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

VOLUME VIII

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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.

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

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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

		PAGE
	FOREWORD	iii
	SUMMARY	v
	LIST OF ILLUSTRATIONS	xi
	NOMENCLATURE	xv
1.0	INTRODUCTION	1.0-1
2.0	GENERAL DESCRIPTION OF SIMULATION	2.0-1
3.0	SIGN CONVENTIONS	3.0-1
4.0	MODEL 222 TILT ROTOR AIRCRAFT DESCRIPTION	4.0-1
5.0	EQUATIONS OF MOTION	5.0-1
	5.1 AXES SYSTEM	5.0-1
	5.2 AIRCRAFT GROUND TRACK	5.0-3
	5.3 FORCE EQUATIONS	5.0-4
	5.4 MOMENT EQUATIONS	5.0-5
	5.5 EQUATIONS OF MOTION FOR A MASS ELEMENT	5.0-5
	5.6 EQUATIONS OF MOTION FOR NACELLES	5.0-10
	5.7 DETERMINATION OF ROTOR GYROSCOPIC MOMENTS	5.0-13
6.0	AIRFRAME AERODYNAMICS	6.0-1
	6.1 FUSELAGE	6.0-1
	6.2 NACELLES	6.0-3
	6.3 HORIZONTAL TAIL	6.0-4
	6.4 VERTICAL TAIL	6.0-10
	6.5 WING AERODYNAMICS	6.0-12
	6.5.1 BASIC WING AERODYNAMICS	6.0-12
	6.5.2 ROTOR SLIPSTREAM INTERFERENCE	6.10-13

TABLE OF CONTENTS

		PAGE
7.0	ROTOR AERODYNAMICS	7.0-1
7.1	FORMAT AND RANGE OF DATA	7.0-1
7.2	PROGRAMS USED TO COMPUTE ROTOR DATA	7.0-4
7.3	ROTOR SIGN CONVENTION	7.0-10
7.4	CURVE FIT FORMAT	7.0-10
7.5	EFFECT OF WING UPWASH ON ROTOR PERFORMANCE	7.0-12
7.6	ROTOR/ROTOR INTERFERENCE	7.0-12
7.7	ISOLATED ROTOR AERODYNAMICS	7.0-13
7.7.1	THRUST	7.0-13
7.7.2	POWER	7.0-14
7.7.3	NORMAL FORCE	7.0-14
7.7.4	SIDE FORCE	7.0-15
7.7.5	HUB PITCHING MOMENT	7.0-15
7.7.6	HUB YAWING MOMENT	7.0-16
7.8	CORRELATIONS OF ROTOR PREDICTION METHODS WITH TEST DATA	7.0-18
7.8.1	MODEL 213 FOUR BLADE HINGELESS ROTOR CORRELATION	7.0-18
7.8.2	CORRELATION WITH MODEL 222 26-FOOT DIAMETER ROTOR TEST IN NASA-AMES 40x80-FOOT TUNNEL	7.0-18
7.8.3	CORRELATION WITH MODEL 222 1/4.622 SCALE MODEL DATA	7.0-21
8.0	CONTROL SYSTEM DESCRIPTION	8.0-1
8.1	CONTROL AERODYNAMIC CONFIGURATION	8.0-1
8.2	LONGITUDINAL CONTROL	8.0-1
8.3	LATERAL CONTROL	8.0-3

TABLE OF CONTENTS

		PAGE
8.4	DIRECTIONAL CONTROL.	8.0-5
8.5	THRUST/COLLECTIVE CONTROL.	8.0-5
8.6	CONTROL FEEL	8.0-6
8.7	STABILITY AUGMENTATION SYSTEMS	8.0-7
8.8	LOAD ALLEVIATION SYSTEM (LAS)	8.0-8
8.9	THRUST MANAGEMENT SYSTEM	8.0-10
9.0	ENGINE REPRESENTATION	9.0-1
10.0	GROUND EFFECTS	10.0-1
11.0	AIRFRAME REPRESENTATION (PREPROCESSOR)	11.0-1
12.0	AEROELASTIC REPRESENTATION	12.0-1
13.0	CONCLUSIONS AND RECOMMENDATIONS	13.0-1
14.0	REFERENCES	14.0-1

APPENDICES

A.	TREATMENT OF WING FLEXIBILITY	A-1
A.1	WING TWIST	A-1
A.2	WING VERTICAL BENDING	A-5
B.	DERIVATION OF LANDING GEAR EQUATIONS	B-1
C.	VELOCITY AND ACCELERATION TRANSFORMATION AND CENTER OF GRAVITY/INERTIA EQUATIONS	C-1
C.1	VELOCITY TRANSFORMATIONS	C-1
C.2	CENTER OF GRAVITY AND INERTIA EQUATIONS . .	C-5
C.3	PILOT STATION ACCELERATION-BODY AXES . . .	C-8
C.4	AIRCRAFT INERTIAS	C-9

TABLE OF CONTENTS

		PAGE
D.	CALCULATIONS OF SLIPSTREAM-IMMERSED WING AREAS .	D-1
E.	COMPUTER REPRESENTATION	E-1
F.	MATHEMATICAL MODEL INPUT DATA	F-1
	F.1 CONTROL SYSTEM INPUT DATA	F-11
	F.2 ENGINE INPUT DATA	F-26
	F.3 ROTOR AERODYNAMIC INPUT DATA	F-34
	F.4 AIRFRAME AERODYNAMIC INPUT DATA	F-44
	F.5 GEOMETRIC, WEIGHTS AND BALANCE DATA . . .	F-50
	F.6 SIMULATION INPUT DATA	F-53
G.	IN-HOUSE HYBRID SIMULATION	G-1
	G.1 SIMULATION ARCHITECTURE	G-3
	G.2 TRIM LOOPS	G-160
	G.3 SIMULATION PROGRAM OUTPUT	G-238
H.	VALIDATION OF THE MODEL 222 SIMULATION AT AMES RESEARCH CENTER	H-1
	H.1 VALIDATION PLAN AND CRITERIA	H-1
	H.2 SIMULATION ACCEPTANCE	H-3
	H.3 OPERATING INSTRUCTIONS AND LIMITATIONS . .	H-8

LIST OF ILLUSTRATIONS

FIGURE NO.	TITLE	PAGE
1.1	SUMMARY OF USES FOR PILOTED SIMULATION . .	.1.0-2
2.1	SALIENT FEATURES OF MATH MODEL	.2.0-5
4.1	MODEL 222 TILT ROTOR RESEARCH AIRCRAFT . .	.4.0-3
5.1	AXES SYSTEMS	.5.0-2
6.1	VARIATION OF HORIZONTAL TAIL DOWNWASH ANGLE WITH THRUST COEFFICIENT	.6.0-5
6.2	CORRELATION OF THEORY WITH TEST FOR PREDICTIONS OF SLIPSTREAM FORCES AND MOMENTS .	.6.0-20
7.1	ROTOR SIGN CONVENTIONS	.7.0-11
7.2	MODEL 213 1/9 SCALE CONVERSION MODEL - 85 FT/SEC DERIVATIVE VARIATION WITH RPM .	.7.0-19
7.3	26 FT. ROTOR TEST STAND IN NASA's 40'x80' TUNNEL	.7.0-20
7.4	CORRELATION OF 26 FT ROTOR TEST DATA WITH VARIOUS ROTOR DERIVATIVE PROGRAMS . . .	.7.0-22
7.5	CORRELATION OF 26 FT ROTOR TEST DATA WITH VARIOUS ROTOR DERIVATIVE PROGRAMS - CYCLIC MOMENT DERIVATIVES	.7.0-23
7.6	CORRELATION OF 26 FT ROTOR TEST DATA WITH VARIOUS ROTOR DERIVATIVE PROGRAMS - CYCLIC FORCE DERIVATIVES	.7.0-24
7.7	ROTOR MOMENT AND AZIMUTH ANGLE DUE TO ANGLE OF ATTACK - CORRELATION WITH 26 FT ROTOR DATA	.7.0-25
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 .	.7.0-27
7.9	COMPARISON OF CALCULATED AND TEST ROTOR HUB FORCE AND MOMENT DERIVATIVES FOR M222 1/4.622 SCALE MODEL (PITCH SWEEP) Ω=386 RPM	.7.0-28
10.1	EFFECT OF ROTOR HEIGHT ON THRUST AUGMENTATION RATIO	10.0-3

LIST OF ILLUSTRATIONS

FIGURE NO.	TITLE	PAGE
A.1	WING GEOMETRY FOR DERIVATION OF FLEXIBILITY .	A-3
A.2	WING BENDING FUNCTIONS	A-10
B.1	GEOMETRY OF LANDING GEAR	B-2
C.1	REFERENCE AXES SYSTEMS	C-2
D.1	GEOMETRY OF ROTOR SLIPSTREAM/WING PLANFORM INTERACTION	D-4
E.1	BLOCK DIAGRAM ELEMENT INDEX NUMBERS . . .	E-2
F.1	MASS PROPERTIES	F-7
F.2	C.G. LIMIT DIAGRAM	F-9
F.3	DIFFERENTIAL LONG. CYCLIC FOR YAW CONTROL VS NACELLE INCIDENCE	F-14
F.4	ROTOR ROLL CONTROL SCHEDULES IN TRANSITION .	F-15
F.5	LONGITUDINAL CYCLIC FOR PITCH CONTROL GAIN VS NACELLE INCIDENCE	F-16
F.6	LOAD ALLEVIATION SYSTEM GAIN SCHEDULE . . .	F-17
F.7	PROGRAMMED CYCLIC, ELEVATOR, AND FLAP DEFLECTION VS NACELLE INCIDENCE	F-18
F.8	ROLL CONTROL DEFLECTION VS STICK DEFLECTION .	F-19
F.9	SPOILER ACTUATOR LIMIT VS AIRSPEED	F-20
F.10	ASSUMED THROTTLE TRAVEL MODEL 222 SIMULATION BOTH ENGINES	F-21
F.11	ENGINE CHARACTERISTICS LYCOMING T53-L13 ENGINE	F-22
F.12	ENGINE CHARACTERISTICS LYCOMING T53-L13 ENGINE	F-23
F.13	THRUST MANAGEMENT SYSTEM-SCHEDULED PARAMETERS	F-24
F.14	THRUST MANAGEMENT SYSTEM - SCHEDULED PARAMETERS	F-25

LIST OF ILLUSTRATIONS

FIGURE NO.	TITLE	PAGE
F.15	TURBINE ENGINE PERFORMANCE - ENGINE CYCLE 1.78	F-30
F.16	TURBINE ENGINE PERFORMANCE - ENGINE CYCLE 1.78	F-31
F.17	TURBINE ENGINE PERFORMANCE - ENGINE CYCLE 1.78	F-32
F.18	TURBINE ENGINE PERFORMANCE - ENGINE CYCLE 1.78	F-33
F.19	COEFFICIENTS OF CURVE FIT EQUATIONS FOR THRUST COEFFICIENT	F-35
F.20	COEFFICIENTS OF CURVE FIT EQUATIONS FOR POWER COEFFICIENT	F-36
F.21	COEFFICIENTS OF CURVE FIT EQUATIONS FOR NORMAL FORCE COEFFICIENT	F-37
F.22	COEFFICIENTS OF CURVE FIT EQUATIONS FOR SIDE FORCE COEFFICIENT	F-38
F.23	COEFFICIENTS OF CURVE FIT EQUATIONS FOR PITCHING MOMENT COEFFICIENT	F-39
F.24	COEFFICIENTS OF CURVE FIT EQUATIONS FOR YAWING MOMENT COEFFICIENT	F-40
F.25	CURVE FIT COEFFICIENTS FOR $\frac{\partial C_{PM}}{\partial Q}$	F-41
F.26	CURVE FIT COEFFICIENTS FOR $\frac{\partial C_{YM}}{\partial R}$	F-42
F.27	CONSTANTS FOR CYCLIC PITCH EFFECTIVENESS IN ROTOR EQUATIONS	F-43
F.28	MODEL 222 DOWNWASH FUNCTIONS @ $C_T=0$, $i_w=+2.0°$	F-47
F.29	VARIATION OF LIFT CURVE SLOPE WITH GROUND HEIGHT	F-48
F.30	ROTOR/ROTOR AND WING/ROTOR INTERFERENCE . .	F-49
F.31	MODEL 222 PILOT STATION REQUIREMENTS . . .	F-54

LIST OF ILLUSTRATIONS

FIGURE NO.	TITLE	PAGE
F.32	MODEL 222 CONTROL FORCE GRADIENTS AND BREAKOUT FORCES	F-55
G.1	UTILIZATION OF THE HYBRID LABORATORY FOR THE MODEL 222 MATH MODEL	G-5
G.2	FOREGROUND OPTIONS	G-8
G.3	GHP PHASE OVERLAY STRUCTURE (DIGITAL CORE ALLOCATIONS)	G-10
G.4	CONTENTS OF REAL TIME TASK - FAST LOOP	G-11
G.5	CONTENTS OF REAL TIME TASK - SLOW LOOP	G-13
G.6	MODEL 222 SIMULATION DIGITAL LISTING	F-15
G.7	ANALOG SYMBOLS	G-161
G.8	ANALOG DIAGRAMS FOR MODEL 222 SIMULATION	G-162
G.9	ANALOG STATIC CHECK ROUTINE (DIGITAL)	G-194
G.10	TYPICAL MODEL 222 TRIM SHEET	G-239
G.11	DEFINITION OF TRIM SHEET PARAMETERS	G-241
G.12	TYPICAL TIME HISTORY RESPONSE TO A .25 INCH LONGITUDINAL STICK PULSE AT 150 KNOTS	G-243

LIST OF TABLES

TABLE NO.	TITLE	PAGE
7.1	RANGE OF ROTOR DATA	7.0-5
8.1	FLIGHT CONTROL MIXING	8.0-2
9.1	ENGINE CYCLE DATA FORMAT	9.0-2
12.1	WING UNCOUPLED FREQUENCIES (BLADES OFF) CRUISE CONFIGURATION	12.0-2

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_{lc}	Longitudinal cyclic angle in rotor wind axes	deg
B'_{lc}	Longitudinal cyclic angle in swashplate axes	deg
B''_{lc}	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_δ}	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_{η_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 = $\frac{550RHP}{\rho\pi\Omega^3R^5}$	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
$D_{YM_{1\rightarrow 7}}$	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
$E_{NF_{1\to4}}$	Coefficients in the equation for the change in normal force coefficient with longitudinal cyclic angle	1/deg
$E_{PM_{1\to7}}$	Coefficients in the equation for the change in hub pitching moment coefficient with longitudinal cyclic angle	1/deg
$E_{SF_{1\to4}}$	Coefficients in the equation for the change in side force coefficient with longitudinal cyclic angle	1/deg
$E_{YM_{1\to7}}$	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	--
$F\phi1$	Lateral-directional SAS function	--
$F\phi2$	Lateral-directional SAS function	--
$F\psi1$	Lateral-directional SAS function	--
$F\psi2$	Lateral-directional SAS function	--
F_a	Aerodynamic force on nacelle	lb
F_{gzn}	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 $= \left[1-\frac{(\Delta\varepsilon)_2}{\varepsilon_2}\right]$	ND
G_{Al_α}	Load alleviation system gain - change in lateral cyclic with angle of attack	deg/deg
G_{Al_β}	Load alleviation system gain - change in lateral cyclic with angle of sideslip	deg/deg
G_{Bl_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_{prl}	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	$slug\text{-}ft^2$
I'_{xx}	Mass roll moment of inertia of the tilting portion of <u>each</u> nacelle about its center of gravity	$slug\text{-}ft^2$
I_{yy}	Vehicle mass pitch moment of inertia about center of gravity	$slug\text{-}ft^2$
I_{yy_o}	Mass pitch moment of inertia of aircraft components about their own center of gravity	$slug\text{-}ft^2$
$I_{yy}^{(F)}$	Mass pitch moment of inertia of fuselage mass element about its center of gravity	$slug\text{-}ft^2$
$I_{yy}^{(W)}$	Mass pitch moment of inertia of wing mass element about its center of gravity	$slug\text{-}ft^2$
I'_{yy}	Mass pitch moment of inertia of the tilting portion of <u>each</u> nacelle about its center of gravity	$slug\text{-}ft^2$
I_{xz}	Vehicle mass product of inertia about center of gravity	$slug\text{-}ft^2$
I_{xz_o}	Mass product of inertia of aircraft components about their own center of gravity	$slug\text{-}ft^2$
$I_{xz}^{(F)}$	Mass product of inertia of fuselage mass element about its center of gravity	$slug\text{-}ft^2$
$I_{xz}^{(W)}$	Mass product of inertia of wing mass element about its center of gravity	$slug\text{-}ft^2$
I'_{xz}	Mass product of inertia of the tilting portion <u>of each</u> nacelle about its center of gravity	$slug\text{-}ft^2$

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
$I^{(F)}_{zz}$	Mass yaw moment of inertia of fuselage mass element about its center of gravity	slug-ft^2
$I^{(W)}_{zz}$	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
$\hat{\underline{i}}$	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
$\hat{\underline{j}}$	Unit vector in j direction	--
K'_A	Wing slipstream correction factor	ND
$\frac{K_{D1}}{T} \rightarrow \frac{K_{D4}}{T}$	Coefficients of curve fit equation for wing download as a function of rotor height/diameter ratio	ND
$\frac{K_{M1}}{T} \rightarrow \frac{K_{M4}}{T}$	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
$K_{\mathcal{N}}$	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
$K_{\delta s}$	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 $C_{n\beta}$	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
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.
$X_{\substack{sprscript \\ subscript}}$	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.
$Y_{\substack{sprscript \\ subscript}}$	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.	
$Z_{\text{subscript}}^{\text{sprscript}}$	Vertical force, measured positive down along body axes	lb.
$\dot{z}_{down}$	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 or N.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

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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
-	Denotes average value
*	Denotes interim calculation or calculation in freestream wind axes
'	Denotes an interim calculation
+	Denotes an interim calculation
^	Denotes an interim calculation
| |	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.

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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

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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

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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

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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.

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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.

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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

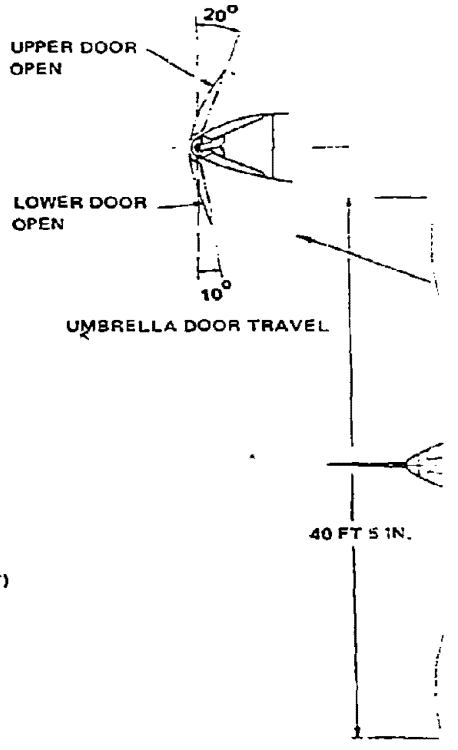
SPAN	8 FT 9 IN.
AREA	43.3 FT^2

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



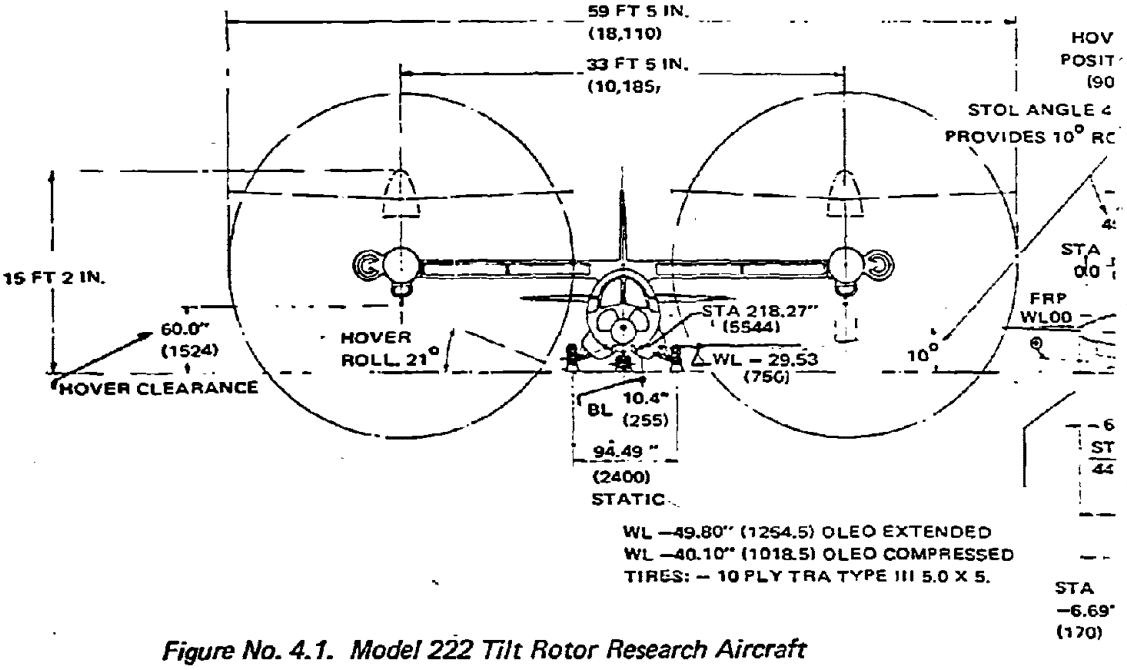
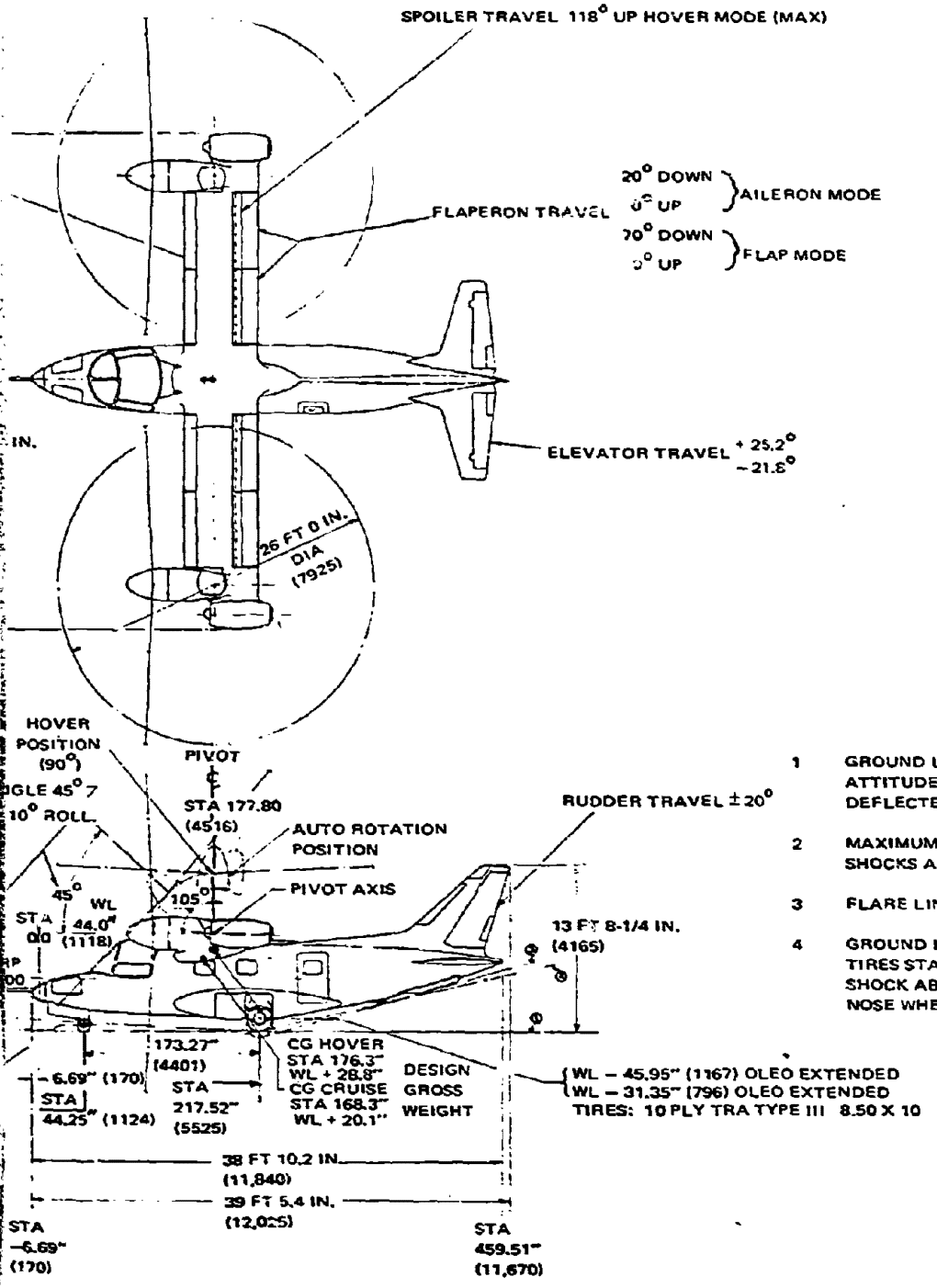


Figure No. 4.1. Model 222 Tilt Rotor Research Aircraft



1 GROUND LINE WITH AIRCRAFT IN THREE POINT ATTITUDE. TIRES AND SHOCKS STATICALLY DEFLECTED.

2 MAXIMUM TAIL DOWN GROUND LINE. MAIN GEAR SHOCKS AND TIRES STATICALLY DEFLECTED.

3 FLARE LINE. FLARE ANGLE 16°

4 GROUND LINE WITH MAIN GEAR SHOCKS AND TIRES STATICALLY DEFLECTED. NOSE GEAR SHOCK ABSORBER FULLY COMPRESSED AND NOSE WHEEL TIRE FLAT.

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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

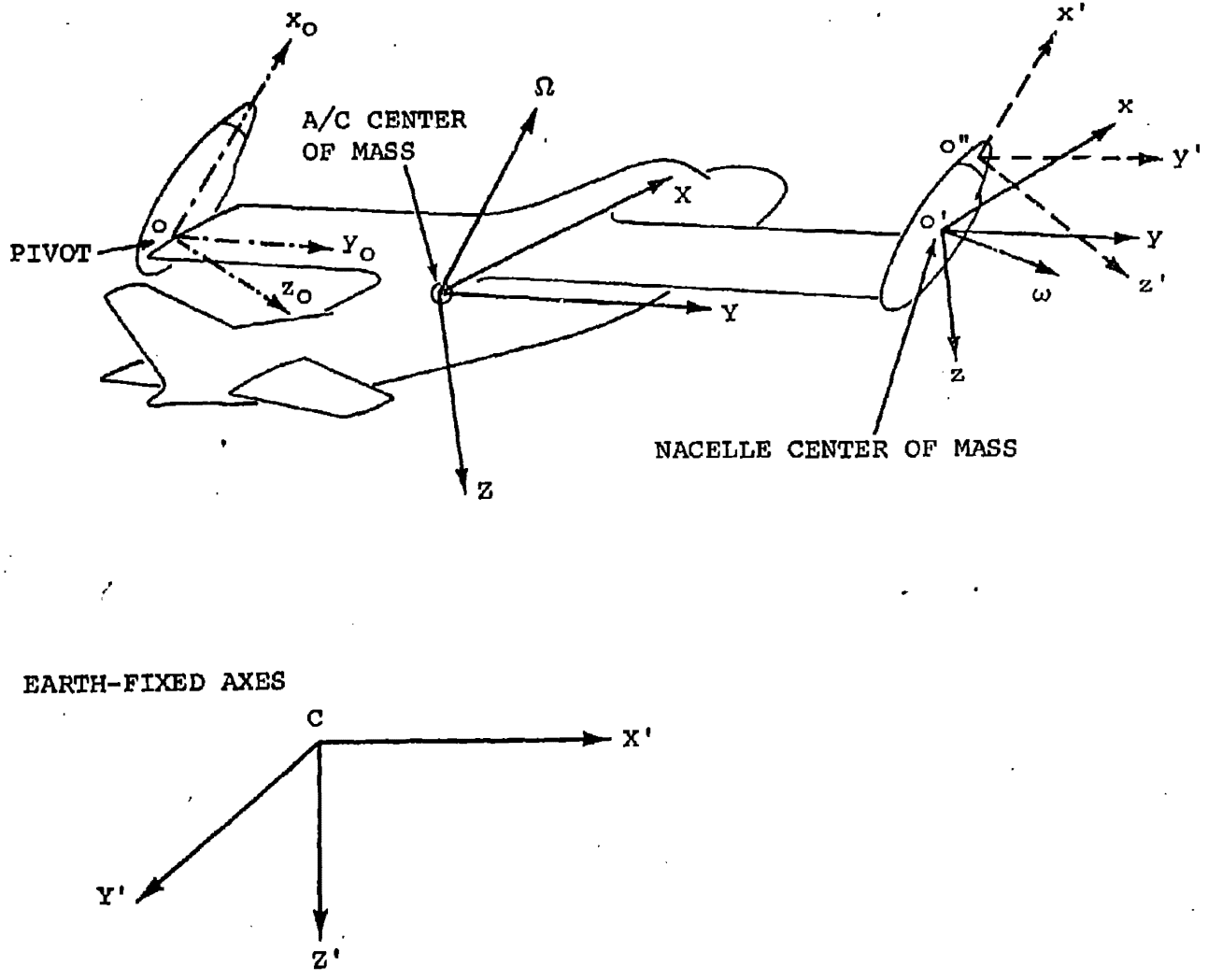


Figure 5.1. Axes Systems

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

$$\underline{V} = U\hat{\underline{i}} + V\hat{\underline{j}} + W\hat{\underline{k}} \qquad (5.1)$$

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

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),

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

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

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

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

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

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

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

which reduces to

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

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

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

Now, with $\underline{r} = X\hat{\underline{i}} + Y\hat{\underline{j}} + Z\hat{\underline{k}}$, 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,

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

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

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

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

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

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

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

$$\underline{\Omega}\times(\bar{I}\underline{\omega}) = (QR\,I_{zz} - QPI_{xz} - RQI_{yy} - R\dot{i}_N I_{yy})\hat{\underline{i}}$$
$$-(PR\,I_{zz} - P^2I_{xz} - PR\,I_{xx} + R^2I_{xz})\hat{\underline{j}}$$
$$+(QR\,I_{xz} + PQI_{yy} + P\dot{i}_N I_{yy} - PQ\,I_{xx})\hat{\underline{k}}$$

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 $\underline{G} = \Delta L\hat{\underline{i}} + \Delta M\hat{\underline{j}} + \Delta N\hat{\underline{k}}$:

$$\Delta L = \dot{P}[I_{xx} + m(Y^2 + Z^2)] - (\dot{R}+PQ)[I_{xz} + m\,XZ]$$

$$+ RQ[I_{zz}-I_{yy}+m(Y^2-Z^2)] + m\,YZ(R^2-Q^2) - I_{yy}R\,\dot{i}_N$$

$$+ m\,(Y\ddot{Z}-2\dot{X}YR - 2\dot{X}ZR + 2Z\dot{Z}P - XY\,(\dot{Q} - PR))$$

$$\Delta M = \dot{Q}\,[I_{yy}+m(X^2+Z^2)] - (R^2-P^2)[I_{xz} + mXZ]$$

$$+ PR\,[I_{xx}-I_{zz} + m(Z^2-X^2)] + I_{yy}\dot{i}_N \qquad (5.19)$$

$$+ m\,[\ddot{X}Z-X\ddot{Z} + 2Q(Z\dot{Z}+X\dot{X})-XY\,(\dot{P}+RQ)+YZ(PQ-\dot{R})]$$

$$\Delta N = \dot{R}\,[I_{zz}+m(X^2+Y^2)] - (\dot{P}-RQ)\,[I_{xz}+m\,XZ] \qquad (5.20)$$

$$+ PQ\,[I_{yy}-I_{xx} + m(X^2-Y^2)] + I_{yy}P\,\dot{i}_N$$

$$+ m\,\,[2X\dot{X}R - Y\ddot{X} - 2XZP - 2Y\dot{Z}Q - YZ\,(\dot{Q}+PR)+XY(Q^2-P^2)]$$

Summing the rolling moment equation:

$$L = I_{XX}\,\dot{P}-I_{XZ}\,(\dot{R}+PQ) + (I_{ZZ}-I_{YY})RQ \qquad (5.21)$$

$$+ m_N(R^2-Q^2)(Z_{NR}-Z_{NL})Y_N + m_N\Big\{Y_N(\ddot{Z}_{NR}-\ddot{Z}_{NL})$$

$$-2Q(\dot{X}_{NR}-\dot{X}_{NL})Y_N-2R(\dot{X}_{NR}Z_{NR} + \dot{X}_{NL}Z_{NL}) + 2P(\dot{Z}_{NR}Z_{NR} +$$

$$\dot{Z}_{NL}Z_{NL})-(\dot{Q}-PR)(X_{NR}-X_{NL})\,Y_N\Big\}+ 2m_fZ_f(P\dot{Z}_f -$$

$$R\dot{X}_f) + 2m_wZ_w(P\dot{Z}_w - R\dot{X}_w)-R\,I^N_{yy}\,(\dot{i}_{NL} + \dot{i}_{NR})$$

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

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

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.

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

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

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

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

$$\underline{h}_p = (\underline{r}-\underline{r}_p) \times m_N\underline{V} + \underline{h}_{o_N}$$
$$= m_n(\underline{r}\times\underline{V}) + \underline{h}_o - m_n\underline{r}_p \times \underline{V} \quad (5.26)$$

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.

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

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

The moment about the pivot is

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

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.

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

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

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

Expansion of these terms results in the following expression

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

$$- \underline{r}\left(\underline{r}_p.\frac{\delta \underline{\Omega}}{\delta t}\right) + \underline{\Omega}\left(\frac{\delta \underline{r}}{\delta t}.\underline{r}_p\right) - 2\frac{\delta \underline{r}}{\delta t}(\underline{r}_p.\underline{\Omega})$$

$$\left. + \underline{r}_p\left(\frac{\delta \underline{r}}{\delta t}.\underline{\Omega}\right) - (\underline{r}_p.\underline{\Omega})(\underline{\Omega}x\underline{r})\right\}$$

We require only the $\hat{\underline{j}}$ 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

$$\Delta M = m_N\left\{\ddot{X}_N Z_{CG} - \ddot{Z}_N X_{CG} + \dot{Z}_{CG}\dot{X}_N + \dot{Z}_N\dot{X}_{CG} + PQ\ Y_N Z_N - RQ\ X_N Y_N\right\} \qquad (5.30)$$

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,

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

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.

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

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

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

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

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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 [. 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: $C_{\ell_F} = 0$

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

$\beta_F = \tan^{-1}\left[\dfrac{V}{\sqrt{U^2 + W^2}}\right]$, $C_{M_F} = \dfrac{M_F}{\frac{1}{2}\rho V_{FUS}^2 S_W C_W}$ 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:

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

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

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

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

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

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

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

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

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

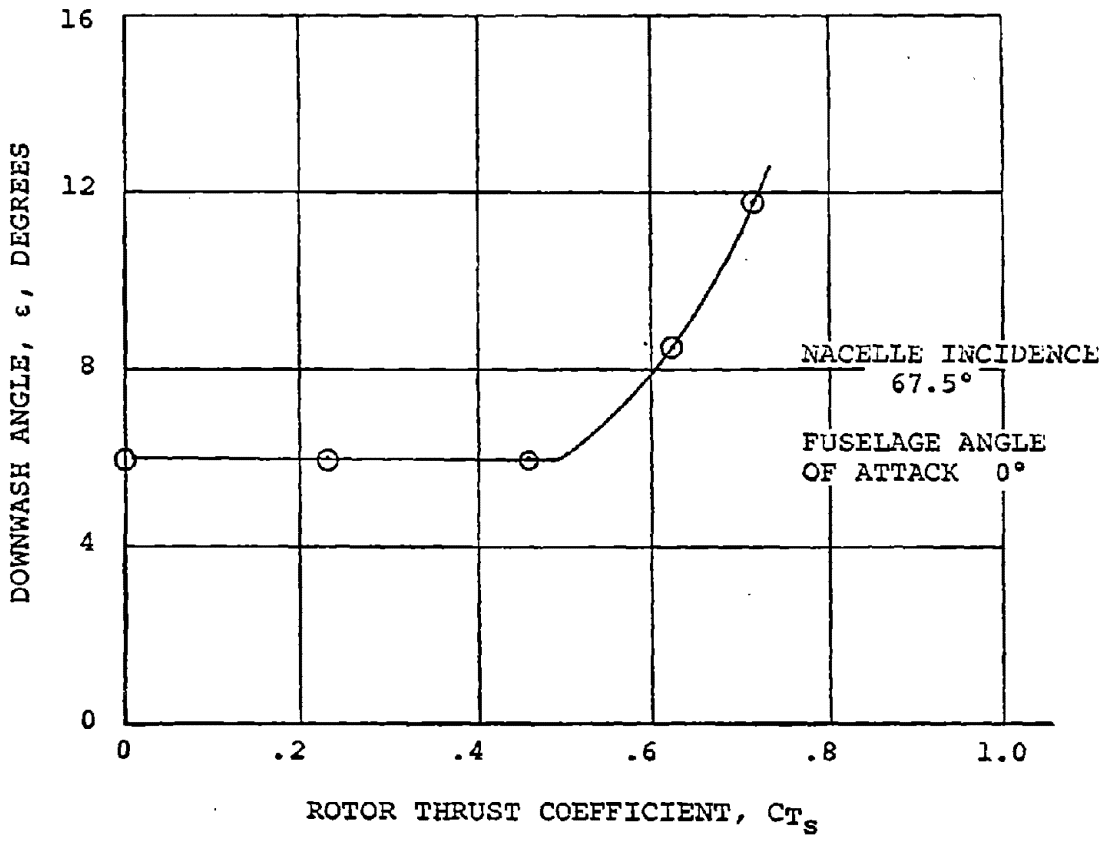


Figure 6.1. Variation of Horizontal Tail Downwash Angle with Thrust Coefficient

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

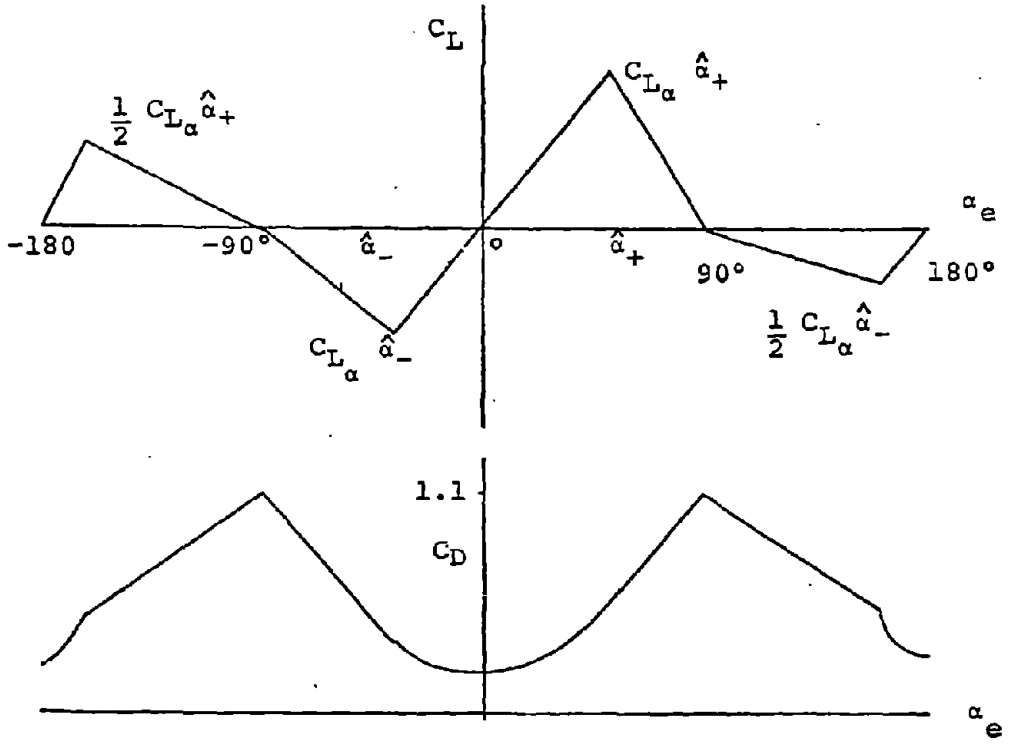
otherwise

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

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

$$C_{D_{HT}} = C_{D_{o_{HT}}} + \frac{2C_{L_{HT}}^2}{\pi AR_{HT}}$$

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

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

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

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

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

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:

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

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

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

$$M^{VT}_{AERO} = Z^{VT}_{AERO}\ (X_{CG}-X_{VT}) + X^{VT}_{AERO}\ (Z_{VT}-Z_{CG})$$

$$N^{VT}_{AERO} = -Y^{VT}_{AERO}\ (X_{CG}-X_{VT})$$

$$L^{VT}_{AERO} = -\ Y^{VT}_{AERO}\ (Z_{VT}-Z_{CG})$$

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.

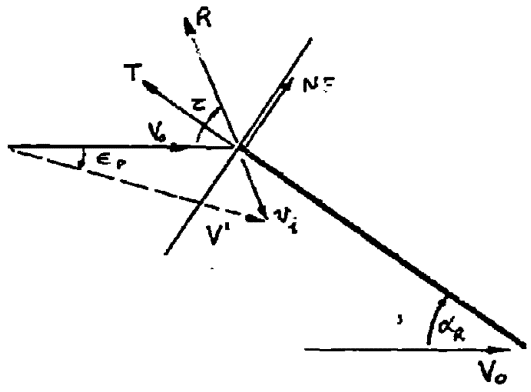
The method uses momentum theory to obtain the direction and

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

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

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)

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

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

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

have been introduced.

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

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

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

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

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

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

$$K_A' = \frac{V_* + \frac{C_{L_{\alpha i}}}{C_{L_\alpha}} v_*}{V_* + v_*}$$

where, from wing theory,

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

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

$$C_{D_S} = K_A'\left\{\frac{S_i}{S}\left(C_L'' \sin\epsilon + C_D'' \cos\epsilon\right) + C_D^*\left(1-C_{T_S}\right)\left(1-\frac{S_i}{S}\right)\right\}$$

$$C_{M_S} = K_A'\left\{\frac{S_i}{S} C_M'' + C_M^*\left(1-C_{T_S}\right)\left(1-\frac{S_i}{S}\right)\right\}$$

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.

