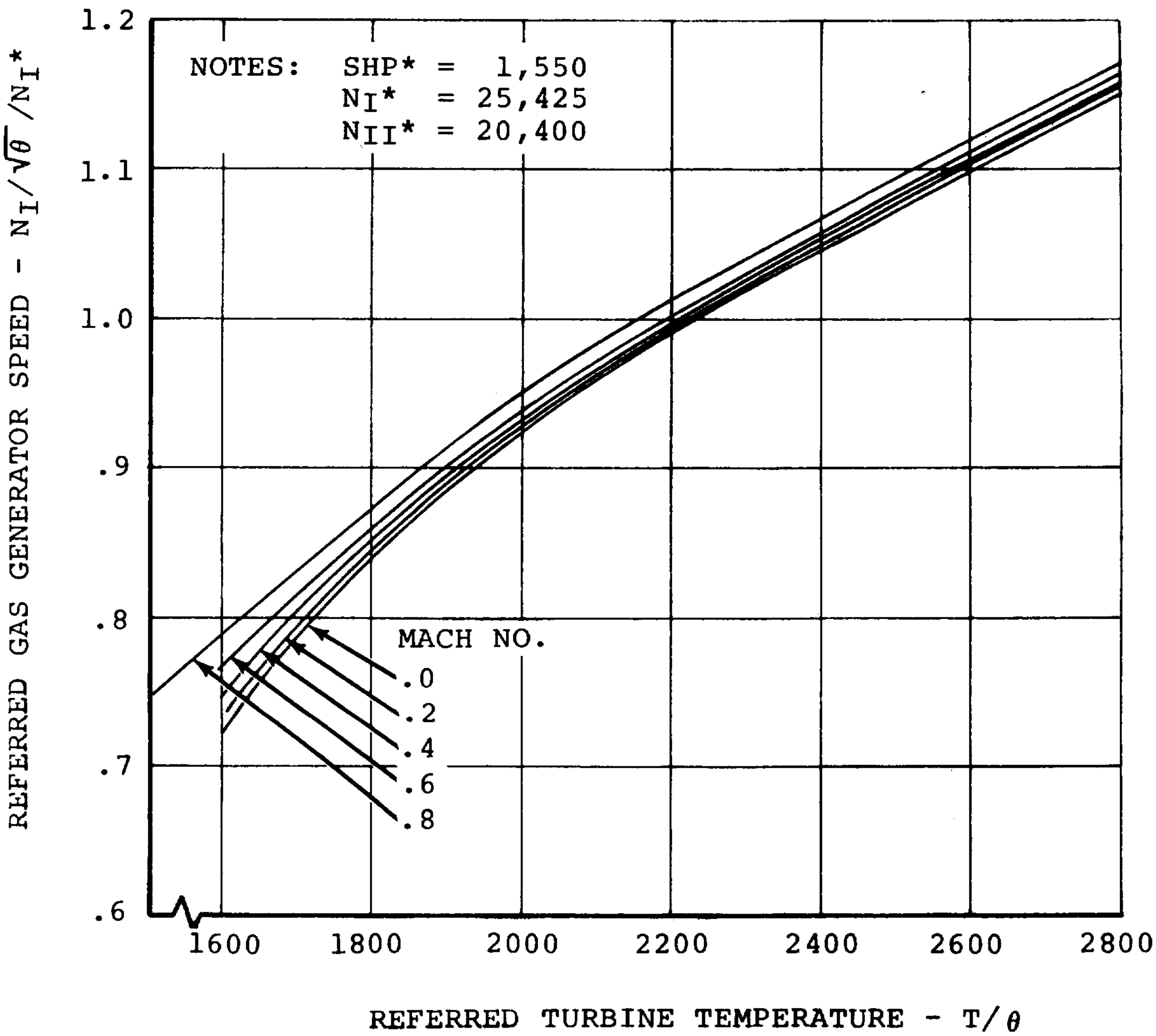


Figure F.17. Turbine Engine Performance - Engine Cycle 1.78

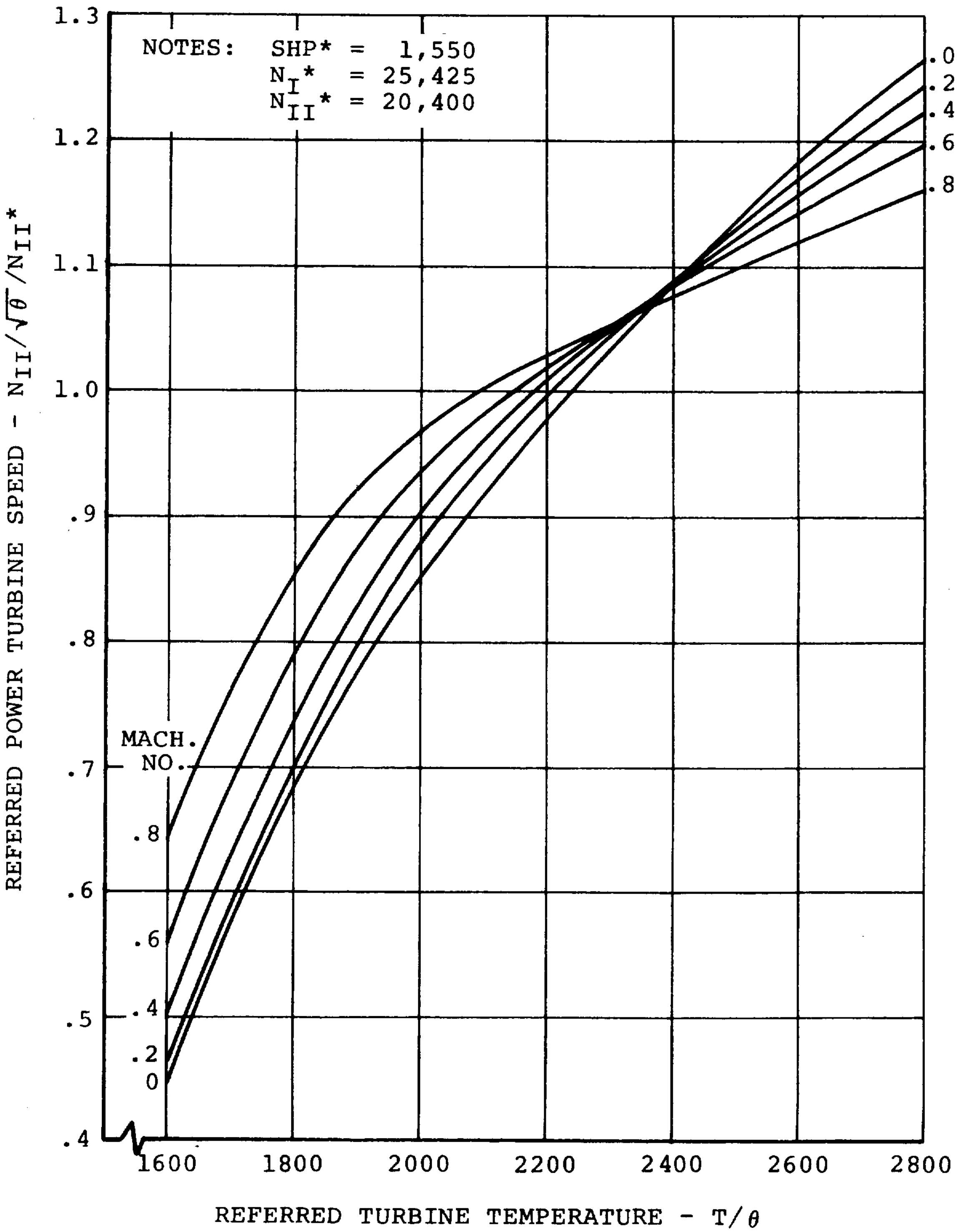


Figure F.18. Turbine Engine Performance - Engine Cycle 1.78

F.3 ROTOR AERODYNAMIC INPUT DATA

The input data for the rotor aerodynamics are given in this section, and are referenced by page number to the equations presented in Appendix E. Tabulated coefficients of the curve fit equations are shown in Figures F.19 to F.27.

F.3.1 Rotor Aerodynamic Input Data

Rotor Thrust (Page E.54)

$\tau_1 = .10$

$\tau_2 = .10$

$R = 13$ Ft.

Rotor Force and Moment Calculations (Page E.60)

$f_{TR} = f_{TL} = 1.0$

$f_{NFR} = f_{NF_L} = 1.0$

$f_{SFR} = f_{SF_L} = 1.0$

$f_{PMR} = f_{PM_L} = 1.0$

$f_{YMR} = f_{YM_L} = 1.0$

$f_{QR} = f_{Q_L} = 1.0$

$f_{PR} = f_{P_L} = 1.0$

$\mu \rightarrow$	0	.1014	.1351	.2027	.3723	.4565	.6432	.8038	1.125
A_{T0}	$.131167 \times 10^{-2}$	$-.539532 \times 10^{-2}$	$-.203368 \times 10^{-1}$	$-.427861 \times 10^{-1}$	$-.470950 \times 10^{-1}$	$-.439534 \times 10^{-1}$	$-.522445 \times 10^{-1}$	$-.708703 \times 10^{-1}$	$-.878713 \times 10^{-1}$
A_{T1}	0	$-.119838 \times 10^{-3}$	$.841758 \times 10^{-4}$	$.481855 \times 10^{-3}$	$.266417 \times 10^{-3}$	0	0	0	0
A_{T2}	0	$.26831x-10^{-5}$	$.260200 \times 10^{-5}$	$.399507 \times 10^{-6}$	$-.596957 \times 10^{-5}$	0	0	0	0
A_{T3}	0	$-.904463 \times 10^{-8}$	$-.127543 \times 10^{-7}$	$-.681927 \times 10^{-8}$	$.36307 \times 10^{-7}$	0	0	0	0
A_{T4}	$.747733 \times 10^{-3}$	$.784148 \times 10^{-3}$	$.254258 \times 10^{-2}$	$.250025 \times 10^{-2}$	$.186317 \times 10^{-2}$	$.108914 \times 10^{-2}$	$.408704 \times 10^{-3}$	$.766317 \times 10^{-3}$	$.704819 \times 10^{-3}$
A_{T5}	0	$.8905 \times 10$	$-.387201 \times 10$	$-.220100 \times 10$	$-.270408 \times 10^{-4}$	0	0	0	0
A_{T6}	0	$-.699401 \times 10^{-7}$	$.413387 \times 10^{-6}$	$.151901 \times 10^{-6}$	$-.510959 \times 10^{-6}$	0	0	0	0
A_{T7}	0	$.156844 \times 10^{-9}$	$-.151355 \times 10^{-8}$	$-.407612 \times 10^{-9}$	$.306610 \times 10^{-7}$	0	0	0	0
A_{T8}	$.120357 \times 10^{-4}$	$.996174 \times 10^{-5}$	$-.926255 \times 10^{-4}$	$-.825240 \times 10^{-5}$	$-.307987 \times 10^{-5}$	$.100012 \times 10^{-4}$	$.214303 \times 10^{-4}$	$.163128 \times 10^{-4}$	$.161866 \times 10^{-4}$
A_{T9}	0	$-.592706 \times 10^{-8}$	$.371573 \times 10^{-5}$	$.215847 \times 10^{-6}$	$-.111356 \times 10^{-6}$	0	0	0	0
A_{T10}	0	$-.10436 \times 10^{-8}$	$-.449157 \times 10^{-7}$	$-.725582 \times 10^{-9}$	$.769226 \times 10^{-7}$	0	0	0	0
A_{T11}	0	$.388825 \times 10^{-11}$	$.168184 \times 10^{-9}$	$-.196520 \times 10^{-11}$	$-.167159 \times 10^{-8}$	0	0	0	0

NOTE: α and $\theta_{0.75}$ must be in degrees when these coefficients are used in the thrust equation.

Figure F.19. Coefficients of Curve Fit Equations for Thrust Coefficient

$\mu \rightarrow$	0	.1014	.1351	.2027	.3723	.4565	.6432	.8038	1.125
A_{P0}	$.118188\times10^{-3}$	$.117752\times10^{-3}$	$.575597\times10^{-3}$	$.204675\times10^{-3}$	$.283014\times10^{-3}$	$.362823\times10^{-3}$	$.511711\times10^{-3}$	$.539983\times10^{-3}$	$.12581\times10^{-2}$
A_{P1}	0	$.262107\times10^{-5}$	$-.835529\times10^{-5}$	$-.551959\times10^{-5}$	$-.952757\times10^{-5}$	0	0	0	0
A_{P2}	0	$.379347\times10^{-7}$	$.973647\times10^{-7}$	$.145048\times10^{-6}$	$-.615163\times10^{-7}$	0	0	0	0
A_{P3}	0	$-.147777\times10^{-9}$	$-.180303\times10^{-9}$	$-.391787\times10^{-9}$	$.131638\times10^{-8}$	0	0	0	0
A_{P4}	$.223227\times10^{-1}$	$.143376\times10^{0}$	$.143289\times10^{0}$	$.304517\times10^{0}$	$.383466\times10^{0}$	$.466013\times10^{0}$	$.662959\times10^{0}$	$.854989\times10^{0}$	$.114909\times10^{-1}$
A_{P5}	0	$-.263395\times10^{-2}$	$-.391803\times10^{-2}$	$-.56844\times10^{-2}$	$-.278572\times10^{-2}$	0	0	0	0
A_{P6}	0	$.115613\times10^{-4}$	$.421318\times10^{-4}$	$.336549\times10^{-4}$	$.129237\times10^{-4}$	0	0	0	0
A_{P7}	0	$-.239424\times10^{-7}$	$-.174886\times10^{-6}$	$-.109523\times10^{-6}$	$-.595181\times10^{-6}$	0	0	0	0
A_{P8}	$.601436\times10^{1}$	$.153503\times10^{1}$	$-.759331\times10^{0}$	$-.718612\times10^{1}$	$-.297074\times10^{-1}$	$.186185\times10^{-1}$	$-.810072\times10^{-1}$	$.960492\times10^{-3}$	$.631924\times10^{0}$
A_{P9}	0	$.212258\times10^{0}$	$.443411\times10^{0}$	$.50642\times10^{0}$	$-.477549\times10^{-2}$	0	0	0	0
A_{P10}	0	$-.297147\times10^{-2}$	$-.703113\times10^{-2}$	$-.624918\times10^{-2}$	$.327815\times10^{-3}$	0	0	0	0
A_{P11}	0	$.985059\times10^{-5}$	$.27991\times10^{-4}$	$.221158\times10^{-4}$	$-.543824\times10^{-5}$	0	0	0	0

NOTE: α must be in degrees when these coefficients are used in the power equation.

Figure F.20. Coefficients of Curve Fit Equations for Power Coefficient

	$\mu=0$	$\mu=.1014$	$\mu=.1351$	$\mu=.2027$	$\mu=.3723$	$\mu=.4565$
A_{NF0}	0	$-.154857\times10^{-5}$	$.204691\times10^{-5}$	$.450018\times10^{-4}$	$-.982094\times10^{-4}$	$.179585\times10^{-6}$
A_{NF1}	0	$.467546\times10^{-5}$	$.942028\times10^{-5}$	$.211604\times10^{-4}$	$.19641\times10^{-3}$	$.323623\times10^{-3}$
A_{NF2}	0	$-.285003\times10^{-7}$	$-.100977\times10^{-6}$	$-.251209\times10^{-6}$	$-.639116\times10^{-5}$	$.684873\times10^{-6}$
A_{NF3}	0	$.128888\times10^{-10}$	$.270048\times10^{-9}$	$.746916\times10^{-9}$	$.657985\times10^{-7}$	$-.249423\times10^{-7}$
A_{NF4}	0	$-.102821\times10^{-3}$	$.224724\times10^{-3}$	$.929207\times10^{-3}$	$-.157595\times10^{-2}$	$-.809587\times10^{-4}$
A_{NF5}	0	$.749984\times10^{-3}$	$.125801\times10^{-2}$	$.178593\times10^{-2}$	$.24356\times10^{-2}$	$.572817\times10^{-2}$
A_{NF6}	0	$-.945697\times10^{-5}$	$-.132674\times10^{-4}$	$-.217638\times10^{-4}$	$.234598\times10^{-3}$	$.109167\times10^{-2}$
A_{NF7}	0	$.293263\times10^{-7}$	$.348545\times10^{-7}$	$.65423\times10^{-7}$	$-.470641\times10^{-5}$	$-.963463\times10^{-4}$
A_{NF8}	0	$.109342\times10^{0}$	$.275072\times10^{-1}$	$-.543699\times10^{-1}$	$.443939\times10^{-1}$	$.53212\times10^{-2}$
A_{NF9}	0	$.943903\times10^{-1}$	$.696523\times10^{-1}$	$.18035\times10^{0}$	$-.138981\times10^{-1}$	$.159926\times10^{0}$
A_{NF10}	0	$-.108604\times10^{-2}$	$-.923809\times10^{-3}$	$-.232838\times10^{-2}$	$.632501\times10^{-3}$	$-.115516\times10^{0}$
A_{NF11}	0	$.317682\times10^{-5}$	$.29846\times10^{-5}$	$.738683\times10^{-5}$	$-.814596\times10^{-5}$	$.994553\times10^{-2}$

	$\mu=.5147$	$\mu=.6432$	$\mu=.772$	$\mu=.9008$	$\mu=1.03$	$\mu=1.158$
A_{NF0}	$.137987\times10^{-5}$	$.161374\times10^{-5}$	$.245107\times10^{-5}$	$-.132502\times10^{-6}$	$-.173383\times10^{-5}$	$.585875\times10^{-5}$
A_{NF1}	$.439095\times10^{-3}$	$.760961\times10^{-3}$	$.109347\times10^{-2}$	$.140037\times10^{-2}$	$.170687\times10^{-2}$	$.199778\times10^{-2}$
A_{NF2}	$.228487\times10^{-5}$	$.440349\times10^{-6}$	$.823616\times10^{-6}$	$-.191532\times10^{-6}$	$-.139327\times10^{-5}$	$-.209278\times10^{-5}$
A_{NF3}	$-.762918\times10^{-7}$	$-.152524\times10^{-7}$	$-.545001\times10^{-7}$	$.257742\times10^{-7}$	$.512513\times10^{-7}$	$.76607\times10^{-7}$
A_{NF4}	$-.792358\times10^{-3}$	$-.58501\times10^{-3}$	$-.578165\times10^{-4}$	$-.185878\times10^{-3}$	$.212865\times10^{-2}$	$-.228619\times10^{-2}$
A_{NF5}	$.665352\times10^{-2}$	$.282596\times10^{-2}$	$-.625689\times10^{-2}$	$-.258884\times10^{-2}$	$-.513321\times10^{-2}$	$.123733\times10^{-1}$
A_{NF6}	$-.208908\times10^{-3}$	$.266667\times10^{-3}$	$.122656\times10^{-2}$	$.658596\times10^{-3}$	$.878786\times10^{-3}$	$-.583625\times10^{-3}$
A_{NF7}	$.776787\times10^{-5}$	$-.517496\times10^{-5}$	$-.361453\times10^{-4}$	$-.249126\times10^{-4}$	$-.316126\times10^{-4}$	$.101001\times10^{-4}$
A_{NF8}	$.324054\times10^{-1}$	$.487661\times10^{-1}$	$-.60177\times10^{-1}$	$.804597\times10^{-2}$	$-.162981\times10^{0}$	$.466581\times10^{-1}$
A_{NF9}	$-.688518\times10^{-1}$	$.113439\times10^{0}$	$.642961\times10^{0}$	$.208291\times10^{-1}$	$.515108\times10^{0}$	$-.898786\times10^{0}$
A_{NF10}	$.875982\times10^{-2}$	$-.243064\times10^{-1}$	$-.967895\times10^{-1}$	$-.520537\times10^{-2}$	$-.665886\times10^{-1}$	$.324115\times10^{-1}$
A_{NF11}	$-.327294\times10^{-3}$	$.563958\times10^{-3}$	$.300992\times10^{-2}$	$.261473\times10^{-3}$	$.221409\times10^{-2}$	$-.439838\times10^{-3}$

NOTE: α must be in degrees when these coefficients are used in the normal force equation.

Figure F.21. Coefficients of Curve Fit Equations for Normal Force Coefficient

	$\mu=0$	$\mu=.1014$	$\mu=.1351$	$\mu=.2027$	$\mu=.3723$	$\mu=.4565$
A_{SF0}	0	$.291745\times10^{-6}$	$.115843\times10^{-5}$	$.564885\times10^{-4}$	$.610186\times10^{-8}$	$.237281\times10^{-7}$
A_{SF1}	0	$-.12407\times10^{-5}$	$-.106448\times10^{-5}$	$.633856\times10^{-6}$	$.557813\times10^{-4}$	$.650575\times10^{-5}$
A_{SF2}	0	$.113747\times10^{-7}$	$.671759\times10^{-8}$	$-.252897\times10^{-7}$	$-.598734\times10^{-6}$	$.769321\times10^{-7}$
A_{SF3}	0	$-.245443\times10^{-10}$	$-.440653\times10^{-11}$	$.119483\times10^{-9}$	$-.659238\times10^{-8}$	$-.349334\times10^{-8}$
A_{SF4}	0	$.143202\times10^{-3}$	$.317272\times10^{-3}$	$.147537\times10^{-2}$	$-.842079\times10^{-4}$	$.117121\times10^{-4}$
A_{SF5}	0	$-.830999\times10^{-4}$	$-.118232\times10^{-3}$	$-.544752\times10^{-4}$	$-.550991\times10^{-4}$	$-.300935\times10^{-2}$
A_{SF6}	0	$.958551\times10^{-7}$	$.242609\times10^{-6}$	$-.267651\times10^{-5}$	$-.171925\times10^{-4}$	$-.563082\times10^{-4}$
A_{SF7}	0	$.200043\times10^{-8}$	$.227584\times10^{-8}$	$.163762\times10^{-7}$	$.296356\times10^{-6}$	$.233296\times10^{-5}$
A_{SF8}	0	$-.193731\times10^{-2}$	$-.509539\times10^{-2}$	$-.833551\times10^{-1}$	$.686884\times10^{-2}$	$-.759009\times10^{-3}$
A_{SF9}	0	$.407909\times10^{-2}$	$.722497\times10^{-2}$	$.315085\times10^{-2}$	$-.101352\times10^{-1}$	$.111362\times10^{-1}$
A_{SF10}	0	$-.450147\times10^{-4}$	$-.916859\times10^{-4}$	$.612312\times10^{-4}$	$.130744\times10^{-2}$	$.411265\times10^{-2}$
A_{SF11}	0	$.124524\times10^{-6}$	$.285967\times10^{-6}$	$-.428818\times10^{-6}$	$-.239885\times10^{-4}$	$-.168146\times10^{-3}$

	$\mu=.5147$	$\mu=.6432$	$\mu=.772$	$\mu=.9008$	$\mu=1.03$	$\mu=1.158$
A_{SF0}	$.136092\times10^{-5}$	$.976607\times10^{-6}$	$-.97825\times10^{-6}$	$.786968\times10^{-6}$	$-.216019\times10^{-5}$	$-.253321\times10^{-5}$
A_{SF1}	$-.23559\times10^{-4}$	$-.130694\times10^{-3}$	$-.316773\times10^{-3}$	$-.557452\times10^{-3}$	$-.809093\times10^{-3}$	$-.109376\times10^{-2}$
A_{SF2}	$.127659\times10^{-5}$	$-.366955\times10^{-6}$	$-.859884\times10^{-6}$	$-.124574\times10^{-6}$	$-.856051\times10^{-7}$	$.385756\times10^{-5}$
A_{SF3}	$-.572509\times10^{-7}$	$.121016\times10^{-7}$	$.301607\times10^{-7}$	$.115477\times10^{-7}$	$.178906\times10^{-7}$	$-.120107\times10^{-6}$
A_{SF4}	$.119258\times10^{-2}$	$-.100898\times10^{-3}$	$.725157\times10^{-3}$	$.258719\times10^{-4}$	$.167271\times10^{-3}$	$.130762\times10^{-2}$
A_{SF5}	$-.740273\times10^{-2}$	$-.367008\times10^{-2}$	$-.55614\times10^{-2}$	$-.320731\times10^{-2}$	$-.721592\times10^{-2}$	$.259621\times10^{-3}$
A_{SF6}	$.104627\times10^{-2}$	$.662111\times10^{-4}$	$.25791\times10^{-3}$	$-.165071\times10^{-3}$	$.327913\times10^{-3}$	$-.372471\times10^{-3}$
A_{SF7}	$-.487885\times10^{-4}$	$-.2585357\times10^{-5}$	$-.751767\times10^{-5}$	$.278601\times10^{-6}$	$-.134919\times10^{-4}$	$.126176\times10^{-4}$
A_{SF8}	$-.177106\times10^{0}$	$.363417\times10^{-2}$	$-.600228\times10^{-1}$	$-.274394\times10^{-1}$	$.157176\times10^{-1}$	$-.693893\times10^{-1}$
A_{SF9}	$.683888\times10^{0}$	$-.104633\times10^{0}$	$-.660259\times10^{-1}$	$-.178098\times10^{0}$	$.175384\times10^{0}$	$-.835669\times10^{-2}$
A_{SF10}	$-.161739\times10^{0}$	$-.18044\times10^{-2}$	$-.812251\times10^{-2}$	$.208395\times10^{-1}$	$-.938934\times10^{-2}$	$.198682\times10^{-1}$
A_{SF11}	$.75356\times10^{-2}$	$.896371\times10^{-4}$	$.125335\times10^{-3}$	$-.295016\times10^{-3}$	$.401628\times10^{-3}$	$-.916932\times10^{-3}$

NOTE: α must be in degrees when these coefficients are used in the side force equation.

Figure F.22. Coefficients of Curve Fit Equations for Side Force Coefficient

	$\mu=0$	$\mu=.1014$	$\mu=.1351$	$\mu=.2027$	$\mu=.3723$	$\mu=.4565$
A_{PM0}	0	$.377218 \times 10^{-5}$	$.688095 \times 10^{-5}$	$-.79344 \times 10^{-5}$	$-.310285 \times 10^{-6}$	$-.884622 \times 10^{-8}$
A_{PM1}	0	$.539482 \times 10^{-5}$	$.125905 \times 10^{-4}$	$.316671 \times 10^{-4}$	$.820375 \times 10^{-4}$	$.141415 \times 10^{-4}$
A_{PM2}	0	$-.12652 \times 10^{-6}$	$-.252414 \times 10^{-6}$	$-.581828 \times 10^{-6}$	$-.27116 \times 10^{-6}$	$.345339 \times 10^{-7}$
A_{PM3}	0	$.537895 \times 10^{-9}$	$.101607 \times 10^{-8}$	$.226169 \times 10^{-8}$	$-.151223 \times 10^{-7}$	$-.105759 \times 10^{-8}$
A_{PM4}	0	$.172117 \times 10^{-3}$	$.562525 \times 10^{-3}$	$.201324 \times 10^{-2}$	$.193688 \times 10^{-3}$	$-.738879 \times 10^{-5}$
A_{PM5}	0	$.146772 \times 10^{-2}$	$.1652 \times 10^{-2}$	$.206142 \times 10^{-2}$	$.464123 \times 10^{-2}$	$-.159412 \times 10^{-2}$
A_{PM6}	0	$-.11507 \times 10^{-4}$	$-.121292 \times 10^{-4}$	$-.131115 \times 10^{-4}$	$-.229179 \times 10^{-4}$	$.508798 \times 10^{-5}$
A_{PM7}	0	$.185794 \times 10^{-7}$	$.164608 \times 10^{-7}$	$.913233 \times 10^{-8}$	$-.119169 \times 10^{-6}$	$-.10134 \times 10^{-6}$
A_{PM8}	0	$-.165488 \times 10^{-1}$	$-.189205 \times 10^{-1}$	$.766096 \times 10^{-1}$	$-.133686 \times 10^{-1}$	$.955878 \times 10^{-3}$
A_{PM9}	0	$.181983 \times 10^{-2}$	$.224173 \times 10^{-3}$	$-.692308 \times 10^{-2}$	$-.487350 \times 10^{-2}$	$.216812 \times 10^{-1}$
A_{PM10}	0	$-.236138 \times 10^{-4}$	$.16657 \times 10^{-6}$	$.684175 \times 10^{-4}$	$.362062 \times 10^{-3}$	$-.13177 \times 10^{-2}$
A_{PM11}	0	$.796661 \times 10^{-7}$	$-.470343 \times 10^{-8}$	$-.176422 \times 10^{-6}$	$-.598035 \times 10^{-5}$	$.362472 \times 10^{-4}$

	$\mu=.5147$	$\mu=.6432$	$\mu=.772$	$\mu=.9008$	$\mu=1.03$	$\mu=1.158$
A_{PM0}	$-.163818 \times 10^{-6}$	$-.771885 \times 10^{-6}$	$-.248968 \times 10^{-5}$	$.145349 \times 10^{-6}$	$.168996 \times 10^{-5}$	$.274231 \times 10^{-6}$
A_{PM1}	$-.177418 \times 10^{-5}$	$-.922672 \times 10^{-4}$	$-.202383 \times 10^{-3}$	$-.308712 \times 10^{-3}$	$-.383796 \times 10^{-3}$	$-.470485 \times 10^{-3}$
A_{PM2}	$.356703 \times 10^{-7}$	$.111958 \times 10^{-6}$	$.704986 \times 10^{-6}$	$.536055 \times 10^{-7}$	$-.912361 \times 10^{-7}$	$.25489 \times 10^{-6}$
A_{PM3}	$-.137756 \times 10^{-8}$	$-.216285 \times 10^{-9}$	$-.328566 \times 10^{-7}$	$.53226 \times 10^{-9}$	$-.27077 \times 10^{-9}$	$-.640161 \times 10^{-8}$
A_{PM4}	$.401368 \times 10^{-4}$	$.225413 \times 10^{-4}$	$.778302 \times 10^{-3}$	$-.483831 \times 10^{-3}$	$-.497667 \times 10^{-3}$	$-.321648 \times 10^{-3}$
A_{PM5}	$-.240092 \times 10^{-2}$	$-.399324 \times 10^{-2}$	$-.641948 \times 10^{-2}$	$-.70195 \times 10^{-2}$	$-.100188 \times 10^{-1}$	$-.687551 \times 10^{-2}$
A_{PM6}	$-.120839 \times 10^{-4}$	$-.665199 \times 10^{-4}$	$-.128724 \times 10^{-3}$	$-.119008 \times 10^{-3}$	$-.416504 \times 10^{-4}$	$-.344122 \times 10^{-3}$
A_{PM7}	$.387065 \times 10^{-6}$	$.204615 \times 10^{-5}$	$.638786 \times 10^{-5}$	$.396756 \times 10^{-5}$	$.168316 \times 10^{-5}$	$.12192 \times 10^{-4}$
A_{PM8}	$-.227747 \times 10^{-2}$	$.261322 \times 10^{-1}$	$-.424198 \times 10^{-1}$	$.428319 \times 10^{-1}$	$.392666 \times 10^{-1}$	$.256492 \times 10^{-1}$
A_{PM9}	$-.751961 \times 10^{-1}$	$-.183726 \times 10^{0}$	$.359543 \times 10^{-1}$	$.143102 \times 10^{-1}$	$.949637 \times 10^{-1}$	$-.135728 \times 10^{0}$
A_{PM10}	$.10527 \times 10^{-2}$	$.210223 \times 10^{-1}$	$-.33401 \times 10^{-3}$	$.856042 \times 10^{-2}$	$.12569 \times 10^{-1}$	$.336543 \times 10^{-1}$
A_{PM11}	$-.393332 \times 10^{-4}$	$-.726143 \times 10^{-3}$	$-.78287 \times 10^{-4}$	$-.33099 \times 10^{-3}$	$-.435573 \times 10^{-3}$	$-.115452 \times 10^{-2}$

NOTE: α must be in degrees when these coefficients are used in the pitching moment equation.

Figure F.23. Coefficients of Curve Fit Equations for Pitching Moment Coefficient

	$\mu=0$	$\mu=.1014$	$\mu=.1351$	$\mu=.2027$	$\mu=.3723$	$\mu=.4565$
A_{YM0}	0	$.109092\times10^{-5}$	$.286933\times10^{-7}$	$-.110543\times10^{-4}$	$-.115949\times10^{-4}$	$.75428\times10^{-6}$
A_{YM1}	0	$.126647\times10^{-4}$	$.191392\times10^{-4}$	$.250948\times10^{-4}$	$.442163\times10^{-4}$	$.199993\times10^{-3}$
A_{YM2}	0	$-.148631\times10^{-6}$	$-.229016\times10^{-6}$	$-.220845\times10^{-6}$	$.979871\times10^{-6}$	$.672974\times10^{-6}$
A_{YM3}	0	$.435436\times10^{-9}$	$.68199\times10^{-9}$	$.154233\times10^{-9}$	$-.231738\times10^{-7}$	$-.198906\times10^{-7}$
A_{YM4}	0	$.216295\times10^{-3}$	$.61904\times10^{-3}$	$.303865\times10^{-4}$	$.76278\times10^{-3}$	$-.989016\times10^{-4}$
A_{YM5}	0	$.636091\times10^{-4}$	$.533431\times10^{-4}$	$.880677\times10^{-3}$	$.600766\times10^{-2}$	$.890334\times10^{-2}$
A_{YM6}	0	$.290233\times10^{-5}$	$.265736\times10^{-5}$	$-.16908\times10^{-4}$	$-.24055\times10^{-3}$	$.101251\times10^{-4}$
A_{YM7}	0	$-.182158\times10^{-7}$	$-.164399\times10^{-7}$	$.10332\times10^{-6}$	$.289645\times10^{-5}$	$-.239883\times10^{-6}$
A_{YM8}	0	$-.158447\times10^{-1}$	$-.2112\times10^{-1}$	$-.171322\times10^{-1}$	$-.27995\times10^{-1}$	$.646468\times10^{-2}$
A_{YM9}	0	$.147256\times10^{-2}$	$.323912\times10^{-3}$	$-.426356\times10^{-2}$	$.116529\times10^{-1}$	$.486429\times10^{-1}$
A_{YM10}	0	$-.178633\times10^{-4}$	$-.158877\times10^{-5}$	$.873694\times10^{-4}$	$-.78607\times10^{-3}$	$-.277348\times10^{-2}$
A_{YM11}	0	$.579483\times10^{-7}$	$.374405\times10^{-8}$	$-.533888\times10^{-6}$	$.133698\times10^{-4}$	$.407947\times10^{-4}$

	$\mu=.5147$	$\mu=.6432$	$\mu=.772$	$\mu=.9008$	$\mu=1.03$	$\mu=1.158$
A_{YM0}	$.811278\times10^{-6}$	$-.689819\times10^{-6}$	$-.140611\times10^{-5}$	$-.959155\times10^{-6}$	$.232776\times10^{-5}$	$.776742\times10^{-6}$
A_{YM1}	$.2549\times10$	$.358353\times10^{-3}$	$.40651\times10^{-3}$	$.423457\times10^{-3}$	$.404494\times10^{-3}$	$.400109\times10^{-3}$
A_{YM2}	$.298133\times10^{-6}$	$-.483638\times10^{-6}$	$.711836\times10^{-6}$	$.366298\times10^{-6}$	$-.978679\times10^{-6}$	$.483519\times10^{-6}$
A_{YM3}	$-.7069\times10^{-8}$	$.165027\times10^{-7}$	$-.242848\times10^{-7}$	$-.201739\times10^{-7}$	$.384779\times10^{-7}$	$-.178582\times10^{-7}$
A_{YM4}	$-.138358\times10^{-3}$	$-.376316\times10^{-3}$	$-.111605\times10^{-3}$	$-.498142\times10^{-3}$	$-.859507\times10^{-3}$	$-.170495\times10^{-3}$
A_{YM5}	$.84517\times10^{-2}$	$.731418\times10^{-2}$	$.111654\times10^{-1}$	$.700776\times10^{-2}$	$.495335\times10^{-2}$	$.937562\times10^{-3}$
A_{YM6}	$.511468\times10^{-4}$	$.25651\times10^{-3}$	$-.397326\times10^{-3}$	$-.179799\times10^{-3}$	$.475445\times10^{-3}$	$.428652\times10^{-3}$
A_{YM7}	$-.113402\times10^{-5}$	$-.882347\times10^{-5}$	$.127859\times10^{-4}$	$.100219\times10^{-4}$	$-.172489\times10^{-4}$	$-.224772\times10^{-4}$
A_{YM8}	$.135303\times10^{-3}$	$.322547\times10^{-1}$	$.931734\times10^{-2}$	$.392748\times10^{-1}$	$.62677\times10^{-1}$	$.242592\times10^{0}$
A_{YM9}	$.664771\times10^{-1}$	$.729796\times10^{-1}$	$-.283071\times10^{0}$	$-.697861\times10^{-1}$	$.101986\times10^{0}$	$.629868\times10^{0}$
A_{YM10}	$-.647118\times10^{-2}$	$-.170565\times10^{-1}$	$.292923\times10^{-1}$	$.166632\times10^{-1}$	$-.284635\times10^{-1}$	$-.600989\times10^{-1}$
A_{YM11}	$.140141\times10^{-3}$	$.575827\times10^{-3}$	$-.960904\times10^{-3}$	$-.821801\times10^{-3}$	$.101423\times10^{-2}$	$.245749\times10^{-2}$

NOTE: λ must be in degrees when these coefficients are used in the yawing moment equation.

Figure F.24. Coefficients of Curve Fit Equations for Yawing Moment Coefficient

$\mu \rightarrow$	0	.1014	.1351	.2027	.3723	.4565	.5147	.6432	.7720
H_{PM0}	-1.503×10^{-3}	-1.633×10^{-3}	-1.633×10^{-3}	-1.708×10^{-3}	-2.935×10^{-3}	-2.815×10^{-3}	-2.75×10^{-3}	-2.425×10^{-3}	-2.00×10^{-3}
H_{PM1}	0	0	0	0	0	0	0	0	0
H_{PM2}									
H_{PM3}									
H_{PM4}									
H_{PM5}									
H_{PM6}									
H_{PM7}									
H_{PM8}									
H_{PM9}									
H_{PM10}									
H_{PM11}	0	0	0	0	0	0	0	0	0

$\mu \rightarrow$	.9009	1.03	1.158
H_{PM0}	-1.575×10^{-3}	-1.225×10^{-3}	-0.925×10^{-3}
H_{PM1}	0	0	0
H_{PM2}			
H_{PM3}			
H_{PM4}			
H_{PM5}			
H_{PM6}			
H_{PM7}			
H_{PM8}			
H_{PM9}			
H_{PM10}			
H_{PM11}	0	0	0

NOTE: α must be in degrees when these coefficients are used in the pitching moment rate equation.

Figure F.25. Curve Fit Coefficients for $^{\alpha}C_{PM_{\alpha Q}}$

$\mu \rightarrow$	0	.1014	.1351	.2027	.3723	.4565	.5147	.6432	.7720
J_{YM0}	1.503×10^{-3}	1.633×10^{-3}	1.633×10^{-3}	1.708×10^{-3}	2.935×10^{-3}	2.815×10^{-3}	2.75×10^{-3}	2.425×10^{-3}	2.00×10^{-3}
J_{YM1}	0	0	0	0	0	0	0	0	0
J_{YM2}									
J_{YM3}									
J_{YM4}									
J_{YM5}									
J_{YM6}									
J_{YM7}									
J_{YM8}									
J_{YM9}									
J_{YM10}									
J_{YM11}	0	0	0	0	0	0	0	0	0

$\mu \rightarrow$	.9008	1.03	1.158
J_{YM0}	1.575×10^{-3}	1.225×10^{-3}	$.925 \times 10^{-3}$
J_{YM1}	0	0	0
J_{YM2}			
J_{YM3}			
J_{YM4}			
J_{YM5}			
J_{YM6}			
J_{YM7}			
J_{YM8}			
J_{YM9}			
J_{YM10}			
J_{YM11}	0	0	0

NOTE: α must be in degrees when these equations are used in the hub yawing moment rate equation.

Figure F.26. Curve Fit Coefficients for $\frac{\alpha C_{YM}}{\alpha R}$

$$\left.\begin{aligned} E_{NF_1} &= -.024 \\ E_{NF_2} &= -.002703 \\ E_{NF_3} &= -.000346 \\ E_{NF_4} &= .00039 \end{aligned}\right\} \text{Coeff. of } \frac{dC_{NF}}{dB_{1C}} \sim \frac{1}{DEG}$$

$$\left.\begin{aligned} D_{NF_1} &= .006 \\ D_{NF_2} &= -.0012318 \\ D_{NF_3} &= .000033 \\ D_{NF_4} &= -.0000268 \end{aligned}\right\} \text{Coeff. of } \frac{dC_{NF}}{dA_{1C}} \sim \frac{1}{DEG}$$

$$\left.\begin{aligned} E_{SF_1} &= .0025 \\ E_{SF_2} &= .0011896 \\ E_{SF_3} &= -.00001246 \\ E_{SF_4} &= .00001669 \end{aligned}\right\} \text{Coeff. of } \frac{dC_{SF}}{dB_{1C}} \sim \frac{1}{DEG}$$

$$\left.\begin{aligned} D_{SF_1} &= .025 \\ D_{SF_2} &= .0025356 \\ D_{SF_3} &= -.0002264 \\ D_{SF_4} &= -.000044 \end{aligned}\right\} \text{Coeff. of } \frac{dC_{SF}}{dA_{1C}} \sim \frac{1}{DEG}$$

$$\left.\begin{aligned} E_{PM_1} &= -.0025 \\ E_{PM_2} &= -.0014304 \\ E_{PM_3} &= .0003029 \\ E_{PM_4} &= -.0002938 \\ E_{PM_5} &= -.0001367 \\ E_{PM_6} &= -.0004888 \\ E_{PM_7} &= -.0001767 \end{aligned}\right\} \text{Coeff. of } \frac{dC_{PM}}{dB_{1C}} \sim \frac{1}{DEG}$$

$$\left.\begin{aligned} D_{PM_1} &= -.0015 \\ D_{PM_2} &= .0010726 \\ D_{PM_3} &= -.0001564 \\ D_{PM_4} &= .0001762 \\ D_{PM_5} &= +.0000966 \\ D_{PM_6} &= .000571 \\ D_{PM_7} &= .0000422 \end{aligned}\right\} \text{Coeff. of } \frac{dC_{PM}}{dA_{1C}} \sim \frac{1}{DEG}$$

$$\left.\begin{aligned} E_{YM_1} &= .0025 \\ E_{YM_2} &= -.0013888 \\ E_{YM_3} &= .000336 \\ E_{YM_4} &= -.000187 \\ E_{YM_5} &= -.0000723 \\ E_{YM_6} &= -.0006354 \\ E_{YM_7} &= -.0000098 \end{aligned}\right\} \text{Coeff of } \frac{dC_{YM}}{dB_{1C}} \sim \frac{1}{DEG}$$

$$\left.\begin{aligned} D_{YM_1} &= -.0025 \\ D_{YM_2} &= -.0009883 \\ D_{YM_3} &= .000089 \\ D_{YM_4} &= -.0002866 \\ D_{YM_5} &= -.0001503 \\ D_{YM_6} &= -.0004564 \\ D_{YM_7} &= -.0001993 \end{aligned}\right\} \text{Coeff of } \frac{dC_{YM}}{dA_{1C}} \sim \frac{1}{DEG}$$

Figure F.27. Constants for Cyclic Pitch Effectiveness in Rotor Equations

F.4 AIRFRAME AERODYNAMIC INPUT DATA

The input data for the airframe aerodynamic data are given in this section and are referenced by page number to the equations presented in Appendix E. Plotted aerodynamic data are presented in Figures F.28 to F.30 .

F.4.1 Input Data

PAGE	
E.21	$C_{L_{\alpha W}} = 3.94$ 1/rad
E.28	$C_{L_{MAX}} = 1.232$
E.31	$K_{20} = -.0975$/RAD
	$K_{21} = -.0916$/RAD
	$K_{22} = .015$
	$K_{\ell} = 1.0$
	$K_{\eta} = 1.0$
E.32	$f_{eu} = 60\ ft^2$
	$D/T = .05$
	$K_{D1/T} = 0.0$
	$K_{D2/T} = 0.0$
	$K_{D3/T} = .05$
	$K_{D4/T} = .05$
	$K_{M1/T} = 0.0$
	$K_{M2/T} = 0.0$
	$K_{M3/T} = 0.0$
	$K_{M4/T} = 0.0$
E.36	$\tau_{HT} = .52$
	$\alpha_{HT_{STALL}} = 16$ DEG
	$C_{L_{\alpha HT}} = .061$ 1/DEG
	$C_{D_{OHT}} = .0084202$
E.39	$\frac{d\sigma}{d\beta} = -.025$
	$\tau_{VT} = .55$
	$\alpha_{VT_{STALL}} = 20.0$ DEG
	$C_{x_{\alpha VT}} = .0546$ 1/DEG
	$C_{D_{OVT}} = .0078915$

PAGE	
E.43	$\eta_{HT} = 1.0$
	$\eta_{VT} = 1.0$
	$\alpha_N \leq .5236$RAD/>.5236RAD
E.44	$C_{DON} = .001821/-.016179$
	$K_{30} = .04773/-.2034$
	$K_{31} = .16086/-.071138$
	$K_{32} = .1087$
	$C_{MON} = 0$
	$K_{34} = 0$
	$K_{35} = 0$
	$K_{36} = -.1087$
	$K_{37} = 0$
	$K'_{36} = -.1087$
	$K'_{37} = 0$
	$C_{NON} = 0$
	$K_{38} = 0$
	$K_{39} = 0$
	$K_{40} = 0$
	$K_{41} = 0$
E.49	$C_{DOF} = .0075705$
	$K_o = 18$
	$K_1 = -.03581$
	$K_2 = .2561$
	$\Delta C_{DLG} = .05$
	$K_3 = .922$/RAD
	$K_4 = 0$
	$K_5 = .67709$
	$K_6 = 0$
	$K_7 = -.478$

E.49 $K_8 = 0$
$K_9 = -.131/RAD$
$K_{10} = 0$
$C_{MOF} = .0001883$
$C_{NOF} = 0$
$\Delta C_{MLG} = 0$
$K_{42} = .0537$

E.52 $T_1 = 0$
$T_2 = -.04808$
$T_3 = .3795$

E.54 $\tau_1 = .1$
$\tau_2 = .1$

E.60 $f_{TR} = f_{NFR} = f_{SFR} = f_{PMR} = f_{YMR} = f_{QR} = f_{PR} = 1.0$

E.66 $\frac{dC_{Mwc/4}}{dC_L} = -.03215$
$C_1 = -.065$
$C_2 = -.0025\ 1/DEG$
$C_3 = 0.0\ 1/DEG^2$
$C_{L\alpha} = 3.94/RAD$

Wing Aerodynamic Input Data

Coefficients of $\sum_{v=0}^{4} \sum_{u=0}^{4} [A_{D_{(u+5v)}} \delta^u \alpha^v]$ (Page E.26)

$A_{D0} = .582990 \times 10^{-3}$

$A_{D1} = .126170 \times 10^{-2}$

$A_{D2} = .391649 \times 10^{-4}$

$A_{D3} = .110058 \times 10^{-5}$

$A_{D4} = -.159415 \times 10^{-7}$

$A_{D5} = .245484 \times 10^{-3}$

$A_{D6} = .265950 \times 10^{-3}$

$A_{D7} = .404673 \times 10^{-5}$

$A_{D8} = -.152693 \times 10^{-6}$

$A_{D9} = .102320 \times 10^{-8}$

$A_{D10} = -.313543 \times 10^{-5}$

$A_{D11} = .624554 \times 10^{-6}$

$A_{D12} = .141804 \times 10^{-6}$

$A_{D13} = -.821732 \times 10^{-8}$

$A_{D14} = .119984 \times 10^{-9}$

$A_{D15} = -.474069 \times 10^{-5}$

$A_{D16} = .771740 \times 10^{-6}$

$A_{D17} = -.800800 \times 10^{-7}$

$A_{D18} = .208761 \times 10^{-8}$

$A_{D19} = -.114899 \times 10^{-10}$

$A_{D20} = .238184 \times 10^{-6}$

$A_{D21} = .196213 \times 10^{-7}$

$A_{D22} = -.204613 \times 10^{-8}$

$A_{D23} = .133330 \times 10^{-10}$

$A_{D24} = .492127 \times 10^{-13}$

NOTES: δ, α in degrees.

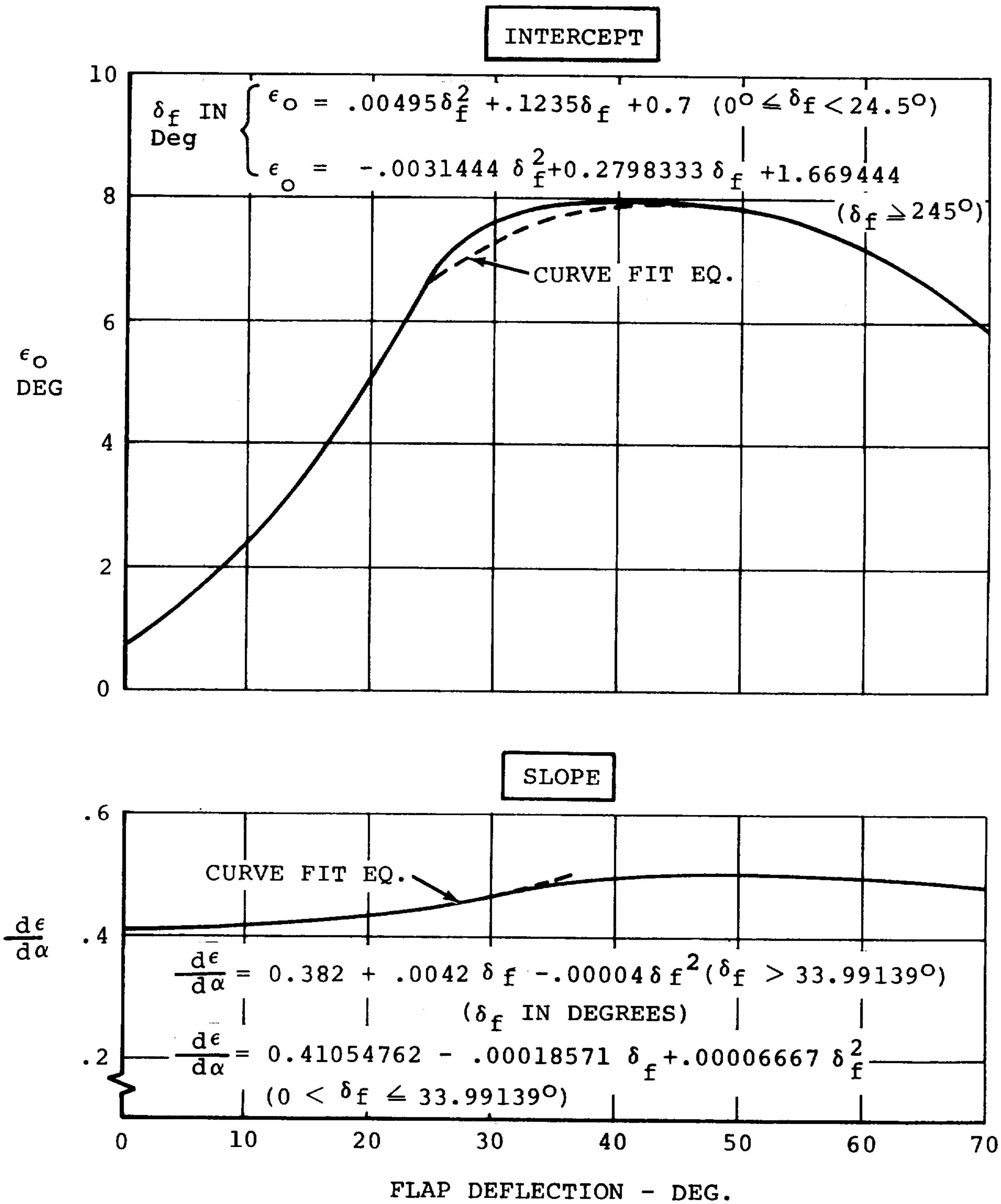


Figure F.28. Model 222 Downwash Functions @ $C_T = 0$, $i_w = +2.0^\circ$

REF: APPENDIX B-7 ETKIN

FOR TAIL;

$$\frac{a_g}{a} = 1.2103 - .038\ h_T + .00184h_T^2;\ h_T \leqslant 6.3219$$

$$\frac{a_g}{a} = 1.1096 - .01284\ h_T + .00038h_T^2;\ h_T > 6.3219$$

$$\frac{a_g}{a} = 1.00;\ h_{T_{c/4}} \geqslant 17.'$$

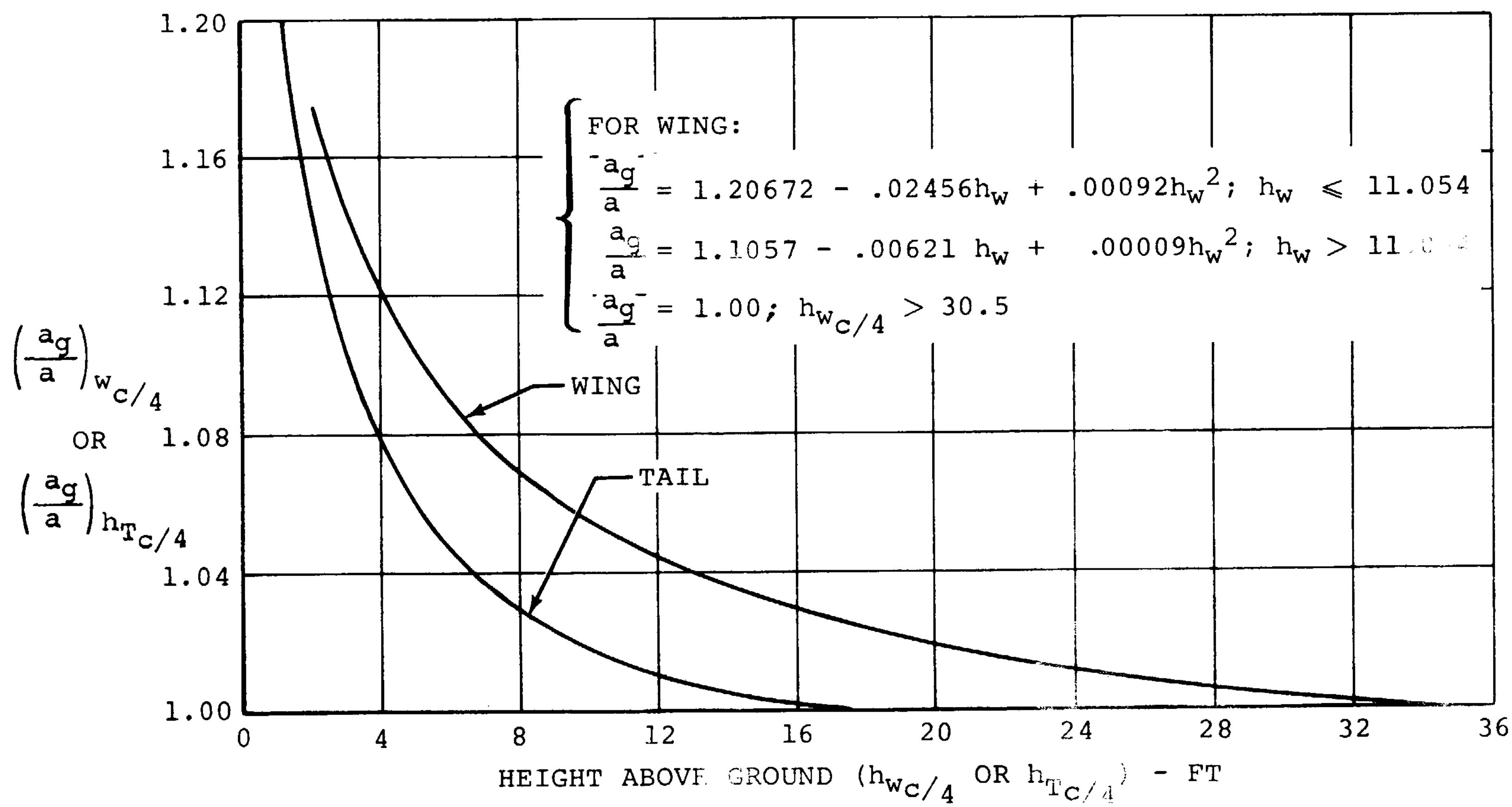
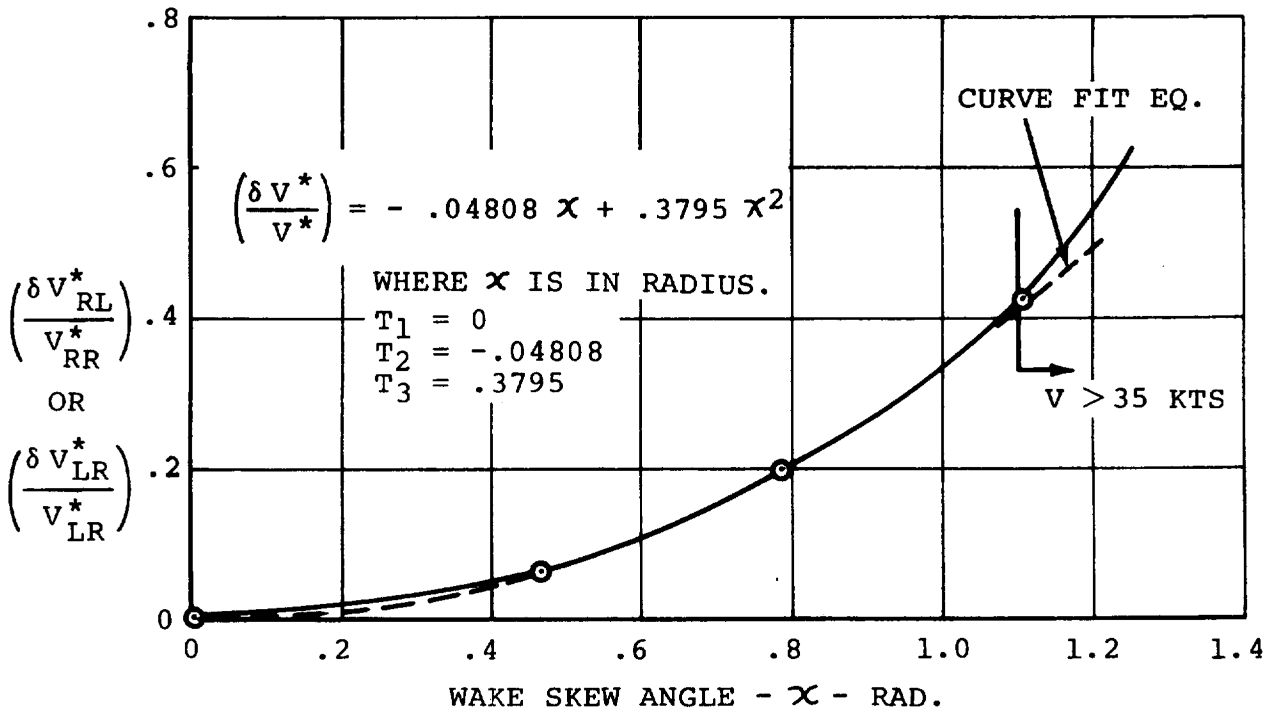
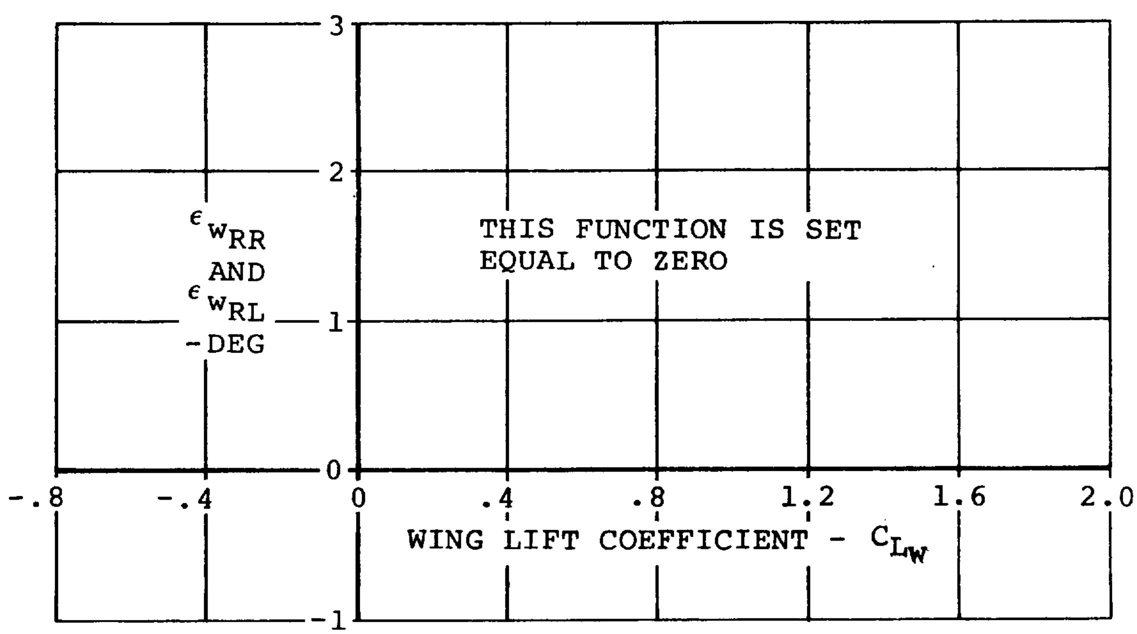


Figure F.29. Variation of Lift Curve Slope with Ground Height



ESTIMATED ROTOR/ROTOR INTERFERENCE PARAMETER



WING ON ROTOR INTERFERENCE

Figure F.30. Rotor/Rotor and Wing/Rotor Interference

F.5 GEOMETRIC, WEIGHTS AND BALANCE DATA

The input data for the Model 222 geometry, weights and balance are presented in this section, and are referenced in Appendix E. Input data for the preprocessor calculations are not presented, but are easily obtainable from an aircraft three-view drawing and the weights and balance data presented in this section. It should be emphasized that the lengths and inertias presented here were calculated using the preprocessor.

F.5.1 Input Data

Page		Page	
E.16	X_{WAC} = .84 ft	E.23,E.17	i_W = 2 DEG
	Y_{WAC} = 8.333 ft	E.31	b_W = 33.417 ft
			$\bar{Y}$ = 6.92 ft
	Z_{WAC} = .4 ft	E.32	$X_{c/2}$ = -.25 ft
	L_S = 4.94 ft	E.35	i_{HT} = 0.0
	Y_N = 16.666 ft	E.36	AR_{HT} = 4.255
E.18	X_{HT} = -19.45 ft	E.39	AR_{VT}= 1.768
	Z_{HT} = 2.51 ft		S_{HT} = 58.3 ft^2
	X_{VT} = -18.04 ft		S_{VT} = 43.3 ft^2
	Z_{VT} = -1.0226 ft	E.46	Z_{G_1} = 7.08 ft
E.19	A = 530929 ft^2		Z_{G_2} = 7.08 ft
	R = ft		Z_{G_3} = 7.53 ft
E.20	PC = 2.36 ft, F_{IN}=0°		Y_{G_1} = -3.86 ft
	h_p = .33 ft		Y_{G_2} = 3.86 ft
	c_W = 5.983 ft		Y_{G_3} = 0
	S_W = 200 ft^2		

Page		
E.46	X_{G_1}	$= -3.7$ ft
	X_{G_2}	$= -3.7$ ft
	X_{G_3}	$= 10.67$
	r_1	$= 1.065$ ft
	r_2	$= 1.065$ ft
	r_3	$= .60$ ft
	K_{ST_1}	$= 3840$ lb/ft
	K_{ST_2}	$= 3840$ lb/ft
	K_{ST_3}	$= 3840$ lb/ft
	D_{ST_1}	$= 600$ lb/ft/sec
	D_{ST_2}	$= 600$ lb/ft/sec
	D_{ST_3}	$= 600$ lb/ft/sec
	μ_0	$= .03$
	μ_1	$= .005$
	μ_s	$= .5$
E.50	X_{FAC}	$= .84$ ft
	Z_{FAC}	$= 3.66$ ft
E.61	I_P	$= 564$ slu-ft^2
E.62	I_E	$= 1.47$ slug-ft^2
E.64	K_{W_1}	$= .59678 \times 10^{-4}$
	K_{W_2}	$= .1637 \times 10^{-4}$
	K_{W_3}	$= .58356 \times 10^{-5}$
	K_{W_4}	$= .2959 \times 10^{-2}$
	K_{W_5}	$= .1656 \times 10^{-2}$

Page		
E.64	ζ_{W_1}	$= .5$
	ζ_{W_2}	$= .5$
	ζ_{W_3}	$= .5$
	ζ_{W_4}	$= .5$
	ζ_{W_5}	$= .5$
	K_{W_6}	$= .1709 \times 10^{-4}$
	K_{W_7}	$= .05768 \times 10^{-4}$
	K_{W_8}	$= .1221 \times 10^{-5}$
	K_{W_9}	$= .0847 \times 10^{-2}$
	$K_{W_{10}}$	$= .0559 \times 10^{-2}$
	ω_{W1}	$= 19.92$ rad/sec
	ω_{W2}	$= 19.92$ rad/sec
	ω_{W3}	$= 19.92$ rad/sec
	ω_{W4}	$= 19.92$ rad/sec
E.66	$K_{\theta t}$	$= 0.98 \times 10^6$ FT-LB/RAD
	$\dfrac{X_{WAC}}{C_W}$	$= .275$
E.79	Y_{PA}	$= 0$
	ℓ_{PA}	$= 6.75$ ft
	Z_{PA}	$= 4.75$ ft

E.68 to
E.78 Equations of motion input constant (Weight = 12321 lb, nominal CG)

m_W = 138.32 slugs

m_N = 43.39 slugs

m_f = 157.88

m = 382.98 (12321 LBS)

$I_{xx}^{(f)} = 789.3$ slug-ft^2

$I_{yy}^{(f)} = 10845.6$ slug-ft^2

$I_{zz}^{(f)} = 10707.4$ slug-ft^2

$I_{xz}^{(f)} = 399.9$ slug-ft^2

$I_{xx}^{(w)} = 23978.4$ slug-ft^2

$I_{yy}^{(w)} = 664.8$ slug-ft^2

$I_{zz}^{(w)} = 24513.6$ slug-ft^2

$I_{xz}^{(w)} = 384.5$ slug-ft^2

$I_{xx}' = 22.5$ slug-ft^2

$I_{yy}' = 194.0$ slug-ft^2

$I_{zz}' = 195.4$ slug-ft^2

$I_{xz}' = -20.0$ slug-ft^2

ℓ_f = .6917 ft

h_f = 4.075 ft

ℓ_w = -.775 ft

h_w = .30417

Y_N = 16.666 ft

ℓ = 3.3624 ft

λ = 2.841 DEG

L_s = 4.94 ft

F.6 SIMULATION INPUT DATA

This section presents the input data required to drive the Flight Simulator for Advanced Aircraft (FSAA). Figure F.31 shows the instrumentation requirements and Figure F.32 shows the Model 222 control force gradients and breakout forces.

CAB INSTRUMENTATION:

Instrument	Range
Vertical Situation Indicator	±90° Pitch and Roll
Horizontal Situation Indicator	±120° Heading
Airspeed	0 → 520 KIAS
Pressure Altimeter	0 → 10,000 Ft
Radar Altimeter	0 → 1000 Ft
Rate of Climb	± 6000 FT/MIN
Turn and Bank	± 3 Needle Widths
	± 1 1/2 Ball Widths
"g" Meter	-1, +3 "g"
Nacelle Angle	0 → 120°
Clock	
Sideward Velocity	± 40 Knots
Angle of Attack	± 20°
Wing Flap Position	0 → 100°
Rotor Speed	0 → 125%
Engine Torque Meters (2)	0 → 125%

PRIMARY FLIGHT CONTROLS

Stick (±6° Long.; ±5" Lateral)
Pedals (±2.5")
Power Lever (0→8" Normal; 0→10" Emergency)
Nacelle Position thumb Switch

MISCELLANEOUS EQUIPMENT AND FEATURES

Back Drives to Trim Stick and Pedals while in Initial Condition (I.C.)
Landing Gear Up - Down Switch with Indicator Light
SAS ON-OFF Switch
Detent Switches on Spring Cartridges (Pedals & Lateral Stick)
Magnetic Brake on Pedals, Long. and Lateral Controls
Long. and Lateral Beep Force Trim on Stick
Power Lever Null Meter
Toe Brakes
Specified Force Feel System

Figure F.31. Model 222 Pilot Station Requirements

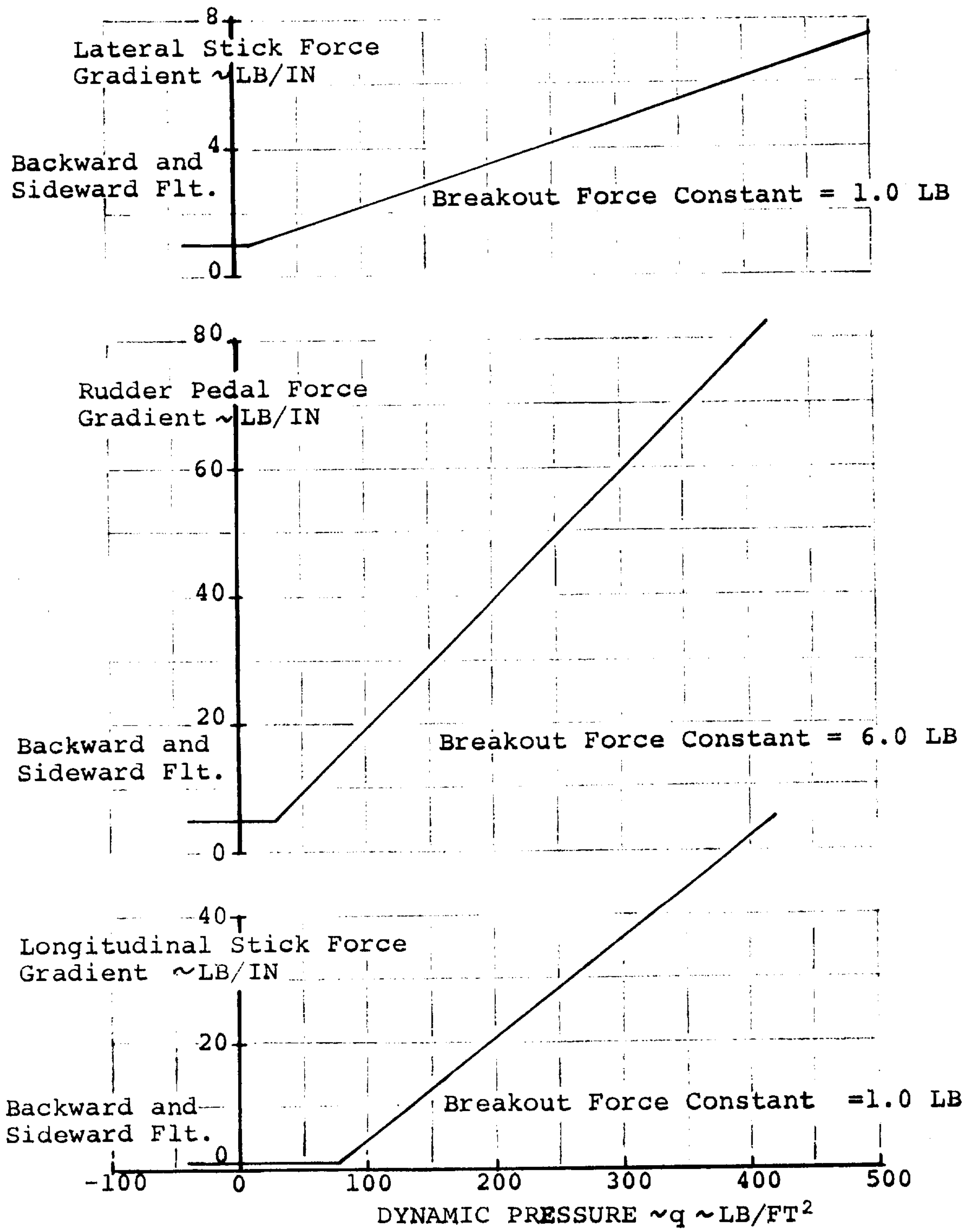


Figure F.32. Model 222 Control Force Gradients and Breakout Forces

APPENDIX G - IN-HOUSE HYBRID SIMULATION

The math model described in this report was mechanized in the Boeing Hybrid Simulation Laboratory for the purpose of developing and evaluating math model simplifications. This was accomplished in a parallel time frame to the NASA simulation, which also used the described math model.

The Hybrid Simulation Laboratory is a large scale hybrid computation complex. It is capable of providing simultaneous operation of several hybrid and analog simulations, depending on problem size. The complex is totally state of the art, with recent acquisition of two mini-computers for the purpose of multivariable function generation.

The Hybrid Simulation Laboratory complex is comprised of the following elements:

- Digital

  IBM 360/44 system

  - 25600 byte core
  - 32 priority interrupts
  - 16 hi-speed floating point register
  - 2 hi-speed, 1 low speed channels

  2 - 800 B.P.I. tape transport

  1 - 2311 disk system

  2 - 2315 disk system

  1 - hi-speed card read/punch

  1 - hi-speed line printer

2 - alpha-meric scope/keyboard

1 - console typewriter

1 - ball printer

Basic Computer Arts Function Generation System (BOA)

1 - Interdata processor with 24000 byte core

1 - Interdata processor with 16000 byte core

2 - 16 channels analog to digital

2 - 16 channels digital to analog

2 - read only memory software systems

- Analog

  4 - 3/4 expanded Applied Dynamics (AD-4)

  771 amplifiers (all solid state)

  4 resolver expansions

  2 display consoles

  10 ufd integrator system in 6 decades

  1 - 1/8 expanded AD4 maintenance console

  128 channels 100 KC analog to digital converters

  128 channels digital to analog converters

  1 applied dynamics 256

- Analog Output

  4 - 8 channel Brush strip chart recorders

  4 - 8 channel Varian Statos III strip chart recorders

  4 - XY plotters

- <u>Software System</u>

  Integrated disk resident state of the art system embracing "real time" languages:

  Assembly Language

  Modified Fortran IV, Level G
  and non-real time languages

  Non-procedural block modeling, DSL/44

  Fortran IV, Level G

  Full utility system

  Other special hybrid oriented programs

G.1 SIMULATION ARCHITECTURE

The tilt rotor simulation model utilized the entire hybrid facility. When tied to Boeing's Nudge Base Simulator, four consoles of Applied Dynamics from (AD-4's) analog, the Applied Dynamics 256 (AD-256) and two Simulator Laboratory analog computers were in use. In addition the IBM 360/44 digital computer and two Basic Computing Acts (BCA) function generators were utilized. Figure G.1 shows the utilization of the hybrid facility and also shows the location of the major elements of the tilt rotor mathematical model.

In programming the digital portion of the tilt rotor simulation, core size and execution time were of immediate concern. Along with the complex wing and rotor representations, there was a large number of functions which had to be handled in the digital computer with trade-offs considered on core used if functions were programmed as tables and execution time for digital table look-up versus curve-fit equations. In most cases, curve-fit equations were used to program functions. A program was written to curve fit the various functions needed, and the equation programmed for the real time task.

The single largest difficulty was the rotor representation. To program the curve-fit equations for each of the eight functions, for both rotors, would take 30 milliseconds (timing estimates without rotor indicated only 10 milliseconds were available). To program as tables and look-up answers, would not only take too long, but use too much core. So the rotor data was put in the function generation mini-computers (BCA). To get the rotor data into format for the BCA, several steps had to be executed; 1) data points were input to the curve-fit program which punched out the coefficients of the curve-fit expansion, 2) these coefficients were input to a program that punched data in the correct format at the correct breakpoints to be input to 3) the BCA program which punched a deck of cards that are input to the function generator mini-computer.

Although the BCA enabled the programming of the rotor without using digital time or core, it did not have enough room to hold 8 functions x 2 rotors for the rotor 'maps' of the size required. To obviate this, the BCA was multiplexed, such that only one rotor's results would be calculated each BCA cycle, with the left and right rotor being alternated. In this case it took 8 milliseconds per BCA cycle, resulting in a total rotor update every 16 milliseconds.

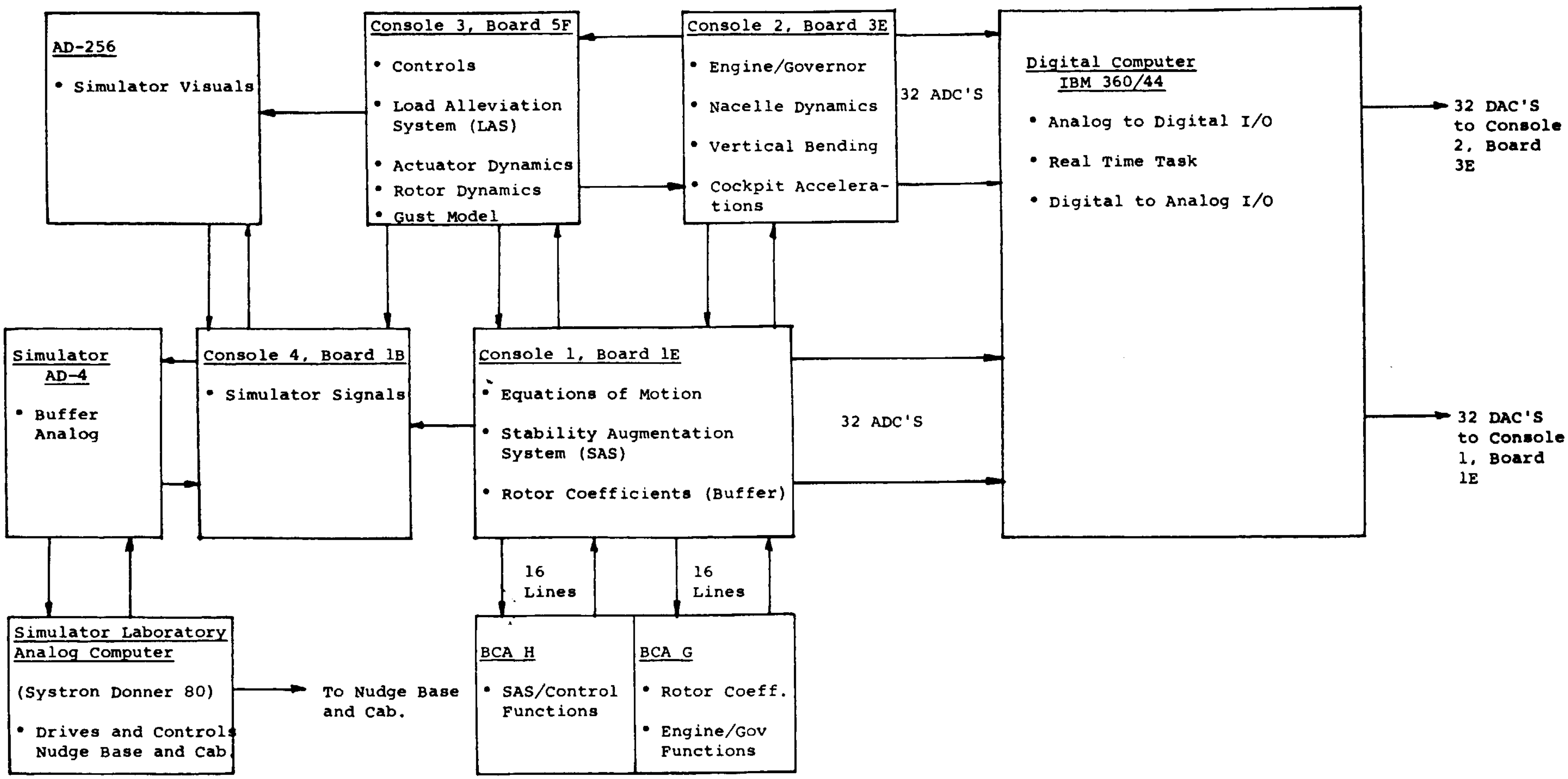


Figure G.1. Utilization of the Hybrid Laboratory for the Model 222 Math Model

As programming progressed, timing estimates showed the time frame would be a problem. The objective was a 40. millisecond (ms) time frame which results in 7 updates/cycle for the 3.5 cycle per second first mode vertical bending calculations. Due to the large number of angles and trigonometric functions, the complexity of the model and the real time requirement, every effort was made to reduce the time frame.

A parallel real time task method, where a 40 ms. time frame could be achieved, was selected. This method had two real time tasks, a 'Fast' real time task that was calculated every frame and a 'Slow' real time task that was executed every 3 frames. Thus, it was important to separate the equations to ensure only low frequency equations were placed in the slow loop. In order to minimize execution time, the system routines for taking the sine, cosine and square root, having unnecessary accuracy at the expense of time, were discarded and replaced by streamlined routines. Since there are a total of 21 sine-cosine pairs and 20 square-roots, the saving was substantial. The need for the time savings is emphasized by the fact that at present, using the parallel real time task, the total execution time is 38 ms. leaving 2 ms. for the foreground options, shown in Figure G.2 to be executed. The 40 ms. time frame objective has been achieved.

The digital portions of the simulation were programmed using the General Hybrid Program (GHP) structure, which utilizes a

- Direct control of the analog computer state and the interval timer (initial condition, hold, operate)
- Change aircraft trim conditions (airspeed, lateral speed, altitude, rate of climb, trim pitch attitude, trim nacelle angle)
- Control of line printer real-time printout
- Control of line printer trim printout
- Ability to change values of simulation flags (landing gear on/off ground effect on/off, vertical bending on/off, wing twist on/off)
- Ability to change real time phases (dual phase, total phase, plot phase; used to plot any digital function)

Figure G.2. Foreground Options

phase overlay scheme. The basic phase overlay structure is shown in Figure G.3. This figure also summarizes what is contained in each phase. Of most interest to this discussion are three phases; 1) the Preprocess phase, 2) the Run phase and 3) the Dual phase. The Preprocess phase loads the simulation data and sets up the analog computer by setting the potentiometers to the correct values and by reading out a test condition to ensure that no components are statically bad. Once the analogs are set up and checked, control is transferred by GHP to the run phase. This phase is in control while actually 'running' hybrid and executing the real time task. It is in the run phase that various options are provided, while the simulation is being used. These foreground options have been described in Figure G.2. The two line printer options, the line printer trim sheet and the line printer real time printout, are powerful tools allowing visibility into the simulation equations.

The Dual phase contains the two real time tasks, the fast (RTFAST) and the slow (RTSLOW). Figures G.4 and G.5 show what each real time task contains. The execution time of RTFAST is 32 ms. while that of RTSLOW is 18 ms. Since RTFAST is executed every 'frame' but RTSLOW only every 3 frames, the execution time is 32 + 18/3 or 38 ms.