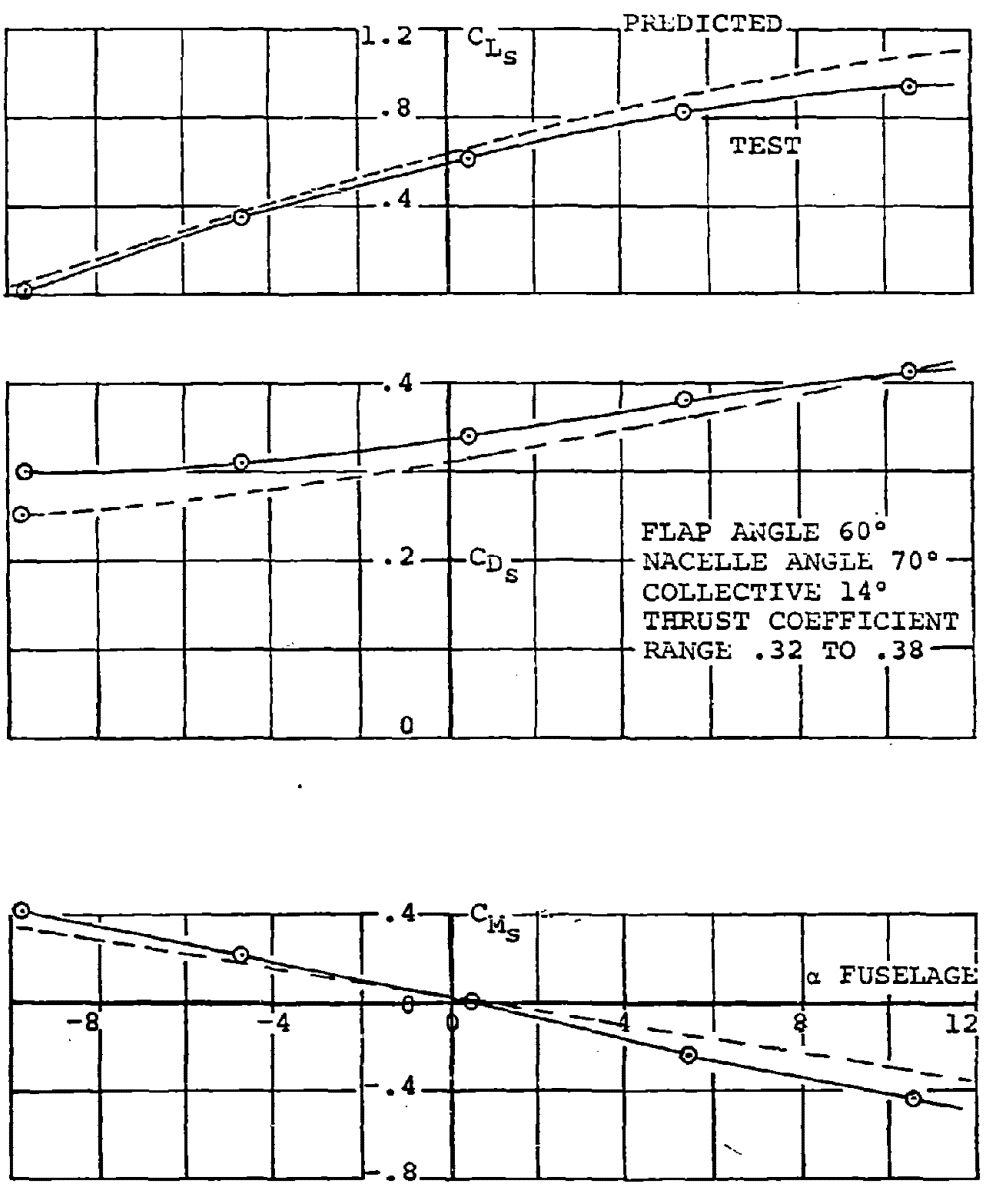


Figure 6.2. Correlation of Theory with Test for Predictions of Slipstream Forces and Moments

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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:

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

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

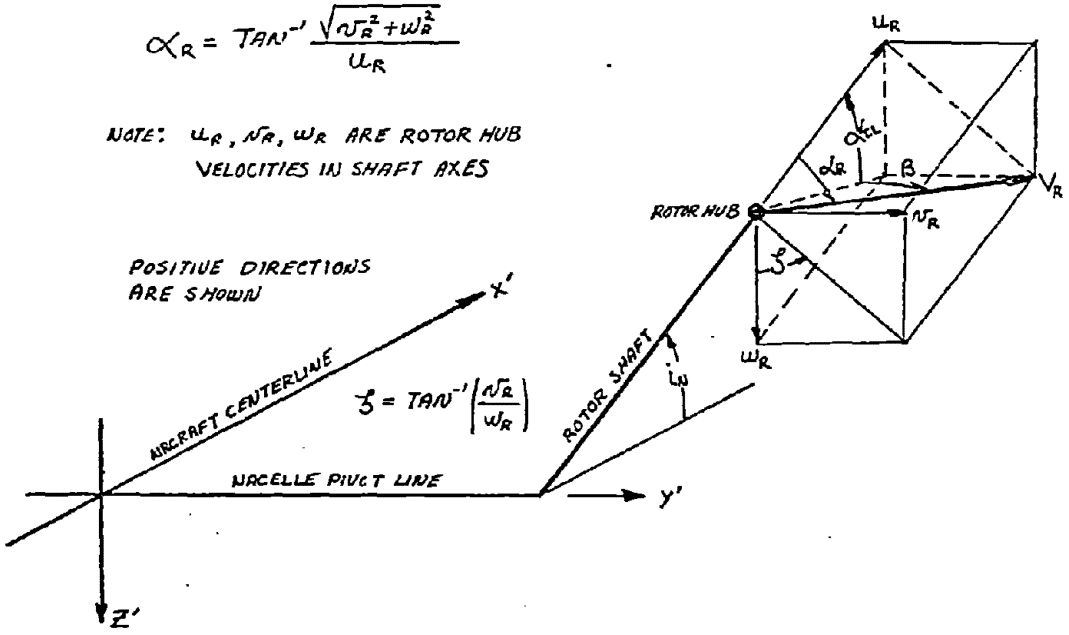
Forward speed and tip speed were combined to form rotor advance ratio and collective pitch or thrust were retained. Rotor angles of attack and sideslip and body axis roll, pitch and yaw rates were combined into a resultant angle of attack. Longitudinal and lateral cyclic pitch angles are retained. By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

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

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

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

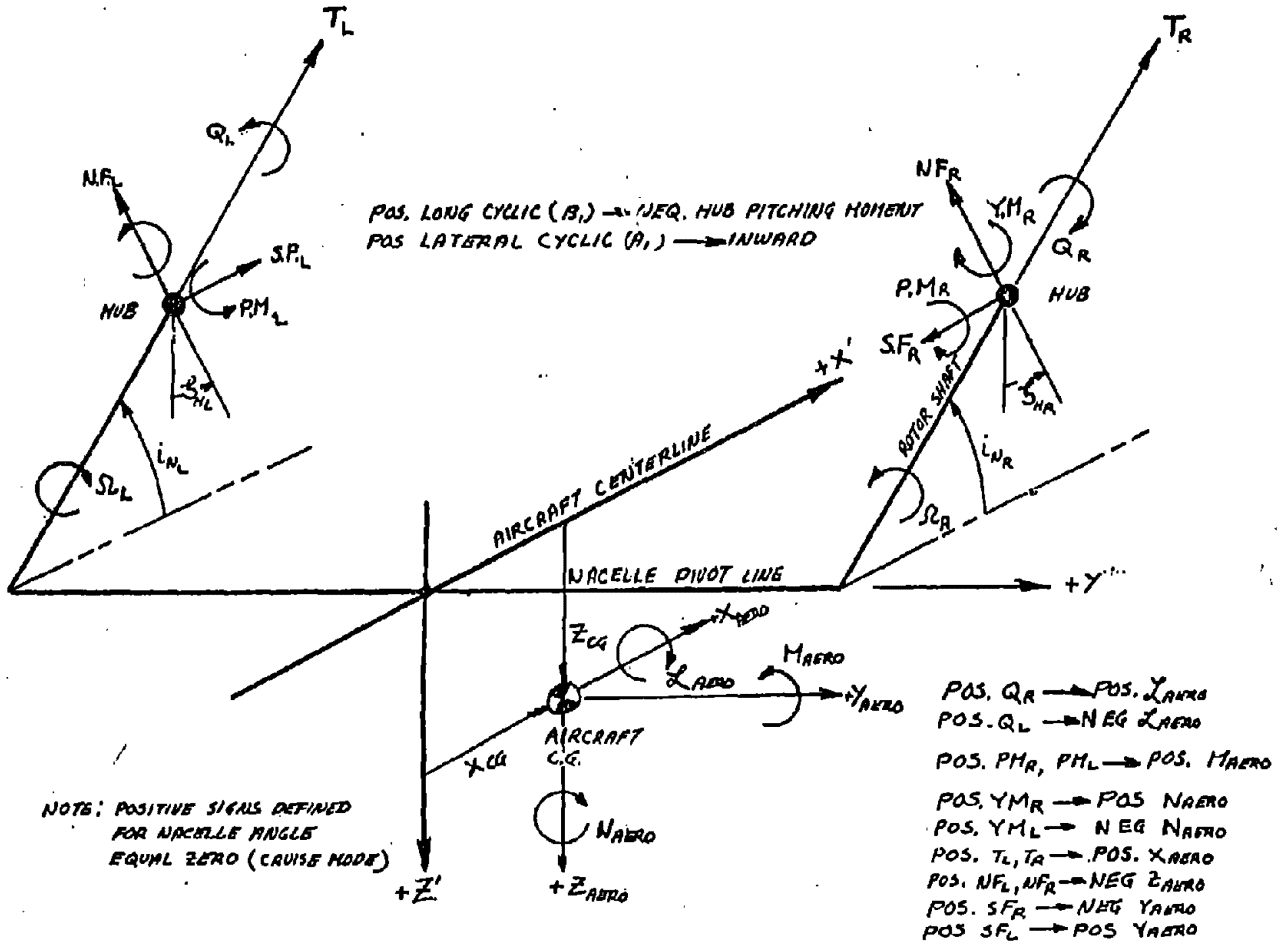


Figure 7.1. Rotor Sign Conventions

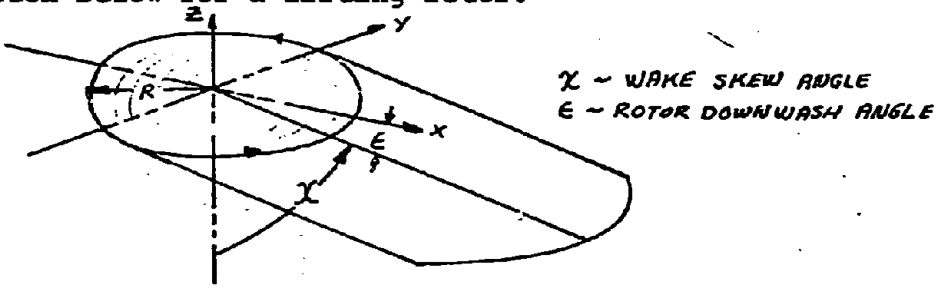
All of the rotor forces and moments are curve fit in this format. The coefficients of the equation were obtained from a least squares fit of the computed rotor data. The criteria used to determine the final coefficients was to have not more than a 5% difference between the curve fit equations and the 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 $$C_{T_{ORR}} = \sum_{v=0}^{2} \sum_{u=0}^{3} [A_{T_{(u+4v)}} \alpha_{RR}^{u} \theta_{0.75}^{v}]$$

[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 $\mu \left[\mu = \frac{V}{V_t}\right]$ 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

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

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

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

εi_{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

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

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

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

where: $$C_{SF_{O_{RR}}} = \sum_{v=0}^{2} \sum_{u=0}^{3} \left[A_{SF}(u+4v)\alpha_{RR}^{u} C_{T'_{RR}}^{v} \right]$$

$A_{SF}(u+4v)$=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: $$C_{PM_{O_{RR}}} = \sum_{v=0}^{2} \sum_{u=0}^{3} \left[A_{PM}(u+4v)\alpha_{RR}^{u} C_{T'_{RR}}^{v} \right]$$

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

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

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

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

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

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

ζ_{HR} = right rotor sideslip angle

i_{NR} = right nacelle velocity

i_{NR} = right nacelle angle

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

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

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

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

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

7.7.6 Hub Yawing Moment

$$C_{YM_{RR}} = C_{YM_{o_{RR}}} + \frac{dC_{YM_{RR}}}{dA_{1C_R}} A_{1C_R} + \frac{dC_{YM_{RR}}}{dB_{1C_R}} B_{1C_R} + \frac{dC_{YM_{RR}}}{dR} R_{NR}^{R}$$

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

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

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

$J_{YM}(u+4v)$ 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

i_{NR} = Right nacelle velocity

i_{NR} = Right nacelle angle

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

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

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

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

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

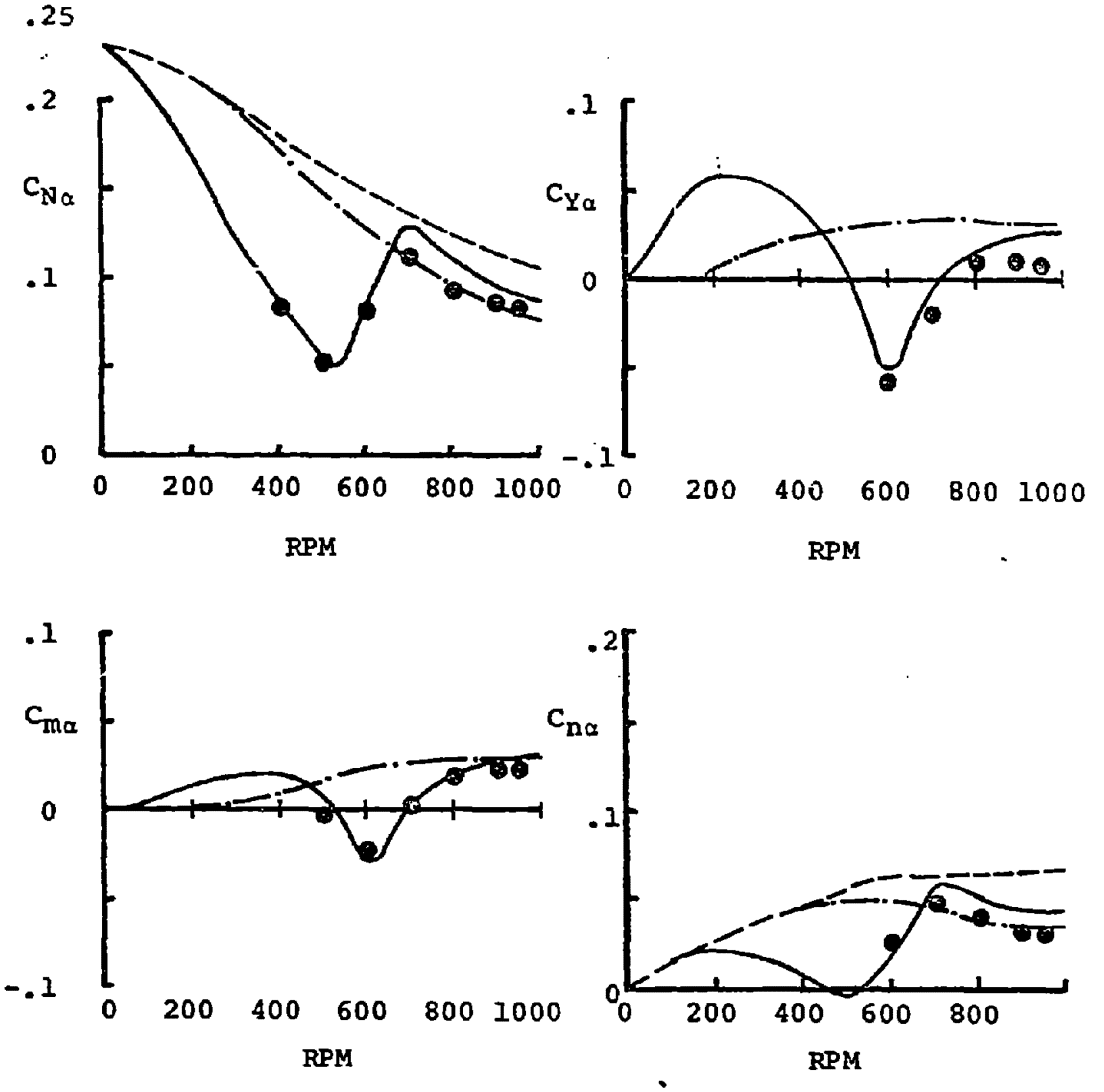


Figure 7.2. Model 213 1/9 Scale Conversion Model – 85 Ft/Sec Derivative Variation with RPM

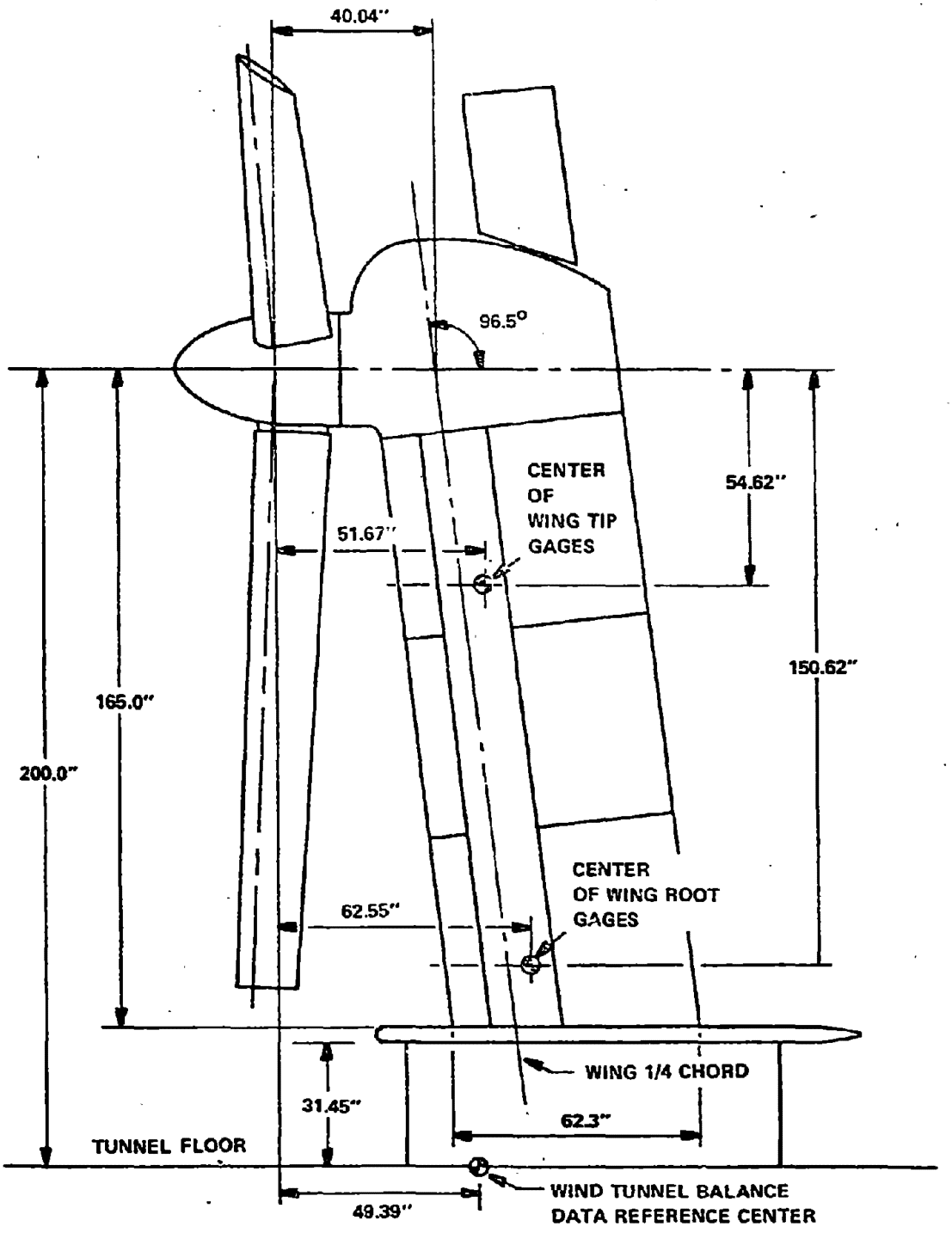


Figure 7.3. 26 Ft. Rotor Test Stand in NASA's 40' x 80' Tunnel

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

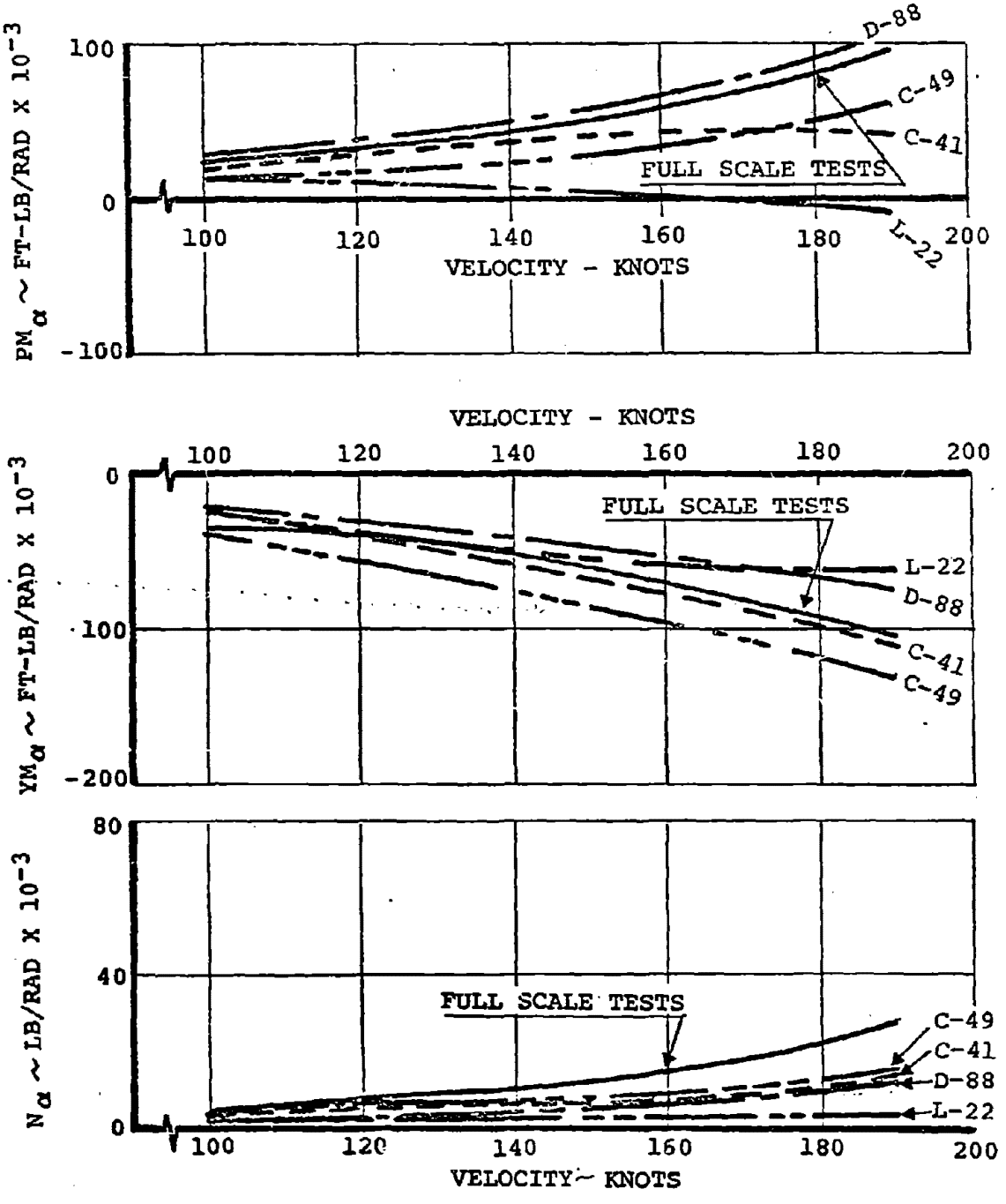


Figure 7.4. Correlation of 26 Ft Rotor Test Data with Various Rotor Derivative Programs

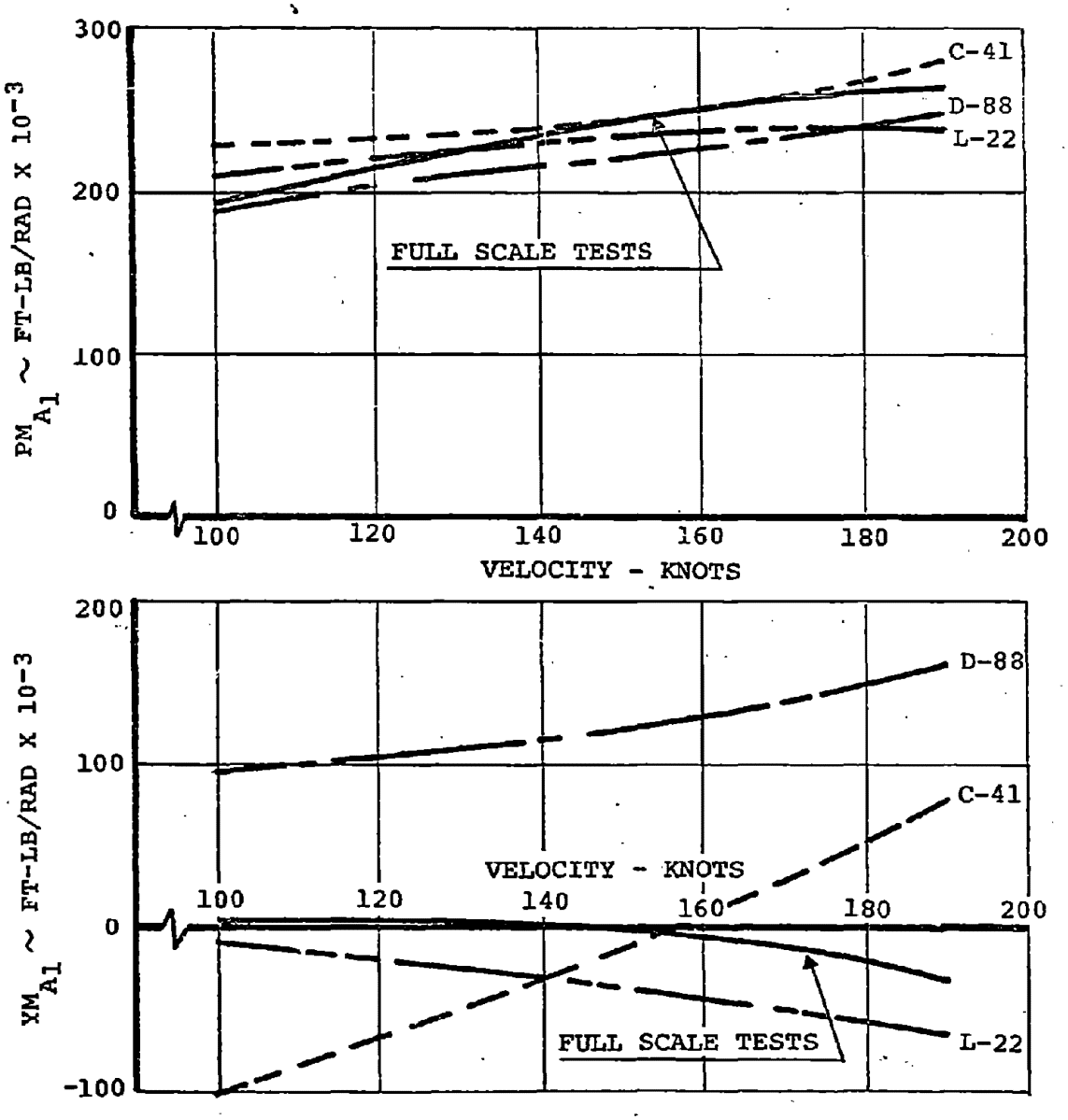


Figure 7.5. Correlation of 26 Ft Rotor Test Data with Various Rotor Derivative Programs — Cyclic Moment Derivatives

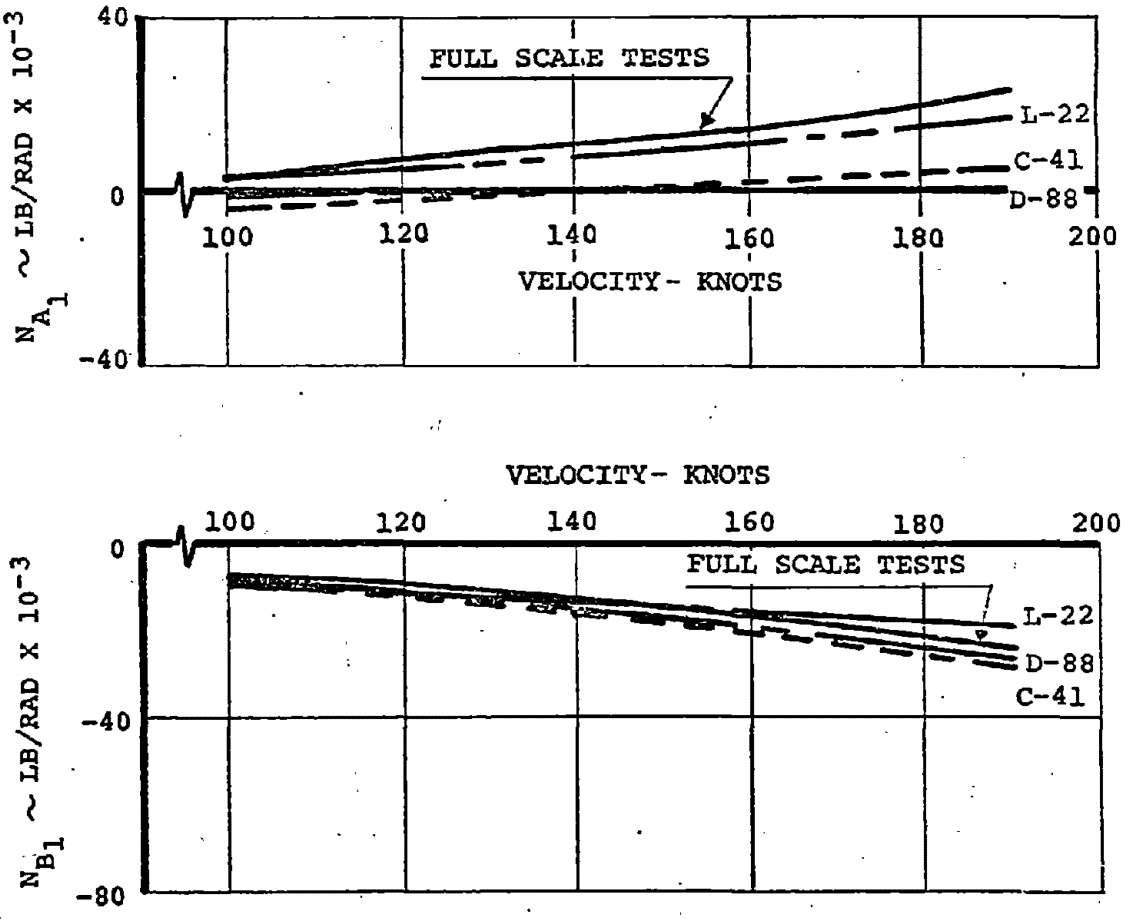


Figure 7.6. Correlation of 26 Ft Rotor Test Data with Various Rotor Derivative Programs — Cyclic Force Derivatives

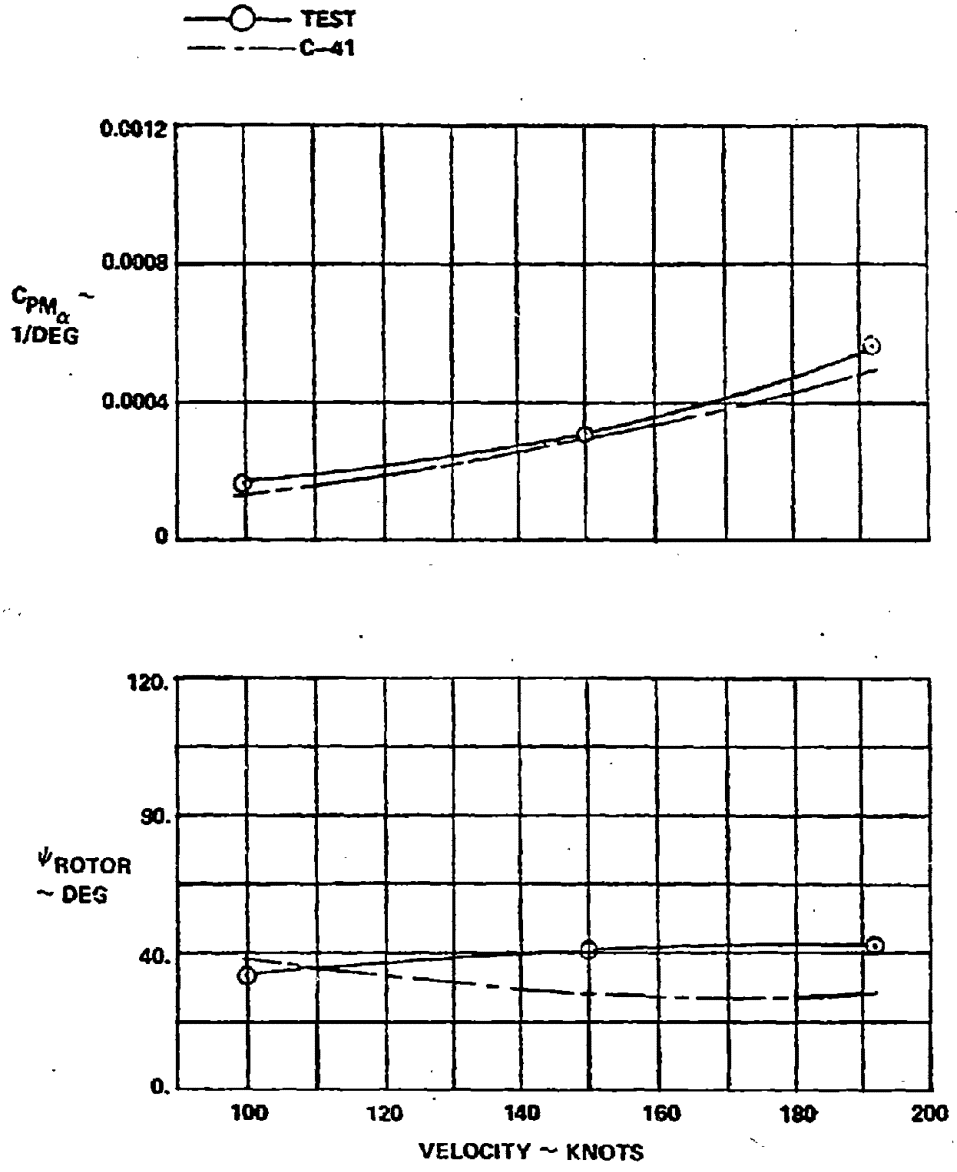


Figure 7.7. Rotor Moment and Azimuth Angle Due to Angle of Attack – Correlation with 26 Ft Rotor Data

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.

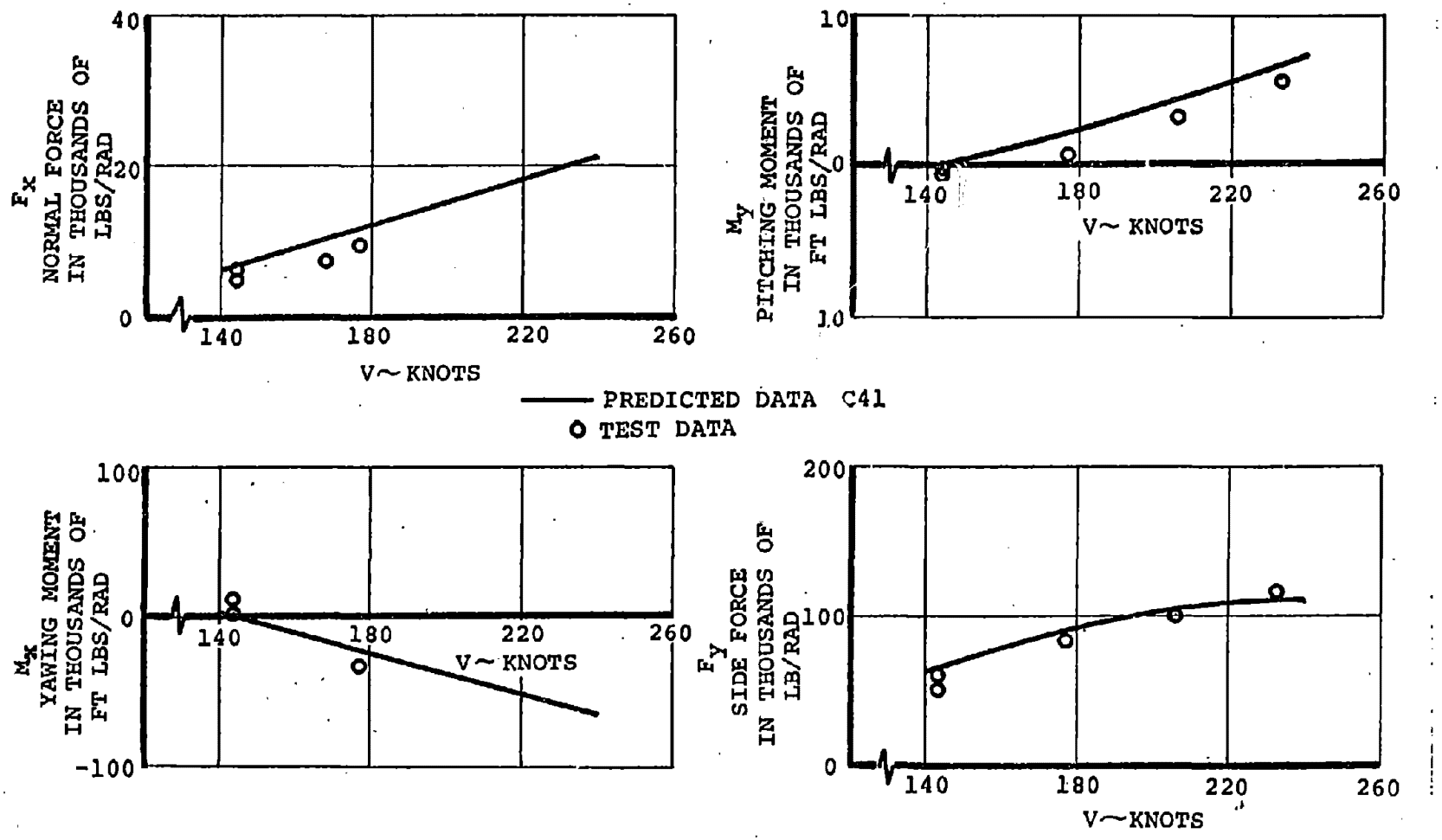


Figure 7.8. Comparison of Calculated and Test Rotor Hub Force and Moment Derivatives for M222 1/4.622 Scale Model (Yaw Sweep) Ω = 386 RPM

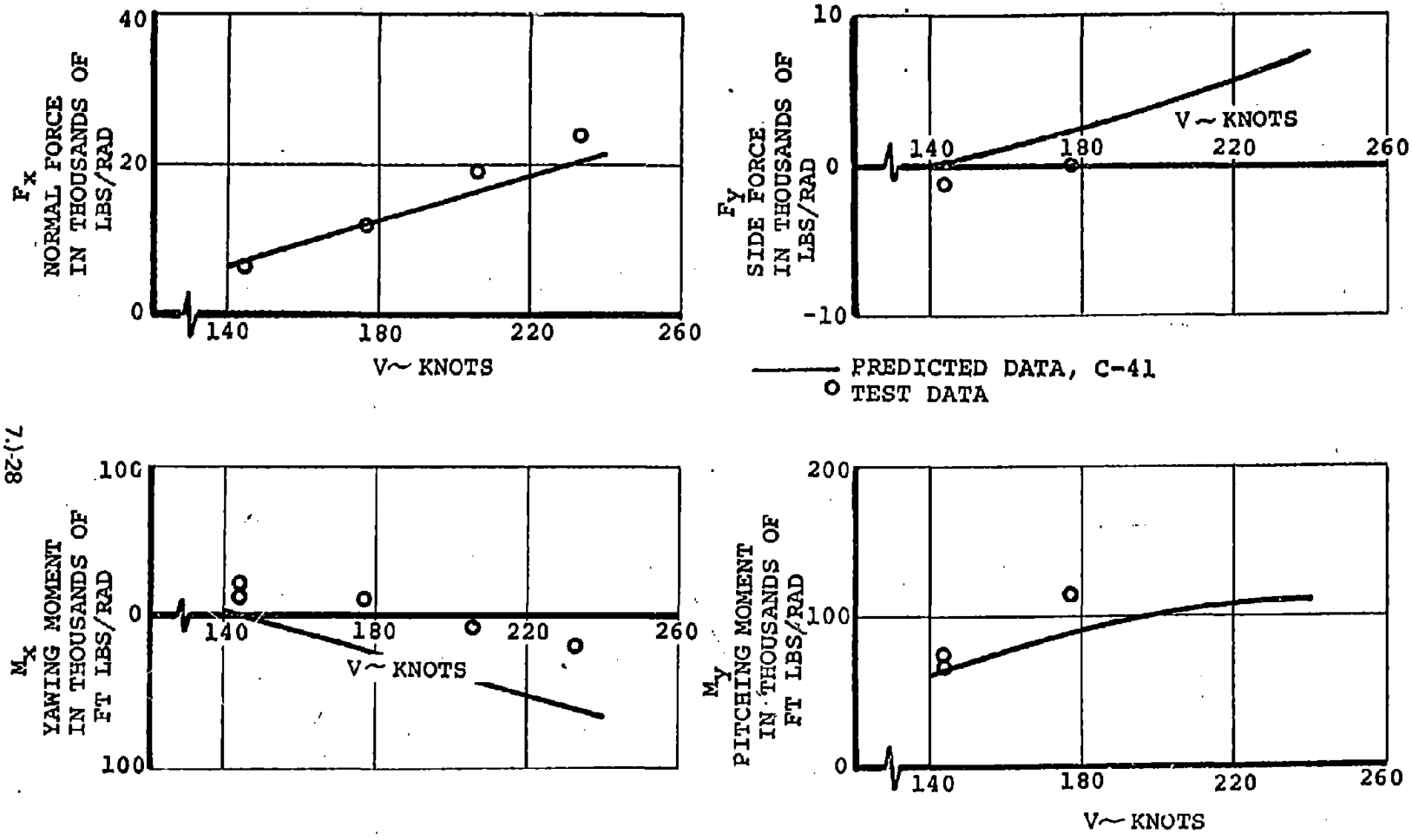


Figure 7.9. Comparison of Calculated and Test Rotor Hub Force and Moment Derivatives for M222 1/4.622 Scale Model (Pitch Sweep) Ω = 386 RPM

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
Helicopter (Hover)	
Pitch	Longitudinal Cyclic
Roll	Differential Collective
Yaw	Differential Longitudinal Cyclic and Differential Nacelle Tilt
Height Control	Collective/Engine Power
Transition	
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
Airplane	
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

GROUND EFFECTS

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)

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

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

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

$$= \text{Rotor hub height above the ground}$$

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

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

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

or

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

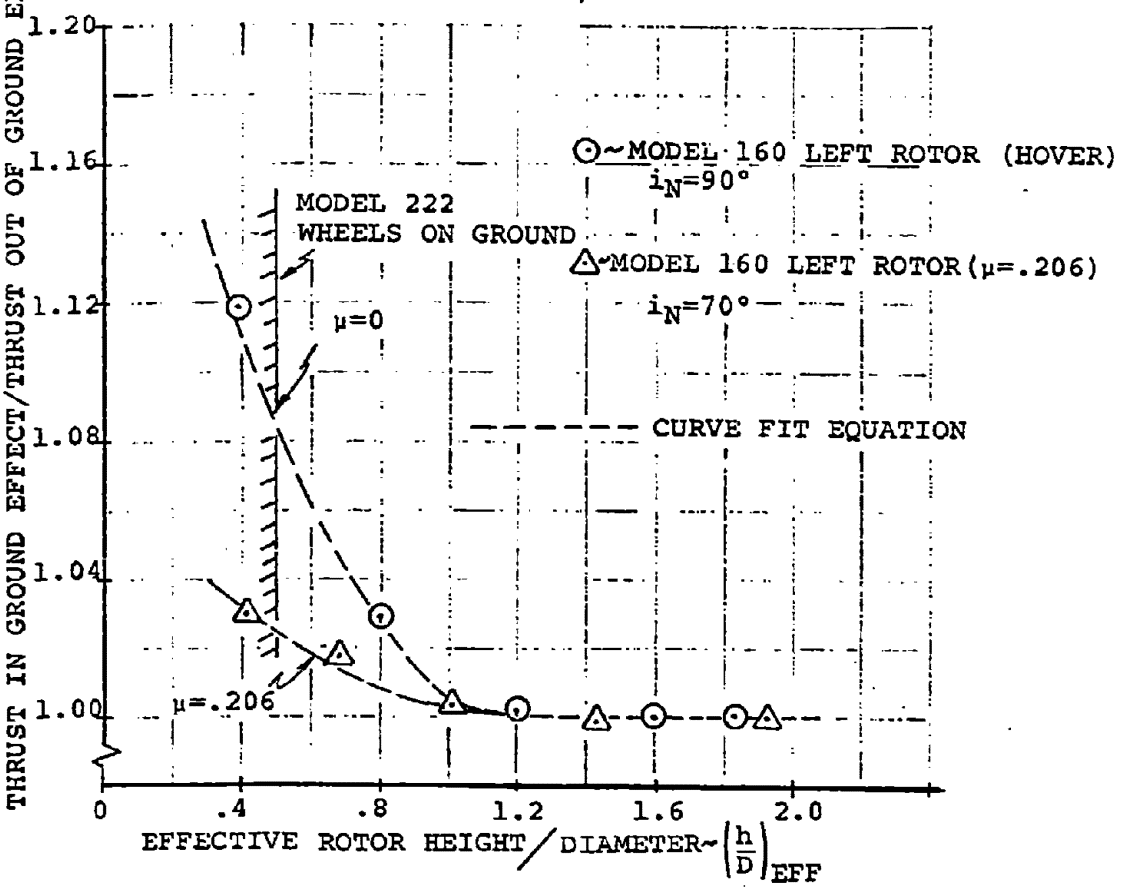


Figure 10.1. Effect of Rotor Height on Thrust Augmentation Ratio

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)

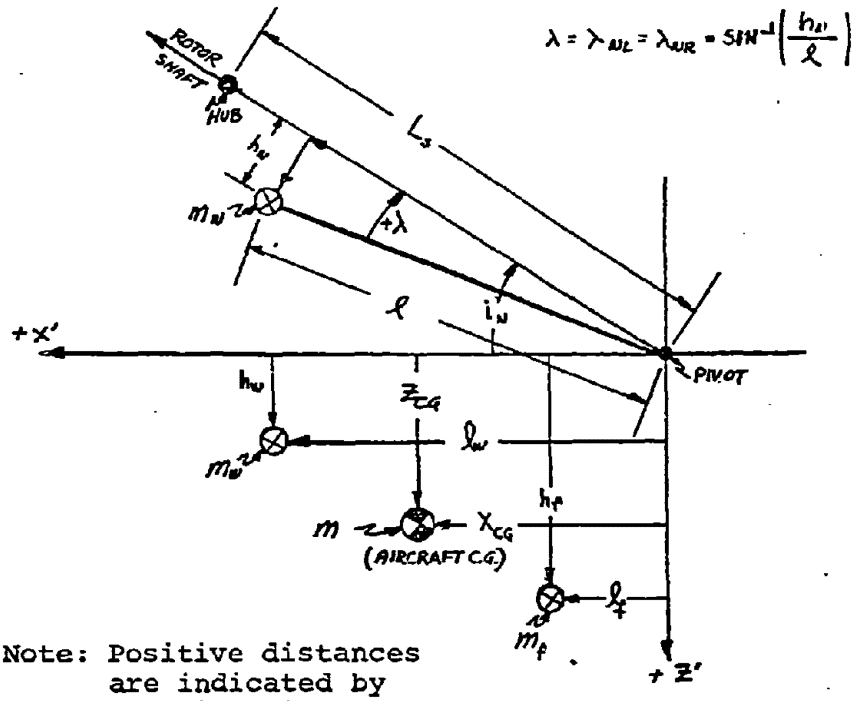
These three mass elements along with their respective distances from the nacelle pivot to the center of each mass element are used to compute the aircraft center of gravity distances with

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

Cm_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.

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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,

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

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

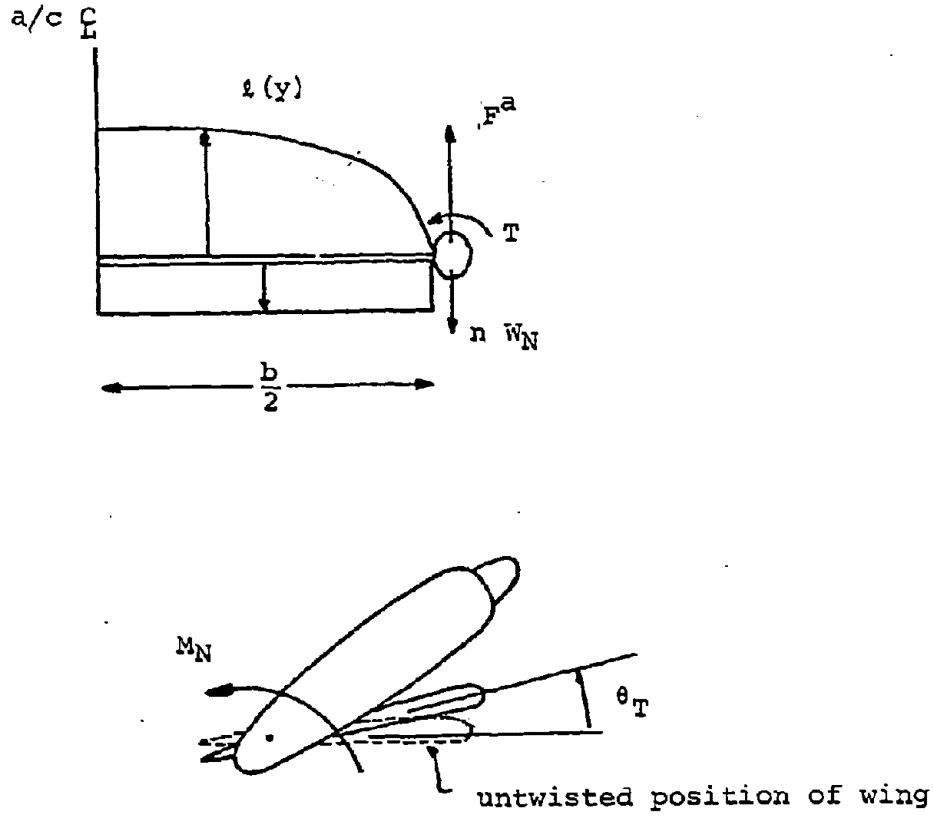


Figure A.1. Wing Geometry for Derivation of Flexibility

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

$$k = \frac{4}{\pi} \frac{C_{L_\alpha}}{a_o} \tag{A-6}$$

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

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

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

$$C_{m_{c/4}} = C_{m_o} + \frac{dC_{m_{c/4}}}{dC_\ell} C_\ell \tag{A-8}$$

and therefore

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

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

$$T = M_{actuator} + M_{GYRO} + \frac{1}{4}\rho V^2 c^2 C_{m_o} b + \frac{1}{2}\rho V^2 c^2 \left(\frac{dC_{m_{c/4}}}{dC_\ell} + \frac{x}{c}\right)\int_o^{b/2} C_\ell dy \tag{A-10}$$

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

$$T = K_\theta \theta_T = M_{actuator} + M_{gyro} + \frac{1}{4}\rho V^2 b c^2 C_{m_o} + \frac{1}{2}\rho V^2 c^2 \left(\frac{dC_{m_{c/4}}}{dC_\ell} + \frac{x}{c}\right) \times \frac{C_{L_\alpha} b}{6\pi}\left(3\pi\alpha_{RIGID} + 4\theta_T\right) \tag{A-11}$$

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_o 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:

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

- Bending due to nacelle net vertical load.

  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

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

- Bending due to wing weight.

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

- Bending due to nacelle torque (rolling moment)

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

Total bending moment at station y is therefore

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

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

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

the curvature of the wing due to bending is

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

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

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

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

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

$$- \frac{nW_wb^3}{8EI_o}\phi_4 + \frac{Tb^3}{4EI_o}\phi_5 \qquad \text{(A-22)}$$

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

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

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

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

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 ϕ_1 - ϕ_5 appropriate to these stations.

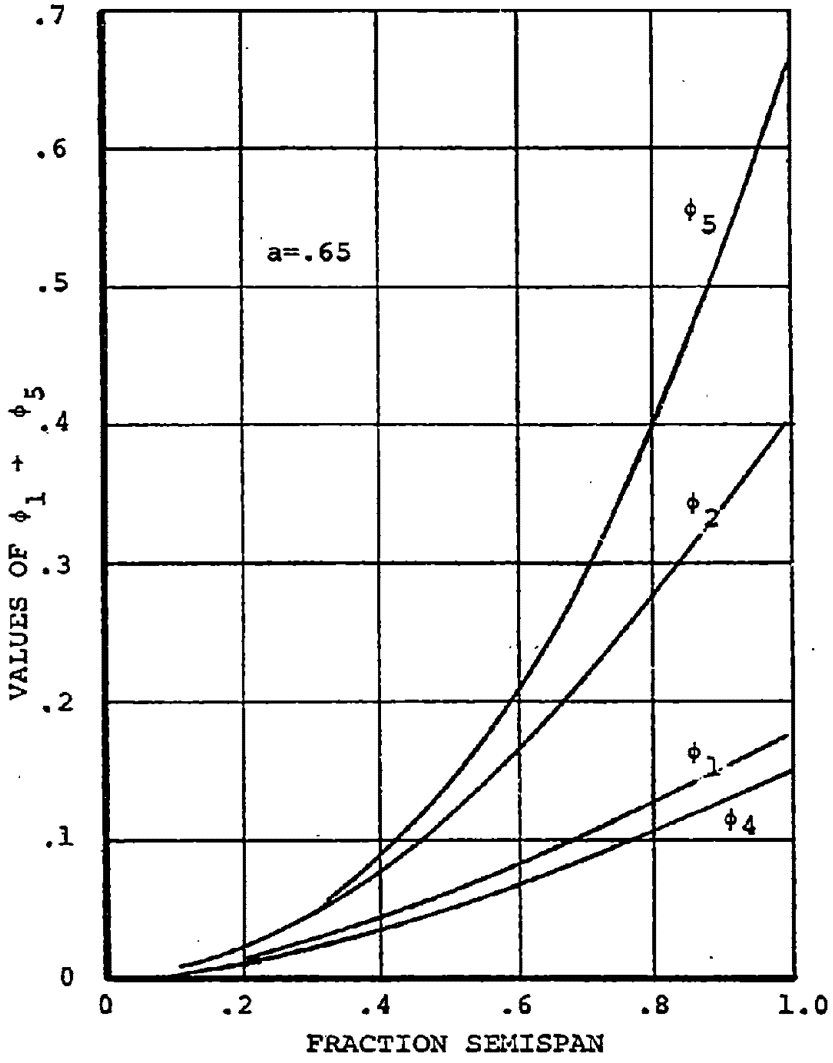


Figure A.2. Wing Bending Functions

APPENDIX B
DERIVATION OF LANDING GEAR EQUATIONS

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

$$h_\theta = X \sin\theta - Z \cos\theta - r \qquad \text{(B-1)}$$

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

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

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

$$h = H_{CG} + h_\theta - h_\phi \qquad \text{(B-3)}$$

and the oleo deflection during ground contact is given by

$$h_T = \frac{H_{CG} + h_\theta - h_\phi}{\cos\phi \cos\theta} \qquad \text{(B-4)}$$

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

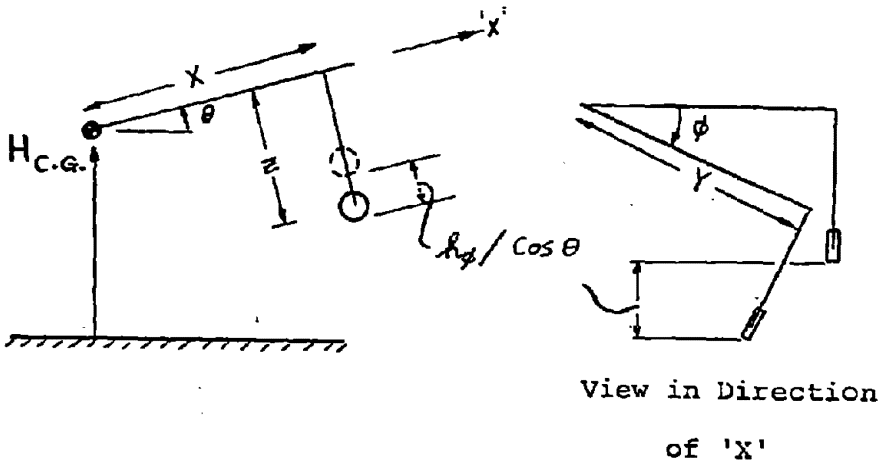


Figure B.1. Geometry of Landing Gear

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;

$$\Delta X_n = F_{\mu_n} - F_{GZ_n}\theta \tag{B-9}$$

$$\Delta Y_n = F_{s_n} + F_{GZ_n}\phi \tag{B-10}$$

$$\Delta Z_n = F_{\mu_n}\theta - F_{s_n}\phi + F_{GZ_n} \tag{B-11}$$

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

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

$$\Delta N_n = -\Delta X_n Y_n + X_n \Delta Y_n \tag{B-14}$$

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 TRANSFORMATION AND CENTER OF GRAVITY/INERTIA EQUATIONS

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,

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

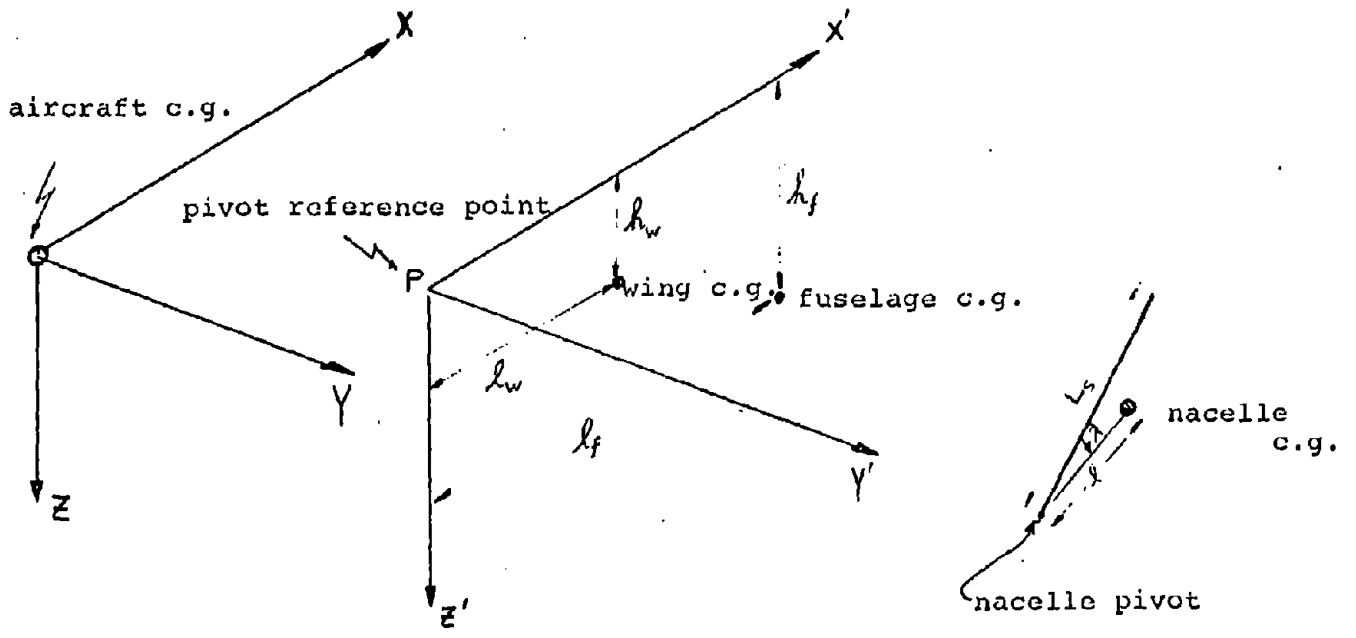


Figure C.1. Reference Axes Systems

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

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

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.

Velocity of Horizontal Tail Aerodynamic Center

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

Velocity of Vertical Tail Aerodynamic Center

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

Velocity of Left Wing Aerodynamic Center - Body Axes

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

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

$$\begin{aligned} u_{LW} &= u'_{LW} \cos i_w - w'_{LW} \sin i_w \\ v_{LW} &= v'_{LW} \\ w_{LW} &= w'_{LW} \cos i_w + w'_{LW} \sin i_w \end{aligned} \qquad \text{(C-8)}$$

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

Velocity of Left Rotor Hub - Body Axes

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

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.

$$u_{RL} = u'_{RL} \cos i_{NL} - w'_{RL} \sin i_{NL}$$

$$v_{RL} = v'_{RL} \qquad \text{(C-10)}$$

$$w_{RL} = w'_{RL} \sin i_{NL} + w'_{RL} \cos i_{NL}$$

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 $P_X P_Y P_Z P$ 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

$$X_f = \ell_f - X'_{CG}$$

$$X_f = h_f - Z_{CG} \qquad \text{(C-11)}$$

Wing CG Relative to Aircraft CG

$$X_w = \ell_w - X'_{CG} \qquad \text{(C-12)}$$

$$Z_w = h_w - Z'_{CG}$$

Nacelle CG Relative to Aircraft CG

$$X_{NR} = \ell \cos (i_{NR} - \lambda) - X'_{CG}$$

$$X_{NL} = \ell \cos (i_{NL} - \lambda) - X'_{CG} \qquad \text{(C-13)}$$

$$Z_{NR} = \ell \sin (i_{NR} - \lambda) - Z'_{CG}$$

$$Z_{NL} = \ell \sin (i_{NL} - \lambda) - Z'_{CG}$$

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

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

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

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

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

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

Center of Gravity Acceleration Relative to Pivot Point

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

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

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

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

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

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

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 $a_{x_{CG}} = \frac{Z_{AERO}}{m}$ 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,

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

where I_{xx}^{f}, 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

$$I_{xx}^N = I_{xx_o}^N + (I_{zz_o}^N - I_{xx_o}^N) \sin^2 i_N - I_{xz_o} \sin 2i_N$$

$$I_{yy}^N = I_{yy_o}^N \qquad \text{(C-18)}$$

$$I_{zz}^N = I_{zz_o}^N + (I_{xx_o}^N - I_{zz_o}^N) \sin^2 i_N + I_{xz_o} \sin 2i_N$$

$$I_{xz}^N = I_{xz_o}^N \cos 2i_N + \frac{1}{2} (I_{xx_o} - I_{zz_o}) \sin 2i_N$$

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

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

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

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

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

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

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

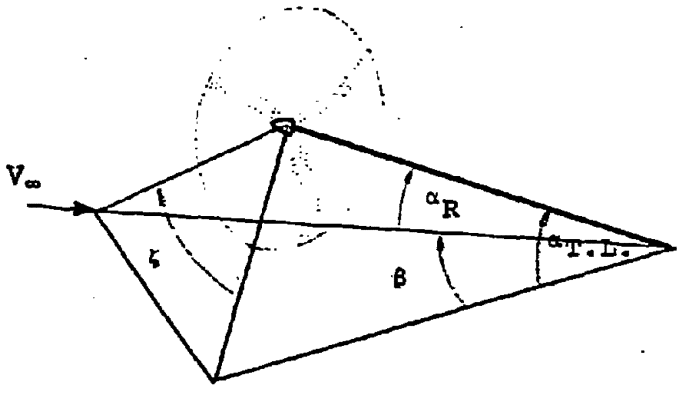
$$\left. + Z_{NR} \sin\ (i_{NR} - \lambda)\right] + 2m_N Y_N^2$$

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

APPENDIX D
CALCULATIONS OF SLIPSTREAM-IMMERSED WING AREAS

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

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

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

$$\alpha_{T.L.} = \alpha_f + i_N \qquad \text{(D-2)}$$

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

$$\zeta = \text{Tan}^{-1}\left[\frac{\text{Tan } \beta}{\text{Sin } \alpha_{T.L.}}\right] \qquad \text{(D-3)}$$

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] $PR = OO' \sin \zeta$ (D-5)

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

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

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

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

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

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

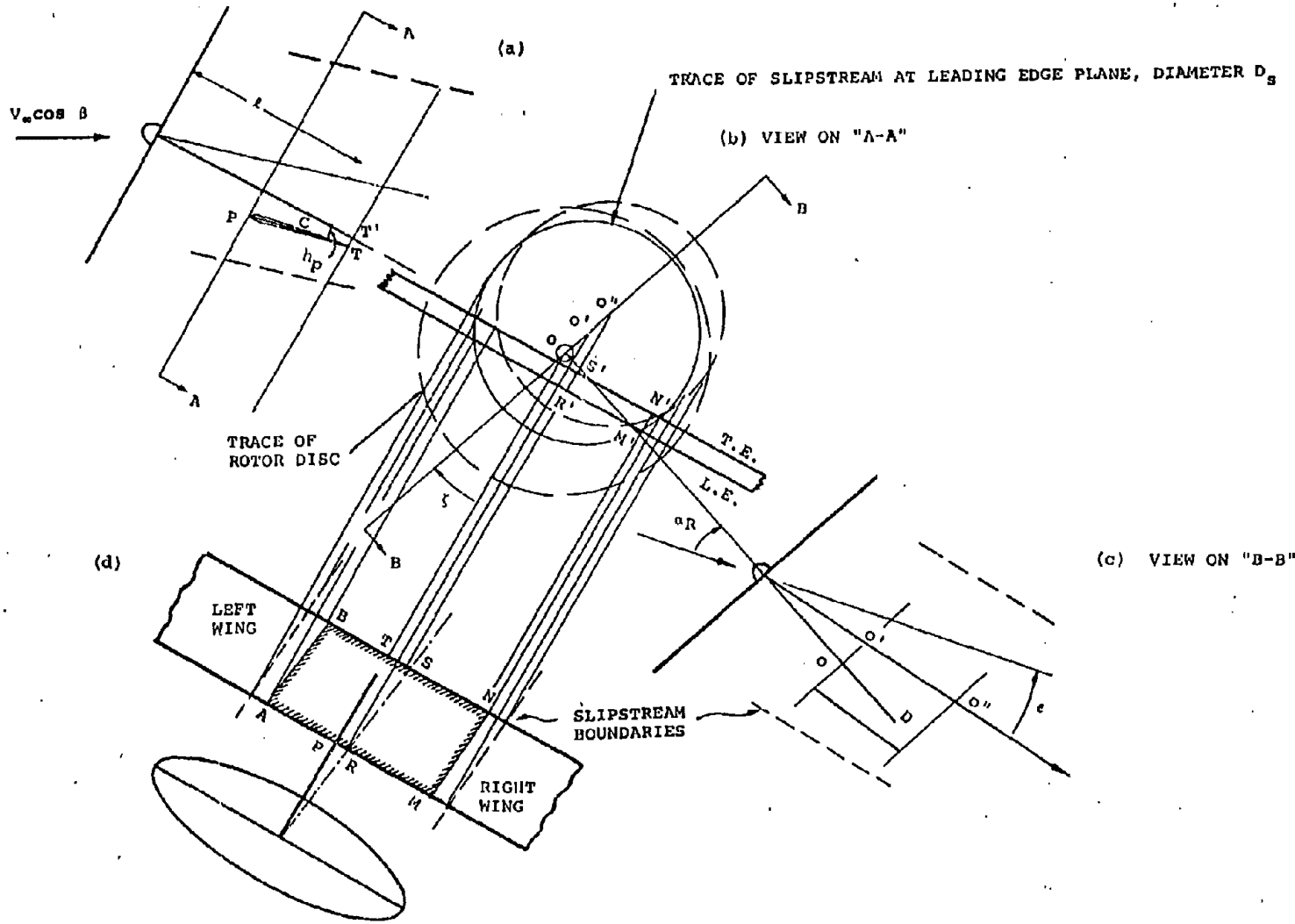


Figure D.1. Geometry of Rotor Slipstream/Wing Planform Interaction

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

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

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

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

If we write

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

then, using the above equations,

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

and

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

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.

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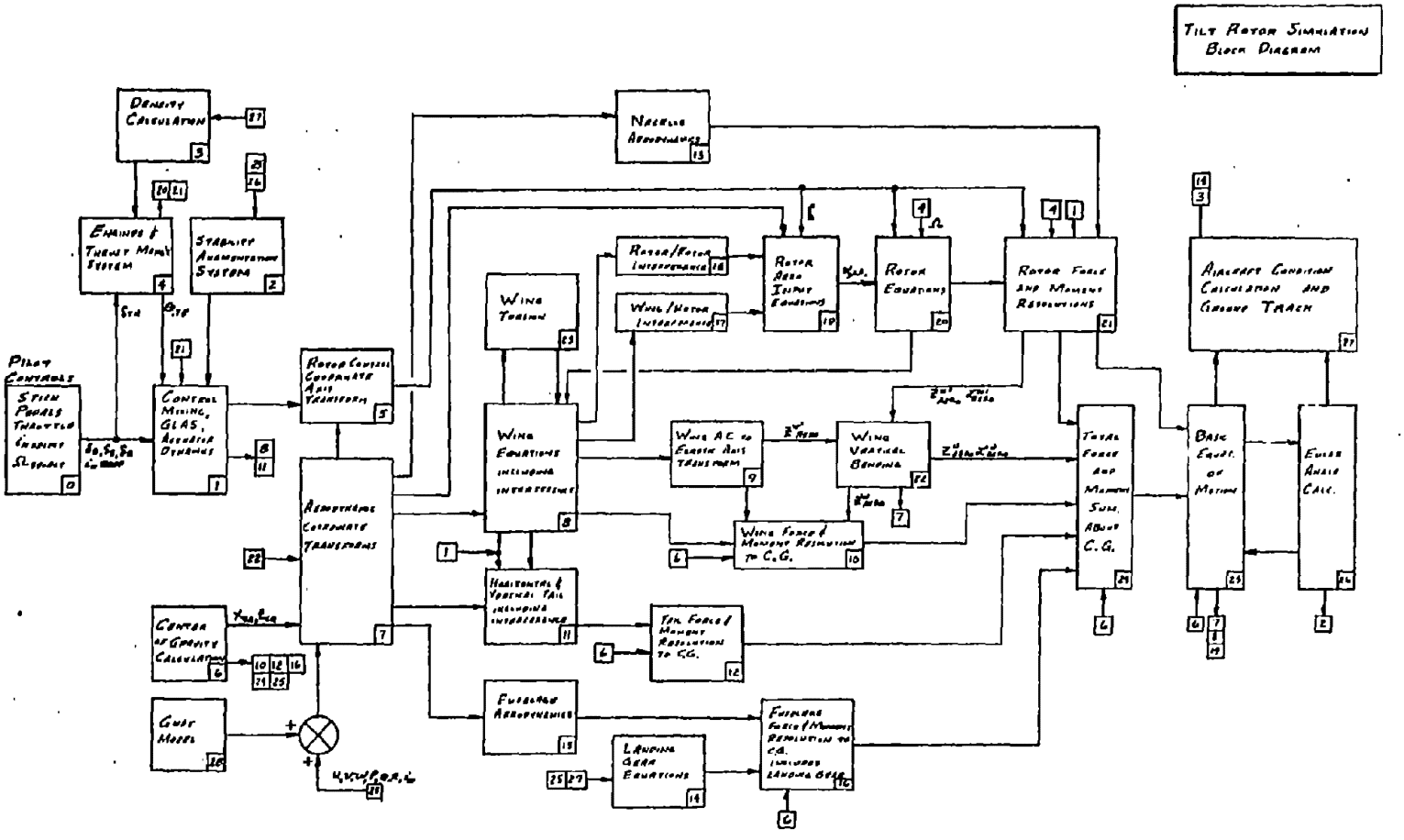
APPENDIX E
COMPUTER REPRESENTATION

APPENDIX E COMPUTER REPRESENTATION

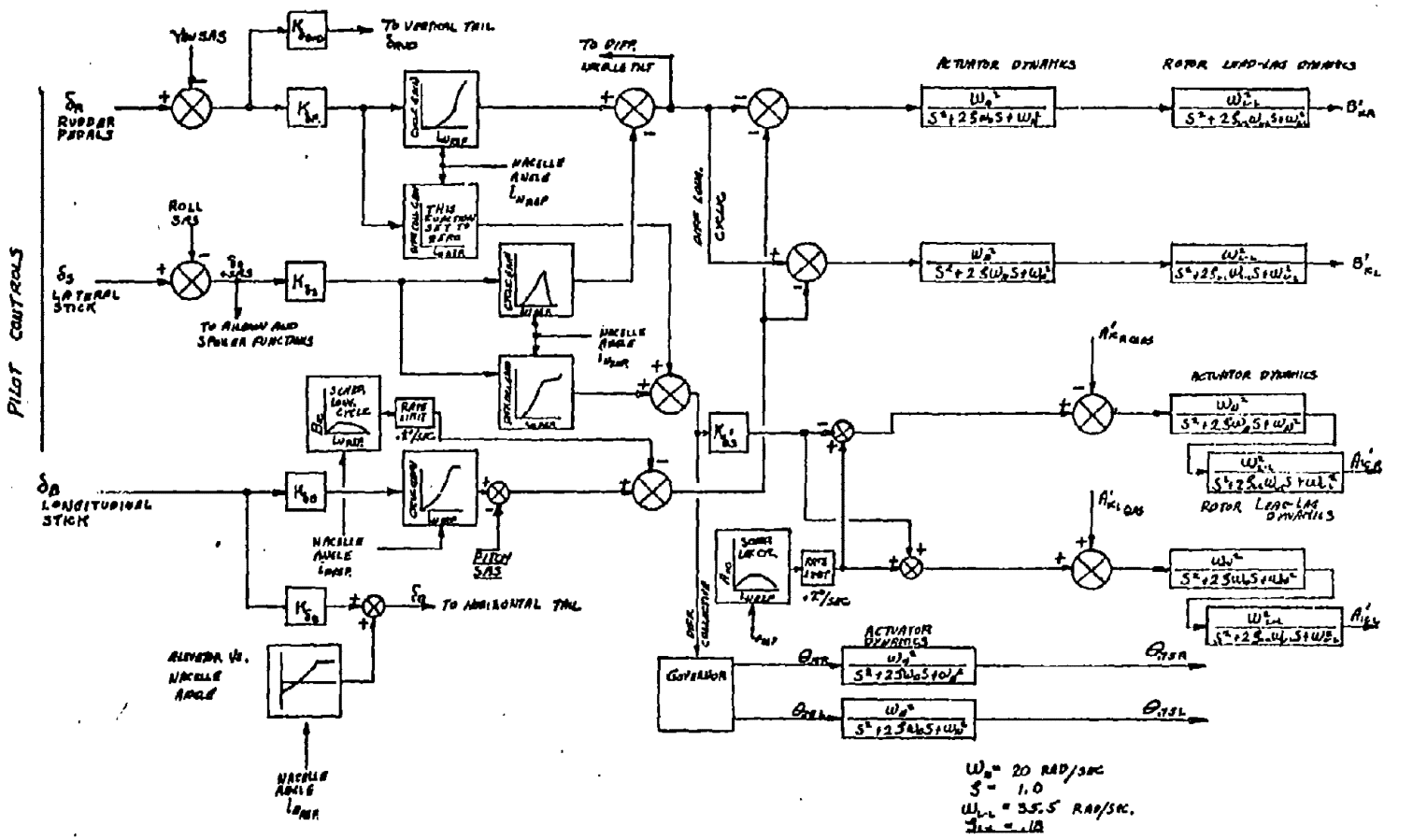
The equations derived in previous sections of this report have been collected and written in a format to facilitate computer programming. The complete set of equations which define the Model 222 simulation mathematical model are contained in this section. The computer block diagram for the simulation 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

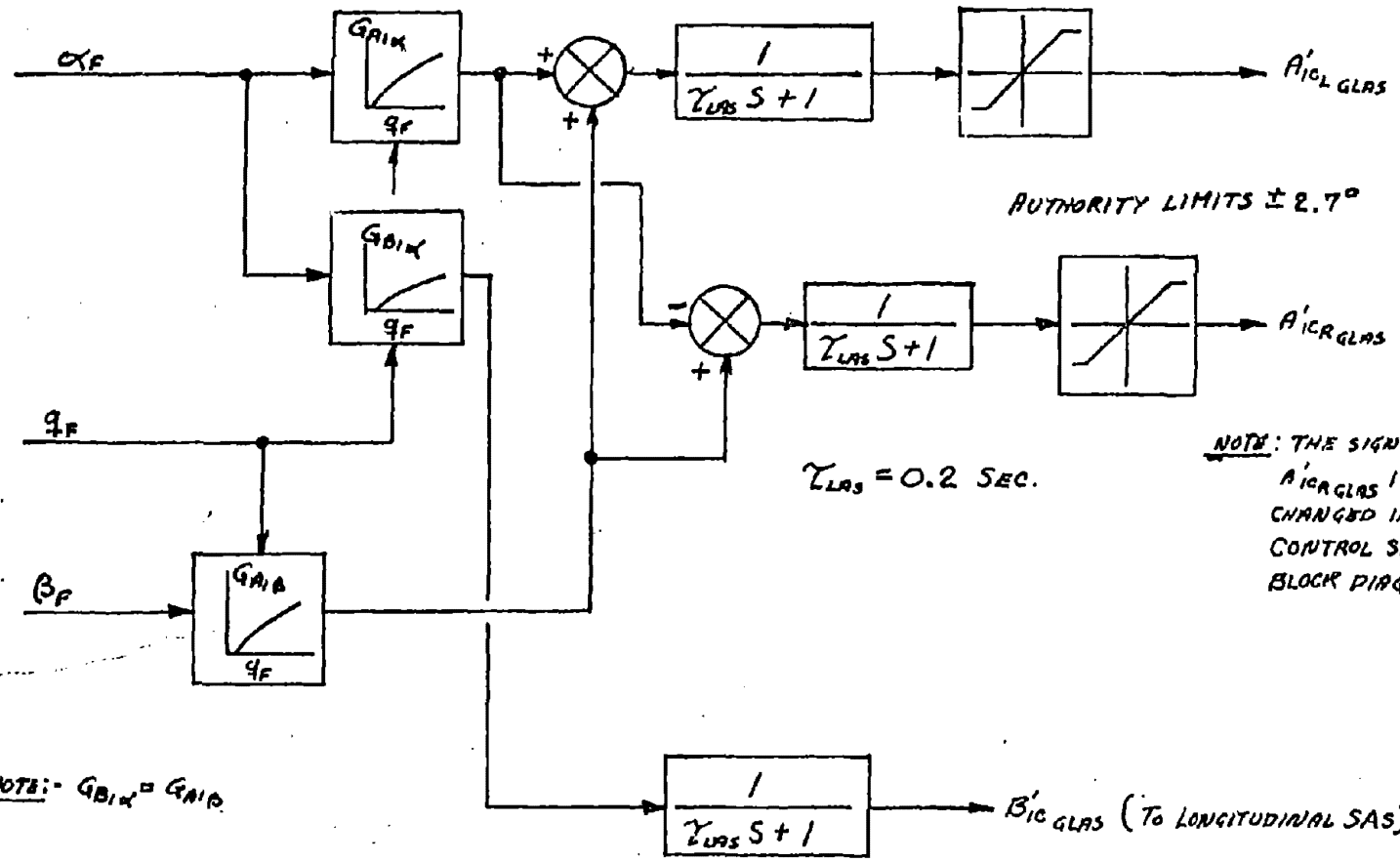

TILT ROTOR SIMULATION BLOCK DIAGRAM
DENSITY CALCULATION
ENGINES & THRUST MODEL SYSTEM
STABILITY AUGMENTATION SYSTEMS
PILOT CONTROLS
STICK, PEDALS, THROTTLE, ENGINEER SLEDGE
CONTROL MIXING, GLAS, ACTUATOR DYNAMICS
ROTOR CONTROL COORDINATE AXIS TRANSFORM
AEROTHRUST COORDINATE TRANSFORMS
CENTER OF GRAVITY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

PRELIMINARY CONTROL SYSTEM BLOCK DIAGRAM



MODEL 222 LOAD ALLEVIATION SYSTEM (LAS)

(FOR PIVOT MOMENTS - SINGLE COMMON LONG. ACTUATOR)



AUTHORITY LIMITS ± 2.7°

$\tau_{LAS} = 0.2$ SEC.

NOTE: THE SIGN OF $A'_{IC_{R\,GLAS}}$ IS CHANGED IN THE CONTROL SYSTEM BLOCK DIAGRAM

NOTE:- $G_{BI\alpha} = G_{AIB}$

E-5

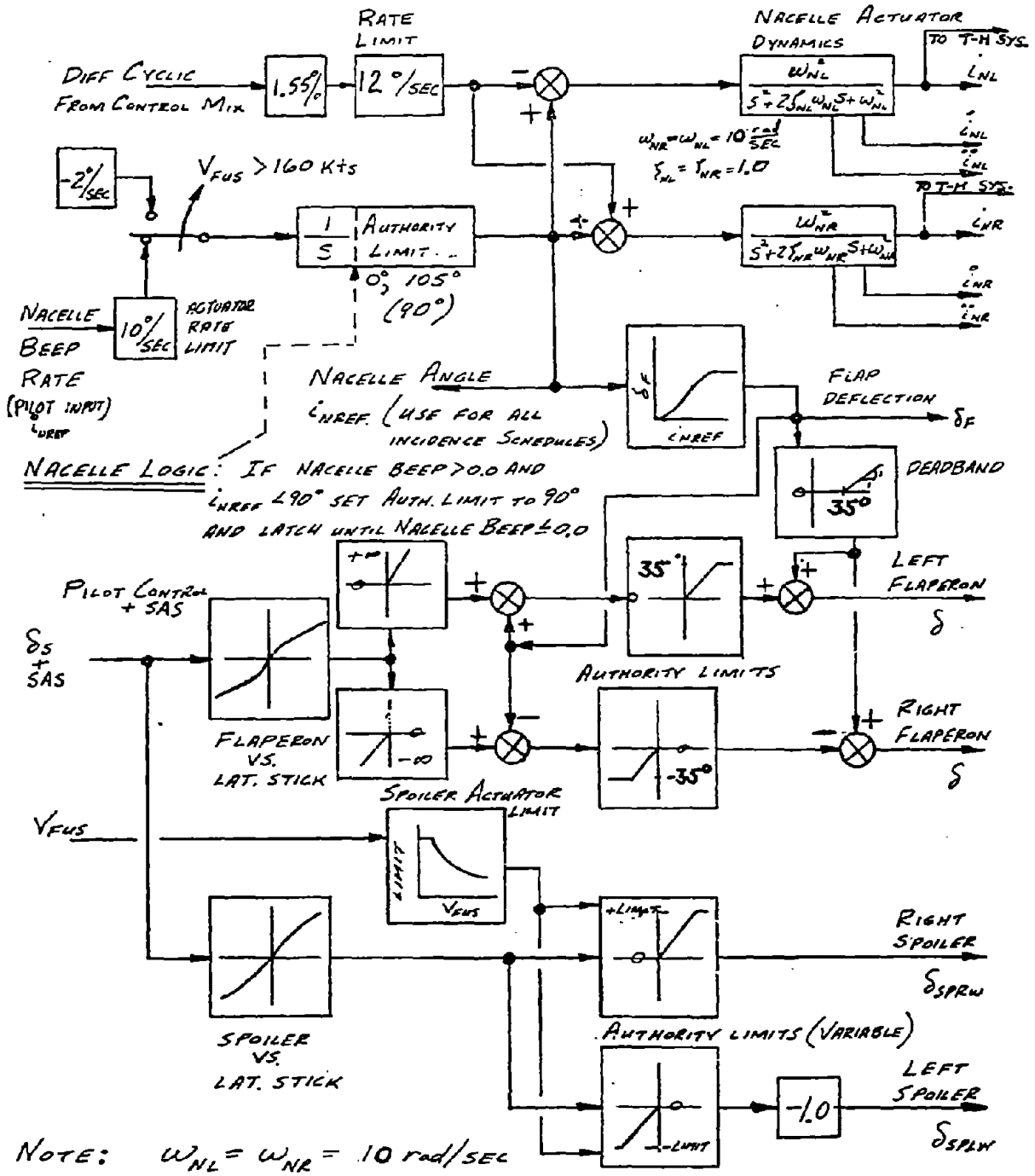
GOVERNING EQUATIONS

$A'_{IC_{L\,GLAS}} = G_{AI\alpha}\,\alpha + G_{AIB}\,\beta$

$A'_{IC_{R\,GLAS}} = G_{AI\alpha}\,\alpha - G_{AIB}\,\beta$

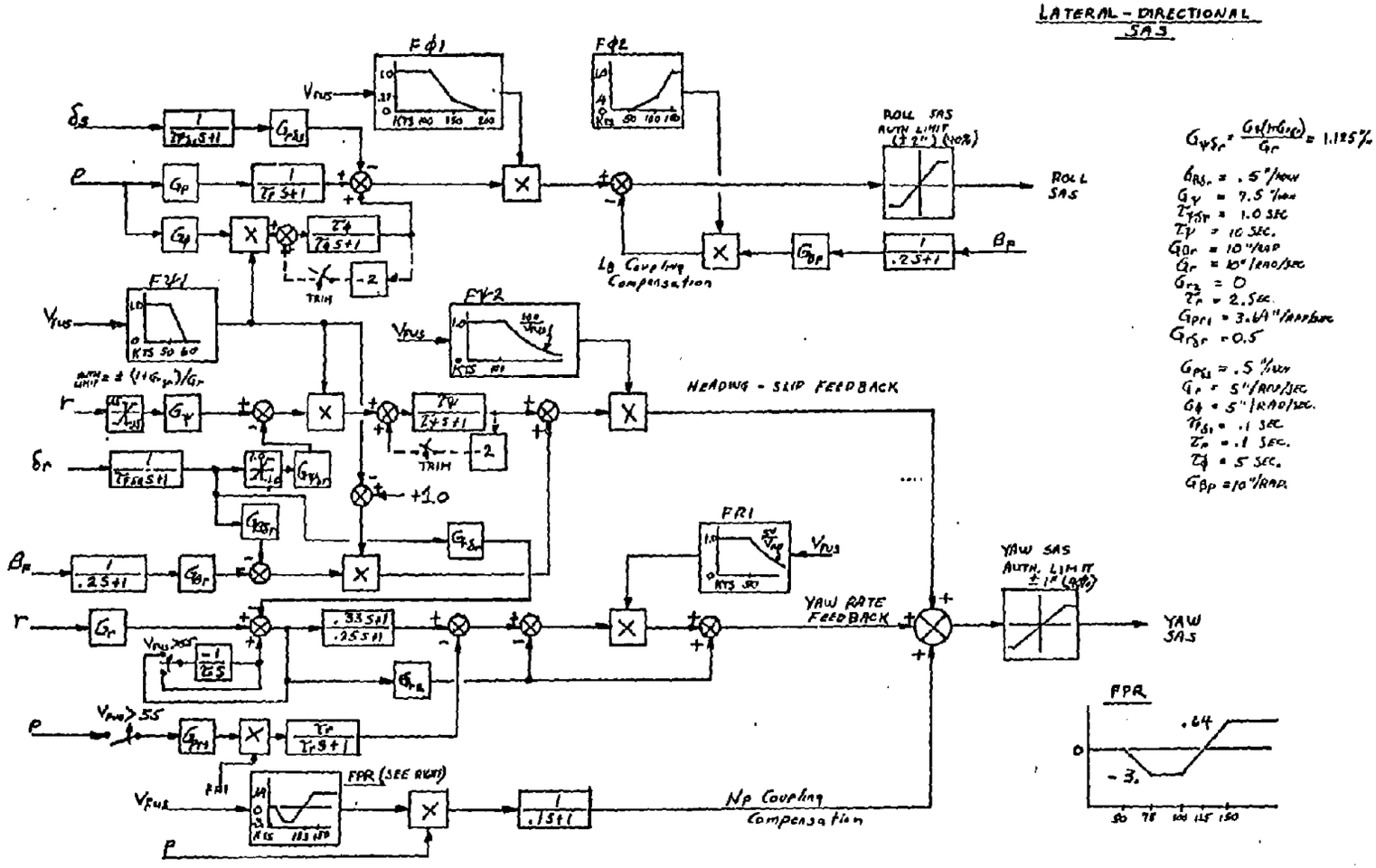
$B'_{IC\,GLAS} = G_{BI\alpha}\,\alpha$

MODEL 222
NACELLE, FLAP, FLAPERON, & SPOILER CONTROLS

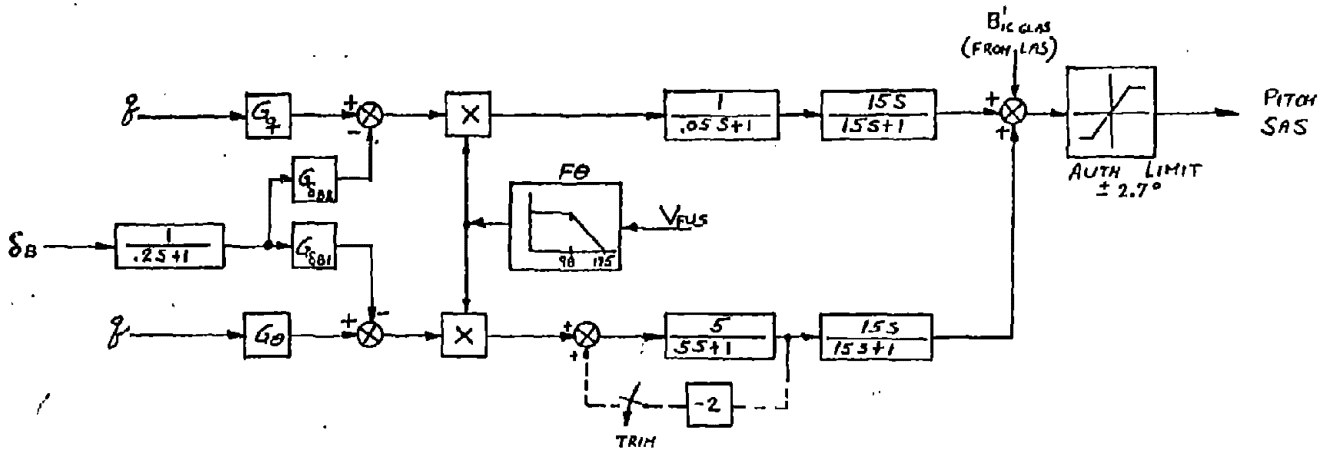


NOTE: $\omega_{NL} = \omega_{NR} = 10$ rad/sec

$\zeta_{NL} = \zeta_{NR} = 1.0$ (critical)


LATERAL - DIRECTIONAL SAS
ROLL SAS
YAW SAS
HEADING - SLIP FEEDBACK
YAW RATE FEEDBACK
Lβ Coupling Compensation
Nβ Coupling Compensation
TRIM
FPR (SEE RIGHT)
FPR
ROLL SAS AUTH. LIMIT (±2°) (10%)
YAW SAS AUTH. LIMIT ±1° (5%)
$G_{\psi S_r} = \frac{G_\delta(nG_{\delta_{RC}})}{G_r} = 1.125\%$
G_{RS_r} = .5°/KNOT
G_ψ = 7.5 °/sec
$\tau_{\psi_{SR}}$ = 1.0 SEC
τ_ψ = 10 SEC.
$G_{\delta r}$ = 10°/RAD
G_r = 10° LEAD/SEC
G_{r_β} = 0
τ_r = 2.5 SEC.
$G_{\beta P_1}$ = 3.6A°/RAD/SEC
$G_{r_{\delta r}}$ = 0.5
$G_{P_{SS}}$ = .5 °/sec
G_p = 5°/RAD/SEC
G_ϕ = 5°/RAD/SEC.
τ_{β_1} = .1 SEC
τ_β = .1 SEC.
τ_ϕ = 5 SEC.
$G_{\beta P}$ = 10°/RAD
E-7

LONGITUDINAL SAS

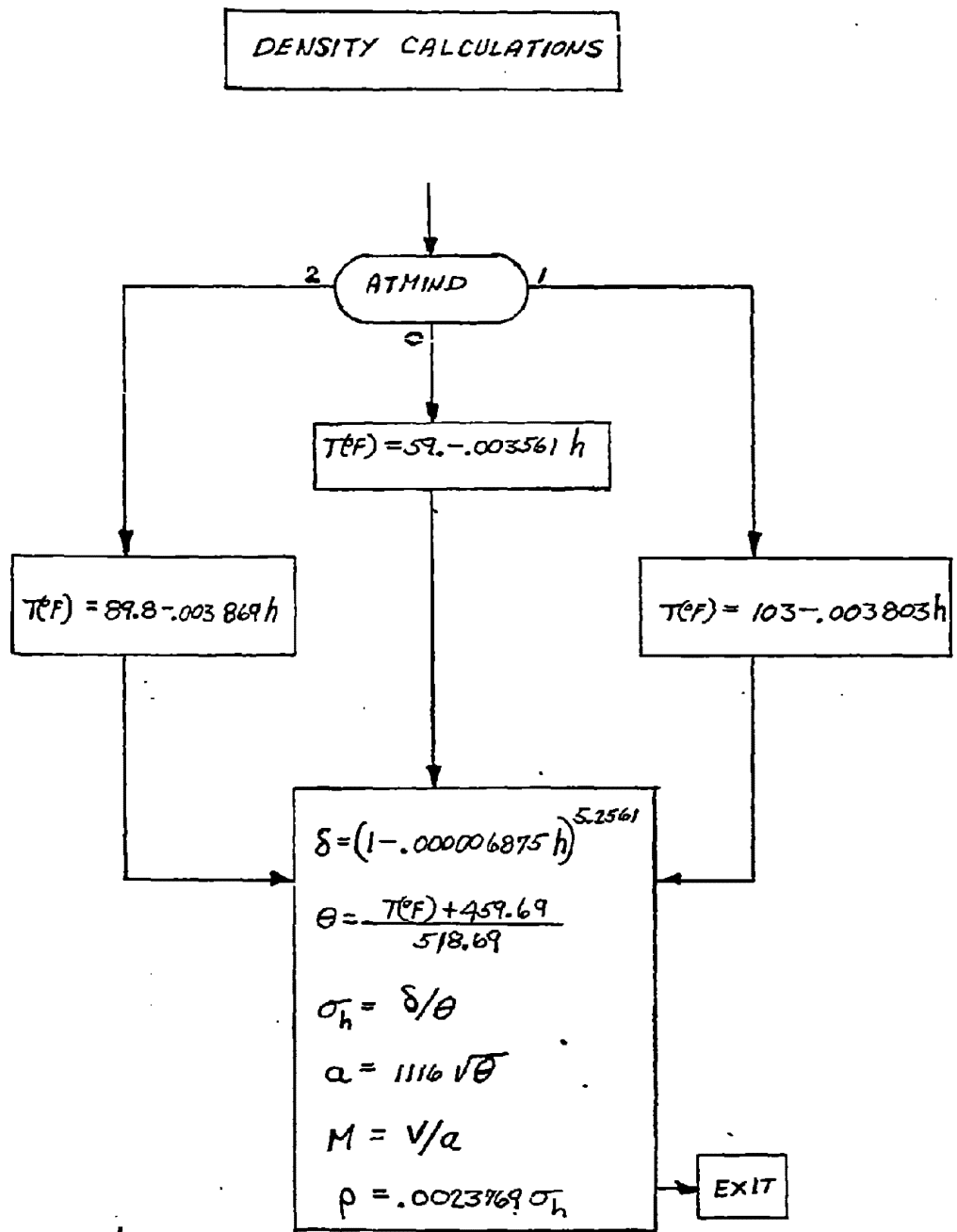


$G_q = 0.50$ DEG/RAD/SEC

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

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

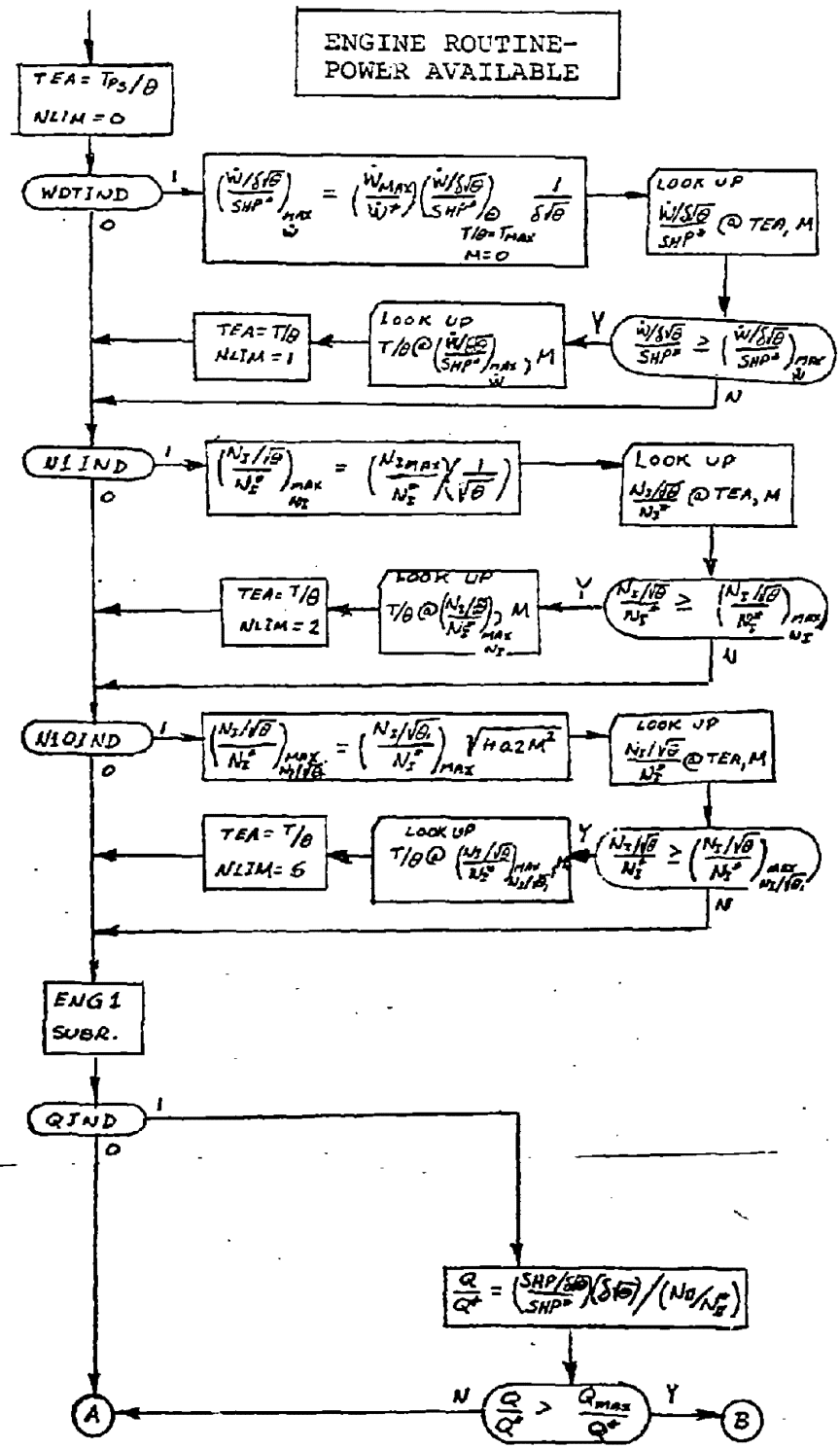
$G_{\delta_{B_2}} = 0$ DEG/INCH

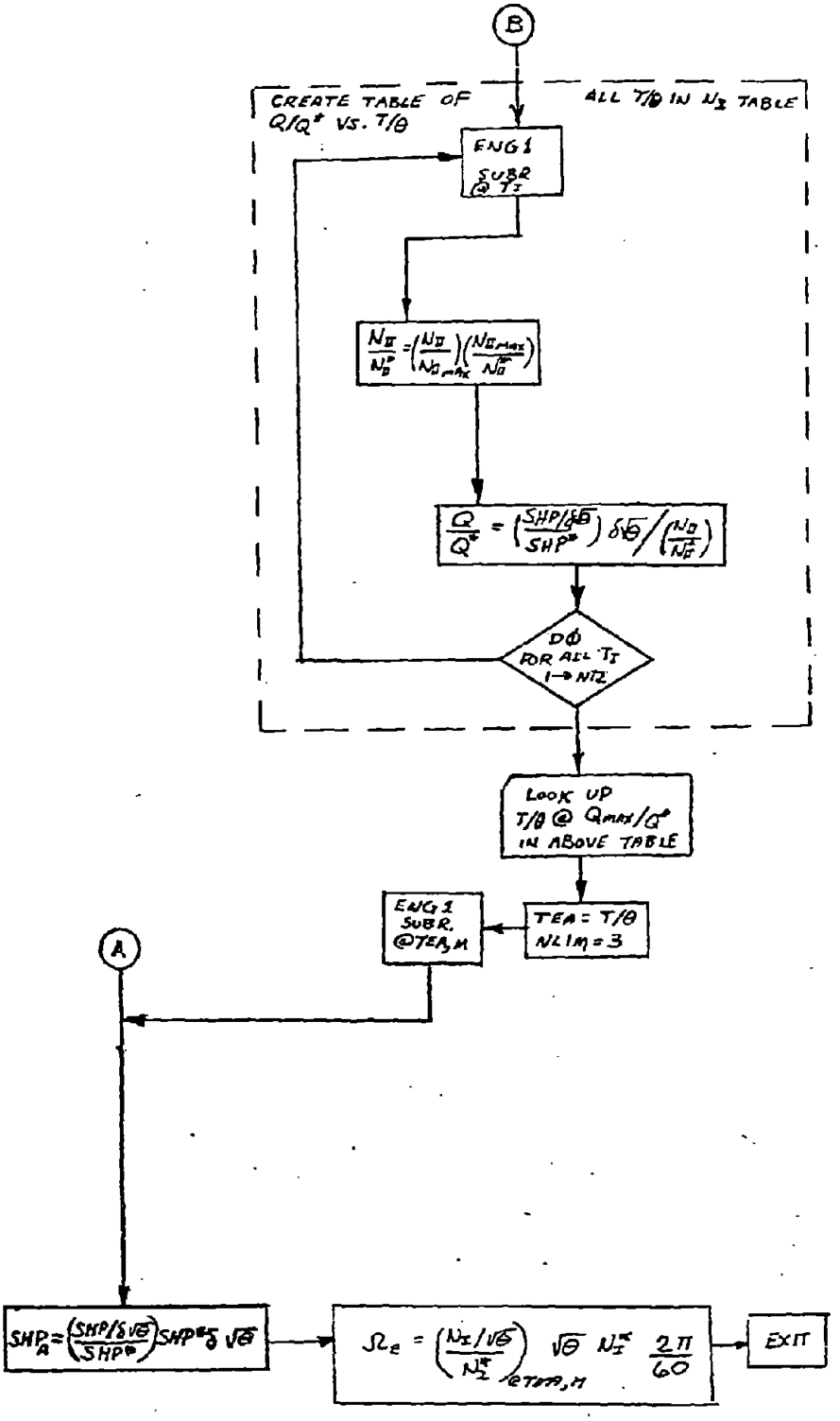


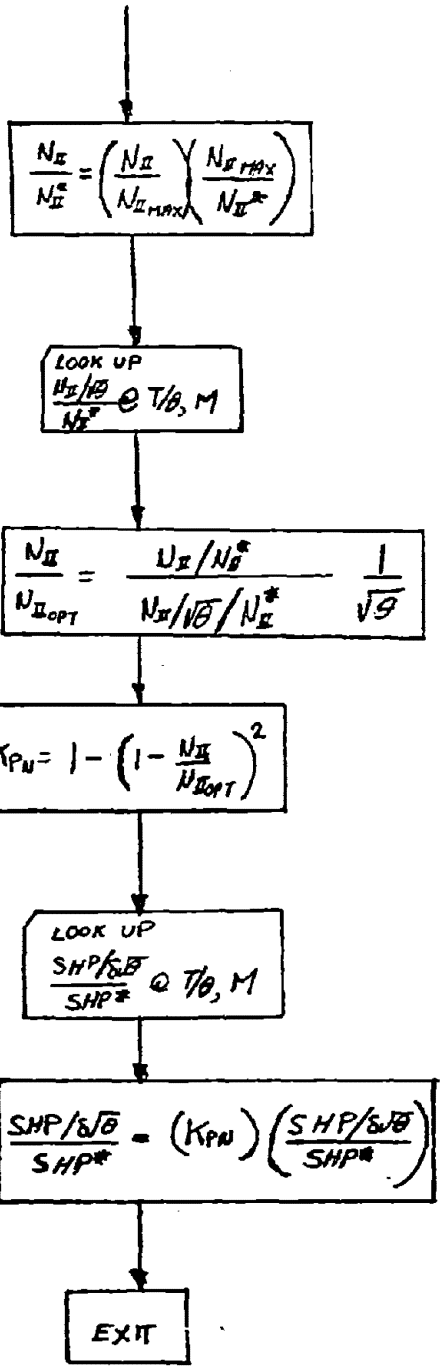
INPUT: h

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

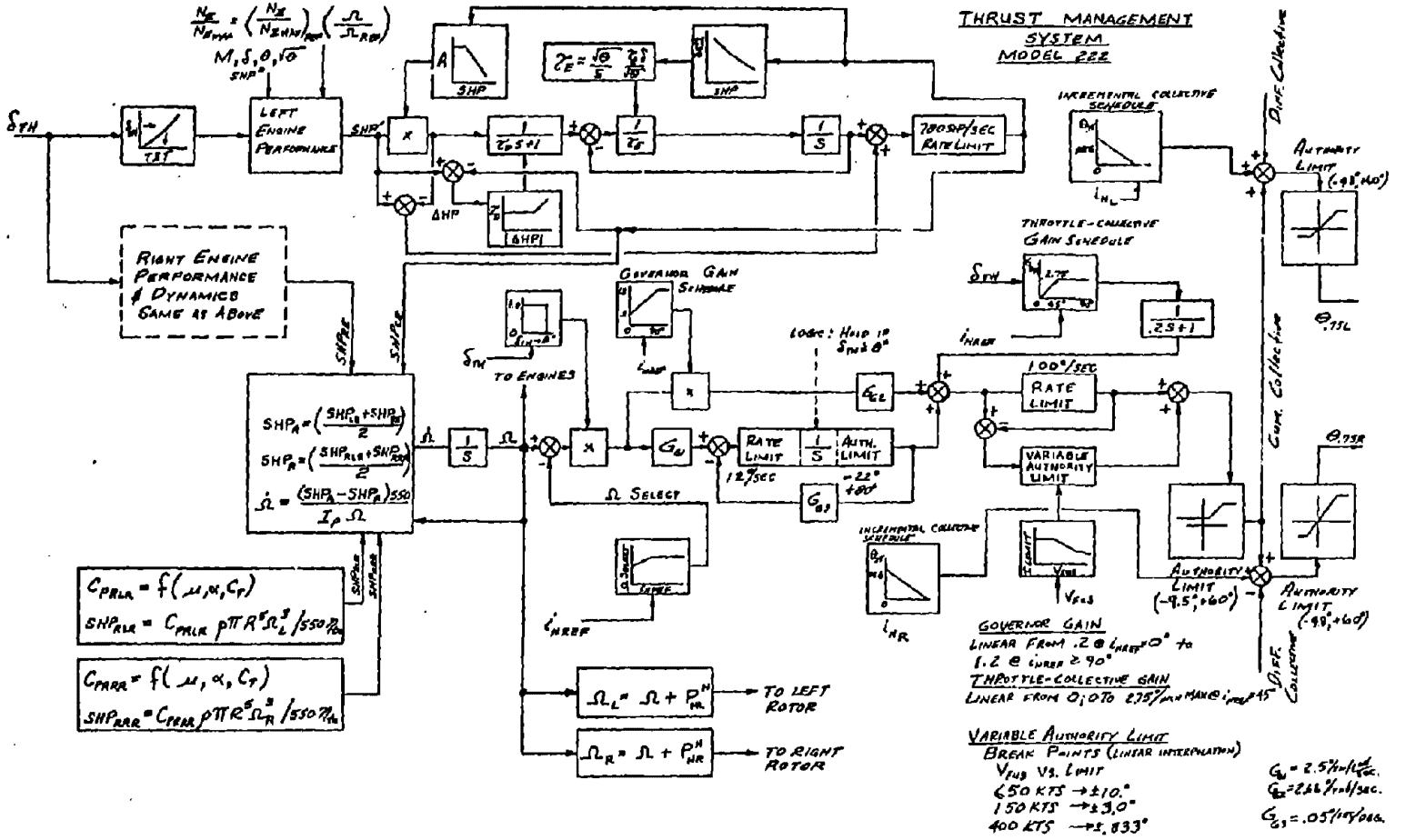
OUTPUT: $\delta, \theta, \sigma, a, M, \rho$


ENGINE ROUTINE-
POWER AVAILABLE
TEA = TPS/θ
NLIM = 0
WDTIND
LOOK UP
TEA, M
TEA = T/θ
NLIM = 1
LOOK UP
NLIND
LOOK UP
TEA, M
TEA = T/θ
NLIM = 2
LOOK UP
N1OIND
LOOK UP
TEA, M
TEA = T/θ
NLIM = 6
LOOK UP
ENG1
SUBR.
QIND
Y
N
I
O
A
B


B
CREATE TABLE OF Q/Q* VS. T/θ
ALL T/θ IN N1 TABLE
ENG 1 SUBR @ TI
$\frac{N_{II}}{N_{II}^*} = \left(\frac{N_{II}}{N_{II\,max}}\right)\left(\frac{N_{II\,max}}{N_{II}^*}\right)$
$\frac{Q}{Q^*} = \left(\frac{SHP/\delta\sqrt{\theta}}{SHP^*}\right)\delta\sqrt{\theta}\Big/\left(\frac{N_{II}}{N_{II}^*}\right)$
DΦ FOR ALL TI 1→NTI
LOOK UP T/θ @ Qmax/Q* IN ABOVE TABLE
ENG 1 SUBR @TEA,M
TEA = T/θ
NLIM = 3
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



ENG 1 SUBROUTINE, FLOW CHART


THRUST MANAGEMENT
SYSTEM
MODEL 222
LEFT ENGINE PERFORMANCE
RIGHT ENGINE PERFORMANCE & DYNAMICS SAME AS ABOVE
780SHP/SEC RATE LIMIT
INCREMENTAL COLLECTIVE SCHEDULE
THROTTLE-COLLECTIVE GAIN SCHEDULE
GOVERNOR GAIN SCHEDULE
LOGIC: HOLD IF δTH ≥ θ°
TO ENGINES
100°/SEC RATE LIMIT
RATE LIMIT
AUTH. LIMIT
12%/SEC
-22° +80°
VARIABLE AUTHORITY LIMIT
Ω SELECT
AUTHORITY LIMIT (-9.5°,+60°)
AUTHORITY LIMIT (-9.9°,+60°)
DIFF. COLLECTIVE
COM. COLLECTIVE
TO LEFT ROTOR
TO RIGHT ROTOR
GOVERNOR GAIN
LINEAR FROM .2 @ iNREF 0° to
1.2 @ iNREF ≥ 90°
THROTTLE-COLLECTIVE GAIN
LINEAR FROM 0; 0 TO 2.75°/MIN MAX @ iNREF 45°
VARIABLE AUTHORITY LIMIT
BREAK POINTS (LINEAR INTERPOLATION)
VFUS VS. LIMIT
650 KTS → ±10.°
150 KTS → ±3.0°
400 KTS → ±.833°
GW = 2.5%/KT/SEC.
GΩ = 2.86%/rad/sec.
GΩ3 = .05°/KT/DEG.