The digital listing for the simulation program is shown in Figure G.6. This listing contains the fast and slow real

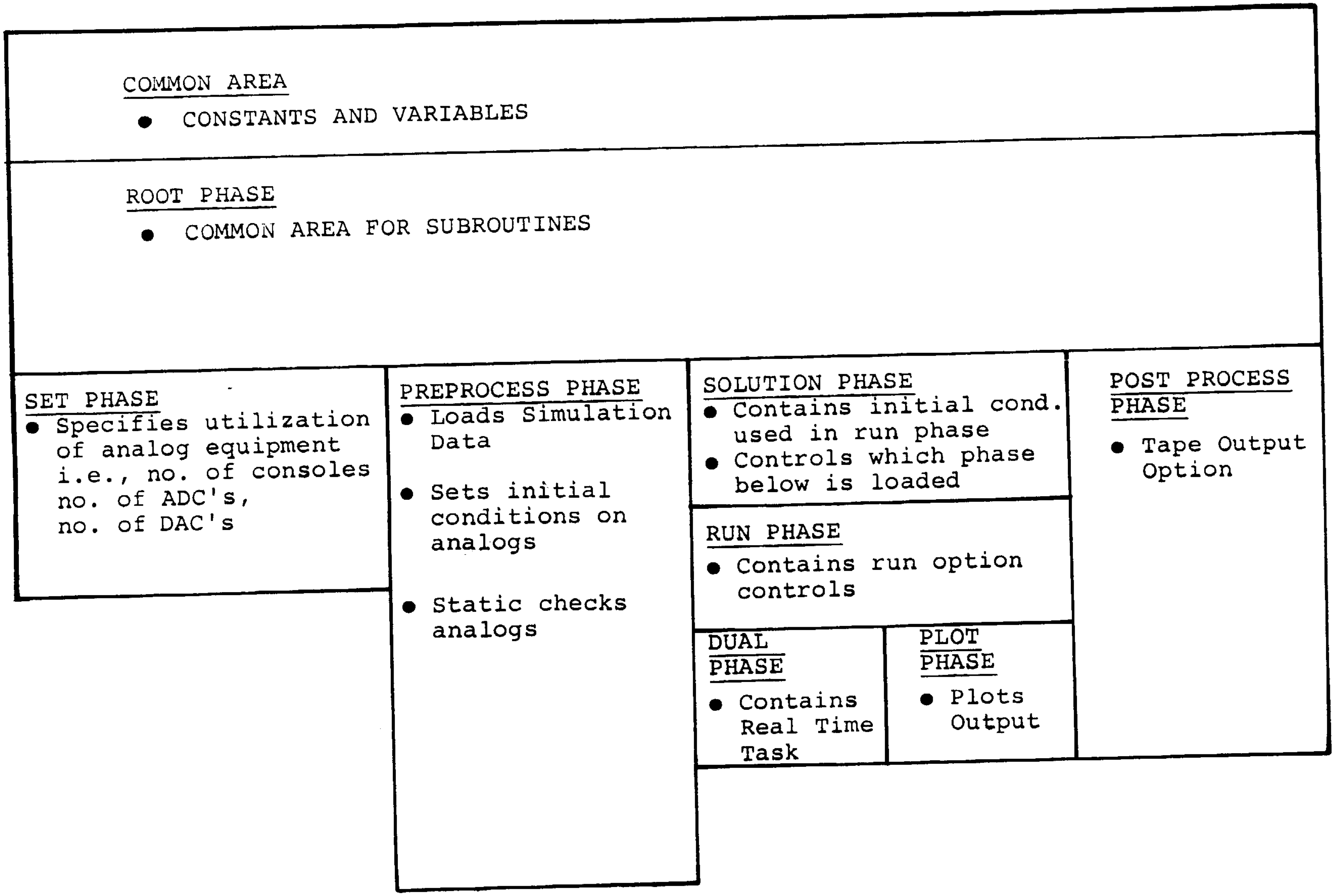


Figure G.3. GHP Phase Overlay Structure (Digital Core Allocations)

1. ANALOG TO DIGITAL I/O
   - Reads analog ADC lines
   - Converts to floating point

2. ENTRY FOR STATIC CHECK OF FAST REAL TIME TASK
   - Used for test cases W/O I/O

3. ANGLE INITIALIZATION SECTION
   - Sin, cos i_{NL} & i_{NR}
   - $I_{NACELLE}$
   - Sin, cos $i_{NL}-\lambda$, $i_{NR}-\lambda$ using trig
   - $\delta_{FLAP}{}^2$

4. VELOCITY SECTION (VELOCITIES, VELOCITIES^2, FREESTREAM, DYN. PRESSURE, TRANSFORM.)
   - Fuselage (also α_{fus}, β_{fus}, sin , cos)
   - Doors open/close logic-f(i_{NAC},q_{FUSE})
   - Rotor Hub - body axes, shaft axes, free-stream
   - Wing A/C - body axes, chord axes, free-stream
   - Tail

5. ROTOR SECTION - LEFT AND RIGHT
   - α,ζ, sin, cos of α and ζ
   - Rotor angular rate transform. p,q,R
   - Ω, V_{TIP}, μ, Ω^2, μ^2
   - Rotor control axes transform A_{1C}, B_{1C} WRT ϕ_p, ζ
   - Rotor EQS for CNF, CSF, CP, CYM
   - Forces and moments from coefficients T, N.F., S.F., M,N,Q
   - Hub moments - Nacelle axes
   - Resolution of forces & moments - body axes at tip
   - Summation with nacelle aero
   - Gust load alleviation system

6. WING SECTION - LEFT AND RIGHT
   - q_{LW}, q_{RW}, q_{WING}
   - Doors open/close check
   - If doors open
     - Calc. X,Y,Z, L,M,N_{AERO}
     - Leave wing section & Set q's=0
   - If doors closed
     - α, β, α_{SSO}, α_{RIG}, $\bar{\alpha}$
     - Aileron, Spoiler, Flap contribution to lift, drag, moment; Call AILSP
     - Contribution due to totally washed wing; call CLCDCM
     - Contribution due to totally unwashed wing; call CLCDCM C_L; Call CCF2
     - α, sin & cosα, sin & cosβ, sin & cos ϵ_p
     - α, β check for stall
     - Aero Calc & resolution
     - Wing/rotor interference

7. TAIL SECTION
   - ϵ_{TAIL}, ϵ_o if necessary; logic for doors open/closed
   - α_{HT}, sin, cos$(\alpha_{HT}-i_{HT})$
   - 7 region $C_{L_{HT}}$, $C_{D_{HT}}$ curve
   - β_{VT}, α_{VT}, σ, sin, cos $(\beta_{VT}-\sigma)$
   - 7 Region C_{LVT}, C_{DVT}, curve
   - If doors open; 1/2 efficiency of horizontal tail
   - Vertical tail Aero
   - Total tail Aero

8. EQUATION OF MOTION SECTION
   - Call gear subroutine
   - Total Fuse Aero
   - Calculate total aircraft Aero X_{AERO}, Y_{AERO}, Z_{AERO}, L_{AERO}, M_{AERO}, N_{AERO}
   - Break Z_{AERO}, L_{AERO}, M_{AERO} into vertical bending/non-vertical bending parts
   - EOM coefficients
   - Vertical bending equations with flag
   - Torsion equation with flag
   - Fill DAC array (64)

9. DIGITAL TO ANALOG I/O
   - Convert DACS to integer
   - Write values

Figure G.4. Contents of Real Time Task – Fast Loop

1. ANALOG TO DIGITAL I/O

- Reads discretes
- Assigns flags to discretes
- Check for trim sheet flag
- Read 3rd console ADCS if required

2. ENTRY FOR STATIC CHECK OF SLOW REAL TIME TASK

- Used for test cases w/o I/o

3. PRELIMINARY CALCULATIONS

- $\sin^2 i_{NL}$, i_{NR}; sin, cos $2i_{NR}$, $2i_{NL}$; h^2, q_{FUSE}
- XCG, ZCG
- V_{NORTH}, V_{EAST}, ground track

4. AIR & ENGINE MODEL

- δ, T°F, ρ, a, M, $\sqrt{1-M^2}$
- TEA, preliminary engine routine calculations
- SHP, ΩE, %Q; call engine

5. FUSELAGE SECTION

- C_{DF}, C_{LF}, C_{YF}, C_{MF}, C_{NF}
- Aero calculation

6 GROUND EFFECT SECTION (WING & ROTOR)

- $(ag/a)w$, K_{99}, (T_{TGE}/T_{OGE}), D/T, (M/T)

7. NACELLE SECTION LEFT & RIGHT

- α_{NAC}, β_{NAC}; sin & cos α_{NAC}, β_{NAC}
- C_D, C_L, C_Y, C_M, C_N nacelle
- Aero calculation

8. WING IMMERSED AREA SECTION - LEFT & RIGHT

- τ, V_*, Look-up v_*,
- ε_p, C_{TSR}
- $\bar{\zeta}$, $\bar{\alpha}_R$, $\bar{\varepsilon}_p$ $\bar{C}_{T_s}$, $\sin\zeta$ $\cos\zeta$ $\bar{\zeta}$, $\sin\zeta$ $\cos(\bar{I}_{NAC} - \bar{I}_W)$, $\tan(\bar{\alpha}_R - \bar{\varepsilon}_p)$
- ζ_{R1}, ζ_{R2}, ζ_{R3}, ζ_{R4}
- S_{i_R}, S_{i_L}, S_{i_L}/S, S_{i_R}/S, S_{i_T}, AR_i, C_{L_i}, K_a

9. ROTOR/ROTOR INTERFERENCE

10. GROUND EFFECT - TAIL

- $H_{W_{C/4}}$, $H_{T_{C/4}}$, $(a_q/a)_t$

Figure G.5. Contents of Real Time Task – Slow Loop

```
1        SUBROUTINE DTEAST
2        COMMON/CONST1/ ISCOPE,IFLAG(10C),IDSPC(4,8),MIFCB(2),MICNT(2),
        *          FDSIM ,IPAS        ,MILMSK       ,NFRAME(2),KONFR(2)
3        COMMON/Z-NG/  NWDTIP,NLIM  ,NLTHID, IPIND ,NQIND ,NPNOID ,
        *          NWDTMX,CNLMX ,ENLTMX, IZMX ,FQMX  ,SHPSTR
        *      ,   EWDTPE,EMISTR,ROFC  ,TZERO ,TCOEF
4        COMMON/FLAGS/ IWARN1(1C),IWARN2(1C),ISENCE(2),IWPEVT(2),ICONDP,
        1 ITRIM,JTRIM,KTRIM,NPLIT,NPLIT2,IPHASE,ISLOW,SWLG,GBUTON,
        2 ISTA,ISTP,NSLT,NVB,ATEST
5        LOGICAL*1   IWARN1,IWARN2
6        COMMON/HYPI/PROJ  ,NCONSL,NPCS(2),NCHAIN(2),IFRAME(2),NADCS(2),
        *          ADNOS(4),NDACS(4),IPOX(4),IFC(4),NCON(4) ,LFTR(4) ,
        *          IC(19)  ,ISTIC   ,HOLD(19),ISTHO,OPERA(19),
        *          ISTGO   ,DIGAN(19),ISTDA  ,ANDIG(19),ISTAD,
        *          IC2(19) ,ISTIC2   ,HOLD2(19),ISTHO2 ,OPERA2(19),
        *          ISTDO2  ,DIGAN2(19),ISTDA2  ,ANDIG2(19),ISTAD2, IGN,
        *          ISTDIT  ,IRUNIT,IAD,IDC,IOC21,ICLR,ITSC,ILEX,ISETC ,
        *          MCNT1S  ,IDURC(4)   ,ISHRC(4) ,ISYNC(4) , NIOS  ,
        *          IHJR     ,ISCHAN     ,ISEASE(2),TSREQD(2), IRCTS(4),
        *          TAUL(4) ,IPSNOS(1,2),DTIM(2) ,TRIM(19) ,ISTRM ,
        *          TRIM2(19),ISTRM2
7        COMMON/HYPI1/ KAS(2,2)
8        COMMON/MTOTS/ SINIW ,COSIW ,SINLAM,COSLAM,SUMIXX,SUMIXZ,SUMIYY,
        *          SUMIZZ,XECON ,XELCON,YHCON ,XXICON,XXJCON,XZICON,
        *          YYICON,YYJCON,ZECON ,ZRLCON,ZXCON ,ZZICON,ZZJCON,
        *          SLAC  ,HTSTLL,VTSTLL,OOVDSK,ARWING,CPHIP ,SPHIP ,
        *          CVDTIM,
        *          COEF1 ,COEF2 ,COEF3 ,COEF4 ,COEF5 ,COEF6 ,COEF7 ,
        *          COEF8 ,COEF9 ,COEF10,COEF11,COEF12,COEF13,COEF14,
        *          COEF15,COEF16,COEF17,COEF18,COEF19,COEF20,COEF21,
        *          COEF22,COEF24,COEF24,COEF25,COEF26,COEF27,COEF28,
        *          COEF29,COEF30,COEF31,COEF32,COEF33,COEF34,COEF35
        *      ,   COEF36,COEF37,COEF38,COEF39,COEF40,COEF41,COEF42
9        COMMON/KAI/ SCADC1(32),SCADC2(32),SCADC3(32),SCADC4(32),
        *          SCDAC1(32),SCDAC2(32),SCDAC3(32),SCDAC4(32),
        *       [illegible],PRIME,[illegible],UPRIME,VPRIME,WPRIME,THE   ,PHI    ,    30  IE
        *       [illegible]  ,[illegible] ,[illegible] ,DUM12 ,DUM13 ,DUM14 ,DUM15 ,HDOT   ,
        *       [illegible],DELAIS,DELSPR,DELSPL,CTLPRM,CNEPL ,CSEPL ,CPMPL ,
        *       CYMPL ,CPL   ,CTLPRM,CPEPR ,CSEPR ,CPMPR ,CYMPR ,C22    ,
        *       [illegible],AINC ,[illegible],SINL  , ICLPR,ICLPR,AICRPR,BICRPR,
        *       [illegible],[illegible],DUM43 ,DUM44 ,DUM45 ,DUM46 ,DUM47 ,DUM48 ,   80   35
        *       [illegible],[illegible]ST ,VSTOT ,RGUST ,PGUST ,QGUST ,RGUST ,OMDOT ,   80   35
        *       [illegible] ,TPS   ,[illegible],SMAGLP,ENGL  ,ENGR  ,DELFLV,DELFLR
        *      , DELFLT ,DELST ,[illegible]T ,DELT4 ,DELRS ,DELSS ,DELRS ,TH75R ,
        *       TH75L ,A[illegible](23)
10       COMMON/KMAP/ ENF1  ,ENF2  ,ENF3  ,ENF4  ,DNF1  ,DNF2  ,DNF3  ,    1  TO  7
        *          DNF4  ,ESF1  ,ESF2  ,ESF3  ,ESF4  ,DSF1  ,DSF2  ,    8  TO 14
        *          DSF3  ,DSF4  ,EPM1  ,EPM2  ,EPM3  ,EPM4  ,EPM5  ,   15  TO 21
        *          EPM6  ,EPM7  ,DPM1  ,DPM2  ,DPM3  ,DPM4  ,DPM5  ,   22  TO 28
        *          DPM6  ,DPM7  ,EYM1  ,EYM2  ,EYM3  ,EYM4  ,EYM5  ,   29  TO 35
        *          EYM6  ,EYM7  ,DYM1  ,DYM2  ,DYM3  ,DYM4  ,DYM5  ,   36  TO 42
        *          DYM6  ,DYM7
11       COMMON/[illegible]1/ AINHT ,AINV  ,ALAMDA,ALHTST,ALVTST,AREAHT,AREAW ,    1  TO  7
        [illegible],[illegible] ,ARVT  ,AVEYAC,AVEYCS,BLS   ,CDOF  ,CDOHT ,CDOVT ,    [illegible] TO 16
        [illegible],CLALHT,CLALW ,[illegible],C[illegible]N ,CNO[illegible] ,CNOLN ,CNORN ,CYALVT,   17  T   25
```

Figure G.6. Model 222 Simulation Digital Listing

```
       3OCPLG ,DCMLC ,FINPP ,DOVT  ,DSOBET,EFFHI ,EFFVT ,FIE   ,FINDEG,   26 TO 34
       *FIP   ,FIXXF ,FIXXPR,FIXXW ,FIXZF ,FIXZPR,FIXZW ,FIYYF ,FIYYPR,   35 TO 43
       *FIYYW ,FIZZF ,FIZZPR,FIZZW ,HP    ,OMREF ,PC    ,PI    ,ROTRAD,   44 TO 52
       *SPEPR ,SRWPR ,SG    ,SHF   ,SIW   ,SK2   ,SK1   ,SK2   ,SK3   ,   53 TO 61
       *SK4   ,SK5   ,SK6   ,SK7   ,SK8   ,SK9   ,SK10  ,SK20  ,SK21  ,   62 TO 70
       *SK22  ,CDONLO,SK30LO,SK31LO,SK32  ,CDONHI,SK34  ,SK35  ,SK36  ,   71 TO 79
       *SK37  ,SK38  ,SK39  ,SK40  ,SK41  ,SK42  ,SK43  ,SK44  ,SK45  ,   80 TO 88
       *SK46  ,SK47  ,SK48  ,SK49  ,SK50  ,SL    ,SLF   ,SLPA  ,SLW   ,   89 TO 97
       *SM    ,SMF   ,SMN   ,SMW   ,SPAN  ,TAUHT ,TAUVT ,XFAC  ,XHT   ,   98 TO106
       *XWAC  ,XVT   ,YN    ,YPA   ,YWAC  ,ZFAC  ,ZHT   ,ZPA   ,ZWAC  ,
       *ZVT   ,CLOAL ,PHIPH ,SK30HI,EN2REF,XWC2  ,BT1   ,BT2   ,BT3   ,
       *BKD1T ,BKD2T ,BKD3T ,BKM1T ,BKM2T ,BKM3T ,BKM4T ,SK31HI,
       *FEH   ,CLMAX ,ALBRK ,BKLSW ,BKNSW ,SQFPRM,DEG20 ,DGTORD,HTVTKT,   133TO141
       *PIOV2 ,RDTODG,ROTEPS,SKEPS ,ALNGBK,TAURT1,TAURT2
12      COMMON/DACIO/ DAC1(32),DAC2(32)
13      COMMON/XLINTP/ AKEY(16),AMEM(2),BKEY(16),BMEM(2),GKEY(10),GMEM
14      COMMON/XEUNC / VSTARG(33), TAJAG(9),SVSTAR(33,9),SQFARG(35),
       1        SAATAB(35),GPATAB(35),ALFTAB(35)
15      COMMON/XCNTRL/ SKOLR,SKOLS,SKOLR,SKOLE,SKDLRO,TH75LP,TH75LN,
       1        TAUGLS,GLSLM,TAUGIC,GICLM,CNTRBL(4),OMA,ETAA,
       2        SKDA  ,GTH,TAUTH,OMSC,OMSLP,OMLM,GOMG,SKDCOL,THRTLM,THOMLP,
       3        THOMLN,SHPLM,GTHGOV,OMRD,ETARD,TTMSLP,TTMSLN,GOB1,GOB2,
       4        TAUDR,GO,GTHF,TAUO1,TAUO2,TAUTHF,GLP,GLPSLP,GPDS,TAUPDS,
       5        GP,TAUP,GBETP,TAUHET,GPHI,TAUPHI,GPSIDR,GBETDR,GRDR,TAJDR,
       6        GPSI,TAUPSI,GBETR,TAUPR,GPR1,TAUPR1,GR,TAJR1,TAJR2,TAUR3,
       6        PLM,DPLM,DLBL4,DLSLM,DLRLM,
       7        TOMDLM,GOLTH,SKW1,SHW2,SHW3,SKW4,SKW5,
       8        SKW6,SKW7,SKW8,SKW9,SKW10,GGUST,TAUGST,OMWR,ETAW3,GINRF,
       9        OMIRF,ETAIRF,SKTHTW,SC1,SC2,DCMDCL,AINPLM,TAUR01,TAUR02,
       A        TAUFF,TAUCYR,DCYRLM,AL,ASLP,ALIM,TAUSHP,DELALM,
       B        DLFLP
16      COMMON/INITVR/
       1 AVEIN  ,CILAML,CILAMR,COSINL,COSINR,COSPSI,C2INL ,C2INR ,DLFPSQ,    1 -  9
       2 HSQ    ,SILAML,SILAMR,SININL,SININR,SINPSI,SSQINL,SSQINR,S2INL ,   10 - 18
       3 S2INR                                                              19
17      COMMON/CGSTV2/
       1 VEAST  ,VNORTH,XCG    ,XDTCG ,ZCG   ,ZDTCG                          1 -  6
18      COMMON/ENGVAR/
       1 AMACH  ,AMACSQ,DEL    ,EMAXN1,EMAXN2,EMXWOT,EN2STR,ESMACH,OMEGEL,   1 -  9
       2 OMECEP,ONGVTC,OMVFSM,OVSOTH,OVTHDL,ROE   ,ROEOV2,SHPPRL,SHPPRR,   10 - 18
       3 SMA    ,SOLMX,SOTHTC,SOWDTX,TDEGF ,TEAL  ,TEAR  ,THCDEL,THETC      19 - 27
       4,PCTCL,PCTOR                                                       28 TO 29
19      COMMON/VELVAR/
       1 AMUL   ,AMULSQ,AMUR   ,AMURSQ,WROTL ,CMOTL ,CMOTR ,OMEGAL,OMEGAR,   1 -  9
       2 OMSOL  ,OMSOR ,UHT    ,ULW   ,ULWPR ,ULWSQ ,UP    ,URL   ,URLPR ,   10 - 18
       3 UPLURL,URP    ,URPPR  ,URPURR,URW   ,URWPR ,URWSQ ,USQ   ,UVT   ,   19 - 27
       4 VALFLW,VALFRW,VALFS  ,VALNCL,VALNCR,VBETVT,VLW   ,VLWPR ,VLWSQ ,   28 - 36
       5 VP     ,VRL    ,VRLPR  ,VRLVPL,VRR   ,VRRPR ,VRRVRR,VRW   ,VRWPR ,   37 - 45
       6 VRWSQ  ,VSQ    ,VTIPL  ,VTIPR ,VTOTAL,VTOTLR,VTOTRR,VVT   ,VZETL ,   46 - 54
       7 VZETR  ,WHT    ,WLW    ,WLWPR ,WLWSQ ,WP    ,WRL   ,WRLPR ,WRLWRL,   55 - 63
       8 WRW    ,WRWPR  ,WRWSQ  ,WRR   ,WRRPR ,WRRWRR,WSQ   ,WVT             64 - 71
20      COMMON/FUSVAR/
       1 ALARF  ,ALARFP,ALFSQ  ,ALPHF ,AMARF ,AMARFP,ANARF ,ANARFP,BETAF ,   1 -  9
       2 BETFSQ,CBCMF ,CDF    ,CLF   ,CMF   ,CNF   ,COSALF,COSBTF,CYF   ,   10 - 18
       3 CLLG   ,CMLG  ,CNLG   ,DXLG  ,DYLG  ,DZLG  ,DFSW  ,SBFCAF,SBFSAF,   19 - 27
```

Figure G.6. (Continued)

```
       4 SINALF,SINBTF,COF    ,XAERF ,XAREP ,YAERF ,YAREP ,ZAERF ,ZAREP     28 - 36
       *     ,SINTHE,COSTHE,SINPHI,COSPHI
21      COMMON/GEEVAR/
       1 AGEVAT,AGEVAW,BIGX  ,BK92  ,BMOVTL,BMOVTR,COKCOR,CLTCOR,CLWCOR,    1 - 9
       2 DDVTL ,DDVTR ,EPPPM ,GFF   ,HGEFLR,HGEFRR,HLHUB ,HRHUB ,HTC4  ,   10 - 18
       3 HWC4  ,PRI1  ,PRI2  ,SHI   ,TICFL ,TICFR                          19 - 24
22      COMMON/NACVAR/
       1 ALLNSQ,ALPHLN,ALPHRN,ALRNSQ,BETALN,BETARN,BTLNSQ,BTRNSQ,CALLN ,    1 - 9
       2 CALRN ,CBETLN,CBETRN,CDLN  ,CDDLN ,CDDRN ,CDRN  ,CLLN  ,CLRN  ,   10 - 18
       3 CMLN  ,CMRN  ,CNLN  ,CNRN  ,CYLN  ,CYRN  ,DLLNC ,DLRNC ,DMLNC ,   19 - 27
       4 DMRNC ,DNLNC ,DNRNC ,DXLNC ,DXRNC ,DYLNC ,DYRNC ,DZLNC ,DZRNC ,   27 - 36
       5 SALLN ,SALRN ,SBETLN,SBETRN,SOLNC ,SORNC ,TNAC1 ,TNAC2            36 - 44
23      COMMON/ROTVAR/
       1 AICL  ,AICLDP,AICR  ,AICRDP,ALARNC,ALLRH ,ALARNL,ALARNR,ALRRH ,    1 - 9
       2 ALPHLR,ALPHRR,AMARNC,AMARNL,AMARNR,AMLRH ,AMRNLP,AMRNRP,AMROTL,   10 - 18
       3 AMROTR,AMRRH ,ANARNC,ANARNL,ANARNR,ANLRH ,ANROTL,ANROTR,ANRRH ,   19 - 27
       4 BICL  ,BICLDP,BICR  ,BICRDP,CNFAIL,CNFAIR,CNFBIL,CNFBIR,CNFL  ,   28 - 36
       5 CNFR  ,COSZHL,COSZHR,CPMAIL,CPMAIR,CPMBIL,CPMBIR,CPML  ,CPMR  ,   37 - 45
       6 CSFAIL,CSFAIR,CSFBIL,CSFBIR,CSFL  ,CSFR  ,CTL   ,CTR   ,CYMAIL,   46 - 54
       7 CYMAIR,CYMBIL,CYMBIR,CYML  ,CYMR  ,FIPCML,FIPCMR,FNORML,FNORMR,   55 - 63
       8 FSIDEL,FSIDER,PNLN  ,PNLR  ,PNRN  ,PNRR  ,QNLN  ,QNLR  ,QNRN  ,   64 - 72
       9 QNRR  ,RNLN  ,RNLR  ,RNRN  ,RNRR  ,ROPIR4,ROPIR5,SHPROL,SHPROR,   73 - 81
       A SINZHL,SINZHR,TL    ,TOROL ,TOROR ,TR    ,TRMAR1,TRMAR2,TRMAR3,   82 - 90
       B TRMAR4,TRMHR1,TRMHR2,XAERNC,XAERNL,XAERNR,YAERNC,YAERNL,YAERNR,   91 - 99
       C ZAERNC,ZAERNL,ZAERNR,ZETHL ,ZETHR                                100- 104
24      COMMON/WNGVAR/
       1 ALARWG,ALLWPR,ALPHLW,ALPHRW,ALRGLW,ALRGRW,ALRWPR,ALWSSO,AMARLW,    1 - 9
       2 AMARRW,AMARWG,ANARWG,ARILW ,ARIRW ,ARWSSO,ATAULR,ATAURR,AVEALR,   10 - 18
       3 AVEALW,AVECLW,AVECTS,AVEEPR,AVEZET,BETALW,BETARW,BKALPR,BKARPR,   19 - 27
       4 CALLW ,CALPW ,CAVINW,CAVZET,CBETLW,CBETRW,CEPLW ,CEPRW ,CDCNTL,   28 - 36
       5 CDCNTR,CDDUM ,CDLWAO,CDLWPR,CDLWSS,CDRWAO,CDRWPR,CDRWSS,CDSLW ,   37 - 45
       6 CDSRW ,CLAVE ,CLCNTL,CLCNTR,CLDUM ,CLILW ,CLIRW ,CLLWAO,CLLWPR,   46 - 54
       7 CLLWSS,CLRWAO,CLRWPR,CLRWSS,CLSLW ,CLSRW ,CLSW  ,CLZERO,CMCNTL,   55 - 63
       8 CMCNTR,CMLWAO,CMLWSS,CMRWAO,CMRWSS,CMSLW ,CMSRW ,CNSW  ,CTAULP,   64 - 72
       9 CTAURP,CTSLP ,CTSPR ,DCDDF ,DCDLDA,DCDLSP,DCDRDA,DCDRSP,DCLDF ,   73 - 81
       A DCLLDA,DCLLSP,DCLRDA,DCLRSP,DCLSPW,DCMDF ,DCMLDA,DCMLSP,DCMRDA,   82 - 90
       B DCMRSP,DCMSPW,EPILP ,EPIRL ,EPPLP ,EPPRR ,EPWRL ,EPWRR ,FESLR ,   91 - 99
       C FESRR ,SALLW ,SALRW ,SAVINW,SAVZET,SBETLW,SBETRW,SEPLW ,SEPRW ,  100- 108
       D SGNULW,SGNURW,SIL   ,SILW  ,SIR   ,SIRW  ,SIT   ,STAULR,STAURR,  109- 117
       E SVSTAR,SVSTRL,SOLW  ,SORFSL,SORFSR,SORW  ,SOWING,TAULR ,TAURR ,  118- 126
       F TAVAER,TRMWG1,TRMWG5,TRMWG6,TRMWG7,TRMWG8,TZET1 ,TZET2 ,TZET3 ,  127- 135
       G TZET4 ,TZET5 ,TZET6 ,VSTAR ,VSTARL,XAERLW,XAERRW,XAERWG,YAERLW,  136- 144
       H YAERRW,YAERWG,ZAERLW,ZAERRW,ZAERWG,ZETR1 ,ZETR2 ,ZETR3 ,ZETR4   145- 153
25      COMMON/WNGVR2/
       1 TRMWG8,TRMWG9,TMWG10,TMWG11,HWACR ,HDTACR,HWACL ,HDTACL,HIR   ,   1 TO 9
       2 HIDTR ,HIL   ,HIDTL ,AMACTL,AMACTR,THTLAC,THTRAC
26      COMMON/TAILVR/
       1 ALARHT,ALART ,ALARVT,ALPHHT,ALPHVT,AMARHT,AMART ,AMARVT,ANARHT,    1 - 9
       2 ANART ,ANARVT,BETVT ,CALTHF,CBETSG,CDHT  ,CDVT  ,CLHT  ,CYVT  ,   10 - 18
       3 CPTAIL,CPZERO,SALTHT,SBETSG,SIGMA ,TRMHT ,TRMVT ,XAERT ,XARHT ,   19 - 27
       4 XARVT ,YAERT ,YARHT ,YARVT ,ZAERT ,ZARHT ,ZARVT ,EPTL1 ,ALHTPR,   28 TO 36
       5 ALHTE ,ALHTP ,ALHTM ,CLAT  ,TRMHT2,TRMHT3,CLHTST,CDHTST,ALVTPR,   37 TO 45
       6 ALVTE ,ALVTP ,ALVTM ,CYAT  ,TRMVT2,TRMVT3,CYVTST,CDVTST           46 TO 53
27      COMMON/FIXVAR/
       1 ALAERO,AMAERO,ANAERO,CMCW  ,FIXX  ,FIXZP ,FIXZQ ,FIXZR ,FIYY  ,    1 - 9
```

Figure G.6. (Continued)

```
          2 FIZZ  ,FJXX  ,FJYY  ,FJZZ  ,OOVIXX,OOVIYY,OOVIZZ,PP    ,PQ    ,  10 - 18
          3 PR    ,RR    ,RO    ,TERM1 ,TERM2 ,TERM3 ,TERM4 ,TERM5 ,TERM6 ,  19 - 27
          4 TERMP1,TERMQ1,TERMR1,TERM1R,TERM2R,TERM3R,TERM1L,TERM2L,TERM3L,  28 - 36
          5 TRMTT1,TRMTTP,XAERO ,XF    ,XFMFLF,XL    ,XLCOS ,XLSIN ,XR    ,  37 - 45
          6 XRCOS ,XRSIN ,XW    ,XWMWLW,YAERO ,ZAERO ,ZF    ,ZFMFHF,ZL    ,  46 - 54
          7 ZLCOS ,ZLSIN ,ZR    ,ZRCOS ,ZRSIN ,ZW    ,ZWMWHW,P     ,Q     ,  55 - 63
          8 R     ,U     ,V     ,W
 28        COMMON/TRMCON/ UTRIM,VTRIM,HTRIM,HDTRIM,THTRIM,AITRIM,
          1               SKTRIM(13)
 29        COMMON/XPAR3/ CONS1 ,CONS2 ,CONS3 ,CONS4 ,CONS5 ,CONS6 ,CONS7 ,   1 TO  7
          1              CONS8 ,CONS9 ,CONS10,CONS11,CONS12,CONS13,CONS14,   8 TO 14
          2              CONS15,CONS16,CONS17,CONS18,CONS19,CONS20,CONS21,  15 TO 21
          3              CONS22,CONS23,CONS24,CONS25,CONS26,CONS27,CONS28,  22 TO 28
          4              CONS29,CONS30,CONS31,CONS32,CONS33,CONS34,CONS35,  29 TO 35
          5              CONS36,CONS37,CONS38,CONS39,CONS40,CONS41,CONS42,  36 TO 42
          6              CONS43,CONS44,CONS45,CONS46,CONS47,CONS48,CONS49,  43 TO 49
          7              CONS50,CONS51,CONS52,CONS53,CONS54,CONS55,CONS56,  50 TO 56
          8              CONS57,CONS58,CONS59,CONS60,CONS61,CONS62,CONS63,  57 TO 63
          9              CONS64,CONS65,CONS66,CONS67,CONS68,CONS69,CONS70,  64 TO 70
          A              DBRK1 ,DBRK2 ,DBRK3 ,DBRK4 ,DBRK5 ,DBRK6 ,DBRK7 ,  71 TO 77
          B              DBRK8 ,DBRK9 ,DBRK10,DBRK11,DBRK12,DBRK13,DBRK14,  78 TO 84
          *              DBRK15,DBRK16,DBRK17,DBRK18,DBRK19,DBRK20,DBRK21   85 TO 91
          D             ,SFTL  ,SFNFL ,SFSFL ,SFPML ,SFYML ,SFQL  ,SFPL  ,
          E              SFTR  ,SFNFR ,SFSFR ,SFPMR ,SFYMR ,SFQR  ,SFPR
          F             ,CONS71,CONS72,CONS73,CONS74,CONS75,CONS76,CONS77   106TO112
          G             ,CONS78,CONS79,CONS80,CONS81                        113TO116
 30        DIMENSION ADC(64)
 31        EQUIVALENCE (ADC(1), PPRIME)
       C
       C
       C     TABLE OF PRE-COOKED COEFFICIENTS DEFINITION C
       C   XFCON =    SLF*(1.-SMF/SM) -SLW*SMW/SM
       C   ZFCON =    SHF*(1.-SMF/SM) -SHW*SMW/SM
       C   XWCON =    SLW*(1.-SMW/SM) -SLF*SMF/SM
       C   ZWCON =    SHW*(1.-SMW/SM) -SHF*SMF/SM
       C   XPLCON=  -(SMF*SLF +SMW*SLW)/SM
       C   ZPLCON=  -(SMF*SHF +SMW*SHW)/SM
       C   XXICON=    SUMIXX + 2.*SMN*YN*YN
       C   YYICON=    SUMIYY
       C   ZZICON=    SUMIZZ + 2.*SMN* YN*YN
       C   XZICON=    FIXZF + FIXZW
       C   XXJCON=    SUMIZZ -SUMIYY +2.*SMN*YN*YN
       C   YYJCON=   (FIXXF -FIZZF)+(FIXXW-FIZZW)
       C   ZZJCON=   (SUMIYY-SUMIXX) -2.*SMN* YN*YN
       C   COEF1 =    SL*SMN/SM
       C   COEF2 =    SL*(1. -SMN/SM)
       C   COEF3 =    FIXXPR -FIZZPR
       C   COEF4 =    SL*SMN
       C   COEF5 =    SMF * SHF
       C   COEF6 =    SMW * SHW
       C   COEF7 =    SMF * SLF
       C   COEF8 =    SMW * SLW
       C   COEF9 =    SL*SMN*YN
       C     COEF10=  1. / SM
       C   COEF11= BKLSW*AVEYAC/2./SPAN
```

Figure G.6. (Continued)

```
C       COEF12= PKMSW*AVEYAC/2./SPAN
C       COEF13 =        (FIYYPR+SL*SL*SMN*(1.-SMN/SM))
C       COEF16= AREAW*SPAN              (S * B )   .
C       COEF17= CHORD/SPAN              (C / B )   . WING CHARACTERISTICS
C          COEF18=  S / 2
C       COEF19 =  PI*ROTRAD*ROTRAD*ROTRAD*ROTRAD
C       COEF20 =  COEF19 * ROTRAD
C       COEF21 =  1./(.5*PI * ARHT)
C       COEF22 =  1./(.5*PI * ARVT)
C       COEF23 =  AREAHT * EFFHT
C       COEF24 =  AREAVT * EFFVT
C       COEF25 =   1./(2.*PI* ROTRAD*ROTRAD)
C       COEF26 =  CHORD /2.
C       COEF27 =  1./CHORD/CHORD
C       COEF28 =  1./(AREAW/2.)
C       COEF29 =   PI * ARWING
C          COEF30=  1./(PI*ARWING)
C          COEF31=  S * C /2
C          COEF32= S * C /2 *CLALPH*(DCMDCL+XWAC/C )
C          COEF33= S * C /2 *CLALPH*(DCMDCL+XWAC/C ) *4/3/PI *YN/YWAC
C          COEF34=  YWAC / YN / K TH TWIST
C       COEF35=  B = 
C          TABLE OF INTERMEDIATE CALCULATIONS
C       ZRSIN =  ZR* SIN(INR-LAMDA)
C       ZRCOS =  ZR* COS(INR-LAMDA)
C       XRSIN=   XR* SIN(INR-LAMDA)
C       XRCOS=   XR* COS(INR-LAMDA)
C       ZLSIN =  ZL* SIN(INL-LAMDA)
C       ZLCOS =  ZL* COS(INL-LAMDA)
C       XLSIN =  XL* SIN(INL-LAMDA)
C       XLCOS =  XL* COS(INL-LAMDA)
C       ZFMFHF=   SMF* SHF * ZF
C       ZWMWHW=   SMW* SHW * ZW
C       XFMFLF=   SMF* SLF * XF
        XWMWLW=   SMW* SLW * XW
C       TERM1 =  (IXXPR-IZZPR)*(SSQINR + SSQINL)
C       TERM2 =  (IXZPR)*( S2INR +S2INL)
C       TERM3 =  (SL *SMN)*(ZRSIN +ZLSIN)
C       TERM4 =  (IXXPR-IZZPR)*(S2INR +S2INL) * 0.5
C       TERM5 =   IXZPR *(C2INR+C2INL)
C       TERM6 =   (SL *SMN) *(XRCOS + XLCOS)
C       DOVIXX=   1./FIXX
C       DOVIYY=   1./FIYY
C       DOVIZZ=   1./FIZZ
C       PQ =       P*Q
C       PQ =       P*Q
C       QR =       
C       PR =       P*R
C       RP =       R*P
C          FOR TT CALC USE FOLLOWING TRIG IDENTITIES WHERE
C             A= INCIDENCE ANGLE INR,INL     B = LAMDA
C          COS(A-B)  = COS(A)*COS(-B)  -SIN(A)*SIN(-B)
C                    = COS(A)*COS(B)   +SIN(A)*SIN(B)
C          SIN(A-B)  = SIN(A)*COS(-B)  +COS(A)*SIN(-B)
C                    = SIN(A)*COS(B)   -COS(A)*SIN(B)
```

Figure G.6. (Continued)

```
         C
         C        SIN(2A) = 2.*SIN(A)*COS(A)
         C        COS(2A) = 1. - 2.*SIN(A)*SIN(A)
         C
         C
         C        DISCRETE LINE  ALLOCATION
         C
         C            CONSOLE  1
         C
         C        BIT NUMBER    DGS NUMBER   FUNCTION
         C           31            17          PANIC
         C           30            16          TRIM
         C           29            15          CONSOLE OPERATE
         C
         C        HORIZONTAL TAIL
         C
         C          1. IF HWC/4 GT 50 FT.    GEF = 0.
         C          2. IF  V  LE  30 KT   TAIL AERO = 0.
         C          3. IF  DEL FLAP GT  75 DEG    EPSILON TAIL = 0.
         C          4. IF  CTS LT 0.5  EPSILON P = 0.
         C          5. LIMIT RANGE OF ABS(ALPHHT) TO (ALHTSTALL - 2. DEG) AND
         C               PRINT WARNING
         C        VERTICAL  TAIL
         C          1. LIMIT THE RANGE OF ABS(ALPHVT) TO(ALVTSTALL -2 DEG) AND
         C               PRINT WARNING
 32
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A P D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
****I************************** S Y N T A X   E R R O R ************************        E  ))
 33               CALL TRACK('RTFAST  ',1)
         C
         C           READ ADCS
 34               CALL USFAID(ANDIG )
 35               KPAN = 301
 36      40       GO TO(40,50,500),ISTAD
         C
         C           CONVERT TO FLOATING POINT
```

Figure G.6. (Continued)

```
   37      5     CALL ANGELT(KAP(IPSN3S(7,1))),ADC,E6,SCADCL )
           C
   38
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
****I*************************  S Y N T A X   E R R O R  ************************          E  ))
   39              ENTRY TSTRTE
           C
   40              CALL SINCOS(AINR,SININR ,COSINR )
   41              CALL SINCOS(AINL,SININL ,COSINL )
   42              AVEIN  =  0.5*(AINL +AINR)
           C
   43              CILAMR =  COSLAM*COSINR +SINLAM* SININR
   44              CILAML =  COSLAM*COSINL +SINLAM* SININL
   45              SILAMR =  COSLAM*SININR -SINLAM* COSINR
   46              SILAML =  COSLAM*SININL -SINLAM* COSINL
           C
   47              DLEPSQ =  DELELP * DELELP
           C
           C
   48
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
                                         ( B L A N K   C A R D )
****I*************************  S Y N T A X   E R R O R  ************************          E  *P
           C        C.G. VELOCITY W.R.T. PIVOT (NON ROTATING AXES)
   49              XDTCG  =  -COEF1*(AINDTL*SILAML+AINDTR*SILAMR )
   50              YDTCG  =  -COEF1*(AINDTL*CILAML+AINDTR*CILAMR )
           C
   51              T=  TIME + TGUST
```

Figure G.6. (Continued)

```
      V =   VPRIME + VGUST
      W =   WPRIME + WGUST
      P =   PPRIME + PGUST
      Q =   QPRIME + QGUST
      R =   RPRIME + RGUST
      USQ= U*U
      VSQ=  V*V
      WSQ=  W*W
      VALFS=  FSQRT(USQ+WSQ,WORK)
      ALPHF=  ATAN2(W,U)
      BETAF=  ATAN2(V,VALFS)
      VTOTAL=  FSQRT(USQ+VSQ+WSQ,WORK)
      SQF= RDEDV2 *(USQ+VSQ+WSQ)
      IF(SQF.GT.SQFPRM) GO TO 130
      NCLOSE  = 0
      SQFPRM= DBRK18+DBRK19
      GO TO 140
  130 NCLOSE= 1
      SQFPRM= DBRK18-DBRK19
  140 CONTINUE
C        GLAS SYSTEM
      CALL LINT(GKEY,GMEM,GMEM,ISTG,SQF,GAATAB,GA1ALF,GBATAB,GB1ALF,
     1             ALFTAB,ALFREF)
      GA1BET = GB1ALF
      ALFGLS= ALPHF*RDTODG
      BETGLS = BETAF*RDTODG
      A1CLGS= ALFGLS*GA1ALF+BETGLS*GA1BET
      A1C2GS= BETGLS*GA1BET-ALFGLS*GA1ALF
      B1CGLS= ALFGLS*GB1ALF
C        FUSELAGE PIVOT VELOCITY
      UP =   U - Q*ZCG -XDTCG
      VP =   V + R*ZCG-P* XCG
      WP =   W + Q*XCG -ZDTCG
C
C
C        LEFT ROTOR HUB VELOCITY - BODY AXES
      URLPR  = UP +R*YN -BLS*SININL*(Q+AINDTL)+Q* H1L
      VRLPR  = VP +BLS*(R*COSINL+P*SININL) -P* H1L
      WRLPR  = WP -P*YN-BLS*(Q+AINDTL)*COSINL +H1DTL
C
C        RIGHT ROTOR HUB VELOCITY - BODY AXES
      URRPR  =UP-R*YN -BLS*SININR*(Q+AINDTR) +Q* H1R
      VRRPR  =VP +BLS*(R*COSINR +P*SININR) -P* H1R
      WRRPR  = WP +P*YN -BLS*(Q+AINDTR)*COSINR +H1DTR
C
C        LEFT ROTOR HUB VELOCITY - SHAFT AXES
      URL= URLPR*COSINL -WRLPR*SININL
      VRL=  VRLPR
      WRL=  URLPR*SININL +WRLPR*COSINL
C
C        RIGHT ROTOR HUB VELOCITY - SHAFT AXES
      URR  =  URRPR*COSINR -WRRPR*SININR
      VRR  =  VRRPR
      WRR=    URRPR*SININR +WRRPR*COSINR
C
```

Figure G.6. (Continued)

```
      C        FREE STREAM VELOCITY
 94            ULUWL = URL *URL
 95            VRLVRL=  VRL*VRL
 96            WRLWRL=  WRL*WRL
 97            URRURR = URR * URR
 98            VRRVRR=  VRR*VRR
 99            WRRWRR=  WRR*WRR
 100           VTOTRR=  FSQRT(URRURR+VRRVRR+WRRWRR,WORK)
 101           VTOTLL=  FSQRT(URLURL+VRLVRL+WRLWRL,WORK)
 102           WROTL=  WRL+EPWRL*URL
 103           WROTR=  WRR + EPWRR*URR
 104           VZETL= FSQRT(VRLVRL+WROTL*WROTL,WORK)  + ROTEPS
 105           VZETR=  FSQRT(VRRVRR+WROTR*WROTR,WORK)  + ROTEPS
      C          LEFT WING A.C. VELOCITY - BODY AXES
 106           ULWPP= UP+R*YWAC+Q*(ZWAC+HWACL)
 107           VLWPP=  VP+R*XWAC-P*(ZWAC+HWACL)
 108           WLWPP= WP +P* YWAC -Q*  XWAC + HDTACL
      C          LEFT WING A.C. VELOCITY - CHORD AXES
 109           ULW = ULWPP*COSIW -WLWPP *SINIW
 110           VLW = VLWPP
 111           WLW = ULWPP*SINIW  +WLWPP* COSIW
      C
      C          RIGHT WING A.C. VELOCITY - BODY AXES
 112           URWPP=  UP-R*YWAC+Q*(ZWAC+HWACR)
 113           VRWPP =  VP+R*XWAC-P*(ZWAC+HWACR)
 114           WRWPP = WP +P* YWAC -Q*  XWAC + HDTACR
      C
      C          RIGHT WING A.C. VELOCITY - CHORD AXES
 115           URW = URWPP*COSIW - WRWPP*SINIW
 116           VRW = VRWPP
 117           WRW = URWPP*SINIW +WRWPP *COSIW
      C
      C
      C          FREE STREAM VELOCITY
      C
 118           VLWSQ =  VLW * VLW
 119           WLWSQ =  WLW * WLW
 120           ULWSQ =  ULW * ULW
      C
 121           VALFLW=  FSQRT(ULWSQ+WLWSQ,WORK)
      C
 122           URWSQ =   URW* URW
 123           VRWSQ =   VRW* VRW
 124           WRWSQ =   WRW* WRW
 125           VALFRW=  FSQRT(URWSQ+WRWSQ,WORK)
      C
      C
 126           UHT   = UP + ZHT *Q
 127           WHT   = WP -  XHT *Q
      C
      C          VERTICAL TAIL AERO COORDINATE TRANSFORM
 128           UVT =  UP + Q* ZVT
 129           VVT =  VP + R* XVT -P*ZVT
 130           WVT =  WP - Q* XVT
 131           VRETVT=  FSQRT(UVT*UVT+WVT*WVT,WORK)
```

Figure G.6. (Continued)

```
      C
132
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
****I************************ S Y N T A X   E R R O R ************************          E ))
      C
      C       ROTOR INPUT EQUATIONS (AE?))
      C         NOTE ALPHRR AND ALPHLR ARE DEFINED BETWEEN 0 AND 180 DEGREES
      C              I.E.  90 +OR- 90 DEGREES
133         ALPHLR=  ATAN2(VZETL,URL)  + EPIRL
134         ZETHL=  ATAN2(VPL,WROTL)
135         CALL SINCOS(ZETHL,SINZHL,COSZHL)
      C
136         ALPHRR=  ATAN2(VZETR,URR)  + EPILR
137         ZETHR=  ATAN2(VRR,WROTR)
138         CALL SINCOS(ZETHR,SINZHR,COSZHR)
      C       VELOCITIES
      C
      C       ROTOT ANGULAR RATE TRANSFORMS
      C
      C       LEFT ROTOR - NACELLE AXES
139         PNLN= P*COSINL - R*SININL
140         QNLN= Q+AINDTL
141         RNLN= P*SININL +R*COSINL
      C       LEFT ROTOR - WIND AXES
142         PNLR=  PNLN
143         QNLR= QNLN*COSZHL -RNLN*SINZHL
144         RNLR= RNLN*COSZHL +QNLN*SINZHL
      C
      C       RIGHT ROTOR - NACELLE AXES
145         PNRN=  -P*COSINR +R*SININR
146         QNRN= Q+AINDTR
147         RNRN=-P*SININR -R*COSINR
      C       RIGHT ROTOR - WIND AXES
148         PNRR=  PNRN
149         QNRR= QNRN*COSZHR +RNRN*SINZHR
150         RNRR= RNRN*COSZHR -QNRN*SINZHR
      C
151         OMEGAL=  OMEGA + PNLR
152         OMEGAR=  OMEGA + PNRR
153         OMSQL =   OMEGAL * OMEGAL
```

Figure G.6. (Continued)

```
      AMSQR =  OMEGAR * OMEGAR
      VTIPL =  ROTRAD * OMEGAL
      VTIPR =  ROTRAD * OMEGAR
      AMUL  =VT TEL / VTIPL
      AMUR  =VT TER / VTIPR
      AMULSQ = AMUL * AMUL
      AMURSQ = AMUR * AMUR
C
C
C       ROTOR CONTROL COORDINATE AXIS TRANSFORM
C         LEFT ROTOR
      AICLPP =  AICLPP *CPHIP +BICLPP*SPHIP
      BICLPP = -AICLPP *SPHIP +BICLPP*CPHIP
C
      AICL   =   AICLDP*COSZHL -BICLDP*SINZHL
      BICL   =   AICLDP*SINZHL +BICLDP*COSZHL
C
C         RIGHT ROTOR
      AICRPP=   AICRPP*CPHIP + BICRPR*SPHIP
      BICRPP=  -AICRPP*SPHIP + BICRPP*CPHIP
C
      AICR   =   AICRDP*COSZHR +BICRDP*SINZHR
      BICR   =  -AICRDP*SINZHR +BICRDP*COSZHR
C
C       ROTOR EQUATIONS
C
      ENFRI  =  ENF1*CTR  +ENF2*AMURSQ  +ENF3*AMUR   + ENF4
      DNFAI  =  DNF1*CTR  +DNF2*AMURSQ  +DNF3*AMUR   + DNF4
      ESFRI  =  ESF1*CTR  +ESF2*AMURSQ  +ESF3*AMUR   + ESF4
      DSFAI  =  DSF1*CTR  +DSF2*AMURSQ  +DSF3*AMUR   + DSF4
      IF(AMUR.GT. DRRK9)  GO TO 15
      EPMRIR =  EPM1*CTR  +EPM2*AMURSQ  +EPM3*AMUR   + EPM4
      DPMAIR =  DPM1*CTR  +DPM2*AMURSQ  +DPM3*AMUR   + DPM4
      EYMRIR =  EYM1*CTR  +EYM2*AMURSQ  +EYM3*AMUR   + EYM4
      DYMAIR =  DYM1*CTR  +DYM2*AMURSQ  +DYM3*AMUR   + DYM4
      GO TO 16
   15 CONTINUE
      EPMRIR =  EPM1*CTR  +EPM5*AMURSQ  +EPM6*AMUR  +EPM7
      DPMAIR =  DPM1*CTR  +DPM5*AMURSQ  +DPM6*AMUR  +DPM7
      EYMRIR =  EYM1*CTR  +EYM5*AMURSQ  +EYM6*AMUR  +EYM7
      DYMAIR =  DYM1*CTR  +DYM5*AMURSQ  +DYM6*AMUR  +DYM7
   16 CONTINUE
C
      ENFR   = ENFRR +ENFAIR*AICR  +ENFRIR *BICR
      ESFR   = ESFRR +ESFAIR*AICR  +ESFRIR *BICR
      EPMR   = EPMRR +EPMAIR*AICR  +EPMRIR *BICR
      EYMR   = EYMRR +EYMAIR*AICR  +EYMRIR *BICR
C
      ENFRIL =  ENF1*CTL  +ENF2*AMULSQ  +ENF3*AMUL   + ENF4
      DNFAIL =  DNF1*CTL  +DNF2*AMULSQ  +DNF3*AMUL   + DNF4
      ESFRIL =  ESF1*CTL  +ESF2*AMULSQ  +ESF3*AMUL   + ESF4
      DSFAIL =  DSF1*CTL  +DSF2*AMULSQ  +DSF3*AMUL   + DSF4
      IF(AMUL.GT. DRRK9)  GO TO 17
      EPMRIL =  EPM1*CTL  +EPM2*AMULSQ  +EPM3*AMUL   + EPM4
      DPMAIL =  DPM1*CTL  +DPM2*AMULSQ  +DPM3*AMUL   + DPM4
```

Figure G.6. (Continued)

```
      CYMBIL  =  EYM1*CTL +EYM2*AMULSQ +EYM3*AMUL  + EYM4
      CYMAIL  =  DYM1*CTL +DYM2*AMULSQ +DYM3*AMUL  + DYM4
      GO TO 180
170   CONTINUE
      CPMBIL  =  EPM1*CTL +EPM5*AMULSQ +EPM6*AMUL +EPM7
      CPMAIL  =  DPM1*CTL +DPM5*AMULSQ +DPM6*AMUL +DPM7
      CYMBIL  =  EYM1*CTL +EYM5*AMULSQ +EYM6*AMUL +EYM7
      CYMAIL  =  DYM1*CTL +DYM5*AMULSQ +DYM6*AMUL +DYM7
180   CONTINUE
      CNFL   = CNFPL +CNFAIL*AICL +CNFBIL* BICL
      CSFL   = CSFPL +CSFAIL*AICL +CSFBIL* BICL
      CPML   = CPMPL +CPMAIL*AICL +CPMBIL *BICL
      CYML   = CYMPL +CYMAIL*AICL +CYMBIL *BICL
C
C        CALCULATIONS OF FORCES AND MOMENTS FROM COEFFICIENTS
      ROPIR4 =  COEF19 * ROE
      ROPIR5 =  COEF20 * ROE
      CTL=  CTLPRM*TIGEL
      TL      =  CTL * ROPIR4 * OMSQL
      FNORML  =  CNFL *ROPIR4 *OMSQL
      FSIDEL  =  CSFL *ROPIR4 * OMSQL
      AMROTL  =  CPML *ROPIR5 * OMSQL
      ANROTL  =  CYML *ROPIR5 * OMSQL
      TORQL=  CPL*ROPIR5*OMSQL
C
       CTR=  CTRPRM*TIGER
      TR      =  CTR  * ROPIR4 * OMSQR
      FNORMR  =  CNFR * ROPIR4 * CMSQR
      FSIDER  =  CSFR * ROPIR4 * CMSQR
      AMROTR  =  CPMR * ROPIR5 * OMSQR
      ANROTR  =  CYMR * ROPIR5 * OMSQR
      TORQR=  CPR*ROPIR5*CMSQR
      OMDTL=  OMDOT
      OMDTR=  OMDOT
C
C         HUB MOMENTS  -  NACELLE AXES
      FIPOML=  FIP*OMEGAL
      FIPOMR=  FIP*OMEGAR
      TRMHB1=  FIE*OMEGEL * R
      TRMHB2=  FIE*OMEGER * R
      TRMHB3=  AMROTL*COSZHL-ANROTL*SINZHL
      TRMHB4= -ANROTL*COSZHL-AMROTL*SINZHL
      TRMHB5= AMROTR*COSZHR+ANROTR*SINZHR
      TRMHB6= ANROTR*COSZHR-AMROTR*SINZHR
C             LEFT
      ALLRH=  -TORQL   -FIP*OMDTL
      AMLRH=  TRMHB3-FIPOML*RNLN
      ANLRH= TRMHB4+FIPOML*CNLN
C             RIGHT
      ALRRH=  TORQR   + FIP*OMDTR
      AMRRH=  TRMHB5-FIPOMR*RNRN
      ANRRH=  TRMHB6-FIPOMR*CNRN
C
C          ROTOR FORCE AND MOMENT RESOLUTION
C             PRELIMINARY CALCULATIONS
```

Figure G.6. (Continued)

```
241          TRMHA7= ENORML*COSZHL +FSIDEL*SINZHL
242          TRMHA8= -ENORMR*COSZHR+FSIDER*SINZHR
243          TRMAR1=  TRMHA7-DZLNC
244          TRMAR2=  TRMHA8 +DZRNC
245          TRMHB9= FSIDEL*COSZHL-ENORML*SINZHL
246          TRMHB1 =  -FSIDER*COSZHR-ENORMR*SINZHR
       C        LEFT TIP PIVOT - BODY AXES AT TIP
247          XAERNL = (TL+DXLNC)*COSINL - SININL*TRMAR1
248          YAERNL=  TRMHB9 +DYLNC
249          ZAERNL=  -(TL+DXLNC)*SININL -COSINL*TRMAR1
       C
250          TRMAR3=  AMLRH +DMLNC + BLS*YAERNL
       C
251          ALARNL=  (ALLRH+DLLNC)*COSINL +SININL*TRMAR3
       C
252          AMRNLP=  AMLRH + DMLNC +BLS*TRMAR1
       C
253          AMARNL=  AMRNLP -TRMH10
254          ANARNL=  COSINL*TRMAR3 -SININL*(ALLRH+DLLNC) +FIE*OMEGEL*C
       C
       C        RIGHT TIP PIVOT - BODY AXES AT TIP
255          XAERNR=  (TR+DXRNC)*COSINR +SININR*TRMAR2
256          YAERNR=  TRMH10 +DYRNC
       C
       C
257          ZAERNR=  -(TR+DXRNC)*SININR +COSINR*TRMAR2
       C
258          TRMAR4=  AMRRH + DMRNC +BLS*YAERNR
       C
259          ALARNR=  (ALRRH+DLRNC)*COSINR +SININR*TRMAR4
       C
260          AMRNRP=  AMRRH +DMRNC -BLS*TRMAR2
       C
261          AMARNR=  AMRNRP - TRMHB2
262          ANARNR=  COSINR*TRMAR4 -SININR*(ALRRH+DLRNC)+FIE*OMEGER*C
       C
263          XAERNC  =  XAERNL + XAERNR
264          YAERNC  =  YAERNL + YAERNR
265          ZAERNC  =  ZAERNL + ZAERNR
266          ALARNC  =  ALARNL + ALARNR
267          AMARNC  =  AMARNL + AMARNR
268          ANARNC  =  ANARNL + ANARNR
       C
269
                              ( B L A N K   C A R D )
                              ( B L A N K   C A R D )
                              ( B L A N K   C A R D )
                              ( B L A N K   C A R D )
                              ( B L A N K   C A R D )
                              ( B L A N K   C A R D )
                              ( B L A N K   C A R D )
                              ( B L A N K   C A R D )
                              ( B L A N K   C A R D )
                              ( B L A N K   C A R D )
                              ( B L A N K   C A R D )
```

Figure G.6. (Continued)

```
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
****I************************* S Y N T A X   E R R O R ***********************   & +L
            SQWING =   SQF + 0.5*DOVDSK*(TR +TL )
            SQLW   =      RDEOV2 *(ULWSQ+VLWSQ+WLWSQ)+ TL * DOVDSK
            SQRW   =      RDEOV2*(URWSQ+VRWSQ+WRWSQ)  + TR * DOVDSK
            IF(NCLOSE.EQ.1)  GO TO 420
            FINPR=   FINDEG-DBRK17
      C        EQUATIONS FOR DOORS OPEN
            SGNULW= 1.0
            IF(ULW.LT.0.) SGNULW= -1.0
            SGNURW= 1.0
            IF(URW.LT.0.0) SGNURW= -1.0
            XAERLW=  -SGNULW*FFU*SQLW*(1.-CTSLR)
            XAERRW=  -SGNURW*FFU*SQRW*(1.-CTSPR)
            YAERLW =  0.
            YAERRW=  0.
            ZAERLW =  DOVTL*TL
            ZAERRW =  DOVTR*TR
            AMARLW=  -XWC2*ZAERLW + BMOVTL * TL
            AMARRW =  -XWC2*ZAERRW + BMOVTR*TR
            ALARWG=  .5*SPAN*(ZAERRW*(1.-0.5*SIRW)-ZAERLW*(1.-0.5*SILW))
            ANARWG =  0.
      C         SET WING DYNAMIC PRESSURE = TO HARD 0.0  FOR THETA TWIST EQ
            SQWING = 0.0
            SQLW=  0.0
            SQRW=  0.0
      C
            AVECLW=  0.0
            GO TO 430
      420   CONTINUE
      C         EQUATIONS FOR DOORS CLOSED
            FINPR=  FINDEG + DBRK17
      C
      C
      C         ANGLE OF ATTACK AND SIDESLIP
            ALPHLW=  ATAN2(WLW,ULW)   +THTLAC
            BETALW=  ATAN2(VLW,VALFLW)
      C
            ALPHRW=  ATAN2(WRW,URW)   + THTRAC
            BETARW=  ATAN2(VRW,VALFRW)
      C
            ALWSSO  =  ALPHLW  - EPPLR
            ARWSSO  =  ALPHRW  - EPPRR
            ALRGLW  =  ALWSSO  - THTLAC
            ALRGRW  =  ARWSSO  - THTRAC
```

Figure G.6. (Continued)

```
 304          AVEALW  =  0.5 *(ALPHLW + ALPHRW )
        C
        C
        C        CALCULATE LIFT AND DRAG INCREMENTS
        C
        C        FLAP , AILERON , SPOILER CONTRIBUTION
        C
        C
        C        REVISED 11/29/72
        C
 305          CALL AILSP(  DFLAIL     ,DELSPL,DCLLDA,DCDLDA,DCMLDA,DCLLSP,DCDLSP,
             * DCMLSP)
 306          CALL AILSP(  DFLAIR     ,DELSPR,DCLRDA,DCDRDA,DCMRDA,DCLRSP,DCDRSP,
             * DCMRSP)
        C
 307          CDCNTL= DCDLDA+DCDLSP
 308          CMCNTL= DCMLDA+DCMLSP
        C
 309          CDCNTR= DCDRDA+DCDRSP
 310          CMCNTR= DCMRDA+DCMRSP
        C
        C            CONTRIBUTION DUE TO TOTALLY DOWNWASHED WING (ALPHA - EPSILON)
        C
 311          CALL CLCDCM(ALWSSO,  DFLAIL     ,DCLLDA,DCLLSP,CDCNTL,CMCNTL,
             * CLLWSS,CDLWSS,CMLWSS,CLDUM,CDDUM)
 312          CALL CLCDCM(ARWSSO,  DFLAIR     ,DCLRDA,DCLRSP,CDCNTR,CMCNTR,
             * CLRWSS,CDRWSS,CMRWSS,CLDUM,CDDUM)
        C
        C
        C            CONTRIBUTION DUE TO TOTALLY UN-WASHED WING  ( ALPHA )
        C
        C
 313          CALL CLCDCM(ALPHLW,  DFLAIL     ,DCLLDA,DCLLSP,CDCNTL,CMCNTL,
             * CLLWAO,CDLWAO,CMLWAO,CLLWPR,CDLWPR)
 314          CALL CLCDCM(ALPHRW,  DFLAIR     ,DCLRDA,DCLRSP,CDCNTR,CMCNTR,
             *   CLRWAO,CDRWAO,CMRWAO,CLRWPR,CDRWPR)
        C
 315          CALL CLF1(DELFLP,CLZERO)
 316          CALL CLF2(ALPHF+AINW,CLZERO,0.0,CLAVE)
        C
        C
 317          ALLWPR= ALPHLW - AINW -THTLAC
 318          ALRWPR=  ALPHRW - AINW - THTRAC
 319          SALLW=  ALLWPR
 320          CALLW=  1.0
 321          SALRW=  ALRWPR
 322          CALRW=  1.0
 323          SBETLW=  BETALW
 324          CBETLW=  1.0
 325          SBETRW=  BETARW
 326          CBETRW=  1.0
 327          IWARN1( 7)=  .FALSE.
 328          IWARN1( 8)=  .FALSE.
 329          IWARN1( 9)=  .FALSE.
 330          IWARN1(10)=  .FALSE.
```

Figure G.6. (Continued)

```
      IF(ALWSSO.GT.DEG20) IWARNI( 7)=  .TRUE.
      IF(ARWSSO.GT.DEG20) IWARNI( 8)=  .TRUE.
      IF(ALPHLW.GT.DEG20) IWARNI( 9)=  .TRUE.
      IF(ALPHRW.GT.DEG20) IWARNI(10)=  .TRUE.
      CALL SINCOS(EPPLR,SEPLW,CEPLW)
      CALL SINCOS(EPPRR,SEPRW,CEPRW)
C
C
      TRMWG5 =  (1.-CTSLR)*(1.-SILW)
      TRMWG6 =  (1.-CTSRR)*(1.-SIRW)
      CLSLW =   (SILW*(CLLWSS*CEPLW-CDLWSS*SEPLW) + CLLWAO* TRMWG5)*
     *  BKALPR
      CDSLW =   (SILW*(CLLWSS*SEPLW+CDLWSS*CEPLW) + CDLWAO* TRMWG5)*
     *  BKALPP
      CMSLW =   (SILW*CMLWSS + CMLWAO* TRMWG5)*BKALPR
C
      CLSRW =   (SIRW*(CLRWSS*CEPRW -CDRWSS*SEPRW)+ CLRWAO* TRMWG6)*
     *  BKARPR
      CDSRW =   (SIRW*(CLRWSS*SEPRW +CDRWSS*CEPRW)+ CDRWAO* TRMWG6)*
     *  BKARPP
      CMSRW =   (SIRW*CMRWSS + CMRWAO *TRMWG6 )*BKARPR
C
      DCLSPW= 0.25*((1.-.5*SILW)*(CLSLW-CLLWAO*(1.-AVECTS))-(1.-.5*
     * SIRW)*(CLSRW-CLRWAO*(1.-AVECTS)))
      DCNSPW= .25*((1.-.5*SIRW)*(CDSRW-CDRWAO*(1.-AVECTS))-(1.-.5*
     * SILW)*(CDSLW-CDLWAO*(1.-AVECTS)))
C
      CLSW= (1.-AVECTS)*(BETAF*(SK20+SK21*CLAVE)+COEF11*(CLLWAO
     * -CLRWAO)) + DCLSPW
      CNSW= (1.-AVECTS)*(BETAF*SK22*CLAVE*CLAVE+COEF12*(CDRWAO
     * -CDLWAO-     CLRWAO*(ALPHRW-AINW )-CLLWAO*(AINW-ALPHLW ))) +DCNSPW
C
      TRMWG7=  SQLW * COEF18
      TRMWG8=  SQRW * COEF18
C
C
      ZAERLW = -TRMWG7 *(CLSLW*CALLW +CDSLW*CBETLW*SALLW )
      XAERLW =  TRMWG7 *(CLSLW*SALLW -CDSLW*CBETLW*CALLW )
      YAERLW = -TRMWG7 *CDSLW * SBETLW
      AMAPLW =  TRMWG7 *CHORD *CMSLW * CBETLW
     * -XWAC*ZAERLW + ZWAC*XAERLW
C
C
      ZAERRW = -TRMWG8 *(CLSRW*CALRW +CDSRW*CBETRW*SALRW )
      XAERRW =  TRMWG8 *(CLSRW*SALRW -CDSRW*CBETRW*CALRW )
      YAERRW = -TRMWG8 * CDSRW * SBETRW
      AMARRW =  TRMWG8 *CHORD * CMSRW * CBETRW
     *  -XWAC*ZAERRW  +ZWAC*XAERRW
C
      AVECLW=  0.5*(CLSRW+CLSLW)/(1.01-AVECTS)
   43  CONTINUE
      XAERWG =  XAERLW + XAERRW
      YAERWG =  YAERLW + YAERRW
      ZAERWG=  ZAERLW + ZAERRW
      ALARWG =  CLSW * SCWING * COEF15
```

Figure G.6. (Continued)

```
                                   SUBROUTINE  PTFA                                    PAGE  17

            AMARK  =  AMARK  +  ...
         *  +XCG*Z+...  -ZCG*XAF...
            AMARK  =  ...SQ...
      C
      C
      C        WING/BODY  INTERFERENCE
      C
            PWEL = (CONS...+CONS...)...AVECLW
            TPWRR = POWEL
      C        ANGLE OF ATTACK
      C

                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
                                 ( B L A N K   C A R D )
****************************** S Y N T A X   E R R O R ************************     **
      C
      C        TAIL AERODYNAMICS
      C
      C          HORIZONTAL TAIL   AERO COORDINATE TRANSFORM
      C        AERO INPUT EQUATIONS
      C
      C
      C        HORIZONTAL TAIL ANGLE OF ATTACK
      C
            IF(...GT...) GO TO 24.
            ...TAIL= ...(...)...
            GO TO ...
      24    CONTINUE
            DELERPZ= ...(...DELAT+DELAT...)
            IF(DELERPZ.GE.DA...K1) GO TO 242
            ...= ...DELERPZ*(CONS41*DELERPZ+CONS42)+CONS43)
            GO TO 243
      242   ...= ...(DELERPZ*(CONS75*DELERPZ+CONS76)+CONS77)
      243   CONTINUE
            IF(DELERP...GT.CONS81) GO TO 245
            ...= CONS7...+DELERPZ*(CONS7...+CONS8...*DELERPZ)
            GO TO ...
      245   CONTINUE
            ...= ...CONS7...+DELERPZ*(CONS73+CONS74*DELERPZ)
```

Figure G.6. (Continued)

```
248   CONTINUE
      EPTL1 =  EPZERO+DEPDAL*(AVEALW- SLAC*WDOT/(U*U+0.01))
       IF(AVEFPP.LT.EPTL1 ) GO TO 260
      EPTAIL=  AVEFPP*(1.-GEF)*DOVFSM
      GO TO 265
260    CONTINUE
       EPTAIL=  EPTL1*(1.-GEF)*DOVFSM
 265   CONTINUE
250   CONTINUE
      IF(UPRIME.LE.0.) EPTAIL= 0.
      ALPHHT=  ATAN2(WHT,UHT)  -EPTAIL + AINHT
      IF(ALPHHT.GT.PI) ALPHHT=ALPHHT-2.*PI
      IF(ALPHHT.LT.-PI)  ALPHHT=ALPHHT+2.*PI
      CALL SINCOS(ALPHHT-AINHT,SALIHT,CALIHT)
C
C        TAIL REVISION   9/6/72
C
      ALHTPR   = TAUHT *DFLELV
      ALHTE    = ALPHHT + ALHTPR
      ALHTP    = HTSTLL + ALHTPR
      ALHTM    = -HTSTLL + ALHTPR
      CLAT     = CLALHT *CLTCOP
      TRMHT2   = 0.5 * ALHTP
      TRMHT3   = 0.5 * ALHTM
      IWARN1(5)=  .TRUE.
      IF(ALHTE) 270,277,276
270   IF(ALHTE.GT.(-PI +TRMHT2)) GO TO 272
C        REGION 7
      CLHT =  CLAT *( ALHTE +PI)
      CDHT =  CDOHT + CLHT*CLHT *COEF21
      GO TO 288
272   IF(ALHTE.GT. -PIOV2) GO TO 274
C        REGION 6
      CLHTST =  CLAT *TRMHT2
      CLHT   =  CLHTST *(ALHTE+PIOV2)/(-PIOV2+TRMHT2)
      CDHTST = CDOHT +CLHTST*CLHTST *COEF21
      CDHT = CDHTST -(1.1-CDHTST)*(ALHTE+PI-TRMHT2)/(TRMHT2 -PIOV2)
      GO TO 288
274      IF(ALHTE .GT.ALHTM) GO TO 276
C        REGION 5
      CLHTST =  CLAT * ALHTM
      CLHT   =  CLHTST *(PIOV2+ALHTE)/(PIOV2+ALHTM)
      CDHTST = CDOHT +CLHTST*CLHTST *COEF21
      CDHT   = CDHTST +(1.1-CDHTST)*(ALHTE-ALHTM)/(-PIOV2 -ALHTM)
      GO TO 288
276   IF(ALHTE .GT.ALHTP) GO TO 278
C        REGION 1
277   CLHT   =  CLAT * ALHTE
      CDHT   =  CDOHT + CLHT*CLHT *COEF21
      IWARN1(5)=  .FALSE.
      GO TO 288
278   IF(ALHTE.GT.PIOV2)  GO TO 280
C        REGION 2
      CLHTST   =  CLAT *ALHTP
      CLHT     =  CLHTST*(PIOV2-ALHTE)/(PIOV2-ALHTP)
```

Figure G.6. (Continued)

```
      CDHTST  =  CDOHT +CLHTST*CLHTST* COEF21
      CDHT    =  CDHTST+(1.1-CDHTST)*(ALHTE-ALHTP)/(PIOV2-ALHTP)
      GO TO  238
  239 IF(ALHTE .GT.(PI -TRMHT3)) GO TO 242
C        REGION 3
      CLHTST = CLAT *  TRMHT3
      CLHT    = CLHTST*(ALHT--PIOV2)/(PIOV2 -TRMHT3)
      CDHTST = CDOHT +CLHTST*CLHTST* COEF21
      CDHT =  CDHTST +(1.1-CDHTST)*(ALHTE-PI+TRMHT3)/(TRMHT3 -PIOV2 )
      GO TO  238
C        REGION 4
  242 CLHT =  CLAT *(ALHTE -PI)
      CDHT =  CDOHT + CLHT*CLHT*COEF21
  238 CONTINUE
C        VERTICAL TAIL AERO COORDINATE TRANSFORM
      BETVT=  ATAN2(VVT,VBETVT)
      ALPHVT=  -BETVT+BETAF*DSDBET
      IF(ALPHVT.GT.PI)  ALPHVT= ALPHVT-2.*PI
      IF(ALPHVT.LT.-PI) ALPHVT=ALPHVT+2.*PI
      SIGMA=  DSDBET*BETAF
      CALL SINCOS(BETVT-SIGMA,SBETSG,CBETSG)

      ALVTR   =    TAUVT * DELR
      ALVTE    =    ALPHVT  + ALVTR
      ALVTP    =    VTSTLL  + ALVTR
      ALVTM    =   -VTSTLL  + ALVTR
      CYAT     =    CYALVT  * DPVFSM
      TRMVT2   =    0.5 *ALVTP
      TRMVT3   =    0.5 *ALVTM
C
      LWARN1(-)=  .TRUE.
      IF(ALVTE) 290,297,296
  290 IF(ALVTE.GT.(-PI +TRMVT2)) GO TO 292
C        REGION 7
      CYVT   =    CYAT* (ALVTE +PI)
      CDVT   =    CDOVT + CYVT*CYVT * COEF22
      GO TO  300
  292 IF(ALVTE.GT. -PIOV2) GO TO 294
C        REGION 6
      CYVTST =  CYAT * TRMVT2
      CYVT = CYVTST *(ALVTE+PIOV2)/(-PIOV2+TRMVT2)
      CDVTST =  CDOVT +CYVTST*CYVTST *COEF22
      CDVT    =  CDVTST-(1.1-CDVTST)*(ALVTE+PI -TRMVT2)/(TRMVT2 -PIOV2)
      GO TO  300
  294 IF(ALVTE.GT.ALVTM ) GO TO 296
C        REGION 5
      CYVTST =  CYAT * ALVTM
      CYVT = CYVTST *(PIOV2+ALVTE)/(PIOV2+ALVTM)
      CDVTST =  CDOVT +CYVTST *CYVTST *COEF22
      CDVT    =  CDVTST +(1.1-CDVTST)*(ALVTE-ALVTM)/(-PIOV2 -ALVTM)
      GO TO  300
  296 IF(ALVTE .GT.ALVTP) GO TO 298
C        REGION 1
  297 CYVT   = CYAT * ALVTE
      CDVT   =  CDOVT  +CYVT*CYVT *COEF22
```

Figure G.6. (Continued)

```
478          IWARN1(6)=  .FALSE.
479          GO TO 308
480    298   IF(ALVTE .GT.PIOV2) GO TO 302
       C        REGION 2
481          CYVTST  =  CYAT * ALVTP
482          CYVT    =  CYVTST *(PIOV2 -ALVTE)/(PIOV2 -ALVTP)
483          CDVTST  =  CDOVT +CYVTST*CYVTST * COEF22
484          CDVT    =  CDVTST +(1.1-CDVTST)*(ALVTE -ALVTP)/(PIOV2-ALVTP)
485          GO TO 308
486    300   IF(ALVTE .GT.(PI -TRMVT3)) GO TO 302
       C        REGION 3
487          CYVTST  =   CYAT * TRMVT3
488          CYVT    =  CYVTST *(ALVTE -PIOV2)/(PIOV2 -TRMVT3)
489          CDVTST  =  CDOVT + CYVTST*CYVTST* COEF22
490          CDVT = CDVTST+(1.1-CDVTST)*(ALVTE-PI+TRMVT3)/(TRMVT3-PIOV2)
491          GO TO 308
       C        REGION 4
492    302   CYVT =  CYAT *(ALVTE -PI)
493          CDVT =  CDOVT + CYVT *CYVT * COEF22
494    303   CONTINUE
       C
       C        TOTAL TAIL FORCE AND MOMENT RESOLUTION
       C
       C
       C
       C
       C
       C
495          TRMHT =   SQF* COEF23
       C
       C        CHANGE MADE TO HALVE EFFHT FOR I NAC  GT  FINDEG
496          IF(NCLOSE.EQ.0.AND.UPRIME.GT.0.) TRMHT= TRMHT*0.5
       C
       C
497          XARHT =  TRMHT*(CLHT*SALIHT -CDHT*CALIHT *CBETSG)
498          YARHT = -TRMHT* SBETSG *CDHT
499          ZARHT = -TRMHT *(CLHT*CALIHT +CDHT*CBETSG*SALIHT )
500          ALARHT=   -YARHT *(ZHT- ZCG)
501          AMARHT=    ZARHT*(XCG-XHT) +XARHT*(ZHT-ZCG)
502          ANARHT=    -YARHT *(XCG -XHT )
       C
       C
503          TRMVT =    SQF* COEF24
       C
504          XARVT = -TRMVT*CALIHT*(CDVT*CBETSG +CYVT*SBETSG)
505          YARVT =  TRMVT*(CYVT*CBETSG -CDVT*SBETSG )
506          ZARVT = -TRMVT*SALIHT*(CDVT*CBETSG + CYVT*SBETSG )
507          ALARVT=    - YARVT *(ZVT -ZCG)
508          AMARVT =  ZARVT *(XCG-XVT)+XARVT *(ZVT-ZCG)
509          ANARVT =  -YARVT *(XCG -XVT)
       C
510          XAERT  =  XARHT + XARVT
511          YAERT  =  YARHT + YARVT
512          ZAERT  =  ZARHT + ZARVT
513          ALAERT  =  ALARHT + ALARVT
514          AMAERT  =  AMARHT + AMARVT
```

Figure G.6. (Continued)

```
      ANAET  =  ANAGHT + ANARVT
C
           ( B L A N K   C A R D )
           ( B L A N K   C A R D )
           ( B L A N K   C A R D )
           ( B L A N K   C A R D )
           ( B L A N K   C A R D )
           ( B L A N K   C A R D )
           ( B L A N K   C A R D )
           ( B L A N K   C A R D )
           ( B L A N K   C A R D )
           ( B L A N K   C A R D )
           ( B L A N K   C A R D )
           ( B L A N K   C A R D )
****I************************ S Y N T A X   E R R O R ************************   & +4
C
      IF(SFLG.NE.1.0) GO TO 800
      CALL LEAF
  800 CONTINUE
C
      XAERF= XAERF + DXLG
      YAERF= YAERF + DYLG
      ZAERF= ZAERF + DZLG
      ALAERF= ALAERF+ DLLG
      AMAERF= AMAERF+ DMLG
      ANAERF= ANAERF+ DNLG
C
C
C       ELASTIC AXES TO C.G. TRANSFORM
C         AERODYNAMIC FORCES AND MOMENTS RESOLVED TO THE
C          TOTAL CENTER OF GRAVITY
C
      XAERO  =  XAERNC +XAERF +XAERT +XAERWG
      YAERO  =  YAERNC +YAERF +YAERT +YAERWG
C        ZAERO BROKEN INTO TERMS  1) FOR VETICAL BENDING
C                                 2) NOT FOR VERTICAL BENDING
      ZAERVB=  ZAERNC + ZAERWG
      ZAERG=  ZAERF + ZAERT
      ZAERO=  ZAERVB + ZAERG
C
C
C       LAERO BROKEN INTO TERMS  1) FOR VETICAL BENDING
C                                2) NOT FOR VERTICAL BENDING
C
      ALARVB=  ALARNC+YNE(ZAERVB-ZAERNL)
      ALARG=  ALARF+ALAFT+ALARWG+ZCG*YAERNC
      ALAERO=  ALARVB+ALARG
C
C       MAERO BROKEN INTO TERMS  1) FOR VETICAL BENDING
C                                2) NOT FOR VERTICAL BENDING
C
      AMARVB=  XCG*ZAERNC
      AMARG=  AMARNC+AMARF+AMART+AMARWG-ZCG*XAERNC
      AMAERO=  AMARVB+AMARG
C
      ANAERO=  ANARNC +ANARF +ANART +ANARWG
```

Figure G.6. (Continued)

```
          * +YN*(XAERNL-XAERNR)-XCG*YAERNC
538          RQ =       R*Q
539          PQ =       P*Q
540          RR =       R*R
541          PR =       P*R
542          PP =       P*P
543          RQ =       R*Q
      C         PDOT EQUATION   CROSS TERMS
544          TERMP1 = -FJXX * RQ +FIXZP* PQ
      C         QDOT EQUATION   CROSS TERMS
545          TERMQ1 = -FJYY * PR -FIXZQ*(PP -RR)
      C         RDOT EQUATION    CROSS TERMS
546          TERMR1 = -FJZZ * PQ -FIXZR* RQ
      C         AINDDR  EQUATION   CROSS TERMS
547          TERM1R =  COEF4*COEF2*( PR*(1.-2.*SILAMR*SILAMR)- (RR-PP)*SILAMR*
          *  CILAMR )
548          TERM2R =  -(RR -PP)* FIZZPR*SININR *COSINR +COEF1*(XAERO*SILAMR
          *   + ZAERO*CILAMR )
549          TERM3R =    COEF9*(PQ*SILAMR +RQ*CILAMR)
      C
      C         AINDDL EQUATION  CROSS TERMS
550          TERM1L =  COEF4*COFF2*( PR*(1.-2.*SILAML*SILAML)-(RR-PP)*SILAML *
          *  CILAML )
551          TERM2L =  -(RR-PP)* FIZZPR *SININL*COSINL +COEF1*(XAERO*SILAML
          * +  ZAERO*CILAML )
552          TERM3L =  -COEF9*(PQ* SILAML + RQ*CILAML )
553          IF(NVR.EQ.1) GO TO 60
554          H1R=  0.
555          H1DTR= 0.
556          H1L= 0.
557          H1DTL= 0.
558          HWACR= 0.
559          HDTACR= 0.
560          HWACL= 0.
561          HDTACL= 0.
562          GO TO 70
563     60   CONTINUE
564          TRMH1S=  COEF10*ZAERO
565          H1R=SKW1*ZAERNP+SKW2*ZAERPW+SKW3*ALARNR-TRMH1S*(SKW4+SKW5)
566          H1DTR= DVDTIM*(H1R-H1ROLD)
567          H1ROLD=  H1R
568          H1L=SKW1*ZAERNL+SKW2*ZAERLW-SKW3*ALARNL-TRMH1S*(SKW4+SKW5)
569          H1DTL= DVDTIM*(H1L-H1LOLD)
570          H1LOLD=  H1L
571          HWACR= SKW6*ZAERNR+SKW7*ZAERRW+SKW8*ALARNR-TRMH1S*(SKW9+SKW10)
572          HDTACR=  DVDTIM*(HWACR-HACROD)
573          HACROD=  HWACR
574          HWACL= SKW6*ZAERNL+SKW7*ZAERLW-SKW8*ALARNL-TRMH1S*(SKW9+SKW10)
575          HDTACL=  DVDTIM*(HWACL-HACLOD)
576          HACLOD=  HWACL
577     70   CONTINUE
      C          TERMS FOR THETA TWIST EQUATION
578          CMDW=  SC1 + SC2*DELFLP
      C
579          TRMTL1=  SOLW*(1.-CTSLR)
```

Figure G.6. (Continued)

```
          TRMTTW= COEF(1)*CMO
          TRMTOT= SQRHF(1.-CTSQR)
          TMHB11= AMACLP+TERML1+TERM2L+TERM3L
          TMHB12= AMACRP+TERMR1+TERM2R+TERM3R
          AMACTR= AMACRP+TMHB12
          AMACTL= AMACLP+TMHB11
          THTRAC= 0.
          THTLAC= 0.
          IF(NTW .NE.1) GO TO 72
          THTRAC= COEF34*(AMACTR-TRMHB2+TRMTR1*(TRMTTW+COEF32*ALRGRW+
         1 COEF33*THTRAC))
          THTLAC= COEF34*(AMACTL-TRMHB1+TRMTL1*(TRMTTW+COEF32*ALRGLW+
         1 COEF33*THTLAC))
   72     CONTINUE
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
C
C            ALPHA FUS
          DACI(20) = -ALPHF
C            ROOT EQUATION -- NON-WING BENDING TERMS
          DACI( 2)= DVIXX*(TERMPL+ALARPS)
C            COEFFICIENT OF ROOT IN THE ROOT EQUATION
          DACI( 3)= FIKZP * DDVIXX
C            ROOT EQUATION -- NON-WING BENDING TERMS
          DACI( 4)= DDVIYY*(TERMOL+AMAR G)
C            COEFFICIENT OF AINODE IN THE ROOT EQUATION
          DACI( 5)= CILAMB * DDVIYX
C            ROOT EQUATION -- REMAINING TERMS
          DACI( 1) = DDVIZZ *(TERMPI + AMAERO )
C            COEFFICIENT OF AINODE IN THE ROOT EQUATION
          DACI(7)= CILAML*DDVIXX
C            ROOT EQUATION  XACC TERM
          DACI( 8) = XACC
C            UTRIM DAC
          DACI(9)= UTRIM
C            VROOT EQUATION  YACC TERM
          DACI(1 ) = YACC
C            VTRIM DAC
```

Figure G.6. (Continued)

```
602        DAC1(11) = VTRIM
     C        WDOT EQUATION  NON-WING BENDING TERMS
603        DAC1(12)=   ZARRG
     C        HTRIM DAC
604        DAC1(13) = -HTRIM
     C        SQRT(ROE/ROEO)*VTOTAL FOR BCA FUNCTIONS
605        DAC1(14)=  FSQRT(ROE/ROEO,WORK)   * U
     C        COEFFICIENT OF AINDDR IN THE QDOT EQUATION
606        DAC1(15)=  (FIYYPR+COEF4*(XRCOS-ZRSIN)) * OOVIYY
     C        VTOTLR FOR MU CALC ON ANALOG
607        DAC1(16)=  VTOTLR
     C        COEFFICIENT OF AINDDL IN THE QDOT EQUATION
608        DAC1(17)=  (FIYYPR+COEF4*(XLCOS-ZLSIN)) * OOVIYY
     C        LEFT ROTOR ALPHA FOR BCA
609        DAC1(18)= -ALPHLR
     C        THETA TRIM DAC
610        DAC1(19) = THTRIM
     C        VTOTRR FOR MU CALC ON ANALOG
611        DAC1(20)=  VTOTRR
     C        AVERAGE ALPHA WING FOR SIMULATOR
612        DAC1(21)=  -AVEALW
     C        RIGHT ROTOR ALPHA TO USE IN BCA
613        DAC1(22)=  -ALPHRR
     C        COEFFICIENT OF PDOT IN THE RDOT EQUATION
614        DAC1(23)=   FIXZR * OOVIZZ
     C        PNLR FOR MU CALC ON ANALOG
615        DAC1(24)=  PNLR
     C        COEFFICIENT OF AINDDR IN THE RDOT EQUATION
616        DAC1(25)=   SILAMR * OOVIZZ
     C        PNRR FOR MU CALC ON ANALOG
617        DAC1(26)=  PNRR
     C        COEFFICIENT OF AINDDL IN THE RDOT EQUATION
618        DAC1(27)=   SILAML * OOVIZZ
     C        VNORTH  FOR SIMULATOR
619        DAC1(28)=  -VNORTH
     C        FUSELAGE DYNAMIC PRESSURE FOR SIMULATOR
620        SGNSQF =  1.0
621        IF(U.LT.0.) SGNSQF  = -1.0
622        DAC1(29) =  - SQF * SGNSQF
     C        VEAST  FOR SIMULATOR
623        DAC1(30)=  -VEAST
     C        BETA FUSE FOR CONTROL SYSTEM FEEDBACK
624        DAC1(32)= -BETAF
625        DAC2( 1)=  -CILAMR
626        DAC2(02) = BICGLS
627        DAC2( 3)=  COEF13
628        DAC2(04)=  -AICLGS
629        DAC2( 5)=  SILAMR
     C        MOMENT ARM FOR CG ACCELERATION EQS FOR SIMULATOR
630        DAC2( 6)=  XCG-SLPA
     C        HDOT TRIM DAC
631        DAC2(07) = HDTRIM
     C        AVAILABLE HORSEPOWER RIGHT ENGINE
632        DAC2(8)=  SHPPRR
633        DAC2( 9)=  CILAML
```

Figure G.6. (Continued)

```
           C       S  T(TH-TC)/P
    634            DAC2(10)= -SOTHT/DEL
    635            DAC2(11)=  COEF1
    636            DAC2(12)=  TAUR12
    637            DAC2(13)=  -STLAM
    638            DAC2(14)=  TMU
           C         INPPR TRIM
    639            DAC2(15) = AITRIM
           C         RCE*PI*C**5/IP   FUR GOV.
           C         ROOT EQUATION    WING BENDING TERMS
    640            DAC2(16)=  DOVIXX*ALARVP
    641            DAC2(17)=  ROPIER
           C         QROT EQUATION    WING BENDING TERMS
    642            DAC2(18)=  DOVIYY*AMARVP
           C         WROT EQUATION    WING BENDING TERMS
    643            DAC2(20)=   ZARV
           C         QNR  FOR ROTOR
    644            DAC2(21)=  -QNRP
    645            DAC2(22)= AICPSC
           C         QNLP FOR ROTOR
    646            DAC2(23)=  -QNLP
           C         RNR  FOR ROT
    647            DAC2(25)=  RNR
           C         RNLP FOR ROT
    648            DAC2(27)=  RNLP
           C         DE    T  FROM ENGINE  FOR SIMULATION
    649            DAC2(30)=   RCTOR
                                            ( B L A N K   C A R D )
                                            ( B L A N K   C A R D )
                                            ( B L A N K   C A R D )
                                            ( B L A N K   C A R D )
                                            ( B L A N K   C A R D )
                                            ( B L A N K   C A R D )
                                            ( B L A N K   C A R D )
                                            ( B L A N K   C A R D )
                                            ( B L A N K   C A R D )
                                            ( B L A N K   C A R D )
                                            ( B L A N K   C A R D )
                                            ( B L A N K   C A R D )
                                            ( B L A N K   C A R D )
                                            ( B L A N K   C A R D )
                                            ( B L A N K   C A R D )
                                            ( B L A N K   C A R D )
                                            ( B L A N K   C A R D )
    650            CALL DACELT(KA (IPSNOS(4,1)),DAC1,64,SCDAC1,ISELT )
    651            KPAN = 39
    652            IWARN1(13)=  .FALSE.
    653            IF(ISELT.  ,2)  IWARN1(13)=  .TRUE.
    654      53    CONTINUE
    655            KPAN = 39
    656      54    GO TO(54,55, ),ISTDA
    657      55    CONTINUE
    658            CALL      (DIGAN)
    659            CALL    TEX
                     (1) =
```

Figure G.6. (Continued)

```
          CALL TRACK('RTFAST  ',2)
          RETURN
   500    DO 510 J=1,32
   510    CALL DISABL(J-1)
   520    IPAN=  KPAN
          RETURN
          END
```

Figure G.6. (Continued)

SUBROUTINE REFAST

```
[illegible]    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-   REFERENCES   -+ +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

[illegible]    -   36*
[illegible]    -   [illegible]   [illegible]
[illegible]    -   [illegible]   [illegible]
[illegible]    -   [illegible]   [illegible]
[illegible]    -   [illegible]   [illegible]
13[illegible]  -   55     [illegible]
14[illegible]  -   [illegible]  71*
15[illegible]  -   173    179*
16[illegible]  -   178    184*
17[illegible]  -   [illegible]  [illegible]
18[illegible]  -   198    [illegible]
24[illegible]  -   373    373*
242   -   375    378*
244   -   377    379*
24[illegible]  -   [illegible]  [illegible]
2[illegible]   -   [illegible]  [illegible]
2[illegible]   -   [illegible]  [illegible]
26[illegible]  -   397    [illegible]
265   -   [illegible]  [illegible]
27[illegible]  -   [illegible]  [illegible]
27[illegible]  -   [illegible]  41[illegible]
27[illegible]  -   [illegible]  418*
2[illegible]   -   4[illegible]7  419   424*
2[illegible]   -   407    425*
2[illegible]   -   424    429*
28[illegible]  -   423    435*
28[illegible]  -   435    441*
28[illegible]  -   411    417   4[illegible]   428   434   4[illegible]   443*
2[illegible]   -   459    459*
2[illegible]   -   459    46[illegible]
294   -   463    46[illegible]
2[illegible]   -   458    455   475*
297   -   459    47[illegible]*
2[illegible]   -   475    4[illegible]
[illegible]    -   [illegible]  4[illegible]
[illegible]    -   [illegible]  4[illegible]
[illegible]    -   462    466   4[illegible]   4[illegible]   4[illegible]   491   494*
4[illegible]   -   [illegible]  346*
4[illegible]   -   [illegible]  35[illegible]*
5[illegible]   -   [illegible]  636   663*
51[illegible]  -   [illegible]  [illegible]
5[illegible]   -   465*
5[illegible]   -   554*
54[illegible]  -   556*
55[illegible]  -   656    657*
8[illegible]   -   517    51[illegible]*
A[illegible]   -   [illegible]  [illegible]   37[illegible]
* ADCELT  -   [illegible]
ADC3      -   [illegible]
AGOVAT    -   [illegible]
AGOVAW    -   [illegible]
ATCL      -   23[illegible]  [illegible]   [illegible]   [illegible]   2[illegible]7   25[illegible]
ATCLDP    -   [illegible]  [illegible]   16[illegible]   [illegible]
```

Figure G.6. (Continued)