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

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

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

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

$$u'_{LW} = u_p + Z_{WAC}\, q + Y_{WAC}\, r + q\, h_{ILWAC}$$

$$v'_{LW} = v_p + X_{WAC}\, r - Z_{WAC}\, p - p\, h_{ILWAC}$$

$$w'_{LW} = w_p - Y_{WAC}\, p - X_{WAC}\, q + \dot{h}_{ILWAC}$$

RIGHT WING A.C. VELOCITY – BODY AXES

$$u'_{RW} = u_p + Z_{WAC}\, q - Y_{WAC}\, r + q\, h_{IRWAC}$$

$$v'_{RW} = v_p + X_{WAC}\, r - Z_{WAC}\, p - p\, h_{IRWAC}$$

$$w'_{RW} = w_p + Y_{WAC}\, p - X_{WAC}\, q + \dot{h}_{IRWAC}$$

LEFT ROTOR HUB VELOCITY – BODY AXES

$$u'_{RL} = u_p + r\, Y_N - L_S \sin i_{NL} \left(\dot{i}_{NL} + q\right) + q\, h_{IL}$$

$$v'_{RL} = v_p + L_S \left(r \cos i_{NL} + p \sin i_{NL}\right) - p\, h_{IL}$$

$$w'_{RL} = w_p - p\, Y_N - L_S \left(\dot{i}_{NL} + q\right) \cos i_{NL} + \dot{h}_{IL}$$

RIGHT ROTOR HUB VELOCITY – BODY AXES

$$u'_{RR} = u_p - r\, Y_N - L_S \sin i_{NR} \left(\dot{i}_{NR} + q\right) + q\, h_{IR}$$

$$v'_{RR} = v_p + L_S \left(r \cos i_{NR} + p \sin i_{NR}\right) - p\, h_{IR}$$

$$w'_{RR} = w_p + p\, Y_N - L_S \left(\dot{i}_{NR} + q\right) \cos i_{NR} + \dot{h}_{IR}$$

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

$$\tau_{RR} = \alpha_{RR} + \tan^{-1}\left(\frac{NF_R}{T_R}\right)$$

$$R_{RR} = \sqrt{T_R^2 + N.F_R^2 + SF_R^2}$$

$$V_{*_R} = \frac{V_{RR}}{\sqrt{\frac{|R_{RR}|+10}{2\rho A}}}$$

$$v_{*_R}^4 + 2 V_{*_R} v_{*_R}^3 \cos\tau_{RR} + v_{*_R}^2 V_{*_R}^2 = 1 \quad \text{(Solve for } v_{*_R}\text{)}$$

$$\epsilon_{P_{RR}} = \tan^{-1} \frac{v_{*_R} \sin\tau_{RR}}{V_{*_R} + v_{*_R}\cos\tau_{RR}}$$

$$C_{TS\,RR} = \frac{\cos(\tau_{RR} - \alpha_{RR})}{\cos(\tau_{RR} - \alpha_{RR}) + \frac{V_{*R}^2}{4}}$$

$$\tau_{LR} = \alpha_{LR} + \tan^{-1}\left(\frac{N.F_L}{T_L}\right)$$

$$R_{LR} = \sqrt{T_L^2 + N.F_L^2 + S.F_L^2}$$

$$V_{*_L} = \frac{V_{LR}}{\sqrt{\frac{|R_{LR}|+10}{2\rho A}}}$$

$$v_{*_L}^4 + 2 V_{*_L} v_{*_L}^3 \cos\tau_{LR} + v_{*_L}^2 V_{*_L}^2 = 1 \quad \text{(solve for } v_{*_L}\text{)}$$

$$\epsilon_{P_{LR}} = \tan^{-1} \frac{v_{*_L} \sin\tau_{LR}}{V_{*_L} + v_{*_L}\cos\tau_{LR}}$$

$$C_{TS\,LR} = \frac{\cos(\tau_{LR} - \alpha_{LR})}{\cos(\tau_{LR} - \alpha_{LR}) + \frac{V_{*L}^2}{4}}$$

WING EQUATIONS (Cont'd.)

$$\bar{\xi} = (\xi_{HR} + \xi_{HL}) .5$$

$$\bar{\alpha}_R = (\alpha_{RR} + \alpha_{LR}) .5$$

$$\left.\begin{aligned} \bar{\epsilon}_p &= (\epsilon_{PRR} + \epsilon_{PLR}) .5 \\ \bar{C}_{TS} &= (C_{TSRR} + C_{TSLR}) .5 \end{aligned}\right\} \text{Used in Tail Aerodynamics}$$

$$\left.\begin{aligned} \bar{i}_N &= (i_{NL} + i_{NR}) .5 \\ C_{LW} &= \frac{(C_{LSRW} + C_{LSLW})}{(1-\bar{C}_{TS})} .5 \end{aligned}\right\} \text{Used in Wing/Rotor Interfer.}$$

$$\xi_{R1} = \left[L_S - PC\cos(\bar{i}_N - i_W) + h_p \sin(\bar{i}_N - i_W)\right] \tan(\bar{\alpha}_R - \bar{\epsilon}_p) \sin\bar{\xi}$$

$$\xi_{R2} = \sqrt{\frac{D^2}{4} - \left\{\left[L_S - PC\cos(\bar{i}_N - i_W) + h_p \sin(\bar{i}_N - i_W)\right] \tan(\bar{\alpha}_R - \bar{\epsilon}_p)\cos\bar{\xi} + PC\sin(\bar{i}_N - i_W) + h_p \cos(\bar{i}_N - i_W)\right\}^2}$$

IF: $\xi_{R2} = 0$ OR Imaginary, $S_{iRW} = 0$ and $S_{iLW} = 0$,
also $\left(\frac{C_{LWi}}{C_{LW}}\right)_{RW} = 0$ and $\left(\frac{C_{LWi}}{C_{LW}}\right)_{LW} = 0.0$

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 $\left(\frac{C_{LWi}}{C_{LW}}\right)_{RW} = 0.0$ and $\left(\frac{C_{LWi}}{C_{LW}}\right)_{LW} = 0.0$

IF: UMBRELLAS OPEN; SET $C_{LW} = 0.0$

UMBRELLA LOGIC:

IF: $i_{NREF} < F_{iN}$ OR $q_F > 8.479^{LB/FT^2}$,
SET UMBRELLAS CLOSED (Hysterosis $F_{iN} \pm 1°$; $q_F \pm .1 \frac{LB}{FT^2}$)

WING EQUATIONS (CONT'd)

$$Si_{RW} = \frac{C_W}{2}\left[\Xi_{R1} + \Xi_{R2} + \Xi_{R3} + \Xi_{R4}\right]$$

$$\left(\frac{Si}{S}\right)_{RW} = 2\left(\frac{Si_R}{S_W}\right)$$

$$Si_T = C_W\left[\Xi_{R2} + \Xi_{R4}\right]$$

$$Si_{LW} = Si_T - Si_R$$

$$\left(\frac{Si}{S}\right)_{LW} = 2\left(\frac{Si_L}{S_W}\right)$$

$$(AR_i)_{LW} = \left(\frac{Si_L}{C_W^2}\right)$$

$$(AR_i)_{RW} = \left(\frac{Si_R}{C_W^2}\right)$$

$$AR_W = \frac{S_W}{C_W^2} \quad \text{(PRELIMINARY)}$$

$$\left(\frac{C_{L\alpha_i}}{C_{L\alpha}}\right)_{LW} = \frac{1}{1 + \frac{C_{L\alpha_W}}{\pi}\left[\frac{1}{(AR_i)_{LW}} - \frac{1}{AR_W}\right]}$$

$$\left(\frac{C_{L\alpha_i}}{C_{L\alpha}}\right)_{RW} = \frac{1}{1 + \frac{C_{L\alpha}}{\pi}\left[\frac{1}{(AR_i)_{RW}} - \frac{1}{AR_W}\right]}$$

$$K'_{AL} = \frac{V_{\Phi_L} + \left(\frac{C_{L\alpha_i}}{C_{L\alpha}}\right)_{LW} N_{\Phi_L}}{V_{\Phi_L} + N_{\Phi_L}}$$

$$K'_{AR} = \frac{V_{\Phi_R} + \left(\frac{C_{L\alpha_i}}{C_{L\alpha}}\right)_{RW} N_{\Phi_R}}{V_{\Phi_R} + N_{\Phi_R}}$$

WING EQUATIONS (CONTINUED)

$$\bar{q}_{fs} = \left[\frac{1}{2}\rho\left(u^2+v^2+w^2\right) + \frac{(T_L + T_R).5}{A} \right]$$

$$q_{fs_{RW}} = \left[\frac{1}{2}\rho\left(u_{RW}^2 + v_{RW}^2 + w_{RW}^2\right) + \frac{T_R}{A} \right]$$

$$q_{fs_{LW}} = \left[\frac{1}{2}\rho\left(u_{LW}^2 + v_{LW}^2 + w_{LW}^2\right) + \frac{T_L}{A} \right]$$

WING EQUATIONS (Cont'd.)

WING ANGLE OF ATTACK AND SIDESLIP

$$\alpha_{LWo} = \sin^{-1}\left[\frac{w_{LW}}{\sqrt{u_{LW}^2 + w_{LW}^2}}\right] + \theta_{tLWAC}$$

$$\alpha_{RWo} = \sin^{-1}\left[\frac{w_{RW}}{\sqrt{u_{RW}^2 + w_{RW}^2}}\right] + \theta_{tRWAC}$$

$$\beta_{LWo} = \sin^{-1}\left[\frac{v_{LW}}{\sqrt{u_{LW}^2 + v_{LW}^2 + w_{LW}^2}}\right]$$

$$\beta_{RWo} = \sin^{-1}\left[\frac{v_{RW}}{\sqrt{u_{RW}^2 + v_{RW}^2 + w_{RW}^2}}\right]$$

$$\alpha_{LWSS_o} = \alpha_{LWo} - \epsilon_{PLR}$$

$$\alpha_{RWSS_o} = \alpha_{RWo} - \epsilon_{PRR}$$

$$\bar{\alpha}_w = (\alpha_{LWo} + \alpha_{RWo}) .5$$

$$\alpha_{LWrigid} = \sin^{-1}\left[\frac{w_{LW}}{\sqrt{u_{LW}^2 + w_{LW}^2}}\right] - \epsilon_{PLR}$$

$$\alpha_{RWrigid} = \sin^{-1}\left[\frac{w_{RW}}{\sqrt{u_{RW}^2 + w_{RW}^2}}\right] - \epsilon_{PRR}$$

$$\alpha'_{LWo} = \alpha_{LWo} - i_w - \theta_{tLWAC}$$

$$\alpha'_{RWo} = \alpha_{RWo} - i_w - \theta_{tRWAC}$$

NOTE: IF α_{LWSS_o} OR $\alpha_{RWSS_o} \geq \alpha_{MAX}$; PRINT OUT STALL WARNING

WING EQUATIONS (CONT'D)

CALCULATION OF INCREMENTAL LIFT, DRAG AND MOMENT COEFFICIENTS

CALCULATE:

$C_{L_{LW_0}} = C_L @ \alpha = \alpha_{LW_{SS_0}}, \quad \delta = \delta_{a_{LW}} + \delta_f, \quad \delta_{SP} = \delta_{SP_L}$

$C_{L_{RW_0}} = C_L @ \alpha = \alpha_{RW_{SS_0}}, \quad \delta = \delta_{a_{RW}} + \delta_f, \quad \delta_{SP} = \delta_{SP_R}$

$C^*_{L_{LW_0}} = C_L @ \alpha = \alpha_{LW_0}, \quad \delta = \delta_{a_{LW}} + \delta_f, \quad \delta_{SP} = \delta_{SP_L}$

$C^*_{L_{RW_0}} = C_L @ \alpha = \alpha_{RW_0}, \quad \delta = \delta_{a_{RW}} + \delta_f, \quad \delta_{SP} = \delta_{SP_R}$

$C_{L_\delta} = C_L @ \alpha_F + i_W, \quad \delta = \delta_f$

CALCULATE:

$\alpha^+_{D.L} = 14.6^\circ - 0.12\ \delta \qquad (0^\circ \le \delta \le 40^\circ)$

$= 9.8^\circ \qquad (\delta > 40^\circ)$

$\alpha^-_{D.L} = -16.7^\circ - .1138\delta \qquad (0^\circ \le \delta < 40^\circ)$

$= -21.25^\circ \qquad (\delta > 40^\circ)$

IF: $\alpha^-_{D.L} \le \alpha \le \alpha^+_{D.L}$

$C_L = 0.134 + C_{L_{\alpha_W}}\alpha + \Delta C_{L_\delta} + F\Delta C_{L_{SP}}$

WHERE:

$\Delta C_{L_\delta} = .0269\,\delta \qquad (0^\circ \le \delta \le 22.22906^\circ)$

$= -2.437137 + .20607\,\delta - .003128\,\delta^2 \qquad (22.22906^\circ < \delta \le 29.786^\circ)$

$= .442188 + .0263\,\delta - .000338\,\delta^2 \qquad (\delta > 29.786^\circ)$

$\Delta C_{L_{SP}} = -0.01132\ \delta_{SP} \qquad (0^\circ \le \delta_{SP} \le 30^\circ)$

$= .076 - .018666\ \delta_{SP} + .00016\ \delta^2_{SP} \qquad (\delta_{SP} > 30^\circ)$

$F = 1.003412 + .011163\,\delta + .002168\,\delta^2 \qquad (0^\circ \le \delta \le 20.1645^\circ)$

$F = -.756323 + .185684\,\delta - .002159\,\delta^2 \qquad (\delta > 20.1645^\circ)$

WING EQUATIONS (CONT'D)

IF: $\alpha^{+}_{W.L} < \alpha \leq \alpha^{T}_{W.L} + 8.534°$

CALCULATE: $C'_{L\,W.L} = 0.134 + C_{L\alpha_W}\alpha^{+}_{W.L} + \Delta C_{L\delta} + F\Delta C_{L_{SP}}$

$\alpha_{DUM} = \alpha - \alpha^{T}_{W.L} + 14.6°$

$\Delta C_{L_{W.L}} = -.00547619\,\alpha^{2}_{DUM} + .18254762\,\alpha_{DUM} - 1.4215715\overline{13}$

$C_L = C'_{L\,W.L} + \Delta C_{L_{W.L}}$ AND PRINT STALL WARNING

IF: $-(\alpha^{+}_{W.L} + 8.534°) < \alpha < 90°$

CALCULATE: $C'_{L\,W.L} = 0.134 + C_{L\alpha_W}\alpha^{+}_{W.L} + \Delta C_{L\delta} + F\Delta C_{L_{SP}}$

$C_L = \dfrac{C'_{L_{WA}}\,(90° - \alpha)}{90° - (\alpha^{+}_{W.L} + 8.534°)}$ AND PRINT STALL WARNING.

IF: $(\alpha^{-}_{W.L} - 8.534°) \leq \alpha < \alpha^{-}_{W.L}$

CALCULATE:

$C'_{L\,W.L} = 0.134 + C_{L\alpha_W}\alpha^{-}_{W.L} + \Delta C_{L\delta} + F\Delta C_{L_{SP}}$

$\alpha_{DUM} = \alpha^{-}_{W.L} - \alpha + 14.6°$

$\Delta C_{L_{W.L}} = -.00547619\,\alpha^{2}_{DUM} + 0.18254762\,\alpha_{DUM} - 1.4215715\overline{13}$

$C_L = C'_{L\,W.L} - \Delta C_{L_{W.L}}$ AND PRINT STALL WARNING

IF: $-90° \leq \alpha < (\alpha^{-}_{W.L} - 8.534°)$

CALCULATE:

$C'_{L\,W.L} = 0.134 + C_{L\alpha_W}\alpha^{-}_{W.L} + \Delta C_{L\delta} + F\Delta C_{L_{SP}}$

$C_L = \dfrac{C'_{L\,W.L}\,(90° + \alpha)}{90° + \alpha^{-}_{W.L} - 8.534°}$ AND PRINT STALL WARNING

NOTE:- α, α_{DUM}, δ, δ_{ALW}, δ_{ARW}, δ_E, $\alpha^{-}_{W.L}$, $\alpha^{+}_{W.L}$, δ_{SPL}, δ_{SPR}, IN DEGREES; $C_{L\alpha_W} \sim 1/$DEGREE

WING EQUATIONS (CONT'D)

CALCULATE:-

$$C_{D_{LW}} = C_D \ @ \ \alpha = \alpha_{LW_{SSO}}, \ \delta = \delta_f + \delta a_{LW}, \ \delta_{SP} = \delta_{SP_L}$$

$$C_{D_{RW}} = C_D \ @ \ \alpha = \alpha_{RW_{SSO}}, \ \delta = \delta_f + \delta a_{RW}, \ \delta_{SP} = \delta_{SP_R}$$

$$C_{D_{LW_0}}^{+'} = C_D \ @ \ \alpha = \alpha_{LW_0}, \ \delta = \delta_f + \delta a_{LW}, \ \delta_{SP} = \delta_{SP_L}$$

$$C_{D_{RW_0}}^{+'} = C_D \ @ \ \alpha = \alpha_{RW_0}, \ \delta = \delta_f + \delta a_{RW}, \ \delta_{SP} = \delta_{SP_R}$$

AS FOLLOWS:

IF: $-20^\circ \leq \alpha \leq 20^\circ$

CALCULATE: $C_D = .00059250\,\alpha^2 + .00210993\,\alpha + .01765 + \sum_{v=0}^{4}\sum_{u=0}^{4}\left[A_{D(u+5v)}\,\delta^u\,\alpha^v\right] + \Delta C_{D_{SP}}$

WHERE: $\Delta C_{D_{SP}} = -.00009878\delta_{SP} + .00000922\delta_{SP}^2$

IF: $20^\circ < \alpha \leq 90^\circ$, $\alpha_{DOWN} = 20^\circ$

CALCULATE: $C_D^+ = 0.31105749 + \sum_{v=0}^{4}\sum_{u=0}^{4}\left[A_{D(u+5v)}\,\delta^u\,\alpha_{DOWN}^v\right] + \Delta C_{D_{SP}}$

$$C_D = C_D^+ + \frac{(1 - C_D^+)}{70^\circ}(\alpha - 20^\circ)$$

IF: $-90^\circ \leq \alpha < -20^\circ$, $\alpha_{DOWN} = -20^\circ$

CALCULATE: $C_D^- = 0.19124389 + \sum_{v=0}^{4}\sum_{u=0}^{4}\left[A_{D(u+5v)}\,\delta^u\,\alpha_{DOWN}^v\right] + \Delta C_{D_{SP}}$

$$C_D = C_D^- - \frac{(1 - C_D^-)}{70^\circ}(\alpha + 20^\circ)$$

NOTE: α, α_{DOWN}, δ, δa_{RW}, δa_{LW}, δ_{SP_R}, δ_{SP_L} IN DEGREES

WING EQUATIONS (CONT'D)

CALCULATE:

$$C_{M_{LW}} = C_M \text{ @ } \alpha = \alpha_{LW_{SSO}}, \quad \delta = \delta_f + \delta a_{LW}$$

$$C_{M_{RW}} = C_M \text{ @ } \alpha = \alpha_{RW_{SSO}}, \quad \delta = \delta_f + \delta a_{RW}$$

$$C'_{M_{LW_0}} = C_M \text{ @ } \alpha = \alpha_{LW_0}, \quad \delta = \delta_f + \delta a_{LW}$$

$$C'_{M_{RW_0}} = C_M \text{ @ } \alpha = \alpha_{RW_0}, \quad \delta = \delta_f + \delta a_{RW}$$

AS FOLLOWS:

IF:- $-20° \leq \alpha \leq 20°$

CALCULATE:- $C_M' = -.030117 - .0003162\,\alpha$

$$\Delta C_{M_\delta} = .0000778\,\delta^2 - .010033\,\delta \qquad (0° \leq \delta \leq 45°)$$

$$\Delta C_{M_\delta} = .0000322\,\delta^2 - .0049045\,\delta - .1384272 \qquad (\delta 745°)$$

$$C_M = C_M' + \Delta C_{M_\delta}$$

IF: $\alpha > 20°$

CALCULATE: $C_M' = -.036491 + \Delta C_{M_\delta}$

$$C_M = C_M' \frac{(90° - \alpha)}{70°}$$

IF $\alpha < -20°$

CALCULATE $C_M' = -.023793 + \Delta C_{M_\delta}'$

$$C_M = C_M' \frac{(90° + \alpha)}{70°}$$

NOTE: $\alpha, \alpha_{SSO}, \delta, \delta a_{RW}, \delta a_{LW}, \delta_{EP_L}, \delta_{SR}$ IN DEGREES

WING EQUATIONS (CONT'D)

CALCULATE :-

$$C_{L_{LW}}'' = C_{L_{LW0}} \quad ; \quad C_{D_{LW}}'' = C_{D_{LW}} \quad ; \quad C_{M_{LW}}'' = C_{M_{LW}}$$

$$C_{L_{RW}}'' = C_{L_{RW0}} \quad ; \quad C_{D_{RW}}'' = C_{D_{RW}} \quad ; \quad C_{M_{RW}}'' = C_{M_{RW}}$$

$$C_{L_{LW_{MAX}}}'' = C_{L_{MAX}} + \Delta C_{L_S} + \Delta C_{L_{SP}}$$

$$C_{L_{RW_{MAX}}}'' = C_{L_{MAX}} + \Delta C_{L_S} + \Delta C_{L_{SP}}$$

$$C_{L_{LW}}^{*'} = C_{L_{RW_0}}^{*} \quad ; \quad C_{D_{RW}}^{*'} = C_{D_{RW_0}}^{*'} \quad ; \quad C_{M_{RW}}^{*'} = C_{M_{RW_0}}^{*'}$$

$$C_{L_{LW}}^{*'} = C_{L_{LW_0}}^{*} \quad ; \quad C_{D_{LW}}^{*'} = C_{D_{LW_0}}^{*'} \quad ; \quad C_{M_{LW}}^{*} = C_{M_{LW_0}}^{*'}$$

$$C_{L_{LW_{MAX}}}^{*} = C_{L_{LW_{MAX}}}''$$

$$C_{L_{RW_{MAX}}}^{*} = C_{L_{RW_{MAX}}}''$$

$$\overline{C_L} = \frac{C_{L_0}\left(\frac{a_g}{a}\right)_W}{\sqrt{1-M^2}}$$

$$C_{L_{LW}}''^{IGE} = C_{L_{LW}}''' \frac{\left(\frac{a_g}{a}\right)_W}{\sqrt{1-M^2}} \quad ; \quad C_{L_{RW}}''^{IGE} = C_{L_{RW}}''' \frac{\left(\frac{a_g}{a}\right)_W}{\sqrt{1-M^2}} \quad ;$$

$$C_{L_{LW}}^{*IGE} = C_{L_{LW}}^{*'} \frac{\left(\frac{a_g}{a}\right)_W}{\sqrt{1-M^2}} \quad ; \quad C_{L_{RW}}^{*IGE} = C_{L_{RW}}^{*'} \frac{\left(\frac{a_g}{a}\right)}{\sqrt{1-M^2}}$$

WING EQUATIONS (CONT'D)

$$\Delta C''^{IGE}_{DLW} = K_{99}\frac{\left(C''^{IGE}_{LLW} - C'''_{LLW}\right)^2}{\pi AR_W}\;;\quad \Delta C''^{IGE}_{DRW} = K_{99}\frac{\left(C''^{IGE}_{LRW} - C'''_{LRW}\right)^2}{\pi AR_W}\;;$$

$$\Delta C^{*IGE}_{DLW} = K_{99}\frac{\left(C^{*IGE}_{LLW} - C^{*\prime}_{LLW}\right)^2}{\pi AR_W}\;;\quad \Delta C^{*IGE}_{DRW} = K_{99}\frac{\left(C^{*IGE}_{LRW} - C^{*\prime}_{LRW}\right)^2}{\pi AR_W}$$

IF: $C''^{IGE}_{LLW} \geq C''_{LLWMAX}$; SET $\Delta C''^{IGE}_{DLW} = 0.0$ & $C''^{IGE}_{LLW} = C''_{LLWMAX}$

IF: $C''^{IGE}_{LRW} \geq C''_{LRWMAX}$; SET $\Delta C''^{IGE}_{DRW} = 0.0$ & $C''^{IGE}_{LRW} = C''_{LRWMAX}$

IF: $C^{*IGE}_{LLW} \geq C^{*}_{LLWMAX}$; SET $\Delta C^{*IGE}_{DLW} = 0.0$ & $C^{*IGE}_{LLW} = C^{*}_{LLWMAX}$

IF: $C^{*IGE}_{LRW} \geq C^{*}_{LRWMAX}$; SET $\Delta C^{*IGE}_{DRW} = 0.0$ & $C^{*IGE}_{LRW} = C^{*}_{LRWMAX}$

IF: $(\alpha_3/\alpha) > 1.0$; SET $K_{99} = -1.0$

$(\alpha_3/\alpha) \leq 1.0$; SET $K_{99} = +1.0$

CALCULATE

$$C''_{LLW} = C''^{IGE}_{LLW}$$

$$C''_{DLW} = C'''_{DLW} + \Delta C''^{IGE}_{DLW}$$

$$C''_{LRW} = C''^{IGE}_{LRW}$$

$$C''_{DRW} = C'''_{DRW} + \Delta C''^{IGE}_{DRW}$$

$$C^{*}_{LLW} = C^{*IGE}_{LLW}$$

$$C^{*}_{DLW} = C^{*\prime}_{DLW} + \Delta C^{*IGE}_{DLW}$$

$$C^{*}_{LRW} = C^{*IGE}_{LRW}$$

$$C^{*}_{DRW} = C^{*\prime}_{DRW} + \Delta C^{*IGE}_{DRW}$$

WING EQUATIONS (cont'd.)

$$C_{LSLW} = K'_{AL}\left\{\left(\frac{S_i}{S}\right)_{LW}\left(C''_{LLW}\cos\epsilon_{PLR} - C''_{DLW}\sin\epsilon_{PLR}\right) + C^{*}_{LLW}\left(1-C_{TSLR}\right)\left[1-\left(\frac{S_i}{S}\right)_{LW}\right]\right\}$$

$$C_{LSRW} = K'_{AR}\left\{\left(\frac{S_i}{S}\right)_{RW}\left(C''_{LRW}\cos\epsilon_{PRR} - C''_{DRW}\sin\epsilon_{PRR}\right) + C^{*}_{LRW}\left(1-C_{TSRR}\right)\left[1-\left(\frac{S_i}{S}\right)_{RW}\right]\right\}$$

$$C_{DSLW} = K'_{AL}\left\{\left(\frac{S_i}{S}\right)_{LW}\left(C''_{LLW}\sin\epsilon_{PLR} + C''_{DLW}\cos\epsilon_{PLR}\right) + C^{*}_{DLW}\left(1-C_{TSLR}\right)\left[1-\left(\frac{S_i}{S}\right)_{LW}\right]\right\}$$

$$C_{DSRW} = K'_{AR}\left\{\left(\frac{S_i}{S}\right)_{RW}\left(C''_{LRW}\sin\epsilon_{PRR} + C''_{DRW}\cos\epsilon_{PRR}\right) + C^{*}_{DRW}\left(1-C_{TSRR}\right)\left[1-\left(\frac{S_i}{S}\right)_{RW}\right]\right\}$$

$$C_{MSLW} = K'_{AL}\left\{\left(\frac{S_i}{S}\right)_{LW}\left(C''_{MLW}\right) + C^{*}_{MLW}\left(1-C_{TSLR}\right)\left[1-\left(\frac{S_i}{S}\right)_{LW}\right]\right\}$$

$$C_{MSRW} = K'_{AR}\left\{\left(\frac{S_i}{S}\right)_{RW}\left(C''_{MRW}\right) + C^{*}_{MRW}\left(1-C_{TSRR}\right)\left[1-\left(\frac{S_i}{S}\right)_{RW}\right]\right\}$$

WING EQUATIONS (cont'd.)

$$\Delta C_{\chi_{TS\ POWER}} = \frac{1}{4}\left\{\left[C_{LSLW} - (1-\bar{C}_{TS})C^{*}_{LLW}\right]\left[1-\frac{1}{2}\left(\frac{S_i}{S}\right)_{LW}\right]\right.$$
$$\left. -\left[C_{LSRW} - (1-\bar{C}_{TS})C^{*}_{LRW}\right]\left[1-\frac{1}{2}\left(\frac{S_i}{S}\right)_{RW}\right]\right\}$$

$$\Delta C_{\eta_{S\ POWER}} = \frac{1}{4}\left\{\left[C_{DSRW} - (1-\bar{C}_{TS})C^{*}_{DRW}\right]\left[1-\frac{1}{2}\left(\frac{S_i}{S}\right)_{RW}\right]\right.$$
$$\left. -\left[C_{DSLW} - (1-\bar{C}_{TS})C^{*}_{DLW}\right]\left[1-\frac{1}{2}\left(\frac{S_i}{S}\right)_{LW}\right]\right\}$$

$$C_{\chi_{SW}} = (K_{20} + K_{21}\bar{C}_L)(1-\bar{C}_{TS})\beta_f + \left(\frac{1-\bar{C}_{TS}}{2b_W}\right)\left(\frac{K_2}{\lambda}\right)\left(C^{*}_{LLW} - C^{*}_{LRW}\right)\bar{Y}_{AC}$$

$$+\Delta C_{\chi_{S\ POWER}}$$

$$C_{\eta_{SW}} = (K_{22}\bar{C}_L^2)(1-\bar{C}_{TS})\beta_f + \left(\frac{1-\bar{C}_{TS}}{2b_W}\right)\left(\frac{K_2}{\lambda}\right)\left\{\left(C^{*}_{DRW} - C^{*}_{DLW}\right)\right.$$
$$\left. -\left[C^{*}_{LRW}\,SIN(\alpha_{RW_0} - i_W) + C^{*}_{LLW}\,SIN(i_W - \alpha_{LW_0})\right]\right\}\bar{Y}_{AC}$$

$$+\ \Delta C_{\eta_{S\ POWER}}$$

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:

$$X^{LW}_{AERO} = fe_u\, q_{SLW}\,(1 - C_{TSLR})\left[\frac{-u_{LW}}{|u_{LW}|+.1}\right]$$

$$X^{RW}_{AERO} = fe_u\, q_{SRW}\,(1 - C_{TSRR})\left[\frac{-u_{RW}}{|u_{RW}|+.1}\right]$$

$$Y^{LW}_{AERO} = 0.0$$

$$Y^{RW}_{AERO} = 0.0$$

$$\left.\begin{aligned} Z^{LWF}_{AERO} &= T_L\left(\frac{D}{T}\right)_L \\ Z^{RWF}_{AERO} &= T_R\left(\frac{D}{T}\right)_R \end{aligned}\right\} \text{GO TO WING BENDING}$$

$$\left.\begin{aligned} M^{LW}_{AERO} &= -X_{\frac{c}{2}}\, Z^{LW}_{AERO} + \left(\frac{M}{T}\right)_L T_L \\ M^{RW}_{AERO} &= -X_{\frac{c}{2}}\, Z^{RW}_{AERO} + \left(\frac{M}{T}\right)_R T_R \end{aligned}\right\} \begin{array}{l} Z^{LW}_{AERO} \text{ \& } Z^{RW}_{AERO} \text{ FROM} \\ \text{WING BENDING} \end{array}$$

$$L^{W}_{AERO} = \left(\frac{b_W}{2}\right)\left\{ Z^{RW}_{AERO}\left[1 - \frac{\left(\frac{S_L}{S}\right)_{RW}}{2}\right] - Z^{LW}_{AERO}\left[1 - \frac{\left(\frac{S_L}{S}\right)_{LW}}{2}\right]\right\}$$

$$N^{W}_{AERO} = 0.0$$

IF: $\left[\frac{h}{D}\right]^{EFF}_{LR} \le 1.3$; $\left(\frac{D}{T}\right)_L = K_{\frac{D1}{T}}\left[\frac{h}{D}\right]^2_{EFF_{LR}} + K_{\frac{D2}{T}}\left[\frac{h}{D}\right]_{EFF_{LR}} + K_{\frac{D3}{T}}$;

& $\left(\frac{M}{T}\right)_L = K_{\frac{M1}{T}}\left[\frac{h}{D}\right]^2_{EFF_{LR}} + K_{\frac{M2}{T}}\left[\frac{h}{D}\right]_{EFF_{LR}} + K_{\frac{M3}{T}}$

IF: $\left[\frac{h}{D}\right]^{EFF}_{LR} > 1.3$; $\left(\frac{D}{T}\right)_L = K_{\frac{D4}{T}}$; & $\left(\frac{M}{T}\right)_L = K_{\frac{M4}{T}}$

IF: $\left[\frac{h}{D}\right]^{EFF}_{RR} \le 1.3$; $\left(\frac{D}{T}\right)_R = K_{\frac{D1}{T}}\left[\frac{h}{D}\right]^2_{EFF_{RR}} + K_{\frac{D2}{T}}\left[\frac{h}{D}\right]_{EFF_{RR}} + K_{\frac{D3}{T}}$

& $\left(\frac{M}{T}\right)_R = K_{\frac{M1}{T}}\left[\frac{h}{D}\right]^2_{EFF_{RR}} + K_{\frac{M2}{T}}\left[\frac{h}{D}\right]_{EFF_{RR}} + K_{\frac{M3}{T}}$

IF: $\left[\frac{h}{D}\right]^{EFF}_{RR} > 1.3$; $\left(\frac{D}{T}\right)_R = K_{\frac{D4}{T}}$; & $\left(\frac{M}{T}\right)_R = K_{\frac{M4}{T}}$

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

$$h_{wc/4} = -Z_{DOWN} + (X_{wAC} - X_{CG})\sin\theta + (Z_{CG} - Z_{wAC})\cos\theta$$

$$h_{Tc/4} = -Z_{DOWN} + (X_{HT} - X_{CG})\sin\theta + (Z_{CG} - Z_{HT})\cos\theta$$

HORIZONTAL TAIL ANGLE OF ATTACK

$$l_{AC} = X_{wAC} - X_{HT} \quad \text{(PRELIMINARY)}$$

$$GEF = \left[b_w^2 + 4(h_{Tc/4} - h_{wc/4})^2 \right] \Big/ \left[b_w^2 + 4(h_{Tc/4} + h_{wc/4})^2 \right]$$

IF: $\dfrac{\bar{\epsilon}_p (1-GEF)}{\sqrt{1-M^2}} \geq \left[\epsilon_o + \dfrac{d\epsilon}{d\alpha}\left(\bar{\alpha}_w - l_{AC}\dfrac{\dot{w}}{u^2}\right)\right]\dfrac{(1-GEF)}{\sqrt{1-M^2}}$

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

IF: $\dfrac{\bar{\epsilon}_p (1-GEF)}{\sqrt{1-M^2}} < \left[\epsilon_o + \dfrac{d\epsilon}{d\alpha}\left(\bar{\alpha}_w - l_{AC}\dfrac{\dot{w}}{u^2}\right)\right]\dfrac{(1-GEF)}{\sqrt{1-M^2}}$

$$\epsilon = \left[\epsilon_o + \frac{d\epsilon}{d\alpha}\left(\bar{\alpha}_w - l_{AC}\frac{\dot{w}}{u^2}\right)\right]\frac{(1-GEF)}{\sqrt{1-M^2}}$$

USE FOR RESOLUTION OF FORCES:

$$\alpha_{HT} = TAN^{-1}\left[\frac{w_{HT}}{u_{HT}}\right] - \epsilon + i_{HT}; \qquad \underline{\text{NOTE:- IF } u<0} \quad \alpha_{HT} = TAN^{-1}\left[\frac{w_{HT}}{u_{HT}}\right] + i_{HT}$$

WHERE $\epsilon_o = f(\delta_L + \delta_R).5$ AND $\dfrac{d\epsilon}{d\alpha} = f(\delta_L + \delta_R).5$

IF: $|\alpha_{HT}| > 180°$; $\quad \alpha_{HT} = -(\text{SIGN}\,\alpha_{HT})360° + \alpha_{HT}$

USE ONLY IN EQ. FOR FORCE AND MOMENT COEFF.

HORIZONTAL AND VERTICAL TAIL AERODYNAMICS (CONT'D)

HORIZONTAL TAIL LIFT AND DRAG

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

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

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

$$C_{L\alpha} = C_{L\alpha_{HT}} \left(\frac{a_T}{a}\right)_{HT} \Big/ \sqrt{1-M^2}$$

WHERE $\left(\frac{a_T}{a}\right)_{HT} = f(h_{TC/\ell})$; $\tau_{HT} = f(\delta_e/\delta_T)$

IF:- $\hat{\alpha}_{HT_-} \le \alpha_{e_{HT}} \le \hat{\alpha}_{HT_+}$

$$C_{L_{HT}} = C_{L\alpha}\,\alpha_{e_{HT}}$$

$$C_{D_{HT}} = C_{D_{0_{HT}}} + \frac{2C_{L_{HT}}^2}{\pi R_{HT}}$$

IF:- $\hat{\alpha}_{HT_+} < \alpha_{e_{HT}} \le 90^\circ$

$$C_{L_{HT}} = C_{L\alpha}\,\hat{\alpha}_{HT_+}\left[\frac{90^\circ - \alpha_{e_{HT}}}{90^\circ - \hat{\alpha}_{HT_+}}\right]$$

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

$$C_{D_{HT_{STALL}}} = C_{D_{0_{HT}}} + \frac{2C_{L_{HT_{STALL}}}^2}{\pi R_{HT}}$$

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

HORIZONTAL AND VERTICAL TAIL AERODYNAMICS (CONT'D)

HORIZONTAL TAIL LIFT AND DRAG (CONT'D)

IF:- $90° < \alpha_{e_{HT}} \leq (180° - .5\,\hat{\alpha}_{HT_-})$

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

$$C_{L_{HT_{STALL}}} = .5\, C_{L_\alpha}\, \hat{\alpha}_{HT_-}$$

$$C_{D_{HT_{STALL}}} = \frac{2\, C_{L_{HT_{STALL}}}^2}{\pi\, AR_{HT}} + C_{D_{0_{HT}}}$$

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

IF:- $(180° - .5\hat{\alpha}_{HT_-}) \leq \alpha_{e_{HT}} \leq 180°$

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

$$C_{D_{HT}} = C_{D_{0_{HT}}} + \frac{2\, C_{L_{HT}}^2}{\pi\, AR_{HT}}$$

IF:- $-90° \leq \alpha_{e_{HT}} < \hat{\alpha}_{HT_-}$

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

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

$$C_{D_{HT_{STALL}}} = C_{D_{0_{HT}}} + \frac{2\, C_{L_{HT_{STALL}}}^2}{\pi\, AR_{HT}}$$

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

HORIZONTAL AND VERTICAL TAIL AERODYNAMICS (CONT'D)

HORIZONTAL TAIL LIFT AND DRAG. (CONT'D)

IF:- $(-180° + .5\hat{\alpha}_{HT_+}) < \alpha_{e_{HT}} < -90°$

$$C_{L_{HT}} = .5\, C_{L_\alpha}\, \hat{\alpha}_{HT_+} \frac{(\alpha_{0_{HT}} + 90°)}{(-90° + .5\hat{\alpha}_{HT_+})}$$

$$C_{L_{HT_{STALL}}} = .5\, C_{L_\alpha}\, \hat{\alpha}_{HT_+}$$

$$C_{D_{HT_{STALL}}} = C_{D_{0_{HT}}} + \frac{2\, C^2_{L_{HT_{STALL}}}}{\pi AR_{HT}}$$

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

IF:- $-180° \le \alpha_{e_{HT}} < (-180° + .5\hat{\alpha}_{HT_+})$

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

$$C_{D_{HT}} = C_{D_{0_{HT}}} + \frac{2\, C^2_{L_{HT}}}{\pi AR_{HT}}$$

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: $|\alpha_{VT}| > 180°$; $\alpha_{VT} = \alpha_{VT} - (\text{SIGN}\,\alpha_{VT})(360°)$ { NOTE: THIS VALUE OF α_{VT} ONLY USED IN CALC. OF FORCE AND MOMENT COEFFICIENTS }

$$\alpha_{eVT} = (\alpha_{VT} + \tau_{VT}\,\delta_{RUD})$$

$$\hat{\alpha}_{VT_+} = (\alpha_{VT_{STALL}} - 2°) + \tau_{VT}\,\delta_{RUD}$$

$$\hat{\alpha}_{VT_-} = -(\alpha_{VT_{STALL}} - 2°) + \tau_{VT}\,\delta_{RUD}$$

$$C_{Y_\alpha} = C_{Y_{\alpha VT}} / \sqrt{1-M^2}$$

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:- $\hat{\alpha}_{VT_-} \le \alpha_{eVT} \le \hat{\alpha}_{VT_+}$

$$C_{YVT} = C_{Y_\alpha}\,\alpha_{eVT}$$

$$C_{DVT} = C_{DoVT} + \frac{2\,C_{YVT}^2}{\pi AR_{VT}}$$

VERTICAL TAIL LIFT AND DRAG (CONT'D)

IF:- $\hat{\alpha}_{VT_+} < \alpha_{eVT} \leq 90°$

$$C_{YVT} = C_{Y\alpha}\,\hat{\alpha}_{VT_+}\left[\frac{90° - \alpha_{eVT}}{90° - \hat{\alpha}_{VT_+}}\right]$$

$$C_{YVT_{STALL}} = C_{Y\alpha}\,\hat{\alpha}_{VT_+}$$

$$C_{DVT_{STALL}} = C_{D_0VT} + \frac{2\,C^2_{YVT_{STALL}}}{\pi AR_{VT}}$$

$$C_{DVT} = C_{DVT_{STALL}} + \frac{(\alpha_{eVT} - \hat{\alpha}_{VT_+} \times 1.1 - C_{DVT_{STALL}})}{90° - \hat{\alpha}_{VT_+}}$$

IF:- $90° < \alpha_{eVT} \leq (180° - .5\,\hat{\alpha}_{VT_-})$

$$C_{YVT} = .5\,C_{Y\alpha}\,\hat{\alpha}_{VT_-}\left(\frac{\alpha_{eVT} - 90°}{90° - .5\,\hat{\alpha}_{VT_-}}\right)$$

$$C_{YVT_{STALL}} = .5\,C_{Y\alpha}\,\hat{\alpha}_{VT_-}$$

$$C_{DVT_{STALL}} = C_{D_0VT} + \frac{2\,C^2_{YVT_{STALL}}}{\pi AR_{VT}}$$

$$C_{DVT} = C_{DVT_{STALL}} + \frac{(\alpha_{eVT} + .5\,\hat{\alpha}_{VT_-} - 180° \times 1.1 - C_{DVT_{STALL}})}{(.5\,\hat{\alpha}_{VT_-} - 90°)}$$

IF:- $(180° - .5\,\hat{\alpha}_{VT_-}) \leq \alpha_{eVT} \leq 180°$

$$C_{YVT} = C_{Y\alpha}\,(\alpha_{eVT} - 180°)$$

$$C_{DVT} = C_{D_0VT} + \frac{2\,C^2_{YVT}}{\pi AR_{VT}}$$

VERTICAL TAIL LIFT AND DRAG (CONT'D)

IF:- $-90° \leq \alpha_{eVT} < \hat{\alpha}_{VT-}$

$$C_{YVT} = C_{Y\alpha}\,\hat{\alpha}_{VT-}\,\frac{(-90° - \alpha_{eVT})}{(-90° - \hat{\alpha}_{VT-})}$$

$$C_{YVT_{STALL}} = C_{Y\alpha}\,\hat{\alpha}_{VT-}$$

$$C_{DVT_{STALL}} = C_{DoVT} + \frac{2\,C^2_{YVT_{STALL}}}{\pi\,AR_{VT}}$$

$$C_{DVT} = C_{DVT_{STALL}} + \frac{(\alpha_{eVT} - \hat{\alpha}_{VT-})(1.1 - C_{DVT_{STALL}})}{(-90° - \hat{\alpha}_{VT-})}$$

IF:- $(-180° + .5\hat{\alpha}_{VT+}) < \alpha_{eVT} < -90°$

$$C_{YVT} = .5\,C_{Y\alpha}\,\hat{\alpha}_{VT+}\,\frac{(\alpha_{eVT} + 90°)}{(-90° + .5\,\hat{\alpha}_{VT+})}$$

$$C_{YVT_{STALL}} = .5\,C_{Y\alpha}\,\hat{\alpha}_{VT+}$$

$$C_{DVT_{STALL}} = C_{DoVT} + \frac{2\,C^2_{YVT_{STALL}}}{\pi\,AR_{VT}}$$

$$C_{DVT} = C_{DVT_{STALL}} - \frac{(\alpha_{eVT} + 180° - .5\hat{\alpha}_{VT+})(1.1 - C_{DVT_{STALL}})}{(.5\,\hat{\alpha}_{VT+} - 90°)}$$

IF:- $-180° \leq \alpha_{eVT} < (-180° + .5\,\hat{\alpha}_{VT+})$

$$C_{YVT} = C_{Y\alpha}\,(\alpha_{eVT} + 180°)$$

$$C_{DVT} = C_{DoVT} + \frac{2\,C^2_{YVT}}{\pi\,AR_{VT}}$$

TAIL EQUATIONS LOGIC

HORIZONTAL TAIL

1. IF $h_{W_{C/4}} > 100$ FT., SET GEF = 0.0
2. IF THE UMBRELLAS OPEN; SET $\epsilon = \frac{\bar{G}_P (1 - GEP)}{\sqrt{1-M^2}}$
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 $M > 0$; SET $\eta_{HT} = .5\eta_{HT}$

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

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

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

$$\mathcal{L}^{HT}_{AERO} = -Y^{HT}_{AERO}\left(Z_{HT}-Z_{CG}\right)$$

$$\mathcal{M}^{HT}_{AERO} = Z^{HT}_{AERO}\left(X_{CG}-X_{HT}\right) + X^{HT}_{AERO}\left(Z_{HT}-Z_{CG}\right)$$

$$\mathcal{N}^{HT}_{AERO} = -Y^{HT}_{AERO}\left(X_{CG}-X_{HT}\right)$$

VERTICAL TAIL

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

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

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

$$\mathcal{L}^{VT}_{AERO} = -Y^{VT}_{AERO}\left(Z_{VT}-Z_{CG}\right)$$

$$\mathcal{M}^{VT}_{AERO} = Z^{VT}_{AERO}\left(X_{CG}-X_{VT}\right) + X^{VT}_{AERO}\left(Z_{VT}-Z_{CG}\right)$$

$$\mathcal{N}^{VT}_{AERO} = -Y^{VT}_{AERO}\left(X_{CG}-X_{VT}\right)$$

TOTAL TAIL CONTRIBUTION

$$X^{T}_{AERO} = X^{VT}_{AERO} + X^{HT}_{AERO} \quad ; \quad Z^{T}_{AERO} = Z^{VT}_{AERO} + Z^{HT}_{AERO} \quad \mathcal{M}^{T}_{AERO} = \mathcal{M}^{VT}_{AERO} + \mathcal{M}^{HT}_{AERO}$$

$$Y^{T}_{AERO} = Y^{VT}_{AERO} + Y^{HT}_{AERO} \quad ; \quad \mathcal{L}^{T}_{AERO} = \mathcal{L}^{VT}_{AERO} + \mathcal{L}^{HT}_{AERO} \quad \mathcal{N}^{T}_{AERO} = \mathcal{N}^{VT}_{AERO} + \mathcal{N}^{HT}_{AERO}$$

NACELLE AERODYNAMICS

NACELLE ANGLE OF ATTACK AND SIDESLIP

$$\alpha_{RN} = \tan^{-1} \frac{W_{AR}}{U_{RR}} \quad ; \; q_{RN} = \frac{1}{2} \rho V_{RR}^2$$

$$\alpha_{LN} = \tan^{-1} \frac{W_{RL}}{U_{RL}} \quad ; \; q_{LN} = \frac{1}{2} \rho V_{LR}^2$$

$$\beta_{RN} = \tan^{-1} \frac{V_{RR}}{\sqrt{U_{RR}^2 + W_{RR}^2}}$$

$$\beta_{LN} = \tan^{-1} \frac{V_{RL}}{\sqrt{U_{RL}^2 + W_{RL}^2}}$$

NACELLE WIND AXIS FORCE & MOMENT COEF.'S

$$C_{DRN} = C_{DORN} + K_{30} |\alpha_{RN}| + K_{31} |\alpha_{RN}^2|$$
$$C_{DLN} = C_{DOLN} + K_{30} |\alpha_{LN}| + K_{31} |\alpha_{LN}^2|$$

} NOTE: CHECK RANGE OF α_{RN} & α_{LN} TO DETERMINE VALUES FOR COEFFICIENTS.