AICLGS	-	76=	628											
AICLPR	-	9CD	161	162										
AICR	-	23CD	167=	185	186	187	188							
AICRDP	-	23CD	165=	167	168									
AICRGS	-	77=	645											
AICRPR	-	9CD	165	166										
* AILSP	-	305*	306*											
AINDTL	-	9CD	49	50	82	84	140							
AINDTR	-	9CD	49	50	85	87	146							
AINHT	-	11CD	395	398AG										
AINL	-	9CD	41AG	42										
AINR	-	9CD	40AG	42										
AINREF	-	9CD												
AINRLM	-	15CD												
AINW	-	11CD	316AG	317	318	348								
AITRIM	-	28CD	639											
AKEY	-	13CD												
ALAERO	-	27CD	533=											
ALAMDA	-	11CD												
ALARF	-	20CD	523=	532										
ALARFP	-	20CD	523											
ALARHT	-	26CD	500=	513										
ALARNC	-	23CD	266=	531										
ALARNL	-	23CD	251=	266	568	574								
ALARNR	-	23CD	259=	266	565	571								
ALARRG	-	532=	533	593										
ALART	-	26CD	513=	532										
ALARVB	-	531=	533	640										
ALARVT	-	26CD	507=	513										
ALARWG	-	24CD	287=	364=	532									
ALBRK	-	11CD												
ALFGLS	-	74=	76	77	78									
ALFREF	-	72AG												
ALFSQ	-	20CD												
ALFTAB	-	14CD	72AG											
ALHTE	-	26CD	400=	407	408	409	412	414	416	418	420	422	424	425
		429	431	433	435	437	439	441						
ALHTM	-	26CD	402=	405	418	419	420	422						
ALHTP	-	26CD	401=	404	424	430	431	433						
ALHTPR	-	26CD	399=	400	401	402								
ALHTST	-	11CD												
ALTM	-	15CD												
ALLNSO	-	22CD												
ALLRH	-	23CD	235=	251	254									
ALLWPP	-	24CD	317=	319										
ALNCBK	-	11CD												
ALPHF	-	20CD	61=	74	316AG	592								
ALPHHT	-	26CD	395=	396	397	398AG	400							
ALPHLN	-	22CD												
ALPHLR	-	23CD	133=	609										
ALPHLW	-	24CD	296=	300	304	313AG	317	333	348					
ALPHRN	-	22CD												
ALPHRR	-	23CD	136=	613										
ALPHRW	-	24CD	298=	301	304	314AG	318	334	348					
ALPHVT	-	26CD	445=	446	447	451								

Figure G.6. (Continued)

```
ALPGLW   -    2400   312=   596
ALPGRW   -    2400   313=   549
ALPNSQ   -    2200
ALPPH    -    2300   239=   259   262
ALPWPP   -    2400   318=   321
ALVTE    -    2600   451=   458   459   461   463   465   467   469   471   473   475   476
              487    432    484   485   438   490   492
ALVTM    -    2600   453=   456   469   470   471   473
ALVTP    -    2600   452=   455   475   481   482   484
ALVTPP   -    2600   450=   451   452   453
ALVTST   -    1100
ALWSSQ   -    2400   300=   302   311AG 331
AMACH    -    1800
AMACLP   -     900   585
AMACRP   -     900   594
AMACSQ   -    1800
AMACTL   -    2500   585=   597
AMACTR   -    2500   594=   539
AMAERO   -    2700   536=
AMARF    -    2000   524=   525
AMARFP   -    2000   524
AMARHT   -    2600   501=   514
AMARLW   -    2400   235=   354=   365
AMARNC   -    2300   267=   535
AMARNL   -    2300   253=   267
AMARNP   -    2300   261=   267
AMARPG   -   535=    536    595
AMARRW   -    2400   236=   358=   365
AMART    -    2600   514=   535
AMARVP   -   534=    536    642
AMARVT   -    2600   508=   514
AMARWG   -    2400   365=   535
AMEM     -    1300
AMLRH    -    2300   236=   252
AMRNLP   -    2300   252=   253   592
AMRNPP   -    2300   260=   261   593
AMROTL   -    2300   215=   231   232
AMROTR   -    2300   222=   233   234
AMRRH    -    2300   239=   260
AMUL     -    1900   157=   159   180   190   191   192   193   194   195   196   197   200
              201    202    203
AMULSQ   -    1900   159=   189   190   191   192   194   195   196   197   200   201   202
              203
AMUR     -    1900   158=   160   169   170   171   172   173   174   175   176   177   180
              181    182    183
AMURSQ   -    1900   160=   169   170   171   172   174   175   176   177   180   181   182
              183
ANAERO   -    2700   537=   597
ANARF    -    2000   525=   537
ANARFP   -    2000   525
ANARHT   -    2600   512=   515
ANARNC   -    2300   268=   537
ANARNL   -    2300   254=   268
ANARNP   -    2300   262=   268
ANART    -    2600   515=   537
```

Figure G.6. (Continued)

```
  ANARVT  -   26CD   509=   515
  ANARWG  -   24CD   238=   366=   577
  ANDIG   -    6CD    34AG
  ANDIG2  -    6CD
  ANLRH   -   23CD   237=   250
  ANROTL  -   23CD   216=   231    232
  ANROTR  -   23CD   223=   233    234
  ANRRH   -   23CD   242=   258
  AREAHT  -   11CD
  AREAVT  -   11CD
  AREAW   -   11CD
  ARHT    -   11CD
  ARILW   -   24CD
  ARIRW   -   24CD
* ARTEX   -   659*
  ARVT    -   11CD
  ARWING  -    8CD
  ARWSSO  -   24CD   301=   303    31245  332
  ASLP    -   15CD
* ATAN2   -   61      62    133    134    136    137    296    297    298    299    395    444
  ATAJLR  -   24CD
  ATAURR  -   24CD
  AVEALR  -   24CD
  AVEALW  -   24CD   304=   386    612
  AVECLW  -   24CD   292=   359=   367
  AVECTS  -   24CD   345    346    347    348    359
  AVEEPP  -   24CD   371    387    389
  AVEIN   -   16CD    42=   367
  AVEYAC  -   11CD
  AVEYCS  -   11CD
  AVEZFT  -   24CD
  AS      -   15CD
  BDNOS   -    6CD
  BETAF   -   20CD    62=    75    347    349    445    448    624
  BETALN  -   22CD
  BETALW  -   24CD   297=   323
  BETARN  -   22CD
  BETARW  -   24CD   219=   325
  BETESQ  -   20CD
  BETGLS  -   75=     76     77
  BETVT   -   26CD   444=   445    449AG
  BIGGLS  -   78=    626
  BICL    -   23CD   144=   205    206    207    208
  BICLDP  -   23CD   142=   163    164
  BICLPP  -    9CD   161    162
  BICR    -   23CD   168=   185    186    187    188
  BICRDP  -   23CD   165=   167    168
  BICRPP  -    9CD   165    166
  BIGX    -   21CD
  BKALPR  -   24CD   339    340    341
  BKARPP  -   24CD   342    343    344
  BKD1T   -   11CD
  BKD2T   -   11CD
  BKD3T   -   11CD
  BKEY    -   13CD
```

Figure G.6. (Continued)

BKLSW	-	1100										
BKM1T	-	1100										
BKM2T	-	1100										
BKM3T	-	1100										
BKM4T	-	1100										
BKNSW	-	1100										
BL00	-	2100										
BLC	-	1100	32	93	94	95	96	97	250	252	258	26
BMEM	-	1300										
BMOVTL	-	2100	235									
BMOVTS	-	2100	236									
BTLNSQ	-	2200										
BTHNSQ	-	2200										
BT1	-	1100										
BT2	-	1100										
BT3	-	1100										
CALIHT	-	2600	30830	437	439	5 4						
CALLN	-	2200										
CALLW	-	2400	320=	351	352							
CAL2N	-	2200										
CALRW	-	2400	322=	355	356							
CAVINW	-	2400										
CAVZET	-	2400										
CBCMF	-	2200										
CBETLN	-	2200										
CBETLW	-	2400	324=	351	352	354						
CBETRN	-	2200										
CBETRW	-	2400	326=	355	356	358						
CBETSS	-	2400	[illegible]	437	439	504	505	506				
CDCNTL	-	2400	[illegible]	311	31349							
CDCNTR	-	2400	[illegible]	[illegible]	[illegible]							
CDDUM	-	2400	[illegible]	[illegible]								
CDF	-	2200										
CDHT	-	2600	410=	415=	422=	424=	433=	439=	442=	437	498	499
CDHTST	-	2600	415=	416	421=	422	432=	433	438=	439		
CDLN	-	2200										
CDLWAC	-	2400	31380	34	345	34						
CDLWPR	-	2400	31390									
CDLWSS	-	2400	31130	340	34							
CDOF	-	1100										
CDOHT	-	1100	41	415	421	426	432	434	442			
CDOLN	-	2200										
CDONHT	-	1100										
CDONLO	-	1100										
CDORN	-	2200										
CDOVT	-	1100	461	466	472	477	483	489	493			
CDRN	-	2200										
CDRWAC	-	2400	31480	343	345	349						
CDRWPR	-	2400	31440									
CDRWSS	-	2400	31230	342	347							
CDSLW	-	2400	341=	346	351	352	353					
CDSRW	-	2400	343=	346	355	356	357					
CDVT	-	2600	461=	467=	473=	477=	486=	492=	497=	504	[illegible]	[illegible]
CDVTST	-	2600	466=	467	472=	478	483=	484	489=	49		
CDWCOR	-	2100										

Figure G.6. (Continued)

```
   CEPLW   -   24CO   335AG   339     340
   CEPRW   -   24CO   336AG   342     343
*  CGGTVR  -   17*
   CHORD   -   11CO   354     358
   CILAML  -   16CO    44=     50     550    551    552    598    633
   CILAMR  -   16CO    43=     50     547    548    549    596    625
   CLALHT  -   11CO   403
   CLALPH  -   11CO
   CLAT    -   26CO   403=    409     413    419    425    430    436    441
   CLAVE   -   24CO   316AG   347     348
*  CLCDCM  -  311*    312*    313*    314*
   CLCNTL  -   24CO
   CLCNTR  -   24CO
   CLDUM   -   24CO   311AG   312AG
   CLF     -   20CO
*  CLF1    -  315*
*  CLF2    -  316*
   CLHT    -   26CO   409=    410     414=   420=   425=   426    431=   437=   441=   442    497    499
   CLHTST  -   26CO   413=    414     415    419=   420    421    430=   431    432    436=   437    438
   CLTLW   -   24CO
   CLTRW   -   24CO
   CLLN    -   22CO
   CLLWAD  -   24CO   313AG   339     345    347    348
   CLLWPR  -   24CO   313AG
   CLLWSS  -   24CO   311AG   339     340
   CLMAX   -   11CO
   CLOAL   -   11CO
   CLRN    -   22CO
   CLRWAD  -   24CO   314AG   342     345    347    349
   CLRWPR  -   24CO   314AG
   CLRWSS  -   24CO   312AG   342     343
   CLSLW   -   24CO   339=    345     351    352    353
   CLSRW   -   24CO   342=    345     355    356    359
   CLSW    -   24CO   347=    364
   CLTCOR  -   21CO   403
   CLWCOR  -   21CO
   CLZERO  -   24CO   315AG   316AG
   CMCNTL  -   24CO   308=    311AG   313AG
   CMCNTR  -   24CO   310=    312AG   314AG
   CMF     -   20CO
   CMLN    -   22CO
   CMLWAD  -   24CO   313AG   341
   CMLWSS  -   24CO   311AG   341
   CMOF    -   11CO
   CMON    -   11CO
   CMOW    -   27CO   578=    580
   CMRN    -   22CO
   CMRWAD  -   24CO   314AG   344
   CMRWSS  -   24CO   312AG   344
   CMSLW   -   24CO   341=    354
   CMSRW   -   24CO   344=    358
   CNF     -   20CO
   CNFAIL  -   23CO   172=    205
   CNFAIR  -   23CO   170=    185
   CNFBIL  -   23CO   189=    205
```

Figure G.6. (Continued)

```
I N D E X                                   SUBROUTINE RTFAST                                   PAGE  34

CNER10   -     2300   149=    195
CNFL     -     2300   205=    213
CNTRL    -      900   205
CNFRR    -      900   195
CNFR     -     2300   195=    ..
CNLN     -     2200
CNOR     -     1100
CNOLN    -     1100
CNORN    -     1100
CNRN     -     2200
CNSW     -     2400   348=    356
CNTRAL   -     1500
COEF1    -      800    49     55      548     551
COEF10   -      900   564
COEF11   -      800   347
COEF12   -      900   348
COEF13   -      900   527     535
COEF14   -      900
COEF15   -      900
COEF16   -      900   354     366
COEF17   -      800
COEF18   -      800   345     357
COEF19   -      800   2..
COEF2    -      800   547     552
COEF20   -      800   21.
COEF21   -      800   41.     415     421     425     432     433     442
COEF22   -      900   451     465     47.     477     483     492     493
COEF23   -      900   435
COEF24   -      800   5.3
COEF25   -      800
COEF26   -      800
COEF27   -      900
COEF28   -      800
COEF29   -      800
COEF3    -      800
COEF30   -      800
COEF31   -      800   53.
COEF32   -      800   529     53.
COEF33   -      900   535     53
COEF34   -      800   539     53.
COEF35   -      900
COEF36   -      800
COEF37   -      800
COEF38   -      800
COEF39   -      900
COEF4    -      800   547     552     606     608
COEF40   -      800
COEF41   -      800
COEF42   -      900
COEF5    -      900
COEF6    -      800
COEF7    -      900
COEF8    -      800
COEF9    -      900   5.      5..
CONST    -     2..
```

Figure G.6. (Continued)

```
CONS10   -    2900
CONS11   -    2900
CONS12   -    2900
CONS13   -    2900
CONS14   -    2900
CONS15   -    2900
CONS16   -    2900
CONS17   -    2900
CONS18   -    2900
CONS19   -    2900
CONS2    -    2900
CONS20   -    2900
CONS21   -    2900
CONS22   -    2900
CONS23   -    2900
CONS24   -    2900
CONS25   -    2900
CONS26   -    2900
CONS27   -    2900
CONS28   -    2900
CONS29   -    2900
CONS3    -    2900
CONS30   -    2900
CONS31   -    2900
CONS32   -    2900
CONS33   -    2900
CONS34   -    2900
CONS35   -    2900
CONS36   -    2900
CONS37   -    2900
CONS38   -    2900
CONS39   -    2900
CONS4    -    2900
CONS40   -    2900
CONS41   -    2900    376
CONS42   -    2900    376
CONS43   -    2900    376
CONS44   -    2900
CONS45   -    2900
CONS46   -    2900
CONS47   -    2900
CONS48   -    2900
CONS49   -    2900
CONS5    -    2900
CONS50   -    2900
CONS51   -    2900
CONS52   -    2900
CONS53   -    2900
CONS54   -    2900
CONS55   -    2900
CONS56   -    2900
CONS57   -    2900
CONS58   -    2900
CONS59   -    2900
CONS6    -    2900
```

Figure G.6. (Continued)

```
CONS60   -   2900
CONS61   -   2900
CONS62   -   2900
CONS63   -   2900
CONS64   -   2900
CONS65   -   2900   367
CONS66   -   2900   367
CONS67   -   2900
CONS68   -   2900
CONS69   -   2900
CONS7    -   2900
CONS70   -   2900
CONS71   -   2900
CONS72   -   2900   334
CONS73   -   2900   334
CONS74   -   2900   [illegible]
CONS75   -   2900   [illegible]
CONS76   -   2900   [illegible]
CONS77   -   2900   [illegible]
CONS78   -   2900   341
CONS79   -   2900   341
CONS8    -   2900
CONS80   -   2900   [illegible]
CONS81   -   2900   [illegible]
CONS9    -   2900
CONTRL   -   [illegible]
COSALF   -   2[illegible]
COSBTE   -   2[illegible]
COSINE   -   1500   [illegible] [illegible] [illegible] 33 [illegible] [illegible] [illegible] [illegible] 14[illegible] 247 24[illegible] 251
             25[illegible]   521
COSINB   -   1500   [illegible] [illegible] [illegible] 86 87 91 93 14[illegible] 147 25[illegible] 2[illegible]7 259
             2[illegible]   5[illegible]
COSIW    -   [illegible]   1[illegible] 111 11[illegible] 117
COSLAM   -   [illegible]   [illegible] 44 45 46
COSPHI   -   2[illegible]
COSPSI   -   1[illegible]
COSTHE   -   2[illegible]
COSZHL   -   2300   1[illegible] 14[illegible] [illegible] [illegible] [illegible] [illegible]31 [illegible]32 [illegible]41 24[illegible]
COSZHP   -   2300   1[illegible] 1[illegible] [illegible] [illegible]7 [illegible] 233 234 2[illegible] 24[illegible]
CPHIP    -   900    161 1[illegible] 16[illegible] 1[illegible]
CPI      -   900    [illegible]17
CPMAIL   -   2300   1[illegible]= [illegible]= [illegible]7
CPMAIR   -   2300   175= [illegible]= 187
CPMBIL   -   2300   174= [illegible]= [illegible]7
CPMBIR   -   2300   174= 1[illegible]= 187
CPML     -   2300   [illegible]7= [illegible]
CPMPL    -   900    [illegible]7
CPMPR    -   900    1[illegible]7
C[illegible] -   2300   1[illegible] 22[illegible]
C[illegible] -   900    [illegible]4
CSFAIL   -   2300   1[illegible]2= [illegible]
CSFAIR   -   2300   172= [illegible]
CSFBIL   -   2300   1[illegible]1= [illegible]
CSFBIR   -   2300   171= 1[illegible]
CSFL     -   2300   [illegible]= [illegible]
```

Figure G.6. (Continued)

```
 CSFPL    -   9C0   206
 CSFPR    -   9C0   186
 CSFR     -  23C0   186=   221
 CTAULR   -  24C0
 CTAURR   -  24C0
 CTL      -  23C0   189    190    191    192    194    195    196    197    200    201    202    203
             211=   212
 CTLPRM   -   9C0   211
 CTR      -  23C0   169    170    171    172    174  . 175    176    177    180    181    182    183
             218=   219
 CTRPRM   -   9C0   218
 CTSLR    -  24C0   279    337    579
 CTSRR    -  24C0   280    338    581
 CYALVT   -  11C0   454
 CYAT     -  26C0   454=   460    464    470    476    481    487    492
 CYF      -  20C0
 CYLN     -  22C0
 CYMAIL   -  23C0   197=   203=   208
 CYMAIR   -  23C0   177=   183=   188
 CYMBIL   -  23C0   196=   202=   208
 CYMBIR   -  23C0   176=   182=   188
 CYML     -  23C0   208=   216
 CYMPL    -   9C0   208
 CYMPR    -   9C0   138
 CYMR     -  23C0   138=   223
 CYRN     -  22C0
 CYVT     -  26C0   460=   461    465=   471=   476=   477    482=   488=   492=   493    504    505
             506
 CYVTST   -  26C0   464=   465    466    470=   471    472    481=   482    483    487=   488    489
 C2INL    -  16C0
 C2INR    -  16C0
*DACFLT   -  650*
*DACIO    -   12*
 DAC1     -  12C0   592=   593=   594=   595=   596=   597=   598=   599=   600=   601=   602=   603=
             604=   605=   606=   607=   608=   609=   610=   611=   612=   613=   614=   615=   616=
             617=   618=   619=   622=   623=   624=   650AG
 DAC2     -  12C0   625=   626=   627=   628=   629=   630=   631=   632=   633=   634=   635=   636=
             637=   638=   639=   640=   641=   642=   643=   644=   645=   646=   647=   648=   649=
 DBRK1    -  29C0   375
 DBRK10   -  29C0
 DBRK11   -  29C0
 DBRK12   -  29C0
 DBRK13   -  29C0
 DBRK14   -  29C0
 DBRK15   -  29C0
 DBRK16   -  29C0
 DBRK17   -  29C0   274    295
 DBRK18   -  29C0    67     70
 DBRK19   -  29C0    67     70
 DBRK2    -  29C0
 DBRK20   -  29C0
 DBRK21   -  29C0
 DBRK3    -  29C0
 DBRK4    -  29C0
 DBRK5    -  29C0
```

Figure G.6. (Continued)

```
DBRK6    -    29CD
DBRK7    -    29CD
DBRK8    -    29CD
DBRK9    -    29CD   173      193
DCDDF    -    24CD
DCDLDA   -    24CD   305AG    307
DCDLG    -    11CD
DCDLSP   -    24CD   305AG    307
DCDRDA   -    24CD   306AG    309
DCDRSP   -    24CD   306AG    309
DCLDF    -    24CD
DCLLDA   -    24CD   305AG    311AG    313AG
DCLLSP   -    24CD   305AG    311AG    313AG
DCLRDA   -    24CD   306AG    312AG    314AG
DCLRSP   -    24CD   306AG    312AG    314AG
DCLSPW   -    24CD   345=     347
DCMDCL   -    15CD
DCMDF    -    24CD
DCMLDA   -    24CD   305AG    308
DCMLG    -    11CD
DCMLSP   -    24CD   305AG    308
DCMRDA   -    24CD   306AG    310
DCMRSP   -    24CD   306AG    310
DCMSPW   -    24CD   346=     348
DCYPLM   -    15CD
DEG2R    -    11CD   331      332      333      334
DEL      -    18CD   534
DELALM   -    15CD
DELBS    -     9CD
DELBT    -     9CD
DELELV   -     9CD   339
DELEP7   -   374=    375      376      378      380      381      384
DELELP   -     9CD    47      315AG    578
DELRS    -     9CD
DELRT    -     9CD
DELRUD   -     9CD   45
DELSPL   -     9CD   305AG
DELSPR   -     9CD   306AG
DELSS    -     9CD
DELST    -     9CD
DELTH    -     9CD
DEPDAL   -   381=    384=     386
DFLAIL   -     9CD   305AG    311AG    313AG    374
DFLAIR   -     9CD   306AG    312AG    314AG    374
DGTORD   -    11CD   376      378
DIGAN    -     6CD   558AG
DIGAN2   -     6CD
DISABL   -   564*
DLBLM    -    15CD
DLFLPR   -    15CD
DLFPSB   -    16CD    47=
DLLG     -    22CD   533
DLLNC    -    22CD   251      254
DLRLM    -    15CD
DLRNC    -    22CD   259      262
```

Figure G.6. (Continued)

DLSLM	-	15C0				
DMLG	-	20C0	524			
DMLNC	-	22C0	252			
DMRNC	-	22C0	260			
DNF1	-	10C0	170	190		
DNF2	-	10C0	170	190		
DNF3	-	10C0	170	190		
DNF4	-	10C0	170	190		
DNLG	-	20C0	525			
DNLNC	-	22C0	250			
DNRNC	-	22C0	258			
DOVT	-	11C0				
DOVTL	-	21C0	283			
DOVTR	-	21C0	284			
DPM1	-	10C0	175	181	195	201
DPM2	-	10C0	175	195		
DPM3	-	10C0	175	195		
DPM4	-	10C0	175	195		
DPM5	-	10C0	191	201		
DPM6	-	10C0	191	201		
DPM7	-	10C0	181	201		
DRLM	-	15C0				
DSDBET	-	11C0	445	448		
DSF1	-	10C0	172	192		
DSF2	-	10C0	172	192		
DSF3	-	10C0	172	192		
DSF4	-	10C0	172	192		
DTIM	-	6C0				
DUM12	-	9C0				
DUM13	-	9C0				
DUM14	-	9C0				
DUM15	-	9C0				
DUM43	-	9C0				
DUM44	-	9C0				
DUM45	-	9C0				
DUM46	-	9C0				
DUM47	-	9C0				
DUM48	-	9C0				
DXLG	-	20C0	520			
DXLNC	-	22C0	247	249		
DXRNC	-	22C0	255	257		
DYLG	-	20C0	521			
DYLNC	-	22C0	248			
DYM1	-	10C0	177	183	197	203
DYM2	-	10C0	177	197		
DYM3	-	10C0	177	197		
DYM4	-	10C0	177	197		
DYM5	-	10C0	183	203		
DYM6	-	10C0	183	203		
DYM7	-	10C0	183	203		
DYRNC	-	22C0	256			
DZLG	-	20C0	522			
DZLNC	-	22C0	243			
DZRNC	-	22C0	244			
EFFHT	-	11C0				

Figure G.6. (Continued)

```
          EFFVT    -   11C0
          EMAXN1   -   19C0
          EMAXN2   -   13C0
          EMXWOT   -   18C0
          ENFL     -    9C0
          ENFR     -    9C0
          ENF1     -   10C0   169    189
          ENF2     -   10C0   169    189
          ENF3     -   10C0   169    189
          ENF4     -   10C0   169    189
     *    ENG      -    3*
     *    ENGVAR   -   18*
          EN1MX    -    3C0
          EN1STP   -    3C0
          EN1TMX   -    3C0
          EN2MX    -    3C0
          EN2REF   -   11C
          EN2STP   -   18C0
     *    FCMVAR   -   27*
          EPILR    -   24C0   136
          EPIRL    -   24C0   133
          EPM1     -   10C0   174    180    194    2
          EPM2     -   10C0   174    194
          EPM3     -   10C0   174    194
          EPM4     -   10C0   174    194
          EPM5     -   10C0   180    200
          EPM6     -   10C0   180    200
          EPM7     -   10C0   180    200
          EPPLR    -   24C0   3      335AG
          EPPRM    -   21C0
          EP  RR   -   24C0   331    336AG
          EPTAIL   -   26C0   371=   388=   391=   394=   395
          EPTL1    -   25C0   386=   387    391
          EPWRL    -   24C0   1 2    367=   368
          EPWRR    -   24C0   133    369=
          EPZERO   -   26C0   376=   378=   386
          EQMX     -    3C0
          ESF1     -   10C0   171    191
          ESF2     -   10C0   171    1 1
          ESF3     -   10C0   171    1 1
          ESF4     -   10C0   171    191
          ETAA     -   15C0
          ETAIRF   -   15C0
          ETARD    -   15C0
          ETAWB    -   15C0
          EVDTMX   -    3C0
          EVDTPP   -    3C0
          EYM1     -   10C0   176    192    196    2 2
          EYM2     -   10C0   176    196
          EYM3     -   10C0   176    196
          EYM4     -   10C0   176    196
          EYM5     -   10C0   182    202
          EYM6     -   10C0   182    202
          EYM7     -   10C0   182    202
          FEW      -   11C0   279    29
```

Figure G.6. (Continued)

```
  FIC      -   11C0    229     230     254     262
  FINDEG   -   11C0    274     295
  FINPR    -   11C0    274=    295=
  FIP      -   11C0    227     228     235     238
  FIPOML   -   23C0    227=    236     237
  FIPOMR   -   23C0    228=    239     240
  FIXX     -   27C0
  FIXXF    -   11C0
  FIXXPR   -   11C0
  FIXXW    -   11C0
  FIXZF    -   11C0
  FIXZP    -   27C0    544     594
  FIXZPR   -   11C0
  FIXZQ    -   27C0    545
  FIXZR    -   27C0    546     614
  FIXZW    -   11C0
  FIYY     -   27C0
  FIYYF    -   11C0
  FIYYPR   -   11C0    606     608
  FIYYW    -   11C0
  FIZZ     -   27C0
  FIZZF    -   11C0
  FIZZPR   -   11C0    548     551
  FIZZW    -   11C0
  FJXX     -   27C0    544
  FJYY     -   27C0    545
  FJZZ     -   27C0    546
* FLAGS    -    4*
  FNORML   -   23C0    213=    241     245
  FNORMR   -   23C0    220=    242     246
  FSIDEL   -   23C0    214=    241     245
  FSIDER   -   23C0    221=    242     246
  FSMACH   -   18C0
           THE VARIABLE- FSQRT   -IS USED BEFORE IT IS DEFINED
  FSQRT    -   60      63      100     101     104     105     121     125     131     605
* FUSVAR   -   20*
  GAATAB   -   14C0    72AG
  GAIALF   -   72AG    76      77
  GAIBET   -   73=     76      77
  GBATAB   -   14C0    72AG
  GBETDR   -   15C0
  GBETP    -   15C0
  GBETP    -   15C0
  GBUTON   -    4C0
  GBIALF   -   72AG    73      78
  GDB1     -   15C0
  GDB2     -   15C0
  GDLTH    -   15C0
* GEAR     -   519*
  GEF      -   21C0    371     389     391
* GEFVAP   -   21*
  GGUST    -   15C0
  GICLM    -   15C0
  GINRF    -   15C0
  GKEY     -   13C0    72AG
```

Figure G.6. (Continued)

```
   I N D E X                                        SUBROUTINE RTFAST                                   PAGE   41

GLPSLP   -    15C0
GLPO     -    15C0
GLSLM    -    15C0
GMEM     -    13C0      72AG
GOMG     -    15C0
GP       -    15C0
GPOS     -    15C0
GPHI     -    15C0
GPRI     -    15C0
GPSI     -    15C0
GPSIDP   -    15C0
GQ       -    15C0
GR       -    15C0
GRDR     -    15C0
GTH      -    15C0
GTHF     -    15C0
GTHGOV   -    15C0
H        -     3C0
         THE VARIABLE- HACLOD  -IS USED BEFORE IT IS DEFINED
HACLOD   -   575       576=
         THE VARIABLE- HACROD  -IS USED BEFORE IT IS DEFINED
HACROD   -   572       573=
HDOT     -     7C0
HDTACL   -    25C0    114       561=      575=
HDTACR   -    25C0    113       559=      572=
HDTRIM   -    28C0    631
HGEFLR   -    21C0
HGEFRR   -    21C0
HLHUB    -    21C0
HOLD     -     6C0
HOLD2    -     6C0
HP       -    11C0
HRHUB    -    21C0
HSQ      -    16C0
HTC4     -    21C0
HTRIM    -    28C0    674
HTSTLL   -     8C0    471       472
HTVTKT   -    11C0
HWACL    -    25C0    136       137       560=      574=      575       576
HWACR    -    25C0    112       113       558=      571=      572       573
HWC4     -    21C0
* HYBCON -     5*
* HYBIO  -     7*
HIDTL    -    25C0     34       557=      569=
HIDTR    -    25C0     37       555=      566=
HIL      -    25C0     82        83       556=      568=      569       570
         THE VARIABLE- HILOLD  -IS USED BEFORE IT IS DEFINED
HILOLD   -   569       570=
HIR      -    25C0     85        36       554=      565=      566       567
         THE VARIABLE- HIROLD  -IS USED BEFORE IT IS DEFINED
HIROLD   -   566       567=
IAD      -     6C0
IC       -     6C0
ICDSPC   -     2C0
ICLP     -     6C0
```

Figure G.6. (Continued)

```
  ICONOP  -   4C0
  IC2     -   6C0
  IDURC   -   6C0
  IFC     -   6C0
  IFCHAN  -   6C0
  IFLAG   -   2C0
  IFRAME  -   6C0
  IGN     -   6C0
  IHJB    -   6C0
  ILEX    -   6C0
* INITVR  -   16*
  IOC     -   6C0
  IOC21   -   6C0
  IPAN    -   2C0    665=
  IPHASE  -   4C0
  IPSNOS  -   6C0    37AG    650AG
  IRCTS   -   6C0
  IRCX    -   6C0
  IRUNIT  -   6C0
  ISCOPE  -   2C0
  ISENCE  -   4C0
  ISETC   -   6C0
  ISHRC   -   6C0
  ISLOW   -   4C0
  ISTA    -   4C0
  ISTAD   -   6C0    36
  ISTAD2  -   6C0
  ISTB    -   4C0
  ISTDA   -   6C0    656
  ISTDA2  -   6C0
  ISTFLT  -  650AG   653
  ISTG    -   72AG
  ISTGO   -   6C0
  ISTGO2  -   6C0
  ISTHO   -   6C0
  ISTHO2  -   6C0
  ISTIC   -   6C0
  ISTIC2  -   6C0
  ISTPIT  -   6C0
  ISTRM   -   6C0
  ISTRM2  -   6C0
  ISYNC   -   6C0
  ITRIM   -   4C0
  ITSC    -   6C0
  IWARN1  -   4C0    5LG     327=    328=    329=    330=    331=    332=    333=    334=    406=    427=    457=
             478=    652=    653=
  IWARN2  -   4C0    5LG
  IWREVT  -   4C0
  J       -  663DD   664IG
  JTRIM   -   4C0
  KAR     -   7C0    37AG    650AG
  KONER   -   2C0    660=
  KPAN    -   35=    651=    655=    665
  KTRIM   -   4C0
  LETR    -   6C0
```

Figure G.6. (Continued)

```
     I N D E X                          SUBROUTINE RTFAST                         PAGE   43

*    LINT     -    72*
     MICNT    -     200
     MIFCB    -     200
     MONDIG   -     600
*    NACVAR   -    22*
     NADCS    -     600
     NCHAIN   -     600
     NCLOSE   -    66=      69=      273      370      436
     NCON     -     600
     NCONSL   -     600
     NDACS    -     600
     NFRAME   -     200
     NGFF     -     400
     NICS     -     600
     NOSIM    -     200
     NPCS     -     600
     NPLOT    -     400
     NPLOT2   -     400
     NSIND    -     300
     NSOID    -     300
     NTWST    -     400     543
     NVR      -     400     553
     NWOTIC   -     300
     NIN      -     300
     NITHID   -     300
     N2IND    -     300
     OMA      -    1500
     OMDOT    -     900     225      226
     OMDTL    -    1200     225=     235
     OMDTS    -    1200     226=     238
     OMEGA    -     900     151      152
     OMEGAL   -    1900     151=     153      155      227
     OMEGAS   -    1900     152=     154      156      228
     OMEGEL   -    1900     228      254
     OMEGEP   -    1900     230      262
     OMGS     -    1500
     OMIPF    -    1500
     OMLM     -    1500
     OMRD     -    1100
     OMPFF    -    1100
     OMSLP    -    1500
     OMSOL    -    1500     153=     212      213      214      215      216      217
     OMSOS    -    1500     154=     219      220      221      222      223      224
     OMZR     -    1500
     OMSVTC   -    1900
     COVDSK   -     900     270      271      272
     COVESM   -    1900     371      448      501      554
     COVIXX   -    2700     593      594      596      598      604
     COVIYY   -    2700     595      605      608      642
     COVIZZ   -    2700     597      614      616      613
     OPERA    -     600
     OPERA2   -     600
     OVSTIM   -     300     566      562      572      575
     OVSOTH   -    1900
     OVTHOL   -    1900
```

Figure G.6. (Continued)

```
  P        -  27C0   54=    80    83    84    86    87   107   108   113   114   129   139
              141   145    147   539   541   542
  PC       -  11C0
  PCTQL    -  18C0
  PCTQR    -  18C0   649
  PGUST    -   9C0    54
  PHI      -   9C0
  PHIPH    -  11C0
  PI       -  11C0   396    397   408   409   416   435   439   441   446   447   459   460
              467   486    490   492
  PILMSK   -   2C0
  PIOV2    -  11C0   412    414   416   420   422   429   431   433   437   439   463   465
              467   471    473   480   482   484   488   490
  PNLN     -  23C0   139=   142
  PNLR     -  23C0   142=   151   615
  PNRN     -  23C0   145=   148
  PNRR     -  23C0   148=   152   617
  PP       -  27C0   542=   545   547   548   550   551
  PPRIME   -   9C0   31F0    54
  PQ       -  27C0   539=   544   546   549   552
  PR       -  27C0   541=   545   547   550
  PROJ     -   6C0
  PSI      -   9C0
  Q        -  27C0    55=    79    81    82    84    85    87   106   108   112   114   126
              127   128    130   140   145   254   262   538   539   543
  QFSW     -  22C0
  QGUST    -   9C0    55
  QNLN     -  23C0   140=   143   144   237
  QNLR     -  23C0   143=   646
  QNRN     -  23C0   146=   149   150   240
  QNRR     -  23C0   149=   644
  QPRIME   -   9C0    55
  R        -  27C0    56=    80    82    83    85    86   106   107   112   113   129   139
              141   145    147   229   230   538   540   541   543
  RDTODG   -  11C0    74     75
  RESLR    -  24C0
  RESRR    -  24C0
* RETURN   -  662*   666*
  RGUST    -   9C0    56
  RLM      -  15C0
  RNLN     -  23C0   141=   143   144   236
  RNLR     -  23C0   144=   648
  RNRN     -  23C0   147=   149   150   239
  RNRR     -  23C0   150=   647
  ROF      -  18C0   209    210   605
  ROFOV2   -  18C0    54    271   272
  ROED     -   3C0   605
  ROPIR4   -  23C0   209=   212   213   214   219   220   221
  ROPIR5   -  23C0   210=   215   216   217   222   223   224   541
  ROTEPS   -  11C0   104    105
  ROTRAD   -  11C0   155    156
* ROTVAR   -  23*
  RPRIME   -   9C0    56
  RQ       -  27C0   539=   543=   544   546   549   552
  RR       -  27C0   540=   545   547   549   550   551
```

Figure G.6. (Continued)

```
      RRI1     -   21CD
      RRI2     -   21CD
*     RTFAST   -    1*
*     RTPASS   -    9*
      SALIHT   -   26CD   398AG    497    499    5 6
      SALLN    -   22CD
      SALLW    -   24CD   319=     351    352
      SALRN    -   22CD
      SALRW    -   24CD   321=     355    356
      SAVINW   -   24CD
      SAVZET   -   24CD
      SBETLN   -   22CD
      SBETLW   -   24CD   323=     353
      SBETRN   -   22CD
      SBETRW   -   24CD   325=     357
      SBETSG   -   26CD   449AG    498    5 4    505    506
      SBFCAF   -   22CD
      SBFPR    -   11CD
      SBFSAF   -   22CD
      SBWPR    -   11CD
      SB1      -   21CD
      SCADC1   -    9CD    373
      SCADC2   -    9CD
      SCADC3   -    9CD
      SCADC4   -    9CD
      SCDAC1   -    9CD   459AG
      SCDAC2   -    9CD
      SCDAC3   -    9CD
      SCDAC4   -    9CD
      SC1      -   15CD   578
      SC2      -   15CD   578
      SEPLW    -   24CD   335AG    339    343
      SEPRW    -   24CD   336AG    342    343
      SENFL    -   22CD
      SENFR    -   22CD
      SEPL     -   22CD
      SEPML    -   22CD
      SEPMR    -   22CD
      SEPR     -   29CD
      SERL     -   22CD
      SERR     -   29CD
      SESFL    -   22CD
      SESFR    -   22CD
      SETL     -   29CD
      SETR     -   22CD
      SEYML    -   22CD
      SEYMR    -   29CD
      SG       -   11CD
      SGNSDF   -   42 =   421=     422
      SGNILW   -   24CD   275=     276=   279
      SGNIRW   -   24CD   277=     278=   280
      SHF      -   11CD
      SHPLM    -   15CD
      SHPRPL   -   13CD
      SHPRPR   -   19CD    332
```

Figure G.6. (Continued)

```
SHPRQL   -   23CO
SHPRQP   -   23CO
SHPSTP   -    3CO
SHW      -   11CO
SHW2     -   15CO
SHW3     -   15CO
SIGMA    -   26CO   448=    449AG
SIL      -   24CO
SILAML   -   16CO   46=     49      550     551     552     618     637
SILAMR   -   16CO   45=     49      547     548     549     616     629
SILW     -   24CO   287     337     339     340     341     345     346
SINALF   -   20CO
SINBTF   -   20CO
SINCOS   -   40*    41*     135*    138*    335*    336*    398*    449*
SININL   -   16CO   41AG    44      46      82      83      88      90      139     141     247     249     251
             254    551
SININR   -   16CO   40AG    43      45      85      86      91      93      145     147     255     257     259
             262    548
SINIW    -    8CO   109     111     115     117
SINLAM   -    8CO   43      44      45      46
SINPHI   -   20CO
SINPSI   -   16CO
SINTHE   -   20CO
SINZHL   -   23CO   135AG   143     144     163     164     231     232     241     245
SINZHR   -   23CO   138AG   149     150     167     168     233     234     242     246
SIR      -   24CO
SIRW     -   24CO   287     338     342     343     344     345     346
SIT      -   24CO
SKDA     -   15CO
SKDCOL   -   15CO
SKDLB    -   15CO
SKDLE    -   15CO
SKDLR    -   15CO
SKDLRD   -   15CO
SKDLS    -   15CO
SKFPS    -   11CO
SKTHTW   -   15CO
SKTRIM   -   28CO
SKW1     -   15CO   565     568
SKW10    -   15CO   571     574
         THE VARIABLE- SKW2     -IS USED BEFORE IT IS DEFINED
SKW2     -   565    568
         THE VARIABLE- SKW3     -IS USED BEFORE IT IS DEFINED
SKW3     -   565    568
SKW4     -   15CO   565     568
SKW5     -   15CO   565     568
SKW6     -   15CO   571     574
SKW7     -   15CO   571     574
SKW8     -   15CO   571     574
SKW9     -   15CO   571     574
SK0      -   11CO
SK1      -   11CO
SK10     -   11CO
SK2      -   11CO
SK20     -   11CO   347
```

Figure G.6. (Continued)

SK21	-	[illegible]								
SK22	-	1100	[illegible]							
SK3	-	110								
SK30HI	-	1100								
SK30LO	-	1100								
SK31HI	-	1100								
SK31LO	-	1100								
SK32	-	1100								
SK34	-	1100								
SK35	-	1100								
SK36	-	1100								
SK37	-	1100								
SK38	-	1100								
SK39	-	1100								
SK4	-	1100								
SK40	-	1100								
SK41	-	1100								
SK42	-	1100								
SK43	-	1100								
SK44	-	1100								
SK45	-	1100								
SK46	-	1100								
SK47	-	1100								
SK48	-	1100								
SK49	-	1100								
SK5	-	1100								
SK50	-	1100								
SK6	-	1100								
SK7	-	1100								
SK8	-	1100								
SK9	-	1100								
SL	-	1100	[illegible]							
SLAC	-	[illegible]00	[illegible]							
SLF	-	1100								
SLPA	-	1100	[illegible]							
SLW	-	1100								
SM	-	1100								
SMA	-	1800								
SMF	-	1100								
SMN	-	1100								
SMW	-	1100								
SPAN	-	1100	237							
SPHIP	-	[illegible]	141	142	165	166				
SQF	-	2000	54=	65	72A[illegible]	272	435	503	622	
SQFARG	-	1400								
SQFPRM	-	1100	65	67=	70=					
SQLNC	-	2200								
SQLP	-	2400	271=	279	232=	149	570			
[illegible]	-	1900								
[illegible]	-	240								
[illegible]	-	240								
[illegible]	-	[illegible]								
[illegible]	-	[illegible]	272=	280	31=	35[illegible]	[illegible]21			
[illegible]	-	[illegible]	344							
[illegible]		[illegible]								

Figure G.6. (Continued)

```
SWING   -  24C0   27=    289=   364    356
SSCINL  -  16C0
SSCINR  -  15C0
STAILP  -  24C0
STAIRR  -  24C0
SUMIXX  -   8C0
SUMIXZ  -   8C0
SUMIYY  -   8C0
SUMIZZ  -   8C0
SVSTAB  -  14C0
SVSTAR  -  24C0
SVSTRL  -  24C0
SWLG    -   4C0   517
SWLG2   -   9C0
S2INL   -  16C0
S2INR   -  16C0
* TAILVR  -  26*
TAUAG   -  14C0
TAUBET  -  15C0
TAUCYR  -  15C0
TAUDB   -  15C0
TAUDR   -  15C0
TAUFF   -  15C0
TAUGIC  -  15C0
TAUGLS  -  15C0
TAUGST  -  15C0
TAUHT   -  11C0   333
TAUL    -   6C0
TAULR   -  24C0
TAUP    -  15C0
TAUPDS  -  15C0
TAUPHI  -  15C0
TAUPR   -  15C0
TAUPR1  -  15C0
TAUPSI  -  15C0
TAUQ1   -  15C0
TAUQ2   -  15C0
TAURD1  -  15C0
TAURD2  -  15C0
TAURR   -  24C0
TAURT1  -  11C0
TAURT2  -  11C0
TAUR1   -  15C0
TAUR2   -  15C0
TAUR3   -  15C0
TAUSHP  -  15C0
TAUTH   -  15C0
TAUTHE  -  15C0
TAUVT   -  11C0   450
TAVAEP  -  24C0
TCOEF   -   3C0
TDEGF   -  18C0
TFAL    -  19C0
TEAR    -  18C0
TERMP1  -  27C0   544=   593
```

Figure G.6. (Continued)

```
TERMO1   -   27C0   545=   595
TERMR1   -   27C0   546=   597
TERM1    -   27C0
TERM1L   -   27C0   550=   592
TERM1R   -   27C0   547=   583
TERM2    -   27C0
TERM2L   -   27C0   551=   582
TERM2R   -   27C0   548=   583
TERM3    -   27C0
TERM3L   -   27C0   552=   582
TERM3R   -   27C0   549=   583
TERM4    -   27C0
TERM5    -   27C0
TERM6    -   27C0
THCDEL   -   19C0
THE      -    9C0
THETC    -   13C0
THOMLN   -   15C0
THOMLP   -   15C0
THRTLM   -   15C0
THTLAC   -   25C0   236    312    317    537=   593=
THTRAC   -   25C0   239    313    318    536=   594=
THTWIN   -   23C0   611
TH75L    -    9C0
TH75LN   -   15C0
TH75LP   -   15C0
TH75R    -    9C0
TIGEL    -   21C0   211
TIGER    -   21C0   213
TL       -   23C0   212=   247    249    270    271    283    295
TWHA10   -   244=   254
TWHA11   -   582=   535    638
TWHA12   -   583=   544    636
TWWG10   -   25C0
TWWG11   -   25C0
TWAC1    -   22C0
TWAC2    -   22C0
TOMDLM   -   15C0
TOPOL    -   23C0   217=   235
TOROR    -   23C0   224=   243
TPSR     -    9C0
TR       -   23C0   219=   255    257    271    272    284    286
* TRACK  -   33*    661
TRIM     -   16C0
TRIM2    -   16C0
TRMAR1   -   23C0   243=   247    249    252
TRMAR2   -   23C0   244=   255    257    261
TRMAR3   -   23C0   250=   251    254
TRMAR4   -   23C0   259=   259    262
* TRMCON -   28*
TRMHA1   -   23C0   229=   253    595
TRMHA2   -   23C0   230=   261    589
TRMHA3   -   231=   236
TRMHA4   -   232=   237
TRMHA5   -   233=   239
```

Figure G.6. (Continued)

I N D E X

```
TRMHB6   -    234=    240
TRMHB7   -    241=    243
TRMHB8   -    242=    244
TRMHB9   -    245=    248
TRMHT    -     26CO   495=    496=    497     498     499
TRMHT2   -     26CO   404=    408     413     414     416
TRMHT3   -     26CO   405=    435     436     437     439
TRMHIS   -    564=    565     568     571     574
TRMTL1   -    579=    590
TRMTR1   -    581=    589
TRMTTL   -     27CO
TRMTTR   -     27CO
TRMTTW   -    580=    589     590
TRMVT    -     26CO   503=    504     505     506
TRMVT2   -     26CO   455=    459     464     465     467
TRMVT3   -     26CO   456=    486     487     488     490
TRMWG1   -     24CO
TRMWG4   -     25CO
TRMWG5   -     24CO   337=    339     340     341
TRMWG6   -     24CO   339=    342     343     344
TRMWG7   -     24CO   349=    351     352     353     354
TRMWG8   -     24CO   350=    355     356     357     358
TRMWG9   -     25CO
TSBASE   -      6CO
TSREQD   -      6CO
* TSTRTF -     39*
TTMSLN   -     15CO
TTMSLP   -     15CO
TZERO    -      3CO
TZET1    -     24CO
TZET2    -     24CO
TZET3    -     24CO
TZET4    -     24CO
TZET5    -     24CO
TZET6    -     24CO
U        -     27CO    51=     57      61      79     385     505     621
UGUST    -      9CO    51
UHT      -     19CO   126=    395
ULW      -     19CO   109=    120     276     296
ULWPR    -     19CO   106=    109     111
ULWSQ    -     19CO   120=    121     271
UP       -     19CO    79=     82      85     105     112     126     128
UPRIME   -      9CO    51     394     495
URL      -     19CO    88=     94     102     133
URLPR    -     19CO    82=     88      90
URLURL   -     19CO    94=    101
URR      -     19CO    91=     97     103     136
URRPR    -     19CO    85=     91      93
URRURR   -     19CO    97=    100
URW      -     19CO   115=    122     278     298
URWPR    -     19CO   112=    115     117
URWSQ    -     19CO   122=    125     272
* USEAIO -     34*    658*
USQ      -     19CO    57=     60      63      64
UTRIM    -     28CO   600
```

Figure G.6. (Continued)

```
  UVT      -   1900   128=    131
  V        -   2700    52=     58     62     90
  VALFLW   -   1900   121=    297
  VALFRW   -   1900   125=    299
  VALFS    -   1900    60=     62
  VALNCL   -   1900
  VALNCR   -   1900
  VBETVT   -   1900   131=    444
  VEAST    -   1700   623
* VELVAR   -   19*
  VGUST    -    900    52
  VLW      -   1900   110=    118    297
  VLWPR    -   1900   107=    110
  VLWSQ    -   1900   118=    271
  VNORTH   -   1700   619
  VP       -   1900    80=     93     86    107    113    129
  VPRIME   -    900    52
  VRL      -   1900    89=     95    134
  VRLPR    -   1900    83=     89
  VRLVRL   -   1900    95=    101    104
  VRR      -   1900    97=     98    137
  VRRPR    -   1900    86=     92
  VRRVRR   -   1900    98=    100    105
  VRW      -   1900   116=    123    299
  VRWPR    -   1900   113=    116
  VRWSQ    -   1900   123=    272
  VSQ      -   1900    58=     63     64
  VSTAR    -   2400
  VSTARG   -   1400
  VSTARL   -   2400
  VTIPL    -   1900   155=    157
  VTIPR    -   1900   156=    158
  VTOTAL   -   1900    63=
  VTOTLR   -   1900   101=    157    607
  VTOTPR   -   1900   10?=    158    611
  VTRIM    -   2900   602
  VTSTLL   -    800   452     453
  VVT      -   1900   129=    444
  VZFTL    -   1900   104=    133
  VZFTR    -   1900   105=    136
  W        -   2700    53=     59     61     81
  WDOT     -    900   396
  WGUST    -    900    53
  WHT      -   1900   127=    135
  WLW      -   1900   111=    119    296
  WLWPR    -   1900   108=    109    111
  WLWSQ    -   1900   119=    121    271
* WNGVAR   -   24*
* WNGVR2   -   25*
             THE VARIABLE- WORK    -IS USED BEFORE IT IS DEFINED
  WORK     -     60    63     100    101    104    105    121    125    131    605
  WP       -   1900    81=     84     87    108    114    127    130
  WPRIME   -    900    53
  WRL      -   1900    90=     96    102
  WRLPR    -   1900    84=     88     90
```

Figure G.6. (Continued)

```
  WRLWRL  -   19C0    95=    101
  WROTL   -   19C0   132=    104    134
  WROTR   -  103=    105     137
  WRR     -   19C0    93=     99    103
  WRRPR   -   19C0    87=     91     93
  WRRWRR  -   19C0    99=    100
  WRW     -   19C0   117=    124    298
  WRWPR   -   19C0   114=    115    117
  WRWSQ   -   19C0   124=    125    272
  WSQ     -   19C0    59=     60     63     64
  WVT     -   19C0   130=    131
  XAERF   -   20C0   522=    526
  XAERLW  -   24C0   279=    352=   354    361
  XAERNC  -   23C0   263=    526    535
  XAERNL  -   23C0   247=    263    537
  XAERNR  -   23C0   255=    263    537
  XAERO   -   27C0   526=    548    551    599
  XAERRW  -   24C0   290=    356=   358    361
  XAERT   -   26C0   512=    526
  XAERWG  -   24C0   361=    365    526
* XAIO    -    9*
  XARFP   -   20C0   520
  XARHT   -   26C0   497=    501    512
  XARVT   -   26C0   504=    508    510
  XCG     -   17C0    30      81    365    501    502    508    509    534    537    630
* XCNTRL  -   15*
  XDTCG   -   17C0    49=     79
  XF      -   27C0
  XFAC    -   11C0
  XFCON   -    8C0
  XFMFLF  -   27C0
* XFUNC   -   14*
  XHT     -   11C0   127     501    502
  XL      -   27C0
  XLCOS   -   27C0   608
* XLINTP  -   13*
  XLSIN   -   27C0
* XMAP    -   10*
* XPAR1   -   11*
* XPAR3   -   29*
  XR      -   27C0
  XRCOS   -   27C0   606
  XRLCON  -    8C0
  XRSIN   -   27C0
  XVT     -   11C0   129     130    503    509
  XW      -   27C0
  XWAC    -   11C0   107     108    113    114    354    358
  XWCON   -    8C0
  XWC2    -   11C0   295     286
  XWMWLW  -   27C0
  XXICON  -    8C0
  XXJCON  -    8C0
  XZICON  -    8C0
  YAERF   -   20C0   521=    527
  YAERLW  -   24C0   281=    353=   362
```

Figure G.6. (Continued)

```
YAERNC   -   23C0   254=   527   532   537
YAERNL   -   23C0   248=   250   264
YAERNR   -   23C0   256=   258   264
YAERO    -   27C0   527=   601
YAERRW   -   24C0   282=   357=  362
YAERT    -   26C0   511=   527
YAERWG   -   24C0   362=   527
YARFP    -   20C0   521
YARHT    -   26C0   498=   502   502   511
YARVT    -   26C0   505=   507   509   511
YN       -   11C0    82     84    85    87   531   537
YPA      -   11C0
YWAC     -   11C0   106   108   112   114
YYICON   -    8C0
YYJCON   -    8C0
ZAERF    -   20C0   522=   529
ZAERLW   -   24C0   283=   285   287   351=   354   363   569   574
ZAERNC   -   23C0   265=   528   534
ZAERNL   -   23C0   243=   245   531   568   573
ZAERNR   -   23C0   257=   265   521   565   571
ZAERO    -   27C0   532=   543   551   564
ZAERRW   -   24C0   234=   236   287   355=   357   463   555   571
ZAERT    -   24C0   512=   528
ZAERWG   -   24C0   353=   355   523
ZARFP    -   20C0   522
ZARHT    -   26C0   499=   501   512
ZARRG    -   522=   523   603
ZARV3    -   528=   530   643
ZARVT    -   26C0   506=   508   512
ZCG      -   17C0    79     81   363   522   531   537   538   532   535
ZDTCG    -   17C0    57=    91
ZETHL    -   23C0   134=   135AC
ZETH2    -   23C0   137=   138AC
ZETR1    -   24C0
ZETR2    -   24C0
ZETR3    -   24C0
ZETR4    -   24C0
ZF       -   27C0
ZFAC     -   11C0
ZFCON    -    8C0
ZFMFHF   -   27C0
ZHT      -   11C0   126   521   601
ZL       -   27C0
ZLCOS    -   27C0
ZLSIN    -   27C0   638
ZPA      -   11C0
ZR       -   27C0
ZRCOS    -   27C0
ZRLCON   -    8C0
ZRSIN    -   27C0   536
ZVT      -   11C0   128   129   537   538
ZW       -   27C0
ZWAC     -   11C0   106   107   112   113   354   358
ZWCON    -    8C0
ZWMWHW   -   27C0
```

Figure G.6. (Continued)

```
ZZICON  -    8CO
ZZJCON  -    8CO
        +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-
```

Figure G.6. (Continued)

```
  1        SUBROUTINE RTSLOW
  2        COMMON/CONTRL/ ISCOPE,IFLAG(10),ICDSPC(4,4),MIECB(2),MICNT(2),
          *               NOSIM ,IPAN       ,PILMSK      ,NFRAME(2),KONER(2)
  3        COMMON/HYBCON/PROJ  ,NCINSL,NPCS(2),NCHAIN(2),IFRAME(2),NADCS(2),
          *              PDNOS(4),NDACS(4),IRCK(4),IFC(4),NCON(4) ,LETR(4) ,
          *              IC(19)  ,ISTIC   ,HOLD(19),ISTHO,OPERA(19),
          *              ISTOP   ,DIGAN(19),ISTDA  ,ANDIG(19),ISTAD,
          *              IC2(19) ,ISTIC2   ,HOLD2(19),ISTHO2 ,OPERA2(19),
          *              ISTOP2  ,DIGAN2(19),ISTDA2  ,ANDIG2(19),ISTAD2, IGN,
          *              ISTPIT  ,IRUNIT,IAD,IOC,IOC21,ICLP,ITSC,ILFX,ISETC ,
          *              MONDIS  ,IOURC(4)   ,ISHRC(4) ,ISYNC(4) , NIOS  ,
          *              IHJR    ,IFCHAN     ,TSBASE(2),TSREQO(2), IRCTS(4),
          *               TAUL(4) ,IPSNOS(10,2),DTIM(2) ,TRIM(19) ,ISTRM ,
          *               TRIM2(19),ISTRM2
  4        COMMON/HYBIO/ KAR(200)
  5        COMMON/ENG/  NWDTID,NIIND ,NITHID,N2IND ,NQIND ,NRNDID ,
          *             ENDTMX,ENIMX ,ENITMX,EN2MX ,EQMX   ,SHPSTR
          *       ,     ENDTPR,ENISTR,R1EC   ,TZERO ,TCOEF
  6        COMMON/FLAGS/ IWARN1(16),IWARN2(16),ISENCE(2),IWREVT(2),ICONDP,
          1 ITRIM,JTRIM,KTRIM,NPLOT,NPLOT2,IPHASE,ISLOW,SWLG,SHUTON,
          2 ISTA,ISTP,NGIF,NVP,NTWCT
  7        LOGICAL*1  IWARN1,IWARN2
  8        COMMON/ATPASS/ STLIW ,COSLW ,SINLAM,COSLAM,SUMIXX,SUMIXZ,SUMIYY,
          *               SUMIZZ,XECON ,XPLCON,XWCON ,XXICON,XXJCON,XZICON,
          *               YYICON,YYJCON,ZECON ,ZRLCON,ZWCON ,ZZICON,ZZJCON,
          *               SLAC   ,UTSTLL,VTSTLL,OOVRSK,ARWING,CPHIP ,SPHIP ,
          *               OVOTIM,
          *               COEF1 ,COEF2 ,COEF3 ,COEF4 ,COEF5 ,COEF6 ,COEF7 ,
          *               COEF8 ,COEF9 ,COEF10,COEF11,COEF12,COEF13,COEF14,
          *               COEF15,COEF16,COEF17,COEF18,COEF19,COEF20,COEF21,
          *               COEF22,COEF23,COEF24,COEF25,COEF26,COEF27,COEF28,
          *               COEF29,COEF30,COEF31,COEF32,COEF33,COEF34,COEF35
          *      ,        COEF36,COEF37,COEF38,COEF39,COEF40,COEF41,COEF42
  9        COMMON/XAIO/ SCADC1(32),SCADC2(32),SCADC3(32),SCADC4(32),
          *             SCDAC1(32),SCDAC2(32),SCDAC3(32),SCDAC4(32),
          1        PPRIME,QPRIME,RPRIME,UPRIME,VPRIME,WPRIME,THE   ,PHI   ,   30  16
          *        PSI   ,WDOT  ,H     ,DUM12 ,DUM13 ,DUM14 ,DUM15 ,MDOT  ,
          *        DELAIL,DELAIR,DELSPR,DELSPL,CTLPRM,CNFPL ,CSFPL ,CPMPL ,
          *        CYMPL ,CPL   ,CTLPRM,CNFPR ,CSFPR ,CPMPR ,CYMPR ,CPR   ,
          *        AINDTR,AINR  ,AINDTL,AINL  ,AICLPR,BICLPR,AICRPP,AICRPR,
          6        DELRUD,AINREF,DUM43 ,DUM44 ,DUM45 ,DUM46 ,DUM47 ,DUM48 ,   80  35
          7        SWLG2 ,UGUST ,VGUST ,WGUST ,PGUST ,QGUST ,RGUST ,OMDOT ,   30  35
          *        OMEGA ,TPSP  ,AMACRP,AMACLP,ENFL  ,ENFR  ,DELELV,DELFLP
          *      , DELBT ,DELST ,DELPT ,DELTH ,DELBS ,DELSS ,DELRS ,THTSP ,
          *        THTSL ,ADC3(23)
 10        COMMON/XPAP1/ AIRHT ,AIN4  ,ALAMDA,ALHTST,ALVTST,AREAMT,AREAW ,    1 TO  7
          *AREAVT,ARHT  ,ARVT  ,AVEVAC,AVEVC ,BLS   ,CDOF  ,CDOMT ,CDOVT ,    8 TO 16
          *CHORD ,CLALHT,CLALPH,CMOF  ,CMON  ,CNOF  ,CNCLN ,CNDRN ,CVALVT,   17 TO 25
          DDCDLG ,DCMLG ,FIXPP ,DOVT  ,DSPBET,FFEMT ,FFEVT ,FIF   ,FINDEG,   26 TO 34
          *FIP   ,FIXXF ,FIXXPP,FIXXW ,FIXZF ,FIXZPR,FIXZW ,FIYYF ,FIYYPR,   35 TO 43
          *FIYYW ,FIZZF ,FIZZPP,FIZZW ,HP    ,OMPFF ,PC    ,PI    ,ROTRAD,   44 TO 52
          *SBFPR ,SBWPR ,SC    ,SHF   ,SHW   ,SK0   ,SK1   ,SK2   ,SK3   ,   53 TO 61
          *SK4   ,SK5   ,SK6   ,SK7   ,SK8   ,SK9   ,SK1.  ,SK20  ,SK21  ,   62 TO 70
          *SK22  ,CDONLO,SK31LO,SK31LD,SK32  ,CDONHI,SK34  ,SK35  ,SK36  ,   71 TO 79
          *SK37  ,SK38  ,SK39  ,SK40  ,SK41  ,SK42  ,SK43  ,SK44  ,SK45  ,   80 TO 88
```

Figure G.6. (Continued)

```
     *SK46  ,SK47  ,SK48  ,SK49  ,SK50  ,SL    ,SLF   ,SLPA  ,SLW   ,   89 TO 97
     *SM    ,SMF   ,SMN   ,SMW   ,SPAN  ,TAUHT ,TAUVT ,XFAC  ,XHT   ,   98 TO106
     *XWAC  ,XVT   ,YN    ,YPA   ,YWAC  ,ZFAC  ,ZHT   ,ZPA   ,ZWAC  ,
     *ZVT   ,CLOAL ,PHIPH ,SK30HI,EN2REF,XWC2  ,BT1   ,BT2   ,BT3   ,
     *BKD1T ,BKD2T ,BKD3T ,BKM1T ,BKM2T ,BKM3T ,BKM4T ,SK31HI,
     *FEU   ,CLMAX ,ALBRK ,BKLSW ,BKNSW ,SQFPRM,DEG20 ,DGTORD,HTVTKT,   133T0141
     *PIOV2 ,RDTODG,ROTEPS,SKFPS ,ALNCBK,TAURT1,TAURT2
11    COMMON/SPIO/ RCB1(19),ISTRB1,IADC3(32)
12    COMMON/XLINTP/ AKEY(16),AMEM(2),BKEY(16),BMEM(2),GKEY(10),GMEM
13    COMMON/XFUNC / VSTARG(33), TAUAS(9),SVSTAB(33,9),SQFARG(35),
     1        GAATAB(35),GBATAB(35),ALFTAB(35)
14    COMMON/INITVR/
     1 AVFIN ,CILAML,CILAMR,COSINL,COSINR,COSPSI,C2INL ,C2INR ,DLFPSQ,    1 -  9
     2 HSQ   ,SILAML,SILAMR,SININL,SININR,SINPSI,SSQINL,SSQINR,S2INL ,   10 - 18
     3 S2INR                                                              19
15    COMMON/CGGTVR/
     1 VEAST ,VNORTH,XCG   ,XDTCG ,ZCG   ,ZDTCG                           1 -  6
16    COMMON/ENGVAR/
     1 AMACH ,AMACSQ,DEL   ,EMAXN1,EMAXN2,EMXWDT,EN2STR,FSMACH,OMEGEL,    1 -  9
     2 OMEGER,ONOVTC,OCVFSM,OVSQTH,OVTHDL,ROE   ,ROEOV2,SHPPRL,SHPPRR,   10 - 18
     3 SMA   ,SQN1MX,SQTHTC,SQWDTX,TDEGF ,TEAL  ,TEAR  ,THCDEL,THETC ,   19 - 27
     4,PCTQL,PCTQR                                                       28 TO 29
17    COMMON/VELVAR/
     1 AMUL  ,AMULSQ,AMUR  ,AMURSQ,WROTL ,OMDTL ,OMDTR ,OMEGAL,OMEGAR,    1 -  9
     2 OMSQL ,OMSQR ,UHT   ,ULW   ,ULWPR ,ULWSQ ,UP    ,URL   ,URLPR ,   10 - 18
     3 URLURL,URP   ,URPPR ,URRURR,URW   ,URWPR ,URWSQ ,USQ   ,UVT   ,   19 - 27
     4 VALFLW,VALFRW,VALFS ,VALNCL,VALNCR,VBETVT,VLW   ,VLWPR ,VLWSQ ,   28 - 36
     5 VP    ,VRL   ,VRLPR ,VRLVRL,VRR   ,VRRPR ,VRRVRR,VRW   ,VRWPR ,   37 - 45
     6 VRWSQ ,VSQ   ,VTIPL ,VTIPR ,VTOTAL,VTOTLR,VTOTRR,VVT   ,VZETL ,   46 - 54
     7 VZETR ,WHT   ,WLW   ,WLWPR ,WLWSQ ,WP    ,WRL   ,WRLPR ,WRLWRL,   55 - 63
     8 WRW   ,WRWPR ,WRWSQ ,WRR   ,WRRPR ,WRRWRR,WSQ   ,WVT               64 - 71
18    COMMON/FUSVAR/
     1 ALARF ,ALAPFP,ALFSQ ,ALPHF ,AMARF ,AMARFP,ANARF ,ANARFP,BETAF ,    1 -  9
     2 BETFSQ,CBCMF ,CDF   ,CLF   ,CMF   ,CNF   ,COSALF,COSBTF,CYF   ,   10 - 18
     3 DLLG  ,DMLG  ,DNLG  ,DXLG  ,DYLG  ,DZLG  ,QFSW  ,SBFCAF,SBFSAF,   19 - 27
     4 SINALF,SINBTF,SQF   ,XAEPF ,XARFP ,YAERF ,YARFP ,ZAERF ,ZARFP     28 - 36
     *  ,SINTHE,COSTHE,SINPHI,COSPHI
19    COMMON/GEFVAR/
     1 AGOVAT,AGOVAW,BIGX  ,BK39  ,BMOVTL,BMOVTR,COWCOR,CLTCOR,CLWCOR,    1 -  9
     2 DOVTL ,DOVTR ,EPPRM ,GEF   ,HGEFLR,HGEFRR,HLHUB ,HRHUB ,HTC4  ,   10 - 18
     3 HWC4  ,RRI1  ,RRI2  ,SB1   ,TIGEL ,TIGER                          19 - 24
20    COMMON/NACVAR/
     1 ALLNSQ,ALPHLN,ALPHRN,ALRNSQ,BETALN,BETARN,BTLNSQ,BTRNSQ,CALLN ,    1 -  9
     2 CALRN ,CBETLN,CBETRN,CDLN  ,CDCLN ,CDDRN ,CDRN  ,CLLN  ,CLRN  ,   10 - 18
     3 CMLN  ,CMRN  ,CNLN  ,CNRN  ,CYLN  ,CYRN  ,DLLNC ,DLRNC ,DMLNC ,   19 - 27
     4 DMRNC ,DNLNC ,DNRNC ,DXLNC ,DXRNC ,DYLNC ,DYRNC ,DZLNC ,DZRNC ,   27 - 36
     5 SALLN ,SALRN ,SBETLN,SBETRN,SQLNC ,SQRNC ,TNAC1 ,TNAC2             36 - 44
21    COMMON/ROTVAR/
     1 AICL  ,AICLDP,AICR  ,AICRDP,ALARNC,ALLRH ,ALARNL,ALARNR,ALRRH ,    1 -  9
     2 ALPHLR,ALPHRR,AMARNC,AMARNL,AMARNR,AMLRH ,AMRNLP,AMRNRP,AMROTL,   10 - 18
     3 AMROTR,AMRRH ,ANARNC,ANARNL,ANARNR,ANLRH ,ANROTL,ANROTR,ANRRH ,   19 - 27
     4 BICL  ,BICLDP,BICR  ,BICRDP,CNFAIL,CNFAIR,CNFBIL,CNFBIR,CNFL  ,   28 - 36
     5 CNFR  ,COSZHL,COSZHR,CPMAIL,CPMAIR,CPMBIL,CPMBIR,CPML  ,CPMR  ,   37 - 45
     6 CSFAIL,CSFAIR,CSFBIL,CSFBIR,CSFL  ,CSFR  ,CTL   ,CTR   ,CYMAIL,   46 - 54
     7 CYMAIR,CYMBIL,CYMBIR,CYML  ,CYMR  ,FIPOML,FIPOMR,FNORML,FNORMR,   55 - 63
```

Figure G.6. (Continued)

```
     8 FSIDEL,FSIDER,PNLN  ,PNLR  ,PNRN  ,PNRR  ,QNLN  ,QNLR  ,QNRN  ,   64 - 72
     9 QNRR  ,RNLN  ,RNLP  ,RNRN  ,RNRR  ,ROPIR4,ROPIR5,SHPROL,SHPROR,   73 - 81
     A SINZHL,SINZHR,TL    ,TOROL ,TORQR ,TR    ,TRMAR1,TRMAR2,TRMAR3,   82 - 90
     B TRMAR4,TRMHB1,TRMHB2,XAERNC,XAERNL,XAERNR,YAERNC,YAERNL,YAERNR,   91 - 99
     C ZAERNC,ZAERNL,ZAERNR,ZETHL ,ZETHR                                 100 - 104
22    COMMON/WNGVAR/
     1 ALARWG,ALLWPR,ALPHLW,ALPHRW,ALRGLW,ALRGRW,ALRWPR,ALWSSO,AMARLW,    1 - 9
     2 AMARRW,AMARWG,ANARWG,ARILW ,ARIRW ,ARWSSO,ATAULR,ATAURR,AVEALR,   10 - 18
     3 AVEALW,AVECLW,AVECTS,AVEEPP,AVEZET,BETALW,BETARW,BKALPR,BKARPR,   19 - 27
     4 CALLW ,CALRW ,CAVINW,CAVZET,CBETLW,CBETRW,CEPLW ,CEPRW ,CDCNTL,   28 - 36
     5 CDCNTR,CDOUM ,CDLWAO,CDLWPR,CDLWSS,CDRWAO,CDRWPR,CDRWSS,CDSLW ,   37 - 45
     6 CDSRW ,CLAVE ,CLCNTL,CLCNTR,CLDUM ,CLILW ,CLIRW ,CLLWAO,CLLWPR,   46 - 54
     7 CLLWSS,CLRWAO,CLRWPR,CLRWSS,CLSLW ,CLSRW ,CLSW  ,CLZERO,CMCNTL,   55 - 63
     8 CMCNTR,CMLWAO,CMLWSS,CMRWAO,CMRWSS,CMSLW ,CMSRW ,CNSW  ,CTAULR,   64 - 72
     9 CTAURR,CTSLR ,CTSRR ,DCDDF ,DCDLDA,DCDLSP,DCDRDA,DCDRSP,DCLDF ,   73 - 81
     A DCLLDA,DCLLSP,DCLRDA,DCLRSP,DCLSPW,DCMDF ,DCMLDA,DCMLSP,DCMRDA,   82 - 90
     B DCMRSP,DCLSPW,EPILR ,EPIRL ,EPPLR ,EPPRR ,EPWFL ,EPWRR ,RESLR ,   91 - 99
     C RESRR ,SALLW ,SALRW ,SAVINW,SAVZET,SBETLW,SBETRW,SEPLW ,SEPRW ,  100 - 108
     D SOMUL ,SOMUR ,SIL   ,SILZ  ,SIR   ,SIRW  ,SIT   ,STAULR,STAURR,  109 - 117
     E SVSTAR,SVSTRL,SOLW  ,SOSESL,SOSESR,SORW  ,SOWING,TAJLR ,TAJRR ,  118 - 126
     F TAVAER,TRMWG1,TRMWG5,TRMWG6,TRMWG7,TRMWG8,TZET1 ,TZET2 ,TZET3 ,  127 - 135
     G TZET4 ,TZET5 ,TZET6 ,VSTAR ,VSTARL,XAERLW,XAERRW,XAERWG,YAERLW,  136 - 144
     H YAERRW,YAERWG,ZAERLW,ZAERRW,ZAERWG,ZETR1 ,ZETR2 ,ZETR3 ,ZETR4    145 - 153
23    COMMON/HNGVAR/
     1 TRMWG3,TRMWG4,TMWG1 ,TMWG11,HWACL ,HOTACL,HWACL ,HOTACL,HIR   ,    1 - 9
     2 HIRTR ,HIL   ,HIRTL ,AMACTL,AMACTR,THTLAC,THTRAC
24    COMMON/TAILVR/
     1 ALAEHT,ALAERT,ALAEVT,ALPHHT,ALPHVT,AMARHT,AMART ,AMARVT,ANARHT,    1 - 9
     2 ANART ,ANARVT,BETVT ,CALIHT,CBETSS,CDHT  ,CDVT  ,CLHT  ,CYVT  ,   10 - 18
     3 EPTAIL,EPZERO,SALIHT,SBETSS,SIGMA ,TRMHT ,TRMVT ,XAERT ,XARHT ,   19 - 27
     4 XARVT ,YAERT ,YARHT ,YARVT ,ZAERT ,ZARHT ,ZARVT ,EPTL1 ,ALHTPR,   28 TO 36
     5ALHTE ,ALHTP ,ALHTM ,CLAT  ,TRMHT2,TRMHT3,CLHTST,CDHTST,ALVTPR,   37 TO 45
     6ALVTE ,ALVTP ,ALVTM ,CYAT  ,TRMVT2,TRMVT3,CYVTST,CDVTST            46 TO 53
25    COMMON/EOMVAR/
     1 ALAERO,AMAERO,ANAERO,CMDW  ,FIXX  ,FIXZP ,FIXZQ ,FIXZR ,FIYY  ,    1 - 9
     2 FIZZ  ,FJXX  ,FJYY  ,FJZZ  ,DOVIXX,DOVIYY,DOVIZZ,PP    ,PQ    ,   10 - 18
     3 PR    ,QR    ,RQ    ,TERM1 ,TERM2 ,TERM3 ,TERM4 ,TERM5 ,TERM6 ,   19 - 27
     4 TERM7 ,TERMQ1,TERMQ2,TERMP1,TERMP2,TERMP3,TERMIL,TERMZL,TERMZ3,   28 - 36
     5 TRMTTI,TRMTTP,XAERO ,XF    ,XLAEL ,XL    ,XLCOS ,XLSIN ,X     ,   37 - 45
     6 XPCOS ,XPSIN ,XR    ,XWMHLW,YAERO ,ZAERO ,ZF    ,ZFMFHF,ZL    ,   46 - 54
     7 ZLCOS ,ZLSIN ,ZP    ,ZRCOS ,ZRSIN ,ZR    ,ZWMHW ,P     ,Q     ,   55 - 63
     8 R     ,U     ,V     ,W
26    COMMON/XPAR3/ CONS1 ,CONS2 ,CONS3 ,CONS4 ,CONS5 ,CONS6 ,CONS7 ,    1 TO 7
     1              CONS8 ,CONS9 ,CONS1 ,CONS11,CONS12,CONS13,CONS14,    8 TO 14
     2              CONS15,CONS16,CONS17,CONS18,CONS19,CONS20,CONS21,   15 TO 21
     3              CONS22,CONS23,CONS24,CONS25,CONS26,CONS27,CONS28,   22 TO 28
     4              CONS29,CONS30,CONS31,CONS32,CONS33,CONS34,CONS35,   29 TO 35
     5              CONS36,CONS37,CONS38,CONS39,CONS40,CONS41,CONS42,   36 TO 42
     6              CONS43,CONS44,CONS45,CONS46,CONS47,CONS48,CONS49,   43 TO 49
     7              CONS50,CONS51,CONS52,CONS53,CONS54,CONS55,CONS56,   50 TO 56
     8              CONS57,CONS58,CONS59,CONS60,CONS61,CONS62,CONS63,   57 TO 63
     9              CONS64,CONS65,CONS66,CONS67,CONS68,CONS69,CONS70,   64 TO 70
     A              DBRK1 ,DBRK2 ,DBRK3 ,DBRK4 ,DBRK5 ,DBRK6 ,DBRK7 ,   71 TO 77
     B              DBRK8 ,DBRK9 ,DBRK10,DBRK11,DBRK12,DBRK13,DBRK14,   78 TO 84
     *              DBRK15,DBRK16,DBRK17,DBRK18,DBRK19,DBRK20,DBRK21    85 TO 91
```

Figure G.6. (Continued)

```
     D             ,SFTL   ,SFNFL ,SFSFL ,SFPML ,SFYML ,SFQL   ,SFPL   ,
     E              SFTR   ,SFNFR ,SFSFR ,SFPMR ,SFYMR ,SFQR   ,SFPR
     F             ,CONS71,CONS72,CONS73,CONS74,CONS75,CONS76,CONS77      106T0112
     G             ,CONS78,CONS79,CONS80,CONS81                           113T0116
C         TABLE OF PRE-COOKED COEFFICIENTS DEFINITION D
C       XFCON =    SLF*(1.-SMF/SM) -SLW*SMW/SM
C       ZFCON =    SHF*(1.-SMF/SM) -SHW*SMW/SM
C       XWCON =    SLW*(1.-SMW/SM) -SLF*SMF/SM
C       ZWCON =    SHW*(1.-SMW/SM) -SHF*SMF/SM
C       XRLCON=  -(SMF*SLF +SMW*SLW)/SM
C       ZRLCON=  -(SMF*SHF +SMW*SHW)/SM
C       XXICON=    SUMIXX + 2.*SMN*YN*YN
C       YYICON=    SUMIYY
C       ZZICON=    SUMIZZ + 2.*SMN* YN*YN
C       XZICON=    FIXZF + FIXZW
C       XXJCON=    SUMIZZ -SUMIYY +2.*SMN*YN*YN
C       YYJCON=  (FIXXF -FIZZF)+(FIXXW-FIZZW)
C       ZZJCON=  (SUMIYY-SUMIXX) -2.*SMN* YN*YN
C       COEF1 =    SL*SMN/SM
C       COEF2 =    SL*(1. -SMN/SM)
C       COEF3 =    FIXXPR -FIZZPR
C       COEF4 =    SL*SMN
C       COEF5 =    SMF * SHF
C       COEF6 =    SMW * SHW
C       COEF7 =    SMF * SLF
C       COEF8 =    SMW * SLW
C       COEF9 =    SL*SMN*YN
C          COEF10=  1. / SM
C       COEF11= BKLSW*AVEYAC/2./SPAN
C       COEF12= BKNSW*AVEYAC/2./SPAN
C       COEF13 =       (FIYYPR+SL*SL*SMN*(1.-SMN/SM))
C       COEF16= AREAW*SPAN          (S * B )   .
C       COEF17= CHORD/SPAN          (C / B )   . WING CHARACTERISTICS
C          COEF18=  S / 2
C       COEF19 =   PI*ROTRAD*ROTRAD*ROTRAD*ROTRAD
C       COEF20 =   COEF19 * ROTRAD
C       COEF21 =   1./(0.5*PI * ARHT)
C       COEF22 =   1./(0.5*PI * ARVT)
C       COEF23 =   AREAHT * EFFHT
C       COEF24 =   AREAVT * EFFVT
C       COEF25 =     1./(2.*PI* ROTRAD*ROTRAD)
C       COEF26 =   CHORD /2.
C       COEF27 =   1./CHORD/CHORD
C       COEF28 =   1./(AREAW/2.)
C       COEF29 =     PI * ARWING
C          COEF30=  1./(PI*ARWING)
C          COEF31=  S * C /2
C          COEF32= S * C /2 *CLALPH*(DCMDCL+XWAC/C )
C          COEF33= S * C /2 *CLALPH*(DCMDCL+XWAC/C ) *4/3/PI *YN/YWAC
C          COEF34=  YWAC / YN / K TH TWIST
C       COEF35=  B * B
C          TABLE OF INTERMEDIATE CALCULATIONS
C       ZRSIN =  ZR* SIN(INR-LAMDA)
C       ZRCOS =  ZR* COS(INR-LAMDA)
C       XRSIN=   XR* SIN(INR-LAMDA)
```

Figure G.6. (Continued)

```
C      XRCOS=    XR* COS(INR-LAMDA)
C      ZLSIN =   ZL* SIN(INL-LAMDA)
C      ZLCOS =   ZL* COS(INL-LAMDA)
C      XLSIN =   XL* SIN(INL-LAMDA)
C      XLCOS =   XL* COS(INL-LAMDA)
C      ZFMFHF=    SMF* SHF * ZF
C      ZWMWHW=    SMW* SHW * ZW
C      XFMFLF=    SMF* SLF * XF
C      XWMWLW=    SMW* SLW * XW
C      TERM1 =   (IXXPR-IZZPR)*(SSQINR + SSQINL)
C      TERM2 =   (IXZPR)*( S2INR +S2INL)
C      TERM3 =   (SL *SMN)*(ZRSIN +ZLSIN)
C      TERM4 =   (IXXPR-IZZPR)*(S2INR +S2INL) * 0.5
C      TERM5 =    IXZPR *(C2INR+C2INL)
C      TERM6 =    (SL *SMN) *(XRCOS + XLCOS)
C      OOVIXX=    1./FIXX
C      OOVIYY=    1./FIYY
C      OOVIZZ=    1./FIZZ
C      RQ =       R*Q
C      PQ =       P*Q
C      RR =       R*R
C      PR =       P*R
C      PP =       P*P
C         FOR RIT CALC USE FOLLOWING TRIG IDENTITIES WHERE
C            A= INCIDENCE ANGLE INR,INL    B = LAMDA
C         COS(A-B) = COS(A)*COS(-B) -SIN(A)*SIN(-B)
C                  = COS(A)*COS(B)  +SIN(A)*SIN(B)
C         SIN(A-B) = SIN(A)*COS(-B) +COS(A)*SIN(-B)
C                  = SIN(A)*COS(B)  -COS(A)*SIN(B)
C
C         SIN(2A) = 2.*SIN(A)*COS(A)
C         COS(2A) = 1. - 2.*SIN(A)*SIN(A)
C
C
C         DISCRETE LINE  ALLOCATION
C
C             CONSOLE  I
C
C         BIT NUMBER   DGS NUMBER   FUNCTION
C            31            17          PANIC
C            30            16          TRIM
C            29            15          CONSOLE OPERATE
C
C         HORIZONTAL TAIL
C
C           1. IF HWC/4 GT 50 FT.    GFF = 0.
C           2. IF  V  LE  30 KT    TAIL AERO = 0.
C           3. IF  DEL FLAP GT  75 DEG    EPSILON TAIL = 0.
C           4. IF  CTS LT 0.5  EPSILON P = 0.
C           5. LIMIT RANGE OF ABS(ALPHHT) TO (ALHTSTALL - 2. DEG) AND
C                 PRINT WARNING
C         VERTICAL  TAIL
C           1. LIMIT THE RANGE OF ABS(ALPHVT) TO(ALVTSTALL -2 DEG) AND
C                 PRINT WARNING
C         READ DISCRETES FROM ANALOG
```

Figure G.6. (Continued)

```
      CALL TRACK('RTSLOW  ',1)
 10   CALL REVENT(IFC(1),NCON(1),ISENCE(1),IREVNT,0)
      KPAN = 300
      CALL GETBIT(ISENCE(2),ICONOP,29)
      CALL GETBIT(ISENCE(2),KTRIM,30)
      IF((JTRIM.EQ.0.AND.KTRIM.EQ.0).OR.ITRIM.NE.0) GO TO 36
      CALL USEAIO(RCB1)
      KPAN= 302
      ITRIM= 1
 35   GO TO(35,36,500),ISTRB1
 36   CONTINUE
                            ( B L A N K   C A R D )
                            ( B L A N K   C A R D )
                            ( B L A N K   C A R D )
                            ( B L A N K   C A R D )
                            ( B L A N K   C A R D )
                            ( B L A N K   C A R D )
                            ( B L A N K   C A R D )
                            ( B L A N K   C A R D )
                            ( B L A N K   C A R D )
                            ( B L A N K   C A R D )
                            ( B L A N K   C A R D )
                            ( B L A N K   C A R D )
                            ( B L A N K   C A R D )
                            ( B L A N K   C A R D )
                            ( B L A N K   C A R D )
                            ( B L A N K   C A R D )
      ENTRY TSTRTS
      CALL SINCOS(PSI,SINPSI,COSPSI)
       CALL SINCOS(THE,SINTHE,COSTHE)
      CALL SINCOS(PHI,SINPHI,COSPHI)
      SSQINR = SININR*SININR
      SSQINL = SININL*SININL
      C2INL  =  1.- 2.*SSQINL
      C2INR  =  1.- 2.*SSQINR
      S2INL  =  2.*SININL*COSINL
      S2INR  =  2.*SININR*COSINR
      HSQ=  H*H
      QFSW= SQF*AREAW
      VALNCR=  FSQRT(URRURR+WRRWRR,WORK)
      VALNCL=     FSQRT(URLURL+WRLWRL,WORK)
C
C        CENTER OF GRAVITY CALCULATION
C
C        CG LOCATION W.R.T. PIVOT
      XCG= -XRLCON +COEF1*(CILAML+CILAMR)
      ZCG= -ZRLCON -COEF1*(SILAML+SILAMR)
C
C
C        AIRCRAFT CONDITION CALCULATIONS
C
C        GROUND TRACK
C        NORTHWARD VELOCITY
C
      VNORTH= UPRIME*COSTHE*COSPSI+VPRIME*(SINPHI*SINTHE*COSPSI-
```

Figure G.6. (Continued)

```
                * COSPHI*SINPSI)+WPRIME*(COSPHI*SINTHE*COSPSI+SINPHI*SINPSI)
          C          EASTWARD   VELOCITY
   55               VEAST= UPRIME*COSTHE*SINPSI+VPRIME*(SINPHI*SINTHE*SINPSI+
                *COSPHI*COSPSI)+WPRIME*(COSPHI*SINTHE*SINPSI-SINPHI*COSPSI)
          C          DOWNWARD VELOCITY ON ANALOG
          C
   56
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
****************************** S Y N T A X   E R R O R ************************          ( ))
          C
          C          DENSITY CALCULATIONS
          C          EQUATION FOR DEL FROM CURVE FIT PROGRAM
   57               DEL = .99953834C7 -.3623432996E-04 * H
                + +.5409991?01E-09 *HS) -.37223138C4E-14 *HSQ * H
          C
   58               TDEGF=  TZERO -TCOFF*H
   59               THETC=  .0C1927933*(TDEGF+459.69)
   60               SQTHTC=  FSORT(THETC,WORK)
   61               ONOVTC = 1. / THETC
   62               ROE = ROEO*DEL*ONOVTC
   63               ROEOV2=  ROE * 0.5
   64               SMA=  1116.*SQTHTC
   65               AMACH=  VTOTAL /SMA
   66               AMACSQ= AMACH * AMACH
   67               FSMACH=  FSORT(1.0-AMACSQ,WORK)
   68               OOVFSM =  1./FSMACH
   69               THCDEL=  SQTHTC*DEL
   70               OVTHDL= 1./THCDEL
   71               OVSQTH=  1./SQTHTC
          C
   72               TEAR= TPSP*ONOVTC
   73                FMXWDT = FWDTMX * FWDTPR * OVTHDL
   74               FMAXN1=  FN1MX*OVSQTH
   75               FMAXN2 = FN2REF*OMEGA /OMREF
   76               EN2STR=  FMAXN2*EN2MX
   77               SQWDTX = FMXWDT * FMXWDT
   78                SQN1MX=  FMAXN1 * FMAXN1
   79               CALL ENGINE(TEAR,SHPPRR,OMEGER,PCTOR)
```

Figure G.6. (Continued)

```
        C
        C      DATE 7/10/72  GO FROM DUAL THROTTLE , DUAL ENGINE CALCULATION
        C                    TO SINGLE THROTTLE , SINGLE ENGINE ENGINE CALCULATION
        C
        C                    TO GET BACK TO DUAL  ADD EQS
        C     TEAL=  TPSL*ONOVTC
        C     CALL ENGINE (TEAL,SHPPRL,OMEGEL)
        C
        C
 80           SHPPRL= SHPPRR
 81           OMEGEL=  OMEGER*ENFL
 82           OMEGER = OMEGER*ENFR
        C
        C
        C
 83
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
****I************************ S Y N T A X   E R R O R ************************          E  *E
        C
        C      FUSELAGE AERODYNAMICS
        C           INPUT EQUATIONS
 84           CALL  SINCOS(ALPHF,SINALF,COSALF)
 85           CALL  SINCOS(BETAF,SINBTF,COSBTF)
        C
        C      FUSELAGE FORCES AND MOMENTS (AERODYN INCLUDING GEAR)
        C
        C      WIND AXIS COEFFICIENTS
        C         IF GEAR UP , SWLG = 0     THUS DCDLG,DCMLG = 0.
        C
 86            ALPHFP=  SINALF*COSALF
 87           BETAFP=  SINBTF*COSBTF
        C
 88           CLF= ALPHFP*(SK3+SK4*ABS(ALPHFP) ) +SK42
 89           CDF= CDOF*(1.+SKC*BETAFP*BETAFP*ABS(BETAFP))+SK2*ALPHFP*ALPHFP
             *  +SK1*ABS(ALPHFP)+DCDLG*SWLG2
 90           CYF=  BETAFP*(SK7+SK8*ABS(BETAFP))
```

Figure G.6. (Continued)

```
 91          CMF= CMOF+ALPHFP*(SK5+SK6*ABS(ALPHFP))+DCMLG*SWLG2
 92          CNF=  CNOF+BETAFP*(SK7+SK8*ABS(BETAFP))
       C
       C        BODY AXIS FORCES AND MOMENTS (ABOUT CG)
 93          SBFSAF= SINBTF*SINALF
 94          SBFCAF= SINBTF*COSALF
 95          CBCMF= COEF17 * CMF
 96          ZARFP= QFSW*(-CLF*COSALF-CDF*COSBTF*SINALF-CYF*SBFSAF)
 97          XARFP= QFSW*(-CDF*COSALF+CLF*SINALF-CYF*SBFCAF)
 98          YAPFP= QFSW*(CYF*COSBTF-CDF*SINBTF)
 99          AMARFP= QFSW*CHORD*CMF*COSBTF+ZARFP*(XCG-XFAC)-XARFP*(ZCG-ZFAC)
100          ANARFP= QFSW*SPAN *(CNF*COSALF-CBCMF*SBFSAF) -YARFP*(XCG-XFAC)
101          ALARFP= QFSW*SPAN *(-CBCMF*SBFCAF-CNF*SINALF)   +YAPFP*(ZCG-ZFAC)
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A P D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A P D )
       C        WING AND TAIL ALTITUDE FOR GROUND EFFECT
102          HWC4 = H +(XWAC-XCG)*SINTHE +(ZCG-ZWAC)*COSTHE
103          HTC4 = H +(XHT -XCG)*SINTHE +(ZCG-ZHT) *COSTHE
       C
104          AGOVAT =  1.0
105          IF(NGEF.NE.1)  GO TO 630
106          IF(HTC4 .GT. DBRK14 ) GO TO 620
107          AGOVAT = CONS59 +HTC4*(CONS60 +CONS61*HTC4)
108          GO TO 630
109    620   IF(HTC4 .GE. DBRK15) GO TO 63
110          AGOVAT = CONS62 +HTC4*(CONS63 +CONS64*HTC4)
111    630   CONTINUE
112          CLTCOR= AGOVAT*OOVESM
113          AGOVAW =  1.0
114          BK99=  1.0
115          IF(NGEF.NE.1) GO TO 650
116          IF(HWC4.GT.DBRK10) GO TO 640
117          AGOVAW= CONS44+HWC4*(CONS45+CONS46*HWC4)
118          BK99= -1.0
119          GO TO 650
120    640   IF(HWC4.GE.DBRK11) GO TO 650
121          AGOVAW= CONS47+HWC4*(CONS48+CONS49*HWC4)
122          BK99= -1.0
123    650   CONTINUE
124          CLWCOR=     AGOVAW * OOVESM
125          CDWCOR=  BK99*COEF30
126          HRHUB= H+(RLS*COSINR-XCG)*SINTHE+((DLS*SININR+ZCG)*COSPHI-
            *  YN *SINPHI)*COSTHE
127          IF(AMUR.GE.DBRK12) GO TO 412
128          IGEFR3 = HRHUR/(2.*ROTRAD*(CONS50+ABS(COSPHI*(SINTHE*COSINR +
            *  COSTHE*SININR))))
129          IF(NGEF.NE.1)  GO TO 412
```

Figure G.6. (Continued)

```
I N D E X
 130          IF(HGEFRR.GE.DBRK13) GO TO 412
 131          TIGER  =(HGEFRR*HGEFRR*(CONS51+CONS52*AMUR)+HGEFRR*(CONS53*AMUR
             * +CONS54) +CONS55 +CONS56*AMUR )
 132          DOVTR= BKD1T*HGEFRR*HGEFRR+BKD2T*HGEFRR+BKD3T
 133          BMOVTR= BKM1T*HGEFRR*HGEFRR+BKM2T*HGEFRR+BKM3T
 134          GO TO 413
 135    412   TIGER= 1.0
 136          DOVTR= DOVT
 137          BMOVTR=  BKM4T
 138    413   CONTINUE
 139          IF(AMUL.GE.DBRK12 )  GO TO 414
 140          HLHUB= HRHUB +2.0*YN*SINPHI*COSTHE
 141          HGEFLR = HLHUB/(2.*ROTRAD*(CONS50+ABS(COSPHI*(SINTHE*COSINL +
             *  COSTHE*SININL))))
 142          IF(NGEF.NE.1) GO TO 414
 143          IF(HGEFLR.GE.DBRK13) GO TO 414
 144          TIGEL  =(HGEFLR*HGEFLR*(CONS51+CONS52*AMUL)+HGEFLR*(CONS53*AMUL
             * + CONS54) +CONS55 +CONS56*AMUL )
 145          DOVTL= BKD1T*HGEFLR*HGEFLR+BKD2T*HGEFLR+BKD3T
 146          BMOVTL=  BKM1T*HGEFLR*HGEFLR+BKM2T*HGEFLR+BKM3T
 147          GO TO 415
 148    414   TIGEL= 1.0
 149          DOVTL= DOVT
 150          BMOVTL=  BKM4T
 151    415   CONTINUE
                                      ( B L A N K   C A R D )
                                      ( B L A N K   C A R D )
                                      ( B L A N K   C A R D )
                                      ( B L A N K   C A R D )
                                      ( B L A N K   C A R D )
                                      ( B L A N K   C A R D )
                                      ( B L A N K   C A R D )
                                      ( B L A N K   C A R D )
                                      ( B L A N K   C A R D )
                                      ( B L A N K   C A R D )
                                      ( B L A N K   C A R D )
                                      ( B L A N K   C A R D )
                                      ( B L A N K   C A R D )
                                      ( B L A N K   C A R D )
        C
        C          NACELLE AERODYNAMICS
        C
        C
 152          ALPHLN=  ATAN2(WRL,URL)
 153          ALPHRN=  ATAN2(WRR,URR)
        C
 154          BETALN=  ATAN2(VRL,VALNCL)
 155          BETARN=  ATAN2(VRR,VALNCR)
        C
 156          CALL  SINCOS(ALPHLN,SALLN,CALLN)
 157          CALL  SINCOS(ALPHRN,SALRN,CALRN)
 158          CALL  SINCOS(BETALN,SBETLN,CBETLN)
 159          CALL  SINCOS(BETARN,SBETRN,CBETRN)
        C
 160          TRMNC1=  SALLN*CALLN
```

Figure G.6. (Continued)

```
      TRMNC2=  SALRN*CALRN
      TRMNC3= SBETLN*CBETLN
      TRMNC4= SBETRN*CBETRN
C
C        WIND AXES
      IF(ABS(ALPHLN).GT.ALNCBK)  GO TO 720
      CDOLN=  CDONLO
      SK30L=  SK30LO
      SK31L=  SK31LO
      GO TO 730
  720 CDOLN=  CDONHI
      SK30L=  SK30HI
      SK31L=  SK31HI
   73 CONTINUE
      CDLN=  CDOLN+SK30L*ABS(ALPHLN)+SK31L*ALPHLN*ALPHLN
      CLLN=  SK32*TRMNC1
      CMLN=  CM0N+TRMNC1*(SK34+SK35*ABS(TRMNC1))
      CYLN= TRMNC3*(SK43+SK44*ABS(TRMNC3))
      CNLN = CNOLN+TRMNC3*(SK40+SK41*ABS(TRMNC3))
C
C
      IF(ABS(ALPHRN).GT.ALNCBK)   GO TO 760
      CDORN=  CDONLO
      SK30R=  SK30LO
      SK31R=  SK31LO
      GO TO 770
  760 CDORN=  CDONHI
      SK30R=  SK30HI
      SK31R=  SK31HI
  770 CONTINUE
      CDRN=  CDORN+SK30R*ABS(ALPHRN)+SK31R*ALPHRN*ALPHRN
      CLRN=  SK32*TRMNC2
      CMRN=  CM0N+TRMNC2*(SK34+SK35*ABS(TRMNC2))
      CYRN=   TRMNC4*(SK36+SK37*ABS(TRMNC4))
      CNRN=  CNORN+TRMNC4*(SK38+SK39*ABS(TRMNC4))
C
C        RIGHT NACELLE AERO FORCES  -  BODY AXES
C
      SQLNC=   RHOOV2*(ULFURL+VLFVLF+WRLWRL)
      SQRNC=   RHOOV2*(URRURR+VRRVRR+WRRWRR)
      TNAC1 = SQRNC * COEF18
      TNAC2  =  SQLNC  * COEF18
C
      DZRNC  = -TNAC1*( CLRN*CALRN +SALRN*(CDRN*CBETRN +CYRN*SBETRN ) )
      DXRNC  =  TNAC1*( CLRN*SALRN -CALRN*(CDRN +CYRN*SBETRN) )
      DYRNC  =  TNAC1*( CYRN*CBETRN -CDRN*SBETRN )
      DMRNC  =  TNAC1*CHORD * CMRN *CBETRN
      DNRNC  =  TNAC1*SPAN  *CALRN*(CNRN -COEF17*CMRN*SBETRN )
      DLRNC  = -TNAC1*SPAN  *( COEF17*CMRN*SBETRN*CALRN +CNRN*SALRN )
C
C        LEFT  NACELL AERO FORCES  -  BODY AXES
C
C
      DZLNC  = -TNAC2*( CLLN*CALLN +SALLN*(CDLN*CBETLN +CYLN*SBETLN ) )
      DXLNC  =  TNAC2*(CLLN*SALLN -CALLN*(CDLN +CYLN* SBETLN ) )
```

Figure G.6. (Continued)

```
 204          DYLNC =  TNAC2*(CYLN*CBETLN -CDLN* SBETLN )
 205          DMLNC =  TNAC2*CHORD * CMLN * CBETLN
 206          DNLNC =  TNAC2*SPAN  * CALLN*(CNLN -COEF17*CMLN* SBETLN )
 207          DLLNC = -TNAC2*SPAN  *( COEF17*CMLN*SBETLN*CALLN +CNLN*SALLN )
        C
 208
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
****I************************ S Y N T A X   E R R O R ************************          &  ))
        C
        C       WING AERODYNAMICS
        C
        C         PRELIMINARY CALCULATIONS
        C           RIGHT ROTOR
        C
 209          TAURR =  ALPHRR  +  ATAN2(FNORMR,TR )
 210          RESRR=  FSQRT(TR*TR+FNORMR*FNORMR+FSIDER*FSIDER,WORK)
 211          TRMWG1 =  COEF25 / ROE
 212          SQRESR=  FSQRT((RESRR+1C.)*TRMWG1,WORK)
 213          VSTAR = VTOTRR/SQRESR
        C
 214          ATAURR =  ABS(TAURR)
 215          CALL LINT (AKEY, AMEM,AMEM ,ISTA,VSTAR ,ATAURR,SVSTAB ,SVSTAR  )
 216          KPAN = 32C
 217          IWARN1(11)=  .FALSE.
 218          IF(ISTA.EQ.2) IWARN1(11)= .TRUE.
        C
        C
 219          CALL SINCOS(TAURR,STAURR,CTAURR)
        C
 220          TMWG10=  SVSTAR*STAURR
 221          TMWG11=  VSTAR+SVSTAR*CTAURR
 222          EPPRR=  ATAN2(TMWG10,TMWG11)
 223          CTSPR= 4./(4.+     VSTAR*VSTAR)
        C
        C            LEFT ROTOR
 224          TAULR =  ALPHLR  +  ATAN2(FNORML,TL )
 225          RESLR=  FSQRT(TL*TL+FNORML*FNORML+FSIDEL*FSIDEL,WORK)
 226          SQRESL=  FSQRT((RESLR+1C.)*TRMWG1,WORK)
 227          VSTARL=  VTOTLR/SQRESL
        C
 228          CALL SINCOS(TAULR,STAULR,CTAULR)
        C
```

Figure G.6. (Continued)

```
      ATAULR = ABS(TAULR)
      CALL LINT (BKEY, BMEM,BMEM ,ISTR,VSTARL,ATAULR,SVSTAB ,SVSTPL   )
      IWARNI(12)=  .FALSE.
      KPAN = 321
       IF(ISTR.EQ.2) IWARNI(12)= .TRUE.
C
C
      TRMWG4=  SVSTPL*STAULR
      TRMWG9=  VSTARL+SVSTRL*CTAULR
      EPPLR=  ATAN2(TRMWG4,TRMWG9)
      CTSLR=  4./(4.+      VSTARL*VSTARL)
C
C        CALCULATION OF AMOUNT OF WING AREA IN DOWNWASH - USES AVERAGES
C
      AVEZET =    .5 *(ZETHR +ZETHL )
      AVEALP =   0.5 *(ALPHRR + ALPHLR)
      AVEEPP =   0.5 *(EPPRR + EPPLR )
      AVECTS =   0.5 *(CTSRR + CTSLR )
C
C
      CALL  SINCOS(AVEZET,SAVZET,CAVZET)
      CALL  SINCOS(AVEIN- AINW , SAVINW,CAVINW )
C
      TAVAEP  =  TAN(AVEALR -AVEEPP )
C
      TZET1 = (BLS-PC*CAVINW+HP* SAVINW ) * TAVAEP
      TZET2 =  TZET1*CAVZET +PC*SAVINW +HP*CAVINW
      TZET3 =  ROTRAD*ROTRAD  - TZET2*TZET2
C
      IF(TZET3) 360,360,350
  350 CONTINUE
      ZETR2=  FSQRT(TZET3,WORK)
      ZETR1  =  TZET1 * SAVZET
C
      TZET4 = (BLS -(PC-CHORD)*CAVINW +HP*SAVINW )* TAVAEP
      TZET5 =  TZET4* CAVZET +(PC-CHORD)*SAVINW +HP*CAVINW
      TZET6 =  ROTRAD*ROTRAD - TZET5*TZET5
C
      ZETR3 =  TZET4 * SAVZET
      IF(TZET6) 360,360,355
  355 CONTINUE
      ZETR4=  FSQRT(TZET6,WORK)
C
      GO TO  37
  360 ZETR1=  0.
      ZETR2=  0.
      ZETR3=  0.
      ZETR4=  0.
   37 CONTINUE
      SIR =    COEF24*(ZETR1+ ZETR2 +ZETR3 +ZETR4 )
      SIRW =  COEF23 * SIR
      SIT  =  CHORD *(ZETR2 +ZETR4 )
      SIL  =   SIT - SIR
      SILW =  COEF24 * SIL
      APILW= COEF27*SIL
```

Figure G.6. (Continued)

```
         ARIRW=  COEF27*SIR
         CLILW= COEF29*ARILW/(COEF29*ARILW+CLALPH*(ARWING-ARILW))
         CLIRW= COEF29*ARIRW/(COEF29*ARIRW+CLALPH*(ARWING-ARIRW))
         BKALPR= (VSTAPL+CLILW*SVSTRL)/(VSTARL+SVSTRL)
         BKARPR=  (VSTAR+CLIRW*SVSTAR)/(VSTAR+SVSTAR)
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
C
C          ROTOR/ROTOR INTERFERENCE
   380   IF(V) 400,400,390
   390   BIGX = CONS57  -EPPRR
         RRI1   =  BT1 + BT2* BIGX +BT3 * BIGX *BIGX
         RRI2= RRI1*SVSTAR*SQRESR
         EPPRM=  -ATAN2(RRI2,VTOTLR+1.0)
         EPILR =  0.
         EPIRL = ABS(BETAF)* AINL * EPPRM  * CONS58
         GO TO 410
   400   BIGX = CONS57  - EPPLR
         RRI1   =  BT1 + BT2*BIGX +BT3 * BIGX*BIGX
         RRI2   =  RRI1 *SVSTRL * SQRESL
         EPPRM=  -ATAN2(RRI2,VTOTRR+1.0)
         EPILR = ABS(BETAF)* AINR * EPPRM  * CONS58
         EPIRL =      0.
   410   CONTINUE
         GEF   =  0.
         IF(NGEF.NE.1)  GO TO 200
         IF(HWC4.GE.DBPK16) GO TO 200
         GEF= (COEF35+4.*(HTC4-HWC4)*(HTC4-HWC4))/(COEF35+4.*(HTC4+
     *   HWC4)*(HTC4+HWC4))
   200   CONTINUE
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
                                  ( B L A N K   C A R D )
```

Figure G.6. (Continued)

```
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
                                   ( B L A N K   C A R D )
          C        FUSELAGE
 296               XF = SLF - XCG
 297               ZF = SHF - ZCG
          C        WING
 298               XW = SLW - XCG
 299               ZW = SHW - ZCG
          C        NACELLES
 300               XR = SL* CILAMR -XCG
 301               ZR = -SL* SILAMR -ZCG
          C
 302               XL = SL* CILAML -XCG
 303               ZL = - L* SILAML -ZCG
          C
          C        INTERMEDIATE CALCULATIONS
 304               ZRSIN  =   ZR* SILAMR
 305               ZRCOS  =   ZR* CILAMR
 306               XRSIN  =   XR* SILAMR
 307               XRCOS  =   XR* CILAMR
 308               ZLSIN  =   ZL* SILAML
 309               ZLCOS  =   ZL* CILAML
 310               XLSIN  =   XL* SILAML
 311               XLCOS  =   XL* CILAML
 312               ZFMFHF =   ZF* COEF5
 313               ZWMWHW =   ZW* COEF6
 314               XFMFLF =   XF* COEF7
 315               XWMWLW =   XW* COEF8
 316               TERM1  =   COEF2 *(SSQINR+SSQINL)
 317               TERM2  =   FIXZPP *(S2INR + S2INL)
 318               TERM3  =   COEF4 *(ZRSIN +ZLSIN)
 319               TERM4  =   COEF3 *(S2INR +S2INL)* 0.5
 320               TERM5  =   FIXZPP*(C2INR +C2INL)
 321               TERM6  =   COEF4 *(XRCOS + XLCOS )
          C
          C        INERTIAS
 322               FIXX = XXICON -TERM1 -TERM2 +ZFMFHF+ZWMWHW -TERM3
 323               FIXZP= XZICON +TERM4+ TERM5+ZF*COEF7+ZW*COEF8+COEF4*(ZRCOS+ZLCOS)
 324               FIYY = YYICON+XFMFLF+ZFMFHF+XWMWLW+ZWMWHW+TERM6 -TERM3
 325               FIXZS = FIXZP
 326               FIZZ  = ZZICON +TERM1 +TERM2+XFMFLF+XWMWLW +TERM6
 327               FJXX = FIZZ-FIYY
 328               FJYY = FIXX-FIZZ
 329               FJZZ = FIYY-FIXX
 330               FIXZN = FIXZP
```

Figure G.6. (Continued)

```
          DOVIXX=    1./FIXX
          DOVIYY=    1./FIYY
          DOVIZZ=    1./FIZZ
          ISLOW= 0
          CALL TRACK('RTSLOW  ',2)
          RETURN
    500   DO 510 J=1,32
    510     CALL DISABL(J-1)
    520   IPAN = KPAN
          RETURN
          END
```

Figure G.6. (Continued)

```
  I N D E X                                   SUBROUTINE RTSLOW                                        PAGE   71

SYMBOL     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-   REFERENCES   -+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

10       -    28*
35       -    36*
36       -    32      36      37*
200      -   292     293     295*
350      -   248     249*
355      -   256     257*
360      -   248     256     261*
370      -   259     264*
380      -   276*
390      -   276     277*
400      -   276     284*
410      -   283     290*
412      -   127     129     132     135*
413      -   134     139*
414      -   139     142     143     144*
415      -   147     151*
50       -    36     337*
51       -   337DO   346*
52       -   339*
62       -   106     [illegible]
63       -   105     [illegible]  [illegible]  111*
64       -   116     122*
65       -   115     [illegible]  1[illegible]  124
72       -   164     169*
73       -   168     172*
76       -   178     183*
77       -   182     186*
ABS      -    88      39      [illegible]  [illegible]  [illegible]  124  141  154  173  175  176  177  178
             197     139     13[illegible]  1[illegible]  214  220  282  288
ADC3     -    9C0
AGGVAT   -   19C0    1[illegible]=   117=    11[illegible]=   112
AGGVAW   -   19C0    113=    117=    121=    124
AICL     -   21C0
AICLDP   -   21C0
AICLPP   -    9C0
AICP     -   21C
AICPDP   -   21C0
AICPPP   -    9C0
AINITL   -    9C0
AINDTP   -    9C0
AINHT    -   12C0
AINL     -    9C0    242
AINM     -    9C0    218
AINREF   -    9C0
AINW     -   12C0    229AC
AKEY     -   12C0    215AC
ALAFRO   -   25C0
ALAMDA   -   13C0
ALARE    -   19C0
ALAREP   -   18C0    1[illegible]1=
ALARHT   -   24C0
ALARNC   -   21C0
ALARNL   -   21C0
```

Figure G.6. (Continued)

```
ALAFNR   -   21C0
ALART    -   24C0
ALARVT   -   24C0
ALARWG   -   22C0
ALPRK    -   10C0
ALFSQ    -   18C0
ALFTAB   -   13C0
ALHTE    -   24C0
ALHTM    -   24C0
ALHTP    -   24C0
ALHTPR   -   24C0
ALHTST   -   10C0
ALLNSQ   -   20C0
ALLRH    -   21C0
ALLWPR   -   22C0
ALNCBK   -   10C0    154      178
ALPHF    -   18C0     94AG
ALPHFP   -   86=      38       89       91
ALPHHT   -   24C0
ALPHLN   -   20C0    152=     156AG    164      173
ALPHLR   -   21C0    224      239
ALPHLW   -   22C0
ALPHRN   -   20C0    153=     157AG    179      137
ALPHRR   -   21C0    225      239
ALPHRW   -   22C0
ALPHVT   -   24C0
ALRGLW   -   22C0
ALRGRW   -   22C0
ALRNSQ   -   20C0
ALRRH    -   21C0
ALRWPR   -   22C0
ALVTE    -   24C0
ALVTM    -   24C0
ALVTP    -   24C0
ALVTPR   -   24C0
ALVTST   -   10C0
ALWSSQ   -   22C0
AMACH    -   16C0     55=      56
AMACLP   -    9C0
AMACRP   -    9C0
AMACSQ   -   16C0     56=      57
AMACTL   -   23C0
AMACTR   -   23C0
AMAFRO   -   25C0
AMARF    -   18C0
AMARFP   -   18C0     39=
AMARHT   -   24C0
AMARLW   -   22C0
AMARNC   -   21C0
AMARNL   -   21C0
AMARNR   -   21C0
AMARRW   -   22C0
AMART    -   24C0
AMARVT   -   24C0
AMARWG   -   22C0
```

Figure G.6. (Continued)

```
AMEM    -   12CO   215AG
AMLRH   -   21CO
AMRNLP  -   21CO
AMRNRP  -   21CO
AMROTL  -   21CO
AMROTR  -   21CO
AMRRH   -   21CO
AMUL    -   17CO   139     144
AMULSQ  -   17CO
AMUR    -   17CO   127     131
AMURSQ  -   17CO
ANAERO  -   25CO
ANARF   -   18CO
ANARFP  -   18CO   10=
ANARHT  -   24CO
ANARNC  -   21CO
ANARNL  -   21CO
ANARNR  -   21CO
ANART   -   24CO
ANARVT  -   24CO
ANARWC  -   22CO
ANDIG   -    3CO
ANDIG2  -    3CO
ANLRH   -   21CO
ANROTL  -   21CO
ANROTR  -   21CO
ANRRH   -   21CO
AREAHT  -   10CO
AREAVT  -   10CO
AREAW   -   10CO    49
ARHT    -   10CO
ARILW   -   22CO   270=    272
ARIRW   -   22CO   271=    273
ARVT    -   10CO
ARWING  -    9CO   272     273
ARWSSQ  -   22CO
ATAN2   -  152     153     154     155     2     222     224     236     28     237
ATAJLP  -   22CO   229=    231AG
ATAURP  -   22CO   214=    215AG
AVEALR  -   22CO   239=    244
AVEALW  -   22CO
AVECLW  -   22CO
AVECTS  -   22CO   241=
AVEEPP  -   22CO   24 =    244
AVEIN   -   14CO   243AG
AVEVAC  -   10CO
AVEYCS  -   10CO
AVEZET  -   22CO   238=    242AG
BDNOS   -    3CO
BETAF   -   18CO    85AG   282     288
BETAFP  -   87=     89      90      92
BETALN  -   22CO   154=    158AG
BETALW  -   22CO
BETARN  -   22CO   155=    159AG
BETARW  -   22CO
```

Figure G.6. (Continued)

BETFSQ	-	18CO						
BETVT	-	24CO						
BICL	-	21CO						
BICLDP	-	21CO						
BICLPP	-	9CO						
BICR	-	21CO						
BICRDP	-	21CO						
BICRPR	-	9CO						
BIGX	-	19CO	277=	278	284=	285		
BKALPR	-	22CO	274=					
BKARPR	-	22CO	275=					
BKD1T	-	10CO	132	145				
BKD2T	-	10CO	132	145				
BKD3T	-	10CO	132	145				
BKEY	-	12CO	230AG					
BKLSW	-	10CO						
BKM1T	-	10CO	133	146				
BKM2T	-	10CO	133	146				
BKM3T	-	10CO	133	146				
BKM4T	-	10CO	137	150				
BKNSW	-	10CO						
BK99	-	19CO	114=	118=	122=	125		
BLS	-	10CO	126	245	252			
BMEM	-	12CO	230AG					
BMOVTL	-	19CO	146=	150=				
BMOVTR	-	19CO	133=	137=				
BTLNSQ	-	20CO						
BTRNSQ	-	20CO						
BT1	-	10CO	278	285				
BT2	-	10CO	278	285				
BT3	-	10CO	278	285				
CALIHT	-	24CO						
CALLN	-	20CO	156AG	160	202	203	206	207
CALLW	-	22CO						
CALRN	-	20CO	157AG	161	196	197	200	201
CALRW	-	22CO						
CAVINW	-	22CO	243AG	245	246	252	253	
CAVZET	-	22CO	242AG	246	253			
CBCMF	-	18CO	95=	100	101			
CBETLN	-	20CO	158AG	162	202	204	205	
CBETLW	-	22CO						
CBETRN	-	20CO	159AG	163	196	198	199	
CBETRW	-	22CO						
CBETSG	-	24CO						
CDCNTL	-	22CO						
CDCNTR	-	22CO						
CDDUM	-	22CO						
CDF	-	18CO	39=	96	97	98		
CDHT	-	24CO						
CDHTST	-	24CO						
CDLN	-	20CO	173=	202	203	204		
CDLWAD	-	22CO						
CDLWPR	-	22CO						
CDLWSS	-	22CO						
CDOF	-	10CO	99					

Figure G.6. (Continued)

```
COOHT    -   10C0
COCLN    -   22C0   165=    169=    173
COONHI   -   10C0   169     183
COONLO   -   10C0   165     179
COORN    -   20C0   179=    183=    187
COOVT    -   10C0
CORN     -   20C0   187=    196     197     198
CORWAD   -   22C0
CORWPR   -   22C0
CORWSS   -   22C0
COSLW    -   22C0
COSRW    -   22C0
COVT     -   24C0
COVTST   -   24C0
COWCOP   -   19C0   125=
CEPLW    -   22C0
CEPRW    -   22C0
CGGTVP   -   15*
CHORD    -   10C0    29     139     205     252     253     267
CILAML   -   14C0    52     302     309     311
CILAMR   -   14C0    52     302     305     307
CLALHT   -   10C0
CLALPH   -   10C0   272     273
CLAT     -   24C0
CLAVF    -   22C0
CLCNTL   -   22C0
CLCNTR   -   22C0
CLDUM    -   22C0
CLF      -   19C0    38=     96      97
CLHT     -   24C0
CLHTST   -   24C0
CLILW    -   22C0   272=    274
CLIRW    -   22C0   273=    275
CLLN     -   20C0   174=    202     203
CLLWAD   -   22C0
CLLWPP   -   22C0
CLLWSS   -   22C0
CLMAX    -   10C0
CLOAL    -   10C0
CLRN     -   20C0   198=    196     197
CLRWAD   -   22C0
CLRWPR   -   22C0
CLRWSS   -   22C0
CLSLW    -   22C0
CLSRW    -   22C0
CLSW     -   22C0
CLTCOR   -   19C0   112=
CLWCOF   -   13C0   124=
CLZERC   -   22C0
CMCNTL   -   22C0
CMCNTR   -   22C0
CMF      -   18C0    91=     95      99
CMLN     -   20C0   175=    205     206     207
CMLWAD   -   22C0
CMLWSS   -   22C0
```

Figure G.6. (Continued)

```
CMOF     -   1000    91
CMON     -   1000   175    189
CMOW     -   2500
CMRN     -   2000   189=   199    200    201
CMRWAO   -   2200
CMRWSS   -   2200
CMSLW    -   2200
CMSRW    -   2200
CNF      -   1800    92=   100    101
CNFAIL   -   2100
CNFAIR   -   2100
CNFBIL   -   2100
CNFBIR   -   2100
CNFL     -   2100
CNFPL    -    900
CNFPR    -    900
CNFR     -   2100
CNLN     -   2000   177=   206    207
CNOF     -   1000    92
CNOLN    -   1000   177
CNORN    -   1000   191
CNRN     -   2000   191=   200    201
CNSW     -   2200
COEF1    -    800    52     53
COEF10   -    800
COEF11   -    800
COEF12   -    800
COEF13   -    800
COEF14   -    800
COEF15   -    800
COEF16   -    800
COEF17   -    800    95    200    201    206    207
COEF18   -    800   194    195
COEF19   -    800
COEF2    -    800
COEF20   -    800
COEF21   -    800
COEF22   -    800
COEF23   -    800
COEF24   -    800
COEF25   -    800   211
COEF26   -    800   265
COEF27   -    800   270    271
COEF28   -    800   266    269
COEF29   -    800   272    273
COEF3    -    800   316    319
COEF30   -    800   125
COEF31   -    800
COEF32   -    800
COEF33   -    800
COEF34   -    800
COEF35   -    800   294
COEF36   -    800
COEF37   -    800
COEF38   -    800
```

Figure G.6. (Continued)

COEF39	-	8C0			
COEF4	-	8C0	318	321	323
COEF40	-	8C0			
COEF41	-	8C0			
COEF42	-	8C0			
COEF5	-	8C0	312		
COEF6	-	8C0	313		
COEF7	-	8C0	314	323	
COEF8	-	8C0	315	323	
COEF9	-	8C0			
CONS1	-	26C0			
CONS10	-	26C0			
CONS11	-	26C0			
CONS12	-	26C0			
CONS13	-	26C0			
CONS14	-	26C0			
CONS15	-	26C0			
CONS16	-	26C0			
CONS17	-	26C0			
CONS18	-	26C0			
CONS19	-	26C0			
CONS2	-	26C0			
CONS20	-	26C0			
CONS21	-	26C0			
CONS22	-	26C0			
CONS23	-	26C0			
CONS24	-	26C0			
CONS25	-	26C0			
CONS26	-	26C0			
CONS27	-	26C0			
CONS28	-	26C0			
CONS29	-	26C0			
CONS3	-	26C0			
CONS30	-	26C0			
CONS31	-	26C0			
CONS32	-	26C0			
CONS33	-	26C0			
CONS34	-	26C0			
CONS35	-	26C0			
CONS36	-	26C0			
CONS37	-	26C0			
CONS38	-	26C0			
CONS39	-	26C0			
CONS4	-	26C0			
CONS40	-	26C0			
CONS41	-	26C0			
CONS42	-	26C0			
CONS43	-	26C0			
CONS44	-	26C0	117		
CONS45	-	26C0	117		
CONS46	-	26C0	117		
CONS47	-	26C0	121		
CONS48	-	26C0	121		
CONS49	-	26C0	121		
CONS5	-	26C0			

Figure G.6. (Continued)

	CONS50	-	26C0	128	141							
	CONS51	-	26C0	131	144							
	CONS52	-	26C0	131	144							
	CONS53	-	26C0	131	144							
	CONS54	-	26C0	131	144							
	CONS55	-	26C0	131	144							
	CONS56	-	26C0	131	144							
	CONS57	-	26C0	277	284							
	CONS58	-	26C0	282	288							
	CONS59	-	26C0	107								
	CONS6	-	26C0									
	CONS6C	-	26C0	107								
	CONS61	-	26C0	107								
	CONS62	-	26C0	110								
	CONS63	-	26C0	110								
	CONS64	-	26C0	110								
	CONS65	-	26C0									
	CONS66	-	26C0									
	CONS67	-	26C0									
	CONS68	-	26C0									
	CONS69	-	26C0									
	CONS7	-	26C0									
	CONS7C	-	26C0									
	CONS71	-	26C0									
	CONS72	-	26C0									
	CONS73	-	26C0									
	CONS74	-	26C0									
	CONS75	-	26C0									
	CONS76	-	26C0									
	CONS77	-	26C0									
	CONS78	-	26C0									
	CONS79	-	26C0									
	CONS8	-	26C0									
	CONS80	-	26C0									
	CONS81	-	26C0									
	CONS9	-	26C0									
*	CONTRL	-	2*									
	COSALF	-	18C0	94AG	86	94	96	97	100			
	COSBTF	-	18C0	95AG	87	96	98	99				
	COSINL	-	14C0	46	141							
	COSINR	-	14C0	47	126	128						
	COSIW	-	8C0									
	COSLAM	-	8C0									
	COSPHI	-	18C0	41AG	54	55	126	128	141			
	COSPSI	-	14C0	39AG	54	55						
	COSTHF	-	18C0	40AG	54	55	102	103	126	128	140	141
	COSZHL	-	21C0									
	COSZHR	-	21C0									
	CPHIP	-	8C0									
	CPL	-	9C0									
	CPMAIL	-	21C0									
	CPMAIR	-	21C0									
	CPMBIL	-	21C0									
	CPMBIR	-	21C0									
	CPML	-	21C0									

Figure G.6. (Continued)

```
CPMPL    -     9CO
CPMPR    -     9CO
CPMR     -    21CO
CPR      -     9CO
CSFAIL   -    21CO
CSFAIR   -    21CO
CSFBIL   -    21CO
CSFBIR   -    21CO
CSFL     -    21CO
CSFPL    -     9CO
CSFPR    -     9CO
CSFR     -    21CO
CTAULR   -    22CO   229AG   235
CTAURR   -    22CO   219AG   221
CTL      -    21CO
CTLPRM   -     9CO
CTR      -    21CO
CTPPRM   -     9CO
CTSLR    -    22CO   237=    241
CTSRR    -    22CO   223=    241
CYALVT   -    10CO
CYAT     -    24CO
CYF      -    13CO    95=     96     97     98
CYLN     -    20CO   176=    202    203    204
CYMAIL   -    21CO
CYMAIR   -    21CO
CYMBIL   -    21CO
CYMBIR   -    21CO
CYML     -    21CO
CYMPL    -     9CO
CYMPR    -     9CO
CYMR     -    21CO
CYRN     -    20CO   195=    196    197    198
CYVT     -    24CO
CYVTST   -    24CO
C2INL    -    14CO    44=    320
C2INR    -    14CO    45=    322
DBRK1    -    26CO
DBRK10   -    26CO   116
DBRK11   -    25CO   121
DBRK12   -    26CO   127     139
DBRK13   -    26CO   131     143
DBRK14   -    26CO   136
DBRK15   -    26CO   139
DBRK16   -    26CO   293
DBRK17   -    26CO
DBRK18   -    26CO
DBRK19   -    26CO
DBRK2    -    26CO
DBRK20   -    26CO
DBRK21   -    26CO
DBRK3    -    26CO
DBRK4    -    26CO
DBRK5    -    26CO
DBRK6    -    26CO
```

Figure G.6. (Continued)

DBRK7	-	26C0			
DBRK8	-	26C0			
DBRK9	-	26C0			
DCDDF	-	22C0			
DCDLDA	-	22C0			
DCDLG	-	10C0	89		
DCDLSP	-	22C0			
DCDRDA	-	22C0			
DCDRSP	-	22C0			
DCLDF	-	22C0			
DCLLDA	-	22C0			
DCLLSP	-	22C0			
DCLRDA	-	22C0			
DCLRSP	-	22C0			
DCLSPW	-	22C0			
DCMDF	-	22C0			
DCMLDA	-	22C0			
DCMLG	-	10C0	91		
DCMLSP	-	22C0			
DCMRDA	-	22C0			
DCMRSP	-	22C0			
DCNSPW	-	22C0			
DEG20	-	10C0			
DEL	-	16C0	57=	62	69
DELBS	-	9C0			
DELBT	-	9C0			
DELELV	-	9C0			
DELFLP	-	9C0			
DELRS	-	9C0			
DELRT	-	9C0			
DELRUD	-	9C0			
DELSPL	-	9C0			
DELSPR	-	9C0			
DELSS	-	9C0			
DELST	-	9C0			
DELTH	-	9C0			
DFLAIL	-	9C0			
DFLAIR	-	9C0			
DGTORD	-	10C0			
DIGAN	-	3C0			
DIGAN2	-	3C0			
* DISABL	-	338*			
DLFPSQ	-	14C0			
DLLG	-	18C0			
DLLNC	-	20C0	207=		
DLRNC	-	20C0	201=		
DMLG	-	18C0			
DMLNC	-	20C0	205=		
DMRNC	-	20C0	199=		
DNLG	-	18C0			
DNLNC	-	20C0	206=		
DNRNC	-	20C0	200=		
DOVT	-	10C0	136	149	
DOVTL	-	19C0	145	149	
DOVTR	-	19C0	132	136	

Figure G.6. (Continued)

```
  CSDRFT   -   10C0
  DTIM     -    3C0
  DUM12    -    9C0
  DUM13    -    9C0
  DUM14    -    9C0
  DUM15    -    9C0
  DUM43    -    9C0
  DUM44    -    9C0
  DUM45    -    9C0
  DUM46    -    9C0
  DUM47    -    9C0
  DUM48    -    9C0
  DXLG     -   18C0
  DXLNC    -   20C0   233=
  DXRNC    -   20C0   197=
  DYLG     -   18C0
  DYLNC    -   20C0   234=
  DYRNC    -   20C0   198=
  DZLG     -   18C0
  DZLNC    -   20C0   232=
  DZRNC    -   20C0   196=
  EFFHT    -   10C0
  EFFVT    -   10C0
  EMAXN1   -   15C0    74=     78
  EMAXN2   -   16C0    75=     76
  EMXWDT   -   16C0    77=     77
  ENFL     -    9C0    31
  ENFR     -    9C0    32
* ENG      -    5*
* ENGINE   -   79*
* ENGVAR   -   16*
  EN1MX    -    5C0    74
  EN1STP   -    5C0
  EN1TMX   -    5C0
  EN2MX    -    5C0    76
  EN2REF   -   10C0    75
  EN2STR   -   16C0    76=
* EOMVAP   -   25*
  EPILR    -   22C0   281=    258=
  EPIRL    -   22C0   282=    259=
  EPPLR    -   22C0   236=    240     284
  EPPPM    -   19C0   290=    292     287=    288
  EPPRR    -   28C0   273=    240     277
  EPTAIL   -   24C0
  EPTL1    -   24C0
  EPRRL    -   22C0
  EPWPR    -   22C0
  EPZERO   -   24C0
  EQMX     -    5C0
  EWDTMX   -    5C0    73
  EWDTPP   -    5C0    73
  FEU      -   10C0
  FIE      -   10C0
  FIMDEG   -   10C0
  FIMPR    -   10C0
```

Figure G.6. (Continued)

```
  FIP     -   10C0
  FIPOML  -   21C0
  FIPOMR  -   21C0
  FIXX    -   25C0   322=   328    329    331
  FIXXF   -   10C0
  FIXXPR  -   10C0
  FIXXW   -   10C0
  FIXZF   -   10C0
  FIXZP   -   25C0   323=   325    330
  FIXZPR  -   10C0   317    320
  FIXZQ   -   25C0   325=
  FIXZR   -   25C0   330=
  FIXZW   -   10C0
  FIYY    -   25C0   324=   327    329    332
  FIYYF   -   10C0
  FIYYPR  -   10C0
  FIYYW   -   10C0
  FIZZ    -   25C0   326=   327    328    333
  FIZZF   -   10C0
  FIZZPR  -   10C0
  FIZZW   -   10C0
  FJXX    -   25C0   327=
  FJYY    -   25C0   328=
  FJZZ    -   25C0   329=
* FLAGS   -    6*
  FNORML  -   21C0   224    225
  FNORMR  -   21C0   209    210
  FSIDEL  -   21C0   225
  FSIDER  -   21C0   210
  FSMACH  -   16C0    67=    68
          THE VARIABLE- FSQRT   -IS USED BEFORE IT IS DEFINED
  FSQRT   -   50     51     60     67     210    212    225    226    250    258
* FUSVAR  -   18*
  GAATAB  -   13C0
  GBATAB  -   13C0
  GBUTON  -    6C0
  GEF     -   19C0   291=   294=
* GFFVAR  -   19*
* GETBIT  -   30*     31*
  GKEY    -   12C0
  GMEM    -   12C0
  H       -    9C0   49     57     58     102    103    126
  HDOT    -    9C0
  HDTACL  -   23C0
  HDTACR  -   23C0
  HGEFLR  -   19C0   141=   143    144    145    145
  HGEFRR  -   19C0   128=   130    131    132    133
  HLHUB   -   19C0   140=   141
  HOLD    -    3C0
  HOLD2   -    3C0
  HP      -   10C0   245    246    252    253
  HRHUB   -   19C0   126=   128    140
  HSQ     -   14C0    48=    57
  HTC4    -   19C0   103=   106    107    109    110    294
  HTSTLL  -    8C0
```

Figure G.6. (Continued)

```
   HTVTKT  -   13CD
   HWACL   -   23CD
   HWACR   -   23CD
   HWC4    -   19CD   112=   116    117    120    121    293    294
*  HYBCON  -     3*
*  HYBIO   -     4*
   H10TL   -   23CD
   H10TR   -   23CD
   HIL     -   23CD
   HIR     -   23CD
   IAD     -    3CD
   IADC3   -   11CD
   IC      -    3CD
   ICDSPC  -    2CD
   ICLR    -    3CD
   ICONOP  -    6CD   30AG
   IC2     -    3CD
   IDUPC   -    3CD
   IFC     -    3CD   28AG
   IFCHAN  -    3CD
   IFLAG   -    2CD
   IFRAME  -    3CD
   IGN     -    3CD
   IHJ9    -    3CD
   ILEX    -    3CD
*  INITVR  -   14*
   IOC     -    3CD
   IOC21   -    3CD
   IPAN    -    2CD   339=
   IPHASE  -    6CD
   IPSNDS  -    3CD
   IRCTS   -    3CD
   IRCX    -    3CD
   IREVNT  -   29AG
   IRUNIT  -    3CD
   ISCOPF  -    2CD
   ISENCF  -    6CD   29AG   30AG   31AG
   ISETC   -    3CD
   ISMPC   -    3CD
   ISLOW   -    6CD   334=
   ISTA    -    6CD   215AG  218
   ISTAD   -    3CD
   ISTAD2  -    3CD
   ISTR    -    6CD   230AG  233
   ISTDA   -    3CD
   ISTDA2  -    3CD
   ISTGD   -    3CD
   ISTGD2  -    3CD
   ISTHD   -    3CD
   ISTHD2  -    3CD
   ISTIC   -    3CD
   ISTIC2  -    3CD
   ISTPIT  -    3CD
   ISTRB1  -   11CD   36
   ISTRN   -    3CD
```

Figure G.6. (Continued)

```
  ISTRM2  -     3CO
  ISYNC   -     3CO
  ITRIM   -     6CO    32      35=
  ITSC    -     3CO
  IWARN1  -     6CO    7LG     217=    219=    231=    233=
  IWARN2  -     6CO    7LG
  IWREVT  -     6CO
  J       -   33700    338AG
  JTRIM   -     6CO    32
  KAR     -     4CO
  KONFR   -     2CO
  KPAN    -     29=    34=     216=    232=    339
  KTRIM   -     6CO    31AG    32
  LETR    -     3CO
* LINT    -    215*    230*
  MICNT   -     2CO
  MIECR   -     2CO
  MONDIG  -     3CO
* NACVAR  -     20*
  NADCS   -     3CO
  NCHAIN  -     3CO
  NCON    -     3CO    28AG
  NCONSL  -     3CO
  NDACS   -     3CO
  NFRAME  -     2CO
  NGEF    -     6CO    105     115     129     142     292
  NIOS    -     3CO
  NOSIM   -     2CO
  NPCS    -     3CO
  NPLOT   -     6CO
  NPLOT2  -     6CO
  NQIND   -     5CO
  NRNOID  -     5CO
  NTWST   -     6CO
  NVB     -     6CO
  NWDTID  -     5CO
  N1IND   -     5CO
  N1THID  -     5CO
  N2IND   -     5CO
  OMDOT   -     9CO
  OMDTL   -    17CO
  OMDTR   -    17CO
  OMEGA   -     9CO    75
  OMEGAL  -    17CO
  OMEGAR  -    17CO
  OMEGEL  -    16CO    81=
  OMEGER  -    16CO    79AG    81      82=
  OMREF   -    10CO    75
  OMSQL   -    17CO
  OMSQR   -    17CO
  ONOVTC  -    16CO    61=     62      72
  OOVDSK  -     8CO
  OOVFSM  -    16CO    68=     112     124
  OOVIXX  -    25CO    331=
  OOVIYY  -    25CO    332=
```

Figure G.6. (Continued)

```
  OOVI77   -   25CO   333=
  OPERA    -    3CO
  OPERA2   -    3CO
  OVDTIM   -    9CO
  OVSQTH   -   16CO    71=    74
  OVTHOL   -   15CO    72=    73
  P        -   25CO
  PC       -   10CO   245    246    252    253
  PCTQL    -   16CO
  PCTQR    -   16CO    79AG
  PGUST    -    9CO
  PHI      -    9CO    41AG
  PHIPH    -   10CO
  PI       -   10CO
  PILMSK   -    2CO
  PIOV2    -   10CO
  PNLN     -   21CO
  PNLR     -   21CO
  PNRN     -   21CO
  PNRR     -   21CO
  PP       -   25CO
  PPRIME   -    9CO
  PQ       -   25CO
  PR       -   25CO
  PROJ     -    3CO
  PSI      -    9CO    39AG
  Q        -   25CO
  QESW     -   13CO    49=    96     97     98     99     100    101
  QGUST    -    9CO
  QNLN     -   21CO
  QNLR     -   21CO
  QNRN     -   21CO
  QNRR     -   21CO
  QPRIME   -    9CO
  R        -   25CO
  RCPL     -   11CO    33AG
  RDTODG   -   10CO
  RESLR    -   22CO   225=   226
  RESRR    -   22CO   211=   212
* RETURN   -  335*    34?=
* REVENT   -   28*
  RGUST    -    9CO
  RNLN     -   21CO
  RNLR     -   21CO
  RNRN     -   21CO
  RNRR     -   21CO
  ROE      -   16CO    62=    63    211
  ROEOV2   -   16CO    63=   192    193
  ROEO     -    5CO    62
  ROPIR4   -   21CO
  ROPIR5   -   21CO
  ROTEPS   -   10CO
  ROTRAD   -   10CO   138    141    247    254
* ROTVAR   -   21*
  RPRIME   -    9CO
```

Figure G.6. (Continued)

```
  RQ       -   25CO
  RR       -   25CO
  RRI1     -   19CO   278=    279    285=    286
  RRI2     -   19CO   279=    280    286=    287
* RTPASS   -    8*
* RTSLOW   -    1*
  SALIHT   -   24CO
  SALLN    -   20CO   156AG   160    202     203     207
  SALLW    -   22CO
  SALRN    -   20CO   157AG   161    196     197     201
  SALRW    -   22CO
  SAVINW   -   22CO   243AG   245    246     252     253
  SAVZET   -   22CO   242AG   251    255
  SBETLN   -   20CO   158AG   162    202     203     204     206     207
  SBETLW   -   22CO
  SBETRN   -   20CO   159AG   163    196     197     198     200     201
  SBETRW   -   22CO
  SBETSG   -   24CO
  SBFCAF   -   19CO    94=     97    101
  SBFPR    -   10CO
  SBFSAF   -   18CO    93=     96    100
  SBWPR    -   10CO
  SP1      -   19CO
  SCADC1   -    9CO
  SCADC2   -    9CO
  SCADC3   -    9CO
  SCADC4   -    9CO
  SCDAC1   -    9CO
  SCDAC2   -    9CO
  SCDAC3   -    9CO
  SCDAC4   -    9CO
  SEPLW    -   22CO
  SEPRW    -   22CO
  SFNFL    -   26CO
  SFNFR    -   26CO
  SFPL     -   26CO
  SFPML    -   26CO
  SFPMR    -   26CO
  SFPR     -   26CO
  SFQL     -   26CO
  SFQR     -   26CO
  SFSFL    -   26CO
  SFSFR    -   26CO
  SFTL     -   26CO
  SFTR     -   26CO
  SFYML    -   26CO
  SFYMR    -   26CO
  SG       -   10CO
  SGNULW   -   22CO
  SGNURW   -   22CO
  SHF      -   10CO   207
  SHPPRL   -   16CO    80=
  SHPPRR   -   16CO    79AG    80
  SHPROL   -   21CO
  SHPROR   -   21CO
```

Figure G.6. (Continued)

```
SHPSTR  -    5CO
SHW     -   10CO    239
SIGMA   -   24CO
SIL     -   22CO    268=    269     270
SILAML  -   14CO     53     303     308     310
SILAMP  -   14CO     53     301     304     306
SILW    -   22CO    259=
SINALF  -   18CO    84AG     86      93      96      97     101
SINBTF  -   18CO    85AG     87      93      94      98
SINCOS  -   39*     40*     41*     84*     85*    156*    157*    158*    159*    219*    228*    242*    243*
SININL  -   14CO     43      46     141
SININR  -   14CO     42      47     126     128
SINIW   -    8CO
SINLAM  -    9CO
SINPHI  -   18CO    41AG     54      55     126     140
SINPSI  -   14CO    39AG     54      55
SINTHE  -   18CO    40AG     54      55     102     103     126     128     141
SINZHL  -   21CO
SINZHP  -   21CO
SIR     -   22CO    265=    266     268     271
SIRW    -   22CO    266=
SIT     -   22CO    267=    268
SKEPS   -   10CO
SK0     -   10CO     83
SK1     -   10CO     39
SK10    -   10CO     32
SK2     -   10CO     39
SK20    -   10CO
SK21    -   10CO
SK22    -   10CO
SK3     -   10CO     88
SK30HI  -   10CO    170     194
SK30L   -  166=     170=    173
SK30LO  -   10CO    166     180
SK30R   -  180=     134=    197
SK31HI  -   10CO    171     185
SK31L   -  167=     171=    173
SK31LO  -   10CO    167     181
SK31R   -  181=     185=    187
SK32    -   10CO    174     188
SK34    -   10CO    175     189
SK35    -   10CO    175     189
SK36    -   10CO    190
SK37    -   10CO    190
SK38    -   10CO    191
SK39    -   10CO    191
SK4     -   10CO     93
SK40    -   10CO    177
SK41    -   10CO    177
SK42    -   10CO     99
SK43    -   10CO    176
SK44    -   10CO    176
SK45    -   10CO
SK46    -   10CO
SK47    -   10CO
```

Figure G.6. (Continued)

```
  SK48    -  10CO
  SK49    -  10CO
  SK5     -  10CO    91
  SK50    -  10CO
  SK6     -  10CO    91
  SK7     -  10CO    90
  SK8     -  10CO    90
  SK9     -  10CO    92
  SL      -  10CO   300     301     302     303
  SLAC    -   8CO
  SLF     -  10CO   296
  SLPA    -  10CO
  SLW     -  10CO   298
  SM      -  10CO
  SMA     -  16CO    64=     65
  SMF     -  10CO
  SMN     -  10CO
  SMW     -  10CO
  SPAN    -  10CO   100     101     200     201     206     207
  SPHIP   -   8CO
* SPID    -  11*
  SQF     -  18CO    49
  SQFARG  -  13CO
  SQFPRM  -  10CO
  SQLNC   -  20CO   192=    195
  SQLW    -  22CO
  SQNIMX  -  16CO    78=
  SQRESL  -  22CO   226=    227     286
  SQRESR  -  22CO   212=    213     279
  SQRNC   -  20CO   193=    194
  SQRW    -  22CO
  SQTHTC  -  16CO    60=     64      69      71
  SQWDTX  -  16CO    77=
  SQWING  -  22CO
  SSQINL  -  14CO    43=     44     315
  SSQINR  -  14CO    42=     45     316
  STAULR  -  22CO   228AG   234
  STAURR  -  22CO   219AG   220
  SUMIXX  -   8CO
  SUMIXZ  -   8CO
  SUMIYY  -   8CO
  SUMIZZ  -   8CO
  SVSTAB  -  13CO   215AG   230AG
  SVSTAR  -  22CO   215AG   220     221     275     279
  SVSTRL  -  22CO   230AG   234     235     274     286
  SWLG    -   6CO
  SWLG2   -   9CO    89      91
  S2INL   -  14CO    46=    317     319
  S2INR   -  14CO    47=    317     319
* TAILVR  -  24*
* TAN     -  244
  TAUAG   -  13CO
  TAUHT   -  10CO
  TAUL    -   3CO
  TAULR   -  22CO   224=    228AG   229
```

Figure G.6. (Continued)

```
     I N D E X                                        SUBROUTINE RTSLOW                                              PAGE   99

  TAURR   -     2200     209=     214      219AG
  TAURT1  -     1000
  TAURT2  -     1000
  TAUVT   -     1000
  TAVAEP  -     2200     244=     245      252
  TCOEF   -      500      58
  TDEGF   -     1600      58=      59
  TEAL    -     1600
  TEAR    -     1600      72=      79AG
  TERMP1  -     2500
  TERMQ1  -     2500
  TERMR1  -     2500
  TERM1   -     2500     316=     322      326
  TERM1L  -     2500
  TERM1R  -     2500
  TERM2   -     2500     317=     322      326
  TERM2L  -     2500
  TERM2R  -     2500
  TERM3   -     2500     319=     322      324
  TERM3L  -     2500
  TERM3R  -     2500
  TERM4   -     2500     319=     323
  TERM5   -     2500     320=     323
  TERM6   -     2500     321=     324      325
  THCDEL  -     1600      69=      70
  THF     -      900      40AG
  THETC   -     1600      59=      60       61
  THTLAC  -     2300
  THTRAC  -     2300
  TH75L   -      900
  TH75R   -      900
  TIGEL   -     1900     144=     148=
  TIGER   -     1900     131=     135=
  TL      -     2100     224      225
  TMWG1C  -     2300     220=     222
  TMWG11  -     2300     221=     222
  TNAC1   -     2000     194=     196      197      198      199      200      201
  TNAC2   -     2000     195=     202      203      204      205      206      207
  TORQL   -     2100
  TORQR   -     2100
  TPSP    -      900      72
  TR      -     2100     209      210
  TRACK   -     27*      335*
  TRIM    -      300
  TRIM2   -      300
  TRMAR1  -     2100
  TRMAR2  -     2100
  TRMAR3  -     2100
  TRMAR4  -     2100
  TRMHR1  -     2100
  TRMHR2  -     2100
  TRMHT   -     2400
  TRMHT2  -     2400
  TRMHT3  -     2400
  TRMNC1  -     160*     174      175
```

Figure G.6. (Continued)

```
  TRMNC2  -   161=   138    139
  TRMNC3  -   162=   176    177
  TRMNC4  -   163=   190    191
  TRMTTL  -   25CO
  TRMTTR  -   25CO
  TRMVT   -   24CO
  TRMVT2  -   24CO
  TRMVT3  -   24CO
  TRMWG1  -   22CO   211=   212    226
  TRMWG4  -   23CO   234=   236
  TRMWG5  -   22CO
  TRMWG6  -   22CO
  TRMWG7  -   22CO
  TRMWG8  -   22CO
  TRMWG9  -   23CO   235=   236
  TSBASE  -    3CO
  TSREQD  -    3CO
* TSTRTS  -   38*
  TZERO   -    5CO    58
  TZET1   -   22CO   245=   246    251
  TZET2   -   22CO   246=   247
  TZET3   -   22CO   247=   248    250
  TZET4   -   22CO   252=   253    255
  TZET5   -   22CO   253=   254
  TZET6   -   22CO   254=   256    258
  U       -   25CO
  UGUST   -    9CO
  UHT     -   17CO
  ULW     -   17CO
  ULWPR   -   17CO
  ULWSQ   -   17CO
  UP      -   17CO
  UPRIME  -    9CO    54     55
  URL     -   17CO   152
  URLPR   -   17CO
  URLURL  -   17CO    51    192
  URR     -   17CO   153
  URRPR   -   17CO
  URRURR  -   17CO    50    193
  URW     -   17CO
  URWPR   -   17CO
  URWSQ   -   17CO
* USEAIO  -   33*
  USQ     -   17CO
  UVT     -   17CO
  V       -   25CO   276
  VALFLW  -   17CO
  VALFRW  -   17CO
  VALFS   -   17CO
  VALNCL  -   17CO    51=   154
  VALNCR  -   17CO    50=   155
  VBETVT  -   17CO
  VEAST   -   15CO    55=
* VELVAR  -   17*
  VGUST   -    9CO
```

Figure G.6. (Continued)

```
  VLW     -   17C0
  VLWPR   -   17C0
  VLWSQ   -   17C0
  VNORTH  -   15C0    54=
  VP      -   17C0
  VPRIME  -    9C0    54      55
  VRL     -   17C0   154
  VRLPR   -   17C0
  VRLVRL  -   17C0   192
  VRR     -   17C0   155
  VRRPR   -   17C0
  VRRVRR  -   17C0   193
  VRW     -   17C0
  VRWPR   -   17C0
  VRWSQ   -   17C0
  VSQ     -   17C0
  VSTAR   -   22C0   213=    215AG   221     223     275
  VSTARG  -   13C0
  VSTARL  -   22C0   227=    230AG   235     237     274
  VTIPL   -   17C0
  VTIPR   -   17C0
  VTOTAL  -   17C0    65
  VTOTLR  -   17C0   227     280
  VTOTRR  -   17C0   213     287
  VTSTLL  -    8C0
  VVT     -   17C0
  VZETL   -   17C0
  VZETR   -   17C0
  W       -   25C0
  WDOT    -    9C0
  WGUST   -    9C0
  WHT     -   17C0
  WLW     -   17C0
  WLWPR   -   17C0
  WLWSQ   -   17C0
* WNGVAR  -   22*
* WNGVR2  -   23*
          THE VARIABLE- WORK    -IS USED BEFORE IT IS DEFINED
  WORK    -   50      51      60      67      21?     212     225     226     25?     258
  WP      -   17C0
  WPRIME  -    9C0    54      55
  WRL     -   17C0   152
  WRLPR   -   17C0
  WRLWRL  -   17C0    51     192
  WROTL   -   17C0
  WRR     -   17C0   153
  WRRPR   -   17C0
  WRRWRR  -   17C0    50     193
  WRW     -   17C0
  WRWPR   -   17C0
  WRWSQ   -   17C0
  WSQ     -   17C0
  WVT     -   17C0
  XAERF   -   18C0
  XAERLW  -   22C0
```

Figure G.6. (Continued)

	XAERNC	-	21C0										
	XAERNL	-	21C0										
	XAERNR	-	21C0										
	XAERO	-	25C0										
	XAERRW	-	22C0										
	XAERT	-	24C0										
	XAERWG	-	22C0										
*	XAIO	-	9*										
	XARFP	-	18C0	97=	99								
	XARHT	-	24C0										
	XARVT	-	24C0										
	XCG	-	15C0	52=	99	100	102	103	126	296	298	300	302
	XDTCG	-	15C0										
	XF	-	25C0	296=	314								
	XFAC	-	10C0	99	100								
	XFCON	-	8C0										
	XFMFLF	-	25C0	314=	324	326							
*	XFUNC	-	13*										
	XHT	-	10C0	103									
	XL	-	25C0	302=	310	311							
	XLCOS	-	25C0	311=	321								
*	XLINTP	-	12*										
	XLSIN	-	25C0	310=									
*	XPAP1	-	10*										
*	XPAP3	-	26*										
	XR	-	25C0	305=	306	307							
	XRCOS	-	25C0	307=	321								
	XRLCON	-	8C0	52									
	XRSIN	-	25C0	306=									
	XVT	-	10C0										
	XW	-	25C0	298=	315								
	XWAC	-	10C0	102									
	XWCON	-	8C0										
	XWC2	-	10C0										
	XWMWLW	-	25C0	315=	324	326							
	XYICON	-	8C0	322									
	XXJCON	-	8C0										
	XZICON	-	8C0	323									
	YAERF	-	18C0										
	YAERLW	-	22C0										
	YAERNC	-	21C0										
	YAERNL	-	21C0										
	YAERNR	-	21C0										
	YAERO	-	25C0										
	YAERRW	-	22C0										
	YAERT	-	24C0										
	YAERWG	-	22C0										
	YARFP	-	18C0	98=	100	101							
	YARHT	-	24C0										
	YARVT	-	24C0										
	YN	-	10C0	126	140								
	YPA	-	10C0										
	YWAC	-	10C0										
	YYICON	-	8C0	324									
	YYJCON	-	8C0										

Figure G.6. (Continued)

```
ZAERF    -   18C0
ZAERLW   -   22C0
ZAERNC   -   21C0
ZAERNL   -   21C0
ZAERNR   -   21C0
ZAERO    -   25C0
ZAERRW   -   22C0
ZAERT    -   24C0
ZAERWG   -   22C0
ZAREP    -   18C0    96=    99
ZARHT    -   24C0
ZARVT    -   24C0
ZCG      -   15C0    53=    99    101    102    103    126    297    299    301    303
ZDTCG    -   15C0
ZETHL    -   21C0   238
ZETHR    -   21C0   238
ZETR1    -   22C0   251=   260=   265
ZETR2    -   22C0   252=   261=   265    267
ZETR3    -   22C0   255=   262=   265
ZETR4    -   22C0   258=   263=   265    267
ZF       -   25C0   297=   312    323
ZFAC     -   10C0    99    101
ZFCON    -    8C0
ZFMFHF   -   25C0   312=   322    324
ZHT      -   10C0   103
ZL       -   25C0   303=   308    309
ZLCOS    -   25C0   309=   323
ZLSIN    -   25C0   308=   318
ZPA      -   10C0
ZR       -   25C0   301=   304    305
ZRCOS    -   25C0   305=   323
ZRLCON   -    8C0    53
ZRSIN    -   25C0   304=   318
ZVT      -   10C0
ZW       -   25C0   299=   313    323
ZWAC     -   10C0   102
ZWCON    -    8C0
ZWMWHW   -   25C0   313=   322    324
ZZICON   -    8C0   326
ZZJCON   -    8C0
```

+-

Figure G.6. (Continued)

I N D E X   SUBROUTINE AILSP(DEL,SPOIL,DCLA,DCDA,DCMA,DCLS,DCDS,DCMS)

```
      SUBROUTINE AILSP(DEL,SPOIL,DCLA,DCDA,DCMA,DCLS,DCDS,DCMS)
      COMMON/XPAR1/ XPAR(132),
     *FED    ,CLMAX ,ALBR  ,BKLSW ,BKSSW ,SCFPRM,DEG2D ,DGTORD,HTVTKT,    133TO141
     *PIOV2 ,RDTODG,ROTEPS,SKEPS ,ALNCBK,TAURT1,TAURT2
      COMMON/XPAR3/ CONS1 ,CONS2 ,CONS3 ,CONS4 ,CONS5 ,CONS6 ,CONS7 ,      1 TO  7
     1              CONS8 ,CONS9 ,CONS10,CONS11,CONS12,CONS13,CONS14,      8 TO 14
     2              CONS15,CONS16,CONS17,CONS18,CONS19,CONS20,CONS21,     15 TO 21
     3              CONS22,CONS23,CONS24,CONS25,CONS26,CONS27,CONS28,     22 TO 28
     4              CONS29,CONS30,CONS31,CONS32,CONS33,CONS34,CONS35,     29 TO 35
     5              CONS36,CONS37,CONS38,CONS39,CONS40,CONS41,CONS42,     36 TO 42
     6              CONS43,CONS44,CONS45,CONS46,CONS47,CONS48,CONS49,     43 TO 49
     7              CONS50,CONS51,CONS52,CONS53,CONS54,CONS55,CONS56,     50 TO 56
     8              CONS57,CONS58,CONS59,CONS60,CONS61,CONS62,CONS63,     57 TO 63
     9              CONS64,CONS65,CONS66,CONS67,CONS68,CONS69,CONS70,     64 TO 70
     A              DBRK1 ,DBRK2 ,DBRK3 ,DBRK4 ,DBRK5 ,DBRK6 ,DBRK7 ,     71 TO 77
     B              DBRK8 ,DBRK9 ,DBRK10,DBRK11,DBRK12,DBRK13,DBRK14,     78 TO 84
     *              DBRK15,DBRK16,DBRK17,DBRK18,DBRK19,DBRK20,DBRK21      85 TO 91
     D             ,SFTL  ,SFNFL ,SFSFL ,SFPML ,SFYML ,SFQL  ,SFPL  ,
     E              SFTR  ,SFNFR ,SFSFR ,SFPMR ,SFYMR ,SFQR  ,SFPR
     F             ,CONS71,CONS72,CONS73,CONS74,CONS75,CONS76,CONS77     106TO112
     G             ,CONS78,CONS79,CONS80,CONS81                          113TO116
C
      NOPT= 0
      GO TO 5
      ENTRY CLF1(DEL,CL7)
      NOPT= 1
    5 CONTINUE
C
       IF(DEL.GT.DBRK7) GO TO 30
      DCLA= CONS27*DEL
      GO TO 45
   30 IF(DEL.GT.DBRK8) GO TO 40
      DCLA= CONS28+DEL*(CONS29+CONS30*DEL)
      GO TO 45
   40 DCLA= CONS31+DEL*(CONS32+CONS33*DEL)
   45 CONTINUE
      IF(NOPT.NE.1) GO TO 48
      CL7= DCLA
      RETURN
   48 CONTINUE
C
      DCDA= 0.
C
      IF(DEL.GT.DBRK21) GO TO 50
      DCMA= DEL*(CONS34*DEL+CONS35)
      GO TO 55
   50 DCMA= DEL*(CONS36*DEL+CONS37)  +CONS38
   55 CONTINUE
C
      IF(SPOIL.GT.DBRK20) GO TO 60
      DCLS= CONS39*SPOIL
      GO TO 65
   60 DCLS= CONS40+SPOIL*(CONS57+CONS58*SPOIL)
   65 CONTINUE
C
```

Figure G.6. (Continued)

```
  32          DCDS= CONS69+SPOIL*(CONS70+CONS71*SPOIL)
        C
  33          DCMS= 0.
        C
  34          RETURN
  35          END
```

Figure G.6. (Continued)

```
I N D E X                SUBROUTINE AILSP(DEL,SPOIL,DCLA,DCDA,DCMA,DCLS,DCDS,DCMS)            PAGE   96

SYMBOL    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-   REFERENCES   -+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

  5        -     5       8*
  30       -     9      12*
  40       -    12      15*
  45       -    11      14       16*
  48       -    17      20*
  50       -    22      25*
  55       -    24      26*
  60       -    27      30*
  65       -    29      31*
* AILSP    -     1*
  ALBRK    -     200
  ALNCRK   -     200
  BKLSW    -     200
  BKNSW    -     200
* CLF1     -     6*
  CLMAX    -     200
  CLZ      -     6AS    18*
  CONS1    -     300
  CONS10   -     300
  CONS11   -     300
  CONS12   -     300
  CONS13   -     300
  CONS14   -     300
  CONS15   -     300
  CONS16   -     300
  CONS17   -     300
  CONS18   -     300
  CONS19   -     300
  CONS2    -     300
  CONS20   -     300
  CONS21   -     300
  CONS22   -     300
  CONS23   -     300
  CONS24   -     300
  CONS25   -     300
  CONS26   -     300
  CONS27   -     300    10
  CONS28   -     300    13
  CONS29   -     300    13
  CONS3    -     300
  CONS30   -     300    13
  CONS31   -     300    15
  CONS32   -     300    15
  CONS33   -     300    15
  CONS34   -     300    23
  CONS35   -     300    23
  CONS36   -     300    25
  CONS37   -     300    25
  CONS38   -     300    25
  CONS39   -     300    28
  CONS4    -     300
  CONS40   -     300    30
  CONS41   -     300
```

Figure G.6. (Continued)

```
CONS42  -  300
CONS43  -  300
CONS44  -  300
CONS45  -  300
CONS46  -  300
CONS47  -  300
CONS48  -  300
CONS49  -  300
CONS5   -  300
CONS50  -  300
CONS51  -  300
CONS52  -  300
CONS53  -  300
CONS54  -  300
CONS55  -  300
CONS56  -  300
CONS57  -  300
CONS58  -  300
CONS59  -  300
CONS6   -  300
CONS60  -  300
CONS61  -  300
CONS62  -  300
CONS63  -  300
CONS64  -  300
CONS65  -  300
CONS66  -  300
CONS67  -  300   30
CONS68  -  300   3?
CONS69  -  300   32
CONS7   -  300
CONS70  -  300   32
CONS71  -  300   32
CONS72  -  300
CONS73  -  300
CONS74  -  300
CONS75  -  300
CONS76  -  300
CONS77  -  300
CONS78  -  300
CONS79  -  300
CONS8   -  300
CONS80  -  300
CONS81  -  300
CONS9   -  300
DBRK1   -  300
DBRK10  -  300
DBRK11  -  300
DBRK12  -  300
DBRK13  -  300
DBRK14  -  300
DBRK15  -  300
DBRK16  -  300
DBRK17  -  300
DBRK18  -  300
```

Figure G.6. (Continued)

```
  DBRK19   -   3CO
  DBRK2    -   3CO
  DBRK20   -   3CO    27
  DBRK21   -   3CO    22
  DBRK3    -   3CO
  DBRK4    -   3CO
  DBRK5    -   3CO
  DBRK6    -   3CO
  DBRK7    -   3CO     9
  DBRK8    -   3CO    12
  DBRK9    -   3CO
  DCDA     -   1AG    21=
  DCDS     -   1AG    32=
  DCLA     -   1AG    10=     13=     15=     18
  DCLS     -   1AG    28=     30=
  DCMA     -   1AG    23=     25=
  DCMS     -   1AG    33=
  DEG2R    -   2CO
  DEL      -   1AG    6AG      9       1      12      13      15      22      23      25
  DCTORD   -   2CO
  FFU      -   2CO
  FTVTKT   -   2CO
  K..T     -   5=      7=     17
  RTDV2    -   2CO
  RDIDDC   -   2CO
* RETURN   -   19*    34*
  POTEPS   -   2CO
  SFNFL    -   3CO
  SFNFR    -   3CO
  SFPL     -   3CO
  SFPML    -   3CO
  SFPMR    -   3CO
  SFPR     -   3CO
  SFQL     -   3CO
  SFQR     -   3CO
  SFSFL    -   3CO
  SFSFR    -   3CO
  SFTL     -   3CO
  SFTR     -   3CO
  SFYML    -   3CO
  SFYMR    -   3CO
  SKFPS    -   2CO
  SPOIL    -   1AG    27      29      30      32
  SQFPRM   -   2CO
  TAURT1   -   2CO
  TAURT2   -   2CO
  XPAR     -   2CO
* XPAR1    -   2*
* XPAR3    -   3*
```

Figure G.6. (Continued)

```
  1          SUBROUTINE CLCDCM(ALPHA,DEL,CLDEL,CLSP,CDFASP,CMFASP,CL,CD,CM,
            *  CLP,CDP)
  2          COMMON/XACOEF/ ACDW0 ,ACDW1 ,ACDW2 ,ACDW3 ,ACDW4 ,
            *               ACDW5 ,ACDW6 ,ACDW7 ,ACDW8 ,ACDW9 ,
            *               ACDW10,ACDW11,ACDW12,ACDW13,ACDW14,
            *               ACDW15,ACDW16,ACDW17,ACDW18,ACDW19,
            *               ACDW20,ACDW21,ACDW22,ACDW23,ACDW24
  3          COMMON/XPAR1/ AINHT ,AINW  ,ALAMDA,ALHTST,ALVTST,AREAHT,AREAW ,    1 TO   7
            *AREAVT,ARHT  ,ARVT  ,AVEYAC,AVEYCS,BLS   ,CDOF  ,CDOHT ,CDOVT ,    8 TO  16
            *CHORD ,CLALHT,CLALPH,CMOF  ,CMON  ,CNOF  ,CNOLN ,CNORN ,CYALVT,   17 TO  25
            3DCDLG ,DCMLG ,FINPR ,DOVT  ,DSOBET,EFFHT ,EFFVT ,FIE   ,FINDEG,   26 TO  34
            *FIP   ,FIXXF ,FIXXPR,FIXXW ,FIXZF ,FIXZPR,FIXZW ,FIYYF ,FIYYPR,   35 TO  43
            *FIYYW ,FIZZF ,FIZZPR,FIZZW ,HP    ,OMREF ,PC    ,PI    ,ROTRAD,   44 TO  52
            *SBFPR ,SBWPR ,SG    ,SHF   ,SHW   ,SK0   ,SK1   ,SK2   ,SK3   ,   53 TO  61
            *SK4   ,SK5   ,SK6   ,SK7   ,SK8   ,SK9   ,SK10  ,SK20  ,SK21  ,   62 TO  70
            *SK22  ,CDONLO,SK30LO,SK31LO,SK32  ,CDONHI,SK34  ,SK35  ,SK36  ,   71 TO  79
            *SK37  ,SK38  ,SK39  ,SK40  ,SK41  ,SK42  ,SK43  ,SK44  ,SK45  ,   80 TO  88
            *SK46  ,SK47  ,SK48  ,SK49  ,SK50  ,SL    ,SLF   ,SLPA  ,SLW   ,   89 TO  97
            *SM    ,SMF   ,SMN   ,SMW   ,SPAN  ,TAUHT ,TAUVT ,XFAC  ,XHT   ,   98 TO106
            *XWAC  ,XVT   ,YN    ,YPA   ,YWAC  ,ZFAC  ,ZHT   ,ZPA   ,ZWAC  ,
            *ZVT   ,CLOAL ,PHIPH ,SK30HI,EN2REF,XWC2  ,BT1   ,BT2   ,BT3   ,
            *BKD1T ,BKD2T ,BKD3T ,BKM1T ,BKM2T ,BKM3T ,BKM4T ,SK31HI,
            *FEU   ,CLMAX ,ALBRK ,BKLSW ,BKNSW ,SQFPRM,DEG25 ,DGTORD,HTVTKT,   133TO141
            *PIOV2 ,RDTODG,ROTEPS,SKEPS ,ALNCBK,TAURT1,TAURT2
  4          COMMON/GEFVAR/
            1 AGCVAT,AGOVAW,BIGX  ,BK99  ,BMOVTL,BMOVTR,COWCOR,CLTCOR,CLWCOR,    1 -  9
            2 DOVTL ,DOVTR ,EPPRM ,GEF   ,HGEFLR,HGEFRR,HLHUB ,HRHUB ,HTC4  ,   10 - 18
            3 HWC4  ,RRI1  ,RRI2  ,SB1   ,TIGEL ,TIGER                          19 - 24
  5          COMMON/FLAGS/ IWARN1(16),IWARN2(16),ISFNCE(2),IWREVT(2),ICONDP,
            1 ITRIM,JTRIM,KTRIM,NPLOT,NPLOT2,IPHASE,ISLOW,SWLG,GBUTON,
            2 ISTA,ISTB,NGEF,NVB,NTWST
  6          LOGICAL*1  IWARN1,IWARN2
  7          COMMON/XPAR3/ CONS1 ,CONS2 ,CONS3 ,CONS4 ,CONS5 ,CONS6 ,CONS7 ,    1 TO   7
            1              CONS8 ,CONS9 ,CONS10,CONS11,CONS12,CONS13,CONS14,    8 TO  14
            2              CONS15,CONS16,CONS17,CONS18,CONS19,CONS20,CONS21,   15 TO  21
            3              CONS22,CONS23,CONS24,CONS25,CONS26,CONS27,CONS28,   22 TO  28
            4              CONS29,CONS30,CONS31,CONS32,CONS33,CONS34,CONS35,   29 TO  35
            5              CONS36,CONS37,CONS38,CONS39,CONS40,CONS41,CONS42,   36 TO  42
            6              CONS43,CONS44,CONS45,CONS46,CONS47,CONS48,CONS49,   43 TO  49
            7              CONS50,CONS51,CONS52,CONS53,CONS54,CONS55,CONS56,   50 TO  56
            8              CONS57,CONS58,CONS59,CONS60,CONS61,CONS62,CONS63,   57 TO  63
            9              CONS64,CONS65,CONS66,CONS67,CONS68,CONS69,CONS70,   64 TO  70
            A              DBRK1 ,DBRK2 ,DBRK3 ,DBRK4 ,DBRK5 ,DBRK6 ,DBRK7 ,   71 TO  77
            B              DBRK8 ,DBRK9 ,DBRK10,DBRK11,DBRK12,DBRK13,DBRK14,   78 TO  84
            *              DBRK15,DBRK16,DBRK17,DBRK18,DBRK19,DBRK20,DBRK21    85 TO  91
            D             ,SFTL  ,SFNFL ,SFSFL ,SFPML ,SFYML ,SFQL  ,SFPL  ,
            E              SFTR  ,SFNFR ,SFSFR ,SFPMR ,SFYMR ,SFQR  ,SFPR
            F             ,CONS71,CONS72,CONS73,CONS74,CONS75,CONS76,CONS77    106TO112
            G             ,CONS78,CONS79,CONS80,CONS81                         113TO116
  8          NOPT=  0
  9          GO TO 5
 10          ENTRY CLF2(ALPHA,CLDEL,CLSP,CLZ)
 11          NOPT= 1
 12     5    CONTINUE
        C
```

Figure G.6. (Continued)

```
      ALDEG = ALPHA * RDTODG
      CLALDG= CLALPH*DGTORD
C
      IF(DEL.GT.DBRK2) GO TO 10
      ALNLP= CONS1 +CONS2*DEL
      ALNLM=  CONS3+CONS4*DEL
      GO TO 20
10    ALNLP=  CONS5
      ALNLM=  CONS6
20    CONTINUE
      ALBRK1= ALNLP+DBRK3
      ALBRK2=  ALNLM-DBRK3
C
      IF(DEL.GT.DBRK6)  GO TO 112
      F=  CONS21+DEL*(CONS22+CONS23*DEL)
      GO TO 114
112   F=  CONS24+DEL*(CONS25+CONS26*DEL)
114   CONTINUE
      CL1=  CLOAL+CLDEL+CLSP*F
      IWARN1(4)=  .FALSE.
      IF(ALDEG.GE.ALBRK2) GO TO 100
      CLNLP=  CL1+CLALDG*ALNLM
      CLP= CLNLP*(CONS7+ALDEG)/(CONS7+ALBRK2)
      IWARN1(4)=  .TRUE.
      GO TO 140
100   IF(ALDEG.GE.ALNLM) GO TO 110
      CLNLP=  CL1+CLALDG*ALNLM
      ALDUM= ALNLM-ALDEG+CONS1
      DCLNL= ALDUM*(CONS8*ALDUM+CONS9) +CONS10
      CLP= CLNLP-DCLNL
      IWARN1(4)=  .TRUE.
      GO TO 140
110   IF(ALDEG.GT.ALNLP) GO TO 120
      CLP=  CLALDG*ALDEG+CL1
      GO TO 140
120   IF(ALDEG.GT.ALBRK1) GO TO 130
      CLNLP=  CL1+CLALDG*ALNLP
      ALDUM=  ALDEG-ALNLP+CONS1
      DCLNL = ALDUM*(CONS8*ALDUM+CONS9)+CONS10
      CLP=  CLNLP+DCLNL
      IWARN1(4)=  .TRUE.
      GO TO 140
130   CONTINUE
      CLNLP=  CL1+CLALDG*ALNLP
      CLP= CLNLP*(CONS7-ALDEG)/(CONS7-ALBRK1)
140   CONTINUE
      IF(NOPT.NE.1) GO TO 150
      CLZ=  CLP*CLWCOR
      RETURN
150   CONTINUE
C
      CLPMX= CLMAX+CLDEL+CLSP
      CLIGE=  CLP*CLWCOR
      IF(CLIGE.LT.CLPMX) GO TO 160
      DCDIGE= 0.
```

Figure G.6. (Continued)

```
      CLIGE=  CLPMX
      GO TO 170
  160 DCDIGE= CDWCOP*(CLIGE-CLP)*(CLIGE-CLP)
  170 CONTINUE
C
      ALDUM=  DBRK5
      IF(ALDEG.LT.DBRK4) ALDUM=DBRK4
      IF(ALDEG.GE.DBRK4.AND.ALDEG.LE.DBRK5) ALDUM= ALDEG
C
      CD1=    ACDW0+DEL*(ACDW1+DEL*(ACDW2+DEL*(ACDW3+DEL*ACDW4))) +
     1ALDUM*(ACDW5+DEL*(ACDW6+DEL*(ACDW7+DEL*(ACDW8+DEL*ACDW9)))+
     2ALDUM*(ACDW10+DEL*(ACDW11+DEL*(ACDW12+DEL*(ACDW13+DEL*ACDW14)))+
     3ALDUM*(ACDW15+DEL*(ACDW16+DEL*(ACDW17+DEL*(ACDW18+DEL*ACDW19)))+
     4ALDUM*(ACDW20+DEL*(ACDW21+DEL*(ACDW22+DEL*(ACDW23+DEL*ACDW24))))))
     5)
      IF(ALDEG.GE.DBRK4) GO TO 180
      CDM= CONS11+CD1+CDFASP
      CDP= CDM-(1.-CDM)*(ALDEG-DBRK4)*CONS12
      CMP= (CONS17+CMFASP)*(CONS7+ALDEG)*CONS12
      GO TO 200
  180 IF(ALDEG.GT.DBRK5) GO TO 190
      CDP= ALDEG*(CONS13*ALDEG+CONS14) +CONS15+CD1+CDFASP
      CMP= CONS18+CONS19*ALDEG+CMFASP
      GO TO 200
  190 CDPLUS= CONS16+CD1+CDFASP
      CDP= CDPLUS+(1.-CDPLUS)*(ALDEG-DBRK5)*CONS12
      CMP= (CONS20+CMFASP)*(CONS7-ALDEG)*CONS12
  200 CONTINUE
C
C
      CL= CLIGE
      CD= CDP+DCDIGE
      CM= CMP
C
      RETURN
      END
```

Figure G.6. (Continued)

```
SYMBOL        +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+   REFERENCES   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

5        -    9      12*
10       -    15     19*
20       -    18     21*
100      -    31     36*
110      -    36     43*
112      -    24     27*
114      -    26     28*
120      -    43     46*
130      -    46     53*
140      -    35     42      45      52      55*
150      -    57     60*
160      -    63     67*
170      -    66     68*
180      -    73     78*
190      -    78     82*
200      -    77     81      95*
ACDW0    -    200    72
ACDW1    -    200    72
ACDW10   -    200    72
ACDW11   -    200    72
ACDW12   -    200    72
ACDW13   -    200    72
ACDW14   -    200    72
ACDW15   -    200    72
ACDW16   -    200    72
ACDW17   -    200    72
ACDW18   -    200    72
ACDW19   -    200    72
ACDW2    -    200    72
ACDW20   -    200    72
ACDW21   -    200    72
ACDW22   -    200    72
ACDW23   -    200    72
ACDW24   -    200    72
ACDW3    -    200    72
ACDW4    -    200    72
ACDW5    -    200    72
ACDW6    -    200    72
ACDW7    -    200    72
ACDW8    -    200    72
ACDW9    -    200    72
AGOVAT   -    400
AGOVAN   -    400
AINHT    -    300
AINW     -    300
ALAMDA   -    300
ALBRK    -    300
ALBRK1   -    22=    46      55
ALBRK2   -    23=    31      33
ALDEG    -    13=    31      33      36      38      43      44      46      48      55      70      71      73
              75     76      78      79      80      83      84
ALDUM    -    38=    39      48=     49      69=     70=     71=     72
ALHTST   -    300
```

Figure G.6. (Continued)

```
  I N D E X            SUBROUTINE CLCDCM(ALPHA,DEL,CLDEL,CLSP,CDFASP,CMFASP,CL,CD,CM,            PAGE  103

ALNCBK   -    3CO
ALNLM    -   17=     20=     23      32      36      37      38
ALNL2    -   16=     19=     22      43      47      48      54
ALPHA    -    1AG    12AG    13
ALVTST   -    3CO
AREAHT   -    3CO
AREAVT   -    3CO
AREAW    -    3CO
ARHT     -    3CO
ARVT     -    3CO
AVFYAC   -    3CO
AVEYCS   -    3CO
BIGX     -    4CO
BKD1T    -    3CO
BKD2T    -    3CO
BKD3T    -    3CO
BKLSW    -    3CO
BKM1T    -    3CO
BKM2T    -    3CO
BKM3T    -    3CO
BKM4T    -    3CO
BKNSW    -    3CO
BK99     -    4CO
BLS      -    3CO
BMDVTL   -    4CO
BMDVTR   -    4CO
BT1      -    3CO
BT2      -    3CO
BT3      -    3CO
CD       -    1AG    37=
CDFASP   -    1AG    74      79      92
CDM      -   74=     75
CDOF     -    3CO
CDOHT    -    3CO
CDONHI   -    3CO
CDONLO   -    3CO
CDOVT    -    3CO
CDP      -    1AG    75=     79=     83=     97
CDPLUS   -   92=     93
CDWCOF   -    4CO    67
CD1      -   72=     74      79      82
CHORD    -    3CO
CL       -    1AG    96=
CLALDG   -   14=     32      37      44      47      54
CLALHT   -    3CO
CLALPH   -    3CO    14
* CLCDCM -    1*
CLDEL    -    1AG    12AG    29      61
* CLF2   -   10*
CLIGE    -   62=     63      65=     67      86
CLMAX    -    3CO    51
CLNLP    -   32=     33      37=     43      47=     50      54=     55
CLOAL    -    3CO    29
CLP      -    1AG    33=     40=     44=     50=     55=     58      62      67
CLPMX    -   61=     63      65
```

Figure G.6. (Continued)

[illegible]

[illegible]	-	[illegible]	[illegible]				
[illegible]	-	[illegible]					
[illegible]	-	4	5[illegible]				
[illegible]	-	[illegible]	5[illegible]				
CL1	-	[illegible]	3[illegible]	[illegible]	[illegible]	[illegible]	[illegible]4
CM	-	1[illegible]	3[illegible]				
CMFA[illegible]	-	1A[illegible]	[illegible]		[illegible]		
CMOF	-	3[illegible]					
CMON	-	3[illegible]					
C[illegible]	-	76=	[illegible]	34=	[illegible]		
CNOF	-	300					
CNOLN	-	300					
CNORN	-	300					
CONS1	-	700	16	[illegible]	4[illegible]		
CONS10	-	700	39	[illegible]			
CONS11	-	700	74				
CONS12	-	700	75	[illegible]	[illegible]	[illegible]	
CONS13	-	700	79				
CONS14	-	700	79				
CONS15	-	700	79				
CONS16	-	700	32				
CONS17	-	700	76				
CONS18	-	700	[illegible]				
CONS19	-	700	80				
CONS2	-	700	16				
CONS20	-	700	34				
CONS21	-	700	25				
CONS22	-	700	25				
CONS23	-	700	25				
CONS24	-	700	27				
CONS25	-	700	27				
CONS26	-	700	27				
CONS27	-	700					
CONS28	-	700					
CONS29	-	700					
CONS3	-	700	17				
CONS30	-	700					
CONS31	-	700					
CONS32	-	700					
CONS33	-	700					
CONS34	-	700					
CONS35	-	700					
CONS36	-	700					
CONS37	-	700					
CONS38	-	700					
CONS39	-	700					
CONS4	-	700	17				
CONS40	-	700					
CONS41	-	700					
CONS42	-	700					
CONS43	-	700					
CONS44	-	700					
CONS45	-	700					
CONS46	-	700					
CONS47	-	700					

Figure G.6. (Continued)

```
CONS48  -   7C0
CONS49  -   7C0
CONS5   -   7C0   19
CONS5C  -   7C0
CONS51  -   7C0
CONS52  -   7C0
CONS53  -   7C0
CONS54  -   7C0
CONS55  -   7C0
CONS56  -   7C0
CONS57  -   7C0
CONS58  -   7C0
CONS59  -   7C0
CONS6   -   7C0   20
CONS60  -   7C0
CONS61  -   7C0
CONS62  -   7C0
CONS63  -   7C0
CONS64  -   7C0
CONS65  -   7C0
CONS66  -   7C0
CONS67  -   7C0
CONS68  -   7C0
CONS69  -   7C0
CONS7   -   7C0   33    55    76    84
CONS70  -   7C0
CONS71  -   7C0
CONS72  -   7C0
CONS73  -   7C0
CONS74  -   7C0
CONS75  -   7C0
CONS76  -   7C0
CONS77  -   7C0
CONS78  -   7C0
CONS79  -   7C0
CONS8   -   7C0   39    49
CONS80  -   7C0
CONS81  -   7C0
CONS9   -   7C0   39    40
CYALVT  -   3C0
DBRK1   -   7C0
DBRK10  -   7C0
DBRK11  -   7C0
DBRK12  -   7C0
DBRK13  -   7C0
DBRK14  -   7C0
DBRK15  -   7C0
DBRK16  -   7C0
DBRK17  -   7C0
DBRK18  -   7C0
DBRK19  -   7C0
DBRK2   -   7C0   15
DBRK2C  -   7C0
DBRK21  -   7C0
DBRK3   -   7C0   22    23
```

Figure G.6. (Continued)

```
CBRK4   -   7CO   70    71    73    75
CBRK5   -   7CO   69    71    78    83
CBRK6   -   7CO   24
DBRK7   -   7CO
DBRK8   -   7CO
DBRK9   -   7CO
DCDIGE  -   64=   67=   87
DCDLG   -   3CO
DCLNL   -   39=   40    49=   50
DCMLG   -   3CO
DEG20   -   3CO
DEL     -   1AG   15    16    17    24    25    27    72
DGTORD  -   3CO   14
DOVT    -   3CO
DOVTL   -   4CO
DOVTR   -   4CO
DSDBET  -   3CO
EFFHT   -   3CO
EFFVT   -   3CO
EN2REF  -   3CO
EPPRM   -   4CO
F       -   25=   27=   29
FEU     -   3CO
FIE     -   3CO
FINDEG  -   3CO
FINPR   -   3CO
FIP     -   3CO
FIXXF   -   3CO
FIXXPR  -   3CO
FIXXW   -   3CO
FIXZF   -   3CO
FIXZPR  -   3CO
FIXZW   -   3CO
FIYYF   -   3CO
FIYYPR  -   3CO
FIYYW   -   3CO
FIZZF   -   3CO
FIZZPR  -   3CO
FIZZW   -   3CO
* FLAGS -   5*
GBUTON  -   5CO
GEF     -   4CO
* GEFVAR -  4*
HGEFLR  -   4CO
HGEFRR  -   4CO
HLHUB   -   4CO
HP      -   3CO
HRHUB   -   4CO
HTC4    -   4CO
HTVTKT  -   3CO
HWC4    -   4CO
ICONOP  -   5CO
IPHASE  -   5CO
ISENCE  -   5CO
ISLOW   -   5CO
```