WHERE: $C_{DORN} = C_{DON}$

$C_{DOLN} = C_{DON}$

$$C_{LRN} = K_{32} \sin\alpha_{RN} \cos\alpha_{RN}$$

$$C_{LLN} = K_{32} \sin\alpha_{LN} \cos\alpha_{LN}$$

$$C_{MRN} = C_{MON} + K_{34} \sin\alpha_{RN} \cos\alpha_{RN} + K_{35} (\sin\alpha_{RN} \cos\alpha_{RN}) |\sin\alpha_{RN} \cos\alpha_{RN}|$$

$$C_{MLN} = C_{MON} + K_{34} \sin\alpha_{LN} \cos\alpha_{LN} + K_{35} (\sin\alpha_{LN} \cos\alpha_{LN}) |\sin\alpha_{LN} \cos\alpha_{LN}|$$

SPECIAL CONDITIONS

1. IF: $V_{RR}^2 \leq 1 (ft/sec)^2$; RIGHT NACELLE AERO = 0.0 & HOLD VALUE OF α_{RN} & β_{RN}
2. IF: $V_{LR}^2 \leq 1 (ft/sec)^2$; LEFT NACELLE AERO = 0.0 & HOLD VALUE OF α_{LN} & β_{LN}

NACELLE AERODYNAMICS (Cont'd.)

$$C_{YRN} = K_{36}\,SIN\,\beta_{RD}\,Cos\,\beta_{RD} + K_{37}(SIN\,\beta_{RD}\,Cos\,\beta_{RD})\,|SIN\,\beta_{RD}\,Cos\,\beta_{RD}|$$

$$C_{YLN} = K'_{36}\,SIN\,\beta_{LD}\,Cos\,\beta_{LD} + K'_{37}(SIN\,\beta_{LD}\,Cos\,\beta_{LD})\,|SIN\,\beta_{LD}\,Cos\,\beta_{LD}|$$

$$C_{NRN} = C_{NORN} + K_{38}\,SIN\,\beta_{RD}\,Cos\,\beta_{RD} + K_{39}(SIN\,\beta_{RD}\,(Cos\,\beta_{RD}))\,|SIN\,\beta_{RD}\,Cos\,\beta_{RD}|$$

$$C_{NLN} = C_{NOLN} + K_{40}\,SIN\,\beta_{LD}\,Cos\,\beta_{LD} + K_{41}(SIN\,\beta_{LD}(Cos\,\beta_{LD}))\,|SIN\,\beta_{LD}\,Cos\beta_{LD}|$$

$$C_{ZRN} = C_{ZLN} \equiv 0.0$$

NACELLE FORCES & MOMENTS - NACELLE AXES

RIGHT

$$\Delta X'_{RN} = q_{RN}\,S_w\left[-C_{DRN}\cos\alpha_{RN} + C_{LRN}\sin\alpha_{RN} - C_{YRN}\sin\beta_{RN}\cos\alpha_{RN}\right]\frac{1}{2}$$

$$\Delta Y'_{RN} = q_{RN}\,S_w\left[C_{YRN}\cos\beta_{RN} - C_{DRN}\sin\beta_{RN}\right]\frac{1}{2}$$

$$\Delta Z'_{RN} = q_{RN}\,S_w\left[-C_{LRN}\cos\alpha_{RN} - C_{DRN}\cos\beta_{RN}\sin\alpha_{RN} - C_{YRN}\sin\beta_{RN}\sin\alpha_{RN}\right]\frac{1}{2}$$

$$\Delta \mathcal{L}'_{RN} = q_{RN}\,S_w\,b_w\left[-\left(\frac{C_w}{b_w}\right)C_{MRN}\sin\beta_{RN}\cos\alpha_{RN} - C_{NRN}\sin\alpha_{RN}\right]\frac{1}{2}$$

$$\Delta M'_{RN} = q_{RN}\,S_w\,C_w\left[C_{MRN}\cos\beta_{RN}\right]\frac{1}{2}$$

$$\Delta N'_{RN} = q_{RN}\,S_w\,b_w\left[C_{NRN}\cos\alpha_{RN} - \left(\frac{C_w}{b_w}\right)C_{MRN}\sin\beta_{RN}\cos\alpha_{RN}\right]\frac{1}{2}$$

LEFT

$$\Delta X'_{LN} = q_{LN}\,S_w\left[-C_{DLN}\cos\alpha_{LN} + C_{LLN}\sin\alpha_{LN} - C_{YLN}\sin\beta_{LN}\cos\alpha_{LN}\right]\frac{1}{2}$$

$$\Delta Y'_{LN} = q_{LN}\,S_w\left[C_{YLN}\cos\beta_{LN} - C_{DLN}\sin\beta_{LN}\right]\frac{1}{2}$$

$$\Delta Z'_{LN} = q_{LN}\,S_w\left[-C_{LLN}\cos\alpha_{LN} - C_{DLN}\cos\beta_{LN}\sin\alpha_{LN} - C_{YLN}\sin\beta_{LN}\sin\alpha_{LN}\right]\frac{1}{2}$$

$$\Delta \mathcal{L}'_{LN} = q_{LN}\,S_w\,b_w\left[-\left(\frac{C_w}{b_w}\right)C_{MLN}\sin\beta_{LN}\cos\alpha_{LN} - C_{NLN}\sin\alpha_{LN}\right]\frac{1}{2}$$

$$\Delta M'_{LN} = q_{LN}\,S_w\,C_w\left[C_{MLN}\cos\beta_{LN}\right]\frac{1}{2}$$

$$\Delta N'_{LN} = q_{LN}\,S_w\,b_w\left[C_{NLN}\cos\alpha_{LN} - \left(\frac{C_w}{b_w}\right)C_{MLN}\sin\beta_{LN}\cos\alpha_{LN}\right]\frac{1}{2}$$

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 $h_{Tn} > 0$; $F_{GZn} = 0.0$ #
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 $v = 0$ $F_{sn} = 0.0$

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

$$\alpha_F = \tan^{-1}\frac{w}{u} \qquad \beta_F = \tan^{-1}\frac{v}{\sqrt{u^2+w^2}}$$

$$\alpha'_F = \sin\alpha_F \cos\alpha_F \qquad \beta'_F = \sin\beta_F \cos\beta_F$$

$$V_F = \sqrt{u^2+v^2+w^2}$$

$$q_F = \frac{1}{2}\rho V_F^2 \qquad (q) \text{ SAME AS TAIL DYNAMIC PRESSURE}$$

$$V_{EQS} = V_F\sqrt{\sigma_h}$$

FUSELAGE WIND AXIS COEF'S

$$C_{DF} = C_{DOF}\left(1 + K_0|\beta_F|\beta_F\right) + K_2\alpha_F^2 + K_1|\alpha_F| + \Delta C_{DLG}$$

$$C_{LF} = K_3\alpha'_F + K_4\alpha'_F|\alpha'_F| + K_{42}$$

$$C_{YF} = K_7\beta'_F + K_8\beta'_F|\beta'_F|$$

$$C_{MF} = C_{MOF} + K_5\alpha'_F + K_6\alpha'_F|\alpha'_F| + \Delta C_{MLG}$$

$$C_{NF} = C_{NOF} + K_9\beta'_F + K_{10}\beta'_F|\beta'_F|$$

NOTE: IF GEAR IS UP; $\Delta C_{DLG} \& \Delta C_{MLG} \equiv 0.0$

SPECIAL CONDITIONS

1. IF $V_F^2 \leq 1\ (\text{ft/sec})^2$ 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

$$\bar{i}_N = 0.5 \left(i_{NL} + i_{NR} \right)$$

Average Lift Coef.

$$C_{LW} = 0.5 \frac{\left(C_{LSRW} + C_{LSLW} \right)}{\left(1 - \bar{C}_{TS} \right)}$$

Look-up: ϵ_{WRR} & ϵ_{WRL} @ $\bar{i}_N$ & C_{LW}

Wing Interference Logic

1. IF: *Umbrellas Open*, set $C_{LW} = 0.0$ & $\epsilon = \frac{\bar{\epsilon}_p (1 - GEP)}{\sqrt{1 - M^2}}$

ROTOR / ROTOR INTERFERENCE

POSITIVE SIDESLIP i.e. $v > 0.0$ (LOGIC REQUIRED)

$$\chi = 1.5708 - \epsilon_{PRR}$$

$$\left(\frac{\delta v_{RL}^*}{v_{RR}^*}\right) = T_1 + T_2(\chi) + T_3(\chi)^2$$

$$\delta v_{RL} = \left(\frac{\delta v_{RL}^*}{v_{RR}^*}\right) v_{HR} \sqrt{\frac{R_{RR}}{2\rho\pi R^2}}$$

$$\epsilon'_{iRL} = -\tan^{-1}\left[\frac{\delta v_{RL}}{V_{LR} + 1.0}\right]$$

$$\epsilon_{iRL} = (|\beta_F|)(.40528\, i_{NL})\, \epsilon'_{iRL}$$

$$\epsilon_{iLR} = 0.0$$

NEGATIVE SIDESLIP i.e. $v < 0.0$

$$\chi = 1.5708 - \epsilon_{PLR}$$

$$\left(\frac{\delta v_{LR}^*}{v_{LR}^*}\right) = T_1 + T_2(\chi) + T_3(\chi)^2$$

$$\delta v_{LR} = \left(\frac{\delta v_{LR}^*}{v_{RR}^*}\right) v_{HL} \sqrt{\frac{R_{LR}}{2\rho\pi R^2}}$$

$$\epsilon'_{iLR} = -\tan^{-1}\left[\frac{\delta v_{LR}}{V_{RR} + 1.0}\right]$$

$$\epsilon_{iLR} = (|\beta_F|)(.40528\, i_{NR})\, \epsilon'_{iLR}$$

$$\epsilon_{iRL} = 0.0$$

NOTE: v_{HR} & v_{HL} FROM WING EQUATIONS.

Rotor Aero Input Equations

Right Rotor

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

$$V_{RR} = \sqrt{u_{RR}^2 + v_{RR}^2 + w_{RR}^2} \quad ; \quad \mu_{RR} = \frac{V_{RR}}{\Omega_R R}$$

Left Rotor

$$\alpha_{LR} = \tan^{-1}\left\{ \frac{\sqrt{v_{RL}^2 + (w_{RL} + u_{RL}\epsilon_{wRL})^2}}{u_{RL}} \right\} + \epsilon_{i_{RL}}$$

$$V_{LR} = \sqrt{u_{RL}^2 + v_{RL}^2 + w_{RL}^2} \quad ; \quad \mu_{LR} = \frac{V_{LR}}{\Omega_L R}$$

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

$$P_{NR}^R = P_{NR}^N$$

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

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

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

$$C'_{TRR} = \left[\frac{T_1 S + 1}{T_2 S + 1}\right]\left[C_{TORR}\ \cos A_{IGR}\ \cos B_{IOR}\right]$$

WHERE:-

$$C_{TORR} = \sum_{N=0}^{2}\sum_{u=0}^{3}\left[A_{T(u+4N)}\ \alpha_{RR}^{u}\ \theta_{COS_R}^{N}\right]$$

$$A_{T(u+4N)} = f(\mu_{RR})$$

} INTERPOLATE C_{TORR} LINEARLY BETWEEN μ's

GROUND EFFECT

$$h_{RR} = -Z_{DOWN} + (L_S \cos i_{WR} - X_{CG})\sin\theta + \left[(L_S \sin i_{WR} + Z_{CG})\cos\phi - Y_W \sin\phi\right]\cos\theta$$

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

$$\left(\frac{T_{IGE}}{T_{OGE}}\right)_{RR} = \left[\left(\frac{h}{D}\right)_{RR}^{EFF 2}(.174 - .6216\,\mu_{RR}) + \left(\frac{h}{D}\right)_{RR}^{EFF}(1.4779\,\mu_{RR} - .4143) + 1.2479 - .8806\,\mu_{RR}\right]$$

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

SPECIAL CONDITIONS: IF $\mu_{RR} \geq 0.283$; $\left(\frac{T_{IGE}}{T_{OGE}}\right)_{RR} = 1.0$

OR IF $\left(\frac{h}{D}\right)_{RR}^{EFF} \geq 1.3$; $\left(\frac{T_{IGE}}{T_{OGE}}\right)_{RR} = 1.0$

ROTOR EQUATIONS (CONTINUED)

POWER

$$C_{P_{RR}} = C_{P_{ORR}}$$

WHERE :-

$$C_{P_{ORR}} = \sum_{N=0}^{2} \sum_{u=0}^{3} \left[A_{P(u+4N)} \alpha_{RR}^{u} C_{T_{RR}}^{'N} \right]$$

$$A_{P(u+4N)} = f(\mu_{RR})$$

} INTERPOLATE $C_{P_{ORR}}$ LINEARLY BETWEEN μ's

NORMAL FORCE

$$C_{NF_{RR}} = C_{NF_{ORR}} + \frac{d C_{NF_{RR}}}{d A_{1C_R}} A_{1C_R} + \frac{d C_{NF_{RR}}}{d B_{1C_R}} B_{1C_R}$$

WHERE :-

$$C_{NF_{ORR}} = \sum_{N=0}^{2} \sum_{u=0}^{3} \left[A_{NF(u+4N)} \alpha_{RR}^{u} C_{T_{RR}}^{'N} \right]$$

$$A_{NF(u+4N)} = f(\mu_{RR})$$

} INTERPOLATE $C_{NF_{ORR}}$ LINEARLY BETWEEN μ's

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

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

ROTOR EQUATIONS (CONTINUED)

SIDE FORCE

$$C_{SF_{RR}} = C_{SFORR} + \frac{d C_{SFRR}}{d A_{ICR}} A_{ICR} + \frac{d C_{SFRR}}{d B_{ICR}} B_{ICR}$$

WHERE:-

$$C_{SFORR} = \sum_{N=0}^{2} \sum_{u=0}^{3} \left[A_{SF(u+4N)} \alpha_{RR}^{u} C_{T_{RR}}^{'N} \right]$$

$$A_{SF(u+4N)} = f(\mu_{RR})$$

} INTERPOLATE C_{FORR} LINEARLY BETWEEN μ's

$$\frac{d C_{SFRR}}{d A_{ICR}} = D_{SF_1} C_{TRR} + D_{SF_2} \mu^2_{RR} + D_{SF_3} \mu_{RR} + D_{SF_4}$$

$$\frac{d C_{SFRR}}{d B_{ICR}} = E_{SF_1} C_{TRR} + E_{SF_2} \mu^2_{RR} + E_{SF_3} \mu_{RR} + E_{SF_4}$$

ROTOR EQUATIONS (CONTINUED)

HUB PITCHING MOMENT

$$C_{PM_{RR}} = C_{PM_{0RR}} + \frac{\partial C_{PM_{RR}}}{\partial A_{ICR}} A_{ICR} + \frac{\partial C_{PM_{RR}}}{\partial B_{ICR}} B_{ICR} + \frac{\partial C_{PM_{RR}}}{\partial Q} Q^{R}_{NR}$$

WHERE :-

$$C_{PM_{0RR}} = \sum_{N=0}^{2} \sum_{u=0}^{3} \left[A_{PM(u+4N)} \alpha^{u}_{RR} C'^{N}_{TRR} \right]$$

$$A_{PM(u+4N)} = f(\mu_{RR})$$

$$\frac{\partial C_{PM_{RR}}}{\partial Q} = \sum_{N=0}^{2} \sum_{u=0}^{3} \left[H_{PM(u+4N)} \alpha^{u}_{RR} C'^{N}_{TRR} \right]$$

$$H_{PM(u+4N)} = f(\mu_{RR})$$

INTERPOLATE $C_{PM_{0RR}}$ AND $\frac{\partial C_{PM_{RR}}}{\partial Q}$ LINEARLY BETWEEN μ's

NOTE:-

FOR $\mu_{RR} \leq 0.35$

$$\frac{\partial C_{PM_{RR}}}{\partial B_{ICR}} = D_{PM_1} C_{TRR} + D_{PM_2} \mu^2_{RR} + D_{PM_3} \mu_{RR} + D_{PM_4}$$

FOR $\mu_{RR} > 0.35$, THE COEFFS. ABOVE CHANGE AS FOLLOWS

$D_{PM_2} \equiv D_{PM_5}$

$D_{PM_3} \equiv D_{PM_6}$

$D_{PM_4} \equiv D_{PM_7}$

ROTOR EQUATIONS (CONTINUED)

HUB PITCHING MOMENT (CONTINUED)

$$\frac{d\,C_{PTRR}}{d\,B_{ICR}} = E_{PM_1} C_{TRR} + E_{PM_2} \mu_{RR}^2 + E_{PM_3} \mu + E_{PM_4}$$

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

$$C_{YM_{RR}} = C_{YM_{ORR}} + \frac{d\,C_{YMRR}}{d\,A_{ICR}} A_{ICR} + \frac{d\,C_{YMRR}}{d\,B_{ICR}} B_{ICR} + \frac{d\,C_{YMRR}}{dR} R_{WR}^{R}$$

WHERE:-

$$C_{YM_{ORR}} = \sum_{N=0}^{2} \sum_{u=0}^{3} \left[A_{YM(u+4N)} \alpha_{RR}^{u} C_{T_{RR}}^{'N} \right]$$

$$A_{YM(u+4N)} = f(\mu_{RR})$$

$$\frac{d\,C_{YMRR}}{dR} = \sum_{N=0}^{2} \sum_{u=0}^{3} \left[J_{YM(u+4N)} \alpha_{RR}^{u} C_{T_{RR}}^{'N} \right]$$

$$J_{YM(u+4N)} = f(\mu_{RR})$$

} INTERPOLATE C_{YMRR} AND $\frac{d\,C_{YMRR}}{dR}$ LINEARLY BETWEEN μ's.

ROTOR EQUATIONS (CONTINUED)

HUB YAWING MOMENT (CONTINUED)

FOR $\mu_{RR} \leq 0.35$

$$\frac{d\,C_{YMRR}}{d\,B_{1CR}} = D_{YM_1} C_{TRR} + D_{YM_2} \mu_{RR}^2 + D_{YM_3} \mu_{RR} + D_{YM_4}$$

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

$$T_R = f_{T_R} C_{TRR} \rho \pi R^4 \Omega_R^2$$

$$N.F_R = f_{N.F_R} C_{NFRR} \rho \pi R^4 \Omega_R^2$$

$$S.F_R = f_{S.F_R} C_{SFRR} \rho \pi R^4 \Omega_R^2$$

$$M_R = f_{M_R} C_{PMRR} \rho \pi R^5 \Omega_R^2$$

$$N_R = f_{Y.H_R} C_{YMRR} \rho \pi R^5 \Omega_R^2$$

$$Q_{RREQ} = f_{Q_R} C_{PRR} \rho \pi R^5 \Omega_R^2$$

$$RHP_{RR} = f_{P_R} C_{PRR} \rho \pi R^5 \Omega_R^3 / 550 \quad \text{OR} \quad RHP_{RR} = Q_{RREQ} \left(\frac{\Omega_R}{550}\right)$$

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

$$\mathcal{L}_{RRH} = Q_{REEQ} + I_p \dot{\Omega}_R$$

$$\mathcal{M}_{RRH} = \mathcal{M}_R \cos\zeta_{HR} + \mathcal{N}_R \sin\zeta_{HR} + I_p \Omega_R (p \sin i_{NR} + r \cos i_{NR})$$

$$\mathcal{N}_{RRH} = \mathcal{N}_R \cos\zeta_{HR} - \mathcal{M}_R \sin\zeta_{HR} - I_p \Omega_R (\dot{i}_{NR} + q)$$

Note: Nacelle Axes are right handed systems

ROTOR FORCES & MOMENT RESOLUTION (Cont'd.)

LEFT TIP PIVOT - BODY AXES@TIP (w/NACELLE AERO)

$$X^{NL}_{AERO} = (T_L + \Delta X'_{LN})\cos i_{NL} - \sin i_{NL}\left(N.F_L \cos \zeta_{HL} + S.F_L \sin \zeta_{HL} - \Delta Z'_{LN}\right)$$

$$Y^{NL}_{AERO} = S.F_L \cos \zeta_{HL} - N.F_L \sin \zeta_{HL} + \Delta Y'_{LN}$$

$$Z^{NL'}_{AERO} = -(T_L + \Delta X'_{LN})\sin i_{NL} - \cos i_{NL}\left(N.F_L \cos \zeta_{HL} + S.F_L \sin \zeta_{HL} - \Delta Z'_{LN}\right)$$

$$\mathcal{L}^{NL'}_{AERO} = (\mathcal{L}_{LRH} + \Delta \mathcal{L}'_{LN})\cos i_{NL} + \sin i_{NL}(\mathcal{M}_{LRH} + \Delta \mathcal{M}'_{LN} + L_S Y^{NL}_{AERO})$$

$$\mathcal{M}^{NL}_{AERO} = \mathcal{M}_{LRH} + \Delta \mathcal{M}'_{LN} + N.F_L L_S \cos \zeta_{HL} + S.F_L L_S \sin \zeta_{HL} - L_S \Delta Z'_{LN} - I_E \Omega_{EL} r$$

$$\mathcal{N}^{NL}_{AERO} = \cos i_{NL}(\mathcal{N}_{LRH} + \Delta \mathcal{N}'_{LN} + L_S Y^{NL}_{AERO}) - \sin i_{NL}(\mathcal{L}_{LRH} + \Delta \mathcal{L}'_{LN}) + I_E \Omega_{EL} q$$

NACELLE EQUATION INPUT - LEFT

$$\mathcal{M}_{NLAERO} = \mathcal{M}_{LRH} + \Delta \mathcal{M}'_{LN} + (N.F_L \cos \zeta_{HL} + S.F_L \sin \zeta_{HL} - \Delta Z'_{LN})L_S$$

GLAS INPUTS - LEFT

$$\mathcal{M}_{\substack{NL\,AERO \\ GLAS}} = \mathcal{M}_{LRH} + L_S(N.F_L \cos \zeta_{HL} + S.F_L \sin \zeta_{HL})$$

$$\mathcal{N}_{\substack{NL\,AERO \\ GLAS}} = \mathcal{N}_{LRH} + L_S(S.F_L \cos \zeta_{HL} - N.F_L \sin \zeta_{HL})$$

Rotor Force & Moment Resolution (Cont'd.)

Right Tip Pivot - Body Axes @ Tip (w/ Nacelle Aero)

$$X^{NR}_{AERO} = (T_R + \Delta X'_{RN})\cos i_{NR} + \sin i_{NR}(-N.F_R \cos \zeta_{HR} + S.F_R \sin \zeta_{HR} + \Delta Z'_{RN})$$

$$Y^{NR}_{AERO} = -S.F_R \cos \zeta_{HR} - N.F_R \sin \zeta_{HR} + \Delta Y'_{RN}$$

$$Z^{NR}_{AERO} = -(T_R + \Delta X'_{RN})\sin i_{NR} + \cos i_{NR}(-N.F_R \cos \zeta_{HR} + S.F_R \sin \zeta_{HR} + \Delta Z'_{RN})$$

$$\mathcal{L}^{NR}_{AERO} = (\mathcal{L}_{RRH} + \Delta \mathcal{L}'_{RN})\cos i_{NR} + \sin i_{NR}(\mathcal{M}_{RRH} + L_S Y^{NR}_{AERO} + \Delta \mathcal{M}'_{RN})$$

$$\mathcal{M}^{NR}_{AERO} = \mathcal{M}_{RRH} + \Delta \mathcal{M}'_{RN} + N.F_R L_S \cos \zeta_{HR} - S.F_R L_S \sin \zeta_{HR} - L_S \Delta Z'_{RN} - I_E \Omega_{ER} r$$

$$\mathcal{N}^{NR}_{AERO} = \cos i_{NR}(\mathcal{N}_{RRH} + \Delta \mathcal{N}'_{RN} + L_S Y^{NR}_{AERO}) - \sin i_{NR}(\mathcal{L}_{RRH} + \Delta \mathcal{L}'_{RN}) + I_E \Omega_{ER} q$$

Nacelle Equation Input - Right

$$\mathcal{M}_{NR\,AERO} = \mathcal{M}_{RRH} + \Delta \mathcal{M}'_{RN} + (N.F_R \cos \zeta_{HR} - S.F_R \sin \zeta_{HR} - \Delta Z'_{NR}) L_S$$

GLAS Inputs - Right

$$\mathcal{M}_{\substack{NR\,AERO \\ GLAS}} = \mathcal{M}_{RRH} + L_S(N.F_R \cos \zeta_{HR} - S.F_R \sin \zeta_{HR})$$

$$\mathcal{N}_{\substack{NR\,AERO \\ GLAS}} = \mathcal{N}_{RRH} - L_S(S.F_R \cos \zeta_{HR} + N.F \sin \zeta_{HR})$$

WING VERTICAL BENDING

RIGHT WING TIP DEFLECTION

$$\bar{a}_{RT} = \frac{Z_{AERO}}{m} + Y_N \dot{p}$$

$$\bar{a}_{RWAC} = \frac{Z_{AERO}}{m} + Y_{WAC} \dot{p}$$

$$h_{IR} = K_{w1} Z_{AERO}^{NR'} + K_{w2} Z_{AERO}^{RW'} + K_{w3} \mathcal{L}_{AERO}^{NR'} - K_{w4} \bar{a}_{RT} - K_{w5} \bar{a}_{RWAC}$$

$$\dot{h}_{IR} = \Delta h_{IR} / \Delta t$$

WHERE; Δh_{IR} IS THE DIFFERENCE OF h_{IR} BETWEEN TIME FRAMES AND Δt IS THE TIME FRAME

RIGHT WING A.C. DEFLECTION

$$h_{IRWAC} = K_{w6} Z_{AERO}^{NR'} + K_{w7} Z_{AERO}^{RW'} + K_{w8} \mathcal{L}_{AERO}^{NR'} - K_{w9} \bar{a}_{RT} - K_{w10} \bar{a}_{RWAC}$$

$$\dot{h}_{IRWAC} = \Delta h_{IRWAC} / \Delta t$$

WHERE: Δh_{IRWAC} IS THE DIFFERENCE OF h_{IRWAC} BETWEEN TIME FRAMES AND Δt IS THE TIME FRAME.

FORCE AND MOMENT EFFECTS

$$\ddot{Z}_{AERO}^{NR} = -2 \zeta_{w1} \omega_{w1} \dot{Z}_{AERO}^{NR} - \omega_{w1}^2 Z_{AERO}^{NR} + \omega_{w1}^2 Z_{AERO}^{NR'}$$

$$\ddot{Z}_{AERO}^{RW} = -2 \zeta_{w2} \omega_{w2} \dot{Z}_{AERO}^{RW} - \omega_{w2}^2 Z_{AERO}^{RW} + \omega_{w2}^2 Z_{AERO}^{RW'}$$

$$\ddot{\mathcal{L}}_{AERO}^{NR} = -2 \zeta_{w3} \omega_{w3} \dot{\mathcal{L}}_{AERO}^{IR} - \omega_{w3}^2 \mathcal{L}_{AERO}^{NR} + \omega_{w3}^2 \mathcal{L}_{AERO}^{NR'}$$

FORM Z_{AERO}^{NR}, Z_{AERO}^{RW}, & $\mathcal{L}_{AERO}^{NR}$

WING VERTICAL BENDING (Cont'd.)

LEFT WING TIP DEFLECTION

$$\bar{a}_{LT} = \frac{Z_{AERO}}{m} - Y_N \dot{p}$$

$$\bar{a}_{LWAC} = \frac{Z_{AERO}}{m} - Y_{WAC} \dot{p}$$

$$h_{iL} = K_{w1} Z_{AERO}^{NL'} + K_{w2} Z_{AERO}^{LW'} - K_{w3} \mathcal{L}_{AERO}^{NL'} - K_{w4} \bar{a}_{LT} - K_{w5} \bar{a}_{LWAC}$$

$$\dot{h}_{iL} = \Delta h_{iL} / \Delta t$$

WHERE: Δh_{iL} IS THE DIFFERENCE OF h_{iL} BETWEEN TIME FRAMES AND Δt IS THE TIME FRAME

LEFT WING A.C. DEFLECTION

$$h_{iLWAC} = K_{w6} Z_{AERO}^{NL'} + K_{w7} Z_{AERO}^{LW'} - K_{w8} \mathcal{L}_{AERO}^{NL'} - K_{w9} \bar{a}_{LT} - K_{w10} \bar{a}_{LWAC}$$

$$\dot{h}_{iLWAC} = \Delta h_{iLWAC} / \Delta t$$

WHERE: Δh_{iLWAC} IS THE DIFERENCE OF h_{iLWAC} BETWEEN TIME FRAMES AND Δt IS THE TIME FRAME

FORCE AND MOMENT EFFECTS

$$\ddot{Z}_{AERO}^{NL} = -2 \zeta_{w1} \omega_{w1} \dot{Z}_{AERO}^{NL} - \omega_{w1}^2 Z_{AERO}^{NL} + \omega_{w1}^2 Z_{AERO}^{NL'}$$

$$\ddot{Z}_{AERO}^{LW} = -2 \zeta_{w2} \omega_{w2} \dot{Z}_{AERO}^{LW} - \omega_{w2}^2 Z_{AERO}^{LW} + \omega_{w2}^2 Z_{AERO}^{LW'}$$

$$\ddot{\mathcal{L}}_{AERO}^{NL} = -2 \zeta_{w3} \omega_{w3} \dot{\mathcal{L}}_{AERO}^{NL} - \omega_{w3}^2 \mathcal{L}_{AERO}^{NL} + \omega_{w3}^2 \mathcal{L}_{AERO}^{NL'}$$

FORM Z_{AERO}^{NL}, Z_{AERO}^{LW}, & $\mathcal{L}_{AERO}^{NL}$

WING TORSION

LEFT WING TWIST @ TIP

$$K_{\theta t}\,\theta_{tLW} = M_{NLACT} - I_E \Omega_{EL} r + q_{SLW}\,\frac{c_w^2 b_w}{2}\,C_{M0}(1 - C_{TSLR}) + (1 - C_{TSLR})\,q_{SLW}\,c_w^2\left(\frac{dC_{MWC/4}}{dC_L} + \frac{X_{WAC}}{C_W}\right)\left(\frac{C_{L\alpha} b_w}{6\pi}\right)\left(4\theta_{tLW} + 3\pi\alpha_{LW_{RIGID}}\right)$$

RIGHT WING TWIST @ TIP

$$K_{\theta t}\,\theta_{tRW} = M_{NRACT} - I_E \Omega_{ER} r + q_{SRW}\,\frac{c_w^2 b_w}{2}\,C_{M0}(1 - C_{TSRR}) + (1 - C_{TSRR})\,q_{SRW}\,c^2\left(\frac{dC_{MWC/4}}{dC_L} + \frac{X_{WAC}}{C_W}\right)\left(\frac{C_{L\alpha} b_w}{6\pi}\right)\left(4\theta_{tRW} + 3\pi\alpha_{RWRIGID}\right)$$

WHERE: $C_{M0} = C_1 + C_2 \delta_F + C_3 \delta_F^2$

$$\theta_{tLWAC} = \frac{Y_{WAC}}{Y_N}\,\theta_{tLW}$$

$$\theta_{tRWAC} = \frac{Y_{WAC}}{Y_N}\,\theta_{tRW}$$

NOTE: IF UMBRELLAS ARE OPEN; SET TERMS CONTAINING $q_S(1 - C_{TS})$ 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 ONE 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 THEIR 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 CG.

$$X_f = \ell_f - X_{CG}$$

$$Z_f = h_f - Z_{CG}$$

Wing C.G w.r.t. A/C C.G.

$$X_w = \ell_w - X_{CG}$$

$$Z_w = h_w - Z_{CG}$$

Nacelle C.G.'s w.r.t. A/C C.G.

$$X_R = \ell \cos(i_{NR} - \lambda) - X_{CG}$$

$$Z_R = -\ell \sin(i_{NR} - \lambda) - Z_{CG}$$

$$X_L = \ell \cos(i_{NL} - \lambda) - X_{CG}$$

$$Z_L = -\ell \sin(i_{NL} - \lambda) - Z_{CG}$$

Preliminary Calculations

Inertia Terms

$$\sum_k I_{ij}^{(k)} = I_{ij}^{(f)} + I_{ij}^{(w)} + 2I'_{ij}$$

$$I_{xx} = \sum_k I_{xx}^{(k)} + (I'_{zz} - I'_{xx})(\sin^2 i_{NR} + \sin^2 i_{NL})$$
$$- I'_{xz}(\sin 2i_{NR} + \sin 2i_{NL}) + 2 m_N Y_N^2$$
$$+ m_f h_f Z_f + m_w h_w Z_w +$$
$$- \ell m_N [Z_R \sin(i_{NR} - \lambda) + Z_L \sin(i_{NL} - \lambda)]$$

$$J_{xx} = \sum_k (I_{zz}^{(k)} - I_{yy}^{(k)}) + (I'_{xx} - I'_{zz})(\sin^2 i_{NR} + \sin^2 i_{NL})$$
$$+ I'_{xz}(\sin 2i_{NR} + \sin 2i_{NL}) + 2 m_N Y_N^2$$
$$- (m_f h_f Z_f + m_w h_w Z_w)$$
$$+ \ell m_N [Z_R \sin(i_{NR} - \lambda) + Z_L \sin(i_{NL} - \lambda)]$$

$$I_{xz}^{(p)} = I_{xz}^{(f)} + I_{xz}^{(w)} + \frac{1}{2}(I'_{xx} - I'_{zz})(\sin 2i_{NR} + \sin 2i_{NL})$$
$$+ I'_{xz}(\cos 2i_{NR} + \cos 2i_{NL}) + (m_f \ell_f Z_f + m_w \ell_w Z_w)$$
$$+ m_N \ell [Z_R \cos(i_{NR} - \lambda) + Z_L \cos(i_{NL} - \lambda)]$$

Inertia Terms

$$I_{yy} = \sum_k I_{yy}^{(k)} + m_f(-\ell_f X_f + h_f Z_f) + m_w(\ell_w X_w + h_w Z_w)$$
$$+ m_N \ell\left[X_R \cos(i_{NR}-\lambda) - Z_R \sin(i_{NR}-\lambda)\right]$$
$$+ m_N \ell\left[X_L \cos(i_{NL}-\lambda) - Z_L \sin(i_{NL}-\lambda)\right]$$

$$J_{yy} = \left(I_{xx}^{(f)} - I_{zz}^{(f)}\right) + \left(I_{xx}^{(\omega)} - I_{zz}^{(\omega)}\right) + \ldots$$
$$+\left(I'_{xx} - I'_{zz}\right)\left(\cos 2i_{NR} + \cos 2i_{NL}\right)$$
$$- 2I'_{xz}\left(\sin 2i_{NR} + \sin 2i_{NL}\right) + m_f(-\ell_f X_f + h_f Z_f)$$
$$+ m_w(-\ell_w X_w + h_w Z_w)$$
$$- m_N \ell\left[X_R \cos(i_{NR}-\lambda) + Z_R \sin(i_{NR}-\lambda) + X_L \cos(i_{NL}-\lambda)\right.$$
$$\left. + Z_L \sin(i_{NL}-\lambda)\right]$$

$$I_{xz}^{(f)} = I_{xz}^{(f)} + I_{xz}^{(\omega)} + \frac{1}{2}\left(I'_{xx} - I'_{zz}\right)\left(\sin 2i_{NR} + \sin 2i_{NL}\right)$$
$$+ I'_{xz}\left(\cos 2i_{NR} + \cos 2i_{NL}\right)$$
$$- m_N \ell\left[X_R \sin(i_{NR}-\lambda) + X_L \sin(i_{NL}-\lambda)\right]$$
$$+ m_f h_f X_f + m_w h_w X_w$$

Inertia Terms

$$I_{zz} = \sum_{k} I_{zz}^{(k)} + (I_{xx}' - I_{zz}')(\sin^2 i_{NR} + \sin^2 i_{NL}) + I_{xz}'(\sin 2i_{NR} + \sin 2i_{NL}) + 2 m_N Y_N^2 + m_f l_f X_f + m_w l_w X_w + m_N l [X_R \cos(i_{NR} - \lambda) + X_L \cos(i_{NL} - \lambda)]$$

$$J_{zz} = \sum_{k} (I_{yy}^{(k)} - I_{xx}^{(k)}) + (I_{xx}' - I_{zz}')(\sin^2 i_{NR} + \sin^2 i_{NL}) + I_{xz}'(\sin 2i_{NR} + \sin 2i_{NL}) - 2 m_N Y_N^2 + m_f l_f X_f + m_w l_w X_w + m_N l [X_R \cos(i_{NR} - \lambda) + X_L \cos(i_{NL} - \lambda)]$$

$$I_{xz}^{(r)} = I_{xz}^{(f)} + I_{xz}^{(w)} + \frac{1}{2}(I_{xx}' - I_{zz}')(\sin 2i_{NR} + \sin 2i_{NL}) + I_{xz}'(\cos 2i_{NR} + \cos 2i_{NL}) + m_f h_f X_f + m_w h_w X_w - l m_N [X_R \sin(i_{NR} - \lambda) + X_L \sin(i_{NL} - \lambda)]$$

BASIC EQUATIONS — FINAL SIMPLIFICATION

ROLL EQUATION

$$I_{xx}\dot{p} = -J_{xx}\,rq + I_{xz}^{(p)}(\dot{r} + pq)$$
$$+ \ell m_N Y_N \left\{ \ddot{i}_{NR}^{o} \cos(i_{NR} - \lambda) - \ddot{i}_{NL}^{o} \cos(i_{NL} - \lambda) \right\}$$
$$+ \mathcal{L}_{AERO}$$

PITCH EQUATION

$$I_{yy}\dot{q} = -J_{yy}\,pr - I_{xz}^{(q)}(p^2 - r^2)$$
$$- \ddot{i}_{NR}^{o} \left\{ I'_{yy} + \ell m_N \left[-Z_R \sin(i_{NR} - \lambda) + X_R \cos(i_{NR} - \lambda) \right] \right\}$$
$$- \ddot{i}_{NL}^{o} \left\{ I'_{yy} + \ell m_N \left[-Z_L \sin(i_{NL} - \lambda) + X_L \cos(i_{NL} - \lambda) \right] \right\}$$
$$+ \mathcal{M}_{AERO}$$

YAW EQUATION

$$I_{zz}\dot{r} = -J_{zz}\,pq - (rq - \dot{p})\,I_{xz}^{(r)}$$
$$- \ell m_N Y_N \left\{ \ddot{i}_{NR}^{o} \sin(i_{NR} - \lambda) - \ddot{i}_{NL}^{o} \sin(i_{NL} - \lambda) \right\}$$
$$+ \mathcal{N}_{AERO}$$

BASIC EQUATIONS – FINAL SIMPLIFICATION

ROLL EQUATION

$$I_{xx}\dot{p} = -J_{xx}\,rq + I_{xz}^{(p)}(\dot{r} + pq) + \ell m_N Y_N\left\{\overset{\circ\circ}{i}_{NR}\cos(i_{NR}-\lambda) - \overset{\circ\circ}{i}_{NL}\cos(i_{NL}-\lambda)\right\} + \mathcal{L}_{AERO}$$

PITCH EQUATION

$$I_{yy}\dot{q} = -J_{yy}\,pr - I_{xz}^{(q)}(p^2 - r^2) - \overset{\circ\circ}{i}_{NR}\left\{I'_{yy} + \ell m_N\left[-Z_R\sin(i_{NR}-\lambda) + X_R\cos(i_{NR}-\lambda)\right]\right\} - \overset{\circ\circ}{i}_{NL}\left\{I'_{yy} + \ell m_N\left[-Z_L\sin(i_{NL}-\lambda) + X_L\cos(i_{NL}-\lambda)\right]\right\} + \mathcal{M}_{AERO}$$

YAW EQUATION

$$I_{zz}\dot{r} = -J_{zz}\,pq - (rq - \dot{p})\,I_{xz}^{(r)} - \ell m_N Y_N\left\{\overset{\circ\circ}{i}_{NR}\sin(i_{NR}-\lambda) - \overset{\circ\circ}{i}_{NL}\sin(i_{NL}-\lambda)\right\} + \mathcal{N}_{AERO}$$

Basic Equations

Right Nacelle Actuator Pitching Moment Equation

$$
\begin{aligned}
M_{NRACT} = &-\ddot{i}_{NR}\left[I'_{yy} + \ell^2 m_N\left(1-\frac{m_N}{m}\right)\right] \\
&- \ell^2 m_N\left(1-\frac{m_N}{m}\right)\left[-pr\cos 2(i_{NR}-\lambda) + \dot{q}\right. \\
&\left. + (r^2-p^2)\sin(i_{NR}-\lambda)\cos(i_{NR}-\lambda)\right] \\
&- (r^2-p^2)\left[I'_{zz}\sin i_{NR}\cos i_{NR}\right] - I'_{yy}\dot{q} \\
&+ \ell\frac{m_N}{m}\left[X_{AERO}\sin(i_{NR}-\lambda) + Z_{AERO}\cos(i_{NR}-\lambda)\right] \\
&- \ell m_N Y_N\left\{(\dot{r}-pq)\left[\sin(i_{NR}-\lambda)\right]\right. \\
&\left. - (\dot{p}+rq)\left[\cos(i_{NR}-\lambda)\right]\right\} \\
&+ M_{NRAERO}
\end{aligned}
$$

Note: The above equation must be calculated for wing torsion calculation only

Basic Equations

Left Nacelle Actuator Pitching Moment Equation

$$
\begin{aligned}
M_{HLACT} = &- \ddot{i}_{NL}\left[I'_{yy} + \ell^2 m_N\left(1 - \frac{m_N}{m}\right)\right] \\
&- \ell^2 m_N\left(1 - \frac{m_N}{m}\right)\left[-pr\cos 2(i_{NL} - \lambda) + \dot{q}\right. \\
&\quad \left. + (r^2 - p^2)\sin(i_{NL} - \lambda)\cos(i_{NL} - \lambda)\right] \\
&- (r^2 - p^2)\left[I'_{zz}\sin i_{NL}\cos i_{NL}\right] - I'_{yy}\dot{q} \\
&+ \ell\frac{m_N}{m}\left[X_{AERO}\sin(i_{NL} - \lambda) + Z_{AERO}\cos(i_{NL} - \lambda)\right] \\
&+ \ell m_N V_N\left\{(\dot{r} - pq)\left[\sin(i_{NL} - \lambda)\right]\right. \\
&\quad \left. - (\dot{p} + rq)\left[\cos(i_{NL} - \lambda)\right]\right\} \\
&+ M_{NLAERO}
\end{aligned}
$$

NOTE: The above equation must be calculated for wing torsion calculation <u>only</u>.