Figure G.6. (Continued)

```
  ISTA     -     5CO
  ISTB     -     5CO
  ITRIM    -     5CO
  IWARN1   -     5CO     6LG     31=     34=     41=     51=
  IWARN2   -     5CO     6LG
  IWREVT   -     5CO
  JTPIM    -     5CO
  KTRIM    -     5CO
  NGEF     -     5CO
  NOPT     -     8=      11=     57
  NPLOT    -     5CO
  NPLOT2   -     5CO
  NTWST    -     5CO
  NVB      -     5CO
  OMREF    -     3CO
  PC       -     3CO
  PHIPH    -     3CO
  PI       -     3CO
  PIOV2    -     3CO
  ROTODG   -     3CO     13
* RETURN   -     59*     89*
  ROTFPS   -     3CO
  ROTRAD   -     3CO
  RRI1     -     4CO
  RRI2     -     4CO
  SBFPR    -     3CO
  SBWPR    -     3CO
  SB1      -     4CO
  SFNFL    -     7CO
  SFNFR    -     7CO
  SFPL     -     7CO
  SFPML    -     7CO
  SFPMR    -     7CO
  SFPR     -     7CO
  SFQL     -     7CO
  SFQR     -     7CO
  SFSFL    -     7CO
  SFSFR    -     7CO
  SFTL     -     7CO
  SFTR     -     7CO
  SFYML    -     7CO
  SFYMR    -     7CO
  SG       -     3CO
  SHF      -     3CO
  SHW      -     3CO
  SKFPS    -     3CO
  SK0      -     3CO
  SK1      -     3CO
  SK10     -     3CO
  SK2      -     3CO
  SK20     -     3CO
  SK21     -     3CO
  SK22     -     3CO
  SK3      -     3CO
  SK30HI   -     3CO
```

Figure G.6. (Continued)

```
  SK3CLO   -   3C0
  SK31HI   -   3C0
  SK31LO   -   3C0
  SK32     -   3C0
  SK34     -   3C0
  SK35     -   3C0
  SK36     -   3C0
  SK37     -   3C0
  SK38     -   3C0
  SK39     -   3C0
  SK4      -   3C0
  SK40     -   3C0
  SK41     -   3C0
  SK42     -   3C0
  SK43     -   3C0
  SK44     -   3C0
  SK45     -   3C0
  SK46     -   3C0
  SK47     -   3C0
  SK48     -   3C0
  SK49     -   3C0
  SK5      -   3C0
  SK50     -   3C0
  SK6      -   3C0
  SK7      -   3C0
  SK8      -   3C0
  SK9      -   3C0
  SL       -   3C0
  SLF      -   3C0
  SLPA     -   3C0
  SLW      -   3C0
  SM       -   3C0
  SMF      -   3C0
  SMN      -   3C0
  SMW      -   3C0
  SPAN     -   3C0
  SQFPRM   -   3C0
  SWLG     -   5C0
  TAUHT    -   3C0
  TAURT1   -   3C0
  TAURT2   -   3C0
  TAUVT    -   3C0
  TIGEL    -   4C0
  TIGER    -   4C0
* XACOEF   -   2*
  XFAC     -   3C0
  XHT      -   3C0
* XPAR1    -   3*
* XPAR3    -   7*
  XVT      -   3C0
  XWAC     -   3C0
  XWC2     -   3C0
  YN       -   3C0
  YPA      -   3C0
  YWAC     -   3C0
```

Figure G.6. (Continued)

```
ZFAC     -     300
ZHT      -     300
ZPA      -     300
ZVT      -     300
ZWAC     -     300

+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-
```

Figure G.6. (Continued)

```
  1           SUBROUTINE ENGINE(TEA,SHPOUT,OMENG,PCTORQ)
  2           COMMON/ENG/  NWDTID,N1IND ,N1THID,N2IND ,NQIND ,NRNDID ,
             *             EWDTMX,EN1MX ,EN1TMX,EN2MX ,EQMX  ,SHPSTR
             *           ,  EWDTPR,EN1STR,ROEO  ,TZERO ,TCOEF
  3           COMMON/ENGVAR/
             1 AMACH ,AMACSQ,DEL   ,EMAXN1,EMAXN2,EMXWDT,EN2STR,FSMACH,OMEGEL,    1 -  9
             2 OMEGER,DNOVTC,DOVFSM,DVSQTH,DVTHDL,ROE   ,ROEOV2,SHPPRL,SHPPRR,   10 - 18
             3 SMA   ,SQN1MX,SQTHTC,SQWDTX,TDEGF ,TEAL  ,TEAR  ,THCDEL,THETC     19 - 27
             4,PCTQL,PCTQR                                                       28 TO 29
  4           COMMON/FLAGS/ IWARN1(16),IWARN2(16),ISENCE(2),IWREVT(2),ICONOP,
             1 ITRIM,JTRIM,KTRIM,NPLOT,NPLOT2,IPHASE,ISLOW,SWLG,GBUTON,
             2 ISTA,ISTB,NGEF,NVB,NTWST
  5           LOGICAL*1  IWARN1,IWARN2
        C
        C        ENGINE CHARACTERISTICS USED
        C     NWDTID = 1      FUEL FLOW CUTOFF
        C     N1IND  = 1      N1 CUTOFF
        C     N1THID = 0      NO REFERRED N1 CUTOFF
        C     N2IND  = 2      N2 CUTOFF - NON-OPTIMUM N2 VARIATION
        C     NQIND  = 1      TORQUE CUTOFF
        C     NRNDID = 0      NO REYNOLDS NUMBER CORRECTIONS
        C
  6           TEASQ= TEA * TEA
  7           TEACUB=  TEASQ * TEA
  8           TEA4TH=  TEACUB* TEA
        C        NOTE TEA = TPS / THETC
  9           IF(NWDTID.EQ.0) GO TO 1000
        C        FIND (WDOT/SHP) AT TEA,M
        C
        C        W DOT = F(TEA)  EQUATION FROM CURVE FIT PROGRAM
        C          4TH ORDER IN TEA
 10           EWDOT= -2.0503260368+.3531349130E-02*TEA-.2594440658E-05*TEASQ
             * +.1010425181E-08*TEACUB-.1444138415E-12*TEA4TH
        C
 11           IWARN1( 1)=  .FALSE.
 12           IF(EWDOT.LT.EMXWDT) GO TO 1000
 13           IWARN1( 1)=  .TRUE.
        C        FIND TEA AT MAX WDOT,M
        C
        C        TEA = F(W DOTMX)  FROM CURVE FIT PROGRAM
        C          4TH ORDER IN W DOTMX
 14           TEA = 1587.5624254398-1375.3423740741*EMXWDT+12872.89968281*
             *  SQWDTX-22742.78987105*SQWDTX*EMXWDT+13929.828136431*SQWDTX *
             *  SQWDTX
        C
 15           TEASQ = TEA * TEA
 16           TEACUB= TEASQ * TEA
 17           TEA4TH= TEACUB * TEA
        C
 18     1000  IF(N1IND.EQ.0) GO TO 2000
        C        FIND  N1/N1STAR  AT  TEA,M
        C
        C        N1 = F(TEA,M)  EQUATION FROM CURVE FIT PROGRAM
        C          3RD ORDER IN TEA , 2ND ORDER IN M
 19           EN1 = -2.262254353 +1.2512886559*AMACH+.9621240231*AMACSQ
```

Figure G.6. (Continued)

```
                 * +(.3519588428E-02-.1539742133E-02*AMACH-.1308445977E-02*AMACSQ)*
                 *  TEA +
                 * (-.1316093319E-05+.6259888594E-06*AMACH+.6064941537E-06*AMACSQ)*
                 *  TEASQ +
                 * (.1765905983E-09-.8357285710E-10*AMACH-.9302102725E-10*AMACSQ)*
                 *  TEACUB
            C
  20              IWARN1( 2)=  .FALSE.
  21              IF(EN1.LT.EMAXN1)  GO TO 2000
  22              IWARN1( 2)=  .TRUE.
            C        FIND TEA AT MAX N1,M
            C
            C        TEA = F(N1MAX,M)  EQUATION FROM CURVE FIT PROGRAM
            C          3RD ORDER IN N1MAX , 2ND ORDER IN M
  23              TEA= 4555.7505996075+4266.6351807463*AMACH-10962.24966689*AMACSQ
                 *+(-10591.306223561-14006.740444625*AMACH+34472.653759217*AMACSQ)*
                 *  EMAXN1 +
                 * (10876.686523447+15100.9688113098*AMACH-36112.607870716*AMACSQ)*
                 *  SQN1MX +
                 * (-2601.662341542-5379.0838224301*AMACH+12502.173136418*AMACSQ)*
                 *  SQN1MX*EMAXN1
  24              TEASQ = TEA * TEA
  25              TEACUB = TEASQ * TEA
  26              TEA4TH = TEACUB * TEA
  27              EN1 = EMAXN1
  28        2000  IF(N1THID.EQ.0) GO TO 3000
            C        THIS OPTION WILL BE LEFT BLANK UNTIL NEEDED
  29        3000  CONTINUE
            C
            C        THIS SECTION CORRESPONDS TO THE ENG 1 SUBR BLOCK IN FLOW DIAG
  30              SKPN= 1.
  31              IF(N2IND.NE.2)  GO TO 4000
            C        FIND  N2/N2STAR  AT TEA,M
            C
            C        N2 = F(TEA,M)  EQUATION FROM CURVE FIT PROGRAM
            C        3RD ORDER IN TEA , 2ND ORDER IN M
  32              EN2 = -5.5804780552-2.6637228923*AMACH+1.1263419372*AMACSQ
                 *+(.7055066994E-02+.3351714914E-02*AMACH-.1239191608E-03*AMACSQ)*
                 *  TEA +
                 * (-.2593416699E-05-.1287659251E-05*AMACH-.4369359301E-06*AMACSQ)*
                 *  TEASQ +
                 * (.3385936162E-09+.1505373934E-09*AMACH+.1178189720E-09*AMACSQ)*
                 *  TEACUB
            C
  33              EN2OPT=  EN2STR/EN2* OVSQTH
  34              SKPN= 1.-(1.-EN2OPT)*(1.-EN2OPT)
  35        4000  CONTINUE
  36              SKPR= 1.
  37              IF(NRNOID.EQ.0)  GO TO 5000
            C        THIS OPTION WILL BE LEFT BLANK UNTIL NEEDED
  38        5000  CONTINUE
            C        FIND  SHP/SHPSTAR
            C
            C        SHP = F(TEA,M)  EQUATION FROM CURVE FIT PROGRAM
            C          3RD ORDER IN TEA , 2ND ORDER IN M
```

Figure G.6. (Continued)

```
 39          ESHP   = 2.9433431215-.2571992619*AMACH+1.3604785868*AMACSQ
            *+(-.6857622248E-02+.7364753977E-03*AMACH-.1979318276E-02*AMACSQ)*
            *  TEA +
            * (.4368718891E-05-.3926992714E-06*AMACH+.1001305662E-05*AMACSQ)*
            *  TEASQ +
            * (-.7438074668E-09+.6969538120E-10*AMACH-.1674167095E-09*AMACSQ)*
            *  TEACUB
        C
 40          ENGSHP= SKPN*SKPR*ESHP
        C       END OF ENG 1 SUBR BLOCK
 41          IF(NQIND.EQ.1) GO TO 6000
 42          IF(N2IND.NE.1)  GO TO 8000
        C       THIS OPTION WILL BE LEFT BLANK UNTIL NEEDED
 43          GO TO 8000
 44     6000 IF(N2IND.EQ.2) GO TO 7000
        C       THIS OPTION WILL BE LEFT BLANK UNTIL NEEDED
 45     7000 SHPMAX=  FOMX*EN2STR*DVTHDL
 46          IWARN1( 3)=  .FALSE.
 47          IF(ENGSHP.LT.SHPMAX)  GO TO 8000
 48          IWARN1( 3)=  .TRUE.
 49          ENGSHP= SHPMAX
        C
        C       FIND TEA AT MAX SHP , M
        C
        C       TEA = F(SHP,M) EQUATION FROM CURVE FIT PROGRAM
        C         3RD ORDER IN SHPMAX , 2ND ORDER IN M
        C
 50          TEA= 1550.0865704333-170.1403074663*AMACH-242.7678229176*AMACSQ
            *+(1145.2371955474+149.9327819876*AMACH+706.5669321644*AMACSQ)*
            *  SHPMAX +
            * (-1125.4640744348+74.2324463353*AMACH-792.5722362916*AMACSQ)*
            *  SHPMAX * SHPMAX +
            * (656.3876664347-226.4415181282*AMACH+311.0686620534*AMACSQ)*
            *  SHPMAX*SHPMAX*SHPMAX
 51          TEASQ = TEA * TEA
 52          TEACUB = TEASQ * TEA
 53          TEA4TH = TEACUB * TEA
        C
        C       SINCE TORQUE LIMIT HIT CAUSING A LOWER TEA TO BE REQ , THE
        C         N1 CALCULATION MUST BE RE-CALCULATED
 54          EN1 = -2.262254353 +1.2512986559*AMACH+.9621240231*AMACSQ
            * +(.3519585428E-02-.1539742133E-02*AMACH-.1308445977E-02*AMACSQ)*
            *  TEA +
            * (-.1316C93319E-05+.6259888594E-06*AMACH+.6364941537E-06*AMACSQ)*
            *  TEASQ +
            * (.1765905983E-09-.8357285710E-10*AMACH-.9302102725E-10*AMACSQ)*
            *  TEACUB
        C
 55     8000 IF(N2IND.NE.1) GO TO 9000
        C       THIS OPTION WILL BE LEFT BLANK UNTIL NEEDED
 56     9000 SHPOUT=  ENGSHP*SHPSTR*THCDEL
 57          OMENG= EN1*SQTHTC * EN1STR*0.10471966
 58          PCTORQ  =  100. *THCDEL *ENGSHP /EN2STR
 59          RETURN
 60          END
```

Figure G.6. (Continued)

```
 I N D E X                         SUBROUTINE ENGINE(TEA,SHPOUT,GMENG,PCTORQ)                       PAGE  113

SYMBOL      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-   REFERENCES   -+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

1000    -     9       12      18*
2000    -    19       21      28*
3000    -    23       29*
4000    -    31       35*
5000    -    37       38*
6000    -    41       44*
7000    -    44       45*
8000    -    42       43      47      55*
9000    -    55       56*
AMACH   -    3C0      19      23      32      39      50      54
AMACSQ  -    3C0      19      23      32      39      50      54
DEL     -    3C0
EMAXN1  -    3C0      21      23      27
EMAXN2  -    3C0
EMXWDT  -    3C0      12      14
* ENG   -    2*
* ENGINE -   1*
ENGSHP  -    40=      47      49=     56      58
* ENGVAR -   3*
EN1     -    19=      21      27=     54=     57
EN1MX   -    2C0
EN1STR  -    2C0      57
EN1TMX  -    2C0
EN2     -    32=      33
EN2MX   -    2C0
EN2OPT  -    33=      34
EN2STR  -    3C0      33      45      59
EQMX    -    2C0      45
ESHP    -    39=      40
EWDOT   -    10=      12
EWDTMX  -    2C0
EWDTPR  -    2C0
* FLAGS -    4*
FSMACH  -    3C0
GRUTON  -    4C0
ICONGP  -    4C0
IPHASE  -    4C0
ISENCE  -    4C0
ISLOW   -    4C0
ISTA    -    4C0
ISTB    -    4C0
ITRIM   -    4C0
IWARN1  -    4C0      5LG     11=     13=     20=     22=     46=     48=
IWARN2  -    4C0      5LG
IWREVT  -    4C0
JTRIM   -    4C0
KTRIM   -    4C0
NGEF    -    4C0
NPLOT   -    4C0
NPLOT2  -    4C0
NQIND   -    2C0      41
NRMDID  -    2C0      37
NTWST   -    4C0
```

Figure G.6. (Continued)

```
NVB      -   4CO
NWDTID   -   2CO    9
N1IND    -   2CO    18
N1THID   -   2CO    28
N2IND    -   2CO    31     42     44     55
OMEGFL   -   3CO
OMEGER   -   3CO
OMENG    -   1AG    57=
ONOVTC   -   3CO
OOVFSM   -   3CO
OVSQTH   -   3CO    33
OVTHDL   -   3CO    45
PCTORQ   -   1AG    58=
PCTQL    -   3CO
PCTQR    -   3CO
* RETURN -   59*
ROE      -   3CO
ROEOV2   -   3CO
ROEO     -   2CO
SHPMAX   -   45=    47     49     50
SHPOUT   -   1AG    56=
SHPPRL   -   3CO
SHPPRR   -   3CO
SHPSTR   -   2CO    56
SKPN     -   30=    34=    40
SKPR     -   36=    40
SMA      -   3CO
SQN1MX   -   3CO    23
SQTHTC   -   3CO    57
SQWDTX   -   3CO    14
SWLG     -   4CO
TCOEF    -   2CO
TDFGF    -   3CO
TEA      -   1AG    6      7      8      10     14=    15     16     17     19     23=    24     25
             26     32     39     50=    51     52     53     54
TEACUB   -   7=     8      10     16=    17     19     25=    26     32     39     52=    53     54
TEAL     -   3CO
TEAR     -   3CO
TEASQ    -   6=     7      10     15=    16     19     24=    25     32     39     51=    52     54
TEA4TH   -   8=     10     17=    26=    53=
THCDEL   -   3CO    56     58
THETC    -   3CO
TZERO    -   2CO
```

+-

Figure G.6. (Continued)

```
      SUBROUTINE GEAR
      COMMON/XAIR/ SCADC1(32),SCADC2(32),SCADC3(32),SCADC4(32),
     *             SCDAC1(32),SCDAC2(32),SCDAC3(32),SCDAC4(32),
     1       PPRIME,CPRIME,PPRIME,UPRIME,VPRIME,WPRIME,THE   ,PHI    ,  BD  1E
     *       PSI   ,WDOT  ,H     ,DUM12 ,DUM13 ,DUM14 ,DUM15 ,HDOT  ,
     *       DFLAIL,DFLAIR,DELSPR,DELSPL,CTLPRM,CNFPL ,CSFPL ,CPMPL ,
     *       CYMPL ,CPL   ,CTRPRM,CNFPP ,CSFPR ,CPMPR ,CYMPR ,CPR   ,
     *  ADC(62) ,
     *  ADC3(62)
      COMMON/XGEAR/ XG1   ,XG2   ,XG3   ,XGDUM ,YG1   ,YG2   ,YG3   ,
     *              YGDUM ,ZG1   ,ZG2   ,ZG3   ,ZGDUM ,RAD1  ,RAD2  ,
     *              RAD3  ,RADDUM,SKST1 ,SKST2 ,SKST3 ,SKSTDM,SDST1 ,
     *              SDST2 ,SDST3 ,SDSTDM,FRICT0,FRICT1,FRICTS
     *            , BRK1  ,BRK2  ,BRK3  ,BRKDUM
      COMMON/CGGTVR/
     1 VEAST ,VNORTH,XCG   ,XDTCG ,ZCG   ,ZDTCG                     1 -  6
      COMMON/FUSVAR/
     1 ALARF ,ALAREP,ALFSQ ,ALPHF ,AMARF ,AMAREP,ANARF ,ANAREP,BETAF ,   1 -  9
     2 BETFSQ,CBCMF ,CDF   ,CLF   ,CMF   ,CNF   ,COSALF,COSBTF,CYF   ,  10 - 18
     3 DLLG  ,DMLG  ,DNLG  ,DXLG  ,DYLG  ,DZLG  ,QFSW  ,SBFCAF,SBFSAF,  19 - 27
     4 SINALF,SINBTF,SQF   ,XAERF ,XAREP ,YAERF ,YAREP ,ZAERF ,ZAREP    28 - 36
     *   ,SINTHE,COSTHE,SINPHI,COSPHI
C        N= 1    LEFT MAIN GEAR
C        N= 2    RIGHT MAIN GEAR
C        N= 3    NOSE GEAR
C        N= 4    NOT USED
C
      DIMENSION DX(4),DY(4),DZ(4),DL(4),DM(4),DN(4)
      DIMENSION XG(4),YG(4),ZG(4),RAD(4),SKST(4) ,SDST(4)
      DIMENSION BG(4)
      EQUIVALENCE (XG(1),XG1),(YG(1),YG1),(ZG(1),ZG1  ),(RAD(1),RAD1  )
     *    ,(SKST(1),SKST1 ) ,(SDST(1),SDST1)
      EQUIVALENCE (BG(1),BRK1)
      N= 1
      IF(UPRIME) 75,110,120
   75 SIGNU= -1.0
      GO TO 125
  110 SIGNU= 0.0
      GO TO 125
  120 SIGNU= 1.0
  125 CONTINUE
      IF(VPRIME) 130,140,150
  130 SIGNV= -1.0
      GO TO 155
  140 SIGNV=  0.0
      GO TO 155
  150 SIGNV= 1.0
  155 CONTINUE
C        LANDING GEAR  - A/C LOCATION
   50 XN= XG(N)-XCG
      YN=  YG(N)
      ZN= ZG(N)-ZCG
C
C        STRUT DEFLECTION
      HGTHEN=  XN*SINTHE -ZN*COSTHE -RAD(N)
```

Figure G.6. (Continued)

```
I N D E X
 30          HGPHIN=  COSTHE*(YN*SINPHI+(ZN+RAD(N))*(COSPHI-1.))
 31          DDVCTP=  1./(COSTHE*COSPHI)
 32          HTN=  (H+HGTHEN-HGPHIN) * DDVCTP
       C
 33          IF(HTN.LT.0.) GO TO 100
 34          DX(N)= 0.
 35          DY(N)= 0.
 36          DZ(N)= 0.
 37          DL(N)= 0.
 38          DM(N)= 0.
 39          DN(N)= 0.
 40          GO TO 200
       C        RATE OF STRUT DEFLECTION
 41    100   HTDTN= HDOT*DDVCTP+QPRIME*XN-PPRIME*YN
       C
       C        VERTICAL FORCE
 42          FGZN=  SKST(N)*HTN +SDST(N)*HTDTN
       C        LONGITUDINAL FORCE
 43          FMUN=  (FRICT0+FRICT1*BG(N))*FGZN*SIGNU
       C
       C         SINCE FGZN IS ALWAYS NEGATIVE
       C                IF U GT 0.   FMUN IS NEGATIVE
       C                IF U LT 0.   FMUN IS POSITIVE
       C                IF U EQ 0.   FMUN IS ZERO
       C
       C         SIDE FORCE
 44          FSN= FRICTS*FGZN*SIGNV
       C         SINCE FGZN IS ALWAYS NEGATIVE
       C                IF   V GT  0.    FSN IS NEGATIVE
       C                IF   V LT  0.    FSN IS POSITIVE
       C                IF   V EQ  0.    FSN IS ZERO
       C
       C         FORCE AND MOMENT CONTRIBUTION
 45          DX(N) =  FMUN  - FGZN * THE
 46          DY(N)= FSN+FGZN*PHI
 47          DZ(N)= FMUN*THE-FSN*PHI+FGZN
 48           DM(N)= -DZ(N)*XN+DX(N)*(ZN+RAD(N)+HTN )
 49          DL(N)= DZ(N)*YN -DY(N)*(ZN+RAD(N)+HTN)
 50          DN(N)= -DX(N)*YN +XN*DY(N)
 51    200    N= N+1
 52          IF(N.LE.3) GO TO 50
 53          DXLG= DX(1)+DX(2)+DX(3)
 54          DYLG= DY(1)+DY(2)+DY(3)
 55          DZLG= DZ(1)+DZ(2)+DZ(3)
 56          DLLG =  DL(1)+DL(2) +DL(3)
 57          DMLG =  DM(1)+DM(2) +DM(3)
 58          DNLG =  DN(1)+DN(2) +DN(3)
 59          RETURN
 60           END
```

Figure G.6. (Continued)

```
  I N D E X                                   SUBROUTINE GEAR                                    PAGE  117

SYMBOL     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-   REFERENCES   -+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

50         -   24*      52
75         -   12       13*
1          -   33       41*
11         -   12       15*
12         -   12       17*
125        -   14       16       18*
130        -   19       20*
140        -   19       22*
150        -   19       24*
155        -   21       23       25*
200        -   40       51*
ADC        -    20D
ADC3       -    20D
ALARF      -    50D
ALAREP     -    50D
ALFSQ      -    50D
ALPHF      -    50D
AMACF      -    50D
AMACFP     -    50D
AMAPF      -    50D
AMAPFP     -    50D
BETAF      -    50D
BETFSQ     -    50D
BG         -    ADI     1000     43
BRKDUM     -    30D
BRK1       -    30D     10EQ
BRK2       -    30D
BRK3       -    30D
CBCAF      -    50D
CDF        -    50D
CGGTVP     -    4*
CLF        -    50D
CMF        -    50D
CNF        -    50D
CNFPL      -    20D
CNFPR      -    20D
COSALF     -    50D
COSBTF     -    50D
COSPHI     -    50D      30       31
COSTHF     -    50D      29       30       31
CPL        -    20D
CPMPL      -    20D
CPMPR      -    20D
CPR        -    20D
CSFPL      -    20D
CSFPR      -    20D
CTLPRM     -    20D
CTRPRM     -    20D
CYF        -    50D
CYMPL      -    20D
CYMPR      -    20D
DELSPL     -    20D
DELSPR     -    20D
```

Figure G.6. (Continued)

```
  DFLAIL   -   2CO
  DFLAIR   -   2CO
  DL       -   6DI    37=    49=    56
  DLLG     -   5CO    56=
  DM       -   6DI    38=    48=    57
  DMLG     -   5CO    57=
  DN       -   6DI    39=    50=    58
  DNLG     -   5CO    58=
  DUM12    -   2CO
  DUM13    -   2CO
  DUM14    -   2CO
  DUM15    -   2CO
  DX       -   6DI    34=    45=    48     50     53
  DXLG     -   5CO    53=
  DY       -   6DI    35=    46=    49     50     54
  DYLG     -   5CO    54=
  DZ       -   6DI    36=    47=    49     49     55
  DZLG     -   5CO    55=
  FGZN     -  42=     43     44     45     46     47
  FMUN     -  43=     45     47
  FRICTO   -   3CO    43
  FRICTS   -   3CO    44
  FRICT1   -   3CO    43
  FSN      -  44=     46     47
* FUSVAR   -   5*
* GEAR     -   1*
  H        -   2CO    32
  HDOT     -   2CO    41
  HGPHIN   -  30=     32
  HGTHEN   -  29=     32
  HTDTN    -  41=     42
  HTN      -  32=     33     42     48     49
  N        -  11=     26     27     28     29     30     34     35     36     37     38     39     42
              43      45     46     47     48     49     50     51=    52
  OOVCTP   -  31=     32     41
  PHI      -   2CO    46     47
  PPRIME   -   2CO    41
  PSI      -   2CO
  QFSW     -   5CO
  QPRIME   -   2CO    41
  RAD      -   7DI    9EQ    29     30     48     49
  RADDUM   -   3CO
  RAD1     -   3CO    9EQ
  RAD2     -   3CO
  RAD3     -   3CO
* RETURN   -  59*
  RPRIME   -   2CO
  SBFCAF   -   5CO
  SBFSAF   -   5CO
  SCADC1   -   2CO
  SCADC2   -   2CO
  SCADC3   -   2CO
  SCADC4   -   2CO
  SCDAC1   -   2CO
  SCDAC2   -   2CO
```

Figure G.6. (Continued)

```
   I N D E X

SCDAC3   -    2C0
SCDAC4   -    2C0
SDST     -    7DI    9F0    42
SDSTDM   -    3C0
SDST1    -    3C0    9F0
SDST2    -    3C0
SDST3    -    3C0
SIGNU    -    13=    15=    17=    43
SIGNV    -    20=    22=    24=    44
SINALF   -    5C0
SINBTF   -    5C0
SINPHI   -    5C0    30
SINTHE   -    5C0    29
SKST     -    7DI    9F0    42
SKSTDM   -    3C0
SKST1    -    3C0    9F0
SKST2    -    3C0
SKST3    -    3C0
SQF      -    5C0
THF      -    2C0    45     47
UPRIMF   -    2C0    12
VEAST    -    4C0
VNORTH   -    4C0
VPRIMF   -    2C0    19
WDOT     -    2C0
WPRIMF   -    2C0
XAERF    -    5C0
* XAIO   -    2*
XAREP    -    5C0
XCG      -    4C0    26
XDTCG    -    4C0
XG       -    7DI    9F0    26
XGDUM    -    3C0
* XGEAR  -    3*
XG1      -    3C0    9F0
XG2      -    3C0
XG3      -    3C0
XN       -    26=    29     41     49     50
YAERF    -    5C0
YAREP    -    5C0
YG       -    7DI    9F0    27
YGDUM    -    3C0
YG1      -    3C0    9F0
YG2      -    3C0
YG3      -    3C0
YN       -    27=    30     41     49     50
ZAERF    -    5C0
ZAREP    -    5C0
ZCG      -    4C0    28
ZDTCG    -    4C0
ZG       -    7DI    9F0    28
ZGDUM    -    3C0
ZG1      -    3C0    9F0
ZG2      -    3C0
ZG3      -    3C0
```

Figure G.6. (Continued)

```
ZN       -     28=     29     30     43     49

      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-
SYMBOL  -  =================  ROUTINES IN WHICH THE SYMBOL IS USED  =================
```

Figure G.6. (Continued)

```
ABS      -  RTSLOW
ACDW0    -  CLCDCM
ACDW1    -  CLCDCM
ACDW10   -  CLCDCM
ACDW11   -  CLCDCM
ACDW12   -  CLCDCM
ACDW13   -  CLCDCM
ACDW14   -  CLCDCM
ACDW15   -  CLCDCM
ACDW16   -  CLCDCM
ACDW17   -  CLCDCM
ACDW18   -  CLCDCM
ACDW19   -  CLCDCM
ACDW2    -  CLCDCM
ACDW20   -  CLCDCM
ACDW21   -  CLCDCM
ACDW22   -  CLCDCM
ACDW23   -  CLCDCM
ACDW24   -  CLCDCM
ACDW3    -  CLCDCM
ACDW4    -  CLCDCM
ACDW5    -  CLCDCM
ACDW6    -  CLCDCM
ACDW7    -  CLCDCM
ACDW8    -  CLCDCM
ACDW9    -  CLCDCM
ADC      -  RTFAST
ADCFLT   -  RTFAST
AGOVAT   -  RTSLOW
AGOVAW   -  RTSLOW
AICL     -  RTFAST
AICLPP   -  RTFAST
AICLGS   -  RTFAST
AICLPP   -  RTFAST
AICR     -  RTFAST
AICRPP   -  RTFAST
AICRGS   -  RTFAST
AICRPP   -  RTFAST
AILSP    -  RTFAST
AINDTL   -  RTFAST
AINDTR   -  RTFAST
AINHT    -  RTFAST
AINL     -  RTFAST   RTSLOW
AINR     -  RTFAST   RTSLOW
AINW     -  RTFAST   RTSLOW
AITRIM   -  RTFAST
AKEY     -  RTSLOW
ALAERO   -  RTFAST
ALARF    -  RTFAST
ALARFP   -  RTFAST   RTSLOW
ALARHT   -  RTFAST
ALARNC   -  RTFAST
ALARNL   -  RTFAST
ALARNP   -  RTFAST
ALARRG   -  RTFAST
```

Figure G.6. (Continued)

ALART	-	RTFAST	
ALARVB	-	RTFAST	
ALARVT	-	RTFAST	
ALARWG	-	RTFAST	
ALBRK1	-	CLCDCM	
ALBRK2	-	CLCDCM	
ALDEG	-	CLCDCM	
ALDUM.	-	CLCDCM	
ALFGLS	-	RTFAST	
ALFREF	-	RTFAST	
ALFTAB	-	RTFAST	
ALHTE	-	RTFAST	
ALHTM	-	RTFAST	
ALHTP	-	RTFAST	
ALHTPR	-	RTFAST	
ALLRH	-	RTFAST	
ALLWPR	-	RTFAST	
ALNCPK	-	RTSLOW	
ALNLM	-	CLCDCM	
ALNLP	-	CLCDCM	
ALPHA	-	CLCDCM	
ALPHF	-	RTFAST	RTSLOW
ALPHFP	-	RTSLOW	
ALPHHT	-	RTFAST	
ALPHLN	-	RTSLOW	
ALPHLP	-	RTFAST	RTSLOW
ALPHLW	-	RTFAST	
ALPHRN	-	RTSLOW	
ALPHRP	-	RTFAST	RTSLOW
ALPHRW	-	RTFAST	
ALPHVT	-	RTFAST	
ALRGLW	-	RTFAST	
ALRGRW	-	RTFAST	
ALRRH	-	RTFAST	
ALRWPR	-	RTFAST	
ALVTE	-	RTFAST	
ALVTM	-	RTFAST	
ALVTP	-	RTFAST	
ALVTPP	-	RTFAST	
ALWSSD	-	RTFAST	
AMACH	-	ENGINE	RTSLOW
AMACLP	-	RTFAST	
AMACRP	-	RTFAST	
AMACSC	-	ENGINE	RTSLOW
AMACTL	-	RTFAST	
AMACTR	-	RTFAST	
AMAERO	-	RTFAST	
AMARF	-	RTFAST	
AMARFP	-	RTFAST	RTSLOW
AMARHT	-	RTFAST	
AMARLW	-	RTFAST	
AMARNC	-	RTFAST	
AMARNL	-	RTFAST	
AMARNP	-	RTFAST	
AMARRG	-	RTFAST	

Figure G.6. (Continued)

```
AMARPW   -  RTFAST
AMART    -  RTFAST
AMARVB   -  RTFAST
AMARVT   -  RTFAST
AMARWG   -  RTFAST
AMEM     -  RTSLOW
AMLRH    -  RTFAST
AMRNLP   -  RTFAST
AMRNSP   -  RTFAST
AMROTL   -  RTFAST
AMROTF   -  RTFAST
AMRRH    -  RTFAST
AMUL     -  RTFAST   RTSLOW
AMULSQ   -  RTFAST
AMUR     -  RTFAST   RTSLOW
AMURSQ   -  RTFAST
ANAERO   -  RTFAST
ANARF    -  RTFAST
ANARFP   -  RTFAST   RTSLOW
ANARHT   -  RTFAST
ANARNC   -  RTFAST
ANARNL   -  RTFAST
ANARNP   -  RTFAST
ANART    -  RTFAST
ANARVT   -  RTFAST
ANARWG   -  RTFAST
ANDIG    -  RTFAST
ANLRH    -  RTFAST
ANROTL   -  RTFAST
ANROTR   -  RTFAST
ANRRH    -  RTFAST
APFAW    -  RTSLOW
APILW    -  RTSLOW
APIRW    -  RTSLOW
APTEX    -  RTFAST
APWING   -  RTSLOW
APWSSO   -  RTFAST
ATAN2    -  RTFAST   RTSLOW
ATAULP   -  RTSLOW
ATAURR   -  RTSLOW
AVEALP   -  RTSLOW
AVEALW   -  RTFAST
AVECLW   -  RTFAST
AVECTS   -  RTFAST   RTSLOW
AVEFPP   -  RTFAST   RTSLOW
AVEIN    -  RTFAST   RTSLOW
AVEZET   -  RTSLOW
BETAF    -  RTFAST   RTSLOW
BETAFP   -  RTSLOW
BETALN   -  RTSLOW
BETALW   -  RTFAST
BETARN   -  RTSLOW
BETAPW   -  RTFAST
BETGLS   -  RTFAST
BETVT    -  RTFAST
```

Figure G.6. (Continued)

```
BG       -  GEAR
BICGLS   -  RTFAST
BICL     -  RTFAST
BICLDP   -  RTFAST
BICLPP   -  RTFAST
BICR     -  RTFAST
BICRDP   -  RTFAST
BICRPR   -  RTFAST
BIGX     -  RTSLOW
BKALPR   -  RTFAST   RTSLOW
BKARPP   -  RTFAST   RTSLOW
BKD1T    -  RTSLOW
BKD2T    -  RTSLOW
BKD3T    -  RTSLOW
BKEY     -  RTSLOW
BKM1T    -  RTSLOW
BKM2T    -  RTSLOW
BKM3T    -  RTSLOW
BKM4T    -  RTSLOW
BK99     -  RTSLOW
BLS      -  RTFAST   RTSLOW
BMEM     -  RTSLOW
BMOVTL   -  RTFAST   RTSLOW
BMOVTR   -  RTFAST   RTSLOW
BRK1     -  GEAR
BT1      -  RTSLOW
BT2      -  RTSLOW
BT3      -  RTSLOW
CALIHT   -  RTFAST
CALLN    -  RTSLOW
CALLW    -  RTFAST
CALRN    -  RTSLOW
CALRW    -  RTFAST
CAVINW   -  RTSLOW
CAVZET   -  RTSLOW
CBCMF    -  RTSLOW
CBETLN   -  RTSLOW
CBETLW   -  RTFAST
CBETRN   -  RTSLOW
CBETRW   -  RTFAST
CBETSG   -  RTFAST
CD       -  CLCDCM
CDCNTL   -  RTFAST
CDCNTR   -  RTFAST
CDDUM    -  RTFAST
CDF      -  RTSLOW
CDFASP   -  CLCDCM
CDHT     -  RTFAST
CDHTST   -  RTFAST
CDLN     -  RTSLOW
CDLWAD   -  RTFAST
CDLWPR   -  RTFAST
CDLWSS   -  RTFAST
CDM      -  CLCDCM
CDOF     -  RTSLOW
```

Figure G.6. (Continued)

Figure G.6. (Continued)

```
CLSP     -  CLCDCM
CLSRW    -  RTFAST
CLSW     -  RTFAST
CLTCOR   -  RTFAST    RTSLOW
CLWCOR   -  CLCDCM    RTSLOW
CLZ      -  AILSP     CLCDCM
CLZERO   -  RTFAST
CL1      -  CLCDCM
CM       -  CLCDCM
CMCNTL   -  RTFAST
CMCNTR   -  RTFAST
CMF      -  RTSLOW
CMFASP   -  CLCDCM
CMLN     -  RTSLOW
CMLWAD   -  RTFAST
CMLWSS   -  RTFAST
CMOF     -  RTSLOW
CMON     -  RTSLOW
CMOW     -  RTFAST
CMP      -  CLCDCM
CMRN     -  RTSLOW
CMRWAD   -  RTFAST
CMRWSS   -  RTFAST
CMSLW    -  RTFAST
CMSRW    -  RTFAST
CNF      -  RTSLOW
CNFAIL   -  RTFAST
CNFAIR   -  RTFAST
CNFBIL   -  RTFAST
CNFBIR   -  RTFAST
CNFL     -  RTFAST
CNFPL    -  RTFAST
CNFPR    -  RTFAST
CNFR     -  RTFAST
CNLN     -  RTSLOW
CNOF     -  RTSLOW
CNOLN    -  RTSLOW
CNORN    -  RTSLOW
CNRN     -  RTSLOW
CNSW     -  RTFAST
COEF1    -  RTFAST    RTSLOW
COEF10   -  RTFAST
COEF11   -  RTFAST
COEF12   -  RTFAST
COEF13   -  RTFAST
COEF16   -  RTFAST
COEF17   -  RTSLOW
COEF18   -  RTFAST    RTSLOW
COEF19   -  RTFAST
COEF2    -  RTFAST
COEF20   -  RTFAST
COEF21   -  RTFAST
COEF22   -  RTFAST
COEF23   -  RTFAST
COEF24   -  RTFAST
```

Figure G.6. (Continued)

```
COEF25   -  RTSLOW
COEF26   -  RTSLOW
COEF27   -  RTSLOW
COEF28   -  RTSLOW
COEF29   -  RTSLOW
COEF3    -  RTSLOW
COEF30   -  RTSLOW
COEF31   -  RTFAST
COEF32   -  RTFAST
COEF33   -  RTFAST
COEF34   -  RTFAST
COEF35   -  RTSLOW
COEF4    -  RTFAST    RTSLOW
COEF5    -  RTSLOW
COEF6    -  RTSLOW
COEF7    -  RTSLOW
COEF8    -  RTSLOW
COEF9    -  RTFAST
CONS1    -  CLCDCM
CONS10   -  CLCDCM
CONS11   -  CLCDCM
CONS12   -  CLCDCM
CONS13   -  CLCDCM
CONS14   -  CLCDCM
CONS15   -  CLCDCM
CONS16   -  CLCDCM
CONS17   -  CLCDCM
CONS18   -  CLCDCM
CONS19   -  CLCDCM
CONS2    -  CLCDCM
CONS20   -  CLCDCM
CONS21   -  CLCDCM
CONS22   -  CLCDCM
CONS23   -  CLCDCM
CONS24   -  CLCDCM
CONS25   -  CLCDCM
CONS26   -  CLCDCM
CONS27   -  AILSP
CONS28   -  AILSP
CONS29   -  AILSP
CONS3    -  CLCDCM
CONS30   -  AILSP
CONS31   -  AILSP
CONS32   -  AILSP
CONS33   -  AILSP
CONS34   -  AILSP
CONS35   -  AILSP
CONS36   -  AILSP
CONS37   -  AILSP
CONS38   -  AILSP
CONS39   -  AILSP
CONS4    -  CLCDCM
CONS40   -  AILSP
CONS41   -  RTFAST
CONS42   -  RTFAST
```

Figure G.6. (Continued)

```
CONS43   -  RTFAST
CONS44   -  RTSLOW
CONS45   -  RTSLOW
CONS46   -  RTSLOW
CONS47   -  RTSLOW
CONS48   -  RTSLOW
CONS49   -  RTSLOW
CONS5    -  CLCDCM
CONS50   -  RTSLOW
CONS51   -  RTSLOW
CONS52   -  RTSLOW
CONS53   -  RTSLOW
CONS54   -  RTSLOW
CONS55   -  RTSLOW
CONS56   -  RTSLOW
CONS57   -  RTSLOW
CONS58   -  RTSLOW
CONS59   -  RTSLOW
CONS6    -  CLCDCM
CONS60   -  RTSLOW
CONS61   -  RTSLOW
CONS62   -  RTSLOW
CONS63   -  RTSLOW
CONS64   -  RTSLOW
CONS65   -  RTFAST
CONS66   -  RTFAST
CONS67   -  AILSP
CONS68   -  AILSP
CONS69   -  AILSP
CONS7    -  CLCDCM
CONS70   -  AILSP
CONS71   -  AILSP
CONS72   -  RTFAST
CONS73   -  RTFAST
CONS74   -  RTFAST
CONS75   -  RTFAST
CONS76   -  RTFAST
CONS77   -  RTFAST
CONS78   -  RTFAST
CONS79   -  RTFAST
CONS8    -  CLCDCM
CONS80   -  RTFAST
CONS81   -  RTFAST
CONS9    -  CLCDCM
CONTRL   -  RTFAST     RTSLOW
COSALF   -  RTSLOW
COSBTF   -  RTSLOW
COSINL   -  RTFAST     RTSLOW
COSINR   -  RTFAST     RTSLOW
COSIW    -  RTFAST
COSLAM   -  RTFAST
COSPHI   -  GEAR       RTSLOW
COSPSI   -  RTSLOW
COSTHE   -  GEAR       RTSLOW
COSZHL   -  RTFAST
```

Figure G.6. (Continued)

```
COSZHR   -  RTFAST
CPHIP    -  RTFAST
CPL      -  RTFAST
CPMAIL   -  RTFAST
CPMAIR   -  RTFAST
CPMBIL   -  RTFAST
CPMBIR   -  RTFAST
CPML     -  RTFAST
CPMPL    -  RTFAST
CPMPR    -  RTFAST
CPMR     -  RTFAST
CPR      -  RTFAST
CSFAIL   -  RTFAST
CSFAIR   -  RTFAST
CSFBIL   -  RTFAST
CSFBIR   -  RTFAST
CSFL     -  RTFAST
CSFPL    -  RTFAST
CSFPR    -  RTFAST
CSFR     -  RTFAST
CTAULR   -  RTSLOW
CTAURR   -  RTSLOW
CTL      -  RTFAST
CTLPPM   -  RTFAST
CTR      -  RTFAST
CTRPRM   -  RTFAST
CTSLP    -  RTFAST    RTSLOW
CTSRR    -  RTFAST    RTSLOW
CYALVT   -  RTFAST
CYAT     -  RTFAST
CYF      -  RTSLOW
CYLN     -  RTSLOW
CYMAIL   -  RTFAST
CYMAIR   -  RTFAST
CYMBIL   -  RTFAST
CYMBIR   -  RTFAST
CYML     -  RTFAST
CYMPL    -  RTFAST
CYMPR    -  RTFAST
CYMR     -  RTFAST
CYRN     -  RTSLOW
CYVT     -  RTFAST
CYVTST   -  RTFAST
C2INL    -  RTSLOW
C2INR    -  RTSLOW
DACFLT   -  RTFAST
DACIO    -  RTFAST
DAC1     -  RTFAST
DAC2     -  RTFAST
DBRK1    -  RTFAST
DBRK10   -  RTSLOW
DBRK11   -  RTSLOW
DBRK12   -  RTSLOW
DBRK13   -  RTSLOW
DBRK14   -  RTSLOW
```

Figure G.6. (Continued)

144

```
ENF2     -  RTFAST
ENF3     -  RTFAST
ENF4     -  RTFAST
ENG      -  ENGINE    RTFAST    RTSLOW
ENGINE   -  RTSLOW
ENGSHP   -  ENGINE
ENGVAR   -  ENGINE    RTFAST    RTSLOW
EN1      -  ENGINE
EN1MX    -  RTSLOW
EN1STR   -  ENGINE
EN2      -  ENGINE
EN2MX    -  RTSLOW
EN2OPT   -  ENGINE
EN2REF   -  RTSLOW
EN2STR   -  ENGINE    RTSLOW
EOMVAR   -  RTFAST    RTSLOW
EPILR    -  RTFAST    RTSLOW
EPIRL    -  RTFAST    RTSLOW
EPM1     -  RTFAST
EPM2     -  RTFAST
EPM3     -  RTFAST
EPM4     -  RTFAST
EPM5     -  RTFAST
EPM6     -  RTFAST
EPM7     -  RTFAST
EPPLR    -  RTFAST    RTSLOW
EPPRM    -  RTSLOW
EPPRR    -  RTFAST    RTSLOW
EPTAIL   -  RTFAST
EPTL1    -  RTFAST
EPWRL    -  RTFAST
EPWRR    -  RTFAST
EP7ERO   -  RTFAST
EQMX     -  ENGINE
ESF1     -  RTFAST
ESF2     -  RTFAST
ESF3     -  RTFAST
ESF4     -  RTFAST
ESHP     -  ENGINE
EWDOT    -  ENGINE
EWDTMX   -  RTSLOW
EWDTPR   -  RTSLOW
EYM1     -  RTFAST
EYM2     -  RTFAST
EYM3     -  RTFAST
EYM4     -  RTFAST
EYM5     -  RTFAST
EYM6     -  RTFAST
EYM7     -  RTFAST
F        -  CLCDCM
FEU      -  RTFAST
FGZN     -  GEAR
FIE      -  RTFAST
FINDEG   -  RTFAST
FINPR    -  RTFAST
```

Figure G.6. (Continued)

```
FIP      -  RTFAST
FIPOML   -  RTFAST
FIPCMF   -  RTFAST
FIXX     -  RTSLOW
FIXZP    -  RTFAST   RTSLOW
FIXZPP   -  RTSLOW
FIXZQ    -  RTFAST   RTSLOW
FIXZR    -  RTFAST   RTSLOW
FIYY     -  RTSLOW
FIYYPR   -  RTFAST
FIZZ     -  RTSLOW
FIZZPR   -  RTFAST
FJXX     -  RTFAST   RTSLOW
FJYY     -  RTFAST   RTSLOW
FJZZ     -  RTFAST   RTSLOW
FLAGS    -  CLCDCM   ENGINE    RTFAST    RTSLOW
FMUN     -  GEAR
FNORML   -  RTFAST   RTSLOW
FNORMP   -  RTFAST   RTSLOW
FRICTC   -  GEAR
FRICTS   -  GEAR
FRICTI   -  GEAR
FSIDEL   -  RTFAST   RTSLOW
FSIDER   -  RTFAST   RTSLOW
FSMACH   -  RTSLOW
FSN      -  GEAR
FSQRT    -  RTFAST   RTSLOW
FUSVAR   -  GEAR     RTFAST    RTSLOW
GAATAR   -  RTFAST
GA1ALF   -  RTFAST
GA1BET   -  RTFAST
GBATAR   -  RTFAST
GB1ALF   -  RTFAST
GEAR     -  RTFAST
GEF      -  RTFAST   RTSLOW
GEFVAR   -  CLCDCM   RTFAST    RTSLOW
GETBIT   -  RTSLOW
GKEY     -  RTFAST
GMEM     -  RTFAST
H        -  GEAR     RTSLOW
HACLOD   -  RTFAST
HACROD   -  RTFAST
HDOT     -  GEAR
HDTACL   -  RTFAST
HDTACP   -  RTFAST
HDTRIM   -  RTFAST
HGEFLR   -  RTSLOW
HGEFRR   -  RTSLOW
HGPHIN   -  GEAR
HGTHEN   -  GEAR
HLHUB    -  RTSLOW
HP       -  RTSLOW
HRHUB    -  RTSLOW
HSO      -  RTSLOW
HTC4     -  RTSLOW
```

Figure G.6. (Continued)

```
HTDTN   -  GEAR
HTN     -  GEAR
HTRIM   -  RTFAST
HTSTLL  -  RTFAST
HWACL   -  RTFAST
HWACR   -  RTFAST
HWC4    -  RTSLOW
HYBCON  -  RTFAST   RTSLOW
HYBID   -  RTFAST   RTSLOW
H1DTL   -  RTFAST
H1DTR   -  RTFAST
H1L     -  RTFAST
H1LOLD  -  RTFAST
H1R     -  RTFAST
H1ROLD  -  RTFAST
ICONOP  -  RTSLOW
IFC     -  RTSLOW
INITVR  -  RTFAST   RTSLOW
IPAN    -  RTFAST   RTSLOW
IPSNOS  -  RTFAST
IREVNT  -  RTSLOW
ISENCE  -  RTSLOW
ISLOW   -  RTSLOW
ISTA    -  RTSLOW
ISTAD   -  RTFAST
ISTB    -  RTSLOW
ISTDA   -  RTFAST
ISTFLT  -  RTFAST
ISTG    -  RTFAST
ISTRB1  -  RTSLOW
ITRIM   -  RTSLOW
IWARN1  -  CLCDCM   ENGINF   RTFAST   RTSLOW
J       -  RTFAST   RTSLOW
JTRIM   -  RTSLOW
KAR     -  RTFAST
KONFR   -  RTFAST
KPAN    -  RTFAST   RTSLOW
KTRIM   -  RTSLOW
LINT    -  RTFAST   RTSLOW
N       -  GEAR
NACVAR  -  RTFAST   RTSLOW
NCLOSE  -  RTFAST
NCON    -  RTSLOW
NCEF    -  RTSLOW
NOPT    -  AILSP    CLCDCM
NQIND   -  ENGINE
NRNOID  -  ENGINE
NTWST   -  RTFAST
NVB     -  RTFAST
NWDTID  -  ENGINE
N1IND   -  ENGINE
N1THID  -  ENGINE
N2IND   -  ENGINE
OMDOT   -  RTFAST
OMDTL   -  RTFAST
```

Figure G.6. (Continued)

```
I N D E X                ********** SUPER INDEX **********                PAGE  135

OMDTR   -  RTFAST
OMEGA   -  RTFAST    RTSLOW
OMEGAL  -  RTFAST
OMEGAR  -  RTFAST
OMEGEL  -  RTFAST    RTSLOW
OMEGER  -  RTFAST    RTSLOW
OMENG   -  ENGINE
OMREF   -  RTSLOW
OMSQL   -  RTFAST
OMSQR   -  RTFAST
ONOVTC  -  RTSLOW
OOVCTP  -  GEAR
OOVDSK  -  RTFAST
OOVFSM  -  RTFAST    RTSLOW
OOVIXX  -  RTFAST    RTSLOW
OOVIYY  -  RTFAST    RTSLOW
OOVIZZ  -  RTFAST    RTSLOW
OVDTIM  -  RTFAST
OVSQTH  -  ENGINE    RTSLOW
OVTHDL  -  ENGINE    RTSLOW
P       -  RTFAST
PC      -  RTSLOW
PCTORQ  -  ENGINE
PCTQR   -  RTFAST    RTSLOW
PGUST   -  RTFAST
PHI     -  GEAR      RTSLOW
PI      -  RTFAST
PIOV2   -  RTFAST
PNLN    -  RTFAST
PNLR    -  RTFAST
PNRN    -  RTFAST
PNRR    -  RTFAST
PP      -  RTFAST
PPRIME  -  GEAR      RTFAST
PQ      -  RTFAST
PR      -  RTFAST
PSI     -  RTSLOW
Q       -  RTFAST
QFSW    -  RTSLOW
QGUST   -  RTFAST
QNLN    -  RTFAST
QNLR    -  RTFAST
QNRN    -  RTFAST
QNRR    -  RTFAST
QPRIME  -  GEAR      RTFAST
R       -  RTFAST
RAD     -  GEAR
RAD1    -  GEAR
RCB1    -  RTSLOW
RDTODG  -  CLCDCM    RTFAST
RESLR   -  RTSLOW
RESRR   -  RTSLOW
RETURN  -  AILSP     CLCDCM    ENGINE    GEAR      RTFAST    RTSLOW
REVENT  -  RTSLOW
RGUST   -  RTFAST
```

Figure G.6. (Continued)

```
RMLN     -  RTFAST
RMLR     -  RTFAST
RMRN     -  RTFAST
RMRR     -  RTFAST
ROE      -  RTFAST    RTSLOW
ROEOV2   -  RTFAST    RTSLOW
ROEO     -  RTFAST    RTSLOW
ROPIM6   -  RTFAST
ROPIRS   -  RTFAST
ROTFPS   -  RTFAST
ROTRAD   -  RTFAST    RTSLOW
ROTVAR   -  RTFAST    RTSLOW
RPRIME   -  RTFAST
RQ       -  RTFAST
RR       -  RTFAST
RRI1     -  RTSLOW
RRI2     -  RTSLOW
RTPASS   -  RTFAST    RTSLOW
SALIMT   -  RTFAST
SALLM    -  RTSLOW
SALLW    -  RTFAST
SALRM    -  RTSLOW
SALRW    -  RTFAST
SAVINM   -  RTSLOW
SAVZET   -  RTSLOW
SBETLM   -  RTSLOW
SBETLW   -  RTFAST
SBETRM   -  RTSLOW
SBETRW   -  RTFAST
SBETSG   -  RTFAST
SBFCAF   -  RTSLOW
SBFSAF   -  RTSLOW
SCADC1   -  RTFAST
SCCAC1   -  RTFAST
SC1      -  RTFAST
SC2      -  RTFAST
SDST     -  GEAR
SDST1    -  GEAR
SEPLW    -  RTFAST
SEPRW    -  RTFAST
SGMSQF   -  RTFAST
SGMULW   -  RTFAST
SGMURW   -  RTFAST
SHF      -  RTSLOW
SHPMAX   -  ENGINE
SHPOUT   -  ENGINF
SHPPRL   -  RTSLOW
SHPPRR   -  RTFAST    RTSLOW
SHPSTR   -  ENGINE
SHW      -  RTSLOW
SIGMA    -  RTFAST
SIGNU    -  GEAR
SIGNV    -  GEAR
SIL      -  RTSLOW
SILAML   -  RTFAST    RTSLOW
```

Figure G.6. (Continued)

```
SILAMP   -  RTFAST    RTSLOW
SILW     -  RTFAST    RTSLOW
SINALF   -  RTSLOW
SINBTF   -  RTSLOW
SINCOS   -  RTFAST    RTSLOW
SININL   -  RTFAST    RTSLOW
SININP   -  RTFAST    RTSLOW
SINIW    -  RTFAST
SINLAM   -  RTFAST
SINPHI   -  GEAR      RTSLOW
SINPSI   -  RTSLOW
SINTHE   -  GEAR      RTSLOW
SINZHL   -  RTFAST
SINZHP   -  RTFAST
SIR      -  RTSLOW
SIRW     -  RTFAST    RTSLOW
SIT      -  RTSLOW
SKPN     -  ENGINE
SKPR     -  ENGINE
SKST     -  GEAR
SKST1    -  GEAR
SKW1     -  RTFAST
SKW10    -  RTFAST
SKW2     -  RTFAST
SKW3     -  RTFAST
SKW4     -  RTFAST
SKW5     -  RTFAST
SKW6     -  RTFAST
SKW7     -  RTFAST
SKW8     -  RTFAST
SKW9     -  RTFAST
SKO      -  RTSLOW
SK1      -  RTSLOW
SK10     -  RTSLOW
SK2      -  RTSLOW
SK20     -  RTFAST
SK21     -  RTFAST
SK22     -  RTFAST
SK3      -  RTSLOW
SK30HI   -  RTSLOW
SK30L    -  RTSLOW
SK30LO   -  RTSLOW
SK30P    -  RTSLOW
SK31HI   -  RTSLOW
SK31L    -  RTSLOW
SK31LO   -  RTSLOW
SK31R    -  RTSLOW
SK32     -  RTSLOW
SK34     -  RTSLOW
SK35     -  RTSLOW
SK36     -  RTSLOW
SK37     -  RTSLOW
SK38     -  RTSLOW
SK39     -  RTSLOW
SK4      -  RTSLOW
```

Figure G.6. (Continued)

```
SK40     -  RTSLOW
SK41     -  RTSLOW
SK42     -  RTSLOW
SK43     -  RTSLOW
SK44     -  RTSLOW
SK5      -  RTSLOW
SK6      -  RTSLOW
SK7      -  RTSLOW
SK8      -  RTSLOW
SK9      -  RTSLOW
SL       -  RTSLOW
SLAC     -  RTFAST
SLF      -  RTSLOW
SLPA     -  RTFAST
SLW      -  RTSLOW
SMA      -  RTSLOW
SPAN     -  RTFAST    RTSLOW
SPHIP    -  RTFAST
SPIO     -  RTSLOW
SPOIL    -  AILSP
SQF      -  RTFAST    RTSLOW
SQFPNW   -  RTFAST
SQLNC    -  RTSLOW
SQLW     -  RTFAST
SQN1PX   -  ENGINE    RTSLOW
SQRESL   -  RTSLOW
SQRESR   -  RTSLOW
SQRNC    -  RTSLOW
SQRW     -  RTFAST
SQTHTC   -  ENGINE    RTFAST    RTSLOW
SQWDTX   -  ENGINE    RTSLOW
SQWING   -  RTFAST
SSQINL   -  RTSLOW
SSQINR   -  RTSLOW
STAULR   -  RTSLOW
STAURR   -  RTSLOW
SVSTAB   -  RTSLOW
SVSTAR   -  RTSLOW
SVSTRL   -  RTSLOW
SWLG     -  RTFAST
SWLG2    -  RTSLOW
S2INL    -  RTSLOW
S2INR    -  RTSLOW
TAILVR   -  RTFAST    RTSLOW
TAN      -  RTSLOW
TAUMT    -  RTFAST
TAULR    -  RTSLOW
TAURR    -  RTSLOW
TAUVT    -  RTFAST
TAVAEP   -  RTSLOW
TCOEF    -  RTSLOW
TDEGF    -  RTSLOW
TEA      -  ENGINE
TEACUR   -  ENGINE
TEAR     -  RTSLOW
```

Figure G.6. (Continued)

```
TEASQ    -  ENGINE
TEA4TH   -  ENGINE
TERMP1   -  RTFAST
TERMQ1   -  RTFAST
TERMR1   -  RTFAST
TERM1    -  RTSLOW
TERM1L   -  RTFAST
TERM1R   -  RTFAST
TERM2    -  RTSLOW
TERM2L   -  RTFAST
TERM2R   -  RTFAST
TERM3    -  RTSLOW
TERM3L   -  RTFAST
TERM3R   -  RTFAST
TERM4    -  RTSLOW
TERM5    -  RTSLOW
TERM6    -  RTSLOW
THCDEL   -  ENGINE    RTSLOW
THE      -  GEAR      RTSLOW
THETC    -  RTSLOW
THTLAC   -  RTFAST
THTRAC   -  RTFAST
THTRIM   -  RTFAST
TIGEL    -  RTFAST    RTSLOW
TIGER    -  RTFAST    RTSLOW
TL       -  RTFAST    RTSLOW
TMHB10   -  RTFAST
TMHB11   -  RTFAST
TMHB12   -  RTFAST
TMWG10   -  RTSLOW
TMWG11   -  RTSLOW
TNAC1    -  RTSLOW
TNAC2    -  RTSLOW
TOROL    -  RTFAST
TOROR    -  RTFAST
TPSR     -  RTSLOW
TP       -  RTFAST    RTSLOW
TRACK    -  RTFAST    RTSLOW
TRMAR1   -  RTFAST
TRMAR2   -  RTFAST
TRMAR3   -  RTFAST
TRMAR4   -  RTFAST
TRMCON   -  RTFAST
TRMHB1   -  RTFAST
TRMHB2   -  RTFAST
TRMHB3   -  RTFAST
TRMHB4   -  RTFAST
TRMHB5   -  RTFAST
TRMHB6   -  RTFAST
TRMHB7   -  RTFAST
TRMHB8   -  RTFAST
TRMHB9   -  RTFAST
TRMHT    -  RTFAST
TRMHT2   -  RTFAST
TRMHT3   -  RTFAST
```

Figure G.6. (Continued)

Figure G.6. (Continued)

Figure G.6. (Continued)

```
WVT     -  RTFAST
XACOEF  -  CLCDCM
XAERF   -  RTFAST
XAERLW  -  RTFAST
XAERNC  -  RTFAST
XAERNL  -  RTFAST
XAERNR  -  RTFAST
XAERO   -  RTFAST
XAERRW  -  RTFAST
XAERT   -  RTFAST
XAERWG  -  RTFAST
XAIO    -  GEAR      RTFAST    RTSLOW
XARFP   -  RTFAST    RTSLOW
XARHT   -  RTFAST
XARVT   -  RTFAST
XCG     -  GEAR      RTFAST    RTSLOW
XCNTRL  -  RTFAST
XDTCG   -  RTFAST
XF      -  RTSLOW
XFAC    -  RTSLOW
XFMFLF  -  RTSLOW
XFUNC   -  RTFAST    RTSLOW
XG      -  GEAR
XGEAR   -  GEAR
XG1     -  GEAR
XHT     -  RTFAST    RTSLOW
XL      -  RTSLOW
XLCOS   -  RTFAST    RTSLOW
XLINTP  -  RTFAST    RTSLOW
XLSIN   -  RTSLOW
XMAP    -  RTFAST
XN      -  GEAR
XPAR1   -  AILSP     CLCDCM    RTFAST    RTSLOW
XPAR3   -  AILSP     CLCDCM    RTFAST    RTSLOW
XR      -  RTSLOW
XRCOS   -  RTFAST    RTSLOW
XRLCON  -  RTSLOW
XRSIN   -  RTSLOW
XVT     -  RTFAST
XW      -  RTSLOW
XWAC    -  RTFAST    RTSLOW
XWC2    -  RTFAST
XWMWLW  -  RTSLOW
XXICON  -  RTSLOW
XZICON  -  RTSLOW
YAERF   -  RTFAST
YAERLW  -  RTFAST
YAERNC  -  RTFAST
YAERNL  -  RTFAST
YAERNR  -  RTFAST
YAERO   -  RTFAST
YAERRW  -  RTFAST
YAERT   -  RTFAST
YAERWG  -  RTFAST
YARFP   -  RTFAST    RTSLOW
```

Figure G.6. (Continued)

```
YARHT    - RTFAST
YARVT    - RTFAST
YG       - GEAR
YG1      - GEAR
YN       - GEAR     RTFAST    RTSLOW
YWAC     - RTFAST
YYICON   - RTSLOW
ZAERF    - RTFAST
ZAERLW   - RTFAST
ZAERNC   - RTFAST
ZAERNL   - RTFAST
ZAERNR   - RTFAST
ZAERO    - RTFAST
ZAERRW   - RTFAST
ZAERT    - RTFAST
ZAERWG   - RTFAST
ZARFP    - RTFAST   RTSLOW
ZARHT    - RTFAST
ZARRG    - RTFAST
ZARVB    - RTFAST
ZARVT    - RTFAST
ZCG      - GEAR     RTFAST    RTSLOW
ZDTCG    - RTFAST
ZETHL    - RTFAST   RTSLOW
ZETHR    - RTFAST   RTSLOW
ZETR1    - RTSLOW
ZETR2    - RTSLOW
ZETR3    - RTSLOW
ZETR4    - RTSLOW
ZF       - RTSLOW
ZFAC     - RTSLOW
ZFMFHF   - RTSLOW
ZG       - GEAR
ZG1      - GEAR
ZHT      - RTFAST   RTSLOW
ZL       - RTSLOW
ZLCOS    - RTSLOW
ZLSIN    - RTFAST   RTSLOW
ZN       - GEAR
ZR       - RTSLOW
ZRCOS    - RTSLOW
ZRLCON   - RTSLOW
ZRSIN    - RTFAST   RTSLOW
ZVT      - RTFAST
ZW       - RTSLOW
ZWAC     - RTFAST   RTSLOW
ZWMWHW   - RTSLOW
ZZICON   - RTSLOW
```

****

Figure G.6. (Continued)

**************** TABLE OF CONTENTS ****************

Figure G.6. (Continued)

time tasks (RTFAST and RTSLOW), the aileron-spoiler subroutine (AILSP), the total lift, drag and moment subroutine (CLCDCM), the engine power subroutine (ENGINE), and the landing gear subroutine (GEAR) . The aileron spoiler subroutine calculates the lift, drag and pitching moment increments. The total wing lift,drag, and moment characteristics are computed in subroutine CLCDCM. Engine performance is computed in the engine subroutine and landing gear forces and moments in the gear subroutine. This listing contains an index of all the variables immediately following each subroutine. The index specifies by location number where the particular variable is defined and used in the subroutine. A master index is provided at the end which specifies the subroutine in which a particular variable is located.

In programming the analog portion of the simulation, size also was of prime concern, where in this case size implies an equipment limitation. From the beginning, equipment was allocated with maximum efficiency,but due to the complexity of the engine/governor, the phasing of the controls, the number of second order representations of actuators, and the number of functions needed to program these sections, the result was 1) three analogs used with a minimum of spare equipment and 2) 31 out of 32 BCA channels needed to program functions (includes rotor). When the capability of using the nudge-base simulator is added, the simulation uses every piece of hardware available in the hybrid laboratory. Figure G.7 shows the definition of the symbols used on the analog diagrams for the Model 222 simulation presented in Figure G.8.

The scale factors for any of the elements shown in the analog diagrams may be determined by referring to Figure G.9 , which is the subroutine used to static check the analog boards. The subroutine shows all the equations on the analogs and all of the scale factors. This program is used for static check only, in the operate mode the real time task continuously updates the analog. As an example, if the scale factor (and value) for potentiometer 240, which is used in the pitch equation of motion on board 1E console 1 is required the following steps are taken. Refer to the potentiometer calculation section of Figure G.9. This lies between statement numbers 0416 and 0518. Look up the definition of pot 240 [P1(240)]. This appears in statement number 0444 and is P1(240)=P1C/PMX. P1C is contained in common |X1C|, statement number 0008 and PMX is contained in common |XMAX|, statement number 0013. Substituting numerical values and dividing would yield the scale factor for pot 240.

G.2 TRIM LOOPS

The Model 222 trim loops are on the analog. The aircraft accelerations are used in feedback loops to drive the aircraft into

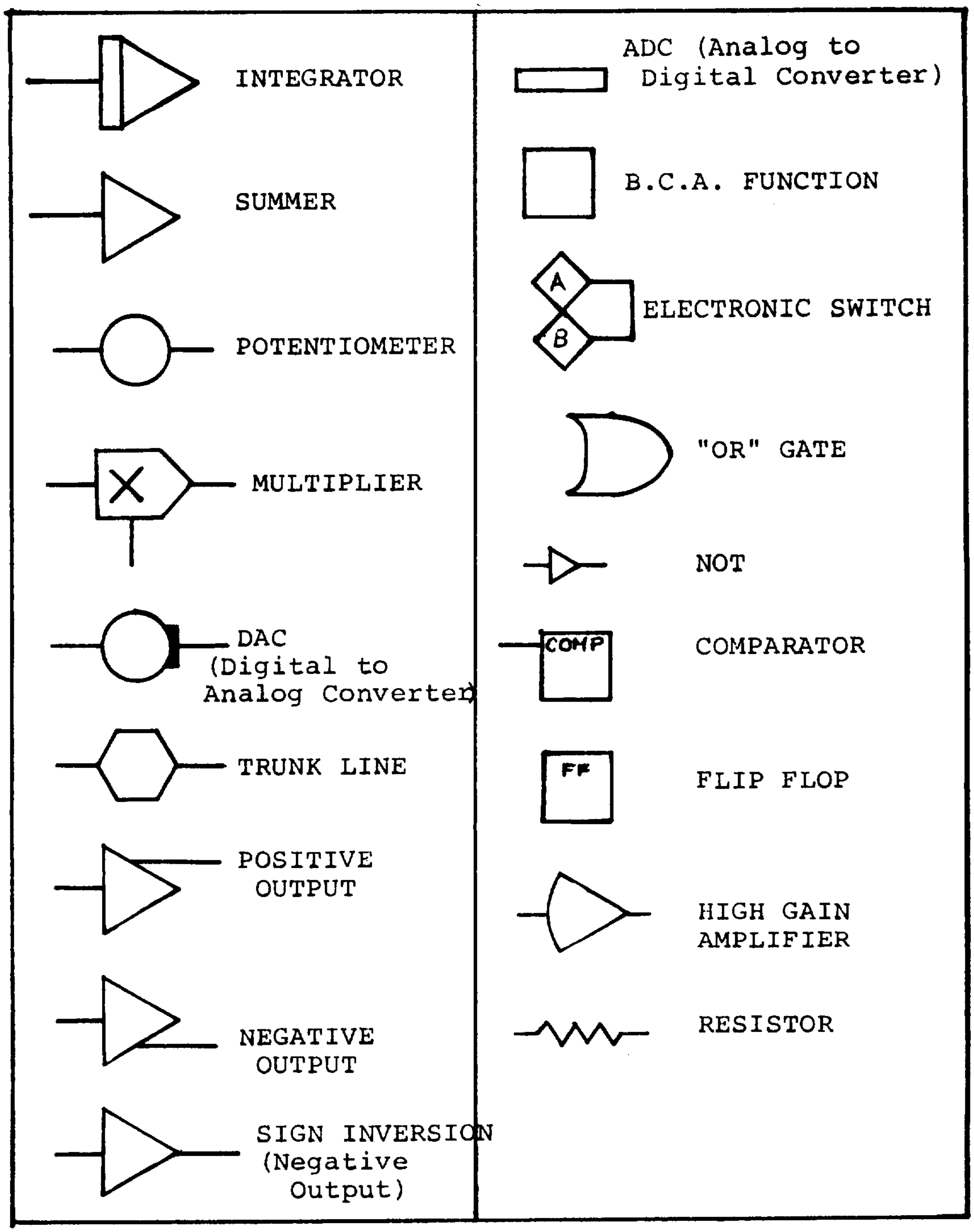


Figure G.7. Analog Symbols

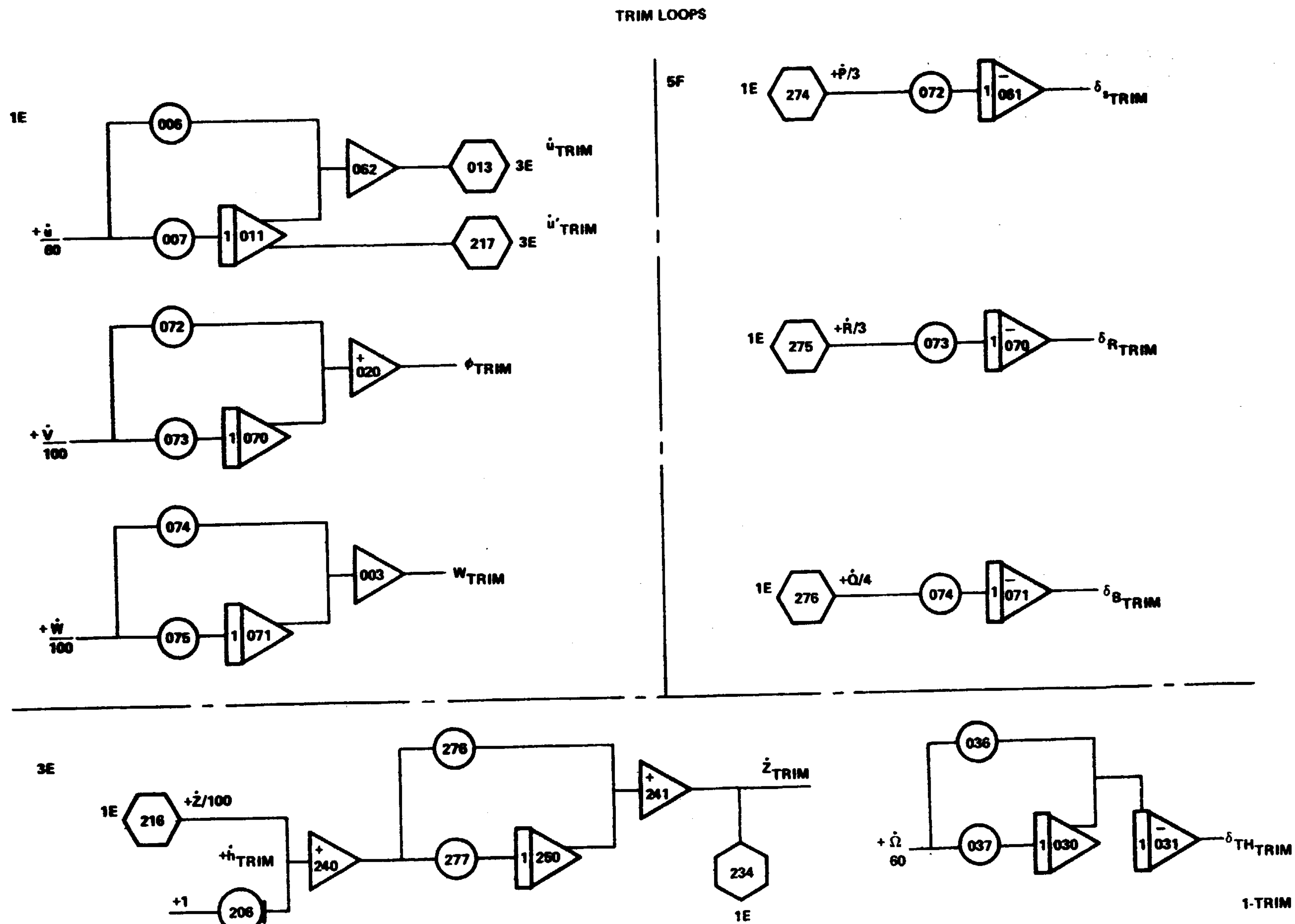


Figure G.8. *Analog Diagrams for Model 222 Simulation*

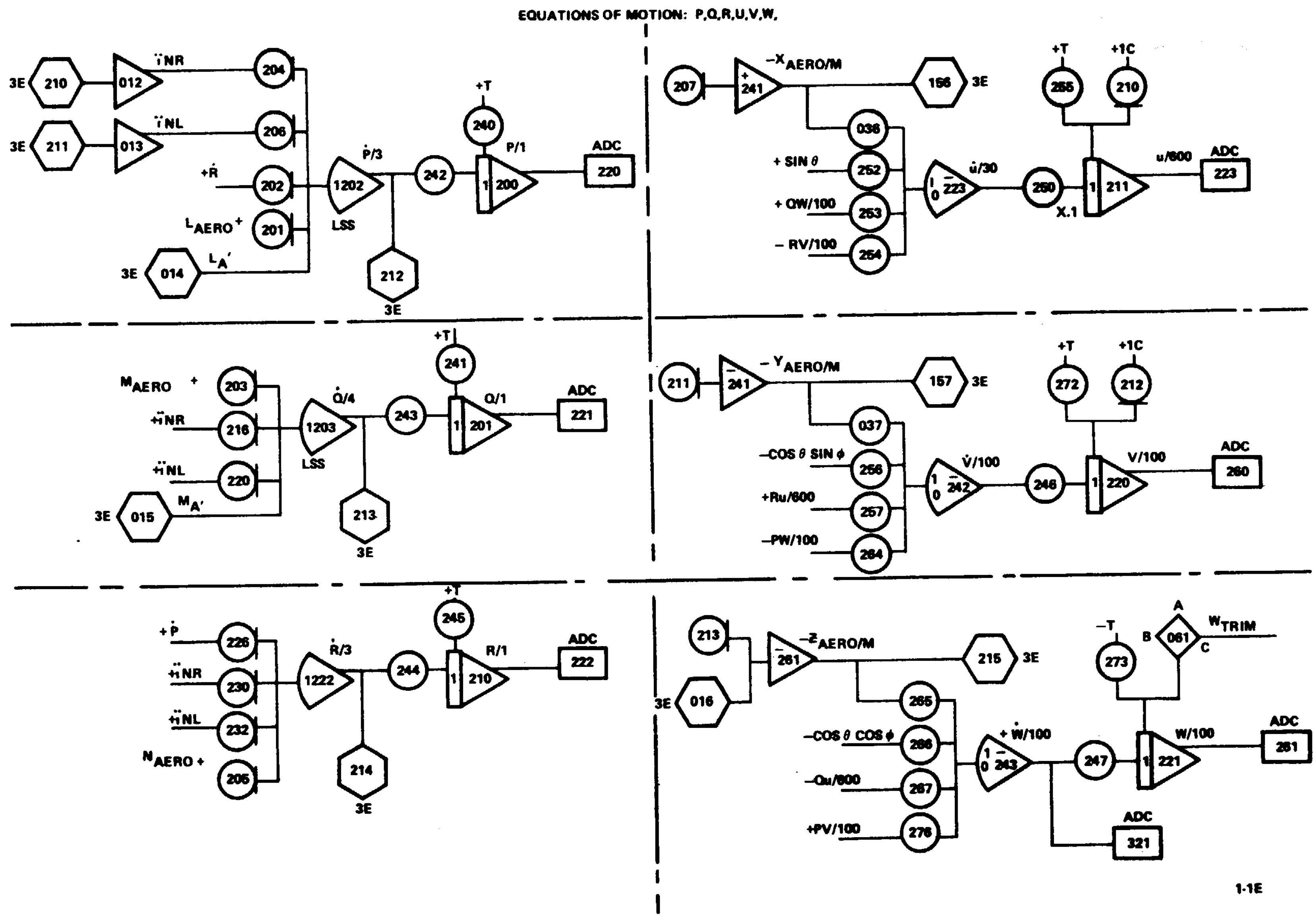


Figure G.8. (Continued)

EQUATIONS OF MOTION: θ, φ, ψ, X, Y, Z

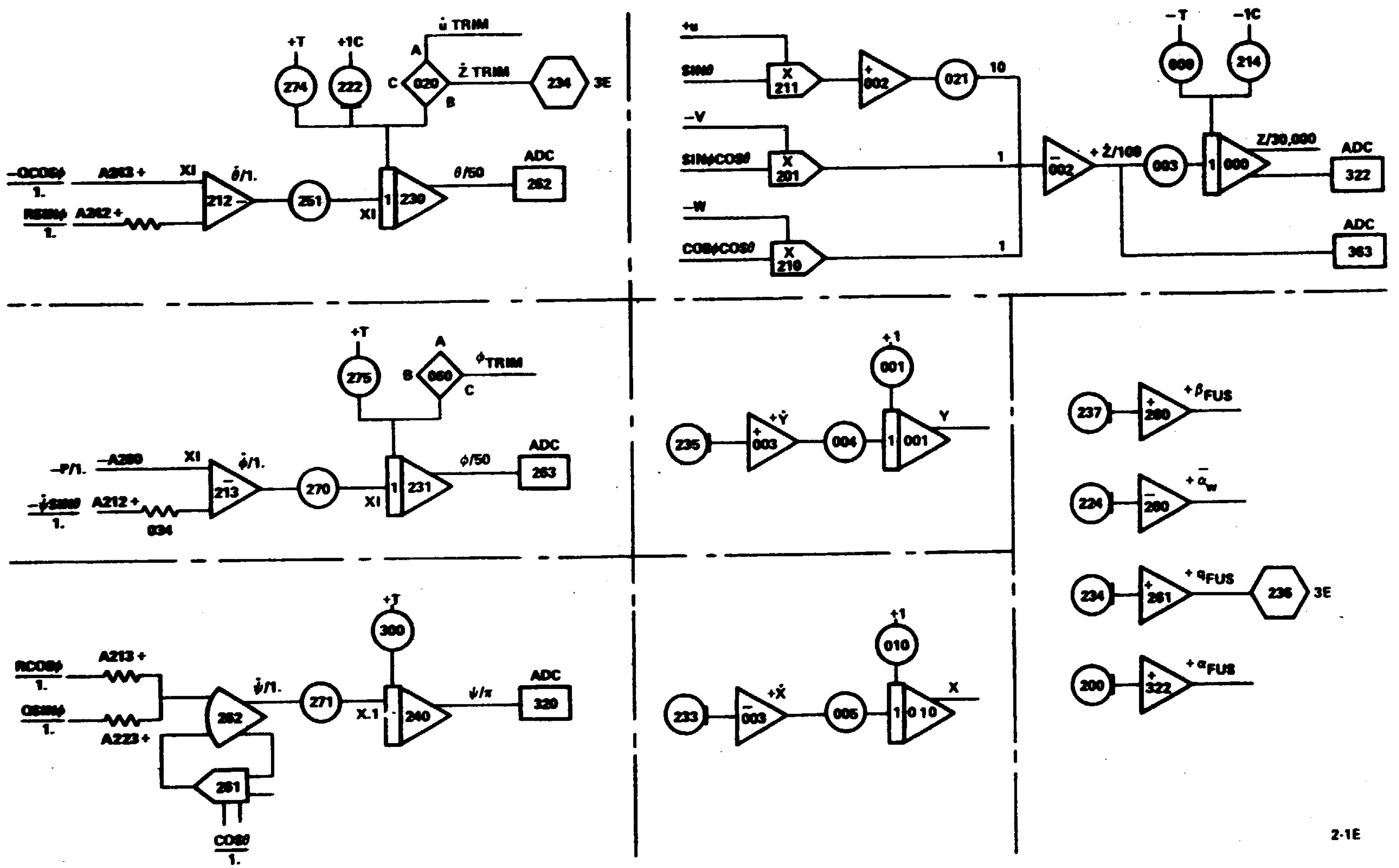


Figure G.8. (Continued)

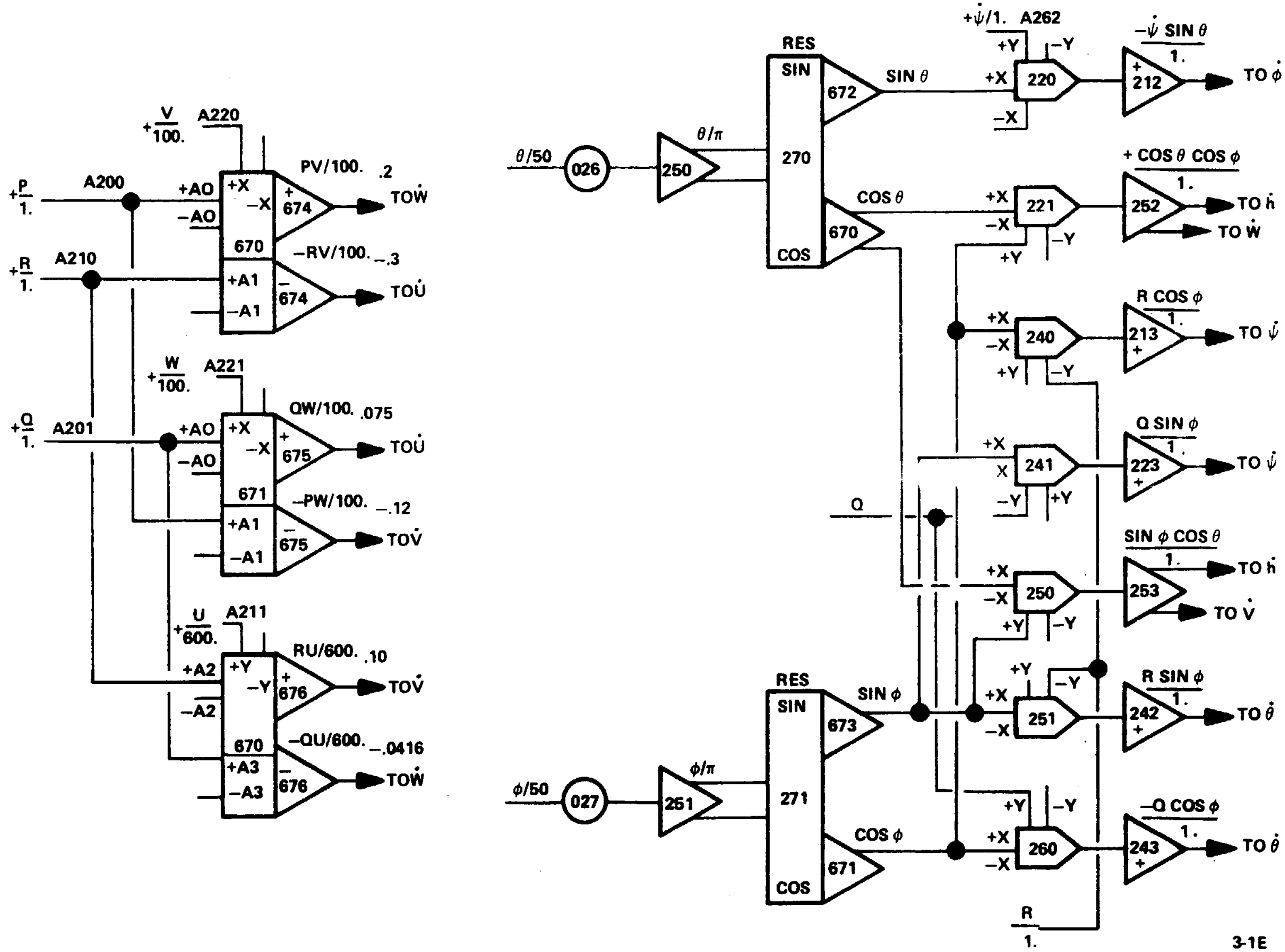


Figure G.8. (Continued)

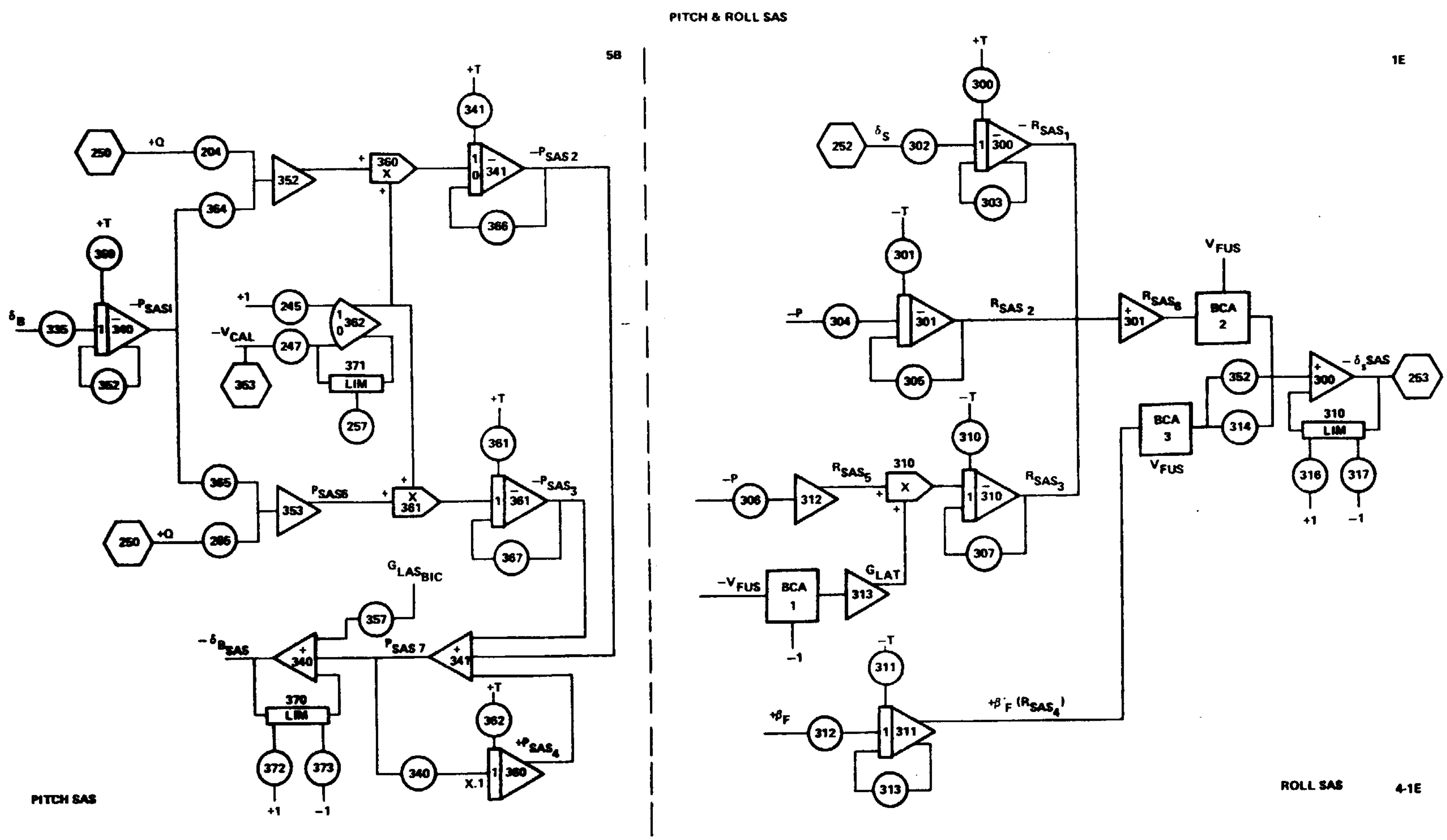


Figure G.8. (Continued)