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

North ward 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)

$$u_{PA} = u_P + qZ_{PA} - rY_{PA}$$

$$v_{PA} = v_P + rl_{PA} - pZ_{PA}$$

$$w_{PA} = w_P + pY_{PA} - ql_{PA}$$

GUST MODEL

The Gust Model to be used with the simulation will coesist 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.,.

$$U = U' + U_g \qquad P = P' + P_g$$
$$V = V' + V_g \qquad Q = Q' + Q_g$$
$$W = W' + W_g \qquad R = R' + R_g$$

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

$$m = \frac{1}{32.174}\left[w'_f + w'_{WT} + w'_{HT} + w'_{VT} + w'_w + w'_{NF} + w'_{CR} + w'_{FUEL} + w'_c\right]$$

$$m_N = \frac{1}{32.174}\left(\frac{w'_{NT}}{2}\right)$$

$$m_f = \frac{1}{32.174}\left[w'_f + w'_{HT} + w'_{VT} + w'_{CR} + w'_c\right]$$

$$m_w = \frac{1}{32.174}\left[w'_w + w'_{FUEL} + w'_{NF}\right]$$

$$\ell'_f = \left[(FS)_p - (FS)_{f_i}\right]\frac{1}{12}$$

$$\ell'_{HT} = \left[(FS)_p - (FS)_{HTCG}\right]\frac{1}{12}$$

$$\ell'_{VT} = \left[(FS)_p - (FS)_{VTCG}\right]\frac{1}{12}$$

$$\ell'_{PA} = \left[(FS)_p - (FS)_{PA}\right]\frac{1}{12}$$

$$\ell'_c = \left[(FS)_p - (FS)_c\right]\frac{1}{12}$$

$$\ell_f = \frac{1}{m_f(32.174)}\left[w'_f \ell'_f + w'_{HT}\ell'_{HT} + w'_{VT}\ell'_{VT} + w'_{CR}\ell_{PA} + w'_c\ell'_c\right]$$

$$\ell'_w = \left[(FS)_p - (FS)_w\right]\frac{1}{12}$$

$$\ell'_{FUEL} = \left[(FS)_p - (FS)_{FUEL}\right]\frac{1}{12}$$

$$\ell'_{NF} = \left[(FS)_p - (FS)_{NF}\right]\frac{1}{12}$$

$$\ell_w = \frac{1}{m_w(32.174)}\left[w'_w \ell'_w + w'_{FUEL}\ell'_{FUEL} + w'_{NF}\ell'_{NF}\right]$$

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.)

$$X_{HT} = \left[(FS)_p - (FS)_{HT}\right] \frac{1}{12}$$

$$Z_{HT} = \left[(WL)_p - (WL)_{HT}\right] \frac{1}{12}$$

$$X_{VT} = \left[(FS)_p - (FS)_{VT}\right] \frac{1}{12}$$

$$Z_{VT} = \left[(WL)_p - (WL)_{VT}\right] \frac{1}{12}$$

$$A = 3.14159\ R^2$$

$$\bar{Y}_{WAC} = \left[(\bar{BL})_{WAC}\right] \frac{1}{12}$$

$$X_{G2} = X_{G1} = \left[(FS)_p - (FS)_{G2}\right] \frac{1}{12}$$

$$Z_{G2} = Z_{G1} = \left[(WL)_p - (WL)_{G2}\right] \frac{1}{12}$$

$$Y_{G2} = \left[(BL)_{G2}\right] \frac{1}{12}$$

$$Y_{G1} = -Y_{G2}$$

$$Y_{G3} = 0.$$

$$Y_{PA} = \left[(BL)_{PA}\right] \frac{1}{12} \quad ; \quad \text{POSITIVE FOR PILOT IN RIGHT SEAT}$$

$$X_{FAC} = \left[(FS)_p - (FS)_{FAC}\right] \frac{1}{12}$$

$$Z_{FAC} = \left[(WL)_p - (WL)_{FAC}\right] \frac{1}{12}$$

PRELIMINARY CALCULATIONS (CONT'D)

$$X_{CL_2} = \left[(FS)_P - (FS)_{CL_2}\right]\frac{1}{12}$$

$$Z_{G3} = \left[(WL)_P - (WL)_{G3}\right]\frac{1}{12}$$

$$X_{G3} = \left[(FS)_P - (FS)_{G3}\right]\frac{1}{12}$$

$$Y_{WF} = \left[(BL)_{WF_{CG}}\right]\frac{1}{12}$$

$$Y_{HT} = \left[(BL)_{HT_{CG}}\right]\frac{1}{12}$$

$$Y_w = \left[(BL)_{W_{CG}}\right]\frac{1}{12}$$

$$Y_{FUEL} = \left[(BL)_{FUEL_{CG}}\right]\frac{1}{12}$$

INERTIA CALCULATIONS

$$\eta'_{f'} = l_f - l'_f$$

$$\delta'_{f'} = h_f - z'_f$$

$$\eta'_{HT} = l_f - l'_{HT}$$

$$\delta'_{HT} = h_f - z'_{HT}$$

$$\eta'_{VT} = l_f - l'_{VT}$$

$$\delta'_{VT} = h_f - z'_{VT}$$

$$\eta'_{CR} = l_f - l_{PR}$$

$$\delta'_{CR} = h_f - z_{PR}$$

PRELIMINARY CALCULATIONS (CONT'D)

$$\eta'_c = l_f - l'_c$$

$$\delta'_c = h_f - z'_c$$

$$I_{yy}^{(f)} = I_{yy_o}^{(w_{f'})} + I_{yy_o}^{(HT)} + I_{yy_o}^{(VT)} + I_{yy_o}^{(CR)} + I_{yy_o}^{(c)} + \frac{W'_f}{32.174}\left(\eta'^2_{f'} + \delta'^2_{f'}\right)$$
$$+ \frac{W'_{HT}}{32.174}\left(\eta'^2_{HT} + \delta'^2_{HT}\right) + \frac{W'_{VT}}{32.174}\left(\eta'^2_{VT} + \delta'^2_{VT}\right)$$
$$+ \frac{W'_{CR}}{32.174}\left(\eta'^2_{CR} + \delta'^2_{CR}\right) + \frac{W'_c}{32.174}\left(\eta'^2_c + \delta'^2_c\right)$$

$$I_{xx}^{(f)} = I_{xx_o}^{(w_{f'})} + I_{xx_o}^{(HT)} + I_{xx_o}^{(VT)} + I_{xx_o}^{(CR)} + I_{xx_o}^{(c)} + \frac{W'_f}{32.174}\delta'^2_{f'} + \frac{W'_{HT}}{32.174}\left(\delta'^2_{HT} + \gamma^2_{HT}\right)$$
$$+ \frac{W'_{VT}}{32.174}\delta'^2_{VT} + \frac{W'_{CR}}{32.174}\delta'^2_{CR} + \frac{W'_c}{32.174}\delta'^2_c$$

$$I_{zz}^{(f)} = I_{zz_o}^{(w_{f'})} + I_{zz_o}^{(HT)} + I_{zz_o}^{(VT)} + I_{zz_o}^{(CR)} + I_{zz_o}^{(c)} + \frac{W'_f}{32.174}\eta'^2_{f'} + \frac{W'_{HT}}{32.174}\left(\eta'^2_{HT} + \gamma^2_{HT}\right)$$
$$+ \frac{W'_{VT}}{32.174}\eta'^2_{VT} + \frac{W'_{CR}}{32.174}\eta'^2_{CR} + \frac{W'_c}{32.174}\eta'^2_c$$

$$I_{xz}^{(f)} = I_{xz_o}^{(w_{f'})} + I_{xz_o}^{(HT)} + I_{xz_o}^{(VT)} + I_{xz_o}^{(CR)} + I_{xz_o}^{(c)} + \frac{W'_f}{32.174}\eta'_{f'}\delta'_{f'}$$
$$+ \frac{W'_{HT}}{32.174}\eta'_{HT}\delta'_{HT} + \frac{W'_{VT}}{32.174}\eta'_{VT}\delta'_{VT} + \frac{W'_{CR}}{32.174}\eta'_{CR}\delta'_{CR}$$
$$+ \frac{W'_c}{32.174}\eta'_c\delta'_c$$

$$H'_{w'_w} = l_w - l'_w$$

$$\Delta'_{w'_w} = h_w - z'_w$$

$$H'_{w'_{FUEL}} = l_w - l'_{FUEL}$$

$$\Delta'_{w'_{FUEL}} = h_w - z'_{FUEL}$$

PRELIMINARY CALCULATIONS (CONT'D)

$$H'_{w'WF} = \ell_w - \ell'_{WF}$$

$$\Delta'_{w'WF} = h_w - z'_{WF}$$

$$I_{yy}^{(w)} = I_{yy_o}^{(w'_w)} + I_{yy_o}^{(w'_{FUEL})} + I_{yy_o}^{(w'_{WF})} + \frac{W'_w}{32.174}\left(H'^2_{w'_w} + \Delta'^2_{w'_w}\right)$$

$$+ \frac{W'_{FUEL}}{32.174}\left(H'^2_{w'_{FUEL}} + \Delta'^2_{w'_{FUEL}}\right) + \frac{W'_{WF}}{32.174}\left(H'^2_{w'_{WF}} + \Delta'^2_{w'_{WF}}\right)$$

$$I_{xx}^{(w)} = I_{xx_o}^{(w'_w)} + I_{xx_o}^{(w'_{FUEL})} + I_{xx_o}^{(w'_{WF})} + \frac{W'_w}{32.174}\left(\Delta'^2_{w'_w} + Y_w^2\right)$$

$$+ \frac{W'_{FUEL}}{32.174}\left(\Delta'^2_{w'_{FUEL}} + Y^2_{FUEL}\right) + \frac{W'_{WF}}{32.174}\left(\Delta'^2_{w'_{WF}} + Y^2_{WF}\right)$$

$$I_{zz}^{(w)} = I_{zz_o}^{(w'_w)} + I_{zz_o}^{(w'_{FUEL})} + I_{zz_o}^{(w'_{WF})} + \frac{W'_w}{32.174}\left(H'^2_{w'_w} + Y_w^2\right)$$

$$+ \frac{W'_{FUEL}}{32.174}\left(H'^2_{w'_{FUEL}} + Y^2_{FUEL}\right) + \frac{W'_{WF}}{32.174}\left(H'^2_{w'_{WF}} + Y^2_{WF}\right)$$

$$I_{xz}^{(w)} = I_{xz_o}^{(w'_w)} + I_{xz_o}^{(w'_{FUEL})} + I_{xz_o}^{(w'_{WF})} + \frac{W'_w}{32.174} H'_{w'_w}\Delta_{w'_w}$$

$$+ \frac{W'_{FUEL}}{32.174} H'_{w'_{FUEL}}\Delta'_{w'_{FUEL}} + \frac{W'_{WF}}{32.174} H'_{w'_{WF}}\Delta'_{w'_{WF}}$$

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.

$$i_{NREF} = K_{T1} \int \dot{u}\, dt + K_{T2}\, \dot{u}$$

$$\phi = -K_{T3} \int \dot{v}\, dt - K_{T4}\, \dot{v}$$

$$w = K_{T5} \int \dot{w}\, dt + K_{T6}\, \dot{w}$$

$$\delta_S = -K_{T7} \int \dot{p}\, dt - K_{T8}\, \dot{p}$$

$$\delta_R = -K_{T9} \int \dot{r}\, dt - K_{T10}\, \dot{r}$$

$$\delta_B = -K_{T11} \int \dot{q}\, dt - K_{T12}\, \dot{q}$$

$$i_{NR} = K_{T13} \iint \ddot{i}_{NR}\, dt\, dt + K_{T14} \int \ddot{i}_{NR}\, dt$$

$$i_{NL} = K_{T13} \iint \ddot{i}_{NL}\, dt\, dt + K_{T14} \int \ddot{i}_{NR}\, dt$$

$$\delta_{TH} = K_{T15} \int \dot{z}_{\underset{e}{DOWN}}\, dt + K_{T16}\, \dot{z}_{\underset{e}{DOWN}}$$

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) $\dot{z}_{\underset{e}{DOWN}} = \dot{z}_{DOWN} - \dot{z}_{\underset{TRIM}{DOWN}}$; set $\dot{z}_{\underset{TRIM}{DOWN}}$ at desired R/C

MATH MODEL TRIM LOOP OPTIONS

1.) When specifying i_{NREF}, form:

$$\theta = K_{TI}\int \dot{u}\,dt + K_{TIB}\dot{u}$$

Note: This option will be commonly used in cruise flight when the nacelles are down and locked.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

MATHEMATICAL MODEL
INPUT DATA

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

MODEL 222 DIMENSIONAL DATA (Continued)

SPAN (LENGTH EACH SIDE)	151.56 IN
CHORD (% OF WING CHORD)	12.65
POSITION OF LE (% OF WING CHORD)	66.0
SWEEP BACK OF HINGE LINE	0°
LEADING EDGE UMBRELLA	
AREA (PLAN)	28.12 FT^2
CHORD (% OF WING CHORD)	18.6
SWEEPBACK OF HINGE LINE	0°
ELEVATORS	
AREA (AFT OF HINGE	18.65 Ft
CHORD (% HORIZONTAL TAIL CHORD)	32.0
SWEEPBACK OF HINGE LINE	0°
RUDDER	
AREA (AFT OF HINGE)	12.60 FT^2
CHORD (% VERTICAL TAIL CHORD)	38.0
SWEEPBACK OF HINGE LINE	31° 42'
ROTORS	
NUMBER OF BLADES (PER ROTOR)	3
DIAMETER	26.0 FT
BLADE AREA (PER BLADE)	18.5 FT^2
GEOMETRIC DISC AREA (TOTAL)	1061.8 FT^2
SOLIDITY RATIO	.115
AIRFOIL SECTION	
ROOT	NACA 23021
STA. 54.60	BV 23021-1.58
TIP	BV 23021-1.58

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

C4

MASS PROPERTIES

(WEIGHT BALANCE AND MOMENTS OF INERTIA)

SUB-GROUPS	WEIGHT	NACELLE HORIZONTAL BALANCE X (F.S.)	Y (W.S.)	Z (W.L.)	INERTIA - SLUG FT^2 I_{XX} (ROLL)	I_{YY} (PITCH)	I_{ZZ} (YAW)	I_{XZ}	NACE BALANCE X (F.S.)	Y (W.S.)
° 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	81			
TILTING	2792	137.5	200.7	42.0	45	386	389		176.4	200.7
OPER. WEIGHT EMPTY	9884	165.8		22.6	48674	12256	57263	490	176.8	
° 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	
° 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	
° 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	
° 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	

NOTE: ° ROTOR BLADE INERTIAS (I_O) ARE NOT INCLUDED IN THE ABOVE VALUES. THE ROTOR BLADE WEI
AT THE HUB ℄.

° ROTOR BLADE WEIGHT (COMPLETE AS REMOVED FROM HUB), BALANCE AND INERTIAS (I_O) ARE AS

BLADE WEIGHT 124 LBS., SPAN BALANCE 54.9" FROM HUB ℄, CHORD BALANCE FROM LEADIN
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

L E	V E R T I C A L			
	INERTIA - SLUG FT^2			
Z (W.L.)	I_{XX} (ROLL)	I_{YY} (PITCH)	I_{YX} (YAW)	I_{XZ}
84.3	389	388	45	
34.6	50751	13308	56238	1141
26.8	55176	14482	50533	1197
25.5	55781	15120	61204	1182
31.6	54826	13971	60290	1104
31.1	53291	13856	58673	1101

T IS ASSUMED TO BE ACTING

LLOWS:

EDGE OF

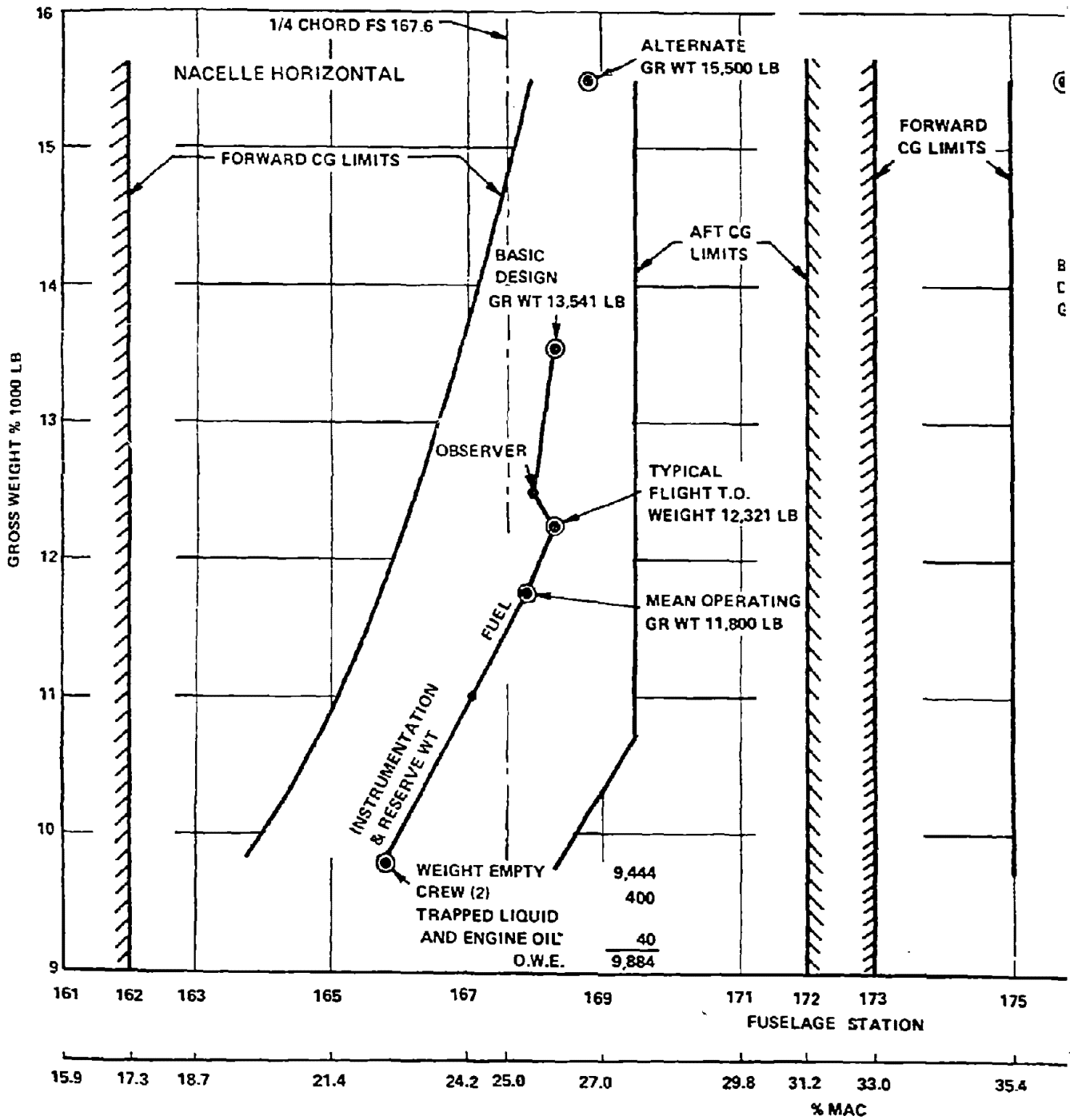
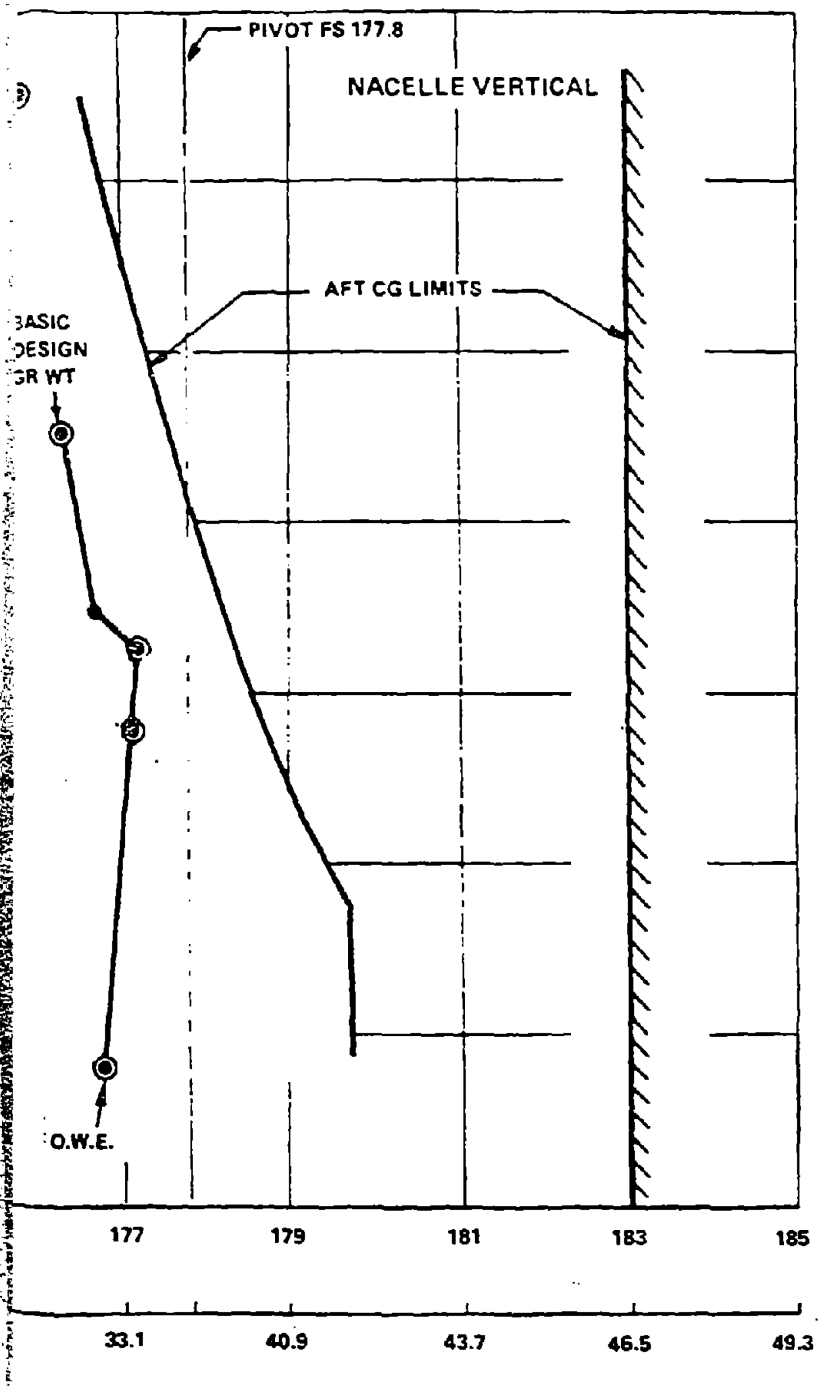


Figure F.2. C.G. Limit Diagram



OPERATIONAL CG LIMITS

STRUCTURAL DESIGN CG LIMITS

• 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

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

Load Alleviation System (LAS) (Page E.5)

τ_{LAS} = 0.2 sec.

LAS Functions

$G_{B_{1_\alpha}}$, $G_{A_{1_\beta}}$, $G_{A_{1_\alpha}}$ vs Dynamic Pressure

Nacelle and Airplane Controls (Page E.6)

Nacelle Actuator Dynamics

$\omega_{NR} = \omega_{NL}$ = 10 rad/sec

$\zeta_{NL} = \zeta_{NR}$ = 1.0

Scheduled Functions

a) Scheduled Flap Angle vs Nacelle Incidence

b) Flaperon vs Lateral Stick

c) Spoiler Deflection vs Lateral Stick

d) Spoiler Actuator Limit

Stability Augmentation System (Page E.7 and E.8)

Gains, time constants and scheduled functions noted on block diagrams.

Roll SAS Authoritiy Limit = $\pm$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

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

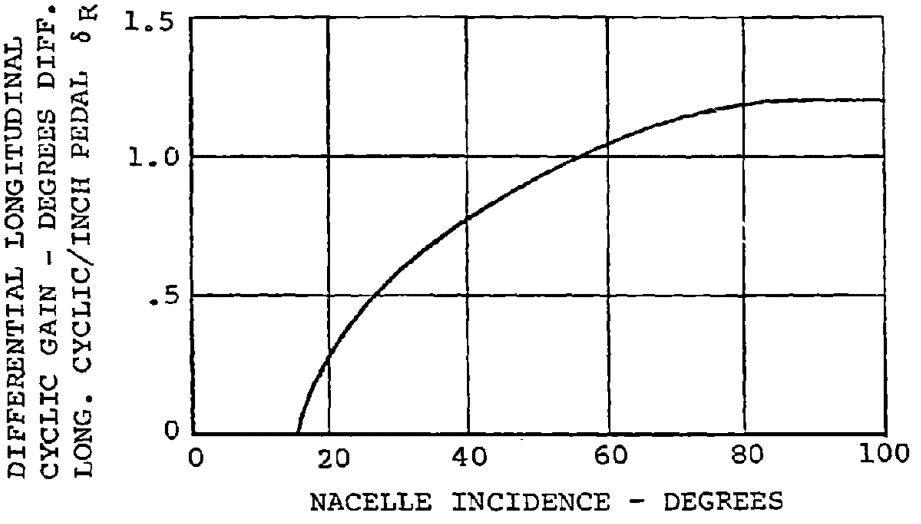
g) Throttle Collective Gain Schedule

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

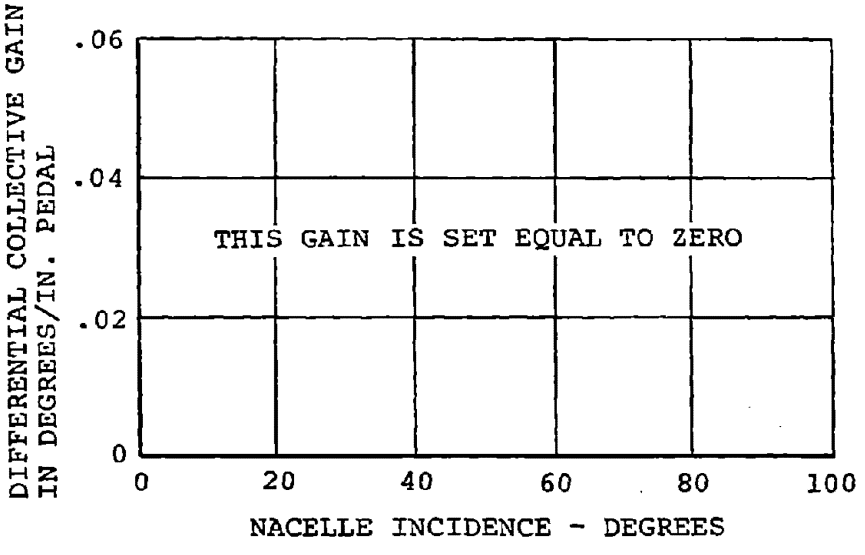


Figure F.3. Differential Long. Cyclic for Yaw Control vs Nacelle Incidence

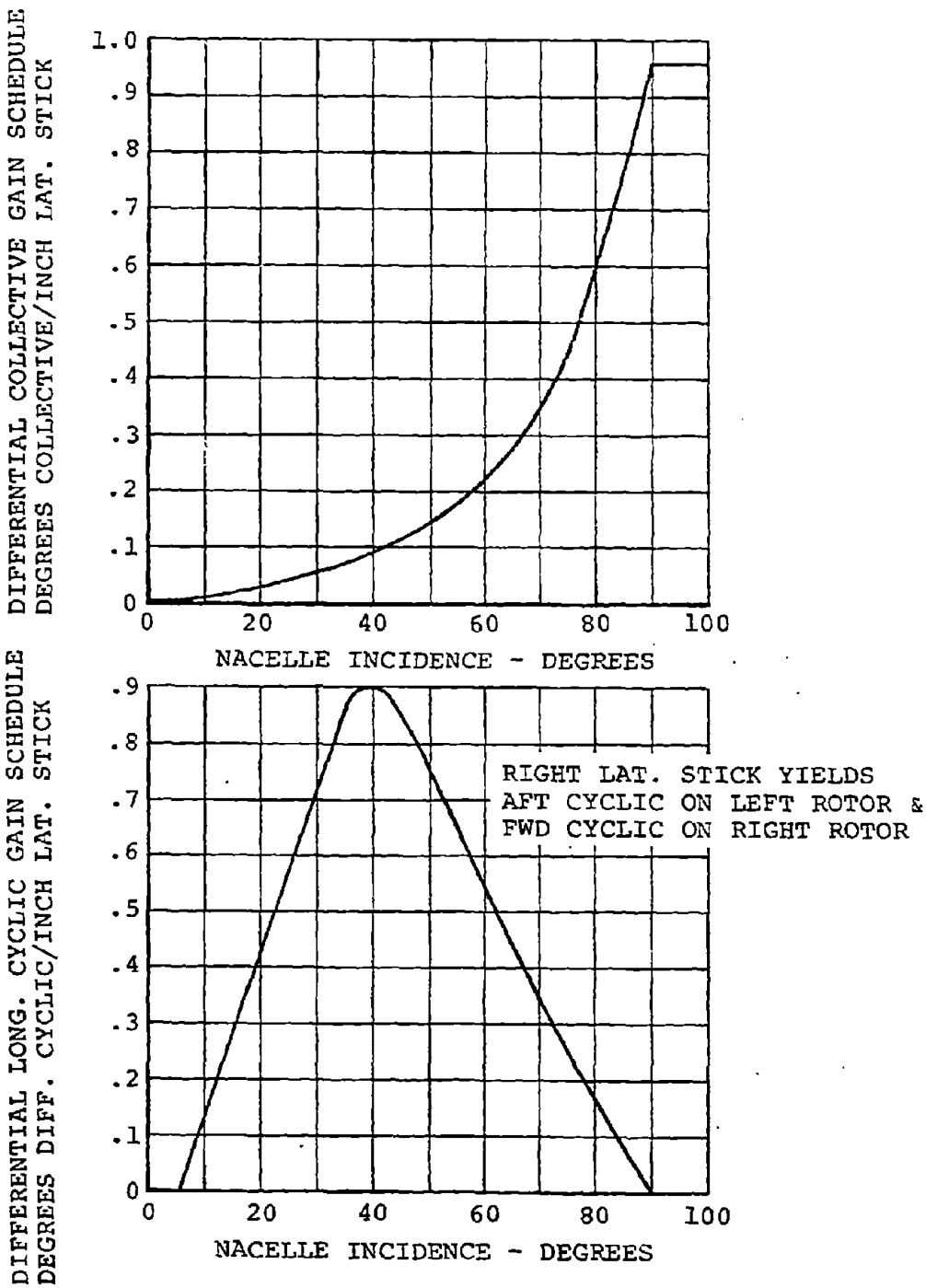


Figure F.4. Rotor Roll Control Schedules in Transition

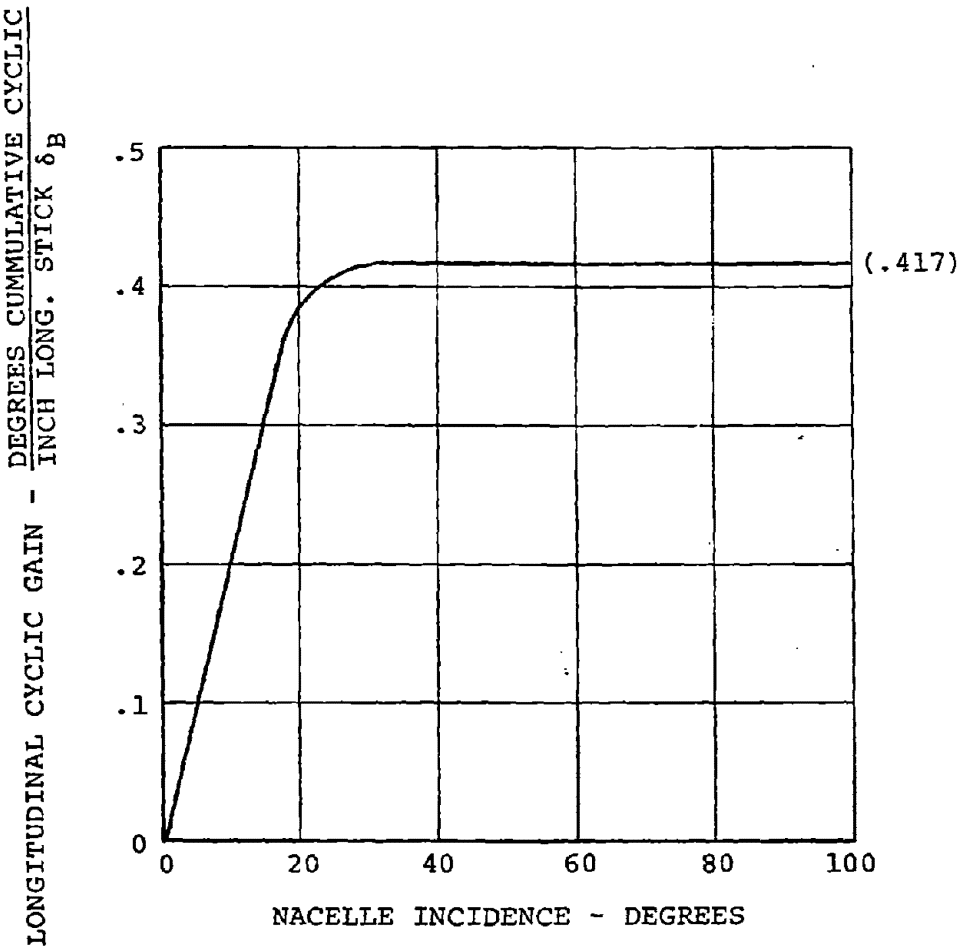


Figure F.5. Longitudinal Cyclic for Pitch Control Gain vs Nacelle Incidence

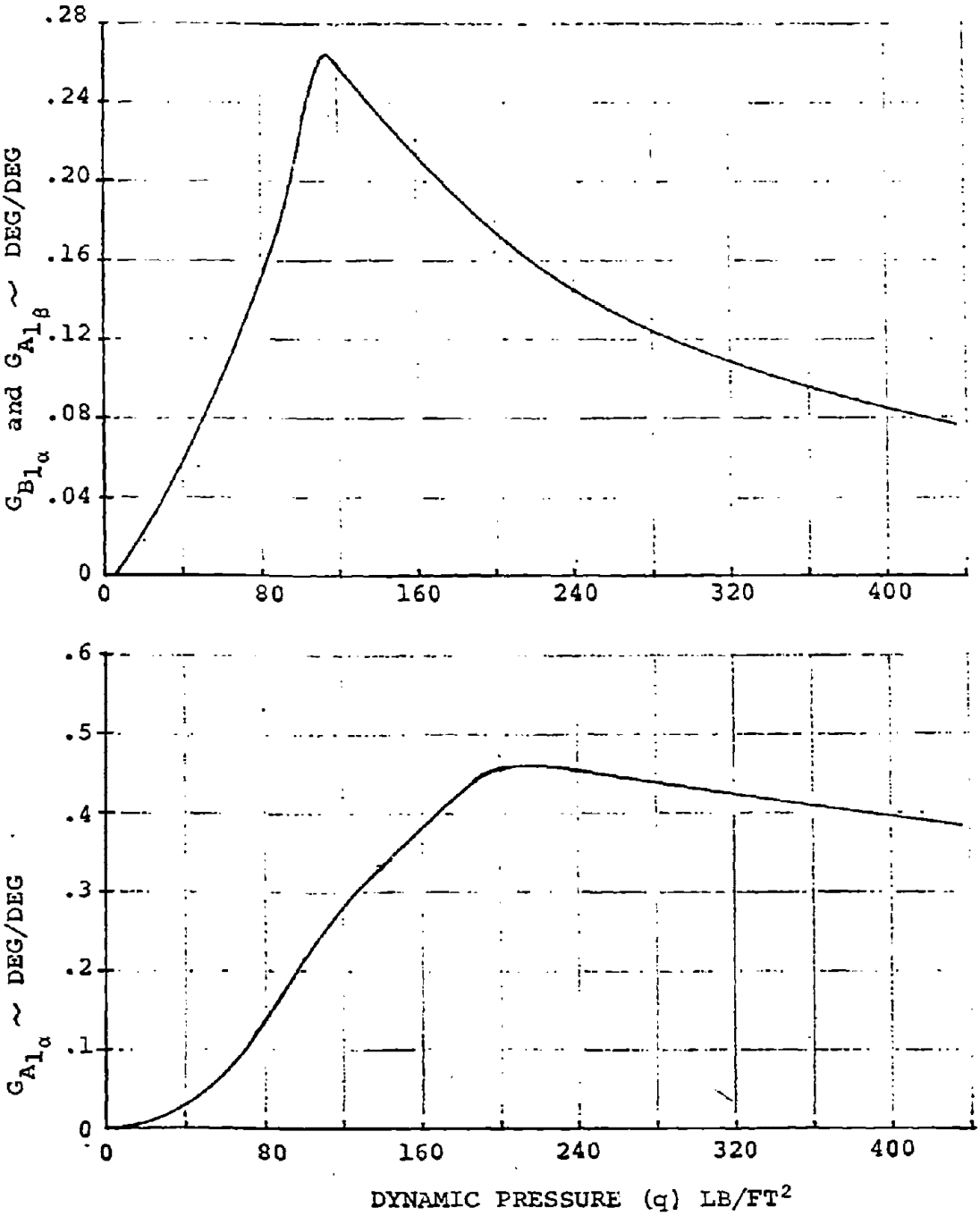


Figure F.6. Load Alleviation System Gain Schedule.

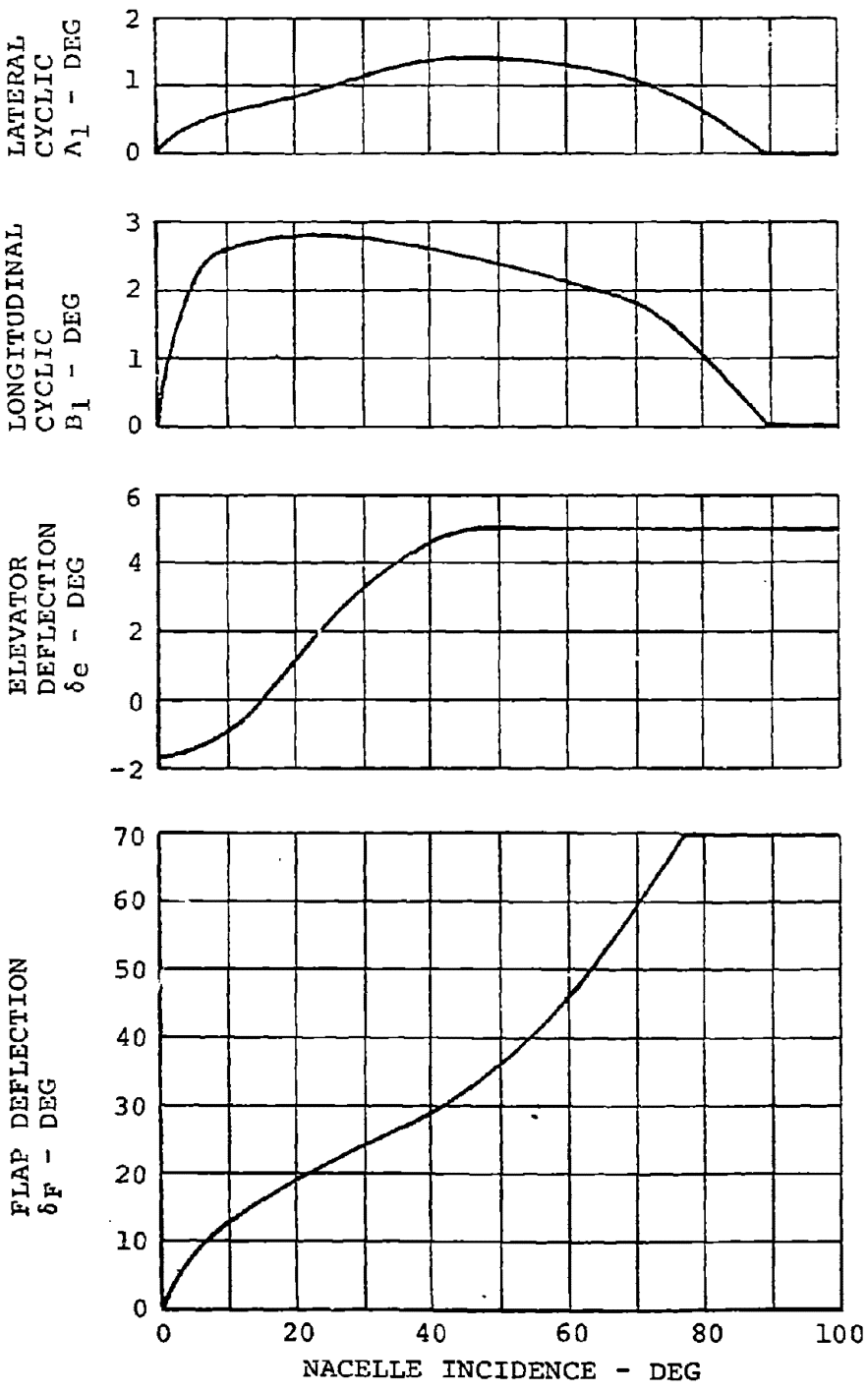


Figure F.7. Programmed Cyclic, Elevator, and Flap Deflection vs Nacelle Incidence

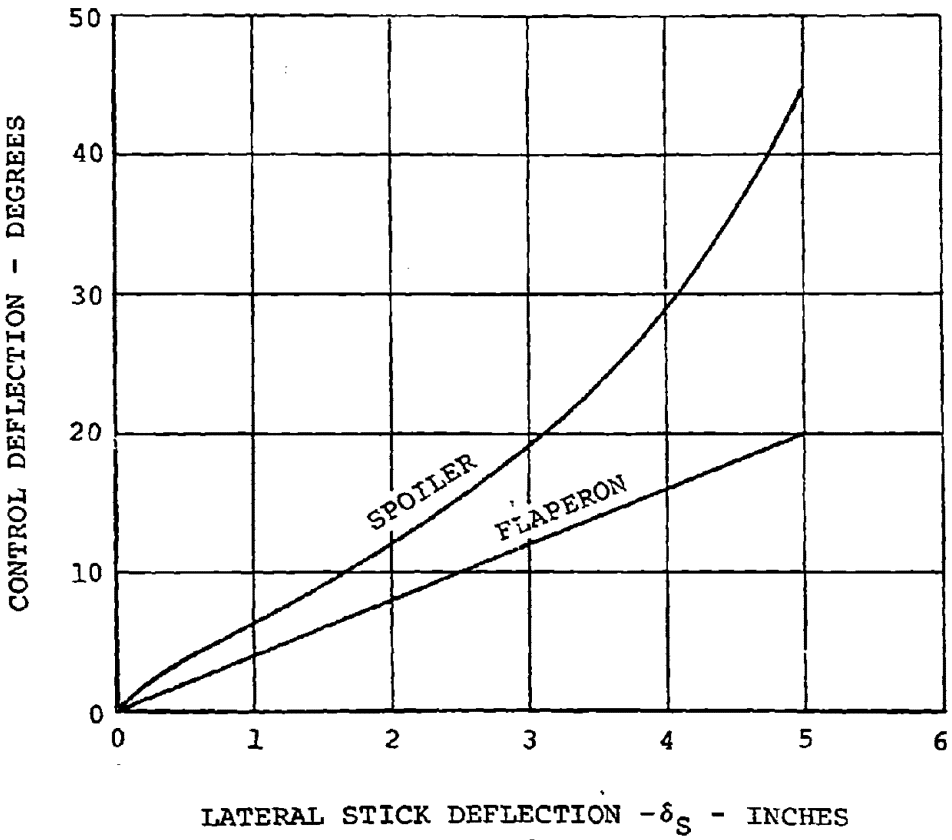


Figure F.8. Roll Control Deflection vs Stick Deflection

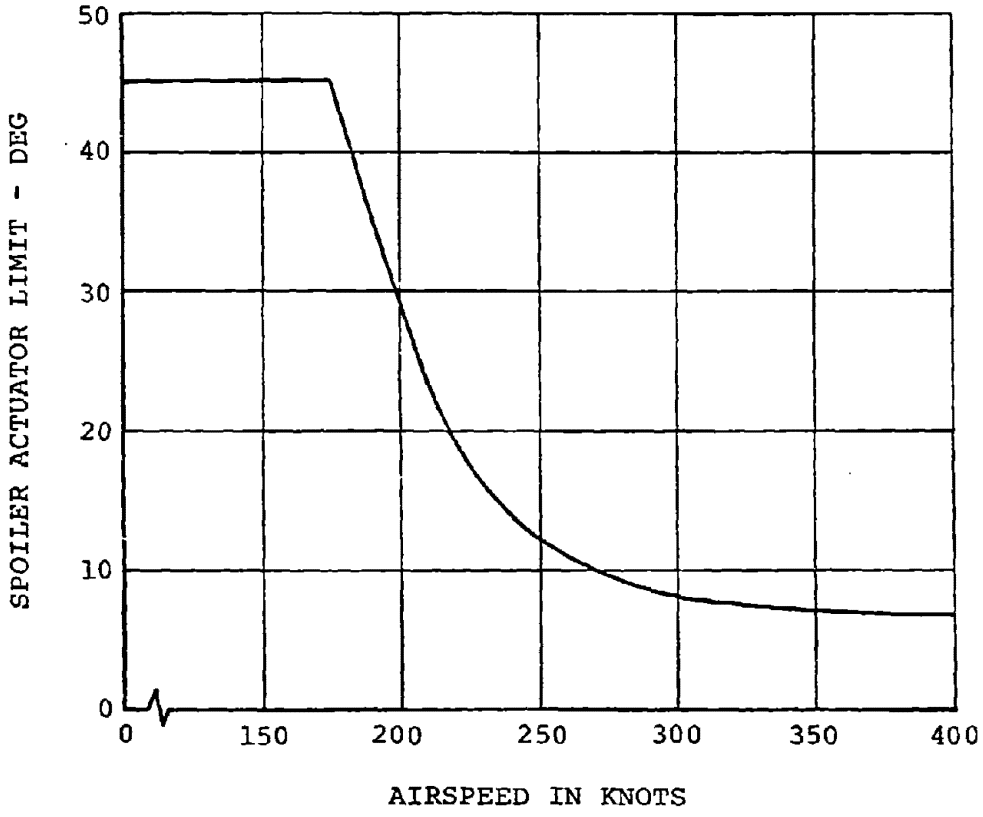


Figure F.9. Spoiler Actuator Limit vs Airspeed

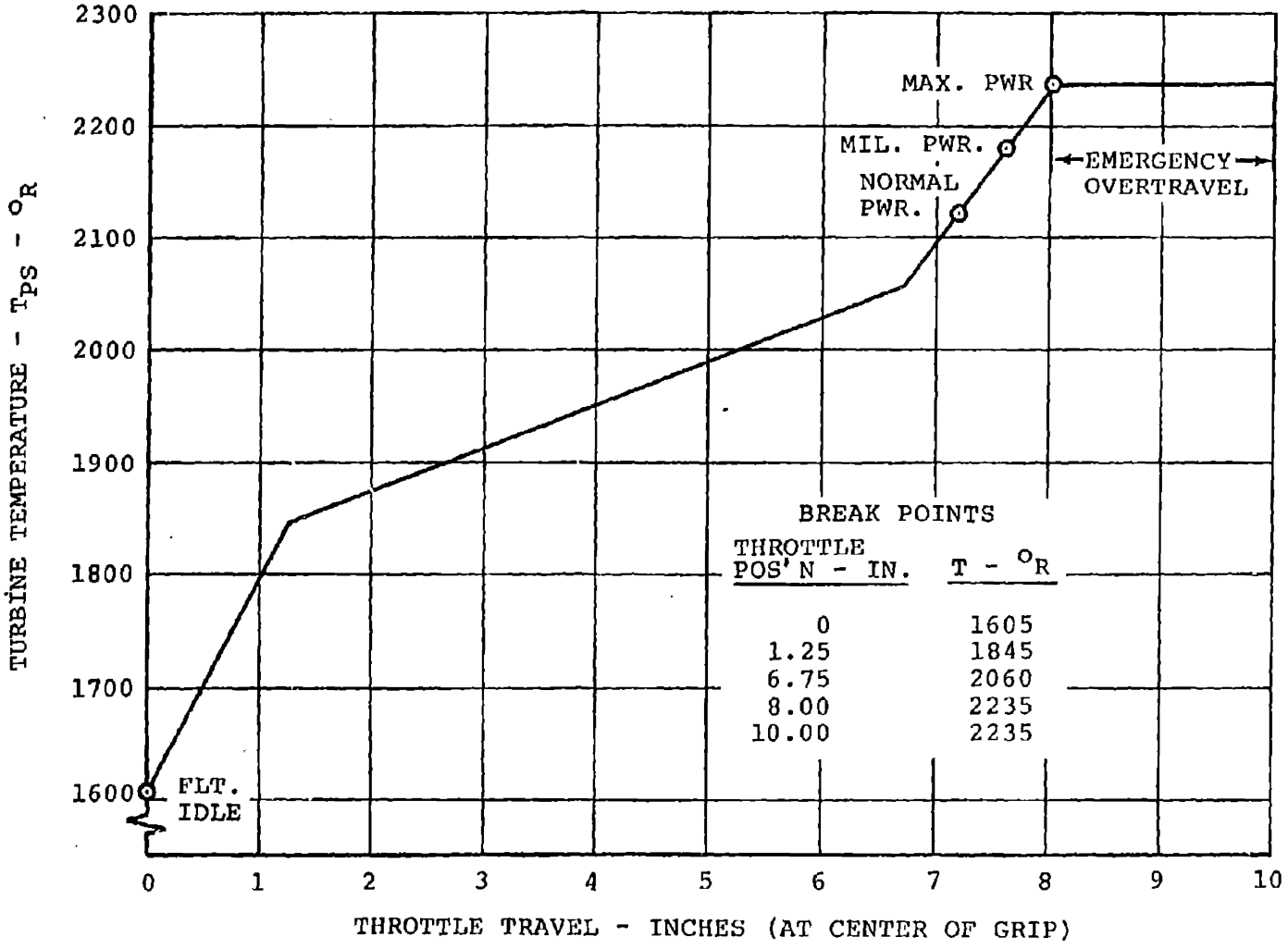
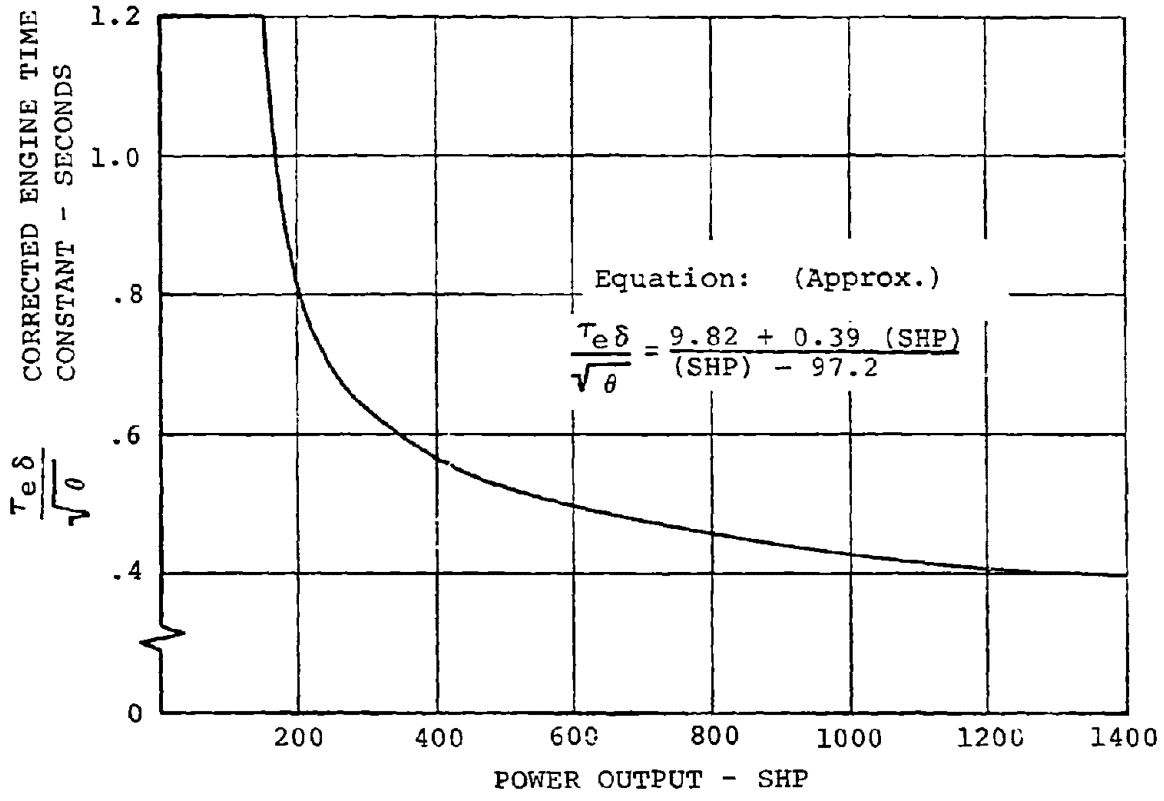


Figure F.10. Assumed Throttle Travel Model 222 Simulation Both Engines



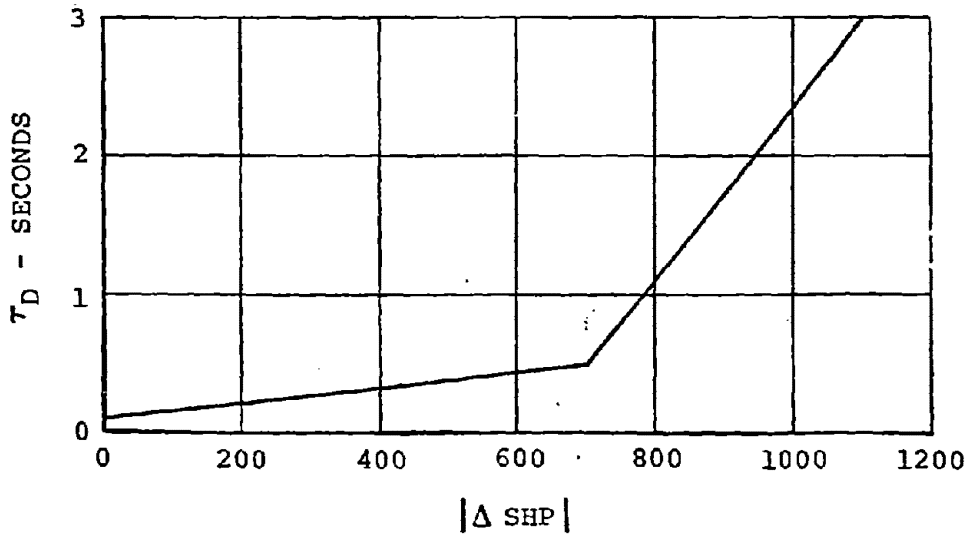


Figure F.11. Engine Characteristics Lycoming T53-L13 Engine

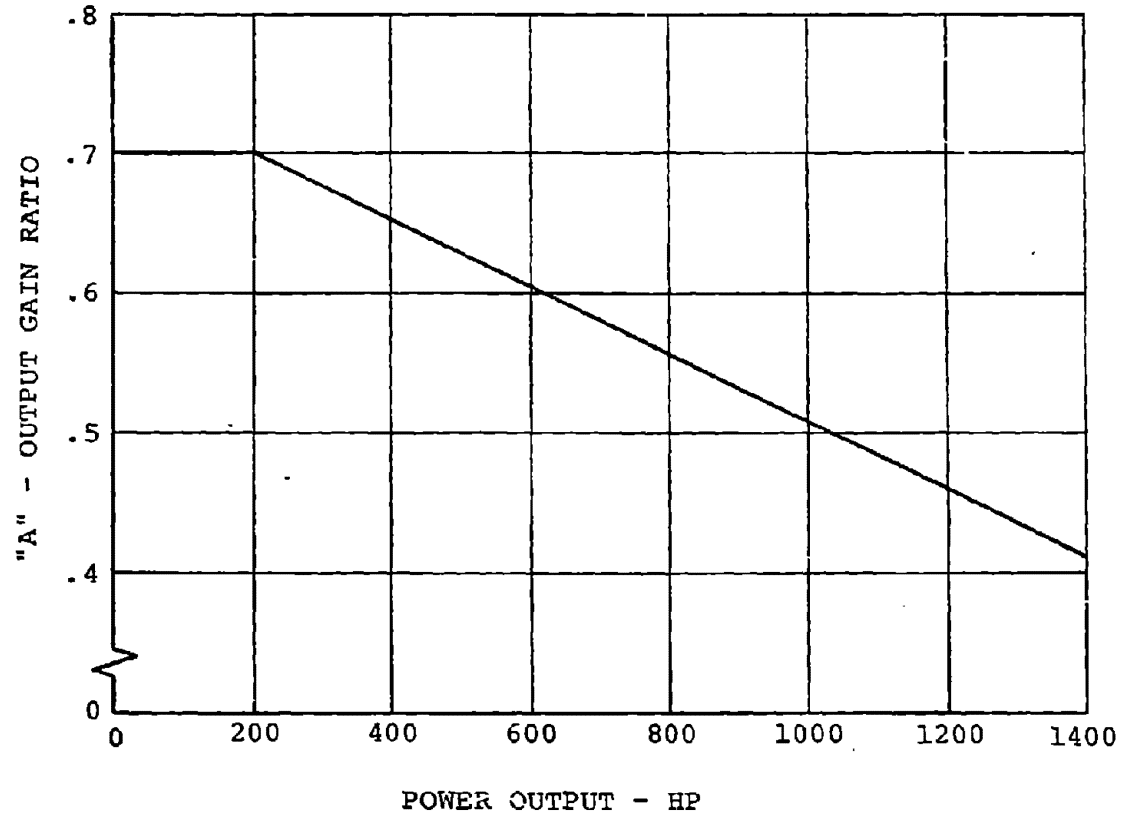


Figure F.12. Engine Characteristics Lycoming T53-L13 Engine

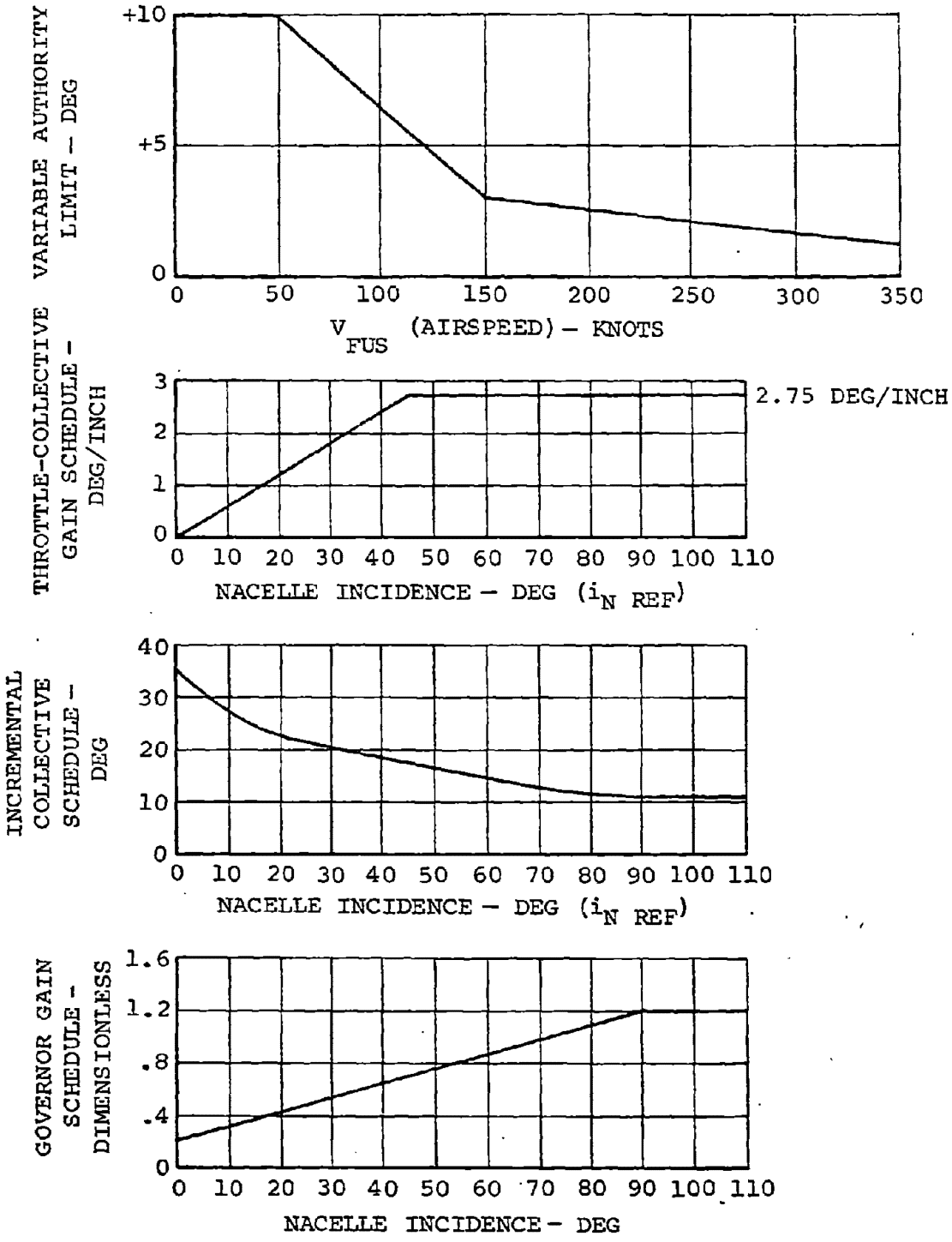


Figure F.13. Thrust Management System-Scheduled Parameters

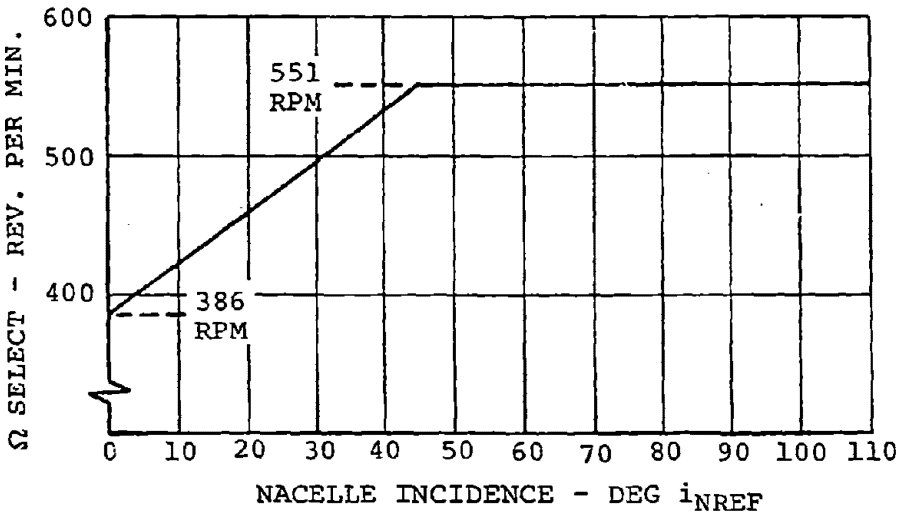


Figure F.14. Thrust Management System-Scheduled Parameters

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/θ=1600	T/θ=1800	T/θ=2000	T/θ=2200	T/θ=2400	T/θ=2600	T/θ=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/θ=1600	T/θ=1800	T/θ=2000	T/θ=2200	T/θ=2400	T/θ=2600	T/θ=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

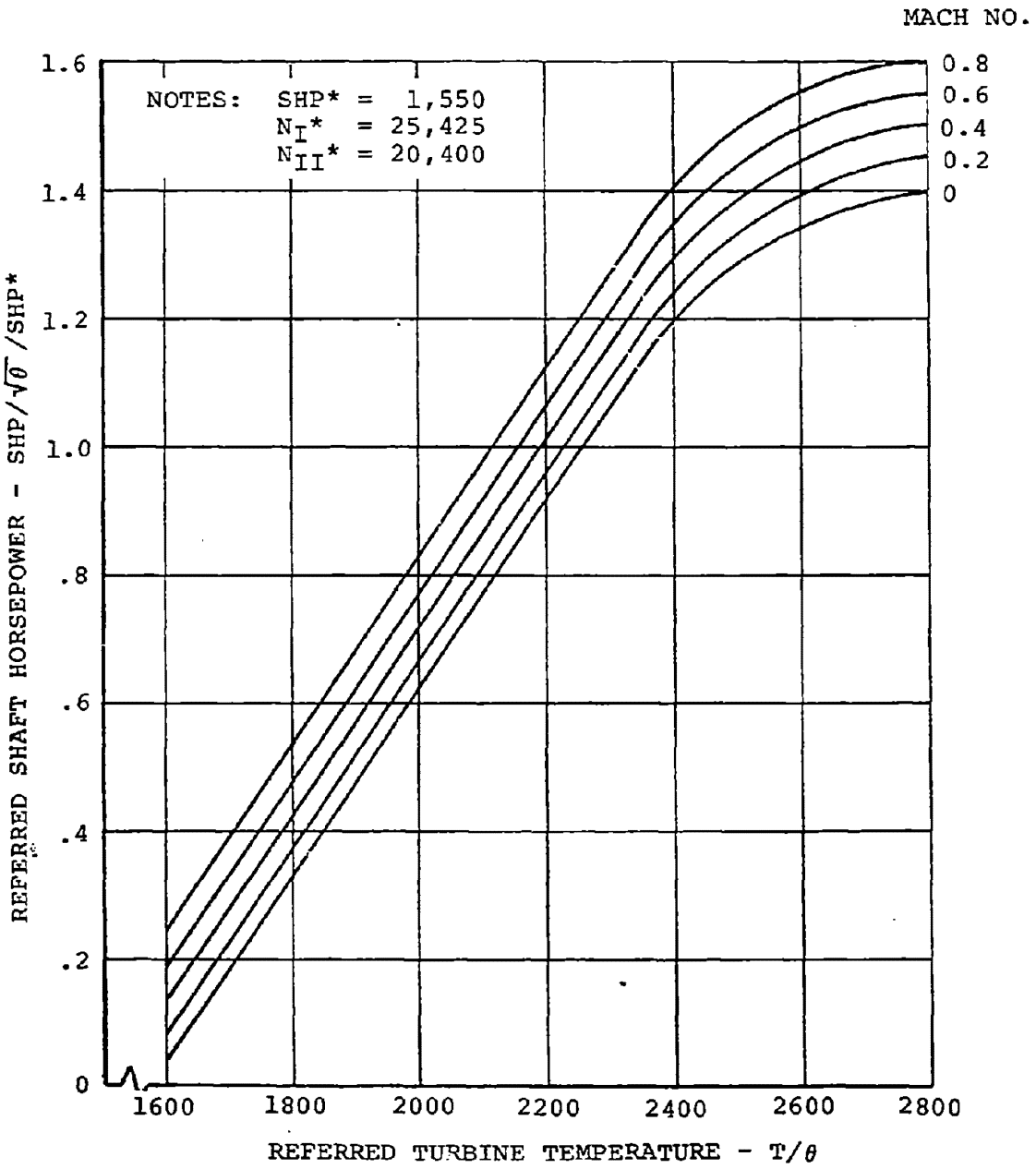


Figure F.15. Turbine Engine Performance - Engine Cycle 1.78

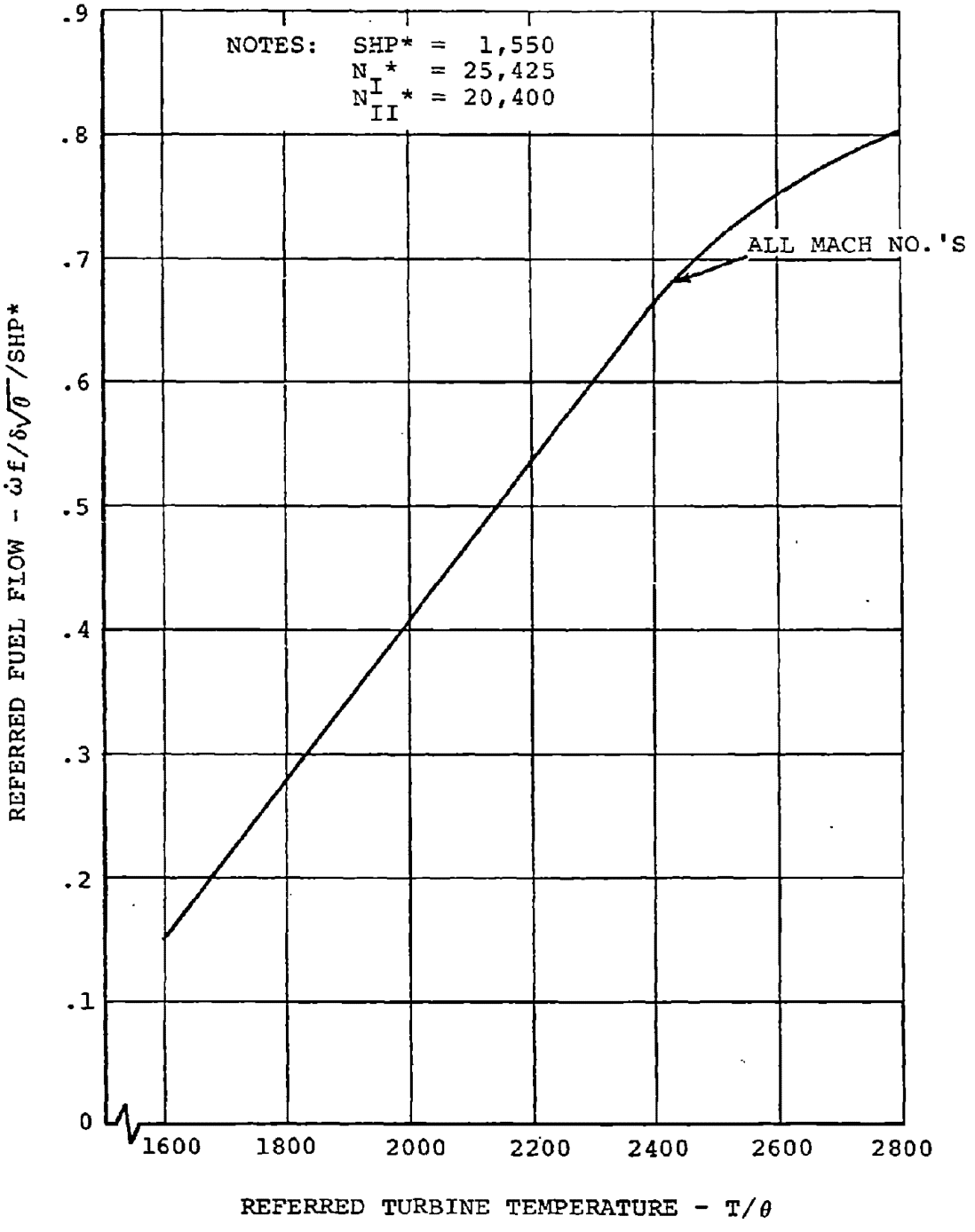


Figure F.16. Turbine Engine Performance - Engine Cycle 1.78

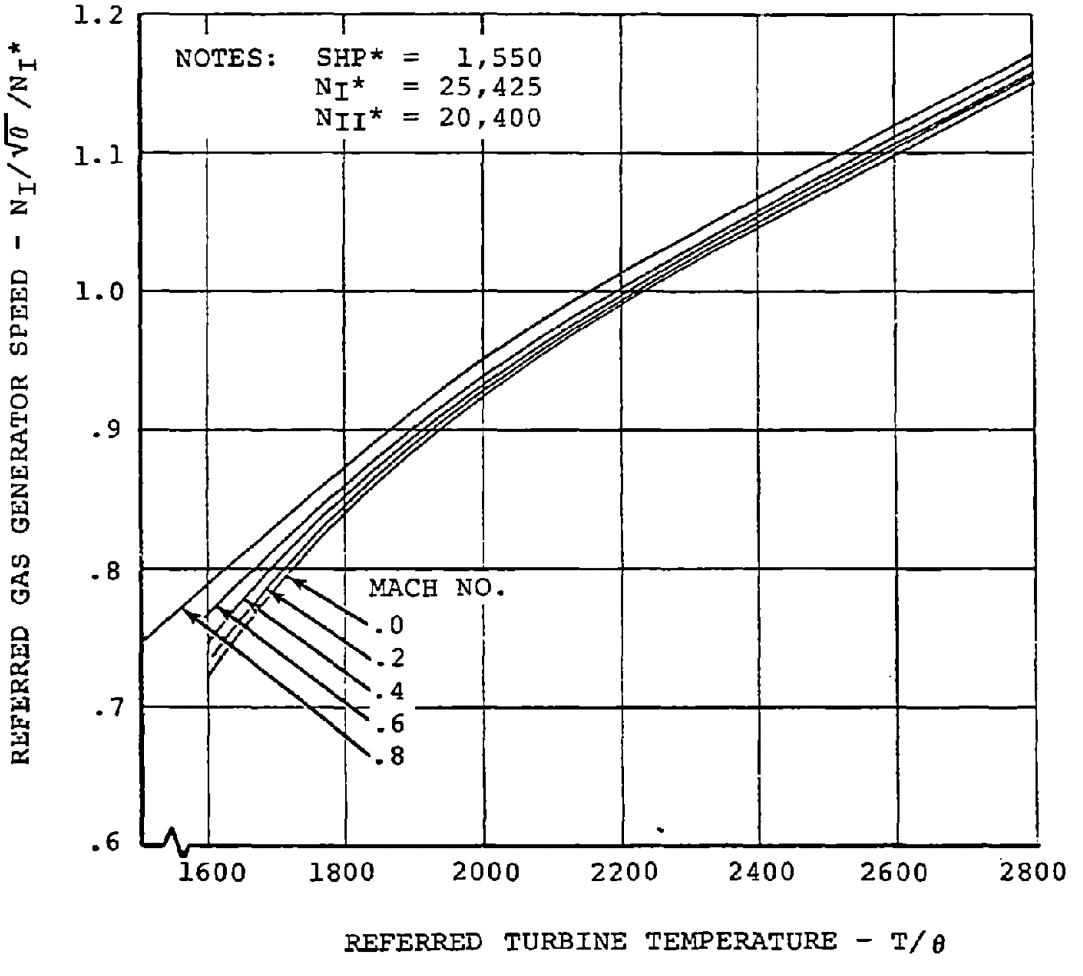


Figure F.17. Turbine Engine Performance - Engine Cycle 1.78

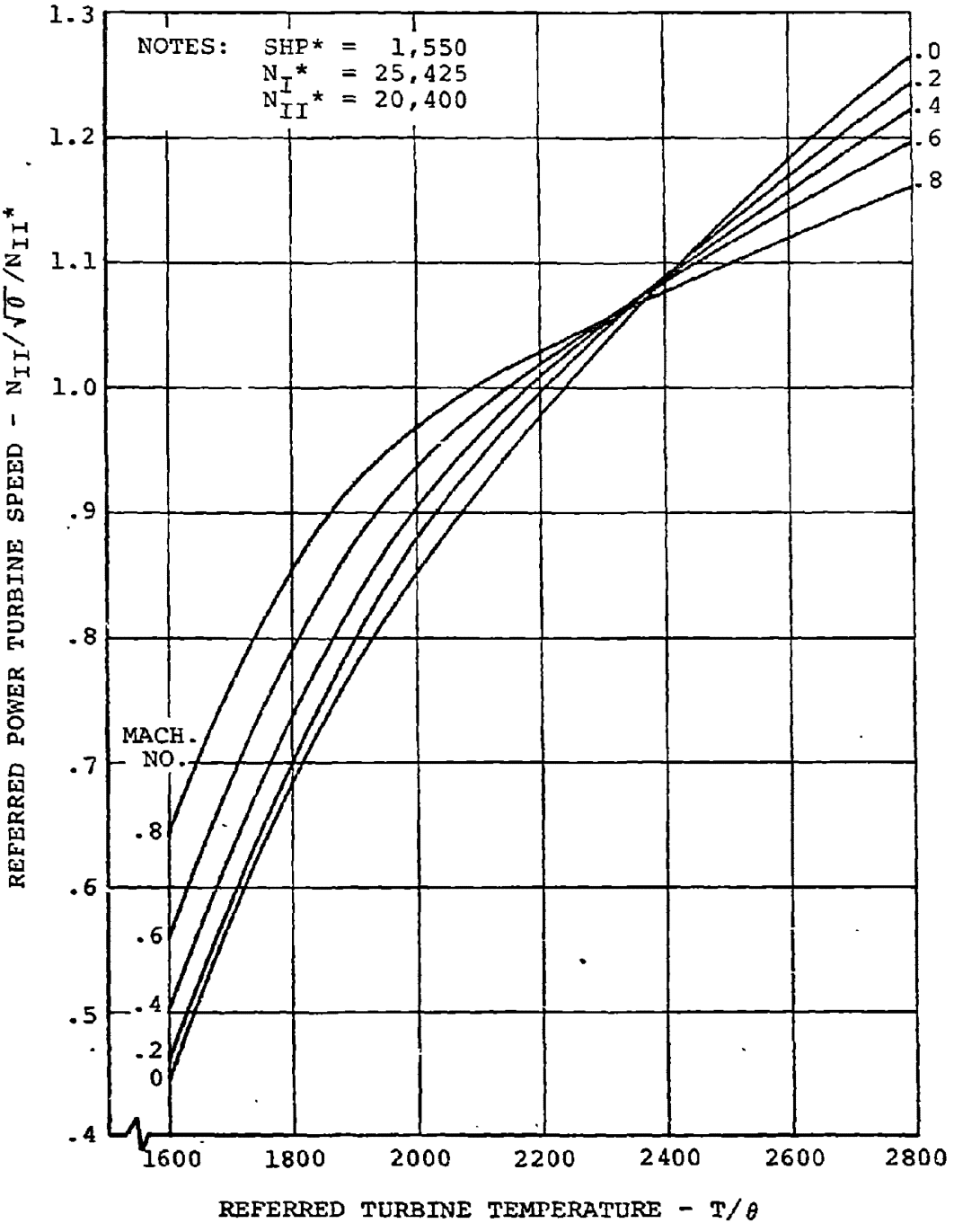


Figure F.18. Turbine Engine Performance - Engine Cycle 1.78

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	$.26831 \times 10^{-5}$	$.260200 \times 10^{-5}$	$.399507 \times 10^{-6}$	$-.596957 \times 10^{-5}$	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	.8905x10	$-.387201 \times 10$	$-.220100 \times 10$	$-.270408 \times 10^{-4}$	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}	$.120357 \times 10^{-4}$	$.996174 \times 10^{-5}$	$-.926255 \times 10^{-4}$	$-.825240 \times 10^{-5}$	$-.307987 \times 10^{-5}$	$.100012 \times 10^{-4}$	$.214393 \times 10^{-4}$	$.163128 \times 10^{-4}$	$.161866 \times 10^{-4}$
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	$.388025 \times 10^{-11}$	$.168184 \times 10^{-9}$	$-.196520 \times 10^{-11}$	$-.167159 \times 10^{-8}$	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}	$.119188 \times 10^{-3}$	$.117752 \times 10^{-3}$	$.575597 \times 10^{-3}$	$.204675 \times 10^{-3}$	$.283014 \times 10^{-3}$	$.362823 \times 10^{-3}$	$.511711 \times 10^{-3}$	$.539983 \times 10^{-3}$	$.12581 \times 10^{-2}$
A_{P1}	0	$.262107 \times 10^{-5}$	$-.835529 \times 10^{-5}$	$-.551959 \times 10^{-5}$	$-.952757 \times 10^{-5}$	0	0	0	0
A_{P2}	0	$.379347 \times 10^{-7}$	$.973647 \times 10^{-7}$	$.145048 \times 10^{-6}$	$-.615163 \times 10^{-7}$	0	0	0	0
A_{P3}	0	$-.147777 \times 10^{-9}$	$-.180303 \times 10^{-9}$	$-.391787 \times 10^{-9}$	$.131638 \times 10^{-8}$	0	0	0	0
A_{P4}	$.223227 \times 10^{-1}$	$.143376 \times 10^{0}$	$.143289 \times 10^{0}$	$.304517 \times 10^{0}$	$.383466 \times 10^{0}$	$.466013 \times 10^{0}$	$.662959 \times 10^{0}$	$.854989 \times 10^{0}$	$.114909 \times 10^{-1}$
A_{P5}	0	$-.263395 \times 10^{-2}$	$-.391803 \times 10^{-2}$	$-.56844 \times 10^{-2}$	$-.278572 \times 10^{-2}$	0	0	0	0
A_{P6}	0	$.115613 \times 10^{-4}$	$.421318 \times 10^{-4}$	$.336549 \times 10^{-4}$	$.129237 \times 10^{-4}$	0	0	0	0
A_{P7}	0	$-.239424 \times 10^{-7}$	$-.174886 \times 10^{-6}$	$-.109523 \times 10^{-6}$	$-.595181 \times 10^{-6}$	0	0	0	0
A_{P8}	$.601436 \times 10^{1}$	$.153503 \times 10^{1}$	$-.759331 \times 10^{0}$	$-.718612 \times 10^{1}$	$-.297074 \times 10^{-1}$	$.186185 \times 10^{-1}$	$-.810072 \times 10^{-1}$	$.960492 \times 10^{-3}$	$.631924 \times 10^{0}$
A_{P9}	0	$.212258 \times 10^{0}$	$.443411 \times 10^{0}$	$.50642 \times 10^{0}$	$-.477549 \times 10^{-2}$	0	0	0	0
A_{P10}	0	$-.297147 \times 10^{-2}$	$-.703113 \times 10^{-2}$	$-.624918 \times 10^{-2}$	$.327815 \times 10^{-3}$	0	0	0	0
A_{P11}	0	$.985059 \times 10^{-5}$	$.27991 \times 10^{-4}$	$.221158 \times 10^{-4}$	$-.543824 \times 10^{-5}$	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

	μ=0	μ=.1014	μ=.1351	μ=.2027	μ=.3723	μ=.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	$.749904\times10^{-3}$	$.125801\times10^{-2}$	$.178593\times10^{-2}$	$.24356\times10^{-2}$	$.572817\times10^{-2}$
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	$-.109604\times10^{-2}$	$-.923809\times10^{-3}$	$-.232838\times10^{-2}$	$.632501\times10^{-3}$	$-.115516\times10^{0}$
A_{NF11}	0	$.317682\times10^{-5}$	$.29846\times10^{-5}$	$.738683\times10^{-5}$	$-.814596\times10^{-5}$	$.994553\times10^{-2}$

	μ=.5147	μ=.6432	μ=.772	μ=.9008	μ=1.03	μ=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

	μ=0	μ=.1014	μ=.1351	μ=.2027	μ=.3723	μ=.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	$.950551\times10^{-7}$	$.242609\times10^{-6}$	$-.267651\times10^{-5}$	$-.171925\times10^{-4}$	$-.563082\times10^{-4}$
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	$.124524\times10^{-6}$	$.285967\times10^{-6}$	$-.428818\times10^{-6}$	$-.239885\times10^{-4}$	$-.168146\times10^{-3}$

	μ=.5147	μ=.6432	μ=.772	μ=.9008	μ=1.03	μ=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

	μ=0	μ=.1014	μ=.1351	μ=.2027	μ=.3723	μ=.4565
A_{PM0}	0	$.377218\times10^{-5}$	$.688095\times10^{-5}$	$-.79344\times10^{-5}$	$-.310285\times10^{-6}$	$-.884622\times10^{-8}$
A_{PM1}	0	$.539482\times10^{-5}$	$.125905\times10^{-4}$	$.316671\times10^{-4}$	$.820375\times10^{-4}$	$.141415\times10^{-4}$
A_{PM2}	0	$-.12652\times10^{-6}$	$-.252414\times10^{-6}$	$-.581828\times10^{-6}$	$-.27116\times10^{-6}$	$.345339\times10^{-7}$
A_{PM3}	0	$.537895\times10^{-9}$	$.101607\times10^{-8}$	$.226169\times10^{-8}$	$-.151223\times10^{-7}$	$-.105759\times10^{-8}$
A_{PM4}	0	$.172117\times10^{-3}$	$.562525\times10^{-3}$	$.201324\times10^{-2}$	$.193688\times10^{-3}$	$-.738879\times10^{-5}$
A_{PM5}	0	$.146772\times10^{-2}$	$.1652\times10^{-2}$	$.206142\times10^{-2}$	$.464123\times10^{-2}$	$-.159412\times10^{-2}$
A_{PM6}	0	$-.11507\times10^{-4}$	$-.121292\times10^{-4}$	$-.131115\times10^{-4}$	$-.229179\times10^{-4}$	$.508798\times10^{-5}$
A_{PM7}	0	$.185794\times10^{-7}$	$.164608\times10^{-7}$	$.913233\times10^{-8}$	$-.119169\times10^{-6}$	$-.10134\times10^{-6}$
A_{PM8}	0	$-.165488\times10^{-1}$	$-.189205\times10^{-1}$	$.766096\times10^{-1}$	$-.133686\times10^{-1}$	$.955878\times10^{-3}$
A_{PM9}	0	$.181983\times10^{-2}$	$.224173\times10^{-3}$	$-.692309\times10^{-2}$	$-.487350\times10^{-2}$	$.216812\times10^{-1}$
A_{PM10}	0	$-.236138\times10^{-4}$	$.16657\times10^{-6}$	$.684175\times10^{-4}$	$.362062\times10^{-3}$	$-.13177\times10^{-2}$
A_{PM11}	0	$.796661\times10^{-7}$	$-.470343\times10^{-8}$	$-.176422\times10^{-6}$	$-.598035\times10^{-5}$	$.362472\times10^{-4}$

	μ=.5147	μ=.6432	μ=.772	μ=.9008	μ=1.03	μ=1.158
A_{PM0}	$-.163818\times10^{-6}$	$-.771885\times10^{-6}$	$-.248968\times10^{-5}$	$.145349\times10^{-6}$	$.168996\times10^{-5}$	$.274231\times10^{-6}$
A_{PM1}	$-.177418\times10^{-5}$	$-.922672\times10^{-4}$	$-.202383\times10^{-3}$	$-.308712\times10^{-3}$	$-.383796\times10^{-3}$	$-.470485\times10^{-3}$
A_{PM2}	$.356703\times10^{-7}$	$.111958\times10^{-6}$	$.704986\times10^{-6}$	$.536055\times10^{-7}$	$-.912361\times10^{-7}$	$.25489\times10^{-6}$
A_{PM3}	$-.137756\times10^{-8}$	$-.216285\times10^{-9}$	$-.328566\times10^{-7}$	$.53226\times10^{-9}$	$-.27077\times10^{-9}$	$-.640161\times10^{-8}$
A_{PM4}	$.401368\times10^{-4}$	$.225413\times10^{-4}$	$.778302\times10^{-3}$	$-.483831\times10^{-3}$	$-.497667\times10^{-3}$	$-.321648\times10^{-3}$
A_{PM5}	$-.240092\times10^{-2}$	$-.399324\times10^{-2}$	$-.641948\times10^{-2}$	$-.70195\times10^{-2}$	$-.100188\times10^{-1}$	$-.687551\times10^{-2}$
A_{PM6}	$-.120839\times10^{-4}$	$-.665199\times10^{-4}$	$-.128724\times10^{-3}$	$-.119008\times10^{-3}$	$-.416504\times10^{-4}$	$-.344122\times10^{-3}$
A_{PM7}	$.387065\times10^{-6}$	$.204615\times10^{-5}$	$.638786\times10^{-5}$	$.396756\times10^{-5}$	$.168316\times10^{-5}$	$.12192\times10^{-4}$
A_{PM8}	$-.227747\times10^{-2}$	$.261322\times10^{-1}$	$-.424199\times10^{-1}$	$.428319\times10^{-1}$	$.392666\times10^{-1}$	$.256492\times10^{-1}$
A_{PM9}	$-.751961\times10^{-1}$	$-.183726\times10^{0}$	$.359543\times10^{-1}$	$.143102\times10^{-1}$	$.949637\times10^{-1}$	$-.135728\times10^{0}$
A_{PM10}	$.10527\times10^{-2}$	$.210223\times10^{-1}$	$-.33401\times10^{-3}$	$.856042\times10^{-2}$	$.12569\times10^{-1}$	$.336543\times10^{-1}$
A_{PM11}	$-.393332\times10^{-4}$	$-.726143\times10^{-3}$	$-.78287\times10^{-4}$	$-.33099\times10^{-3}$	$-.435573\times10^{-3}$	$-.115452\times10^{-2}$

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

	μ=0	μ=.1014	μ=.1351	μ=.2027	μ=.3723	μ=.4565
A_{YM0}	0	.109092x10^{-5}	.286933x10^{-7}	-.110543x10^{-4}	-.115949x10^{-4}	.75428x10^{-6}
A_{YM1}	0	.126647x10^{-4}	.191392x10^{-4}	.250948x10^{-4}	.442163x10^{-4}	.199993x10^{-3}
A_{YM2}	0	-.148631x10^{-6}	-.229016x10^{-6}	-.220845x10^{-6}	.979871x10^{-6}	.672974x10^{-6}
A_{YM3}	0	.435436x10^{-9}	.68199x10^{-9}	.154233x10^{-9}	-.231738x10^{-7}	-.198906x10^{-7}
A_{YM4}	0	.216295x10^{-3}	.61994x10^{-3}	.303865x10^{-4}	.76278x10^{-3}	-.989016x10^{-4}
A_{YM5}	0	.636091x10^{-4}	.533431x10^{-4}	.880677x10^{-3}	.600766x10^{-2}	.890334x10^{-2}
A_{YM6}	0	.290233x10^{-5}	.265736x10^{-5}	-.16908x10^{-4}	-.24055x10^{-3}	.101251x10^{-4}
A_{YM7}	0	-.182158x10^{-7}	-.164399x10^{-7}	.10332x10^{-6}	.289645x10^{-5}	-.239883x10^{-6}
A_{YM8}	0	-.158447x10^{-1}	-.2112x10^{-1}	-.171322x10^{-1}	-.27995x10^{-1}	.646468x10^{-2}
A_{YM9}	0	.147256x10^{-2}	.323912x10^{-3}	-.426356x10^{-2}	.116529x10^{-1}	.486429x10^{-1}
A_{YM10}	0	-.178633x10^{-4}	-.158877x10^{-5}	.873694x10^{-4}	-.78607x10^{-3}	-.277348x10^{-2}
A_{YM11}	0	.579483x10^{-7}	.374405x10^{-8}	-.533808x10^{-6}	.133698x10^{-4}	.407947x10^{-4}

	μ=.5147	μ=.5432	μ=.772	μ=.9008	μ=1.03	μ=1.158
A_{YM0}	.811278x10^{-6}	-.689619x10^{-6}	-.140611x10^{-5}	-.959155x10^{-6}	.232776x10^{-5}	.776742x10^{-6}
A_{YM1}	.2549x10	.358353x10^{-3}	.40651x10^{-3}	.423457x10^{-3}	.404494x10^{-3}	.400109x10^{-3}
A_{YM2}	.290133x10^{-6}	-.483638x10^{-6}	.711836x10^{-6}	.366298x10^{-6}	-.978679x10^{-6}	.483519x10^{-6}
A_{YM3}	-.7069x10^{-8}	.165027x10^{-7}	-.242848x10^{-7}	-.201739x10^{-7}	.384779x10^{-7}	-.178582x10^{-7}
A_{YM4}	-.138358x10^{-3}	-.376316x10^{-3}	-.111605x10^{-3}	-.498142x10^{-3}	-.859507x10^{-3}	-.170495x10^{-3}
A_{YM5}	.84517x10^{-2}	.731418x10^{-2}	.111654x10^{-1}	.700776x10^{-2}	.495335x10^{-2}	.937562x10^{-3}
A_{YM6}	.511468x10^{-4}	.25651x10^{-3}	-.397326x10^{-3}	-.179799x10^{-3}	.475445x10^{-3}	.428652x10^{-3}
A_{YM7}	-.113402x10^{-5}	-.882347x10^{-5}	.127859x10^{-4}	.100219x10^{-4}	-.172489x10^{-4}	-.224772x10^{-4}
A_{YM8}	.135303x10^{-3}	.322547x10^{-1}	.931734x10^{-2}	.392748x10^{-1}	.62677x10^{-1}	.242592x10^{0}
A_{YM9}	.664771x10^{-1}	.729796x10^{-1}	-.283071x10^{0}	-.697861x10^{-1}	.101986x10^{0}	.629868x10^{0}
A_{YM10}	-.647118x10^{-2}	-.179565x10^{-1}	.292923x10^{-1}	.166632x10^{-1}	-.284635x10^{-1}	-.600989x10^{-1}
A_{YM11}	.140141x10^{-3}	.575827x10^{-3}	-.960904x10^{-3}	-.821801x10^{-3}	.101423x10^{-2}	.245749x10^{-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 $\frac{\alpha C_{PM}}{\alpha Q}$

$\mu \rightarrow$	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}	$.925\times10^{-3}$
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 $\frac{\alpha C_{YM}}{\alpha R}$

$$\left.\begin{aligned} E_{NF_1} &= -.024 \\ E_{NF_2} &= -.002703 \\ E_{NF_3} &= -.000346 \\ E_{NF_4} &= .00039 \end{aligned}\right\} \text{Coeff. of } \frac{dC_{NF}}{dB_{1C}} \sim \frac{1}{DEG}$$

$$\left.\begin{aligned} D_{NF} &= .006 \\ D_{NF_1} &= -.0012318 \\ D_{NF_2} &= .000033 \\ D_{NF_3} &= -.0000268 \end{aligned}\right\} \text{Coeff. of } \frac{dC_{NF}}{dA_{1C}} \sim \frac{1}{DEG}$$

$$\left.\begin{aligned} E_{SF} &= .0025 \\ E_{SF_1} &= .0011896 \\ E_{SF_2} &= -.00001246 \\ E_{SF_3} &= .00001669 \end{aligned}\right\} \text{Coeff. of } \frac{dC_{SF}}{dB_{1C}} \sim \frac{1}{DEG}$$

$$\left.\begin{aligned} D_{SF} &= .025 \\ D_{SF_1} &= .0025356 \\ D_{SF_2} &= -.0002264 \\ D_{SF_3} &= -.000044 \end{aligned}\right\} \text{Coeff. of } \frac{dC_{SF}}{dA_{1C}} \sim \frac{1}{DEG}$$

$$\left.\begin{aligned} E_{PM} &= -.0025 \\ E_{PM_1} &= -.0014304 \\ E_{PM_2} &= .0003029 \\ E_{PM_3} &= -.0002938 \\ E_{PM_4} &= -.0001367 \\ E_{PM_5} &= -.0004888 \\ E_{PM_6} &= -.0001767 \end{aligned}\right\} \text{Coeff. of } \frac{dC_{PM}}{dB_{1C}} \sim \frac{1}{DEG}$$

$$\left.\begin{aligned} D_{PM} &= -.0015 \\ D_{PM_1} &= .0010726 \\ D_{PM_2} &= -.0001564 \\ D_{PM_3} &= .0001762 \\ D_{PM_4} &= +.0000966 \\ D_{PM_5} &= .000571 \\ D_{PM_6} &= .0000422 \end{aligned}\right\} \text{Coeff. of } \frac{dC_{PM}}{dA_{1C}} \sim \frac{1}{DEG}$$

$$\left.\begin{aligned} E_{YM} &= .0025 \\ E_{YM_1} &= -.0013888 \\ E_{YM_2} &= .000336 \\ E_{YM_3} &= -.000187 \\ E_{YM_4} &= -.0000723 \\ E_{YM_5} &= -.0006354 \\ E_{YM_6} &= -.0000098 \end{aligned}\right\} \text{Coeff of } \frac{dC_{YM}}{dB_{1C}} \sim \frac{1}{DEG}$$

$$\left.\begin{aligned} D_{YM} &= -.0025 \\ D_{YM_1} &= -.0009883 \\ D_{YM_2} &= .000089 \\ D_{YM_3} &= -.0002866 \\ D_{YM_4} &= -.0001503 \\ D_{YM_5} &= -.0004564 \\ D_{YM_6} &= -.0001993 \end{aligned}\right\} \text{Coeff of } \frac{dC_{YM}}{dA_{1C}} \sim \frac{1}{DEG}$$

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
$K_{22} = .015$
$K_{\alpha} = 1.0$
$K_{\eta} = 1.0$

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/$>.5236$RAD

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)

$A_{D_0} = .582990 \times 10^{-3}$

$A_{D_1} = .126170 \times 10^{-2}$

$A_{D_2} = .391649 \times 10^{-4}$

$A_{D_3} = .110058 \times 10^{-5}$

$A_{D_4} = -.159415 \times 10^{-7}$

$A_{D_5} = .245484 \times 10^{-3}$

$A_{D_6} = .265950 \times 10^{-3}$

$A_{D_7} = .404673 \times 10^{-5}$

$A_{D_8} = -.152693 \times 10^{-6}$

$A_{D_9} = .102320 \times 10^{-8}$

$A_{D_{10}} = -.313543 \times 10^{-5}$

$A_{D_{11}} = .624554 \times 10^{-6}$

$A_{D_{12}} = .141804 \times 10^{-6}$

$A_{D_{13}} = -.821732 \times 10^{-8}$

$A_{D_{14}} = .119984 \times 10^{-9}$

$A_{D_{15}} = -.474069 \times 10^{-5}$

$A_{D_{16}} = .771740 \times 10^{-6}$

$A_{D_{17}} = -.800800 \times 10^{-7}$

$A_{D_{18}} = .208761 \times 10^{-8}$

$A_{D_{19}} = -.114899 \times 10^{-10}$

$A_{D_{20}} = .238184 \times 10^{-6}$

$A_{D_{21}} = .196213 \times 10^{-7}$

$A_{D_{22}} = -.204613 \times 10^{-8}$

$A_{D_{23}} = .133330 \times 10^{-10}$

$A_{D_{24}} = .492127 \times 10^{-13}$

NOTES: δ, α in degrees.