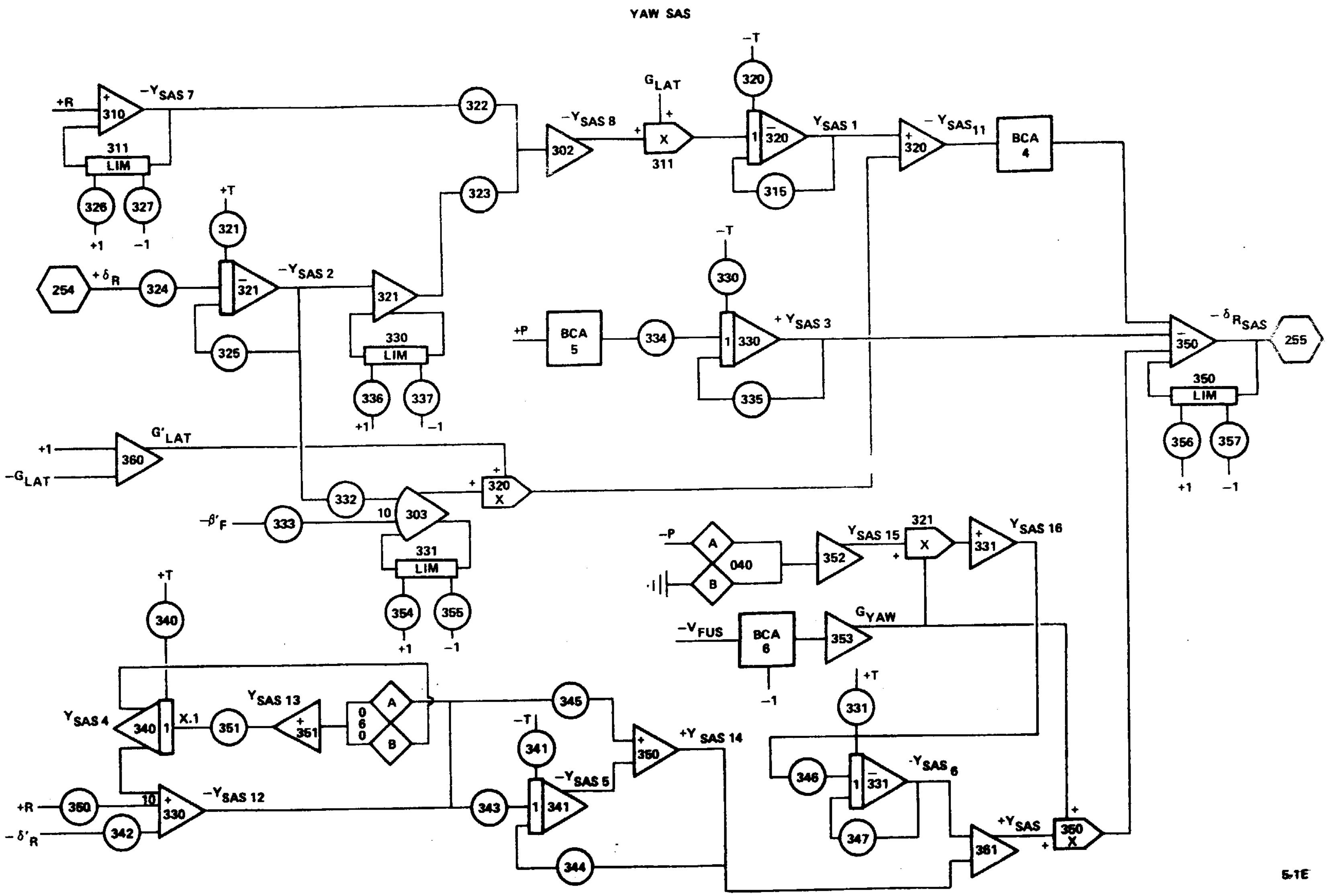
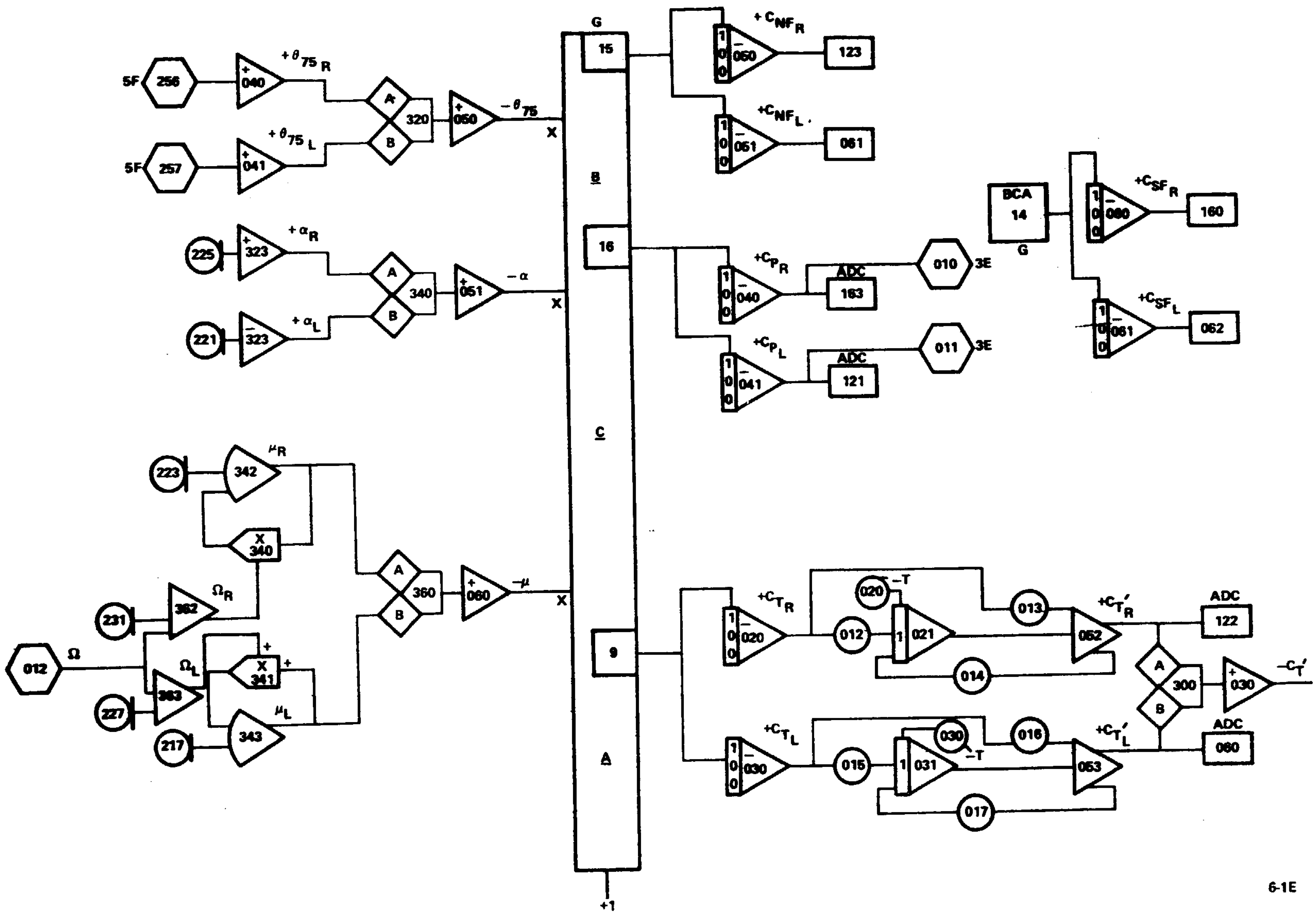


Figure G.8. (Continued)

ROTOR FUNCTIONS



6-1E

Figure G.8. (Continued)

ROTOR FUNCTION LOGIC

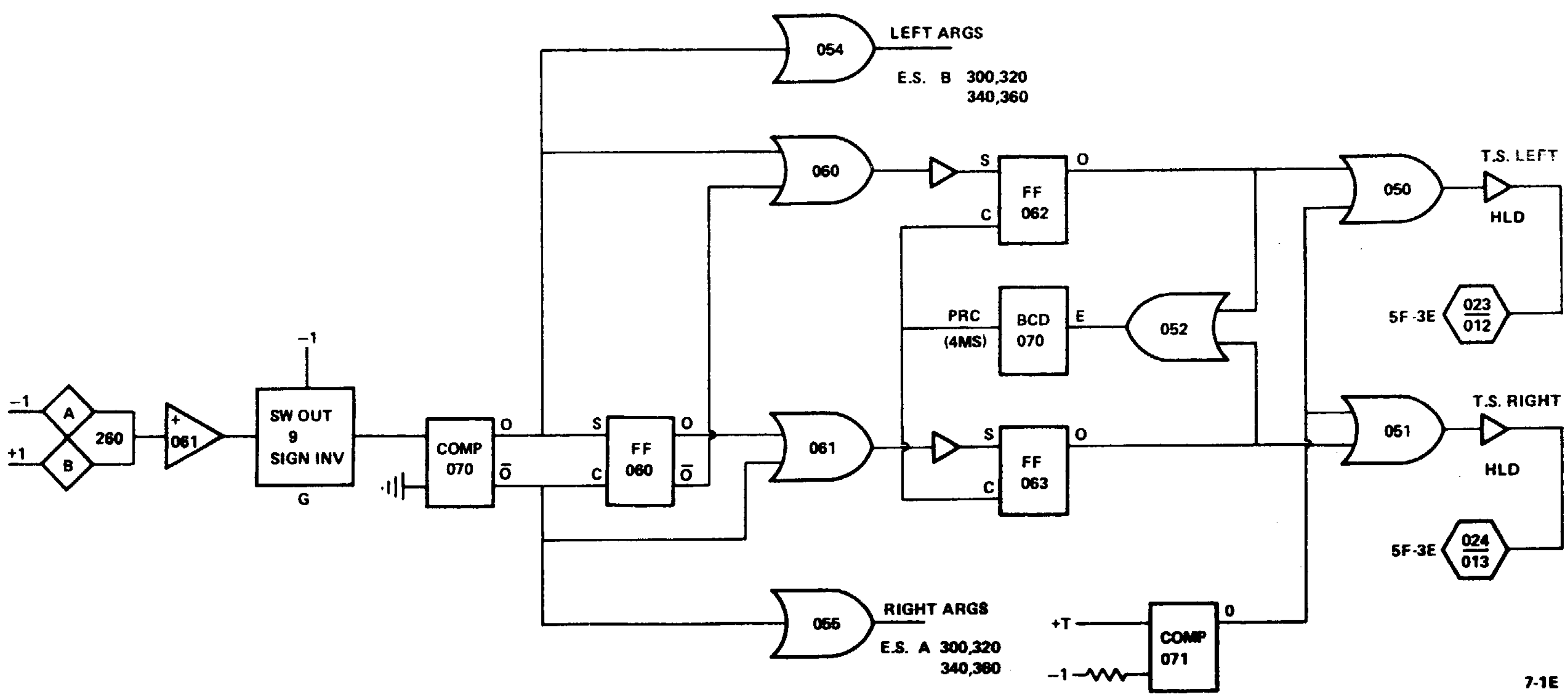


Figure G.8. (Continued)

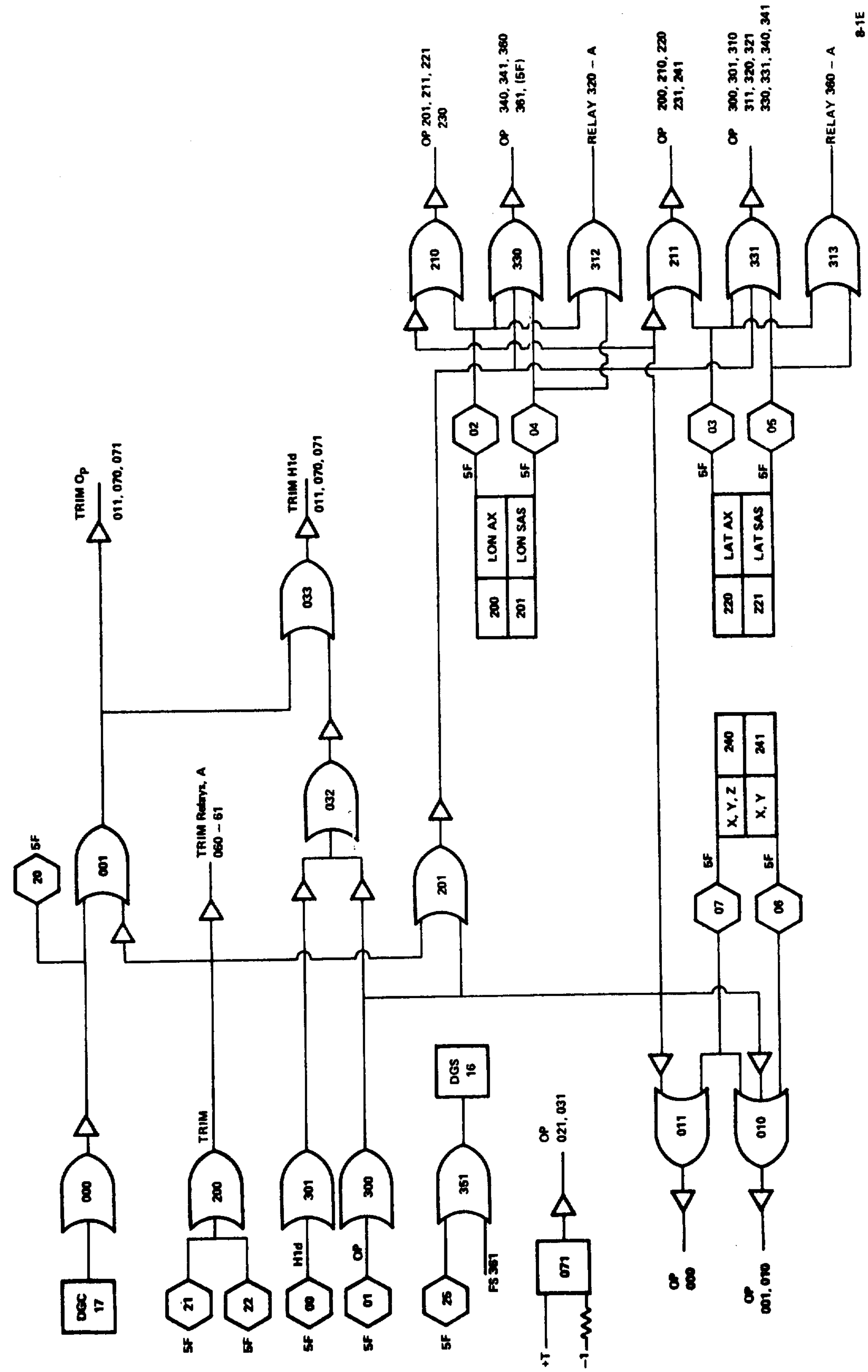


Figure G.8. (Continued)

TRIM LOGIC

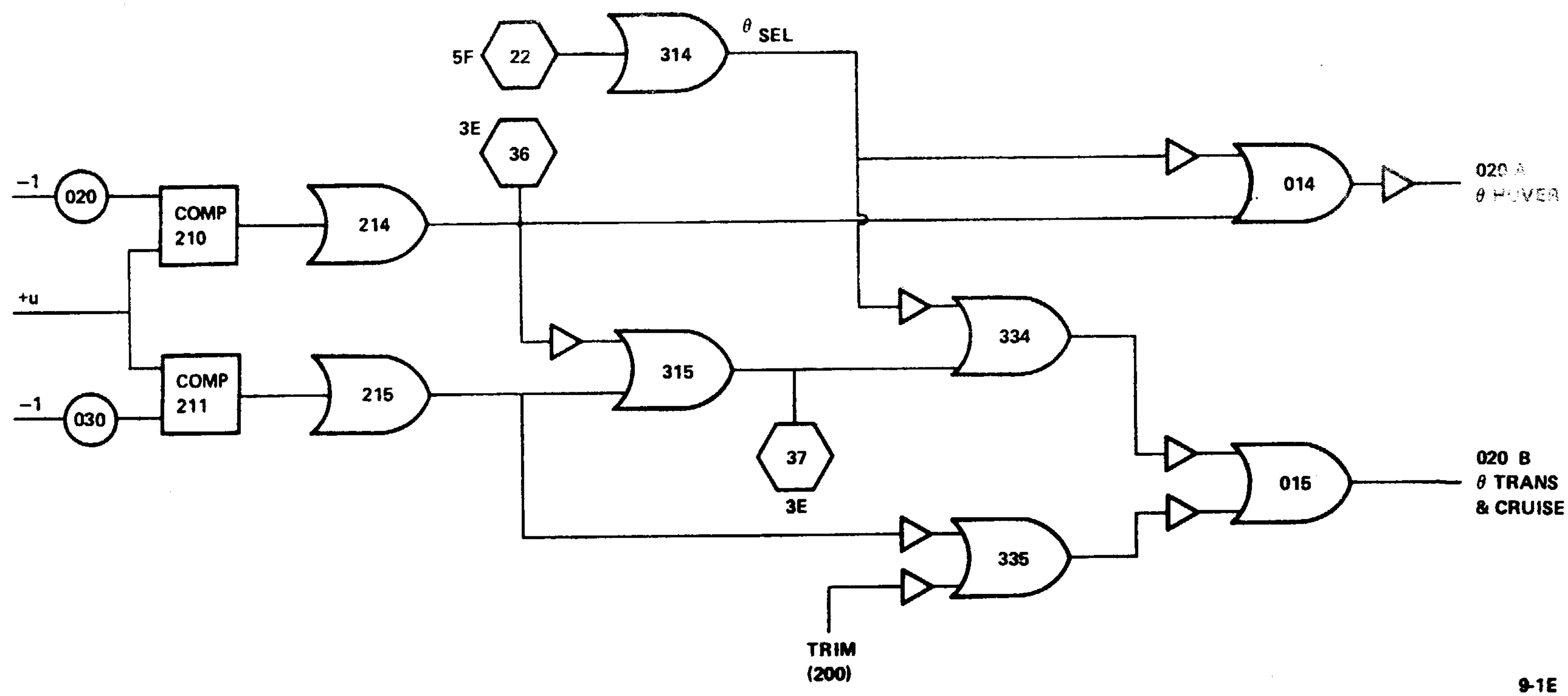


Figure G.8. (Continued)

NACELLES

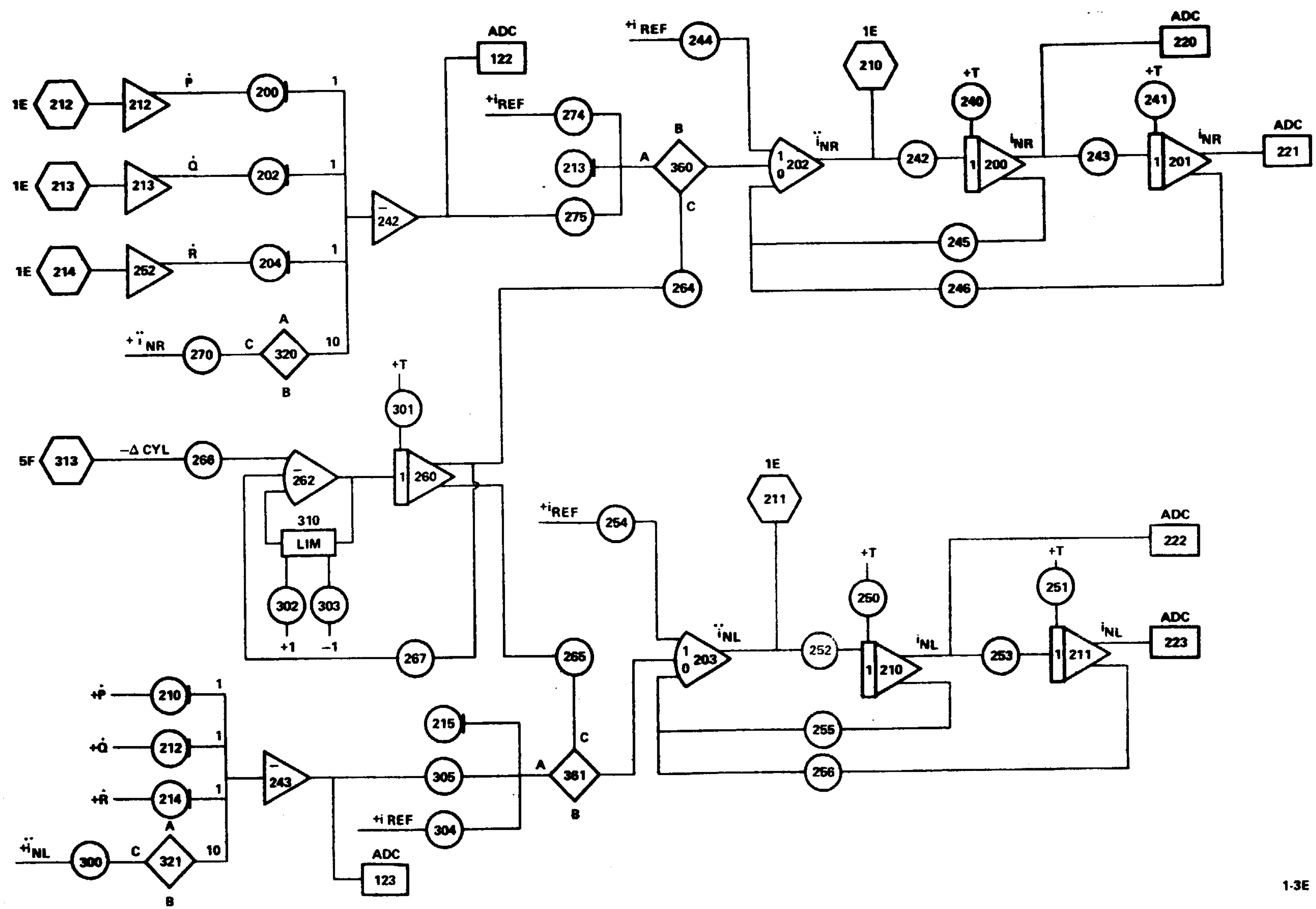


Figure G.8. (Continued)

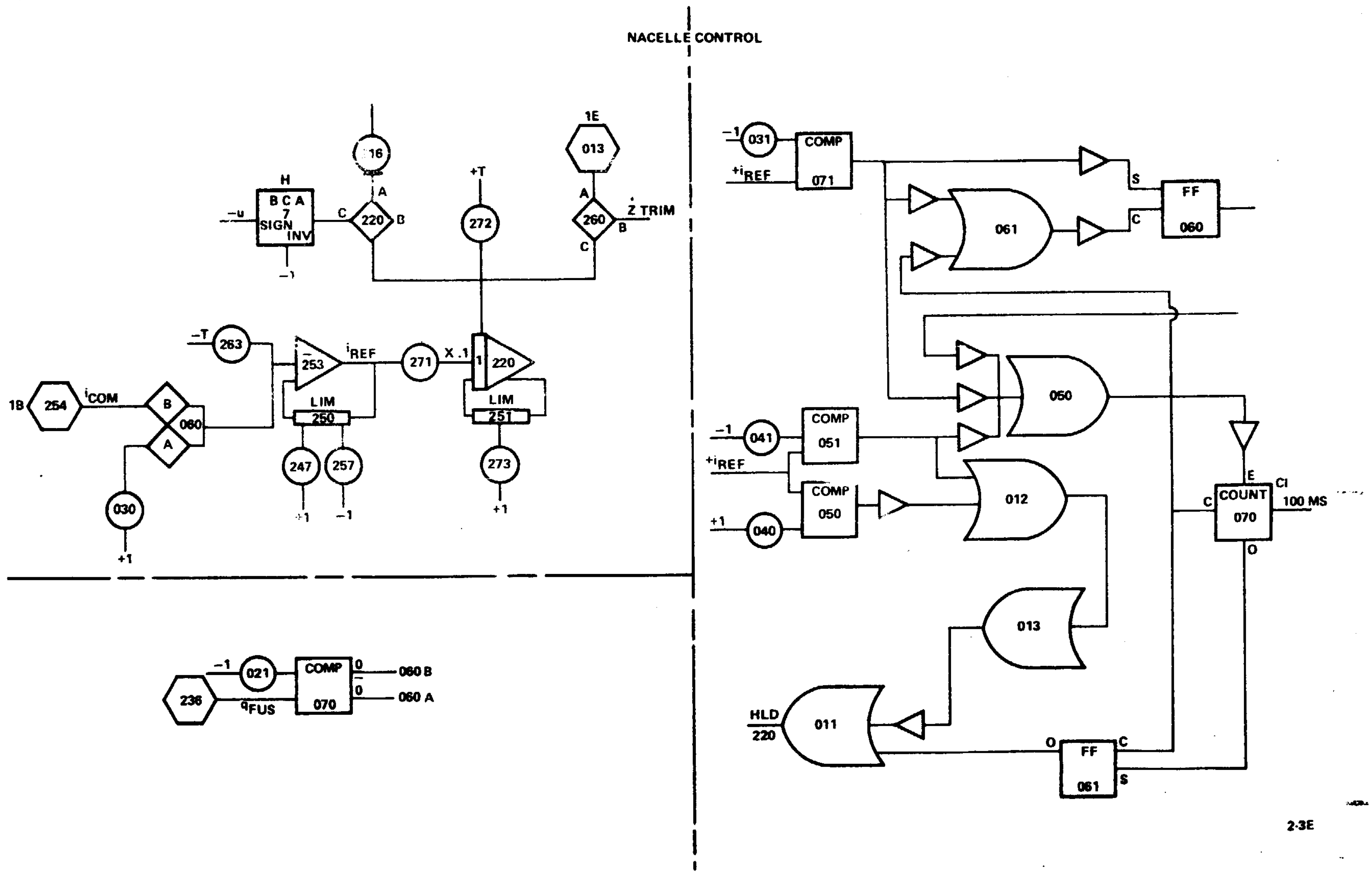


Figure G.8. (Continued)

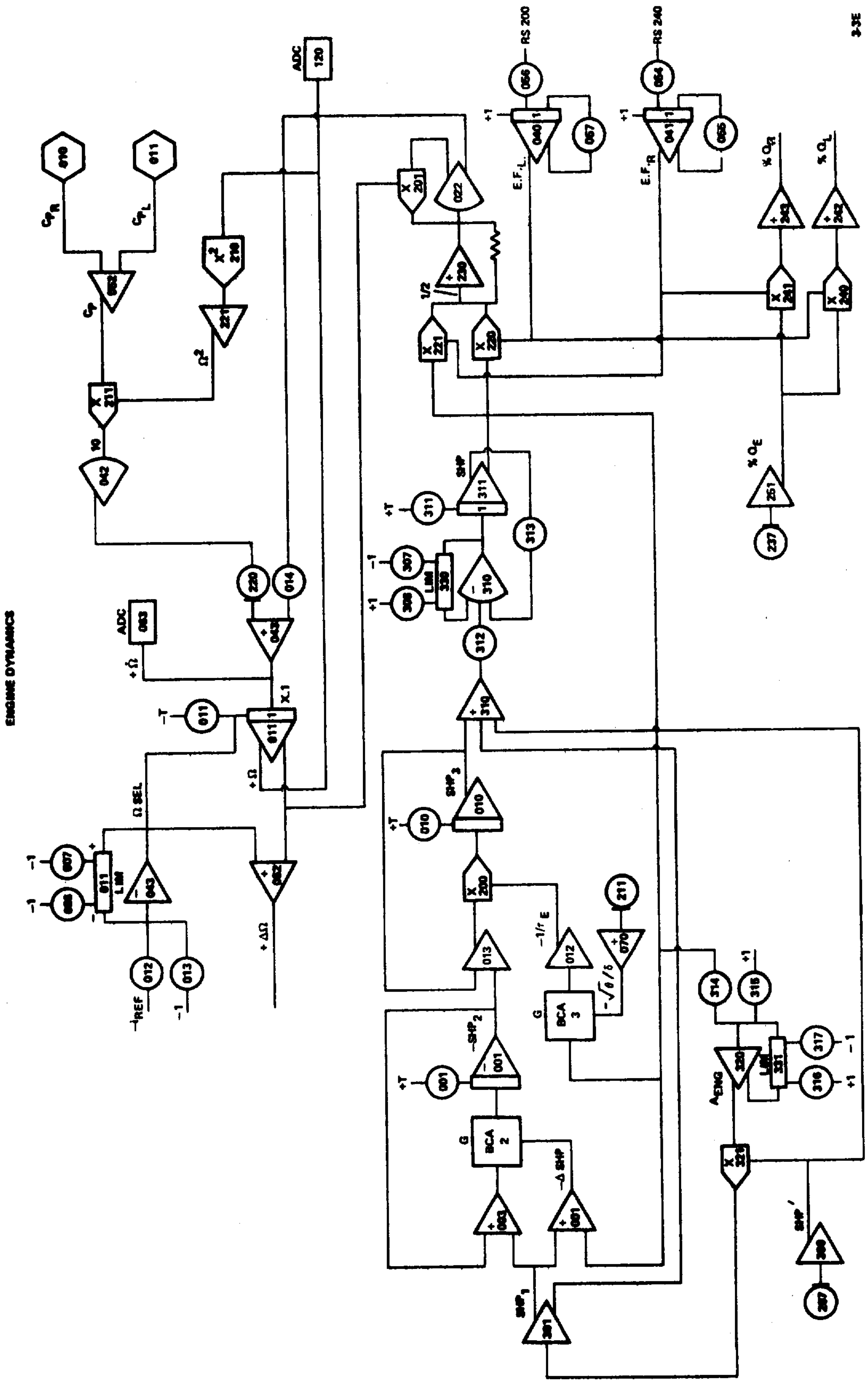


Figure G.8. (Continued)

ROTOR SPEED GOVERNOR

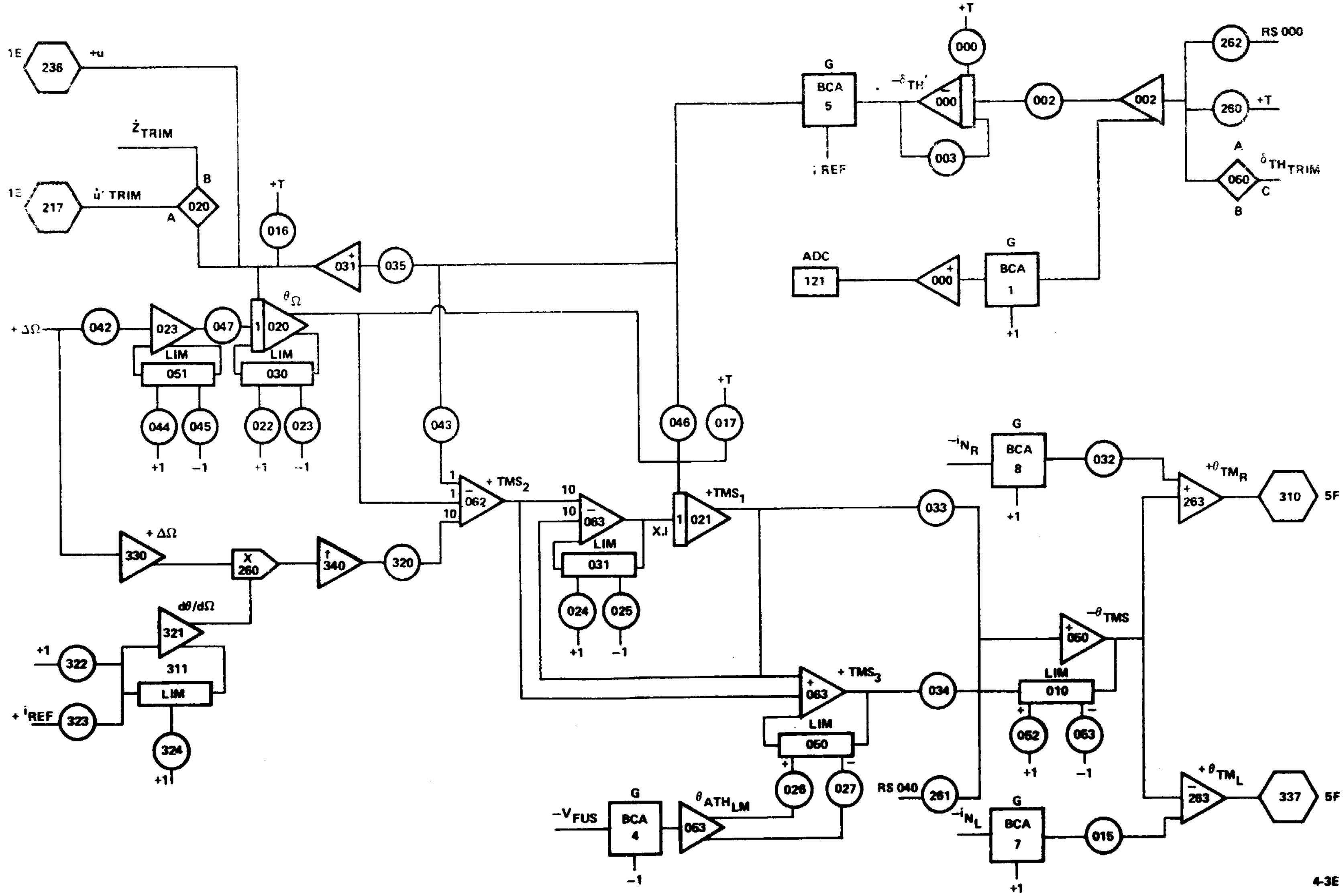


Figure G.8. (Continued)

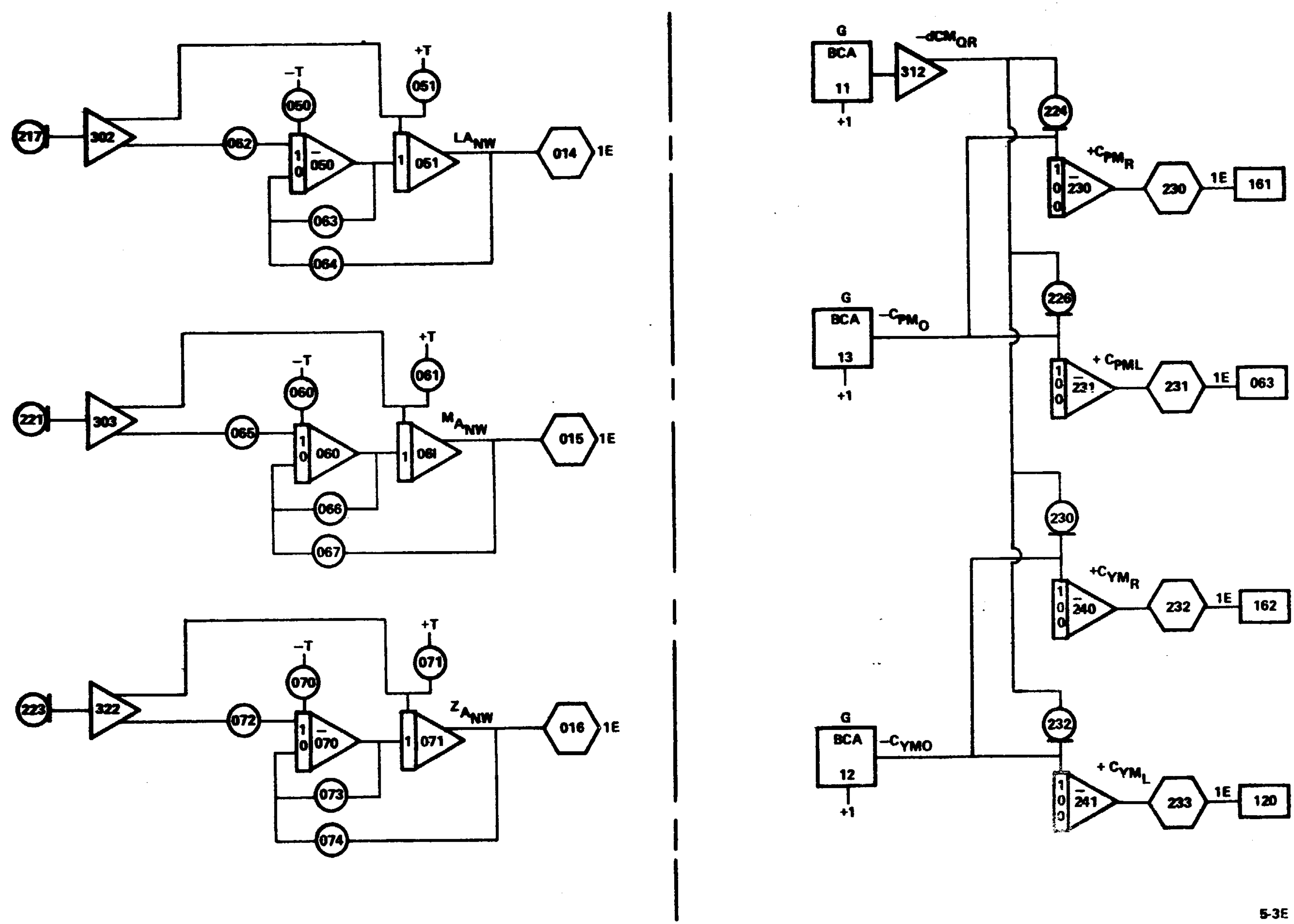


Figure G.8. (Continued)

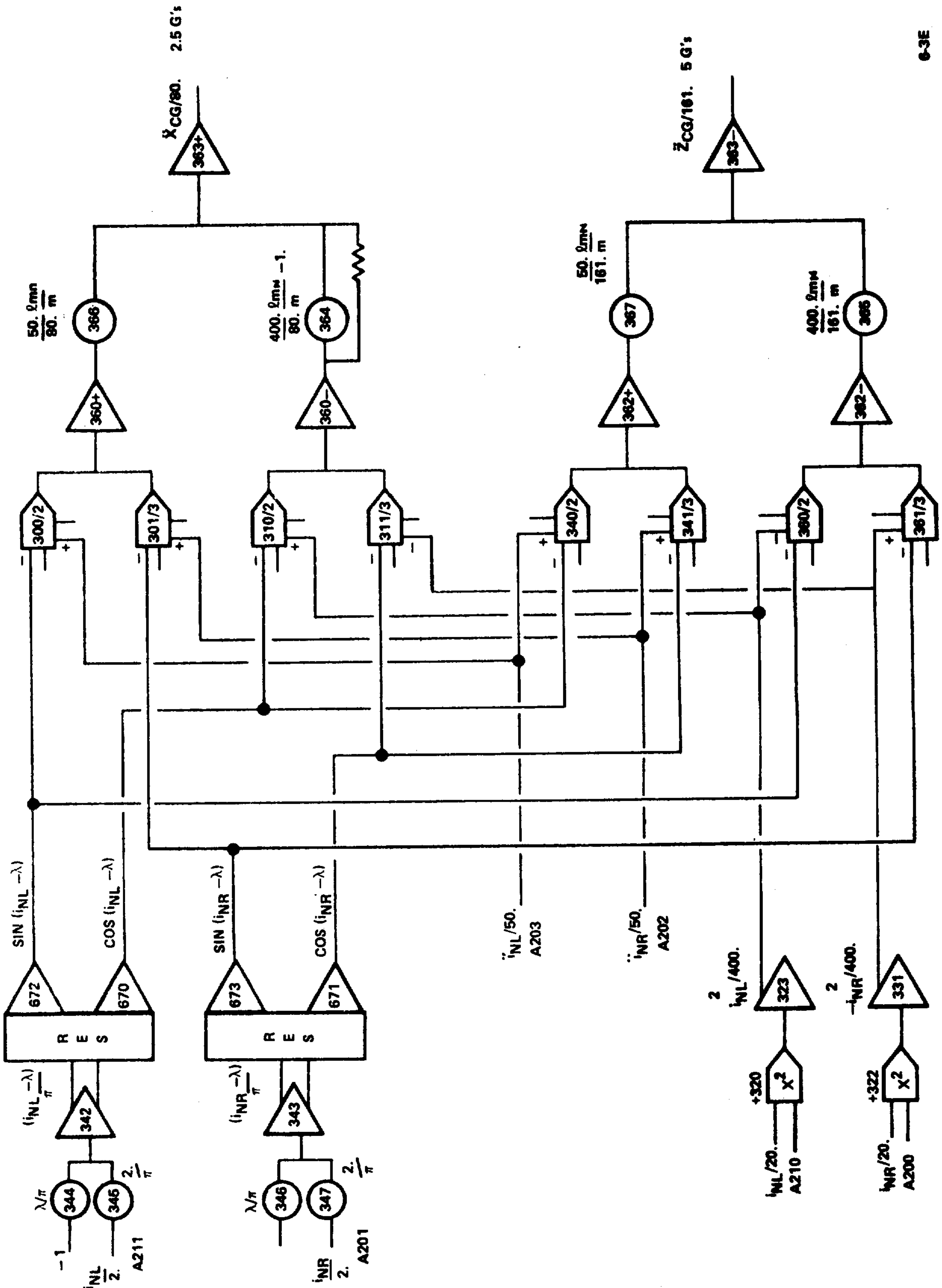


Figure G.8. (Continued)

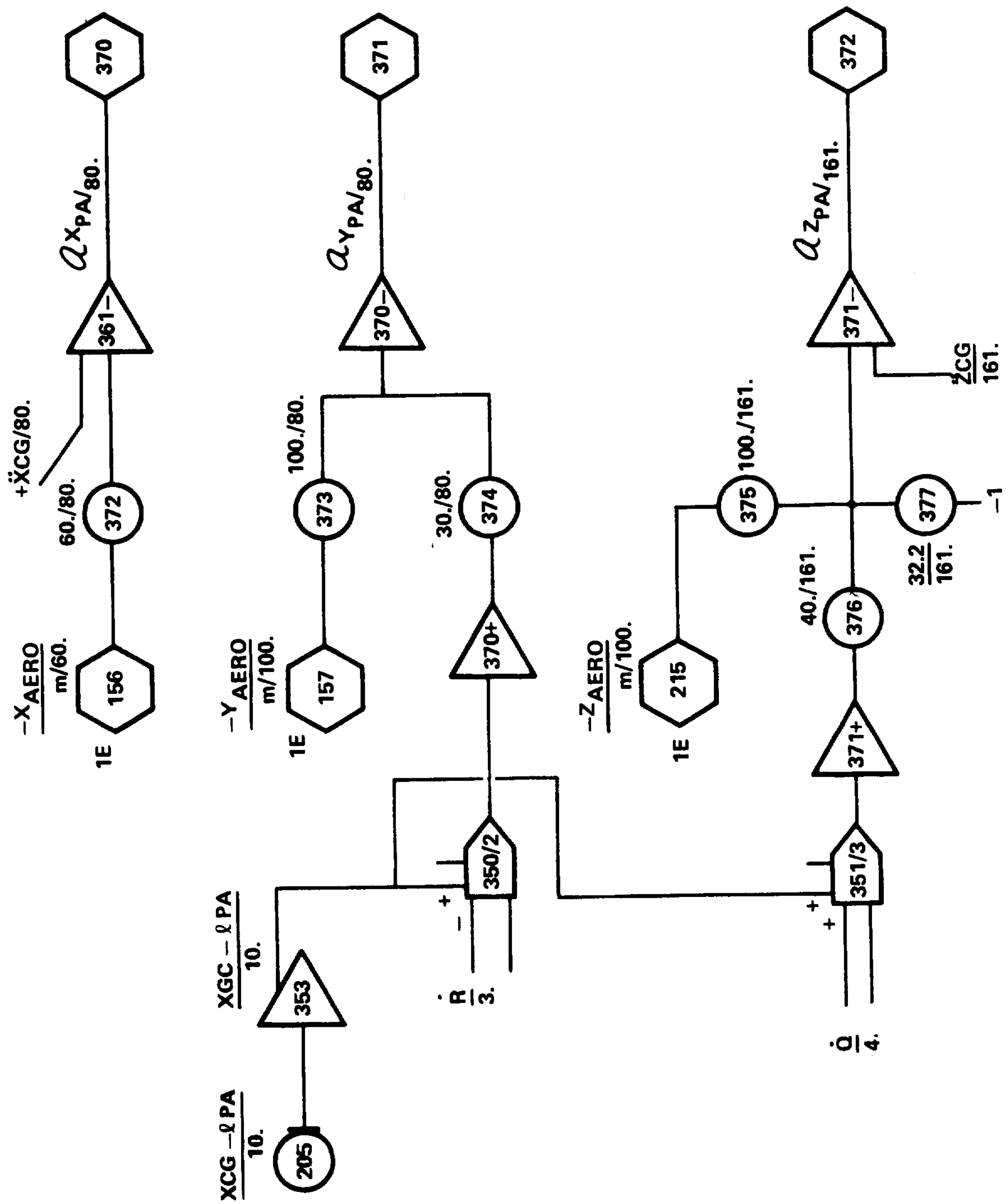


Figure G.8. (Continued)

7-3E

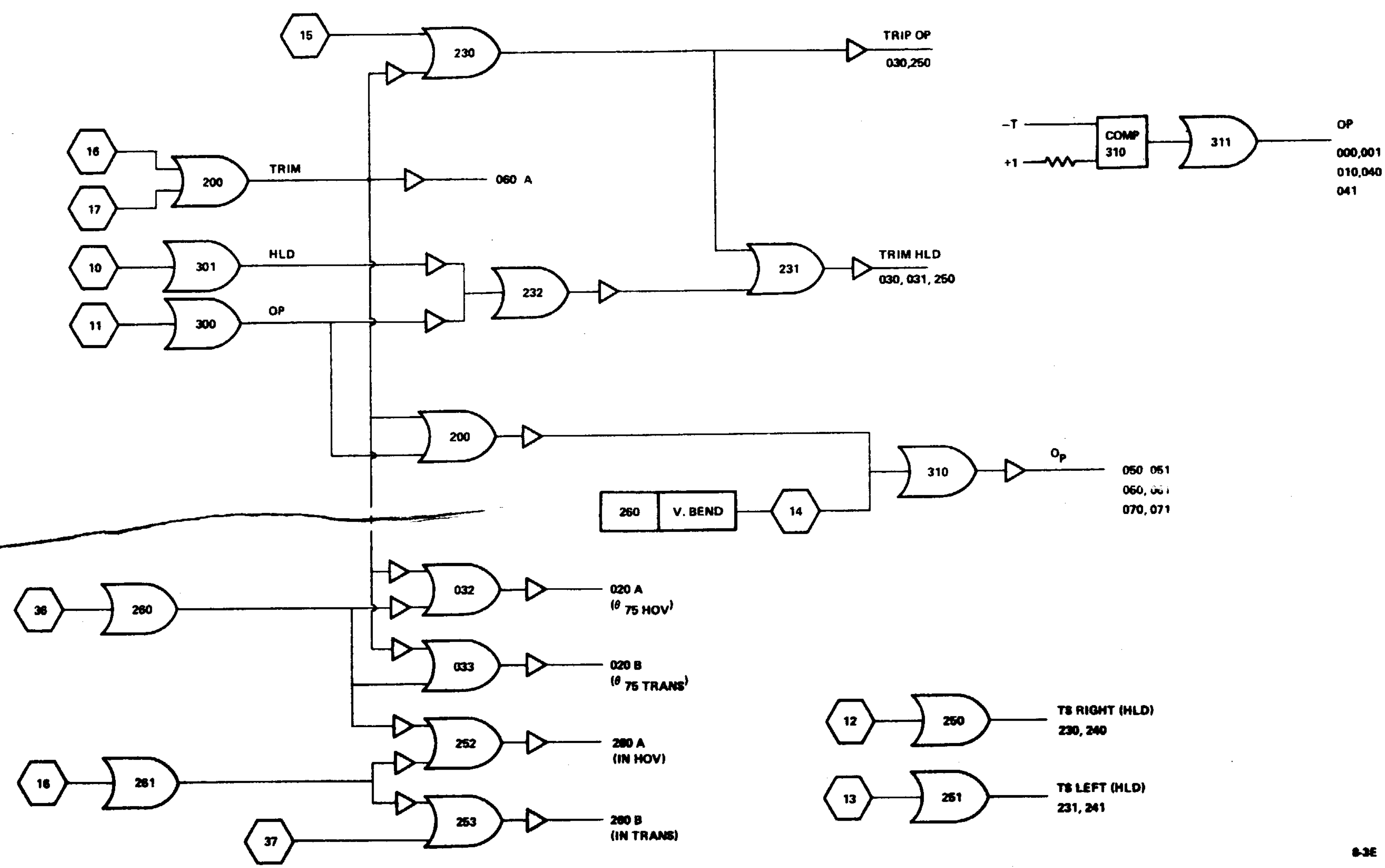


Figure G.8. (Continued)

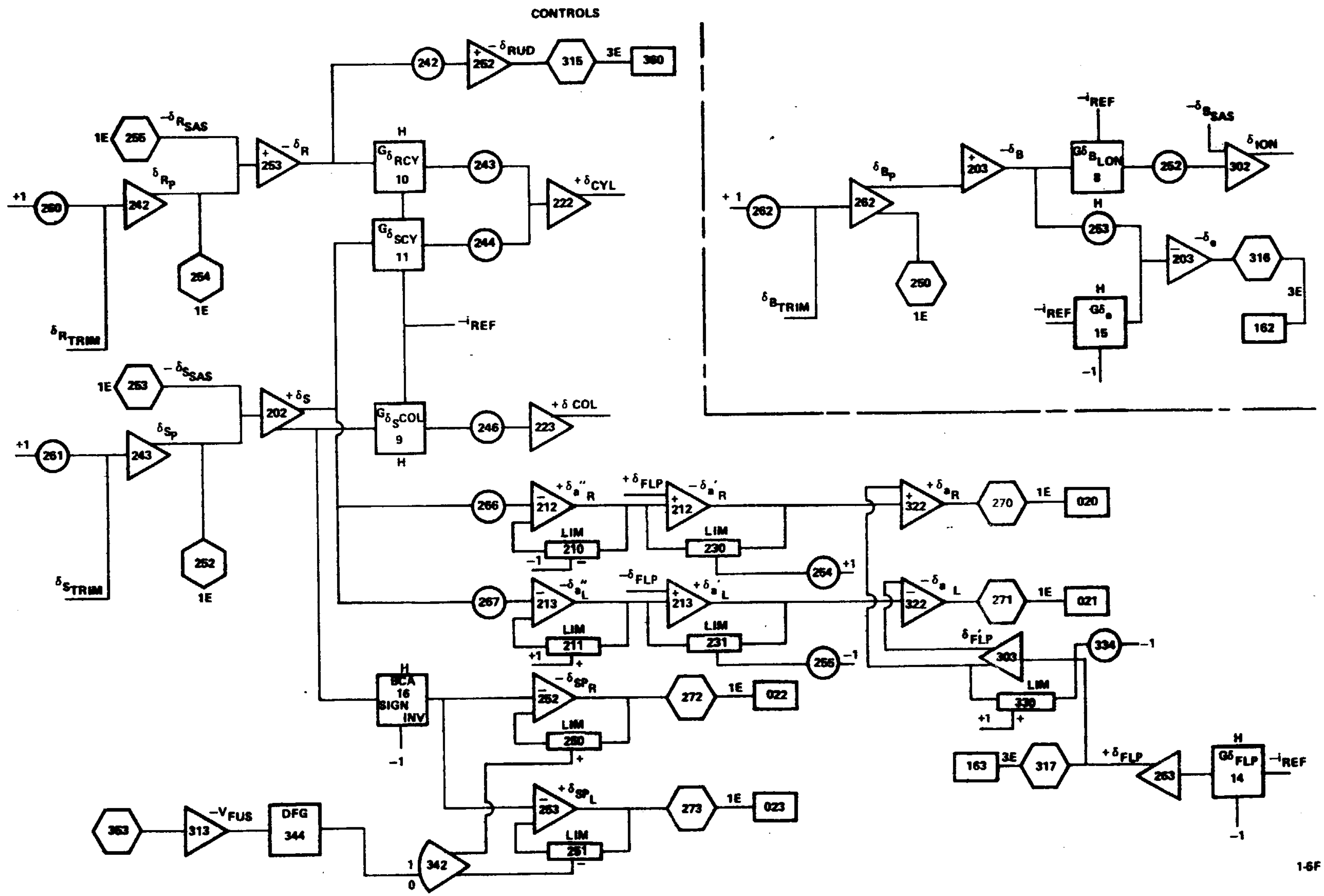


Figure G.8. (Continued)

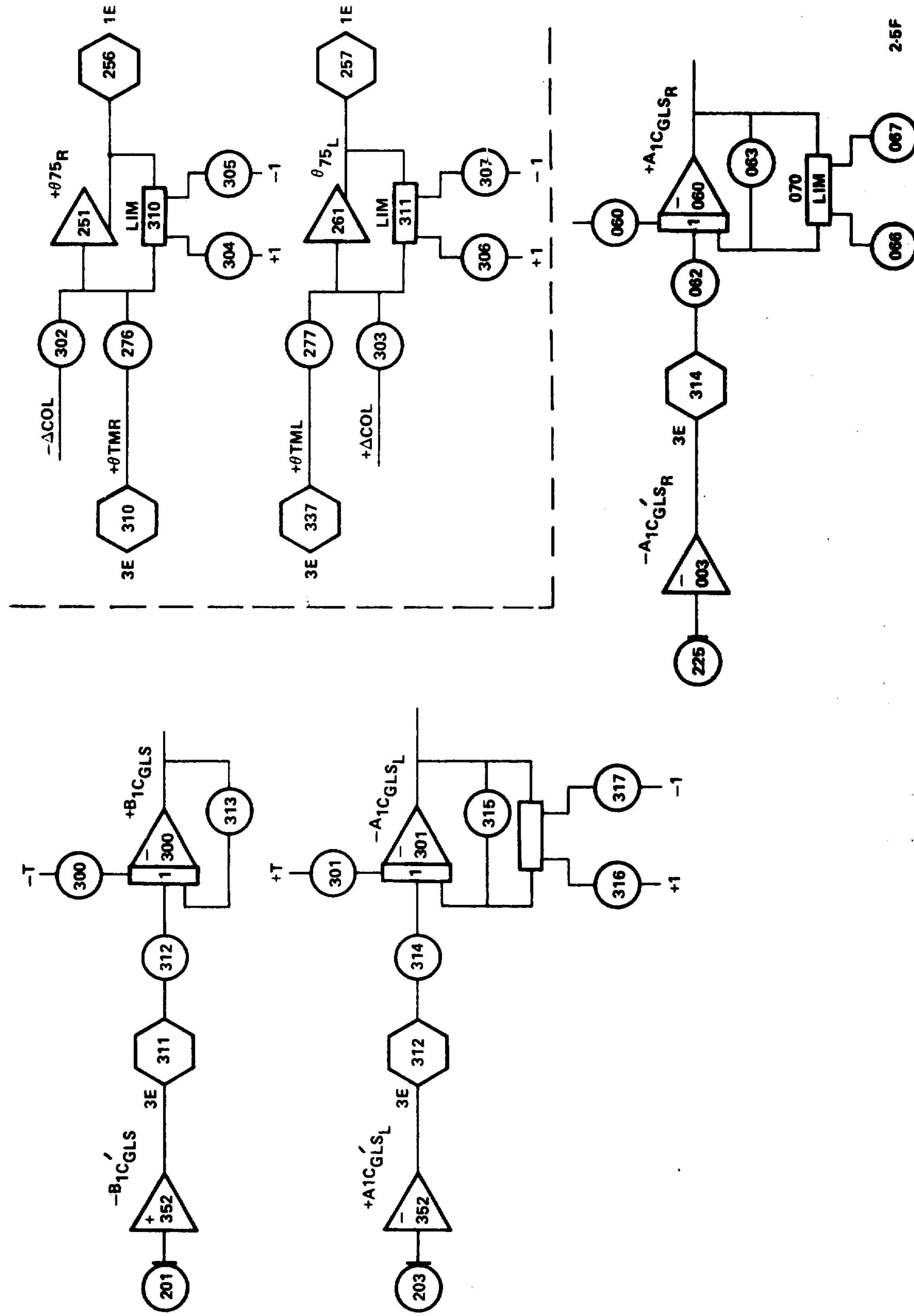
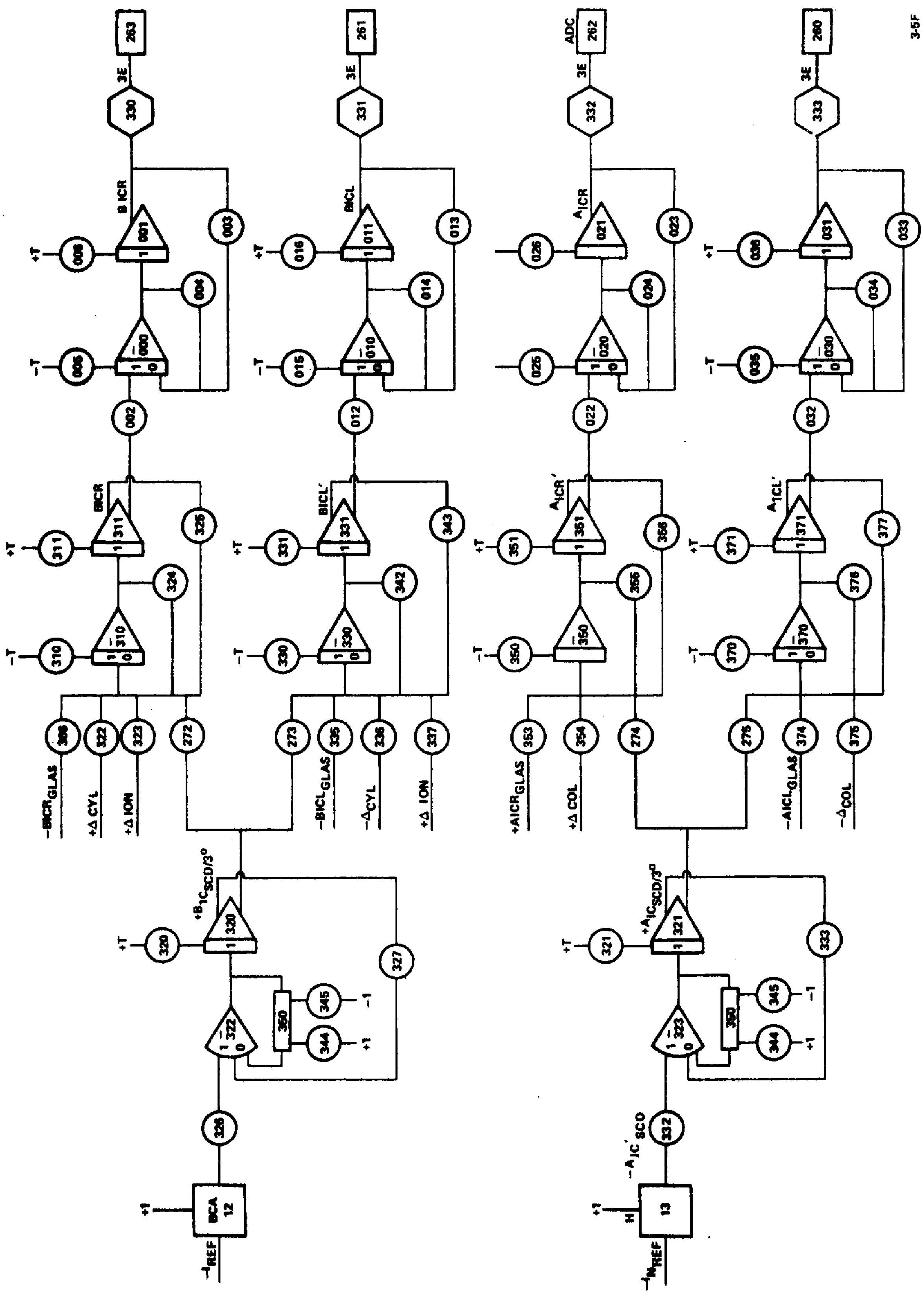


Figure G.8. (Continued)


3-5F
263
261
ADC
262
260
3E
330
331
332
333
B ICR
BICL
A_{ICR}
BICR
BICL'
A_{ICR}'
A_{1CL}'
+T
−T
$+B_{1C_{SCD/3^o}}$
$+A_{IC_{SCD/3^o}}$
$-BICR_{GLAS}$
+Δ CYL
+Δ ION
$-BICL_{GLAS}$
$-\Delta_{CYL}$
+Δ ION
$+AICR_{GLAS}$
+Δ COL
$-AICL_{GLAS}$
$-\Delta_{COL}$
+1
−1
BCA
12
13
H
$-I_{REF}$
$-I_{N_{REF}}$
$-A_{IC}'$ SCO

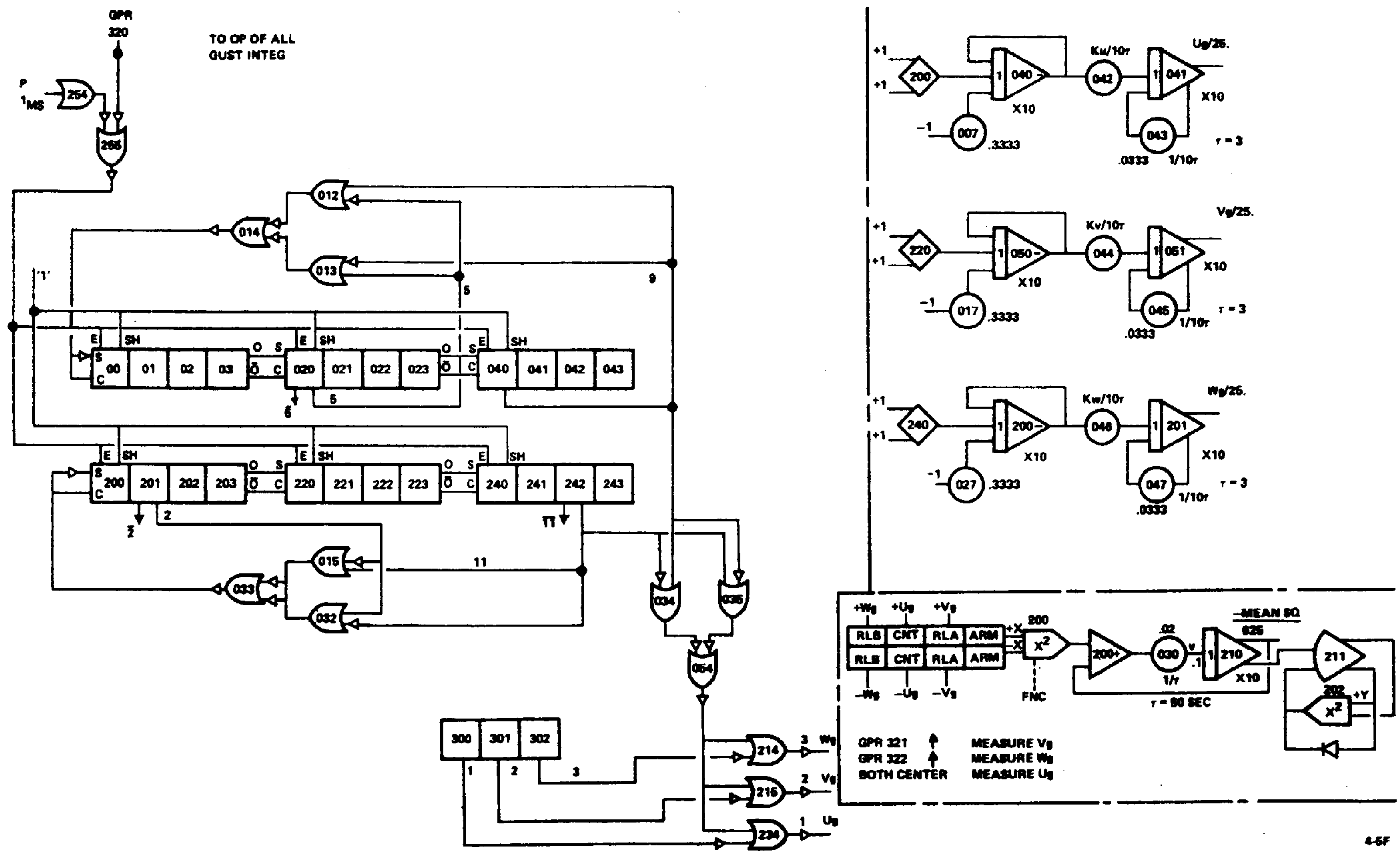


Figure G.8. (Continued)

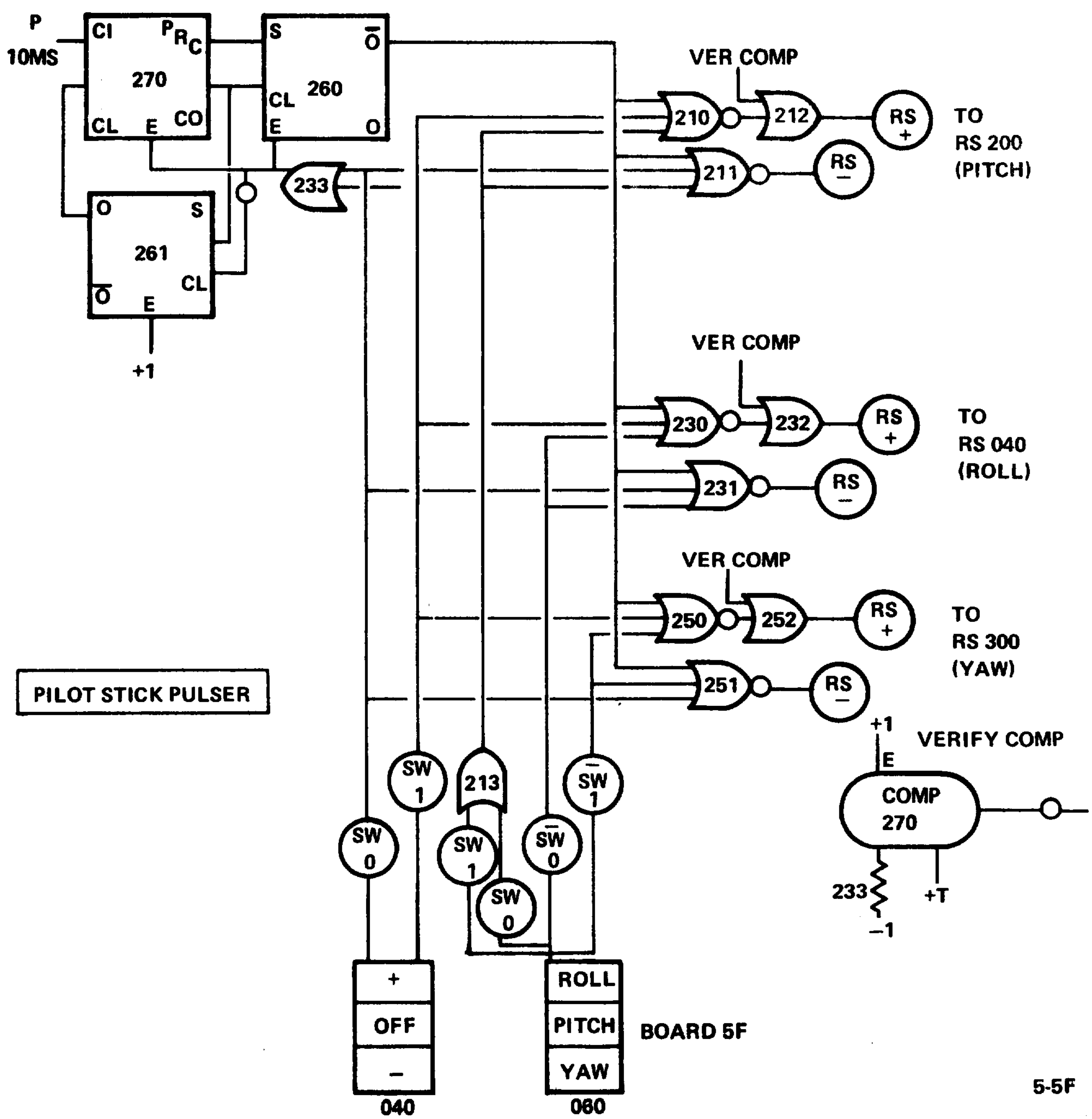


Figure G.8. (Continued)

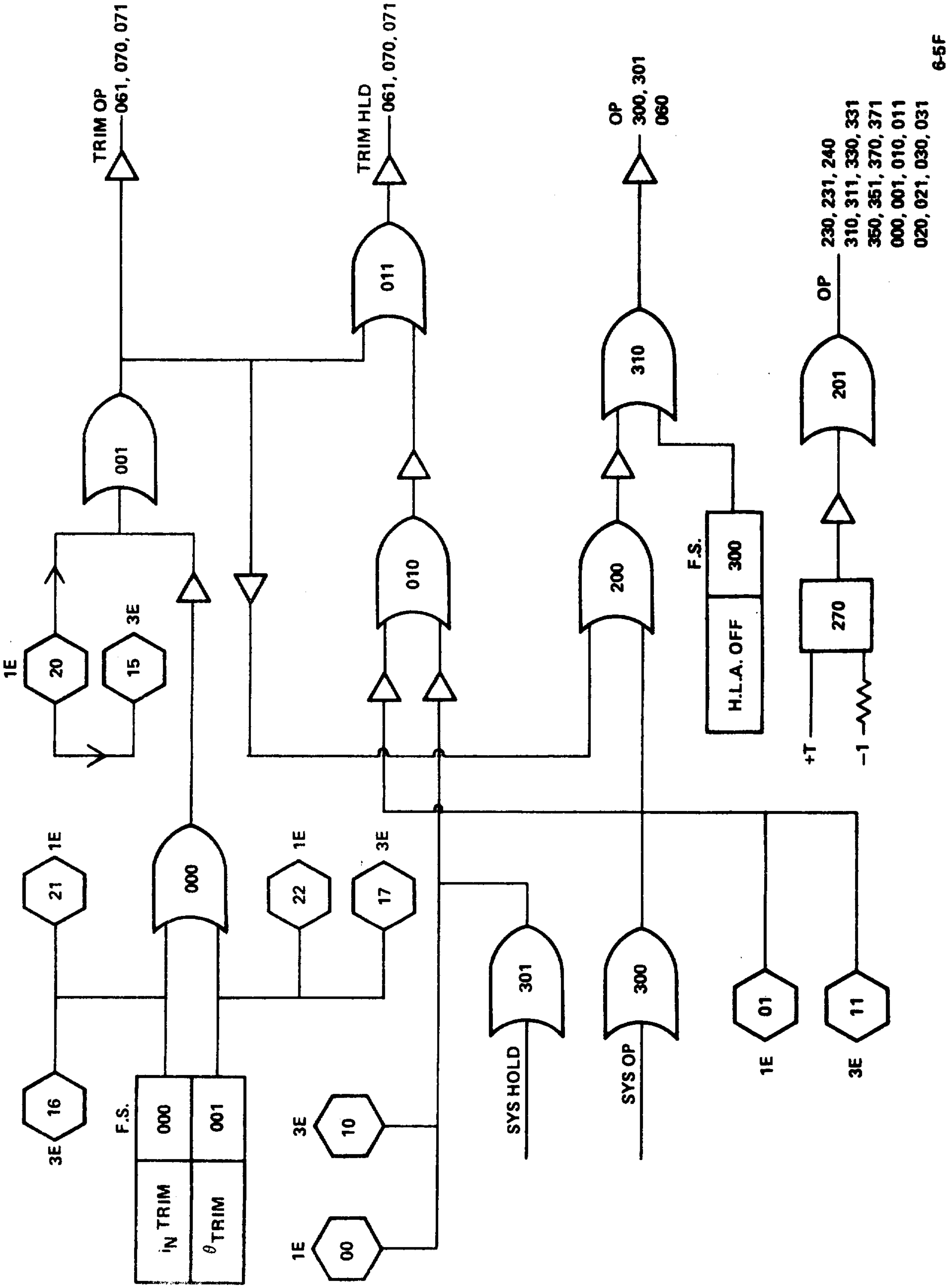


Figure G.8. (Continued)

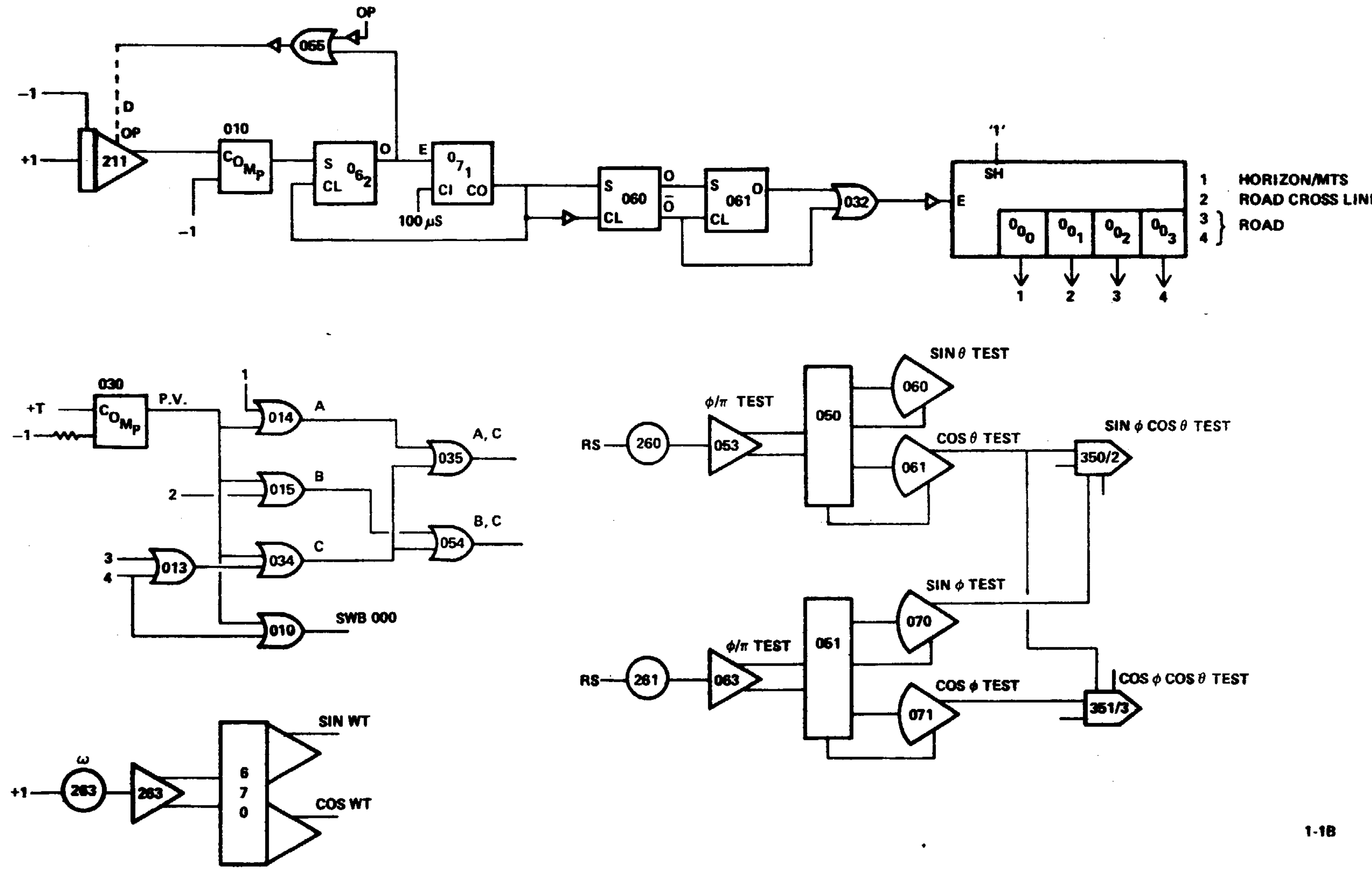
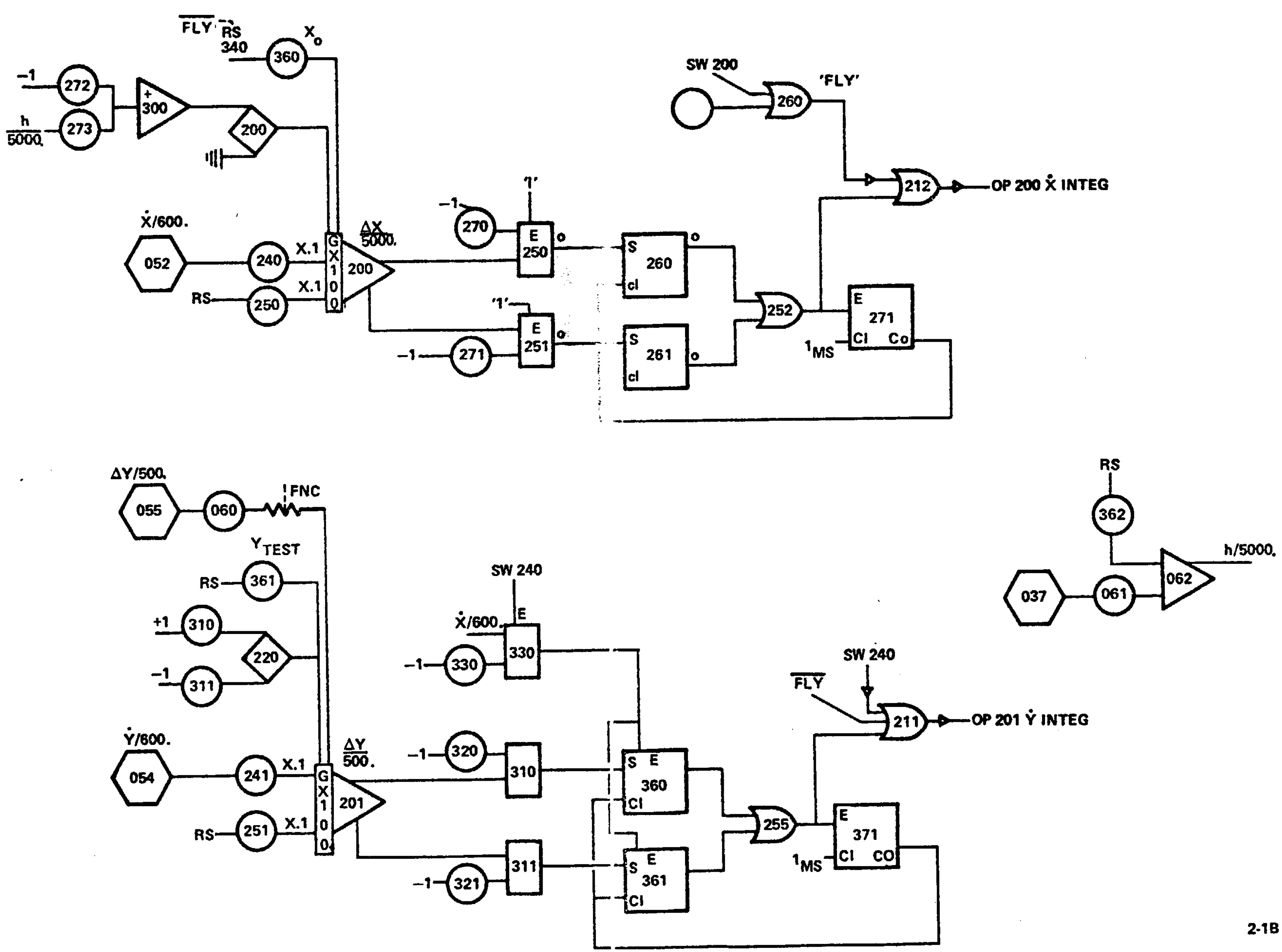


Figure G.8. (Continued)



2-1B

Figure 3.8. (Continued)

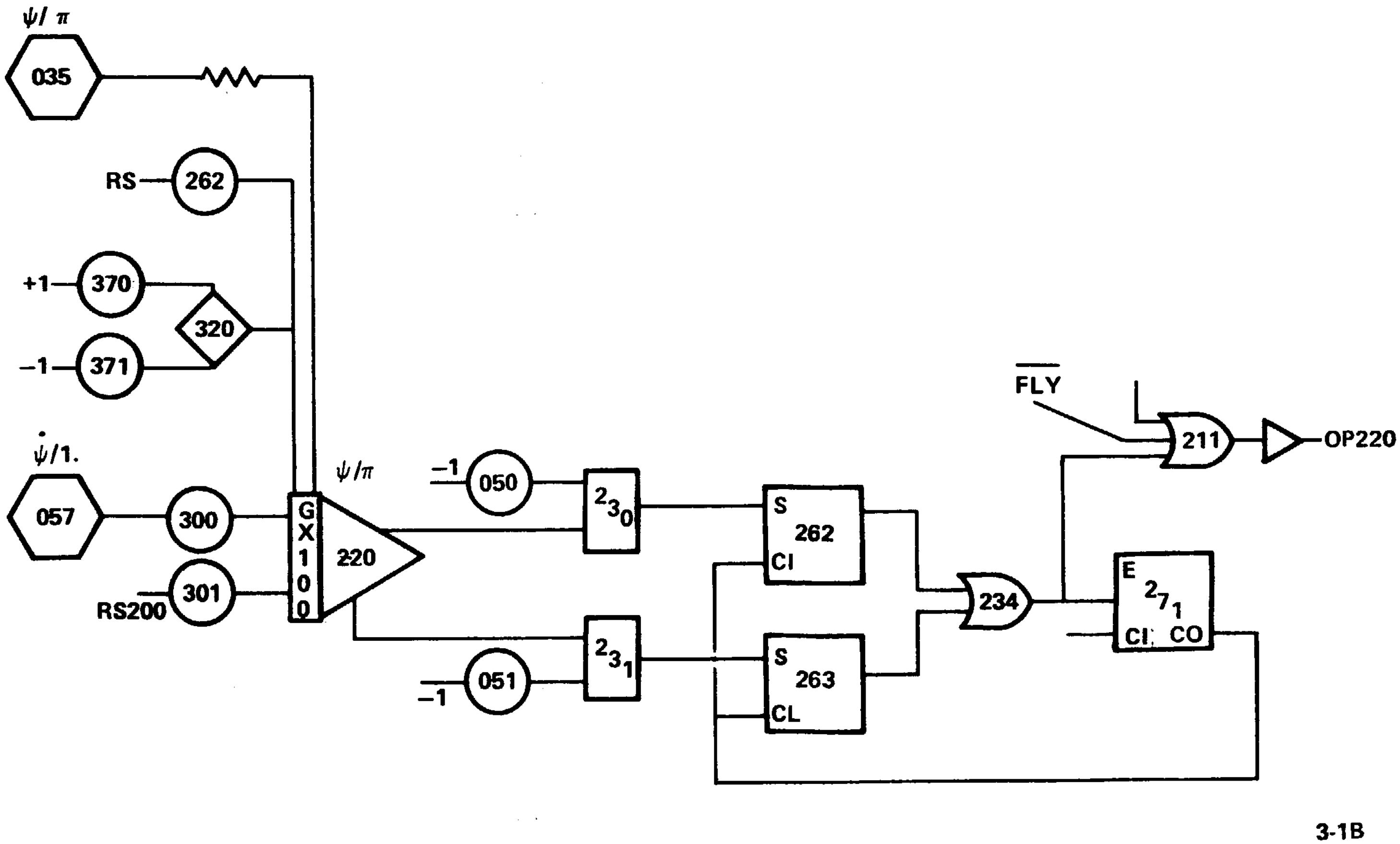


Figure G.8. (Continued)

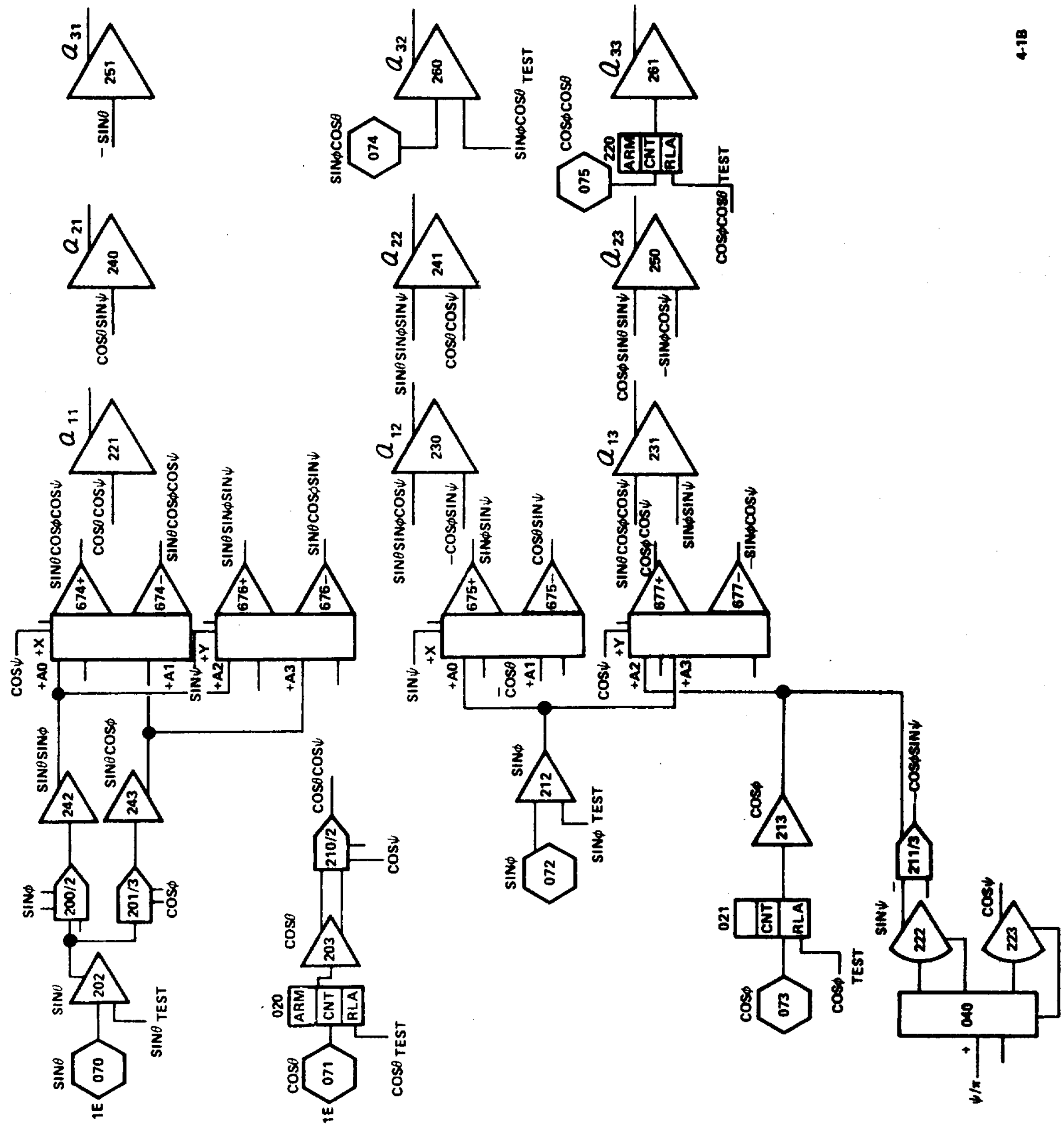


Figure G.8. (Continued)

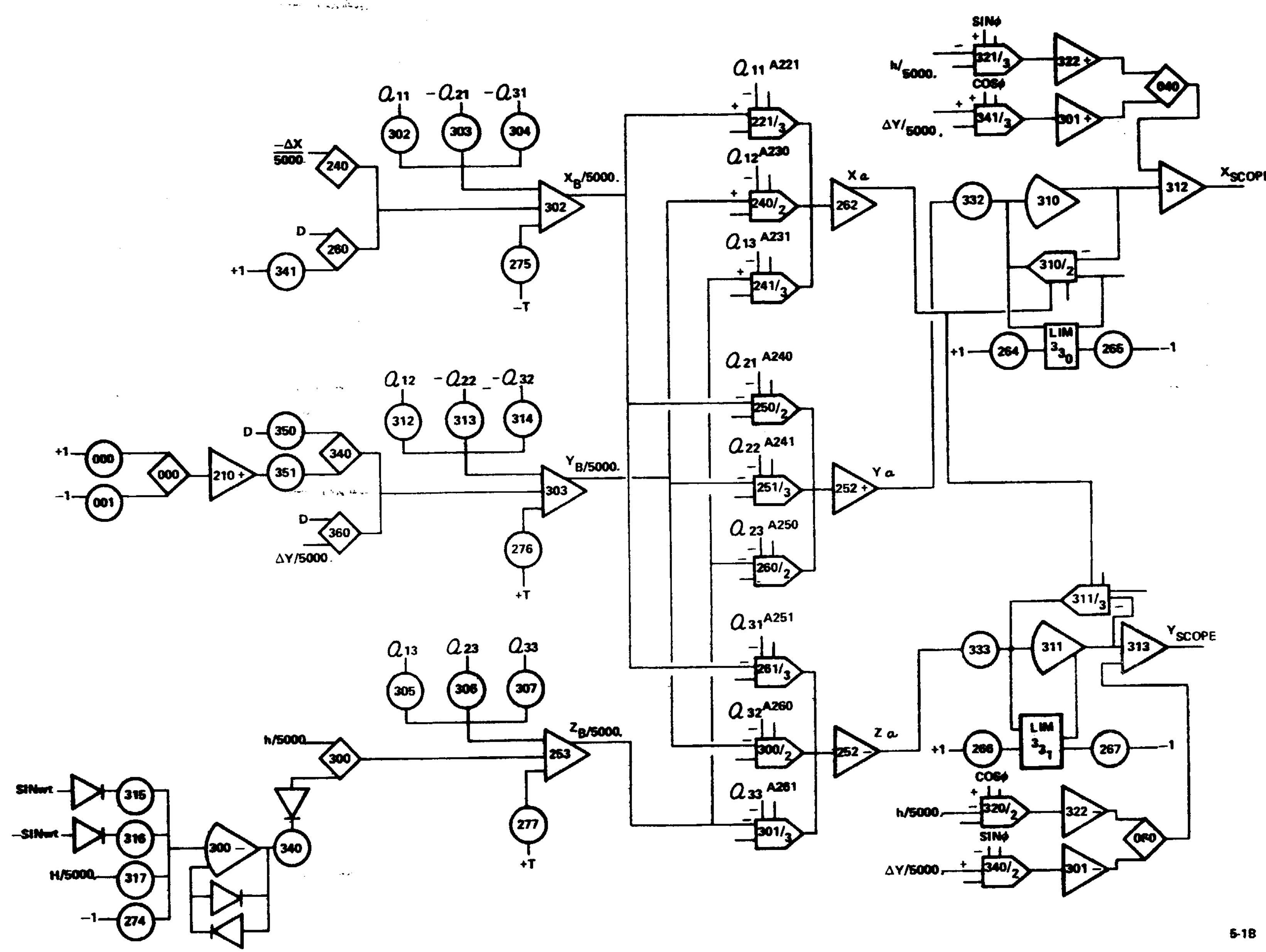


Figure G.8. (Continued)

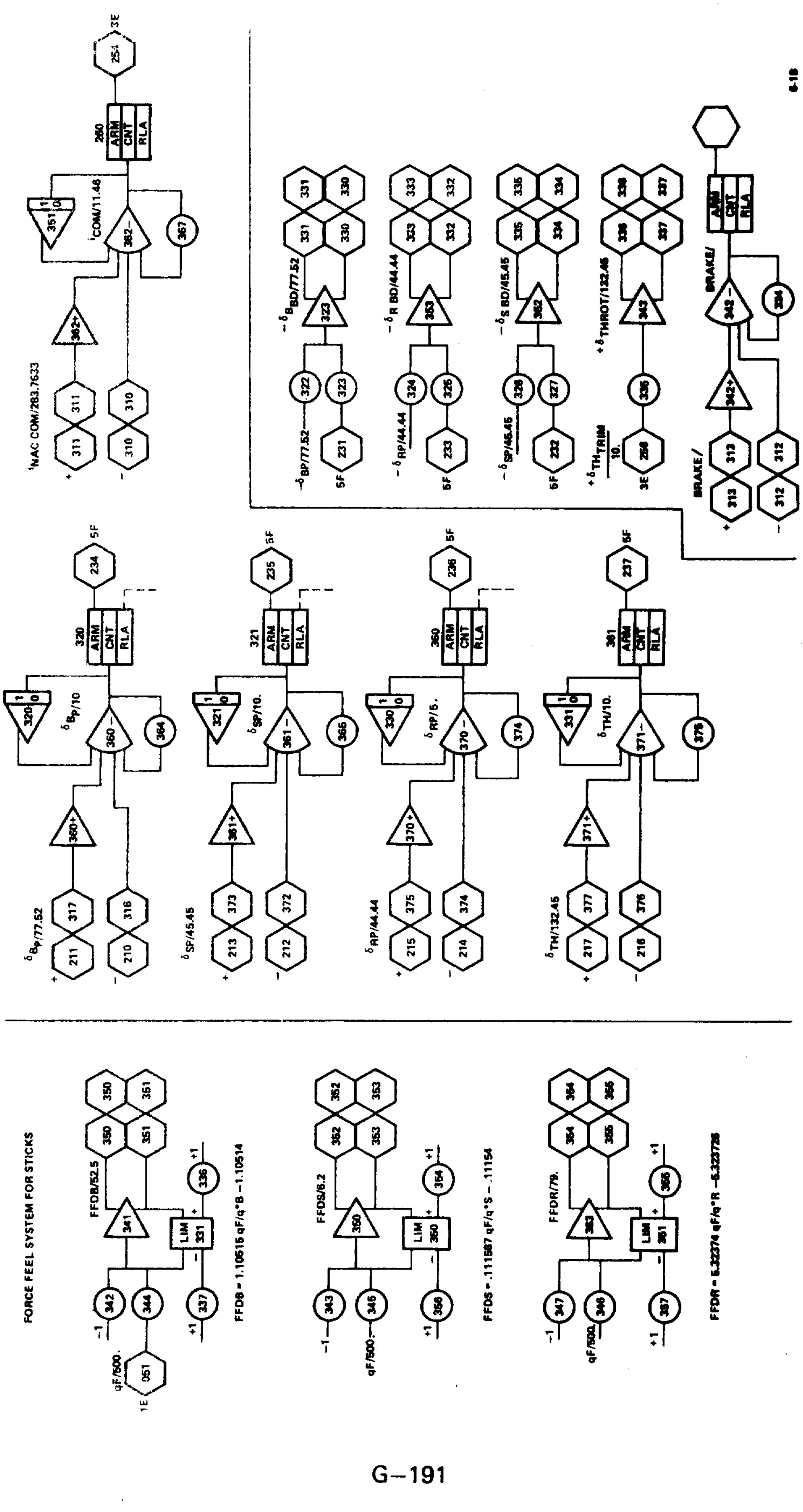


Figure G.8. (Continued)

SIMULATOR TRUNKING – ANALOG SIGNALS

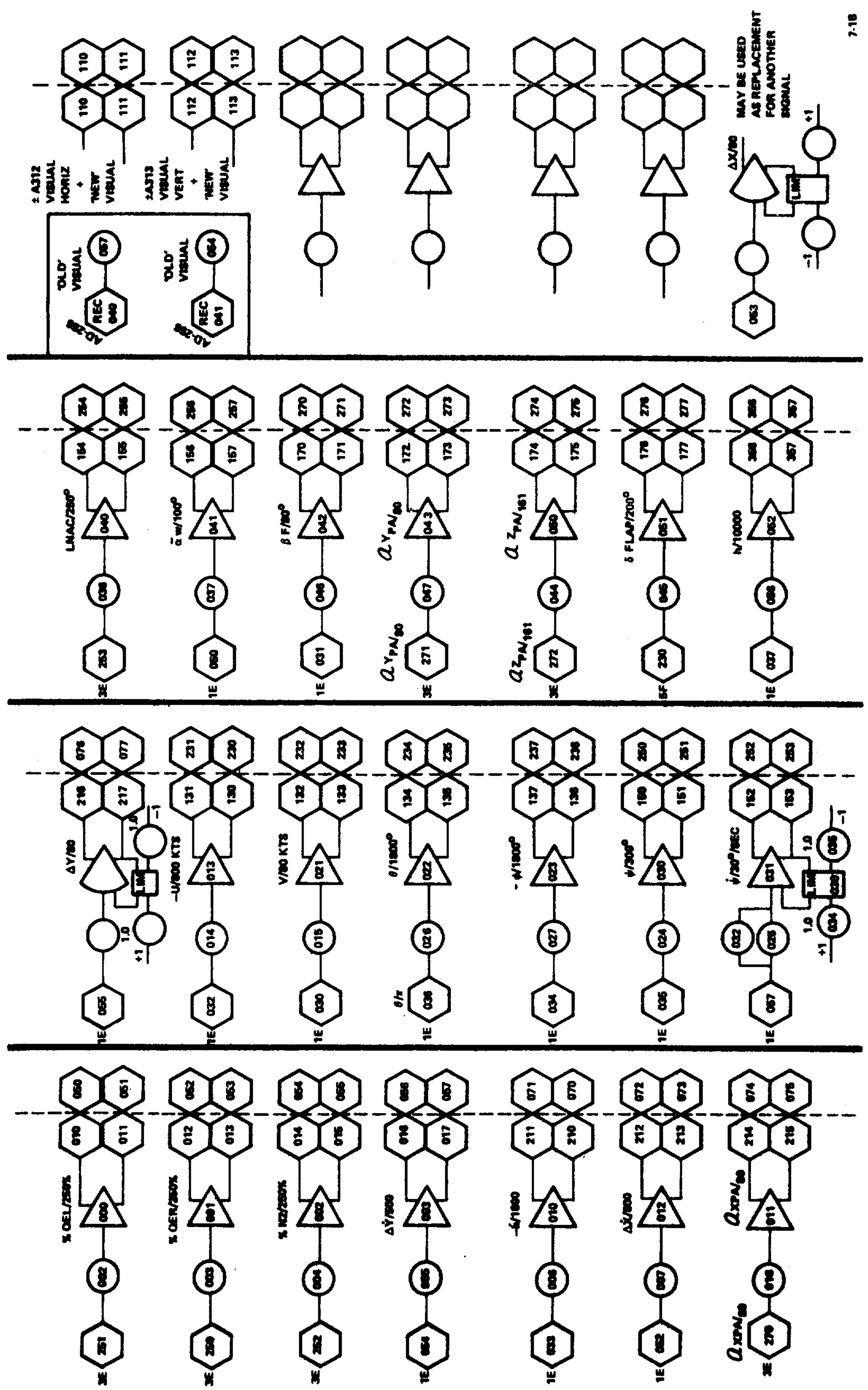


Figure G.8. (Continued)

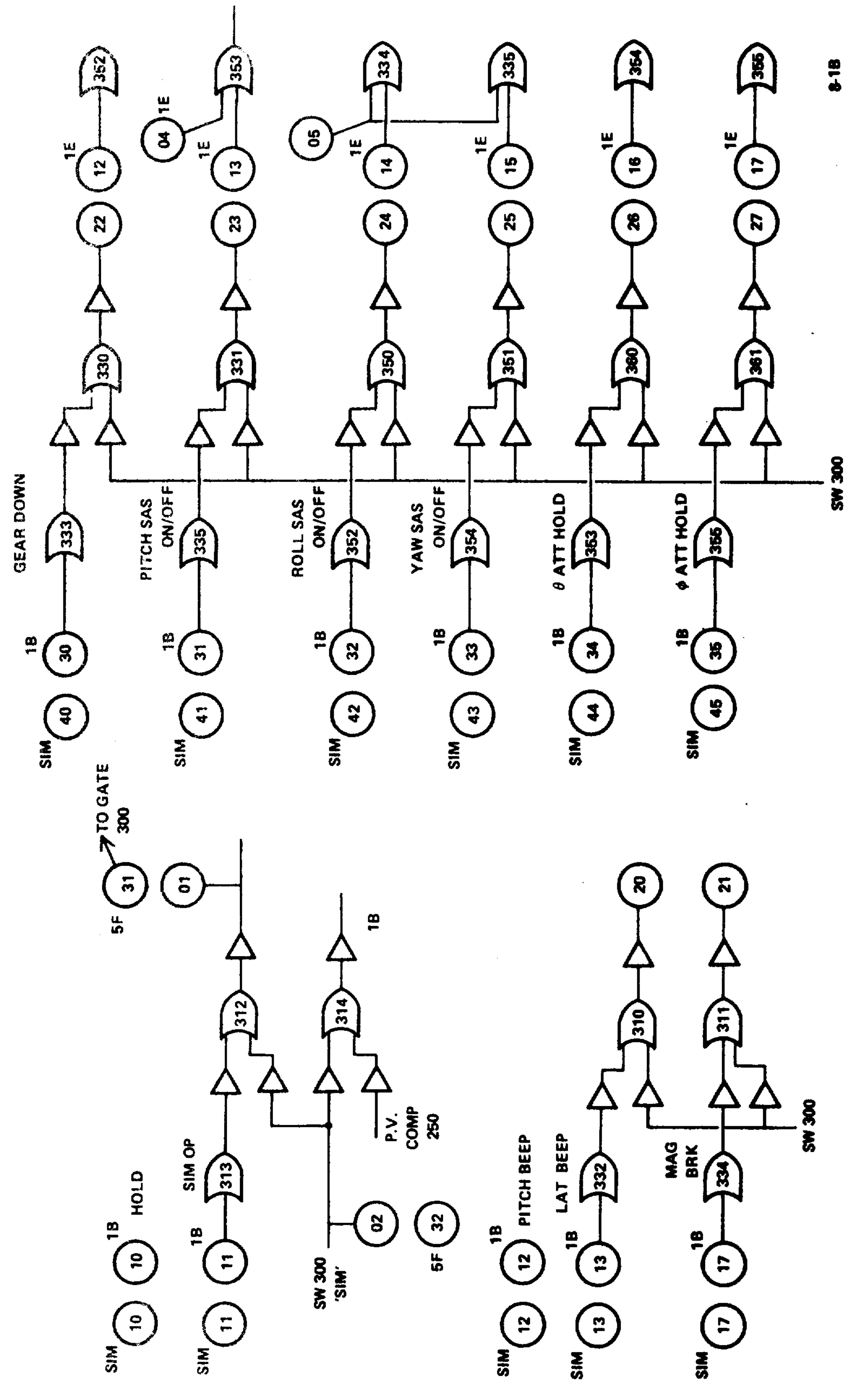


Figure G.8. (Continued)

```
0001              SUBROUTINE STATIC
0002              REAL *8  MATA(5,5),MATB(5),MET
0003              REAL*8 MATSAV(5,5),MAESAV(5)
0004              COMMON/CDATA/ P1(380),P2(380),P3(380),P4(380),ALP(380),ALB(380),
                 *              SJ1(380),TR1(380)
0005              COMMON/FLAGS/ IWARN1(15),IWARN2(15),ISENCC(2),IWREVT(2),ICONDP,
                 1 ITRIM,JTRIM,KTRIM,NPLOT,NPLOT2,IPHASE,ISLOW,SWLG,SOJTN,
                 2 IST1,IST3,NGEF,NVG,MTWST
0006              LOGICAL*1  IWARN1,IWARN2
0007              COMMON/HYBCON/PROJ   ,NCONSL,NPCS(2),NCHAIN(2),IFRAME(2),NADCS(2),
                 *              BDNOS(4),NDACS(4),IRCX(4),IFC(4),NCON(4) ,LETR(4) ,
                 *              IC(19)   ,ISTIC    ,HOLD(19),ISTHO,OPERA(19),
                 *              ISTGO    ,DIGAN(19),ISTDA   ,ANDIG(19),ISTAD,
                 *              IC2(19)  ,ISTIC2    ,HOLD2(19),ISTHO2 ,OPERA2(19),
                 *              ISTGO2   ,DIGAN2(19),ISTDA2   ,ANDIG2(19),ISTAD2, IGN,
                 *              ISTPLT   ,IPUNIT,IAD,IOC,IOC21,ICLR,ITSC,ILEX,ISETC ,
                 *              MONDIG   ,IDUPC(4)    ,ISHRC(4) ,ISYNC(4) , NIOS  ,
                 *              THJB     ,IFCHAN     ,TSBASE(2),TSREQD(2),  IRCTS(4),
                 *              TAUL(4)  ,IPSNOS(10,2),DTIM(2)  ,TRIM(19)  ,ISTRM ,
                 *              TRIM2(19),ISTRM2
             C                                                                          STKCC390
0008              COMMON/YIC/     PIC,QIC,RIC,UIC,VIC,WIC,THEIC,PHIIC,PSIIC,ZIC,YIC,
                 1       XIC,PSAS1,PSAS2,PSAS3,PSAS4,PSAS1,PSAS2,PSAS3,PSAS4,YSAS1,
                 2       YSAS2,YSAS3,YSAS4,YSAS5,YSAS6,SASPL(2),
                 3       TMS1,SHR2IC,SHR3IC,DLTHP,OMEGIC,
                 3       THPMIC,AINLIC,AINLDI,AIDRIC,AINLDT,AINLIC,PDT1,PDT2,GLSPIC,
                 4       GLSAIC,GLSAIL,YICBL(2),GBICP,GAICP ,AICRDI,AICRIC,AICLDI,
                 5       AICLIC,BICRDI,BICRIC,BICLDI,BICLIC,AICRPD,AICRP,AICLPD,
                 6       AICLP,BICRPD,BICRP,BICLPD,BICLP,ALARDI,ALARIC,AMARDI,
                 7       AMARIC,ZAPDIC,ZARIC,DCYIC,SHPIC
0009              COMMON/DIGICS/ XAERO,YAERO,ZAERP,ZARP,ALAERP,ALARP,AMAERP,AMARP,
                 1       AMAERO,GLSB,GLSAR,GLSAL,SHPPRR
0010              COMMON/XIC1/    DELB,DELS,DELR,DELTH,AINCOM,OMGSEL,
                 1       GLATPH,GROLL,GBETPH,GPSIPH,GPRPH,GYAW,AINREF,GOPLON,GOSCOL,
                 2       GDRCYL,GDSCYL,GAIC,GBIC,GDELP,GDE,GDSP,TPS,DVTAUD,DVTAUF,
                 3       THATLM,GOTHRT,BCABLK,THGOVL,THGOVR,SWOIT,CTI,CMDOR,CYMO,
                 4       CPMO,CSFO,CNFO,CPD,DLSPLM
0011              COMMON/TRMCON/ UTRIM,VTRIM,WTRIM,HDTRIM,THTRIM,AITRIM,
                 1              SKTRIM(13)
0012              COMMON/XMAP/ ENE1    ,ENE2    ,ENE3    ,ENE4    ,DNE1    ,DNE2    ,DNE3    ,      1  TO  7
                 *              DNE4    ,ESF1    ,ESF2    ,ESF3    ,ESF4    ,DSF1    ,DSF2    ,      8  TO 14
                 *              DSF3    ,DSF4    ,EPM1    ,EPM2    ,EPM3    ,EPM4    ,EPM5    ,     15  TO 21
                 *              EPM6    ,EPM7    ,DPM1    ,DPM2    ,DPM3    ,DPM4    ,DPM5    ,     22  TO 28
                 *              DPM6    ,DPM7    ,EYM1    ,EYM2    ,EYM3    ,EYM4    ,EYM5    ,     29  TO 35
                 *              EYM6    ,EYM7    ,DYM1    ,DYM2    ,DYM3    ,DYM4    ,DYM5    ,     36  TO 42
                 *              DYM6    ,DYM7
0013              COMMON/XMAX/    PDOTMX,QDOTMX,RDOTMX,UDOTMX,VDOTMX,WDOTMX,UMX,VWMX,
                 1       ZARMX,YDOTMX,XDOTMX,ZMX,YMX,XMX,DEL3MX,DELSMX,DELRMX,
                 2       DLPDMX,DELAMX,DELFMX,DLSPMX,DLTHMX,GLSMX ,TPSMX,THATMX,
```

Figure G.9. Analog Static Check Routine (Digital)

```
             3         SHPMX,THOMMX,TEMOMX,OMEGMX,TTGSMX,DCYLMX,DCOLMX,DLONMX,
             4         XMXEL,AICMX,BICMX,TH75MX,ALFPMX,AMIPMX,CTMX,CPMX,CNFMX,
             5         CSFMX,CPMMX,CYMMX,CPMOMX,CYMRMX,AAFSMX,AIDOMX,AIIDMX,
             6         AINMX,AINRMX,AMACMX,THEMX,PHIMX,PSIMX,GSCYMX,GFCYMX,
             7         GSCOMX,GFCOMX,TAUFMX,GICMX,ALWGMX,SQFMX,XCGMX,PCTOMX,
             8         DLELMX,GUSTMX,
             9         PMX,QMX,RMX,THOMX,PHOMX,PSDMX
0014          COMMON/XPAR1/ AINHT ,AINW   ,ALAMDA,ALHTST,ALVTST,AREAHT,AREAA ,    1  TO  7
             *AREAVT,ARHT  ,ARVT  ,AVEYAC,AVEYCS,BLS   ,CDOF  ,CDOHT ,CDOVT ,     8  TO  16
             *CHORD ,CLALHT,CLALPH,CMOF  ,CMON  ,CNOF  ,CNOLN ,CNORN ,CYALVT,    17  TO  25
             3DCDLG ,DCMLG ,FINPR ,DOVT  ,DSDBET,FFFHT ,EFFVT ,FIE   ,FINDEG,    26  TO  34
             *FIP   ,FIXXF ,FIXXPR,FIXXW ,FIXZF ,FIXZPR,FIXZW ,FIYYF ,FIYYPR,    35  TO  43
             *FIYYW ,FIZZF ,FIZZPR,FIZZW ,HP    ,OMREF ,PC    ,PI    ,ROTRAD,    44  TO  52
             *SBFPR ,SBNPR ,SG    ,SHF   ,SHW   ,SKO   ,SK1   ,SK2   ,SK3   ,    53  TO  61
             *SK4   ,SK5   ,SK6   ,SK7   ,SK8   ,SK9   ,SK10  ,SK20  ,SK21  ,    62  TO  7.
             *SK22  ,COONLO,SK30LO,SK31LO,SK32  ,COONHI,SK34  ,SK35  ,SK36  ,    71  TO  79
             *SK37  ,SK38  ,SK39  ,SK40  ,SK41  ,SK42  ,SK43  ,SK44  ,SK45  ,    8.  TO  88
             *SK46  ,SK47  ,SK48  ,SK49  ,SK50  ,SL    ,SLF   ,SLPA  ,SLW   ,    89  TO  97
             *SM    ,SMF   ,SMN   ,SMW   ,SPAN  ,TAUHT ,TAUVT ,XFAC  ,XHT   ,    98  TO 1.6
             *XWAC  ,XVT   ,YN    ,YPA   ,YWAC  ,ZFAC  ,ZHT   ,ZPA   ,ZWAC  ,
             *ZVT   ,CLDAL ,PHIPH ,SK30HI,FN2PFF,XWCP  ,BT1   ,BT2   ,BT3   ,
             *BKO1T ,BKO2T ,BKO3T ,BKM1T ,BKM2T ,BKM3T ,BKM4T ,SK31HI,
             *FEU   ,CLMAX ,ALBRK ,BKLSW ,BKNSW ,SQFPRM,DEG2O ,PGTORD,HTVTKT,    133TO141
             *PIOV2 ,ROTODG,ROTFPS,SKFPS ,ALNC3K,TAURT1,TAURT2
0015          COMMON/XCNTRL/ SKOLP,SKOLS,SKOL3,SKOLE,SKOLRD,TH75LP,TH75LN,
             1         TAUOLS,GLSL4,TAUSIC,SICLM,TCM,TOMSLP,TOMLM,OTCM,OMA,ETAA,
             2         SKOA  ,GTH,TAUTH,OMGO,OMSLP,OMLM,GOMG,SKOCOL,THETLM,THOMLP,
             3         THOMLN,SHPL4,GTHGOV,OMRD,ETARD,TTMSLP,TTMSLN,GOB1,GOB2,
             4         TAUOB,GQ,GTHE,TAUQ1,TAUQ2,TAUTHE,GLPO,GLPSLP,GPDS,TAUPDS,
             5         GP,TAUP,GBETP,TAUBET,GPHI,TAUPHI,GPSIDR,GBETDR,GRDR,TAUDR,
             6         GPSI,TAUPSI,GBETR,TAUPR,GPR1,TAUPR1,GR,TAUR1,TAUR2,TAUR3,
             6         RLM,DRLM,DLBLM,DLSLM,DLPLM,
             7         TOMDLM,GDLTH,SKW1,SKW2,SKW3,SKW4,SKW5,
             8         SKW6,SKW7,SKW8,SKW9,SKW10,GGUST,TAUGST,OMWB,ETAWB,GIMPF,
             9         OMIPF,ETAIPF,SKTHTW,SC1,SC2,DCMDCL,AINRLM,TAURO1,TAURO2,
             A         TAUFF,TAUCYR,DCYRL4,AO,ASLP,ALIM,TAUSHP,DFLALM,
             B         DLFLP
C016          COMMON/SIMMA7/ AXPAMX,AYPAMX,AZPAMX,XDDMX ,ZDDMX ,FFBMX ,FFSMX ,
             1               FFPMX ,VSTMX ,BTSIMX,USIMX ,HDTSMX,PHISMX,PSISMX,
             2               THESMX,TQSIMX,RPMSMX,AINSMX,AIDSMX,ALWSMX,DEPSMX,
             3               DBBDMX,DSBDMX,DRBDMX,THBDMX,DBPSMX,DSPSMX,DRPSMX,
             4               DTPSMX,XDTSMX,YDTSMX,DXSIMX,DYSIMX,HSIMX ,PSDTSX
             5              ,BRKMX ,BRKSMX,XVISMX,YVISMX,ZVISMX,SCOPMX
C017          COMMON/SIMPAR/ VISIC ,VCAL1 ,VCAL2 ,XHORIZ,YROAD ,QSTAR3,QSTARS,
             1               QSTARR,BOB   ,BOS   ,BOR   ,BSLOPE,SSLOPE,RSLOPE
             2             , FFLMLO,COMIDT,COMDTH,COMDLB,COMDLS,COMDLP,BRAKE ,
             3               VISVER,VISHUR,SCOPLM,FREQMT,BIASMT,PKMT1 ,PKMT2 ,
             4               GZMTS1,GZMTS2,SLX   ,SLY   ,SLZ   ,XBIC  ,YBIC  ,
             5               ZBIC  ,XDTEST,YDTEST
```

Figure G.9. (Continued)

```
0018          COMMON/XPAR3/ XP3(91)
             D              ,SFTL  ,SFJFL ,SFSEL ,SFPML ,SFYML ,SFQL  ,SFRL  ,
             E               SFTR  ,SFJFR ,SFSER ,SFPMR ,SFYMR ,SFQR  ,SFRR
0019          DIMENSION A2P(380),A2N(380),SJ2(380),TR2(380),A3P(380),A3N(380),
             *           SJ3(380),TR3(380)
0020          DIMENSION A4P(380),A4N(380),SJ4(380),TR4(380)
0021          EQUIVALENCE (A1P,A2P),(A1N,A2N),(SJ1,SJ2),(TR1,TR2)
0022          EQUIVALENCE (A1P,A3P),(A1N,A3N),(SJ1,SJ3),(TP1,TR3)
0023          EQUIVALENCE (A1P,A4P),(A1N,A4N),(SJ1,SJ4),(TP1,TR4)
0024          DATA ED4/'IR  '/,IT4/'R   '/
        C
        C
0025          DATA VDEI1/55./
0026          DATA THPCTU/0.6/
0027          DATA AINDET/0.25/
0028          DATA  OINRF/85.9/,ANRATE/2.0/
0029          DATA GBAIS/0.3333/,TAUGMN/50./
        C        DEFINE VALUES TO CERTAIN VARIABLES FOR CHECKOUT PURPOSES
0030          DATA PCTQ/64./,AVEALW/0.4/
0031          DATA ROEU/0.0023780/
        C
        C                        COEFFICIENT
        C     PDOT     QDOT     RDOT     AINDDR    AINDDL
        C
        C     1,1      1,2      1,3      1,4       1,5       PDOT  .
        C                                                           .
        C     2,1      2,2      2,3      2,4       2,5       QDOT   .
        C                                                            .
        C     3,1      3,2      3,3      3,4       3,5       RDOT         EQUATION
        C                                                            .
        C     4,1      4,2      4,3      4,4       4,5       AINDDR .
        C                                                           .
        C     5,1      5,2      5,3      5,4       5,5       AINDDL.
        C
        C
        C
0032          P  =  PIC
0033          Q =  QIC
0034          R= RIC
0035          U=  UIC
0036          V=  VIC
0037          W = WIC
0038          THE = THEIC
0039          PHI= PHIIC
0040          PSI=  PSIIC
0041           H= -ZIC
0042          AINRF = AIRFIC+AINREF
0043          AINR = AINRIC
0044          AINL = AINLIC
```

Figure G.9. (Continued)

```
0045          AINDTL = AINLDI
0046          AINDTR = AINRDI
0047          OMGCUM = XLIM(OMLM,OMGL,OMGL+(OMGSEL+OMSLP*AINRF)
0048          OMEGA = OMEGIC+OMGCUM
0049          THOM = THOMIC+UIC*THOMMX/UMX*THPCTU-GOTHRT*PLTHR*GOLTH
0050          CPMDD = CMDOR
0051          CYMDR = CMDOR
0052          CPL    = CPO
0053          CPR    = CPO
0054          CNFPL =  CNFO                                     STK 0248
0055          CNFPR =  CNFO                                     STK 0249
0056          CSFPL =  CSFO                                     STK 0250
0057          CSFPR =  CSFO                                     STK 0251
0058          CPMOL   = CPMO
0059          CPMOR   = CPMO
0060          CPMOL   = CPMDO
0061          CPMOR   = CPMDO
0062          CYMOL   = CYMO
0063          CYMOR   = CYMO
0064          CYMRL =  CYMDR
0065          CYMRR   = CYMDR
0066          PCTOR = PCTO
0067          PCTOL = PCTO
       C
0068          CONI = SMN*SL*SL*(1.-SMN/SM)+FIXYPF
       C
0069          CALL SINCOS(PHGLS*DGTORD,SPHGLS,CPHGLS)
0070          CALL SINCOS(THE,SINTHE,COSTHE)
0071          CALL SINCOS(PHI,SINPHI,COSPHI)
0072          CALL SINCOS(PSI,SINPSI,COSPSI)
0073          CALL SINCOS(AINR,SININR,COSINR)
0074          CALL SINCOS(AINL,SININL,COSINL)
0075          CALL SINCOS(AINR-ALAMDA,SILAMR,CILAMR)
0076          CALL SINCOS(AINL-ALAMDA,SILAML,CILAML)
0077          CALL SINCOS(2.0*AINR,S2INR,C2INR)
0078          CALL SINCOS(2.0*AINL,S2INL,C2INL)
0079          CALL SINCOS(2.0*(AINR-ALAMDA),SNDUM1,C2LAMR)
0080          CALL SINCOS(2.0*(AINL-ALAMDA),SNDUM2,C2LAML)
0081          SSQINR =   SININR * SININR
0082          SSQINL =   SININL * SININL
0083          CALL SINCOS(AINW,SINIW,COSIW)
0084          AVEIN =   0.5 *(AINR +AINL)
0085          CALL SINCOS(PHIPH,SPHIP,CPHIP)
       C
       C         GROUND TRACK
       C
       C         NORTHWARD VELOCITY
0086          VNORTH= U*COSTHE*COSPSI+V*(SINPHI*SINTHE*COSPSI-COSPHI*SINPSI)
             *    +W*(COSPHI*SINTHE*COSPSI+SINPHI*SINPSI)
```

Figure G.9. (Continued)

```
      C          EASTWARD VELOCITY
0087         VEAST= U*COSTHE*SINPSI+V*(SINPHI*SINTHE*SINPSI+COSPHI*COSPSI)
            *  +W*(COSPHI*SINTHE*SINPSI-SINPHI*COSPSI)
      C          DOWNWARD VELOCITY
0088         VDOWN= -U*SINTHE+V*SINPHI*COSTHE+W*COSPHI*COSTHE
      C
0089         XDOT=  VNORTH
0090         YDOT=  VEAST
0091         ZDOT=  VDOWN
0092         HDOT=  -VDOWN
0093         HSQ=  H*H
      C
      C          CENTER OF GRAVITY CALCULATION
      C
      C
      C          CG LOCATION W.R.T. PIVOT
0094         XCG = (SMF*SLF+SMW*SLW)/SM+SL*SMW/SM*(CILAML+CILAMR)
0095         ZCG = (SMF*SHF+SMW*SHW)/SM-SL*SMW/SM*(SILAML +SILAMR )
      C          CG VELOCITY W.R.T. PIVOT( NON-ROTATING AXES)
0096         XDTCG= -SL*SMW/SM*(AINDTL*SILAML+AINDTR*SILAMR )
0097         ZDTCG= -SL*SMW/SM*(AINDTL*CILAML+ AINDTR *CILAMR)
      C
      C          DENSITY CALCULATIONS
      C          EQUATION FOR DEL FROM CURVE FIT PROGRAM
      C
0098         DEL = .9995883407 -.3623432996E-04 * H
            * +.5429995171E-09 *HSQ -.3720813304E-14 *HSQ * H
      C
0099         TDEGF=  TZERO -TCOEF*H
0100         THETC=  .001927933*(TDEGF+459.69)
0101         SQTHTC= SQRT(THETC)
0102         ONOVTC = 1. / THETC
0103         ROE = ROEO*DEL*ONOVTC
0104         ROPIR5= ROE*PI*ROTRAD**5
0105         VTOTAL= SQRT(U*U+V*V+W*W)
0106         VCALIB = VTOTAL*SQRT(ROE/ROEO)
      C
      C          FUSELAGE- PIVOT VELOCITY
      C
0107         UP =  U - Q*ZCG -XDTCG
0108         VP=  V + P*ZCG -R*XCG
0109         WP=  W + Q*XCG -ZDTCG
      C
      C
      C
      C          FUSELAGE AERODYNAMICS
      C
      C             INPUT EQUATIONS
0110         VALFS=  SQRT(U*U+W*W)
```

Figure G.9. (Continued)

```
0111          ALPHF=  ATAN2(W,U)
0112          BETAF=  ATAN2(V,VALFS)
0113          SQF= 0.5*RDE*VTOTAL*VTOTAL
        C        LEFT ROTOR HUB VELOCITY - BODY AXES
0114          URLPR = UP +R*YN -BLS*SININL*(Q+AINDTL) + Q*HIL
0115          VRLPR = VP +BLS*(R*COSINL+P*SININL ) -P* HIL
0116          WRLPR = WP -P*YN -BLS*(Q+AINDTL)*COSINL + HIDTL
        C        RIGHT ROTOR HUB VELOCITY - BODY AXES
0117          URRPR = UP- R*YN -BLS*SININR*(Q+AINDTR) +Q* HIR
0118          VRRPR = VP + BLS*(R*COSINR+P*SININR) -P* HIR
0119          WRRPR = WP +P*YN -BLS*(Q+AINDTR)*COSINR + HIDTR
        C        LEFT ROTOR HUB VELOCITY - SHAFT AXES
0120          URL =  URLPR*COSINL -WRLPR*SININL
0121          VRL =  VRLPR
0122          WRL =  URLPR*SININL +WRLPR*COSINL
        C        RIGHT ROTOR HUB VELOCITY - SHAFT AXES
0123          URR = URRPR*COSINR -WRRPR*SININR
0124          VRR = VRRPR
0125          WRR = URRPR*SININR +WRRPR*COSINR
        C
        C        ROTOR  INPUT EQUATIONS (AERO)
        C
        C        FREE STREAM VELOCITY
0126          VTOTLR = SQRT(URR*URR +VRR*VRR +WRR*WRR )
0127          VTOTLR = SQRT(URL*URL+ VRL*VRL +WRL*WRL )
0128          WROTL =  WRL+EPWRL*URL
0129          WROTR =  WRR + EPWRR*URR
0130          VZETL =  SQRT(VRLVRL+WROTL*WROTL)
0131          VZETR =  SQRT(VRRVRR+ WROTR*WROTR)
        C        ANGLE OF ATTACK
        C
        C
        C        NOTE  ALPHRR AND ALPHLR ARE DEFINED BETWEEN 0 AND 180 DEGREES
        C                    I.E.  90 +OR- 90  DEGREES
0132          ALPHLR=  ATAN2(VZETL,URL)  + EPIRL
0133          ZETHL=  ATAN2(VRL,WROTL)
0134          CALL SINCOS(ZETHL,SINZHL,COSZHL)
0135          ALPHRR=  ATAN2(VZETR,URR)  + EPILR
0136          ZETHR=  ATAN2(VRR,WROTR)
0137          CALL SINCOS(ZETHR,SINZHR,COSZHR)
        C
        C        ROTOR ANGULAR RATE TRANSFORMS
        C
        C        LEFT ROTOR - NACELLE AXES
0138          PNLN =  P*COSINL - R*SININL
0139          QNLN =   Q + AINDTL
0140          RNLN =   P*SININL + R*COSINL
        C        LEFT ROTOR -  WIND AXES
0141          PNLR  =  PNLN
```

Figure G.9. (Continued)

```
FORTRAN IV     MODEL 44  PS        VERSION 3,  LEVEL 3   DATE  73392                                        PAGE  / 7

0142                 QNLR   =  QNLN*COSZHL -RNLN*SINZHL
0143                 RNLR   =  RNLN*COSZHL +QNLN*SINZHL
             C          RIGHT ROTOR - NACELLE AXES
0144                 PNRN = -P*COSINR + R*SININR
0145                 QNRN =     Q+ AINDTR
0146                 RNRN = - P*SININR -R*COSINR
             C          RIGHT ROTOR - WIND AXES
0147                 PNRR =  PNRN
0148                 QNRR =  QNRN*COSZHR +RNRN*SINZHR
0149                 RNRR = RNRN*COSZHR  -QNRN*SINZHR
             C
0150                 OMEGAL=  OMEGA + PNLR
0151                 OMEGAR=  OMEGA + PNRR
0152                 VTIPL =    ROTRAD * OMEGAL
0153                 VTIPR =    ROTRAD * OMEGAR
0154                 AMUL  = VTOTLR/ VTIPL
0155                 AMUR  = VTOTRR/ VTIPR
0156                 CPMPR = CPMOR -CPMQR*QNRR                                                      STK 0661
0157                 CYMPR = CYMOR +CYMRR*RNRR
0158                 CPMPL = CPMOL -CPMCL *QNLR                                                     STK 0635
0159                 CYMPL = CYMOL +CYMRL*RNLR
             C
             C
             C          BASIC EQUATIONS OF MOTION -- PRELIMINARY CALCULATIONS
             C
             C          FUSELAGE
             C
0160                 XF =   SLF - XCG
0161                 ZF =   SHF - ZCG
             C
             C          WING
0162                 XW =   SLW - XCG
0163                 ZW =   SHW - ZCG
             C
             C          NACELLES
             C
0164                 XR  =   SL  * CILAMR   - XCG
0165                 ZR  = -SL  * SILAMR   - ZCG
             C
0166                 XL  =   SL  * CILAML   - XCG
0167                 ZL  = -SL  * SILAML   - ZCG
             C          INERTIA TERMS
0168                 SUMIXX=  FIXXF + FIXXW + 2.* FIXXPR
0169                 SUMIYY=  FIYYF + FIYYW + 2.* FIYYPR
0170                 SUMIZZ=  FIZZF + FIZZW + 2.* FIZZPR
0171                 SUMIXZ=  FIXZF + FIXZW + 2.* FIXZPR
             C
0172                 FIXX  = SUMIXX+(FIZZPR-FIXXPR)*(SSOINR+SSOINL)-FIXZPR*(S2INR+S2INL)
                    *      +2.*SMN*YN*YN +SHF*SHF*ZF +SMW*SHW*ZW -SL*SMN*(ZR*SILAMR +
```

Figure G.9. (Continued)

```
               *      ZL* SILAML )
             C
0173            FJXX = (SUMIZZ-SUMIYY)+(FIXXPR-FIZZPR)*(SSQINR+SSQINL)-FIXZPR *(
               *      S2INR +S2INL )+2.*SMN*YN*YN -(SHF*SHF*ZF+SMW*SHW*ZW) +
               *      SL*SMN*(ZR * SILAMR +ZL*SILAML)
             C
0174            FIXZP= FIXZF+FIXZW+0.5*(FIXXPR-FIZZPR)*(S2INR+S2INL)+FIXZPR*
               *      (C2INR+C2INL)+(SMF*SLF*ZF+SMW*SLW*ZW)+SMN*SL*(ZR*CILAMR +
               *      ZL* CILAML )
             C
0175            FIYY = SUMIYY+SMF*(SLF*XF+SHF*ZF)+SMW*(SLW*XW+SHW*ZW ) +SMN* SL*
               *      (XP *CILAMR -ZR*SILAMR)+SMN*SL*(XL*CILAML-ZL*SILAML)
             C
0176            FJYY = (FIXXF-FIZZF)+(FIXXW-FIZZW)+(FIXXPR-FIZZPR)*(C2INR+C2INL)
               *      -2.*FIXZPR*(S2INR+S2INL)+SMF*(-SLF*XF+SHF*ZF) +SMW*(-SLW*
               *      XW+SHW*ZW)-SMN*SL*(XR*CILAMR+ZR*SILAMR +XL*CILAML+ZL*SILAML)
             C
0177            FIXZQ = FIXZF+FIXZW+0.5*(FIXXPR-FIZZPR)*(S2INR+S2INL) +FIXZPR*
               *      (C2INR+C2INL)-SMN*SL*(XP*SILAMR +XL* SILAML )
             C
0178            FIZZ  = SUMIZZ +(FIXXPR-FIZZPR)*(SSQINR+SSQINL)+FIXZPR*(S2INR+
               *      S2INL)+2.*SMN* YN*YN+SMF*SLF*XF+SMW*SLW*XW+SMN*SL*(XR*
               *      CILAMR +XL*CILAML)
             C
0179            FJZZ = SUMIYY-SUMIXX +(FIXXPR-FIZZPR)*(SSQINR+SSQINL)+FIXZPR*(
               *      S2INR+S2INL) -2.*SMN* YN*YN+SHF*SLF*XF+SHW*SLW*XW +SMN*SL*
               *      (XR*CILAMR +XL*CILAML)
             C
0180            FIXZR = FIXZF+FIXZW+0.5*(FIXXPR-FIZZPR)*(S2INR+S2INL)+FIXZPR*
               *      (C2INR+C2INL) +SMF*SHF*XF +SMW*SHW*XW -SL*SMN*(XR*SILAMR+
               *      XL*SILAML )
             C
0181            ALARWN = ALARP+ALARIC*FIXX
0182            AMARWN = AMARP+AMARIC*FIYY
0183            ZARWN = ZARP+ZARIC*SM
0184            ALAERO = ALAERP+ALARWN
0185            AMAERO = AMAERP+AMARWN
0186            ZAERO = ZAERP+ZARWN
             C
             C     ROOT EQUATION   CROSS TERMS
             C
0187            TERMP1 = -FJXX*R*Q+P*Q*FIXZP
             C
             C     ROOT EQUATION   CROSS TERMS
0188            TERMQ1 = -FJYY*P*R -FIXZQ*(P*P -R*R)
             C
             C
             C     ROOT EQUATION  CROSS TERMS
0189            TERMR1 = -FJZZ*P*Q -FIXZR*R*Q
```

Figure G.9. (Continued)

```
      C
      C        ROOT EQUATION    ROOT COEFFICIENT
0190         MATA(1,1) =    FIXX
      C        ROOT EQUATION    ROOT COEFFICIENT
0191         MATA(1,2) =  0.
      C        ROOT EQUATION    ROOT COEFFICIENT
0192         MATA(1,3) =     -FIXZP
      C        ROOT EQUATION    AINDOR COEFFICIENT
0193         MATA(1,4) =  -SL*SMN* YN * CILAMR
      C        ROOT EQUATION    AINDOL COEFFICIENT
0194         MATA(1,5) =    SL*SMN* YN * CILAML
      C        ROOT EQUATION    FORCING FUNCTION
0195         MATB(1) =  TERMP1 + ALAERO
      C
      C
      C        ROOT EQUATION    ROOT COEFFICIENT
0196         MATA(2,1) =  0.
      C        ROOT EQUATION    ROOT COEFFICIENT
0197         MATA(2,2)=    FIYY
      C        ROOT EQUATION    ROOT COEFFICIENT
0198         MATA(2,3) =  0.
      C        ROOT EQUATION    AINDOR COEFFICIENT
0199         MATA(2,4)=  FIYYPR+SL*SMN*(-ZR*SILAMR +XR*CILAMR )
      C        ROOT EQUATION    AINDOL COEFFICIENT
0200         MATA(2,5)=  FIYYPR+SL*SMN*(-ZL*SILAML +XL*CILAML )
      C        ROOT EQUATION    FORCING FUNCTION
0201         MATB(2)    =  TERMP1  +  AMAERO
      C
      C
      C        ROOT EQUATION    ROOT COEFFICIENT
0202         MATA(3,1)= - FIXZP
      C        ROOT EQUATION    ROOT COEFFICIENT
0203         MATA(3,2) =  0.
      C        ROOT EQUATION    ROOT COEFFICIENT
0204         MATA(3,3)=  FIZZ
      C        ROOT EQUATION    AINDOR COEFFICIENT
0205         MATA(3,4)=  SMN*SL*YN* SILAMR
      C        ROOT EQUATION    AINDOL COEFFICIENT
0206         MATA(3,5)=  -SMN*SL*YN*SILAML
      C        ROOT EQUATION    FORCING FUNCTION
0207         MATB(3 )   =  TERMP1  + ANAERO
      C
      C        AINDOR EQUATION ROOT COEFFICIENT
0208         MATA(4,1)= 0.
      C        AINDOR EQUATION ROOT COEFFICIENT
0209         MATA(4,2) = 0.
      C        AINDOR EQUATION ROOT COEFFICIENT
0210         MATA(4,3)=  0.
      C        AINDOR EQUATION AINDOR COEFFICIENT
```

Figure G.9. (Continued)

```
0211              MATA(4,4)=  1.0
           C         AINDOR EQUATION AINDOL COEFFICIENT
0212              MATA(4,5) =  0.
           C         AINDOR EQUATION FORCING FUNCTION
0213              MATB(4)= OMIRF**2*(AINPF+GINPF*DCYIC-AINR)-2.*ETAIRF*OMIRF*AINDTR
           C
           C         AINDOL EQUATION PDOT COEFFICIENT
0214              MATA(5,1) = 0.
           C         AINDOL EQUATION QDOT COEFFICIENT
0215              MATA(5,2) = 0.
           C         AINDOL EQUATION RDOT COEFFICIENT
0216              MATA(5,3) = 0.
           C         AINDOL EQUATION AINDOR COEFFICIENT
0217              MATA(5,4) =  0.
           C         AINDOL EQUATION AINDOL COEFFICIENT
0218              MATA(5,5)=  1.0
           C         AINDOL EQUATION FORCING FUNCTION
0219              MATB(5)= OMIRF**2*(AINRF-GINRF*DCYIC-AINL)-2.*ETAIRF*OMIRF*AINDTL
           C         SAVE MATA ARRAY
0220              DO 10 JJ=1,5
0221               MABSAV(JJ)=  MATB(JJ)
0222              DO 20 KK=1,5
0223              MATSAV(JJ,KK)= MATA(JJ,KK)
0224       20      CONTINUE
0225       10     CONTINUE
           C
0226              CALL MATINV(MATA,5,5,MATB,1,DET )
           C
0227              PDOT =  MATB(1)
0228              QDOT =  MATB(2)
0229              RDOT =  MATB(3)
0230              AINDOR= MATB(4)
0231              AINDOL= MATB(5)
           C         RESTORE MATA ARRAY
0232              DO 30 JJ=1,5
0233               MATB(JJ)= MABSAV(JJ)
0234              DO 40 KK=1,5
0235              MATA(JJ,KK)= MATSAV(JJ,KK)
0236       40      CONTINUE
0237       30      CONTINUE
           C
           C         AIRCRAFT CONDITION CALCULATIONS
           C
           C         LINEAR EQUATIONS OF MOTION (PSI,THETA,PHI EULER SYSTEM)
0238              UDOT =   XAERO /SM -SG*SINTHE -Q*W  + R* V
0239              VDOT =   YAERO /SM +SG*COSTHE*SINPHI -R*U + P*W
0240              WDOT =   ZAERO /SM +SG*COSTHE*COSPHI +Q*U - P* V
           C         EULER ANGLE CALCULATION  PSI,THETA,PHI  SYSTEM
0241              THEDOT =   Q*COSPHI - R* SINPHI
```

Figure G.9. (Continued)

```
0242           PHIDOT =  P +(Q*SINPHI + R*COSPHI) * SINTHE /COSTHE
0243           PSIDOT =  (Q* SINPHI +R* COSPHI) / COSTHE
        C
        C         C.G. ACCELERATION W.R.T. PIVOT (NON-ROTATING AXES)
0244           XDDCG= -SL*SMN/SM*(AINDDL*SILAML +AINDTL*AINDTL*CILAML  +AINDDR*
             *       SILAMR +AINDTR*AINDTR*CILAMR  )
0245           ZDDCG= -SL*SMN/SM*(AINDDL*CILAML-AINDTL*AINDTL*SILAML+AINDDR*
             *       CILAMR -AINDTR*AINDTR*SILAMR )
        C
        C         PILOT STATION ACCELERATIONS (BODY AXES)
        C
0246           AVAIL  =  12345678.
0247           ACCXPA=  XAERO/SM - XDDCG
0248           ACCYPA=  YAERO/SM -PDOT*(XCG-SLPA)
0249           ACCZPA=  ZAERO/SM +PDOT*(XCG-SLPA)  - ZDDCG     + SG
        C
        C         PILOT STATION VELOCITIES  (BODY AXES)
0250           UPA= UP+Q*ZPA-R*YPA
0251           VPA= VP+ R*SLPA-P*ZPA
0252           WPA= WP +P*YPA-Q*SLPA
        C
0253           AMACRP = ( SMN*SL*YN*CILAMR*PDOT-(SMN*SL*SL*(1.-SMN/SM)+FIYYPR)
             1         *(QDOT+AINDDR)-SMN*SL*YN*SILAMR*PDOT)
0254           AMACLP = (-SMN*SL*YN*CILAML*PDOT-(SMN*SL*SL*(1.-SMN/SM)+FIYYPR)
             1         *(QDOT+AINDDL)+SMN*SL*YN*SILAML*PDOT)
0255           AIRED = XLIM(AINRLM,-AINRLM,AINCOM)
        C
        C         THRUST MANAGEMENT SYSTEM
        C
0256           DLTHPD = GTH/TAUTH*DELTH - DLTHP/TAUTH
0257           AENG = XLIM(ALIM,-1.0,A0-ASLP*SHPIC)
0258           SHP1 = SHPPRR*AENG
0259           DSHP = SHP1-SHPIC
0260           DSHPP = SHP1-SHP2IC
0261           SHP2D = CVTAUD*DSHPP
0262           DSHPPP = SHP2IC-SHP3IC
0263           SHP3D = CVTAUE*S2THTC/DEL*DSHPPP
0264           SHP4 = SHPPPR+SHP3IC-SHP1
0265           SHPD = XLIM(SHPLM,-SHPLM,(SHP4-SHPIC)/TAUSHP)
0266           QAVL = SHPIC/OMEGA
0267           CPRQ = 0.5 *(CPL+CPF)
0268           QRQD = CPRQ*OMEGA**2
0269           OMDOT = (550.*QAVL-RQRIRS*QRQD)/EIP
0270           DLOMG = OMEGA - OMGCOM
0271           THOMD = XLIM(TOMDLM,-TOMDLM,GOMG*DLOMG)
0272           DTHDOM = XLIM(TOMLM,0.,TOMO+TOMSLP*AINRE)
0273           TMS2 = THOM + DTHDOM*GTOM*DLOMG+GDTHRT*DLTHP*SDLTH
0274           TMS1D = XLIM(THRTLM,-THRTLM,1./.1*(TMS2-TMS1-THOM-GDTHRT*DLTHP*
             1       CDLTH))
```

Figure G.9. (Continued)

```
0275         TMS3=  XLIM(THATLM,-THATLM,TMS2-TMS1-THOM-GDTHRT*DLTHP*GDLTH)
0276         THTMS  = XLIM(TTMSLP,TTMSLN,TMS1+THEM+TMS3+GDTHRT*DLTHP*GDLTH)
0277         THTMSR  =  THTMS+GTHGOV*THGOVR
0278         THTMSL  =  THTMS+GTHGOV*THGOVL
       C
       C
       C       ROTOR  THRUST
       C
0279         CTRPRM  =  ROT1  +  CTO*TAURO1/TAURO2*SFTR
0280         ROT1D  =  CTO/TAURO2*SFTR-CTRPRM/TAURO2
0281         CTLPRM  =  ROT2+CTO*TAURO1/TAURO2*SFTL
0282         ROT2D  =  CTO/TAURO2*SFTL-CTLPRM/TAURO2
       C
       C     SAS (LATERAL, LONGITUDINAL)
       C
       C       PITCH SAS
0283         PSAS1D  =  (DELB-PSAS1)/TAUDB
0284         PSAS5  =  (GQ*Q-GDB2*PSAS1)/TAUQ1
0285         PSAS6  =  (GTHE*Q-GDB1*PSAS1)*TAUTHE/TAUTHE
0286         GLONPH  =  XLIM(1.,0.,GLPO-GLPSLP*VCALIB)
0287         PSAS2D  =  PSAS5*GLONPH-PSAS2/TAUQ1
0288         PSAS3D  =  PSAS6*GLONPH-PSAS3/TAUTHE
0289         PSAS7  =  PSAS2+PSAS3-PSAS4
0290         PSAS4D  =  PSAS7/TAUQ2
0291         DELBS  =  XLIM(DLBLM,-DLBLM,PSAS7+GLSBIC)
       C       ROLL  SAS
0292         RSAS1D  =  (GPDS*DELS-RSAS1)/TAUPDS
0293         RSAS2D  =  (GP*P-RSAS2)/TAUP
0294         RSAS4D  =  (BETAF-RSAS4)/TAUBET
0295         RSAS5=GPHI*P*TAUPHI/TAUPHI
0296         RSAS3D  =  RSAS5*GLATPH-RSAS3/TAUPHI
0297         RSAS6  =  RSAS2+RSAS3-RSAS1
0298         DELSS  =  XLIM(DLSLM,-DLSLM,RSAS6*GROLL-RSAS4*GBETP*GBETPH)
       C       YAW SAS
0299         YSAS2D  =  (DELR-YSAS2)/TAUDR
0300         YSAS7  =  XLIM(RLM,-RLM,R)
0301         YSAS9  =  XLIM(DRLM,-DRLM,YSAS2)
0302         YSAS8  =  (GPSI*YSAS7-GPSIDR*YSAS9)*TAUPSI/TAUPSI
0303         YSAS1D  =  YSAS8*GLATPH-YSAS1/TAUPSI
0304         YSAS10  =  XLIM(DELRMX,-DELRMX,-GBETR*RSAS4-GBETDR*YSAS2)
0305         GLATPR  =  1.-GLATPH
0306         YSAS11  =  YSAS1+YSAS10*GLATPR
0307         YSAS3D  =  (P*GPRPH-YSAS3)/TAUPR
0308         YSAS12  =  GR*R-GRDR*YSAS2-YSAS4
0309         YSAS13  =  YSAS12
0310         IF(VCALIB.LT.VDETI*SKEPS)  YSAS13  =  -YSAS4
0311         YSAS4D  =  YSAS13/TAUR1
0312         YSAS14  =  YSAS12*TAUR2/TAUR3+YSAS5
0313         YSAS5D  =  (YSAS12-YSAS14)/TAUR3
```

Figure G.9. (Continued)

```
0314          YSAS15 = P
0315          IF(VSALIP.LT.VDETI*SKEPS) YSAS15 = 0.
0316          YSAS16 = YSAS15*GYAW
0317          YSAS6D = (GPRI*YSAS16*TAUPRI-YSAS6)/TAUPRI
0318          YSAS17 = YSAS14-YSAS6
0319          DELRS = XLIM(DLRLM,-DLRLM,YSAS11*GPSIPH+YSAS3+YSAS17*GYAW)
        C
        C       CONTROL EQUATIONS
        C
0320          DELBT = DELB
0321          DELST = DELS - DELSS
0322          DELRT = DELR - DELRS
0323          DELRJD = -SKDLRD*DELRT
0324          DELELV = -SKDLE*DELBT + GUE*DGTOR)
0325          DELELP  = GDELP
0326          DELAR2 =-XLIM(0.0,-DELAMX,SKDA*DELST)
0327          DELAL2 = XLIM(DELAMX,0.0,SKDA*DELST)
0328          DELAR1= XLIM(DELAL4,0.,DELAR2+DELELP)
0329          DELAL1= XLIM(DELAL4,0.,DELAL2+DELELP)
0330          DELAR = DELAR1 + DLELPP
0331          DELAL = DELAL1 + DLELPP
0332          DELSPR = XLIM(DLSPLM,0.0,GDSP)
0333          DELSPL = -XLIM(0.0,-DLSPLM,GDSP)
0334          DCYL =  DELRT*SKDLR*GDSCYL-DELST*SKDLS*GDSCYL
0335          DCOL = DELST*SKDLS*GDSCOL
0336          DLON = DELBT*SKDLB*GDBLON-DELRS
0337          DCYRD = XLIM(DCYRLM,-DCYRLM,(DCYL-DCYIC)/TAICYP)
0338          GBICD = XLIM(GICLM,-GICLM,(GBIC-GBICP)/TAUGIC)
0339          GAICD = XLIM(GICLM,-GICLM,(GAIC-GAICP)/TAUGIC)
        C
0340          GLSBD = GLSB/TAUGLS-GLSBIC/TAUGLS
0341          GLSARD = GLSAR/TAUGLS-GLSAIR/TAUGLS
0342          GLSALD = GLSAL/TAUGLS-GLSAIL/TAUGLS
        C
0343          BIRPDD = OMA**2*(GBICP-DCYL-DLON)-2.*ETAA*OMA*BICRP
             1      -    OMA**2*BICRP
0344          BILPDD = OMA**2*(GBICP+DCYL-DLON)-2.*ETAA*OMA*BICLPD
             1      -    OMA**2*BICLP
0345          AIRPDD = OMA**2*(-GLSAIR-SKDCOL*DCOL+GAICP)-2.*ETAA*OMA*AICRPD-
             1           OMA**2*AICRP
0346          AILPDD = OMA**2*(GLSAIL+SKDCOL*DCOL+GAICP)-2.*ETAA*OMA*AICLPD-
             1           OMA**2*AICLP
0347          BICRDD = OMRD**2*BICRP-2.*ETARD*OMRD*BICRDI-OMRD**2*BICRIC
0348          BICLDD = OMRD**2*BICLP-2.*ETARD*OMRD*BICLDI-OMRD**2*BICLIC
0349          AICRDD = OMRD**2*AICRP-2.*ETARD*OMRD*AICRDI-OMRD**2*AICRIC
0350          AICLDD = OMRD**2*AICLP-2.*ETARD*OMRD*AICLDI-OMRD**2*AICLIC
0351          TH75R = XLIM(TH75LP,TH75LN,THTMSR-DCOL)
0352          TH75L = XLIM(TH75LP,TH75LN,THTMSL+DCOL)
        C
```

Figure G.9. (Continued)

```
             C         WING VERTICAL BENDING
             C
 0353              ALAROD = OMWB**2*(ALARP-ALARWN)/FIXX-2.*ETAWB*OMWB*ALAROI
 0354              AMAROD = OMWB**2*(AMARP-AMARWN)/FIYY-2.*ETAWB*OMWB*AMAROI
 0355              ZAROD = OMWB**2*(ZARP-ZAEWN)/SM-2.*ETAWB*OMWB*ZARDIC
             C
 0356              CALL ANDAIN(PROJ,BONDS(1),LETR(1),IFC(1),NCON(1),P1,3,3)
 0357              CALL ANDAIN(PROJ,BONDS(2),LETR(2),IFC(2),NCON(2),P2,3,3)
 0358              CALL ANDAIN(PROJ,BONDS(3),LETR(3),IFC(3),NCON(3),P3,3,3)
 0359              CALL ANDAIN(PROJ,'IF','B',IFC(1),3,P4,3,3)
             C       DAC CALCULATION SECTION
 0360              P1(200) = -ALPHF/ABFSMX
 0361              P1(201) = (ALAERP+TERMP1)/FIXX/PDOTMX
 0362              P1(202)= -MATA(1,3)/FIXX*RDOTMX/PDOTMX
 0363              P1(203) = (AMAERP+TERMQ1)/FIYY/QDOTMX
 0364              P1(204)= -MATA(1,4)/FIXX*AIDDMX/PDOTMX
 0365              P1(205) =  MATB(3) /FIZZ / RDOTMX
 0366              P1(206)= -MATA(1,5)/FIXX*AIDDMX/PDOTMX
 0367              P1(207) =  XAERO/ SM /UDOTMX
 0368              P1(210) = UTRIM*SKEPS/UMX
 0369              P1(211) =  YAERO/ SM /VDOTMX
 0370              P1(212)= VTRIM*SKEPS/VWMX
 0371              P1(213) =   ZAERO / SM / ZARMX
 0372              P1(214)= -HTRIM/ZMX
 0373              P1(215) = VCALIF/UMX
 0374              P1(216)= -MATA(2,4)/FIYY*AIDDMX/QDOTMX
 0375              P1(217) =  VTOTLR/ROTRAD/AMURMX/OMEGMX
 0376              P1(220)= -MATA(2,5)/FIYY*AIDDMX/QDOTMX
 0377              P1(221) =  -ALPHLR / ALFRMX
 0378              P1(222) = THTRIM/THEMX/RDTODG
 0379              P1(223) =  VTOTPR/PGTRAD/AMURMX/OMEGMX
 0380              P1(224)  = -AVEALW/ ALWGMX
 0381              P1(225) =  -ALPHRR / ALFRMX
 0382              P1(226)= -MATA(3,1)/FIZZ*PDOTMX/RDOTMX
 0383              P1(227) = PNLN/OMEGMX
 0384              P1(230)= -MATA(3,4)/FIZZ*AIDDMX/RDOTMX
 0385              P1(231) = PNRN/OMEGMX
 0386              P1(232)= -MATA(3,5)/FIZZ*AIDDMX/RDOTMX
 0387              P1(233)=  -VNORTH/XDOTMX
 0388              SGNSQF= 1.0
 0389              IF(U.LT.0.) SGNSQF  = -1.0
 0390              P1(234)=  -SQF*SGNSQF/SQFMX
 0391              P1(235)=  -VEAST/YDOTMX
 0392              P1(237)  =- BETAF / ABFSMX
 0393              P2(200) =-SMN*SL*YN*CILAMR*PDOTMX/AMACMX
 0394              P2(201) = GLSB/GLSMX
 0395              P2(202) = (SMN*SL*SL*(1.-SMN/SM)+FIYYPR)*QDOTMX/AMACMX
 0396              P2(203) =-GLSAL/GLSMX
 0397              P2(204) = SMN*SL*YN*SILAMR*RDOTMX/AMACMX
```

Figure G.9: (Continued)

```
      P2(205)=  (XCG-SLPA)/XCGMX
      P2(206)= HDTRIM/VWMX/60.
      P2(207) = SHPPRR/SHPMX
      P2(210) = SMN*SL*YN*CILAML*PDOTMX/AMACMX
      P2(211) =-SQTHTC/DEL*TAUEMX/GBUTON
      P2(212) = (SMN*SL*SL*(1.-SMN/SM)+FIYYPP)*PDOTMX/AMACMX
      P2(214) =-SMN*SL*YN*SILAML*PDOTMX/AMACMX
      P2(216)= ATTRIM/ATNMX /RDTODG
      P2(217) =  ALAPP/FIXX/PDOTMX
      P2(220) = RDPIP5/FIP*OMEGMX*CONX   /2./10.
      P2(221) =  AMARP/FIYY/QDOTMX
      P2(223) =  ZARP/SM/ZARMX
      P2(224) = -QNRR / QMX * CPMOMX / CPMMX
      P2(225) = GLSAR/GLSMX
      P2(226) = -QNLR / QMX * CPMOMX / CPMMX
      P2(230) =  RNRR / RMX * CYMRMX / CYMMX
      P2(232) =  RNLR / RMX * CYMRMX / CYMMX
      P2(237)  =   PCTOR / PCTOMX
C
C     BOARD 1E   (CONSOLE 1)     POT. CALCULATION SECTION
C
      P1(000) =-ZIC/ZMX
      P1(001) = YIC/YMX
      P1(003) = VWMX/ZMX/GBUTON
      P1(004) = YDOTMX/YMX/GBUTON
      P1(005) = XDOTMX/XMX/GBUTON
      P1(006) = SKTRIM(01)
      P1(007) = SKTRIM(02)
      P1(010) = XIC/XMX
      P1(012) = 1./TAURO2/GBUTON*SFTR
      P1(013) = TAURO1/TAURO2*SFTR
      P1(014) = 1./TAURO2/GBUTON
      P1(015) = 1./TAURO2/GBUTON*SFTL
      P1(016) = TAURO1/TAURO2*SFTL
      P1(017) = 1./TAURO2/GBUTON
      P1(020) = 87.*SKEPS/UMX
      P1(021) = UMX/VWMX/10.
      P1(026) = THEMX/PI
      P1(027) = PHIMX/PI
      P1(030) = 141.*SKEPS/UMX
      P1(032) =  ROT1 / CTMX
      P1(033) =  ROT2 / CTMX
      P1 (036) =   1./ 10.
      P1 (037) =   1./ 10.
      P1(070)=     VDET1 *SKEPS  / UMX
      P1(072) = SKTRIM(03)
      P1(073) = SKTRIM(04)
      P1(074) = SKTRIM(05)
      P1(075) = SKTRIM(06)
```

Figure G.9. (Continued)

```
0444          P1(240) = PIC/PMX
0445          P1(241) = QIC/QMX
0446          P1(242) = PDOTMX/PMX/GBUTON
0447          P1(243) = QDOTMX/QMX/GBUTON
0448          P1(244) = RDOTMX/RMX/GBUTON
0449          P1(245) = RIC/RMX
0450          P1(246) = VDOTMX/VWMX/GBUTON
0451          P1(247) = WDOTMX/VWMX/GBUTON
0452          P1(250) = UDOTMX/UMX/GBUTON*10.
0453          P1(251) = THDMX/THEMX/GBUTON
0454          P1(252) = SG*1.0/UDOTMX/10.
0455          P1(253) = QMX*VWMX/UDOTMX/10.
0456          P1(254) = RMX*VWMX/UDOTMX/10.
0457          P1(255) = UIC/UMX
0458          P1(256) = SG*1.0/VDOTMX/10.
0459          P1(257) = RMX*UMX/VDOTMX/10.
0460          P1(264) = PMX*VWMX/VDOTMX/10.
0461          P1(265) = ZARMX/WDOTMX/10.
0462          P1(266) = SG*1.0/WDOTMX/10.
0463          P1(267)=  QMX*UMX/WDOTMX/10.
0464          P1(270) = PHDMX/PHIMX/GBUTON
0465          P1(271) = PSDMX/PSIMX/GBUTON*10.
0466          P1(272) = VIC/VWMX
0467          P1(273) = WIC/VWMX
0468          P1(274) = THEIC/THEMX
0469          P1(275) = PHIIC/PHIMX
0470          P1(276) = PMX*VWMX/WDOTMX/10.
0471          P1(277) = PSIIC/PSIMX
0472          P1(300) = RSAS1/DELSMX
0473          P1(301) = RSAS2/DELSMX
0474          P1(302) = GPDS/TAUPDS*DELSMX/DELSMX/GBUTON
0475          P1(303) = 1./TAUPDS/GBUTON
0476          P1(304) = GP/TAUP*PMX/DELSMX/GBUTON
0477          P1(305) = 1./TAUP/GBUTON
0478          P1(306) = GPHI*PMX/DELSMX/GBUTON
0479          P1(307) = 1./TAUPHI/GBUTON
0480          P1(310) = RSAS3/DELSMX
0481          P1(311) = RSAS4/ABFSMX
0482          P1(312) = 1./TAUBET/GBUTON
0483          P1(313) = 1./TAUBET/GBUTON
0484          P1(314) = GBETP*ABFSMX/DELSMX-1.
0485          P1(315) = 1./TAUPSI/GBUTON
0486          P1(316) = DLSLM/DELSMX
0487          P1(317) = DLSLM/DELSMX
0488          P1(320) = YSAS1/DELRMX
0489          P1(321) = YSAS2/DELRMX
0490          P1(322) = GPSI*RMX/DELRMX/GBUTON
0491          P1(323) = GPSIDR/GBUTON
0492          P1(324) = 1./TAUDP*DELRMX/DELRMX/GBUTON
```

Figure G.9. (Continued)

```
0493      P1(325) = 1./TAUDK/GBUTON
0494      P1(326) = RLM/RMX
0495      P1(327) = RLM/RMX
0496      P1(330) = YSAS3/DELRMX
0497      P1(331) = YSAS6/DELRMX
0498      P1(332) = GBETDR/10.
0499      P1(333) = GBETP*ABFSMX/DELRMX/10.
0500      P1(334) = 2./TAUPR*RMX/DELRMX/GBUTON
0501      P1(335) = 1./TAUPR/GBUTON
0502      P1(336) = DRLM/DELRMX
0503      P1(337) = DRLM/DELRMX
0504      P1(340) = YSAS4/DELRMX
0505      P1(341) = YSAS5/DELRMX
0506      P1(342) = GRDR
0507      P1(343) = 1./TAUR3/GBUTON
0508      P1(344) = 1./TAUR3/GBUTON
0509      P1(345) = TAUP2/TAUR3
0510      P1(346) = GPR1*RMX/DELRMX/GBUTON
0511      P1(347) = 1./TAUPR1/GBUTON
0512      P1(350) = CR*RMX/DELRMX/10.
0513      P1(351) = 1./TAUR1/GBUTON/2.1
0514      P1(352) = GBETP*2.+1.0
0515      P1(354) = 1.0
0516      P1(355) = 1.0
0517      P1(356) = DLRLM/DELRMX
0518      P1(357) = DLRLM/DELRMX
       C
       C  BOARD 3F      (CONSOLE 2)       POT. CALCULATION SECTION
       C
0519      P2(330) = DLTHP/DLTHMX
0520      P2(001) = SHP2IC/SHPMX
0521      P2(002) = GTH/TAUTH/GBUTON
0522      P2(003) = 1.0/TAUTH/GBUTON
0523      P2(006) = OMLM/OMEGMX
0524      P2(007) = OMGO/OMEGMX
0525      P2(010) = SHP3IC/SHPMX
0526      P2(011)=  -OMEGIC/OMEGMX
0527      P2(012) = OMSLP*AINMX /OMEGMX
0528      P2(013) = OMGO/OMEGMX
0529      P2(014) = 550./FTP*SHPMX/OMEGMX/OMEGMX
0530      P2(015) = GTHGOV/TTMSMX
0531      P2(016) = THOMIC/THOMMX
0532      P2(017) = TMS1/THOMMX
0533      P2(020) = THPCTU
0534      P2(021) = QINRF/SDFMX
0535      P2(022) = THOMLP/THOMMX
0536      P2(023)=  -THOMLN/THOMMX
0537      P2(024) = THRTLM/THOMMX
0538      P2(025) = THRTLM/THOMMX
```

Figure G.9. (Continued)

```
0539          P2(026) = THATMX/THOMMX
0540          P2(027) = THATMX/THOMMX
0541          P2(030) = AMRATE/AINRMX*DGTORD
0542          P2(031) = 89.5*DGTORD/AINMX
0543          P2(032) = GTHGOV/TTMSMX
0544          P2(033) = THOMMX/TTMSMX
0545          P2(034) = THOMMX/TTMSMX
0546          P2(035) = GDLTH *DLTHMX/THOMMX
0547          P2(036) = SKTRIM(12)
0548          P2(037) = SKTRIM(13)
0549          P2(040) = AINDET*DGTORD/AINRMX
0550          P2(041) = AINDET*DGTORD/AINRMX
0551          P2(042) = GDLTH *DLTHMX/THOMMX
0552          P2(043) = GOMG*OMEGMX/TOMDMX
0553          P2(044) = TOMDLM/TOMDMX
0554          P2(045) = TOMDLM/TOMDMX
0555          P2(046) = GDLTH *DLTHMX/THOMMX
0556          P2(047) = TOMDMX/THOMMX/GBUTON
0557          P2(050) = ALARDI/PDOTMX/10.
0558          P2(051) = ALARIC/PDOTMX
0559          P2(052) = TTMSLP/TTMSMX
0560          P2(053) =-TTMSLN/TTMSMX
0561          P2(054) = 1./TAUEF/GBUTON
0562          P2(055) = 1./TAUEF/GBUTON
0563          P2(056) = 1./TAUEF/GBUTON
0564          P2(057) = 1./TAUEF/GBUTON
0565          P2(060) = AMARDI/QDOTMX/10.
0566          P2(061) = AMARIC/QDOTMX
0567          P2(062) = OMWB**2/10./GBUTON/10.
0568          P2(063) = 2.*ETAWB*OMWB/GBUTON /10.
0569          P2(064) = OMWB**2/10./GBUTON/10.
0570          P2(065) = OMWB**2/10./GBUTON/10.
0571          P2(066) = 2.*ETAWB*OMWB/GBUTON /10.
0572          P2(067) = OMWB**2/10./GBUTON/10.
0573          P2(070) = ZARDIC/ZARMX/10.
0574          P2(071) = ZARIC/ZARMX
0575          P2(072) = OMWB**2/10./GBUTON/10.
0576          P2(073) = 2.*ETAWB*OMWB/GBUTON /10.
0577          P2(074) = OMWB**2/10./GBUTON/10.
0578          P2(240) = AINRDI/AINDMX
0579          P2(241) = AINRIC/AINMX
0580          P2(242) = AIDDMX/AINDMX/GBUTON
0581          P2(243) = AINDMX/AINMX/GBUTON
0582          P2(244) = OMIRE**2*AINMX/AIDDMX/10.
0583          P2(245) = 2.*ETAIRE*OMIRE*AINDMX/AIDDMX/10.
0584          P2(246) = OMIRE**2*AINMX/AIDDMX/10.
0585          P2(247) = AINRLM/AINRMX
0586          P2(250) = AINLDI/AINDMX
0587          P2(251) = AINLIC/AINMX
```

Figure G.9. (Continued)

```
      P2(252) = AIDDMX/AINDMX /GBUTON
      P2(253) = AINDMX/AINMX/GBUTON
      P2(254) = OMIRF**2*AINMX/AIDDMX/10.
      P2(255) = 2.*ETAIRF*OMIRF*AIDDMX/AIDDMX/10.
      P2(256) = OMIRF**2*AINMX/AIDDMX/10.
      P2(257) = AINRLM/AINRMX
      P2(260) = DELTH /DLTHMX
      P2(261) = 0.
      P2(262) = 0.
      P2(263) = AINCOM/AINRMX
      P2(264) = GINRF*OMIRF**2*DCYLMX/AIDDMX/10.
      P2(265) = GINRF*OMIRF**2*DCYLMX/AIDDMX/10.
      P2(266) = 1./TAUCYR/10./GBUTON
      P2(267) = 1./TAUCYR/10./GBUTON
      P2(270) = CON1*AIDDMX/AMACMX  /10.
      P2(271) = AINRMX/AINMX
      P2(272) = AIRFIC/AINMX
      P2(273) = 105.*DGTOPD/AINMX
      P2(274) = 2.*ETAIRF*OMIRF*AINRMX/AIDDMX/10.
      P2(275) = AMACMX/CON1/AIDDMX/10.
      P2(276) = SKTRIM(7)
      P2(277) = SKTRIM( 8)
      P2(300) = CON1*AIDDMX/AMACMX /10.
      P2(301) = DCYIC/DCYLMX
      P2(302) = DCYRLM/DCYLMX/GBUTON
      P2(303) = DCYRLM/DCYLMX/GBUTON
      P2(304) = 2.*ETAIRF*OMIRF*AINRMX/AIDDMX/10.
      P2(305) = AMACMX/CON1/AIDDMX/10.
      P2(306) = SHPLM/SHPMX/GBUTON
      P2(307) = SHPLM/SHPMX/GBUTON
      P2(311) = SHPIC/SHPMX
      P2(312) = 1./TAUSHP/GBUTON/1 .
      P2(313) = 1./TAUSHP/GBUTON/1 .
      P2(314) = ASLP*SHPMX
      P2(315) = A0
      P2(316) = ALIM
      P2(317) = 1.0
      P2(320) = STOM*OMEGMX/TTMSMX/10.
      P2(322) = TOMC/1.
      P2(323) = TOMSLP*AINMAX/1.
      P2(324) = TOMLM/1.
      P2(344)=  ALAMDA/PI
      P2(345)=  AINMX/PI
      P2(346)=  ALAMDA/PI
      P2(347)=  AINMX/PI
      P2(364)=  AINDMX**2/XDDMX*SL*SMN/SM -1.0
      P2(365)=  AINDMX**2/ZDDMX*SL*SMN/SM
      P2(366)=  AIDDMX/XDDMX*SL*SMN/SM
      P2(367)=  AIDDMX/ZDDMX*SL*SMN/SM
```

Figure G.9. (Continued)

```
FORTRAN IV    MODEL 44  PS        VERSION 3,  LEVEL 3   DATE  73092                    PAGE

0637          P2(372)=  UDOTMX/AXPAMX
0638          P2(373)=  VDOTMX/AYPAMX
0639          P2(374)=  RDOTMX*XCGMX/AYPAMX
0640          P2(375)=  WDOTMX/AZPAMX
0641          P2(376)=  UDOTMX*XCGMX/AZPAMX
0642          P2(377)=  SG/AZPAMX
         C
         C    BOARD 5F      (CONSOLE 3)          POT. CALCULATION SECTION
         C
0643          P3(002) = OMRD**2/10./GBUTON/10.
0644          P3(003) = OMRD**2/10./GBUTON/10.
0645          P3(004) = 2.0*ETARD*OMRD/GBUTON/10.
0646          P3(005) = BICRDI/BICMX/10.
0647          P3(006) = BICRIC/BICMX
0648          P3(007) = GRAIS
0649          P3(012) = OMRD**2/10./GBUTON/10.
0650          P3(013) = OMRD**2/10./GBUTON/10.
0651          P3(014) = 2.0*ETARD*OMRD/GBUTON/10.
0652          P3(015) = BICLDI/BICMX/10.
0653          P3(016) = BICLIC/BICMX
0654          P3(017) = GRAIS
0655          P3(022) = OMRD**2/10./GBUTON/10.
0656          P3(023) = OMRD**2/10./GBUTON/10.
0657          P3(024) = 2.0*ETARD*OMRD/GBUTON/10.
0658          P3(025) = AICRDI/AICMX/10.
0659          P3(026) = AICRIC/AICMX
0660          P3(027) = GRAIS
0661          P3(031) = 1./TAUGMN
0662          P3(032) = OMRD**2/10./GBUTON/10.
0663          P3(033) = OMRD**2/10./GBUTON/10.
0664          P3(034) = 2.0*ETARD*OMRD/GBUTON/10.
0665          P3(035) = AICLDI/AICMX/10.
0666          P3(036) = AICLIC/AICMX
0667          P3(042) = GGUST/TAUGST/GBUTON/GUSTMX
0668          P3(043) = 1./TAUGST/GBUTON
0669          P3(044) = GGUST/TAUGST/GBUTON/GUSTMX
0670          P3(045) = 1./TAUGST/GBUTON
0671          P3(046) = GGUST/TAUGST/GBUTON/GUSTMX
0672          P3(047) = 1./TAUGST/GBUTON
0673          P3(062) = GLSAIR/GLSMX
0674          P3(062) = 1./TAUGLS/GBUTON
0675          P3(063) = 1./TAUGLS/GBUTON
0676          P3(066) = GLSLM/GLSMX
0677          P3(067) = GLSLM/GLSMX
0678          P3(072) = SKTRIM(09)
0679          P3(073) = SKTRIM(10)
0680          P3(074) = SKTRIM(11)
0681          P3(242) = SKDLRD*DELRMX/DLRDMX
0682          P3(243) = SKDLR*DELRMX/DCYLMX*GRCYMX
```

Figure G.9. (Continued)

```
      P3(244) = SKDLS*DELSMX/DCYLMY*GSCYMX
      P3(245) = GLPP/10.
      P3(246) = SKDLS*DELSMX/DCOLMX*GSCOMX
      P3(247) = GLPSLP*UMX/10.
      P3(252) = SKDLR*DFLRMX/DLONMX
      P3(253) = SKDLF*DFLRMX/DFLEMX
      P3(254) = DELALM/DELAMX
      P3(255) = DELALM/DELAMX
      P3(257) = 1.0
      P3(260) = DFLR  /DELRMX
      P3(261) = DELS  /DELSMX
      P3(262) = DELB  /DFLBMX
      P3(264) = GQ/TAUQ1*QMX/DLONMX/GBUTON/10.
      P3(265) = GTHE*QMX/DLONMX/GBUTON
      P3(266) = SKDA*DELSMX/DELAMX
      P3(267) = SKDA*DELSMX/DELAMX
      P3(272) = OMA**2*GICMX/BICMX/10./GBUTON/10.
      P3(273) = OMA**2*GICMX/BICMX/10./GBUTON/10.
      P3(274) = OMA**2*GICMX/AICMX/10./GBUTON/10.
      P3(275) = OMA**2*GICMX/AICMX/10./GBUTON/10.
      P3(276) = TTMSMX/TH75MX
      P3(277) = TTMSMX/TH75MX
      P3(300) = GLSBIC/GLSMX
      P3(301) = GLSAIL/GLSMX
      P3(302) = DCOLMX/TH75MX
      P3(303) = DCOLMX/TH75MX
      P3(304) = TH75LP/TH75MX
      P3(305) =-TH75LN/TH75MX
      P3(306) = TH75LP/TH75MX
      P3(307) =-TH75LN/TH75MX
      P3(310) = BICRPD/BICMX/10.
      P3(311) = BICRP /BICMX
      P3(312) = 1./TAUGLS/GBUTON
      P3(313) = 1./TAUGLS/GBUTON
      P3(314) = 1./TAUGLS/GBUTON
      P3(315) = 1./TAUGLS/GBUTON
      P3(316) = GLSLM/GLSMX
      P3(317) = GLSLM/GLSMX
      P3(320) =-GBICP/GICMX
      P3(321) =-GAICP/GICMX
      P3(322) = OMA**2*DCYLMX/BICMX/10./GBUTON/10.
      P3(323) = OMA**2*DLONMX/BICMX/10./GBUTON/10.
      P3(324) = 2.0*ETAA*OMA/GBUTON/10.
      P3(325) = OMA**2/10./GBUTON/10.
      P3(326) = 1./TAUGIC/GBUTON/10.
      P3(327) = 1./TAUGIC/GBUTON/10.
      P3(330) = BICLPD/BICMX/10.
      P3(331) = BICLP /BICMX
      P3(332) = 1./TAUGIC/GBUTON/10.
```

Figure G.9. (Continued)

```
      P3(333) = 1./TAUGIC/GBUTON/10.
      P3(334) = DLFLPC/DLFLMX
      P3(335) = 1./TAUDH*DFLBMX/DLONMX/GBUTON
      P3(336) = OMA**2*DCYLMX/BICMX/10./GBUTON/10.
      P3(337) = OMA**2*DLCNMX/BICMX/10./GBUTON/10.
      P3(340) = 1./TAUQ2/GBUTON/0.1
      P3(341) = PSAS2/DLONMX
      P3(342) = 2.0*ETAA*OMA/GBUTON/10.
      P3(343) = OMA**2/10./GBUTON/10.
      P3(344) = GICLM/GICMX/GBUTON
      P3(345) = GICLM/GICMX/GBUTON
      P3(346) = GICLM/GICMX/GBUTON
      P3(347) = GICLM/GICMX/GBUTON
      P3(350) = AICRPO/ AICMX/10.
      P3(351) = AICRP /AICMX
      P3(352) = 1./TAUDB/GBUTON
      P3(353) = OMA**2*GLSMX/AICMX/GBUTON/10./10.
      P3(354) =SKDCOL*OMA**2*DCOLMX/AICMX/10./GBUTON/10.
      P3(355) = 2.0*ETAA*OMA/GBUTON/10.
      P3(356) = OMA**2/10./GBUTON/10.
      P3(357) = GLSMX/DLONMX
      P3(360) = PSAS1/DLONMX
      P3(361) = PSAS3/DLONMX
      P3(362) = PSAS4/DLONMX
      P3(364) = GD32/TAUQ1/GBUTON/10.
      P3(365) = GDB1/GBUTON
      P3(366) = 1./TAUQ1/GBUTON/10.
      P3(367) = 1./TAUTHE/GBUTON
      P3(370) = AICLPO/AICMX/10.
      P3(371) = AICLP /AICMX
      P3(372) = DLBLM/DLONMX
      P3(373) = DLBLM/DLONMX
      P3(374) = OMA**2*GLSMX/AICMX/GBUTON/10./10.
      P3(375) =SKDCOL*OMA**2*DCOLMX/AICMX/10./GBUTON/10.
      P3(376) = 2.0*ETAA*OMA/GBUTON/10.
      P3(377) = OMA**2/10./GBUTON/10.
C
C
      XBODY= -XIC+VISIC+XHORIZ+XBIC
      YBODY= YROAD+YROAD+VISIC+YIC+YBIC
      ZBODY=  H+ZBIC
C
      SA11 =  COSTHE * COSPSI
      SA12 =  SINPHI *SINTHE *COSPSI - COSPHI * SINPSI
      SA13 =  COSPHI *SINTHE *COSPSI + SINPHI * SINPSI
C
      SA21 =  COSTHE * SINPSI
      SA22 =  SINPHI *SINTHE*SINPSI + COSPHI * COSPSI
      SA23 =  COSPHI *SINTHE *SINPSI -SINPHI * COSPSI
```

Figure G.9. (Continued)

```
                C
0777                  SA31 =   - SINTHE
0778                  SA32 =     SINPHI * COSTHE
0779                  SA33 =   COSPHI * COSTHE
                C
0780                  XACVIS =  -(SA11*XBODY +SA12*YBODY +SA13 *ZBODY)
0781                  YACVIS =  -(SA21*XBODY +SA22*YBODY +SA23 *ZBODY)
0782                  ZACVIS= -(-SA31*XBODY+SA32*YBODY+SA33*ZBODY)
                C
0783                  YSCOPE= ZACVIS/XACVIS*VCAL1*XVISMX/ZVISMX
0784                  XSCOPE= YACVIS/XACVIS*VCAL2*XVISMX/YVISMX
                C
0785                  FFDB=  XLIM(FFBMX,FFLMLO,BSLOPE*SQF/QSTARB +BOB)
0786                  FFDS=  XLIM(FFSMX,FFLMLO,SSLOPE*SQF/QSTARS + BOS)
0787                  FFDR=  XLIM(FFRMX,FFLMLO,RSLOPE*SQF/QSTARR + BOR)
0788                  PCNP=  OMEGA/OMREF*100.
0789                  DRBKDP=  COMDLB-DELB
0790                  DRBKDR=  COMDLR-DELR
0791                  DSBKDP=  COMDLS-DELS
0792                  THBKDR =  -SKTRIM(12)*CMDOT/OMEGMX*DLTHMX
0793                  PSDSIM= XLIM(PSDTSX,-PSDTSX,PSIDOT*RDTODG)
0794                  XSIM=  XLIM(DXSIMX,-DXSIMX,XIC)
0795                  YSIM=  XLIM(DYSIMX,-DYSIMX,YIC)
0796                  IF(NPLOT.EQ.2) GO TO 975
0797                  COMDLB= 0.0
0798                  COMDLS= 0.0
0799                  COMDLR= 0.0
0800                  COMIDT= 0.0
0801                  BRAKE= 0.0
0802            975   CONTINUE     BOARD 1B (CONSOLE 4) SIMULATOR BOARD
                C
0803                  P4(390) =   1.0000
0804                  P4(001) =   1.0000
0805                  P4(002)=  PCTOMX/TQSIMX
0806                  P4(003)=  PCTOMX/TOSIMX
0807                  P4(004)=  CMEGMX/OMREF*100./RPMSMX
0808                  P4(005)= YDDTMX/YDTSMX
0809                  P4(006)=  VWMX/HDTSMX
0810                  P4(007)=  XDDTMX/XDTSMX
0811                  P4(014)=  UMX/SKEPS/USIMX
0812                  P4(015)=  VMMX/SKEPS/VSIMX
0813                  P4(016)=  AXPAMX/AXPAMX
0814                  P4(024)=  PSIMX*RDTODG/PSISMX
0815                  P4(025)=  PSDMX*RDTODG/PSDTSX/2.0
0816                  P4(026)= PI*RDTODG/THESMX
0817                  P4(027)=  PI*RDTODG/PHISMX
0818                  P4(032)=  PSDMX*RDTODG/PSDTSX/2.0
0819                  P4(034)=  PSDTSX/PSDTSX
0820                  P4(035)=  PSDTSX/PSDTSX
```

Figure G.9. (Continued)

```
0821             P4(036)=  AINMX*RDTODG/AINSMX
0822             P4(037)=  ALWGMX*RDTODG/ALWSMX
0823             P4(044)=  AZPAMX/AZPAMX
0824             P4(045)=  DLFLMX/DFPSMX
0825             P4(046)=  ABFSMX*RDTODG/RTSIMX
0826             P4(047)=  AYPAMX/AYPAMX
0827             P4(050)=  0.1475
0828             P4(051)=  0.1475
0829             P4(052)=  DXSIMX/DXSIMX
0830             P4(053)=  DXSIMX/DXSIMX
0831             P4(054)=  1.0000
0832             P4(055)=  XMX/DXSIMX/10.
0833             P4(056)=  ZMX/HSIMX
0834             P4(057)=  1.0000
0835             P4(060)=  YMX/YVISMX
0836             P4(061)=  ZMX/ZVISMX
0837             P4(240) =   XDOTMX / XVISMX  /10.
0838             P4(241) =   YDOTMX / YVISMX / 10.
0839             P4(250)=  XDTEST/XVISMX/10.
0840             P4(251)=  YDTEST/YVISMX/10.
0841             P4(260) =   THE/ PI
0842             P4(261) =   PHI/ PI
0843             P4(262) =   PSI/ PI
0844             P4(263) =   FREQWT / 100.
0845             P4(264) =   SCOPLM
0846             P4(265) =   SCOPLM
0847             P4(266) =   SCOPLM
0848             P4(267) =   SCOPLM
0849             P4(270) =   1.0000
0850             P4(271) =    .0100
0851             P4(272) =  XHORIZ / XVISMX
0852             P4(273) =   ZMX / ZVISMX
0853             P4(274)=  PIASMT/ZVISMX
0854             P4(275) =     YBIC / XVISMX
0855             P4(276) =     YBIC / YVISMX
0856             P4(277) =     ZBIC / ZVISMX
0857             P4(300)=  PSDMX/PI/10.
0858             P4(301)=  0.1500/PI/10.
0859             P4(302) =     SLX / XVISMX
0860             P4(303) =     SLY / XVISMX
0861             P4(304) =     SLZ / XVISMX
0862             P4(305) =     SLX / ZVISMX
0863             P4(306) =     SLY / ZVISMX
0864             P4(307) =     SLZ / ZVISMX
0865             P4(310) =     0.6000
0866             P4(311) =     0.6000
0867             P4(312) =     SLX / YVISMX
0868             P4(313) =     SLY / YVISMX
0869             P4(314) =     SLZ / YVISMX
```

Figure G.9. (Continued)

```
0870            P4(315) =    PKMT1 / ZVISMX
0871            P4(316) =    PKMT2 / ZVISMX
0872            P4(317) =    GZMTS1
0873            P4(320) =    0.6500
0874            P4(321) =    0.6500
0875            P4(322)=  DBPSMX/DBBDMX
0876            P4(323)=  DELBMX/DBBDMX
0877            P4(324)=  DRPSMX/DRBDMX
0878            P4(325)=  DELRMX/DRBDMX
0879            P4(326)=  DSPSMX/DSBDMX
0880            P4(327)=  DELSMX/DSBDMX
0881            P4(330) =    10.* SKFPS / XDOTMX
0882            P4(332) =    VCAL1 * XVISMX / YVISMX
0883            P4(333) =    VCAL2 * XVISMX / ZVISMX
0884            P4(334)=  2.0*BRKMX/BRKSMX
0885            P4(335)=  DLTHMX/THBDMX
0886            P4(336)=  FFBMX/FFBMX
0887            P4(337)=  FFLMLO/FFBMX
0888            P4(340) =    GZMTS2
0889            P4(341) =    XHORIZ / XVISMX
0890            P4(342)=  -BOB/FFBMX
0891            P4(343)=  -BOS/FFSMX
0892            P4(344)=  BSLOPE/QSTARB*SQFMX/FFBMX
0893            P4(345)=  SSLOPE/QSTARS*SQFMX/FFSMX
0894            P4(346)=  RSLOPE/QSTARR*SQFMX/FFRMX
0895            P4(347)=  -BOR/FFRMX
0896            P4(350) =    YBRED / YVISMX
0897            P4(351) =    YROAD / YVISMX
0898            P4(354)=  FFSMX/FFSMX
0899            P4(355)=  FFRMX/FFRMX
0900            P4(356)=  FFLMLC/FFSMX
0901            P4(357)=  FFLMLR/FFRMX
0902            P4(360) =    XIC    / XVISMX
0903            P4(361) =    YIC    / YVISMX
0904            P4(362)=  H/ZMX
0905            P4(364)=  2.0*DELBMX/DBPSMX
0906            P4(365)=  2.0*DELSMX/DSPSMX
0907            P4(367)=  2.0*AINPMX/AIPSMX*RDTDDG
0908            P4(370)=  0.1400
0909            P4(371)=  0.1400
0910            P4(374)=  2.0*DELRMX/DRPSMX
0911            P4(375)=  2.0*DLTHMX/DTPSMX
         C
0912            RETURN
0913            ENTRY STCON1
0914            CALL ANDAIN(PROJ,BONDS(1),LETR(1),IFC(1),NCON(1),AIP,0,5,AIN,1,5,
               *        SJ1,4,5,TR1,6,5)
         C
0915            AIP(380) = ZIC/ZMX
```

BOARD 1E (CONSOLE 1) AMPLIFIER SCALE FACTOR CALCULATION; P DENOTES POSITIVE OUTPUT, N DENOTES NEGATIVE OUTPUT

Figure G.9. (Continued)

```
      AIP(001) = YIC/YMX
      AIP(002) = UIC*SINTHE/UMX
      AIN(002) = ZDOT/VWMX
      AIP(003) = YDOT/YDOTMX
      AIN(003) = XDOT/XDOTMX
      AIP(010) = XIC/XMX
      AIP(011) = 0.0
      AIP(012) = AINDER/AIDDMX
      AIP(013) = AINDDL/AIDDMX
      AIP(020) = -SKTRIM(3)*VDOT/VDOTMX
      AIN(020) = CTO/CTMX
      AIP(021) = ROT1/CTMX
      AIP(030) = -CTRPRM/CTMX
      AIN(030) = CTC/CTMX
      AIP(031) = ROT2/CTMX
      AIP(040) = TH75R/TH75MX
      AIN(040) = CPR/CPMX
      AIP(041) = TH75L/TH75MX
      AIN(041) = CPL/CPMX
      AIP(050) =-TH75R/TH75MX
      AIN(050) = CNFPL/CNFMX
      AIP(051) = -ALPHA/ALFMX
      AIN(051) = CNFPR/CNFMX
      AIP(052) = CTRPRM/CTMX
      AIP(053) = CTLPRM/CTMX
      AIP(060) = -AMUP/AMUPMX
      AIN(060) = CSFPR/CSFMX
      AIP(061) = -1.0
      AIN(061) = CSFPL/CSFMX
      AIP(062) = SKTRIM(1)*UDOT/UDOTMX
      AIP(063) = SKTRIM(5)*WDOT/WDOTMX
      AIP(070) = 0.0
      AIP(071) = 0.0
      AIP(200) = PIC/PMX
      AIP(201) = QIC/QMX
      AIP(202) = PDOT/PDOTMX
      AIP(203) = QDOT/QDOTMX
      AIP(210) = RIC/RMX
      AIP(211) = UIC/UMX
      AIP(212)=  -PSIDOT*SINTHE/PSIMX
      AIN(212) = THEDOT/THDMX
      AIP(213) = R*COSPHI/RMX
      AIN(213) = PHIDOT/PHDMX
      AIP(220) = VIC/VWMX
      AIP(221) = WIC/VWMX
      AIP(222) = RDOT/RDOTMX
      AIP(223) = Q*SINPHI/QMX
      AIN(223) = UDOT/UDOTMX
      AIP(230) = THEIC/THEMX
```

Figure G.9. (Continued)

```
      A1P(231) = PHIIC/PHIMX
      A1P(240) = PSIIC/PSIMX
      A1P(241) =  -XAERO /SM / UDOTMX
      A1N(241) =  -YAERO /SM / VDOTMX
      A1P(242) = R*SINPHI/RMX
      A1N(242) = VDOT/VDOTMX
      A1P(243) =-Q*COSPHI/QMX
      A1N(243) = WDOT/WDOTMX
      A1P(250) = THE/PI
      A1P(251) = PHI/PI
      A1P(252) = COSTHE*COSPHI
      A1P(253) = COSTHE*SINPHI
      A1P(260) =  BETAF / ABFSMX
      A1N(260) =  AVEALW / ALWGMX
      A1P(261) =  SOF     / SOFMX
      A1N(261)= -ZAERO/SM/ZAPMX
      A1P(262) = PSIDOT/PSDMX
      A1P(300) =-DELSS/DELSMX
      A1N(300) =-RSAS1/DELSMX
      A1P(301) =-RSAS6/DELSMX
      A1N(301) = RSAS2/DELSMX
      A1P(302) =-YSAS8/DELRMX/GRUTOM
      A1P(303) = YSAS1I/DELRMX
      A1P(310) =-YSAS7/RMX
      A1N(310) = RSAS3/DELSMX
      A1P(311) = RSAS4/ABFSMX
      A1P(312) =-RSAS5/DELSMX/GRUTOM
      A1P(313) =GLATPH/1.
      A1P(320) =-YSAS11/DELRMX
      A1N(320) = YSAS1/DELRMX
      A1P(321) = YSAS9/DELRMX
      A1N(321) =-YSAS2/DELRMX
      A1P(322) = ALPHF/APFSMX
      A1N(322) =-VCALIB/UMX
      A1P(323) = ALPHRR/ALFRMX
      A1N(323) = ALPHLR/ALFRMX
      A1P(330) =-YSAS12/DELRMX
      A1N(330) = YSAS3/DELRMX
      A1P(331) = YSAS16/PMX
      A1N(331) =-YSAS6/DELRMX
      A1P(340) = YSAS4/DELRMX
      A1P(341) =-YSAS5/DELRMX
      A1P(342) = AMUR/AMURMX
      A1P(343) = AMUL/AMURMX
      A1P(350) = YSAS14/DELRMX
      A1N(350) =-DELRS/DELRMX
      A1P(351) = YSAS13/DELRMX
      A1P(352) =-YSAS15/PMX
      A1P(353) = GYAW/1.
```

Figure G.9. (Continued)

```
1014          TIF(3  ) = GLAT0K/1.
1015          S12(361) = YSASIZ/
1016          S12(362) = OMEGAR/OMEGMX
1017          S12(363) = OMEGAL/OMEGMX
      C       VALUES AT SUMMING JUNCTIONS OF AMPLIFIERS:  BOARD 1E (CONSOLE 1)
1018          SJ1(380) = ZDOT/ZMX/GBUTON
1019          SJ1(001) = YDOT/YMX/GBUTON
1020          SJ1(010) = XDOT/XMX/GBUTON
1021          SJ1(011) = SKTRIM(0,2)*UDOT/UDOTMX
1022          SJ1(020) = 0.0
1023          SJ1(021) = ROT1D/CTMX/GBUTON
1024          SJ1(030) = 0.0
1025          SJ1(031) = ROT2D/CTMX/GBUTON
1026          SJ2(040) = 0.0
1027          SJ2(041) = 0.0
1028          SJ1(050) = 0.0
1029          SJ1(051) = 0.0
1030          SJ1(060) = 0.0
1031          SJ1(061) = 0.0
1032          SJ1(070) = SKTRIM(0,4)*VDOT/VDOTMX
1033          SJ1(071) = SKTRIM(0,6)*WDOT/WDOTMX
1034          SJ1(200) = PDOT/PMX/GBUTON
1035          SJ1(201) = QDOT/QMX/GBUTON
1036          SJ1(210) = RDOT/RMX/GBUTON
1037          SJ1(211) = UDOT/UMX/GBUTON
1038          SJ1(220) = VDOT/VWMX/GBUTON
1039          SJ1(221) = WDOT/VWMX/GBUTON
1040          SJ1(230) = THEDOT/THEMX/GBUTON
1041          SJ1(231) = PHIDOT/PHIMX/GBUTON
1042          SJ1(240) = PSIDOT/PSIMX/GBUTON
1043          SJ1(300) = RSAS1D/DELSMX/GBUTON
1044          SJ1(301) =-RSAS2D/DELSMX/GBUTON
1045          SJ1(310) =-RSAS3D/DELSMX/GBUTON
1046          SJ1(311) = RSAS4D/AHFSMX/GBUTON
1047          SJ1(320) =-YSAS1D/DELRMX/GBUTON
1048          SJ1(321) = YSAS2D/DELRMX/GBUTON
1049          SJ1(330) =-YSAS3D/DELRMX/GBUTON
1050          SJ1(331) = YSAS6D/DELRMX/GBUTON
1051          SJ1(340) = YSAS4D/DELRMX/GBUTON
1052          SJ1(341) =-YSAS5D/DELRMX/GBUTON
      C       BOARD 1E (CONSOLE 1) VALUES OF TRUNK LINES AND ADC'S (FIRST 32 TR'S ARE ADC'S)
1053          TR1(220) = P/PMX
1054          TR1(221) = Q/QMX
1055          TR1(222) = R/RMX
1056          TR1(223) = U/UMX
1057          TR1(260) = V/VWMX
1058          TR1(261) = W/VWMX
1059          TR1(262) = THE/THEMX
1060          TR1(263) = PHI/PHIMX
```

Figure G.9. (Continued)

```
      TR1(320) = PSI/PSIMX
      TR1(321) = WDOT/WDOTMX
      TR1(322) = -ZIC/ZMX
      TR1(363) = ZDOT/VWMX
      TR1(020) =-DELAL/DELAMX
      TR1(021) =  DELAR/DELAMX
      TR1(022) = -DELSPR/DLSPMX
      TR1(023) = DELSPL/DLSPMX
      TR1(060) = CTLPRM/CTMX
      TR1(061) = CNEPL/CNEMX
      TR1(062) = CSEPL/CSEMX
      TR1(063) = CPMPL/CPMMX
      TR1(070)=  SINTHE
      TR1(071)=  COSTHE
      TR1(072)=  SINPHI
      TR1(073)=  COSPHI
      TR1(074)=  SINPHI*COSTHE
      TR1(075)=  COSPHI*COSTHE
      TR1(120) = CYMPL/CYMMX
      TR1(121) = CPL/CPMX
      TR1(122) = CTRPRM/CTMX
      TR1(123) = CNEPR/CNEMX
      TR1(160) = CSEPR/CSEMX
      TR1(161) =   CPMPR/CPMMX
      TR1(162) = CYMPR/CYMMX
      TR1(163) = CPR/CPMX

      TR1(010) = CPR/CPMX
      TR1(011) = CPL/CPMX
      TR1(012) = OMEGA/OMEGMX
      TR1(013) = SKTRIM(C1)*UDOT/UDOTMX
      TR1(014) = ALARWN/FIXX/PDOTMX
      TR1(015) = AMARWN/FIYY/QDOTMX
      TR1(016) = ZARWN/SM/ZARMX
      TR1(110) =-DELTH/DLTHMX
      TR1(111) = -DSHP/SHPMX
      TR1(112) =-SHPIC/SHPMX
      TR1(113) =-AINRF/AINMX
      TR1(114) =-TPS/TPSMX
      TR1(115) = SHPPD/SHPMX/GRUTON
      TR1(116) =-DSHPP/SHPMX
      TR1(117) =-DVTAUE*SQTHTC/DEL/GRUTON
      TR1(130) = SQTHTC/DEL*TAUEMX/GRUTON
      TR1(131) = THATLM/THATMX
      TR1(132) = SQTHET*DLTHP/DLTHMX
      TR1(133) =-DLTHP/DLTHMX
      TR1(134) = DTHDOM*DLOMG/THDMMX/10.
      TR1(135) = DLOMG/OMEGMX
      TR1(136) =-THGOVL/1.
```

Figure G.9. (Continued)

```
      TR1(150) =-CMDOR/CRMCMX
      TR1(151) =-CYM /CYMMX
      TR1(152) =-CRMR/CRMMX
      TR1(153) = AINREF/AINMX
      TR1(154)=  ACCZPA/AZPAMX
      TR1(155)=  ACCYPA/AYPAMX
      TR1(156)=  -XAERO/SM/UDOTMX
      TR1(157)=  -YAERO/SM/VDOTMX
      TR1(170) =-AINR/AINMX
      TR1(171) =-AINL/AINMX
      TR1(172) =-THGOVR/1.
      TR1(210) = AINDDR/AIDDMX
      TR1(211) = AINDDL/AIDDMX
      TR1(212) = PDOT/PDOTMX
      TR1(213) = QDOT/QDOTMX
      TR1(214) = RDOT/RDOTMX
      TR1(215)= -ZAERO/SM/WDOTMX
      TR1(216) = ZDOT/VWMX
      TR1(217) = 0.0
      TR1(230) = CRMDR/CRMMX
      TR1(231) = CRMDL/CRMMX
      TR1(232) = CYMDR/CYMMX
      TR1(233) = CYMDL/CYMMX
      TR1(234) =-SKTRIM(7)*(HDOT-HOTRIM)/VZMX
      TR1(235) = QTC/QMX
      TR1(250) = Q/QMX
      TR1(251) = DELR/DELRMX
      TR1(252) =   DELS/DELSMX
      TR1(253) =-DELSS/DELSMX
      TR1(254) = DELR/DELRMX
      TR1(255) =-DELRS/DELRMX
      TR1(256) = -TH75R/TH75MX
      TR1(257) = -TH75L/TH75MX
      TR1(270) =   DELAR/DELAMX
      TR1(271) =-DELAL/DELAMX
      TR1(272) = -DELSPR/DELSPMX
      TR1(273) = DELSPL/DELSPMX
      TR1(274) = PDOT/PDOTMX
      TR1(275) = RDOT/RDOTMX
      TR1(276) = QDOT/QDOTMX
      TR1(350) =-DELST/DELSMX
      TR1(351) = GDRLDY*DELST/DEL  MX
      TR1(352) =-DELRT/DELRMX
      TR1(353) =-VCALT / MX
      TR1(354) =-DELFT/DELFMX
      TR1(355) = GDSCOL*DELST/GSCEMX/DELSMX
      TR1(356) = GDRCYL*DELRT/GRCYMX/DELRMX
      TR1(357) =-GDSCYL*DELST/GSCYMX/DELSMX
      TR1(370) = DELST/DELSMX
```

Figure G.9. (Continued)

```
1158          TR1(371) =-GAIC/GICMX
1159          TR1(372) =-GBIC/GICMX
1160          TR1(373) = GDFLP/DLFLMX
1161          TR1(374) = GDE/DFLEMX*EGTOR)
1162          TR1(375) = GDSP/DLSPMX
      C
1163          TR1(030) =    V  / VWMX
1164          TR1(031) =   BETAF/ ABFSMX
1165          TR1(032) =  -VCALIB / UMX
1166          TR1(033) =  - HDOT / VWMX
1167          TR1(034) =  - PHI / PI
1168          TR1(035) =    PSI / PSIMX
1169          TR1(036) =    THE / PI
1170          TR1(037) =    H / ZMX
1171          TR1(050) =    AVEALW / ALNGMX
1172          TR1(051) =    SOF / SQFMX
1173          TR1(052) =    XDOT / XDOTMX
1174          TR1(053) =    XIC  / XMX
1175          TR1(054) =    YDOT / YDOTMX
1176          TR1(055) =    YIC  / YMX
1177          TR1(057)=  PSIDOT/PSDMX
1178          TR1(310) =   THE / THEMX
1179          TR1(311) =   PHI / PI
1180          TR1(312) =   PSI / PSIMX
1181          TR1(313) =   XIC / XMX
1182          TR1(314) =   YIC / YMX
1183          TR1(315) =   H   / ZMX
1184          TR1(316) =   XDOT / XDOTMX
1185          TR1(317) =  AVAIL
      C     BOARD 3E (CONSOLE 2) AMPLIFIERS SCALE FACTOR CALCULATION; P DENOTES POSITIVE OUTPUT
1186          RETURN                                                N DENOTES NEGATIVE OUTPUT
1187          ENTRY STCON2
1188          CALL ANDAIN(PROJ,BDNOS(2),LFTP(2),IFC(2),NCON(2),A2P, , ,A2N, ,1, ,
             *        SJ2,4,5,TR2,6,5)
      C
1189          A2P(380) = TPS/TPSMX
1190          A2N(380) =-DLTHP/DLTHMX
1191          A2P(001) =   -DSHP/SHPMX
1192          A2N(001) = -SHP2IC/SHPMX
1193          A2P(002) = DELTH/DLTHMX
1194          A2P(003) =-DSHPP/SHPMX
1195          A2N(003) = -GLSAP/GLSMX
1196          A2P(010) = SHP3IC/SHPMX
1197          A2P(011) = OMEGA/OMEGMX
1198          A2P(012) =-SQTHTC/DEL*CVTAUE/GHJTON
1199          A2P(013) =-DSHPPP/SHPMX
1200          A2P(020) = THOM/THOMMX
1201          A2P(021) = (THOM+TMS1+GDTHRT*DLTHP*GDLTH)/THOMMX
1202          A2P(022) = OAVL*OMEGMX/SHPMX
```

Figure G.9. (Continued)

```
      A2P( 23) = THUMD/TOMDMX
      A2P( 30) = 0.
      A2P( 31) = -GOTHETT*(LTHPAN)ELTH/THOMX
      A2N( 31) =-SKTRIM(12)*RDOT/OMEGMX
      A2P( 40) = 1.0
      A2P(041) = 1.0
      A2P(042)=  QROD/CPMX/OMEGAX**2  *10.*2.
      A2P( 43) = OMDOT/OMEGMX
      A2N( 43) = OMGCOM/OMEGMX
      A2P(050)=  -THTMS/TTMSMX
      A2N(050) = ALARDI/PDOTMX/10.
      A2P(051) = ALARWN/FIXX/PDOTMX
      A2P(052) = CPRQ/CPMX      *2.0                                     STK2391.
      A2P(053) = THATLM/THATMX
      A2N(060) = AMARDI/QDOTMX/10.
      A2P(061) = AMARWN/FIYY/QDOTMX
      A2P(062) = OLOMG/OMEGMX
      A2N(062) =-TMS2/THOMMX
      A2P(063) = TMS3/THOMMX
      A2N(063) = TMS1P/THOMAX
      A2P(070) =   SCTHT / FIT TIJFMX/CPMTHN
      A2N(070) = ZARDIC/ZARMX/10.
      A2P( 71) = ZARWN/FM/ZAFMX
      A2P(200) = AINDBI/AINDMX
      A2P(201) = AINR   /AINMX
      A2P(202) = AINDD  /AIDDMX
      A2P(203) = AINDPL/AIDDMX
      A2P(210) = AINDI /AINDMX
      A2P(211) = AINL   /AINMX
      A2P(212) = PDOT/PDOTMX
      A2P(213) = QDOT/QDOTMX
      A2P(220) = AINRF  /AINMX
      A2P(221) = OMEGA**2/OMEGMX**2
      A2P(230) = SHPIC /SHPMX
      A2N(230) = CPMPR /CPMMX
      A2N(231) = CPMPL/ CPMMX
      A2P(240) = (HDOT-HDTRIM)/VWMX
      A2N(240) = CYMPR/CYMMX
      A2P(241) =-SKTRIM( 7)*(HDOT-HDTRIM)/VWMX
      A2N(241) = CYMPL/CYMMX
      A2P(242) = PCTOL/PCTQMX
      A2N(242) = AMACPR/AMACMX
      A2P(243) = PCTQR /PCTQMX
      A2N(243) = AMACLP/AMACMX
      A2P(250) = 0.0
      A2P(251) =    PCTQP  /  PCTQMX
      A2P(252) = RDOT/RDOTMX
      A2N(253) = AIPFD/AIPFMX
      A2P(260) = DCYIC/DCYLMX
```

Figure G.9. (Continued)

```
      A2N(262) = DCYPD/DCYLMX/GBUTON
      A2P(263) = THTMSP/TTMSMX
      A2N(263) = THTMSL/TTMSMX
      A2P(300) = SHPPRR/SHPMX
      A2P(301) = SHP1/SHPMX
      A2P(302) = ALARP/FIXX/PDOTMX
      A2P(303) = AMARP/FIYY/QDOTMX
      A2P(310) =-SHP4/SHPMX
      A2N(310) = SHPD/SHPMX/GBUTON
      A2P(311) = SHPIC/SHPMX
      A2P(312) = -CMDQR/CPMQMX
      A2P(320) = AENG
      A2P(321) = DTHDOM/1.
      A2P(322) = ZARP/SM/ZARMX
      A2P(323)=  AINLDI**2/AINDMX**2
      A2P(330) = DLOMG/OMEGMX
      A2P(331)=  -AINRDI**2/AINDMX**2
      A2P(340) = DTHDOM*DLOMG/OMEGMX
      A2P(342)=  (AINL-ALAMDA)/PI
      A2P(343)=  (AINR-ALAMDA)/PI
      A2P(352) = -GLSB/GLSMX
      A2N(352) = GLSAL/GLSMX
      A2P(353)=  (XCG-SLPA)/XCGMX
      A2P(360)=  (AINDDL*SILAML+AINDDR*SILAMR)/AINDMX
      A2N(360)=  (AINLDI**2*CILAML+AINRDI**2*CILAMR)/AINDMX**2
      A2N(361)=  ACCXPA/AXPAMX
      A2P(362)=  (AINDDL*CILAML+AINDDR*CILAMR)/AINDMX
      A2N(362)=  (-AINLDI**2*SILAML-AINRDI**2*SILAMR)/AINDMX**2
      A2P(363)=  XDDCG/XDDMX
      A2N(363)=  ZDDCG/ZDDMX
      A2P(370)=  RDOT*(XCG-SLPA)/(RDOTMX*XCGMX)
      A2N(370)=  ACCYPA/AYPAMX
      A2P(371)=  -QDOT*(XCG-SLPA)/(QDOTMX*XCGMX)
      A2N(371)=  ACCZPA/AZPAMX
C  BOARD 3E (CONSOLE 2) VALUES AT SUMMING JUNCTIONS OF AMPLIFIERS
      SJ2(000) = DLTHPD/DLTHMX/GBUTON
      SJ2(001) = SHPPD/SHPMX/GBUTON
      SJ2(010) = SHP30/SHPMX/GBUTON
      SJ2(011) = OMDOT/OMEGMX/GBUTON
      SJ2(020) = THOMD/THOMMX/GBUTON
      SJ2(021) = TMSID/THOMMX/GBUTON
      SJ2(030) = SKTRIM(13)*OMDOT/OMEGMX
      SJ2(031) = 0.
      SJ2(040) = 0.0
      SJ2(041) = 0.
      SJ2(050) =-ALARDD/PDOTMX/10./GBUTON/10.
      SJ2(051) = ALARDI/PDOTMX/GBUTON
      SJ2(060) =-AMARDD/QDOTMX/10./GBUTON/10.
      SJ2(061) = AMARDI/QDOTMX/GBUTON
```

Figure G.9. (Continued)

```
1300      SJ2(070) =-ZARDD/ZARMX/10./GBUTON/10.
1301      SJ2( 71) = ZARDIC/ZARMX/GBUTON
1302      SJ2(200) = AINDDD/AINDMX/GBUTON
1303      SJ2(201) = AINRDI/AINMX/GBUTON
1304      SJ2(210) = AINDDL/AINDMX/GBUTON
1305      SJ2(211) = AINLDI/AINMX/GBUTON
1306      SJ2(220) = AINFD/AINMX /GBUTON
1307      SJ2(230) = 0.
1308      SJ2(231) = 0.0
1309      SJ2(240) = 0.0
1310      SJ2(241) = 0.0
1311      SJ2(250) = -(ZDOT+HPTRIM)*SKTRIM(8)/VVMX
1312      SJ2(260) = DCYRD/DCYLMX/GBUTON
1313      SJ2(311) = SHPD/SHPMX/GBUTON
```

BOARD 3E (CONSOLE 2) VALUES OF TRUNK LINES AND ADC'S (FIRST 32 TR'S ARE ADC'S)

```
1314      TR2(220) = AINRDI/AINMX
1315      TR2(221) = AINR  /AINMX
1316      TR2(222) = AINLDI/AINDMX
1317      TR2(223) = AINL  /AINMX
1318      TR2(260) = AICLIC/AICMX
1319      TR2(261) = BICLIC/BICMX
1320      TR2(262) = AICRIC/AICMX
1321      TR2(263) = BICRIC/BICMX
1322      TR2(320) =-DELRUD/DLRDMX
1323      TR2(321) = AINRF/AINMX
1324      TR2(021) = 0.
1325      TR2(022) = 0.
1326      TR2( 23) = 0.
1327      TR2(060) = 0.
1328      TR2(061) = 0.
1329      TR2(062) = 0.
1330      TR2(063) = OMDOT/OMEGMX
1331      TR2(120) = OMEGA/OMEGMX
1332      TR2(121) = TPS/TPSMX
1333      TR2(122) = AMACRP/AMACMX
1334      TR2(123) = AMACLP/AMACMX
1335      TR2(160) = 1.0
1336      TR2(161) = 1.
1337      TR2(162) =-DELELV/DLELMX
1338      TR2(163) = DLELP/DLELMX

1339      TR2(010) = CPF/CPMX
1340      TR2(011) = CPL/CPMX
1341      TR2(012) = OMEGA/OMEGMX
1342      TR2(013) = SKTRIM(11)*UDOT/UDOTMX
1343      TR2(014) = ALARWN/FLXX/PDOTMX
1344      TR2(015) = AMARWN/FIYY/QDOTMX
1345      TR2(016) = ZARWN/SM/ZARMX
1346      TR2(030) = 0.
```

Figure G.9. (Continued)

```
      TR2(031) = 0.
      TR2(032) = 0.
      TR2(110) =-DELTH/DLTHMX
      TR2(111) = -DSHP/SHPMX
      TR2(112) =-SHPIC/SHPMX
      TR2(113) =-AINRF/AINMX
      TR2(114) =-TPS/TPSMX
      TR2(115) = SHPPD/SHPMX/GBUTON
      TR2(116) =-DSHPP/SHPMX
      TR2(117) =-DVTAUE*SQTHTC/DEL/GBUTON
      TR2(130) = SQTHTC/DEL*TAUEMX/GBUTON
      TR2(131) = THATLM/THATMX
      TR2(132) = GDIHRT*DLTHP/DLTHMX
      TR2(133) =-DLTHP/DLTHMX
      TR2(134) = DTHDOM*DLOMG/THOMMX/10.
      TR2(135) = DLOMG/OMEGMX
      TR2(136) =-THGOVL/1.
      TR2(150) =-CMDOR/CPMSMX
      TR2(151) =-CYMO/CYMMX
      TR2(152) =-CPMO/CPMMX
      TR2(153) = AINEFF/AINMX
      TR2(154)=  ACCZPA/AZPAMX
      TR2(155)=  ACCYPA/AYPAMX
      TR2(156)=  -XAERO/SM/UDOTMX
      TR2(157)=  -YAERO/SM/VDOTMX
      TR2(170) =-AINR/AINMX
      TR2(171) =-AINL/AINMX
      TR2(172) =-THGOVR/1.
      TR2(210) = AINDDR/AIDDMX
      TR2(211) = AINDDL/AIDDMX
      TR2(212) = PDOT/PDDTMX
      TR2(213) = QDOT/QDDTMX
      TR2(214) = RDOT/RDDTMX
      TR2(215)= -ZAERO/SM/WDOTMX
      TR2(216) = ZDOT/VWMX
      TR2(217) = 0.0
      TR2(230) = CPMPR/CPMMX
      TR2(231) = CPMPL/CPMMX
      TR2(232) = CYMPR/CYMMX
      TR2(233) = CYMPL/CYMMX
      TR2(234) =-SKTRIM(7)*(HDOT-HDTRIM)/VWMX
      TR2(235) = UIC/UMX
      TR2(310) = THIMSR/TTMSMX
      TR2(311) =-GLSB/GLSMX
      TR2(312) = GLSAL/GLSMX
      TR2(313) =-DCYL/DCYLMX
      TR2(314) = -GLSAR/GLSMX
      TR2(315) =-DELRUD/DLRDMX
      TR2(316) =-DELELV/DELEMX
```

Figure G.9. (Continued)

FORTRAN IV MODEL 44 PS VERSION 3, LEVEL 3 DATE 73092

```
1396        TR2(317) = DELELP/DLELMX
1397        TR2(330) = BICRIC/BICRMX
1398        TR2(331) = BICLIC/BICLMX
1399        TR2(332) = AICRIC/AICRMX
1400        TR2(333) = AICLIC/AICLMX
1401        TR2(334) = DELTH/DLTHMX
1402        TR2(337) = THTYSL/TTYSMX
      C
1403        TR2(250)=  PCTOL/PCTLMX
1404        TR2(251)=  PCTQR/PCTQMX
1405        TR2(252) =  OMEGA/ OMEGMX
1406        TR2(253) =  AINPF / AINMX
1407        TR2(254)=  COMIDT/AIDRMX
1408        TR2(255) =  COMDTH/ DLTHMX
1409        TR2(256)= -SKTRIM(12)*COMDOT/OMEGMX
1410        TR2(257) =  AVAIL
1411        TR2(370)=  ACCXPA/AXPAMX
1412        TR2(371)=  ACCYPA/AYPAMX
1413        TR2(372)=  ACCZPA/AZPAMX
```

C **BOARD 5F (CONSOLE 3); AMPLIFIER SCALE FACTOR CALCULATION; P DENOTES POSITIVE OUTPUT**
N DENOTES NEGATIVE OUTPUT

```
1414        RETURN
1415        ENTRY STCON3
1416        CALL ANDAIN(PROJ,PONES(3),LETH(3),IHC(3),NCON(3),A3P,1,5,A3N,1,5,
     *                SJ3,4,5,T23,4,5)
      C
1417        A3N(300) = BICRDI/BICRMX/1 .
1418        A3P(301) = BICRIC/BICRMX
1419        A3N(310) = BICLDI/BICLMX/1 .
1420        A3P(311) = BICLIC/BICLMX
1421        A3N(320) = AICRDI/AICRMX/10.
1422        A3P(321) = AICRIC/AICRMX
1423        A3N(330) = AICLDI/AICLMX/1 .
1424        A3P(331) = AICLIC/AICLMX
1425        A3N(340) = 0.
1426        A3P(341) = 0.
1427        A3N(350) =  .
1428        A3P(351) = 0.
1429        A3N(360) = GLSAIR/GLSAMX
1430        A3N(361) = 0.
1431        A3N(370) = 0.
1432        A3N(371) = 0.
1433        A3P(200) = 0.
1434        A3N(200) = 0.
1435        A3P(201) =  .
1436        A3P(202) = DELST/DELSMX
1437        A3P(203) = -DELDT/DELDMX
1438        A3N(203) = -DELELV/DLELMX
1439        A3P(210) = 0.
1440        A3P(211) = 0.
```

Figure G.9. (Continued)

```
1441        A3P(212) = -DELAR1/DELAMX
1442        A3N(212) =  DELAR2/DELAMX
1443        A3P(213) =  DELAL1/DELAMX
1444        A3N(213) = -DELAL2/DELAMX
1445        A3P(222) =  DCYL/DCYLMX
1446        A3P(223) =  DCOL/DCOLMX
1447        A3P(242) = DELR/DELRMX
1448        A3P(243) = DELS/DELSMX
1449        A3P(251) = TH75R/TH75MX
1450        A3P(252) = -DELRUD/DLRDMX
1451        A3N(252) = -DELSPR/DLSPMX
1452        A3P(253) = -DELRT/DELRMX
1453        A3N(253) =  DELSPL/DLSPMX
1454        A3P(261) = TH75L/TH75MX
1455        A3P(262) = DELB/DELBMX
1456        A3P(263) = DELFLP/DLFLMX
1457        A3N(300) = GLSBIC/GLSMX
1458        A3N(301) =-GLSAIL/GLSMX
1459        A3P(302) = DLON/DLONMX
1460        A3P(303) = DLFLPP/DLFLMX
1461        A3N(310) = BICRPD/BICMX/10.
1462        A3P(311) = BICRP /BICMX
1463        A3P(312) = DELAR/DELAMX
1464        A3N(312) =-DELAL/DELAMX
1465        A3P(313) = -VCALIB/UMX
1466        A3P(320) = GBICP/GICMX
1467        A3P(321) = GAICP/GICMX
1468        A3N(322) = GBICD/GICMX/GBUTON
1469        A3N(323) = GAICD/GICMX/GBUTON
1470        A3N(330) = BICLPD/BICMX/10.
1471        A3P(331) = BICLP /BICMX
1472        A3P(340) =-DELBS/DLONMX
1473        A3N(340) =-PSAS1/DLONMX
1474        A3N(341) = PSAS7/DLONMX
1475        A3N(341) =-PSAS2/DLONMX
1476        A3P(342) = DLSPLM/DLSPMX
1477        A3N(350) = AICRPD/AICMX/10.
1478        A3P(351) = AICRP /AICMX
1479        A3P(352) = PSAS5/DLONMX/GBUTON/10.
1480        A3P(353) = PSAS6/DLONMX/GBUTON
1481        A3P(360) = PSAS4/DLONMX
1482        A3N(361) =-PSAS3/DLONMX
1483        A3P(362) = GLONPH/1.
1484        A3N(370) = AICLPD/AICMX/10.
1485        A3P(371) = AICLP /AICMX
      C BOARD 5F (CONSOLE 3) VALUES AT SUMMING JUNCTIONS OF AMPLIFIERS
1486        SJ3(330) =-BICRDD/BICMX/10./GBUTON/10.
1487        SJ3(301) = BICRD1/BICMX/GBUTON
1488        SJ3(310) =-BICLDD/BICMX/10./GBUTON/10.
```

Figure G.9. (Continued)

```
1489     SJ3(311) = BICLDI/BICMX/GRUTON
1490     SJ3(320) =-AICRDD/AICMX/10./GRUTON/10.
1491     SJ3(321) = AICRDI/AICMX/GRUTON
1492     SJ3(330) =-AICLDD/AICMX/10./GRUTON/10.
1493     SJ3(331) = AICLDI/AICMX/GRUTON
1494     SJ3(360) =-GLSARD/GLSMX/GRUTON
1495     SJ3(361) = ROOT*STRIM(29)/ROOTMX
1496     SJ3(370) = ROOT*STRIM(10)/ROOTMX
1497     SJ3(371) =ROOT*STRIM(11)/ROOTMX
1498     SJ3(300) = -GLSBRD/GLSMX/GRUTON
1499     SJ3(301) =  GLSALD/GLSMX/GRUTON
1500     SJ3(310) =-BIRPDD/BICMX/10./GRUTON/10.
1501     SJ3(311) = BICRPD/BICMX/GRUTON
1502     SJ3(320) = GBICD/GICMX/GRUTON
1503     SJ3(321) = GAICD/GICMX/GRUTON
1504     SJ3(330) =-BILPDD/BICMX/10./GRUTON/10.
1505     SJ3(331) = BICLPD/BICMX/GRUTON
1506     SJ3(340) = PSAS1D/DLONMX/GRUTON
1507     SJ3(341) = PSAS2D/DLONMX/GRUTON/10.
1508     SJ3(350) =-AIRPDD/AICMX/10./GRUTON/10.
1509     SJ3(351) = AICRPD/AICMX/GRUTON
1510     SJ3(360) = PSAS4D/DLONMX/GRUTON
1511     SJ3(361) = PSAS3D/DLONMX/GRUTON
1512     SJ3(370) =-AILPDD/AICMX/10./GRUTON/10.
1513     SJ3(371) = AICLPD/AICMX/GRUTON
```

BOARD 5F (CONSOLE 3) VALUES OF TRUNK LINES AND ADC'S (FIRST 32 TR'S ARE ADC'S)

```
1514     TR3(220) =-DELRT/DELRMX
1515     TR3(221) = DELST/DELSMX
1516     TR3(222) =-DELRT/DELRMX
1517     TR3(223) = DELTH/DELTHMX
1518     TR3(260) =-DELRS/DELRMX
1519     TR3(261) =-DELSS/DELSMX
1520     TR3(262) =-DELAS/DELAMX
1521     TR3(263) = TH75R/TH75MX
1522     TR3(320) = TH75L/TH75MX
       C
1523     TR3(330) = 0.
1524     TR3(331) = 0.
1525     TR3(332) = 0.
1526     TR3(250) = Q/QMX
1527     TR3(251) = DELR/DELRMX
1528     TR3(252) =  DELS/DELSMX
1529     TR3(253) =-DELSS/DELSMX
1530     TR3(254) = DELR/DELRMX
1531     TR3(255) =-DELRS/DELRMX
1532     TR3(256) = -TH75R/TH75MX
1533     TR3(257) = -TH75L/TH75MX
1534     TR3(270) =  DELAR/DELAMX
1535     TR3(271) =-DELAL/DELAMX
```

Figure G.9. (Continued)

```
      TR3(272) = -DELSPR/DLSPMX
      TR3(273) = DELSPL/DLSPMX
      TR3(274) = PDOT/PDOTMX
      TR3(275) = RDOT/RDOTMX
      TR3(276) = QDOT/QDOTMX
      TR3(310) = THTMSR/TTMSMX
      TR3(311) =-GLSB/GLSMX
      TR3(312) = GLSAL/GLSMX
      TR3(313) =-DCYL/DCYLMX
      TR3(314) = -GLSAR/GLSMX
      TR3(315) =-DELRUD/DLRDMX
      TR3(316) =-DELFLV/DELEMX
      TR3(317) = DELFLP/DLFLMX
      TR3(330) = BICRIC/BICMX
      TR3(331) = BICLIC/BICMX
      TR3(332) = AICRIC/AICMX
      TR3(333) = AICLIC/AICMX
      TR3(334) = DFLTH/DLTHMX
      TR3(337) = THTMSL/TTMSMX
      TR3(350) =-DELST/DELSMX
      TR3(351) = GDBLCN*DELBT/DELBMX
      TR3(352) =-DFLBT/DELBMX
      TR3(353) =-VCALIB/UMX
      TR3(354) =-DELRT/DELRMX
      TR3(355) = GDSCOL*DELST/GSCOMX/DELSMX
      TR3(356) = GDRCYL*DELRT/GRCYMX/DELRMX
      TR3(357) =-GDSCYL*DELST/GSCYMX/DELSMX
      TR3(370) = DELST/DELSMX
      TR3(371) =-GAIC/GICMX
      TR3(372) =-GBIC/GICMX
      TR3(373) = GDFLP/DLFLMX
      TR3(374) = GDE/DFLEMX*DGTORD
      TR3(375) = GDSP/DLSPMX
C
      TR3(230)=  DELFLP/DLFLMX
      TR3(231) =   DELB / DELBMX
      TR3(232) =   DELS / DELSMX
      TR3(233) =   DELR / DELRMX
      TR3(234) =   COMDLB / DELBMX
      TR3(235) =   COMDLS / DELSMX
      TR3(236) =   COMDLR / DELRMX
      TR3(237) =   AVAIL
C BOARD 1B (CONSOLE 4) AMPLIFIER SCALE FACTOR CALCULATION; P DENOTES POSITIVE OUTPUT
      RETURN                                      N DENOTES NEGATIVE OUTPUT
      ENTRY STCON4
      BDNOS(4) = BD4
      LETR(4) = LT4
      CALL ANDAIN(PROJ,'1B','B',IEC(1),3,A4P,?,5,A4N,1,5,?J4,4,5,TR4,5,
     *5)
```

Figure G.9. (Continued)

```
C
      A4P(000)=  PCTOL/TQSIMX
      A4P(001)=  PCTOR/TQSIMX
      A4P(002)=  PCM2/RPMSMX
      A4P(003)=  YDOT/YDTSMX
      A4P(010)=  -HDOT/HDTSMX
      A4P(011)=  ACCXPA/AXPAMX
      A4P(012)=  XDOT/XDTSMX
      A4P(013)=  -VCALIB/SKEPS/USIMX
      A4P(021)=  V/SKEPS/VSIMX
      A4P(022)=  THE*RDTODG/THESMX
      A4P(023)=  -PHI*RDTODG/PHISMX
      A4P(030)=  PSI*RDTODG/PSISMX
      A4P(031)=  PSDSIM/PSDTSX
      A4P(040)=  AINRF*RDTODG/AINSMX
      A4P(041)=  AVEALW*RDTODG/ALWSMX
      A4P(042)=  BETAF*RDTODG/BTSIMX
      A4P(043)=  ACCYPA/AYPAMX
      A4P(050)=  ACCZPA/AZPAMX
      A4P(051)=  DELELP/DEPSMX
      A4P(052)=  H/HSIMX
      A4P(053)=  0.
      A4P(060)=  0.
      A4P(061)=  1.0000
      A4P(062)=  H/ZMX
      A4P(063)=  0.
      A4P(070)=  0.
      A4P(071)=  1.0000
      A4P(200)  =  XIC    / XVISMX
      A4P(201)  =  YIC    / YVISMX
      A4P(202)  =   SINTHE
      A4P(203)  =   COSTHE
      A4P(210)  =   1.0000
      A4P(211)  =   VISIC  /   XVISMX
      A4P(212)  =   SINPHI
      A4P(213)  =   COSPHI
      A4P(220)  =   PSI  / PI
      A4P(221)  =   SA11
      A4P(222)  =   SINPSI
      A4P(223)  =   COSPSI
      A4P(230)  =   SA12
      A4P(231)  =   SA13
      A4P(240)  =   SA21
      A4P(241)  =   SA22
      A4P(242)  =   SINTHE  *SINPHI
      A4P(243)  =   SINTHE  *COSPHI
      A4P(250)  =   SA23
      A4P(251)  =   SA31
      A4P(252)  =   YACVIS / YVISMX
```

Figure G.9. (Continued)

```
1630          A4N(252) =   ZACVIS / ZVISMX
1631          A4P(253) =   ZBODY / ZVISMX
1632          A4P(260) =   SA32
1633          A4P(261) =   SA33
1634          A4P(262) =   XACVIS / XVISMX
1635          A4P(263) =   FREQMT / 100.
1636          A4P(300)= (XHOPI(Z-H)/XVISMX
1637          A4N(300)=  (RIASMT-H*GZMTSI)/ZVISMX
1638          A4P(302) =   XBODY / XVISMX
1639          A4P(303) =   YBODY / YVISMX
1640          A4P(310)=  XSCOPE/SCOPMX
1641          A4P(311)=  YSCOPE/SCOPMX
1642          A4P(312)= -XSCOPE/SCOPMX-YIC*COSPHI/XVISMX+H*SINPHI/XVISMX
1643          A4P(313)= YSCOPE/SCOPMX+H*COSPHI/YVISMX+YIC*SINPHI/YVISMX
1644          A4P(320)=  0.0000
1645          A4P(321)=  0.0000
1646          A4P(323)=  -DBBKDP/DBBDMX
1647          A4P(330)=  0.0000
1648          A4P(331)=  0.0000
1649          A4P(341)=    FEDB   / FEBMX
1650          A4P(342)=  -BRAKE/BRKSMX
1651          A4N(342)=   BRAKE/BRKMX
1652          A4P(343)=   THBKDR/THBDMX
1653          A4P(350)=    FEDS   / FESMX
1654          A4P(351)  = 0.0
1655          A4P(352)=  -DSBKDR/DSBDMX
1656          A4P(353)=  -DFBKDR/DRBDMX
1657          A4P(360)=  -COMDLB/DBPSMX
1658          A4N(360)=   COMDLB/DELBMX
1659          A4P(361)=     -COMDLS/DSPSMX
1660          A4N(361)=  COMDLS/DELSMX
1661          A4P(362)=  -COMIDT/AIDSMX
1662          A4N(362)=  COMIDT/AINRMX
1663          A4P(363)=  FEDR/FERMX
1664          A4P(370)= -COMDLR/DRPSMX
1665          A4N(370)=  COMDLR/DELRMX
1666          A4P(371)=  -COMDTH/DTPSMX
1667          A4N(371)=   COMDTH/DLTHMX
        C
        C   BOARD 1B (CONSOLE 4) VALUES OF TRUNK LINES (NO ADC'S ON THIS BOARD)
1668          TR4(010)=  PCTQL / TQSIMX
1669          TR4(011)=  -TR4(010)
1670          TR4(012)=  PCTQR/TQSIMX
1671          TR4(013)=  -TR4(012)
1672          TR4(014)=  PCN2/RPMSMX
1673          TR4(015)=  -TR4(014)
1674          TR4(016)=  YDOT/YDTSMX
1675          TR4(017)=  -TR4(016)
1676          TR4(030)  =   V / VWMX
```

Figure G.9. (Continued)

```
      TR4(031) =  BETAF / ABFSMX
      TR4(032) =  -VCALIB / UMX
      TR4(033) =  -HDOT / VWMX
      TR4(034) =  -PHI  / PI
      TR4(035) =  PSI  / PSIMX
      TR4(036) =  THE  / PI
      TR4(037) =  H / ZMX
      TR4(050) =  AVEALW /ALWGMX
      TR4(051) =  SQF  / SQFMX
      TR4(052) =  XDOT / XDOTMX
      TR4(053) =  XIC  / XMX
      TR4(054) =  YDOT / YDOTMX
      TR4(055) =  YIC  / YMX
      TR4(057)= PSIDOT/PSDMX
      TR4(070)= SINTHE
      TR4(071)= COSTHE
      TR4(072)= SINPHI
      TR4(073)= COSPHI
      TR4(074)= SINPHI*COSTHE
      TR4(075)= COSPHI*COSTHE
      TR4(110)= VISHOR
      TR4(111)= -TR4(110)
      TR4(112)= VISVER
      TR4(113)= -TR4(112)
      TR4(130)= VCALIB/SKFPS/USIMX
      TR4(131)= -TR4(130)
      TR4(132)= V/SKFPS/VSIMX
      TR4(133)= -TR4(132)
      TR4(134)= THE*RDTODG/THESMX
      TR4(135)= -TR4(134)
      TR4(136)= PHI*RDTODG/PHISMX
      TR4(137)= -TR4(136)
      TR4(150)= PSI*RDTODG/PSISMX
      TR4(151)= -TR4(150)
      TR4(152)= PSDSIM/PSDTSX
      TR4(153)= -TR4(152)
      TR4(154)= AINRF*RDTODG/AINSMX
      TR4(155)= -TR4(154)
      TR4(156)= AVEALW*RDTODG/ALWSMX
      TR4(157)= -TR4(156)
      TR4(170)= BETAF*RDTODG/BTSIMX
      TR4(171)= -TR4(170)
      TR4(172)= ACCYPA/AYPAMX
      TR4(173)= -TR4(172)
      TR4(174)= ACCZPA/AZPAMX
      TR4(175)= -TR4(174)
      TR4(176)= DELFLP/DFPSMX
      TR4(177)= -TR4(176)
      TR4(210)= HDOT/HDTSMX
```

Figure G.9. (Continued)

```
      TR4(211)= -TR4(210)
      TR4(212)= XDOT/XDTSMX
      TR4(213)= -TR4(212)
      TR4(214)= ACCXPA/AYPAMX
      TR4(215)= -TR4(214)
      TR4(230)= DELFLP/DLFLMX
      TR4(231) =   DELB / DELBMX
      TR4(232) =   DELS / DELSMX
      TR4(233) =   DELR / DELRMX
      TR4(234) =   COMDLB / DELBMX
      TR4(235) =   COMDLS / DELSMX
      TR4(236) =  COMDLR / DELRMX
      TR4(237) =  AVAIL
      TR4(250)= PCTOL/PCTQMX
      TR4(251)= PCTQR/PCTQMX
      TR4(252) =   OMEGA / CMEGMX
      TR4(253)= AINRF/AINMX
      TR4(254)= COMIDT/AINRMX
      TR4(255) =   COMDTH / DLTHMX
      TR4(256)=-SKTRIM(12)*OMDOT/OMEGMX
      TR4(257) =   AVAIL
      TR4(270)= ACCXPA/AXPAMX
      TR4(271)= ACCYPA/AYPAMX
      TR4(272)= ACCZPA/AZPAMX
      TR4(310)= -COMIDT/AIDSMX
      TR4(311)= -TR4(310)
      TR4(312)= -BRAKE/BRKSMX
      TR4(313)= -TR4(312)
      TR4(330)= DBRKDR/DBBDMX
      TR4(331)= -TR4(330)
      TR4(332)= DRBKDR/DRBDMX
      TR4(333)= -TR4(332)
      TR4(334)= DSBKDR/DSBDMX
      TR4(335)= -TR4(334)
      TR4(336)= THBKDR/THBDMX
      TR4(337)= -TR4(336)
      TR4(350)= FFDB/FFBMX
      TR4(351)= -TR4(350)
      TR4(352)= FFDS/FFSMX
      TR4(353)= -TR4(352)
      TR4(354)= FFDR/FFRMX
      TR4(355)= -TR4(354)
      TR4(356)= H/HSIMX
      TR4(357)= -TR4(356)
      TR4(370)= -COMDLB/DBPSMX
      TR4(371)= -TR4(370)
      TR4(372)= -COMDLS/DSPSMX
      TR4(373)= -TR4(372)
      TR4(374)= -COMDLR/DRPSMX
```

Figure G.9. (Continued)

```
1775          TR4(375)=  -TR4(374)
1776          TR4(376)=  -COMDTH/DTRSMX
1777          TR4(377)=  -TR4(376)
         C
1778          RETURN
1779          END
```

Figure G.9. (Continued)

equilibrium. The equations for these feedback loops are shown in Appendix E. Several trim options are available: for a given initial condition of altitude, u and v components of velocity, rotor RPM and initial rates (p,q,r) the aircraft can be trimmed with attitude for specified nacelle angle or with nacelle angle for specified attitude. In addition, the aircraft can be trimmed in backwards or sidewards flight. The trim gains used vary with the flight condition. Trim is generally attained in 5-10 seconds for any flight condition using this technique.

G.3 SIMULATION PROGRAM OUTPUT

The primary output of the mathematical model are:

- Trim sheet information
- Dynamic time histories of aircraft response

Figure G.10 shows a typical trim sheet with 180 aircraft parameters printed out and Figure G.11 contains the definitions of all the parameters. Four brush recorders with eight channels of output each are available for recording of the aircraft real time response. Figure G.12 shows a typical example of the output from one recorder. These data are extremely useful in analyzing aircraft responses and in optimizing stability augmentation and control systems.

T I L T R O T O R T R I M D A T A

DATE 03/23/73   TIME 11 HR 2 MIN 40 SEC   FLIGHT NO.=   RUN NO.=   TAPE SEQ. NO.= 0

VTOT= 250.0 KT U = 250.0 KT V = -0.0 KT W = -2.0 KT G.W.= 12320.5 LBS RPM= 385.8 H = 51.5 FT XCG= 9.2 IN ZCG= 21.9 IN

THETA	PHI	PSI	IN REF	TWIST LW	TWIST RW	ROE	TH75 L	TH75 R
-0.44000E 00	0.24500E 0[illegible]	0.0	-0.22918E-01	0.0	0.0	0.23723E-02	0.47136E 02	0.47192E 02
DELB TOT	DELS TOT	DELR TOT	THROTTLE	DELB SAS	DELS SAS	DELR SAS	A1CL	A1CR
-0.12590E 01	-0.75000E-02	0.11000E-01	0.20350E 01	0.0	-0.10000E-02	0.10000E-02	0.73893E-02	0.0
ELEVATOR	RUDDER	DEL L	DEL R	DELSPL	DELSPR	FLAP	B1CL	B1CR
0.23835E 01	0.0	0.63000E-01	0.11700E 00	0.35500E-01	-0.90000E-02	0.90000E-01	0.36629E-02	0.0
TPS	OM ENG	SHP AV	SHP RQL	SHP RQR	IXX	IYY	IZZ	D.PRES F
0.18870E 04	0.23582E 04	0.82417E 03	0.85759E 03	0.88021E 03	0.50275E 05	0.14168E 05	0.60628E 05	0.21152E 03
MU L	THRUST L	NORMAL L	SIDE L	M ROT L	N ROT L	L HUB L	M HUB L	N HUB L
0.80349E 00	0.79523E 03	0.62197E 02	-0.22239E 02	-0.13081E 03	0.29939E 03	-0.11038E 05	0.10502E 03	0.43560E 03
MU R	THRUST R	NORMAL R	SIDE R	M ROT R	N ROT R	L HUB R	M HUB R	N HUB R
0.80389E 00	0.82572E 03	0.13206E 03	-0.50044E 02	-0.35239E 03	0.66683E 03	0.11352E 05	0.34573E 03	-0.71457E 03
X FUSE	X TAIL	X WING L	X WING R	X NAC L	X NAC R	X TIP L	X TIP R	X/M
-0.32474E 03	-0.16235E 03	-0.54[illegible]87E 03	-0.54383E 03	-0.47215E 02	-0.47178E 02	0.74795E 03	0.77836E 03	-0.11876E 00
Y FUSE	Y TAIL	Y WING L	Y WING R	Y NAC L	Y NAC R	Y TIP L	Y TIP R	Y/M
0.19445E 01	0.78296E 0[illegible]	0.30284E-01	0.30555E-01	0.12310E 00	0.12332E 00	0.22726E 02	-0.49107E 02	-0.61603E-01
Z FUSE	Z TAIL	Z WING L	Z WING R	Z NAC L	Z NAC R	Z TIP L	Z TIP R	Z/M
-0.19685E 04	0.52210E 03	-0.55187E 04	-0.56095E 04	0.20065E 02	0.19979E 02	0.82729E 02	0.15328E 03	-0.32217E 02
L FUSE	L TAIL	L WING	M ACT L	L NAC L	L NAC R	L TIP L	L TIP R	L/IXX
-0.35475E 01	0.22225E 01	-0.58618E 03	-0.49072E 04	0.0	0.0	-0.11039E 05	0.11353E 05	0.16997E-01
M FUSE	M TAIL	M WING	M ACT R	M NAC L	M NAC R	M TIP L	M TIP R	M/IYY
-0.17206E 04	0.10696E 05	-0.56448E 04	-0.51483E 04	0.0	0.0	-0.30036E 03	-0.40651E 03	0.10087E-02
N FUSE	N TAIL	N WING	Z WING	N NAC LN	NAC R	N TIP L	N TIP R	N/IZZ
0.17683E 02	-0.14728E 02	0.20164E 02	-0.11128E 05	0.0	0.0	0.57371E 03	-0.90887E 03	-0.13173E-01
ALPH FUS	ALPH HT	ALPHLWSS	ALPHRWSS	AL NAC L	AL NAC R	AL ROT L	AL ROT R	H1 L
-0.44233E 00	-0.18750E 01	0.15366E 01	0.15543E 01	-0.49013E 00	-0.48805E 00	0.51441E 00	0.48941E 00	0.0
BETA FUS	ALPH VT	ALPHA LW	ALPHA RW	CY NAC L	CY NAC R	ZETA L	ZETA R	H1 R
-0.54272E-02	0.14400E-02	0.15458E 01	0.15684E 01	0.57043E-05	0.57144E-05	-0.17966E 03	-0.17965E 03	0.0
CL FUSF	CL HT	CL WNG L	CL WNG R	CL NAC L	CL NAC R	CP L	CT L	CNF L
0.46603E-01	-0.41885E-01	0.25928E 00	0.26346E 00	-0.92982E-03	-0.92587E-03	0.25800E-02	0.22860E-02	0.17879E-03
CD FUSE	CD HT	CD WNG L	CD WNG R	CD NAC L	CD NAC R	CSF L	CPM L	CYM L
0.73200E-02	0.86827E-02	0.23336E-01	0.23539E-01	0.22411E-02	0.22392E-02	-0.63930E-04	-0.22291E-04	0.66203E-04
CM FUSF	CY VT	CM WNG L	CM WNG R	CM NAC L	CM NAC R	CP R	CT R	CNF R
-0.50233E-02	0.84995E-04	-0.31167E-01	-0.31720E-01	0.0	0.0	0.26520E-02	0.23760E-02	0.38000E-03
CN FUSE	CD VT	CL(ROLL)	CN WING	CN NAC L	CN NAC R	CSF R	CPM R	CYM R
0.12411E-04	0.78915E-02	-0.41168E-03	0.14161E-04	0.0	0.0	-0.14400E-03	-0.78000E-04	0.14760E-03
EP ZERO	EP TAIL	EP PRR	EP PLR	EP ILR	EP IRL	EP WRR	EP WRL	OMDOT
0.71116E 00	0.14595E 01	0.14267E-01	0.92668E-02	0.42248E-08	0.0	0.0	0.0	-0.11160E 01

Figure G.10. Typical Model 222 Trim Sheet

TOTAL VELOCITY ~ KTS.	"U" COMPONENT OF VELOCITY ~ KTS.	"V" COMPONENT OF VELOCITY ~ KTS.	"W" COMPONENT OF VELOCITY ~ KTS	GROSS WEIGHT ~ LBS ~	ROTOR RPM	ALTITUDE (h) ~ FT.	LONG. LOCATION OF C.G WITH RESPECT TO PIVOT ~ IN.	VERTICAL LOCATION OF CG WITH RESPECT TO PIVOT ~ IN
PITCH ATTITUDE (θ) ~ DEG.	ROLL ATTITUDE ϕ ~ DEG.	YAW ANGLE (ψ) DEG	REFERENCE NACELLE ANGLE (i_{NREF}) ~ DEG.	LEFT WING TWIST AT TIP - (θ_{TLW}) ~ DEG ~	RIGHT WING TWIST AT TIP - (θ_{TRW}) ~ DEG ~	ATMOSPHERIC DENSITY (ρ) ~ SLUGS/FT^3 ~	LEFT ROTOR COLL. PITCH AT .75 R. $(\theta_{.75L})$ ~ DEG ~	RIGHT ROTOR COLL. PITCH AT .75 R $(\theta_{.75R})$ ~ DEG ~
TOTAL LONG. STICK POSITION (δ_B) ~ IN.	TOTAL LATERAL STICK POSITION (δ_S) ~ IN.	TOTAL RUDDER PEDAL POSITION (δ_r) ~ IN. ~	THROTTLE POSITION (δ_{TH}) ~ IN. ~	LONG. SAS INPUT (δ_{BSAS}) ~ IN ~	LATERAL SAS INPUT (δ_{SSAS}) ~ IN ~	DIRECTIONAL SAS INPUT (δ_{rSAS}) ~ IN. ~	LEFT ROTOR LATERAL CYCLIC PITCH (A_{1CL}) ~ DEG ~	RIGHT ROTOR LATERAL CYCLIC PITCH (A_{1CR}) ~ DEG ~
ELEVATOR DEFLECTION (δ_e) ~ DEG	RUDDER DEFLECTION (δ_{RUD}) ~ DEG	LEFT WING FLAPERON DEFLECTION (δ_{L}) ~ DEG	RIGHT WING FLAPERON DEFLECTION (δ_R) ~ DEG.	LEFT WING SPOILER DEFLECTION (δ_{SPL}) ~ DEG	RIGHT WING SPOILER DEFLECTION (δ_{SPR}) ~ DEG.	FLAP DEFLECTION (δ_F) ~ DEG.	LEFT ROTOR LONG. CYCLIC PITCH (B_{1CL}) ~ DEG ~	RIGHT ROTOR LONG. CYCLIC PITCH (B_{1CR}) ~ DEG ~
ENGINE TURBINE INLET TEMP. (T_{0S}) ~ DEG. ~	ENGINE SPEED (Ω_E) ~ RPM	ENGINE SHAFT POWER AVAILABLE (SHP_A)	LEFT ROTOR POWER REQUIRED (SHP_{RLR})	RIGHT ROTOR POWER REQUIRED (SHP_{RRR})	TOTAL ROLL INERTIA (I_{XX}) ~ SLUG-FT^2 ~	TOTAL PITCH INERTIA (I_{YY}) ~ SLUG-FT^2	TOTAL YAW INERTIA (I_{ZZ}) ~ SLUG-FT^2 ~	DYNAMIC PRESSURE (q_0) ~ LB/FT^2
LEFT ROTOR ADVANCE RATIO (μ_{LR})	RIGHT ROTOR THRUST (T_R) ~ LB	LEFT ROTOR NORMAL FORCE (NF_L) ~ LB	LEFT ROTOR SIDE FORCE (SF_L) ~ LB	LEFT ROTOR PITCHING MOMENT (M_L) ~ FT-LB	LEFT ROTOR YAWING MOMENT (N_L) ~ FT-LB	TOTAL ROLL MOMENT AT LEFT HUB $(\mathcal{L}_{LAH})$ ~ FT-LB ~	TOTAL PITCH MOMENT AT LEFT HUB (M_{LAH}) ~ FT-LB ~	TOTAL YAW MOMENT AT LEFT HUB (N_{LAH}) ~ FT-LB ~
RIGHT ROTOR ADVANCE RATIO (μ_{RR})	LEFT ROTOR THRUST (T_L) ~ LB	RIGHT ROTOR NORMAL FORCE (NF_R) ~ LB	RIGHT ROTOR SIDE FORCE (SF_R) ~ LB	RIGHT ROTOR PITCHING MOMENT (M_R) ~ FT-LB	RIGHT ROTOR YAWING MOMENT (N_R) ~ FT-LB	TOTAL ROLL MOMENT AT RIGHT HUB $(\mathcal{L}_{RAH})$ ~ FT-LB ~	TOTAL PITCH MOMENT AT RIGHT HUB (M_{RAH}) ~ FT-LB ~	TOTAL YAW MOMENT AT RIGHT HUB (N_{RAH}) ~ FT-LB ~
FUSELAGE LONG. FORCE (X^F_{AERO}) ~ LB ~	EMPENNAGE LONG. FORCE (X^T_{AERO}) ~ LB ~	LONG. FORCE ON LEFT WING (X^{LW}_{AERO}) ~ LB ~	LONG. FORCE ON RIGHT WING (X^{RW}_{AERO}) ~ LB ~	LEFT NACELLE LONG. FORCE $(\Delta X'_{LN})$ ~ LB ~	RIGHT NACELLE LONG. FORCE $(\Delta X'_{RN})$ ~ LB ~	LEFT TIP PIVOT LONG. FORCE (X^{NL}_{AERO}) ~ LB ~	RIGHT TIP PIVOT LONG FORCE (X^{NR}_{AERO})	LONG. ACCELERATION AT C.G (X_{AERO}/m) ~ FT/SEC^2 ~
FUSELAGE SIDE FORCE (Y^F_{AERO}) ~ LB ~	EMPENNAGE SIDE FORCE (Y^T_{AERO}) ~ LB ~	SIDE FORCE ON LEFT WING (Y^{LW}_{AERO}) ~ LB ~	SIDE FORCE ON RIGHT WING (Y^{RW}_{AERO}) ~ LB ~	LEFT NACELLE SIDE FORCE $(\Delta Y'_{LN})$ ~ LB ~	RIGHT NACELLE SIDE FORCE $(\Delta Y'_{RN})$ ~ LB ~	LEFT TIP PIVOT SIDE FORCE (Y^{NL}_{AERO}) ~ LB ~	RIGHT TIP PIVOT SIDE FORCE (Y^{NR}_{AERO}) ~ LB ~	LATERAL ACCELERATION AT CG (Y_{AERO}/m) ~ FT/SEC^2 ~
FUSELAGE VERTICAL FORCE (Z^F_{AERO}) ~ LB ~	EMPENNAGE VERTICAL FORCE (Z^T_{AERO}) ~ LB	VERTICAL FORCE ON LEFT WING (Z^{LW}_{AERO}) ~ LB ~	VERTICAL FORCE ON RIGHT WING (Z^{RW}_{AERO}) ~ LB ~	LEFT NACELLE VERTICAL FORCE $(\Delta Z'_{LN})$ ~ LB ~	RIGHT NACELLE VERTICAL FORCE $(\Delta Z'_{RN})$ ~ LB ~	LEFT TIP PIVOT VERTICAL FORCE (Z^{NL}_{AERO}) ~ LB ~	RIGHT TIP PIVOT VERTICAL FORCE (Z^{NR}_{AERO}) ~ LB ~	VERTICAL ACCELERATION AT CG. (Z_{AERO}/m) ~ FT/SEC^2 ~
FUSELAGE ROLLING MOMENT $(\mathcal{L}^F_{AERO})$ ~ FT-LB ~	EMPENNAGE ROLLING MOMENT $(\mathcal{L}^T_{AERO})$ ~ FT-LB ~	WING ROLLING MOMENT $(\mathcal{L}^W_{AERO})$ ~ FT-LB ~	LEFT NACELLE ACTUATOR PITCHING MOMENT (M_{LACT}) ~ FT-LB ~	LEFT NACELLE ROLLING MOMENT $(\Delta\mathcal{L}'_{LN})$ ~ FT-LB ~	RIGHT NACELLE ROLLING MOMENT $(\Delta\mathcal{L}'_{RN})$ ~ FT-LB ~	LEFT TIP PIVOT ROLLING MOMENT $(\mathcal{L}^{NL}_{AERO})$ ~ FT-LB ~	RIGHT TIP PIVOT ROLLING MOMENT $(\mathcal{L}^{NR}_{AERO})$ ~ FT-LB ~	ROLL ACCELERATION AT CG. $(\mathcal{L}_{AERO}/I_{XX})$ ~ RAD/SEC^2 ~
FUSELAGE PITCHING MOMENT (M^F_{AERO}) ~ FT-LB ~	EMPENNAGE PITCHING MOMENT (M^T_{AERO}) ~ FT-LB ~	TOTAL WING PITCHING MOMENT (M^W_{AERO}) ~ FT-LB ~	RIGHT NACELLE ACTUATOR PITCHING MOMENT (M_{RACT}) ~ FT-LB ~	LEFT NACELLE PITCHING MOMENT $(\Delta M'_{LN})$ ~ FT-LB ~	RIGHT NACELLE PITCHING MOMENT $(\Delta M'_{RN})$ ~ FT-LB ~	LEFT TIP PIVOT PITCHING MOMENT (M^{NL}_{AERO}) ~ FT-LB ~	RIGHT TIP PIVOT PITCHING MOMENT (M^{NR}_{AERO}) ~ FT-LB ~	PITCH ACCELERATION AT CG (M_{AERO}/I_{YY}) ~ RAD/SEC^2 ~
FUSELAGE YAWING MOMENT (N^F_{AERO}) ~ FT-LB	EMPENNAGE YAWING MOMENT (N^T_{AERO}) ~ FT-LB	WING YAWING MOMENT (N^W_{AERO}) ~ FT-LB ~	TOTAL WING VERTICAL FORCE (Z^W_{AERO}) ~ LB ~	LEFT NACELLE YAWING MOMENT $(\Delta N'_{LN})$ ~ FT-LB ~	RIGHT NACELLE YAWING MOMENT $(\Delta N'_{RN})$ ~ FT-LB ~	LEFT TIP PIVOT YAWING MOMENT (N^{NL}_{AERO}) ~ FT-LB ~	RIGHT TIP PIVOT YAWING MOMENT (N^{NR}_{AERO}) ~ FT-LB	YAW ACCELERATION AT CG (N_{AERO}/I_{ZZ}) ~ RAD/SEC^2 ~
FUSELAGE ANGLE OF ATTACK (α_F) ~ DEG. ~	HORIZONTAL TAIL ANGLE OF ATTACK (α_{HT}) ~ DEG.	LEFT WING SLIPSTREAM ANGLE OF ATTACK $(\alpha_{LW_{SS}})$ ~ DEG ~	RIGHT WING SLIPSTREAM ANGLE OF ATTACK $(\alpha_{RW_{SS}})$ ~ DEG	LEFT NACELLE ANGLE OF ATTACK (α_{LN}) ~ DEG.	RIGHT NACELLE ANGLE OF ATTACK (α_{RN}) ~ DEG.	LEFT ROTOR RESOLVED ANGLE OF ATTACK (α_{RL}) ~ DEG ~	RIGHT ROTOR RESOLVED ANGLE OF ATTACK (α_{LR}) ~ DEG ~	LEFT TIP DEFLECTION (h_{iL}) ~ IN. ~
FUSELAGE ATTITUDE (θ_F) ~ DEG ~	VERTICAL TAIL ANGLE OF ATTACK (α_{VT}) ~ DEG.	LEFT WING ANGLE OF ATTACK (α_{LW_0}) ~ DEG ~	RIGHT WING ANGLE OF ATTACK (α_{RW_0}) ~ DEG ~	LEFT NACELLE SIDEFORCE COEFF (C_{YLN})	RIGHT NACELLE SIDEFORCE COEFF. (C_{YRN})	LEFT ROTOR SIDESLIP ANGLE (β_{ML}) ~ DEG	RIGHT ROTOR SIDESLIP ANGLE (β_{MR}) ~ DEG ~	RIGHT TIP DEFLECTION (h_{iR}) ~ IN. ~
FUSELAGE LIFT COEFF. (C_{LF})	HORIZONTAL TAIL LIFT COEFF. (C_{LHT})	LEFT WING SLIPSTREAM LIFT COEFF. $(C_{LS_{LW}})$	RIGHT WING SLIPSTREAM LIFT COEFF. (C_{LSRW})	LEFT NACELLE LIFT COEFF (C_{LLN})	RIGHT NACELLE LIFT COEFF. (C_{LRN})	LEFT ROTOR POWER COEFF. $(C_{P_{LR}})$	LEFT ROTOR THRUST COEFF (C_{TLR})	LEFT ROTOR NORMAL FORCE COEFF. $(C_{NF_{LR}})$
FUSELAGE DRAG COEFF. (C_{DF})	HORIZONTAL TAIL DRAG COEFF (C_{DHT})	LEFT WING SLIPSTREAM DRAG COEFF. $(C_{D_{SLW}})$	RIGHT WING SLIPSTREAM DRAG COEFFICIENT $(C_{D_{SRW}})$	LEFT NACELLE DRAG. COEFF (C_{DLN})	RIGHT NACELLE DRAG COEFF (C_{DRN})	LEFT ROTOR SIDE-FORCE COEFF. $(C_{SF_{LR}})$	LEFT ROTOR PITCHING MOMENT COEFF. $(C_{PM_{LR}})$	LEFT ROTOR YAWING MOMENT COEFF. $(C_{YM_{LR}})$
FUSELAGE PITCHING MOMENT COEFF. (C_{MF})	VERTICAL TAIL LIFT COEFF. (C_{LVT})	LEFT WING SLIPSTREAM PITCHING MOMENT COEFF. $(C_{MS_{LW}})$	RIGHT WING SLIPSTREAM PITCHING MOMENT COEFF. (C_{MSRW})	LEFT NACELLE PITCHING MOMENT COEFF. (C_{MLN})	RIGHT NACELLE PITCHING MOMENT COEFF. (C_{MRN})	RIGHT ROTOR POWER COEFF. $(C_{P_{RR}})$	RIGHT ROTOR THRUST COEFF. (C_{TRR})	RIGHT ROTOR NORMAL FORCE COEFF. $(C_{NF_{RR}})$
FUSELAGE YAWING MOMENT COEFF. (C_{NF})	VERTICAL TAIL DRAG COEFF. (C_{DVT})	WING SLIPSTREAM ROLLING MOMENT COEFF. $(C_{\ell_{SW}})$	WING SLIPSTREAM YAWING MOMENT COEFF. (C_{NSW})	LEFT NACELLE YAWING MOMENT COEFF. (C_{YLN})	RIGHT NACELLE YAWING MOMENT COEFF. (C_{YRN})	RIGHT ROTOR SIDE-FORCE COEFF. $(C_{SF_{RR}})$	RIGHT ROTOR PITCHING MOMENT COEFF. $(C_{PM_{RR}})$	LEFT ROTOR YAWING MOMENT COEFF. $(C_{YM_{RR}})$
HOR. TAIL DOWNWASH AT α = ZERO. (ϵ_0) ~ DEG. ~	HORIZONTAL TAIL DOWNWASH ANGLE (ϵ) ~ DEG.	LEFT ROTOR DOWNWASH ANGLE (ϵ_{PRR}) ~ DEG.	RIGHT ROTOR DOWNWASH ANGLE (ϵ_{PLR}) ~ DEG.	INTERFERENCE ANGLE, LEFT ROTOR ON RIGHT (ϵ_{ILR}) ~ DEG	INTERFERENCE ANGLE, RIGHT ROTOR ON LEFT. (ϵ_{IRL}) ~ DEG ~	INTERFERENCE ANGLE RIGHT WING ON ROTOR (ϵ_{WRR}) ~ DEG. ~	INTERFERENCE ANGLE LEFT WING ON ROTOR (ϵ_{WRL}) ~ DEG.	ROTOR ACCEL. $(\dot{\Omega})$ ~ RAD/SEC^2

Figure G.11. Definition of Trim Sheet Parameters

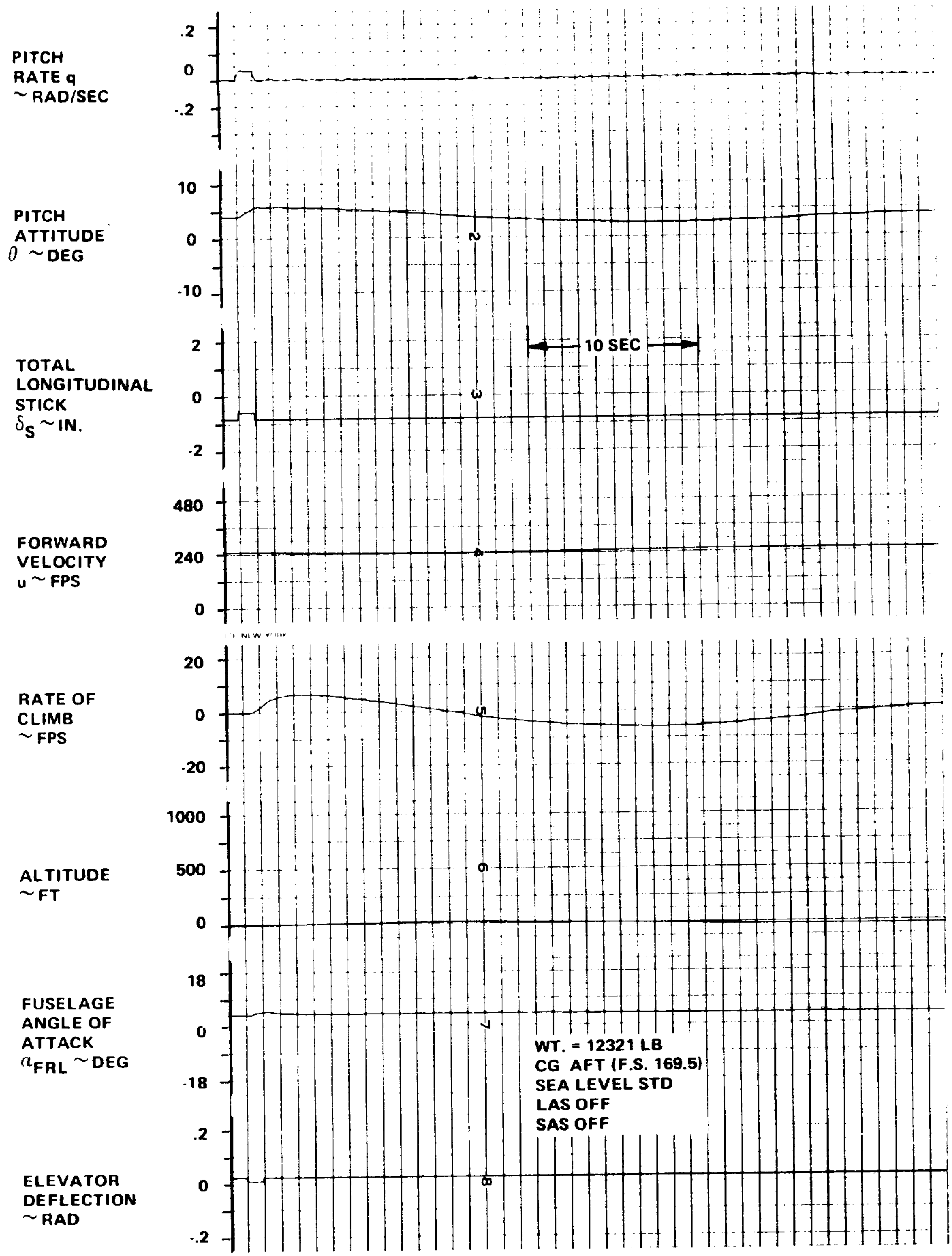


Figure G.12. Typical Time History Response to A .25 Inch Longitudinal Stick Pulse at 150 Knots

APPENDIX H VALIDATION OF THE MODEL 222 SIMULATION AT AMES RESEARCH CENTER

This section presents the validation plan which was submitted to NASA prior to the checkout and validation period at the Ames Research Center, and the simulation acceptance and pilot operating instructions and limitations submitted after the checkout period.

H.1 VALIDATION PLAN AND CRITERIA

Validation of large scale hybrid math model is an extremely time consuming and difficult process. The validation plan and criteria to be used by Boeing Vertol personnel in checking out and validating the NASA Model 222 simulation is developed in the following section. The following items will be considered in this validation:

- Trim Checks
  - Range of data: 25 kt increments from minimum to maximum speed. (including backward and sideward flight).
  - Accuracy (when compared against Boeing Vertol check cases)

Trim Data	Tolerance
Pilot control position	±0.25 in.
Stick and pedal position slope with speed	±10%
Thrust or wing lift	±2 1/2%
Pitch, roll, yaw angles	±1.0°
Collective pitch	±.5°

These requirements are subject to change pending a detailed selection of the trim conditions.

- <u>Dynamic Responses (Response to control pulses)</u>
  - Range of data: An axis by axis check with SAS and LAS systems on and off. Same speeds as for trim data.
  - Accuracy (when compared against Boeing Vertol check cases)

Period	$\pm 10\%$
Time to double (or half) amplitude	$\pm 10\%$

- <u>Stability Derivative Checks</u>
  - Range of data: Selected stability and control derivatives will be obtained at no more than five conditions.

- Accuracy when compared against Boeing Vertol check cases)

  Selected major stability and control derivatives

  $(L_v, N_v, L_p, N_p, L_r, N_r, X_u, M_w, M_w, M_q, Z_w,$

  $L_{\delta_s}, N_{\delta_s}, L_{\delta_r}, N_{\delta_r}, M_{\delta_B}, M_{i_N}, Z_{\delta_{TH}})$ $\pm 10\%$

- <u>Validation of Time Frame</u>

  Run selected dynamic response checks at hover and cruise in real time and 1/10 real time i.e. reduced interval of integration. Damping of predominant modes shall not change by more than $\pm 10\%$.

- <u>Transport Lag Checks</u>

  The transport lag i.e. aircraft response following control input shall not be greater than one to two time frames (average 1 1/2 time frames)

- <u>Pilot acceptance</u> will be based on a subjective comparison between the results obtained in the Boeing nudge base simulator and those obtained on the FSAA.

H.2 SIMULATION ACCEPTANCE

Following the checkout period at Ames, the following simulation acceptance document was submitted.

The math model, as programmed, is considered acceptable for initial evaluations.

The following differences exist between the math model and the aircraft described in Boeing's proposal for Phase II.

1. The data bank in the math model gives very conservative values of power around the autorotation region. The math model uses data from computer program D-88. Boeing's proposal uses data from wind tunnel model tests which were compared with D-88 predictions. The wind tunnel data showed consistently lower power required in and near autorotation. Revision of the rotor data bank to incorporate the wind tunnel data was not practicable within the time available. The extent of the difference is indicated by a minimum rate of descent at 80 knots from the math model of 2600 feet per minute compared to about 2000 feet per minute from the wind tunnel model data as reported in Volume I, Appendix G.

2. There is no autopilot in the math model. This was not required by the contract Statement of Work.

3. The landing gear dynamics in the model are an existing CSC program and do not represent the Model 222. There is some

indication that the CSC gear causes lateral instability on the ground at less than 25% power.

4. The wing bending and torsion modes were not checked out due to lack of time. Data obtained at Vertol indicate that these have no measurable effect on performance or flying qualities.

5. The representation of the SAS gives proper dynamic characteristics in the SAS on and SAS off modes. Individual component failures are not represented because of mechanization differences between the aircraft and the math model.

6. The actuator dynamics, which were included in the math model used on Boeing's nudge base simulator, were removed from the FSAA simultion in order to keep the time frame to a minimum. Evaluation on the Sigma 8 Computer at NASA showed no measurable difference as a result of removing the actuator dynamics. (The actuators have time constants less than the 50 millisecond time frame of the FSAA simulation.)

7. Boeing's proposed aircraft provides a pilot override for flap position and for rpm selection. These are not included in the math model. The chekcout and validation of the tilt rotor math model was accomplished in two phases. These were the math model aceptance and the simulator acceptance.

A. Math Model Acceptance:

1. Trim checks were calculated for a range of speeds from hover to 250 knots in 25 knot intervals. These were checked against previously computed trim conditions.

The results agreed within the tolerances specified in the reference.

2. Due to the limited time available for validation, dynamic responses were not checked over the full range of condition noted in the reference. However, dynamic responses were computed for a representative sample of condition. These compared favorably with those generated at Boeing and were generally within the specified tolerances. Differences could be explained by the different methods which were used to mechanize the equations; e.g., ---in the Boeing hybrid mechanization, rotor data were interpolated parabolicly for angle of attack and linearly for advance ratio. In the NASA mechanization, curve fit equations were solved at each angle of attack and linearly interpolated for advance ratio. This tends to produce differences in areas where the data is highly non-linear such as in transition.

3. Stability derivative checks were made at four speeds; 0, 75, 150 and 250 knots. These were generally within the $\pm 10\%$ accuracy specified by Boeing. Differences between the results are explainable and primarily due to the differenct ways the equations were mechanized.

4. Time frame studies and transport lag checks were made. Neither proved to be problem areas even though the NASA

simulation has a frame time in excess of 50 milliseconds. No lags were apparent in the simulation cab due to transport lag.

B. Boeing Pilot Acceptance:

The simulation is considered acceptable for initial evaluation however, Boeing's evaluation pilot made the following comments:

1. Controls:

   - Power lever location not optimum but acceptable for evaluation using seat arm rest for support.

   - Nacelle tilt switch - spring gradient slightly weak, 5° detents appear to be not in center of available travel. Switch occasionally sticks producing uncommanded nacelle actuation. Suitable for evaluation.

   - Stick forces - breakout and damping poor- difficult to achieve positive trim detent. Occasional shift in stick trim from one run to the next. (Simulator equipment problem)

2. Motion:

   - B V pilot considered motion cues unsatisfactory.

   - Lateral motion washouts and/or recentering produced spurious jerks and pulses which were disorienting.

- Roll angular acceleration cues weak.
- Pitch, yaw and heave satisfactory.
- Longitudinal acceleration cues - long period cab tilt ok, short period were jerky and disconcerting with recentering reversals apparent.

- Summary: There was enough spurious motion that overall the tilt/motion cues were detrimental and the pilot preferred fixed base.

3. Model Flying Qualities:

Generally similar to B V in-house simulation except for:

- Vertical response slightly overdamped.
- Unable to cut engine(s) until last day. As a result, not able to properly check out power lever governor override.

- Pedal fixed turns in prop mode not as well coordinated - 30° banked turns show 1/2 to 3/4 ball slip to T & S indicator, with S/S ind. reading 1° - 2°.

4. Boeing was not able to evaluate the Model 222's response to gusts, since the gust model has not been defined. Response to random turbulence was evaluated.

C. General:

The original time alloted for the checkout and validation of this model was extremely short, particularly in view of the computer software problems and the difficulties encountered in establishing the gains for the FSAA motion drive equations. As a result, the checkout period had to be extended by NASA for two weeks.

H.3 OPERATING INSTRUCTIONS AND LIMITATIONS

As part of the simulation checkout, a set of operating instructions and limitations were prepared. For the most part these refer to the piloted simulation and the mathematical model and do not imply limitations on the Model 222 aircraft.

General:

1. I.C. - Set power lever trim to "0". (suggest using left-hand arm rest)

2. Stick grip has both Mag. brake and vernier "beep" force retrim. If Mag. braking is desired, use only in hover -- advise beep retrimming for transition and prop mode. (In real A/C, Mag. brake will deactivate above 150 KIAS)

3. Flaps and RPM are programmed automatically as a function of nacelle angle. In the Model 222 there will be manual flap and RPM override controls.

4. Nacelle angle has "q" interlock. Nacelles cannot be programmed "up" above 160 KIAS. IF 160 KIAS is exceeded with nacelle angle greater than 0°, they will automatically program to 0° at a rate of 2°/sec.

5. Nacelle angle switch gives nacelle rate proportional to displacement. Switch is spring loaded to center off position and has a detent either side of center, corresponding to approximately ±5°/sec rate. Full displacement will give approximately ±10°/sec. For smoothest nacelle operation, use proportional feature; avoid "flick" type beep inputs.

6. Wing leading edge umbrellas automatically open or close at 50 KIAS.

7. Normal power lever travel is 8". This range represents flight idle to maximum power. There is a soft detent at 8 inches of travel which, when exceeded, overrides the governor. In this condition, the power lever controls collective pitch directly. This is provided for use as desired in autorotation and single engine landings.

8. The Model 222 is designed to go through transition at speeds between zero and 160 knots. Typical trimmed nacelle incidences at various speeds are:

i_N - DEG	90	75	60	30	0
Speed - KEAS	0	52	71	95	150

In investigating handling characteristics in the transition mode, it is recommended that these values be used as initial conditions.

In performing normal transitions to and from hover, it is recommended that the nacelle tilt be used as the primary speed control rather than flying at fixed tilt and using the stick for speed control.

Limitations:

1. Observe torque limits:

   75% twin engine
   100% single engine

2. Autorotation:
   Engines must be failed from console to achieve zero torque. Transitions can be made from airplane to helo mode with power lever full back, but some residual torque remains (10% total) and N_R trims out nominally at 70%.

   - Autorotative sink rate at $i_N=90°$ approximately 3500 ft/min. Minimum rate of sink is about 2600 ft/min at 80 knots at $i_N=60°$ (70% RPM). Model gives higher descent rates than airplane.

   - Power lever has detent at approximately 8". Pushing through detent will override governor (single engine failure or auto collective) and give direct control of collective pitch.

. Technique on engine cut in hover - advance power lever to detent, remaining engine will go to 100% torque. Use override as required, but once into direct C.P. control N_R will bleed off in same manner as turbine helo with one engine over-pitched. At topping power, model gross weight is too high for single engine hover. At max single engine power, vertical speed is -300 FPM.

3. At speeds above the normal flight envelope with nacelles tilted, the math model data bank is extrapolated from a curve fit and is not representative of the full scale aircraft. Speed and nacelle incidence limits for valid simulation are shown in the following table:

i_N - DEG	90	60	45	30
Speed - KEAS	100	125	125	140

These speeds should not be exceeded.

4. Aircraft oscillates if power is reduced below approximately 25% on the ground.

5. The math model is not set up to readily perform SAS or governor hardover studies. These may be approximated by setting the appropriate authority limits.

6. The Model 222 autopilot has not been incorporated into the simulation.