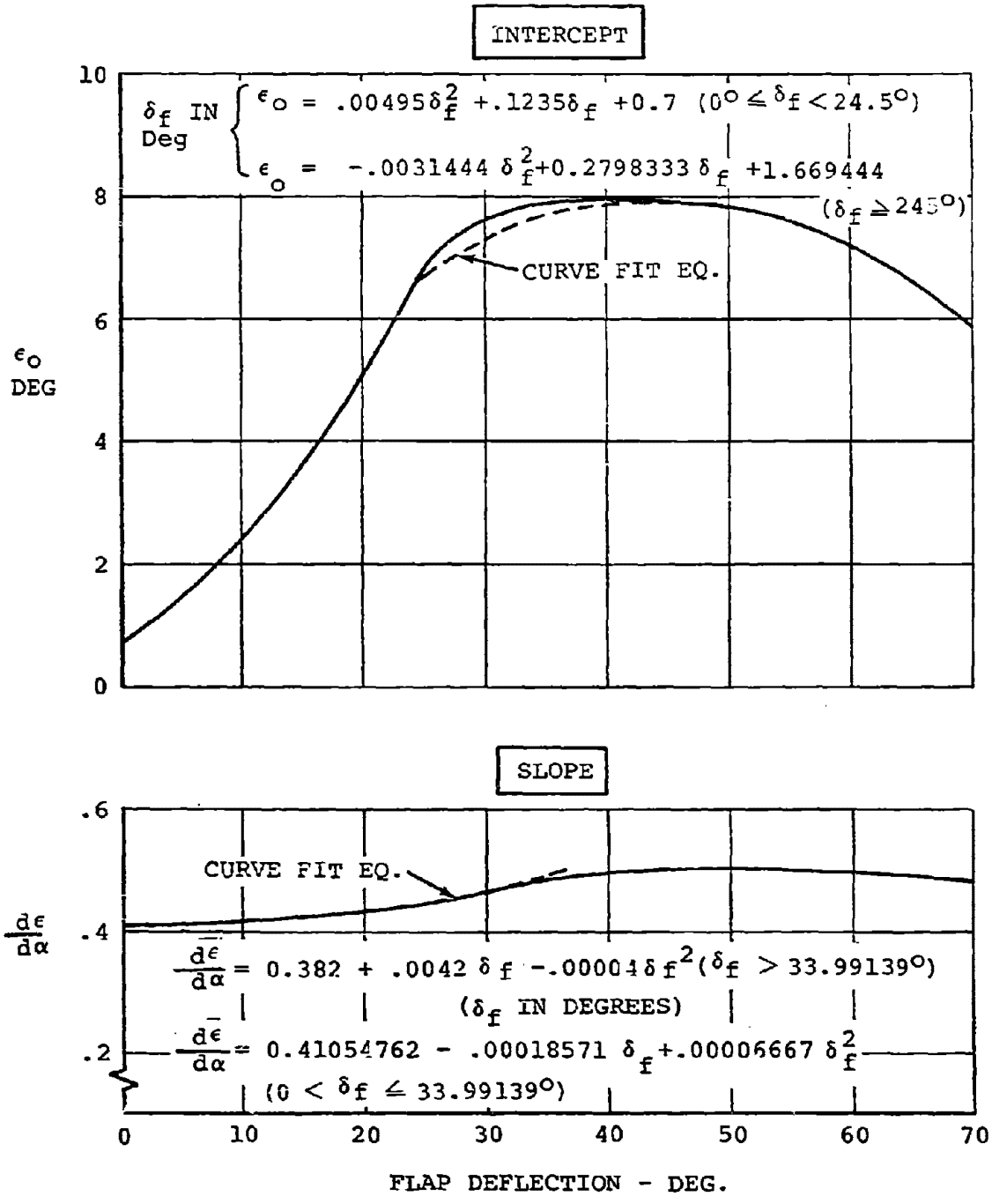


Figure F.28. Model 222 Downwash Functions @ $C_T = 0$, $i_w = +2.0^o$

REF: APPENDIX B-7 ETKIN

FOR TAIL;

$$\frac{a_g}{a} = 1.2103 - .C38\ h_T + .00184h_T^2;\ h_T \leq 6.3219$$

$$\frac{a_g}{a} = 1.1096 - .01284\ h_T + .00038h_T^2;\ h_T > 6.3219$$

$$\frac{a_g}{a} = 1.00;\ h_{T_{c/4}} \geq 17.'$$

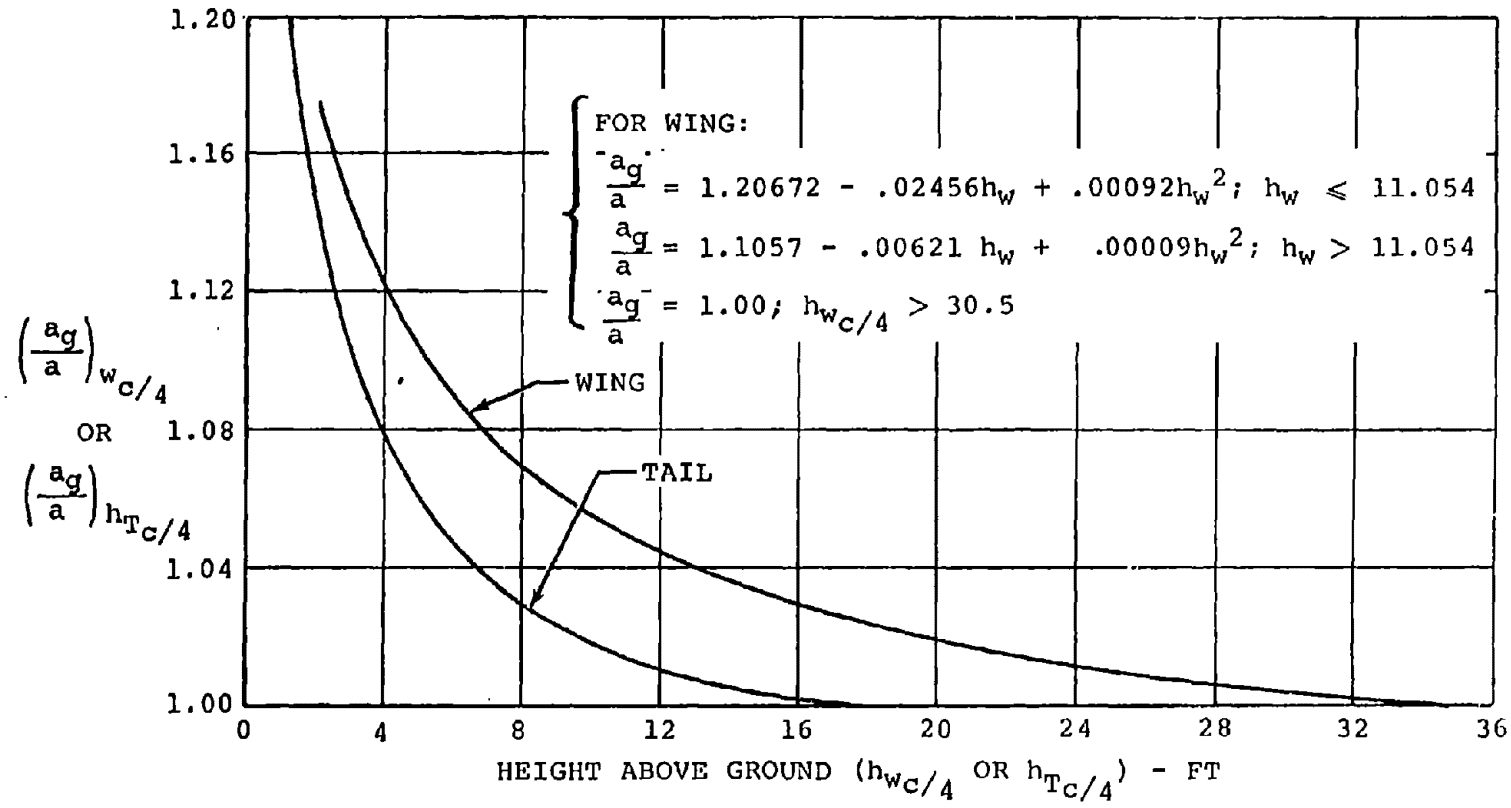
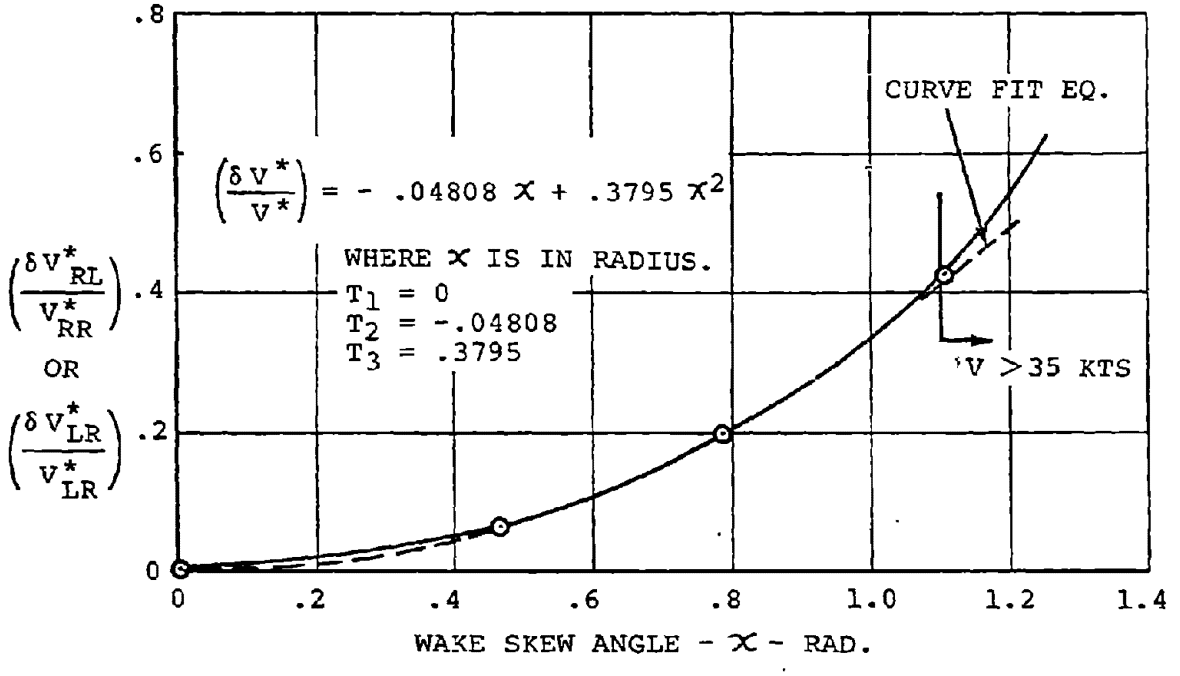
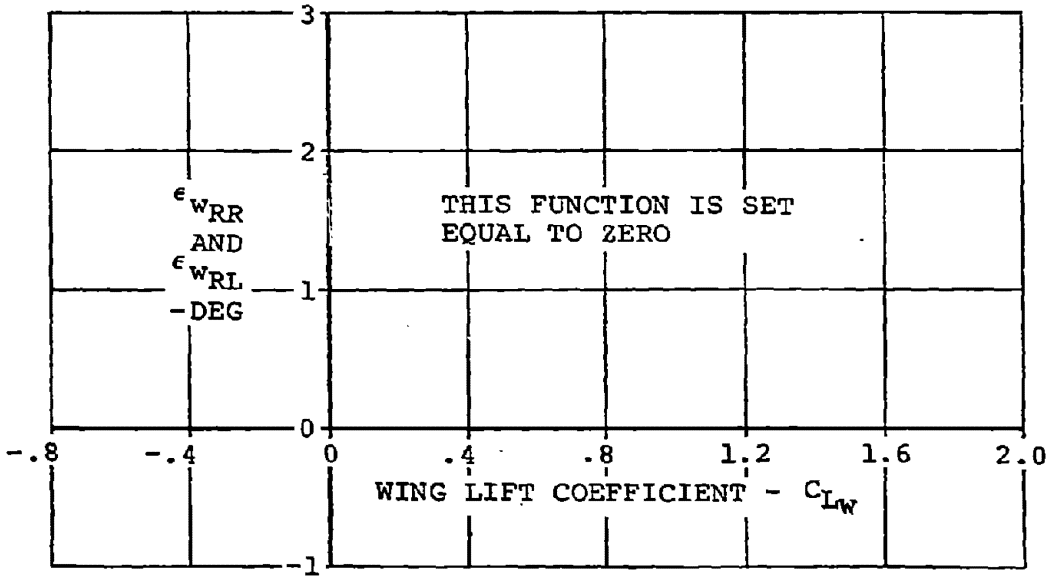


Figure F.29. Variation of Lift Curve Slope with Ground Height



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
	Z_{WAC} = .4 ft		$\bar{Y}$ = 6.92 ft
	L_S = 4.94 ft	E.32	$X_{c/2}$ = -.25 ft
	Y_N = 16.666 ft	E.35	i_{HT} = 0.0
E.18	X_{HT} = -19.45 ft	E.36	AR_{HT} = 4.255
	Z_{HT} = 2.51 ft	E.39	AR_{VT}= 1.768
	X_{VT} = -18.04 ft		S_{HT} = 58.3 ft^2
	Z_{VT} = -1.0226 ft		S_{VT} = 43.3 ft^2
E.19	A = 530929 ft^2	E.46	Z_{G_1} = 7.08 ft
	R = ft		Z_{G_2} = 7.08 ft
E.20	PC = 2.36 ft, F_{IN}=0°		Z_{G_3} = 7.53 ft
	h_p = .33 ft		Y_{G_1} = -3.86 ft
	c_w = 5.983 ft		Y_{G_2} = 3.86 ft
	S_w = 200 ft^2		Y_{G_3} = 0

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 x 10^{-4}
	K_{W_2}	= .1637 x 10^{-4}
	K_{W_3}	= .58356 x 10^{-5}
	K_{W_4}	= .2959 x 10^{-2}
	K_{W_5}	= .1656 x 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}	= .1709x10^{-4}
	K_{W_7}	= .05768x10^{-4}
	K_{W_8}	= .1221x10^{-5}
	K_{W_9}	= .0847x10^{-2}
	$K_{W_{10}}$	= .0559x10^{-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 x10^6FT-LB/RAD
	$\frac{X_{WAC}}{C_w}$	= .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

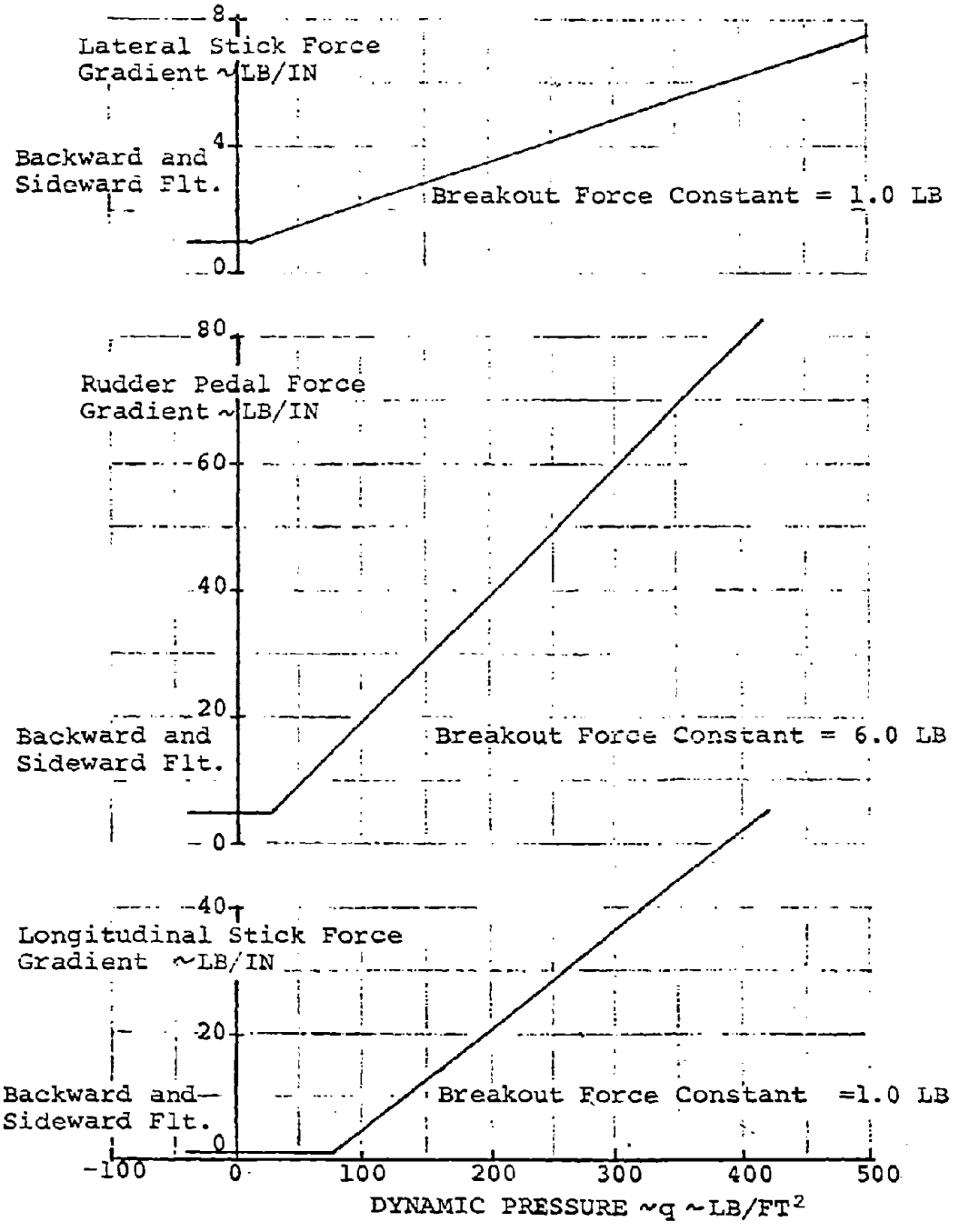


Figure F.32. Model 222 Control Force Gradients and Breakout Forces

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

- Software System

  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.

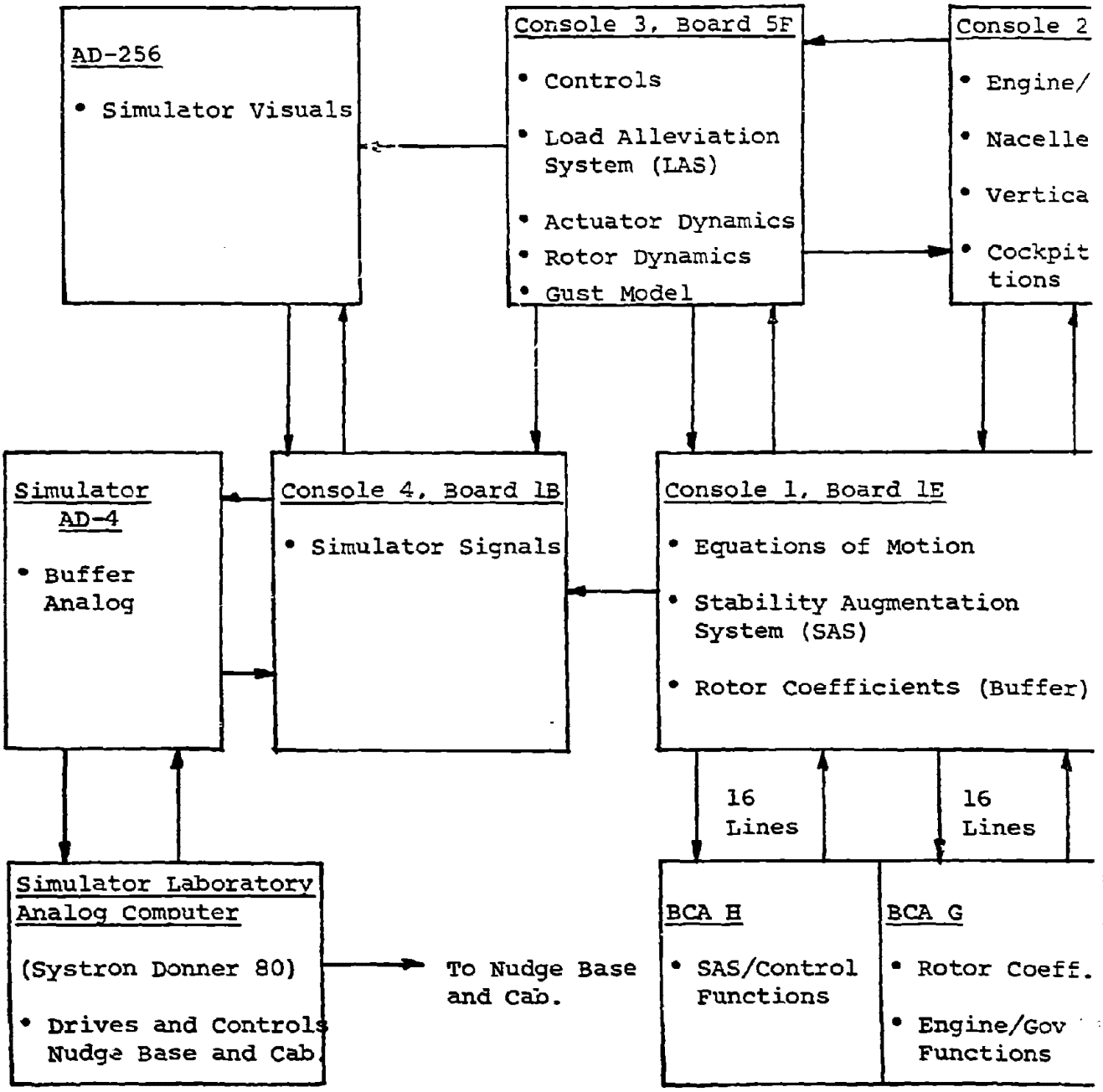
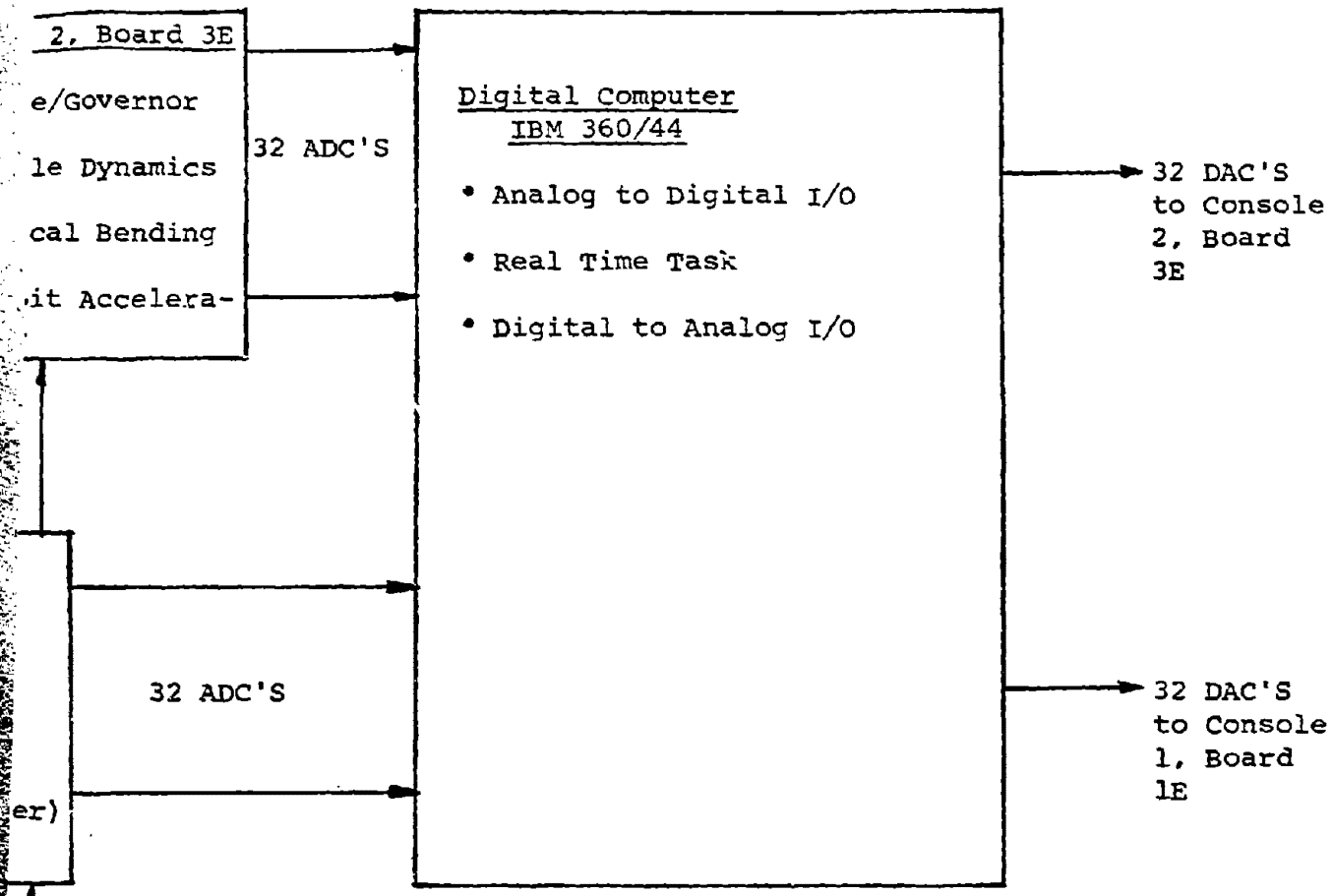


Figure G.1. Utilization of the Hybrid Laboratory for the Model 222 Math Model


2, Board 3E
e/Governor
le Dynamics
cal Bending
it Accelera-
32 ADC'S
Digital Computer
IBM 360/44
• Analog to Digital I/O
• Real Time Task
• Digital to Analog I/O
32 DAC'S
to Console
2, Board
3E
32 ADC'S
er)
32 DAC'S
to Console
1, Board
1E
eff.
ov
s

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

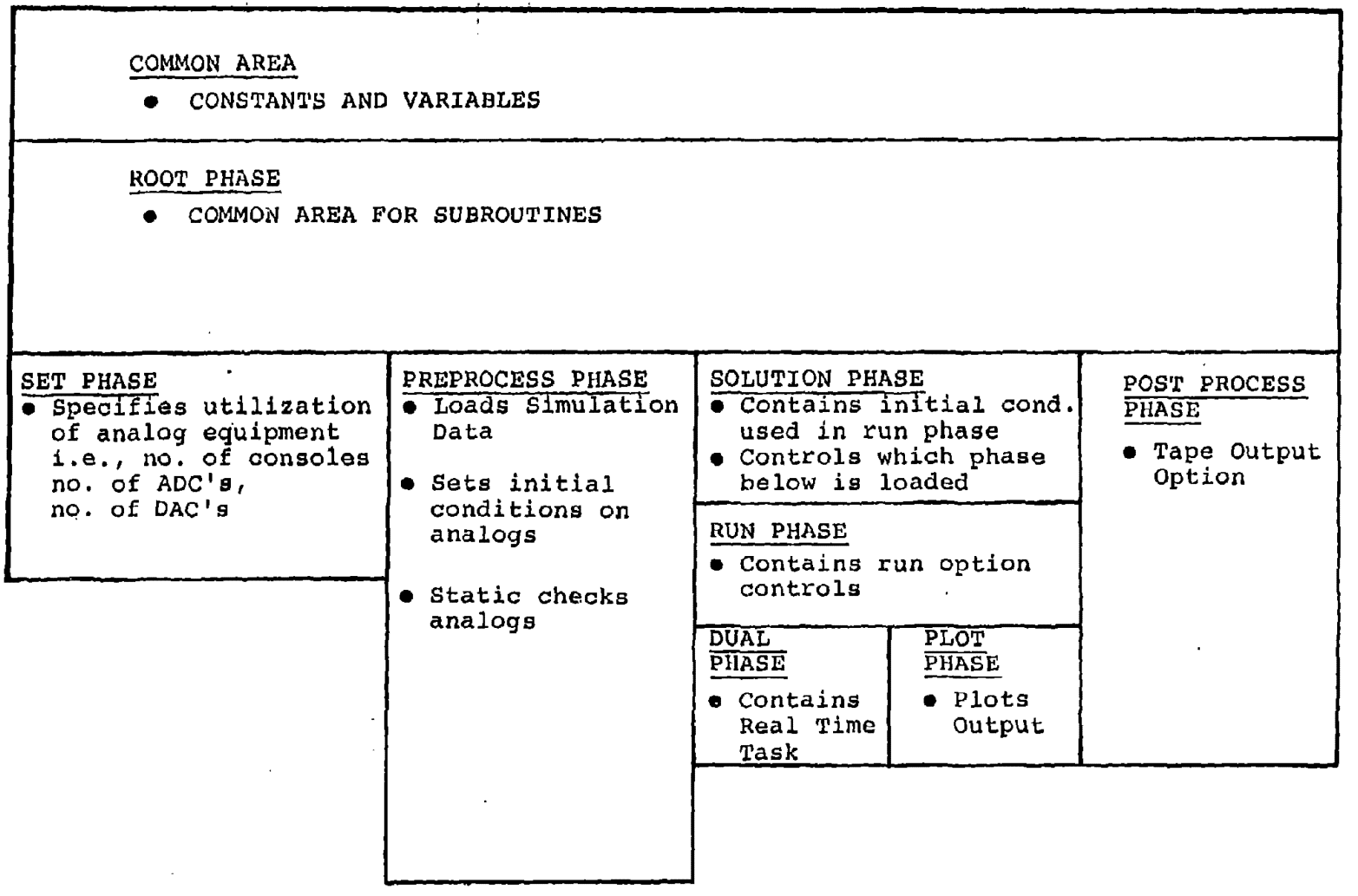


Figure G.3. GHP Phase Overlay Structure (Digital Core Allocations)

- 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 $\bar{C}_L$; 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 $(\beta_{VT}-\alpha)$
- 7 Region C_{LVT}, C_{DVT}, curve
- If doors open; 1/2 efficiency of horizontal tail
- Vertical tail Aero
- Total tail Aero

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

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

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

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

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

Figure G.5. Contents of Real Time Task – Slow Loop

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}
- $\bar{\zeta}$, $\bar{\alpha}_R$, $\bar{\varepsilon}_p$ $\bar{C}_{T_s}$, $\sin\zeta \cos\& \bar{\zeta}$, $\sin\& \cos(\bar{I}_{NAC} - \bar{I}_W)$, $\tan(\bar{\alpha}_R - \bar{\varepsilon}_p)$
- $\zeta_{R1}, \zeta_{R2}, \zeta_{R3}, \zeta_{R4}$
- 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

- $H_{W_{c/4}}$, $H_{T_{c/4}}$, $(a_q/a)_t$

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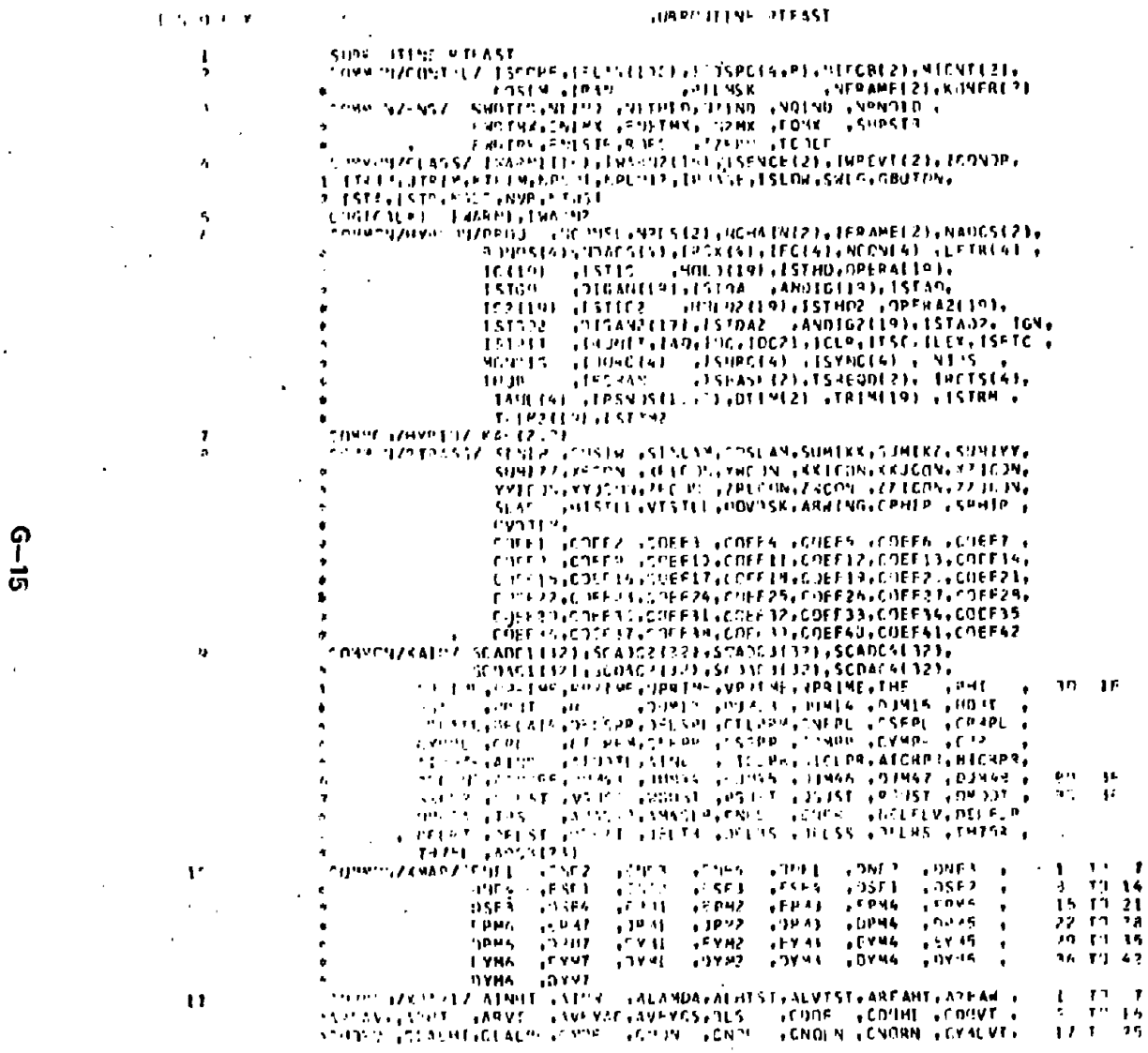


Figure G.6. Model 222 Simulation Digital Listing

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3DDILG ,DCMLC ,EINPR ,DOVI ,ESDAET,EFFMT ,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 ,ROTPAD,   44 TO 52
*PREPR ,SAWDR ,SC ,SHF ,SIN ,SK0 ,SK1 ,SK2 ,SK3 ,   53 TO 61
*SK4 ,SK5 ,SK6 ,SK7 ,SK8 ,SK9 ,SK10 ,SK20 ,SK21 ,   62 TO 70
*SK32 ,SDOVLD,SK33LG,SK33LO,SK32 ,SDOVHI,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
*XHAC ,XVT ,YN ,YPA ,YWAC ,ZFAC ,ZHT ,ZPA ,ZWAC ,
*ZVT ,GLOAL ,PHIPH ,SK30HI,SM2REF,XWC2 ,AT1 ,AT2 ,AT3 ,
*AKD1T ,AKD2T ,AKD3T ,AKMLT ,AKM2T ,AKM3T ,AKM4T ,SK31HI,
*FFD ,ALMAK ,ALBRK ,AKLSW ,AKNSW ,SQFPRM,DEG2D ,DGTORD,HIVTST,   133TO141
*PIOV2 ,ROTWDG,ROTFPS,SKFPS ,ALNGBK,TAURT1,TAURT2
12      COMMON/DACTOR/ DAC1(32),DAC2(32)
13      COMMON/XLINTP/ AKEY1(15),XMEM1(2),AKEY2(15),XMEM2(2),GKEY(13),GMEM
14      COMMON/XFUPC / VSTAMG(33), TAJAS(9),SVSTA3(33,9),SQFAPG(35),
1       SAATAB(35),GPATAB(35),ALFTAB(35)
15      COMMON/XCNTRL/ SKOLR,SKOLS,SKOLP,SKOLF,SKOLRO,TH75LP,TH75LN,
1       TAUGLS,GLSLM,TAUGLG,GILIM,CNTROL(4),GMA,ETAA,
2       SKDA ,GIH,TAUTH,OMSC,OMSLP,OMLM,GOMG,SKDCOL,THRTLM,THOMLP,
3       THOMLM,SUPLM,GTHSOV,OM3),ETARO,TTMSLP,TTMSLN,G081,G082,
4       TAUPO,GLOTHR,TAUDT,TAUPZ,TAUTHF,GLPI,GLPSLP,GPDS,TAUPOS,
5       GP,TAUP,GRSTP,TAUHFT,GPHI,TAUPHI,GPSIOR,GRETOR,GRDR,TAJDR,
6       GPSI,TAUPSI,GRETN,TAUPP,GPRI,TAUPRI,GR,TAJRI,TAJR2,TAUP3,
6       PLM,DPLM,DLBL1,DLSLM,DLPLM,
7       TOMDLM,GDLTH,SKW1,SHW2,S4W3,SKW4,SKW5,
8       SKW6,SKW7,SKW8,SKW9,SKW10,GGUST,TAUGST,OMWR,ETAW3,GINRF,
9       OMIRF,ETAIRF,SKTHTM,SC1,SC2,OMMDCL,AINPLM,TAUR01,TAUR02,
A       TAUIF,TAUCYR,OCYCLM,L,ASLP,ALIM,TAUSHP,DELALM,
B       DLFLP;
16      COMMON/INITVR/
1 AVEIN ,SILAML,SILAMR,COSINL,COSINR,COSPSI,C2INL ,C2INR ,DLEPSO,   1 -  9
2 HSO ,SILAML,SILAMR,SININL,SININR,SINPSI,SSOINL,SSOINR,S2INL ,   10 - 18
3 S2INR                                                           19 -
17      COMMON/CGGTVR/
1 VEAST ,VNORTH,XGG ,XDTGG ,ZGG ,ZDTGG                             1 -  6
18      COMMON/FNSVAR/
1 XMACH ,AMACSQ,QFL ,EMAXN1,EMAXN2,EMXMOT,EN2STR,FSMACH,OMEGFL,   1 -  9
2 OMEGFP,ONOVTC,OBVFSM,OVSQTH,OVTHDL,ROE ,ROEOV2,SHPPRL,SHPPRR,   10 - 18
3 SMA ,SQFLMX,SATHTC,SQWDTX,TDEGF ,TEAL ,TEAR ,THCDEL,THETC    19 - 27
4,PCTCL,PCTDR                                                     28 TO 29
19      COMMON/VELVAR/
1 AMUL ,AMULSQ,AMUR ,AMURSQ,MRATL ,OMDEL ,OMDTR ,OMEGAL,OMEGAR,   1 -  9
2 OMSOL ,OMSTR ,QHT ,ULW ,ULWPR ,ULWSQ ,UP ,URL ,URLPR ,   10 - 18
3 UPLURL,UPR ,URRPR ,URRPRR,URW ,URWPR ,URWSQ ,USQ ,UVT ,   19 - 27
4 VALFLW,VALFRW,VALFS ,VELNOL,VELNOR,VSQTVT,VLW ,VLWPR ,VLWSQ ,   28 - 36
5 VP ,VRL ,VRLPR ,VRLVPL,VRW ,VRWPR ,VRWVRR,VSW ,VSWPR ,   37 - 45
6 VSWSQ ,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 ,WPR ,WRRPR ,WRRWRR,WSQ ,WVT ,   64 - 71
20      COMMON/FUSVAR/
1 ALARF ,ALARFP,ALFSQ ,ALPIF ,AMARF ,AMARFP,ANARF ,ANARFP,BETAF ,   1 -  9
2 BETFSQ,CRFMF ,EDF ,ELF ,EMF ,ENF ,EOSALF,EOSBTF,EYF ,   1 - 19
3 PLLG ,QMLG ,QNLG ,QXLG ,QYLG ,QZLG ,QFSW ,SBFCAF,SBFSAF,   19 - 27
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Figure G.6. (Continued)

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      4 SIMPLE,SINGTF,FOF   ,XAERF ,XAIRF ,YAERF ,YAIRF ,ZAERF ,ZAIRF     28 - 36
      *    ,SINTHF,COSTHF,SINPHI,COSPHI
      COMMON/GREVAR/
21    1 ASPVAT,ASPVAW,RIGX  ,RKRO  ,IMOVTL,RMOVTR,COKCOR,CLTCOR,CLWCOR,    1 -  9
      2 DOVTL ,DOVTR ,EPRRM ,GRF   ,IGEFLG,IOFFRM,ULHUB ,HRHUB ,HTC4  ,   10 - 18
      3 HTC4  ,ZZII  ,PRII  ,SAI   ,TIEFL ,LIGFM                         19 - 24
      COMMON/MACVAR/
22    1 ALPHSQ,ALPHLN,ALPHPN,ALMNSQ,BETALN,BETARN,BTLNSQ,BTRNSQ,CALLN ,    1 -  9
      2 CALLR ,CRETLN,CRETRN,CDLN  ,CDRLN ,CDRRN ,CDRN  ,CLLN  ,CLRN  ,   10 - 18
      3 CMLP  ,CMRN  ,CNLN  ,CNRN  ,CYLN  ,CYRN  ,DLLNC ,DLRNC ,DNLNC ,   19 - 27
      4 DNRNC ,DNLNC ,DNRNC ,DXLNC ,DXRNC ,DYLNC ,DYRNC ,DZLNC ,DZRNC ,   28 - 36
      5 SALLN ,SALRN ,SRETLN,SRETRN,SQLNC ,SQRNC ,TNAC1 ,TNAC2          ,   37 - 44
      COMMON/ROTVAR/
23    1 AIC1  ,AICLOP,AICR  ,AICROP,ALARNC,ALLRH ,ALARNL,ALARNR,ALRRH ,    1 -  9
      2 ALPHLP,ALPHRP,AMARNC,AMARNL,AMARNR,AMLRH ,AMRNLP,AMRNRP,AMROTL,   10 - 18
      3 AMRRHP,AMRRH ,ANARNC,ANARNL,ANARNR,ANLRH ,ANROTL,ANROTR,ANRRH ,   19 - 27
      4 BIC1  ,BICLOP,BICR  ,BICROP,CNEAIL,CNEAIR,CNEBIL,CNEBIR,CNEL  ,   28 - 36
      5 CNER  ,CNSAIL,CNSAIR,CNSBIL,CNSBIR,CPMAIL,CPMAIR,CPMBIL,CPMBIR,   37 - 45
      6 CPML  ,CPMR  ,CSEAIL,CSEAIR,CSEBIL,CSEBIR,CSEL  ,CSER  ,CTL   ,   46 - 54
      7 CTR   ,CYMAIL,CYMAIR,CYMBIL,CYMBIR,CYML  ,CYMR  ,FIPCML,FIPCMR,   55 - 63
      8 FNORML,FNORMR,FSIDEL,FSIDER,GNLN  ,PHLP  ,PNRN  ,PNRR  ,QNLN  ,   64 - 72
      9 QNLR  ,QNRN  ,QNRR  ,RNLN  ,RNLR  ,RNRN  ,RNRR  ,ROPIRS,ROPIRS,SHPROL,SHPROR,   73 - 81
      * SINZIL,SINZRS,TL    ,TORQL ,TORQR ,TS    ,TRMAR1,TRMAR2,TRIAR3,   82 - 90
      0 TRMA24,TRMIR1,TRMIR2,XAERNC,XAIRNC,XAERNR,YAERNC,YAERNL,YAERNR,   91 - 99
      C YAERRC,ZAERNL,ZAERNR,ZETHL ,ZETHR                               100- 104
      COMMON/WNGVAR/
24    1 ALARNC,ALLWRP,ALRWLP,ALPWRP,ALRGLP,ALPGRP,ALRWPR,ALWSSO,AMARLP,    1 -  9
      2 AMARNC,AMARNG,ANARNG,ARILW ,ARIRW ,AAWSSO,ATAULR,ATAURR,AVEALP,   10 - 18
      3 AVEALW,AVEGLW,AVECTS,AVEPRP,AVEZET,BETALW,BETARW,BKALPR,BKARPR,   19 - 27
      4 CALLP ,CALPW ,CAVINW,CAVZET,CRETLW,CRETRW,CEPLW ,CEPRW ,CDONTL,   28 - 36
      5 CDLTSP,CDOUM ,CDLWAD,CDLWPR,CDLWSS,CDRWAD,CDRWPR,CDRWSS,CDSLW ,   37 - 45
      6 CDSPW ,CLAVE ,CLCNTL,CLCNTR,CLDUM ,CLILW ,CLIRW ,CLLWAD,CLLWPR,   46 - 54
      7 CLLWSS,CLRWAD,CLRWPR,CLRWSS,CLSLW ,CLSRW ,CLSW  ,CLZERO,CMCNTL,   55 - 63
      8 CMCNTR,CMLWAD,CMLWSS,CMRWAD,CMRWSS,CMSLW ,CMSRW ,CNSW  ,GTAULP,   64 - 72
      9 GTAURP,GTSLP ,GTSRP ,DCODF ,DCOLDA,DCOLSP,DCORDA,DCORSP,DCLDF ,   73 - 81
      A DCLLDA,DCLLSP,DCLPDA,DCLPSP,DCLSPW,DCMDF ,DCMLDA,DCMLSP,DCMRDA,   82 - 90
      B DCMRSP,DCPISP,EPILP ,EPIRL ,EPRLP ,EPRRP ,EPWRL ,EPWRP ,ERSLR ,   91 - 99
      C RESLP ,SALLP ,SALRP ,SAVELW,SAVERW,SRETLW,SRETRW,SERLW ,SERRW ,  100- 108
      D SGNULW,SGNURW,STIL  ,SILW  ,SIR   ,SIRW  ,SIT   ,STAULR,STAURR,  109- 117
      E SVSTSP,SVSTSL,SOLW  ,SPRESL,SPRESR,SURW  ,SUWING,TAULR,TAURR ,  118- 126
      F TAVSRP,TRIANG,TRMASS,TRMASY,TRMASZ,TRMIRW,TZETL ,TZETR ,TZETR ,  127- 135
      G TZETW ,TZETS ,TZETT ,VSRAT ,VSTAIL,XAERLW,XAERRW,YAERLW,YAERLW,  136- 144
      H YAERRW,YAERWG,ZAERLW,ZAERWG,ZAERWS,ZETRL ,ZETWL ,ZETWR ,ZETRW ,  145- 153
      COMMON/WINGVR/
25    1 TRMASS,TRMASY,TRMSIC,TRMSIL,WPACR ,WPTACP,WWACL ,WPTACL,WLR   ,    1 - 9
      2 WPTRT ,WTL   ,WPTRTL,AMACTL,AMACTR,THTLAC,THTRAC
      COMMON/TAILVR/
26    1 ALPHVT,ALVRT ,CLAPVT,ALPHVT,ALPHVT,AMARHT,AMARVT,VMARHT,VMARVT,    1 -  9
      2 SLAPT ,SLAPVT,ETVT  ,CALTHT,CRETSS,CDHT  ,CDVT  ,CLHT  ,CYVT  ,   10 - 18
      3 CRTAIL,CRZERO,SALTHT,SRETSS,SIGMA ,TRMHT ,TRMVT ,XAERT ,YARHT ,   19 - 27
      4 YARVT ,YAERT ,YARHT ,YARVT ,ZAERT ,ZARHT ,ZARVT ,EPTLI ,ALHTPR,   28 TO 36
      5 ALVTPR,ALHTP ,ALHTM ,CLAT  ,TRMHT2,TRMHT3,CLHTST,CDHTST,ALVTPR,   37 TO 45
      6 ALVTP ,ALATP ,ALVTM ,CYAT  ,TRMVT2,TRMVT3,CYVTST,CDVTST         ,   46 TO 53
      COMMON/CMVAR/
27    1 ALAERO,CMAERO,CMAIRO,CMOM  ,FIXA  ,FIXZR ,FIXZO ,FIXZR ,FIYY  ,    1 -  9
```

Figure G.6. (Continued)

```
     2 FIZZ  ,FJXX  ,FJYY  ,FJZZ  ,DDVIXX,DDVIYY,DDVIZZ,PP    ,PQ    ,   10 - 18
     3 PR    ,RR    ,RD    ,TERM1 ,TERM2 ,TERM3 ,TERM4 ,TERM5 ,TERM6 ,   19 - 27
     4 TERMP1,TERMQ1,TERMR1,TERM14,TERM2R,TERM3R,TERM1L,TERM2L,TERM3L,   28 - 36
     5 TRMTTL,TRMTTP,XAERO ,XF    ,XFMFLF,XL    ,XLCOS ,XLSIN ,XQ-   ,   37 - 45
     6 KRCOS ,XRSIN ,XW    ,XWMWIM,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/TRNCON/ UTRIM,VTRIM,WTRIM,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 ,SFPHL ,SFYML ,SFQL  ,SFRL  ,
     E                SFTR  ,SFNFR ,SFSFR ,SFPHR ,SFYMR ,SFQR  ,SFRR
     F               ,CONS71,CONS72,CONS73,CONS74,CONS75,CONS76,CONS77    106TO112
     G               ,CONS78,CONS79,CONS80,CONS91                         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     XPRCON=  -(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     XYJCON=   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        CONEL=  1. / SM
C     COEF11= RKLSM*AVEYAG/2./SPAN
```

Figure G.6. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

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 HWD/4 GT 55 FT.    DEF = 0.
C         2. IF  V  LE  30 KT    TAIL AERO = 0.
C         3. IF  DEL FLAP GT  26 DEG     EPSILON TAIL = 0.
C         4. IF  CTS LT 3.5  EPSILON P = 0.
C         5. LIMIT RANGE OF ABS(ALPHAT) 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
      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 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 **********************      E  ))
      33          CALL TRACK('RTFAST  ',1)
C
C             READ ADCS
      34          CALL USEATO(ANDIG )
      35          KPAN = 3*1
      36      42  GO TO(4 ,5 ,6 ),ISTAD
C
C             CONVERT TO FLOATING POINT
```

Figure G.6. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

```
      CALL ADCELERAP(IPSP(ISET,III),ADS,A4,SCADC1 )
      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 )
*****|**********************************  S Y N T A X   E R R O R  **********************  G  11
      ENTRY ESTRTF
      C
       CALL SINCOS(EAIR,SINENR ,COSINR )
      CALL SINCOS(EINL,SINENL ,COSINL )
      AVEIS =  ,*SQRT(ASNL +AINR)
      C
      CILAMR =  COSLAM*COSINR *SINLAM* SININR
      CILAML =  COSLAM*COSINL *SINLAM* SININL
      SILAMR =  COSLAM*SININR -SINLAM* COSINR
      SILAML =  COSLAM*SININL -SINLAM* COSINL
      C
      RERR2 =  DELELR * DELELR
      C
      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 )
*****|**********************************  S Y N T A X   E R R O R  **********************  E  88
      C       C,G, VELOCITY W.R.T. PIVOT (NON ROTATING AXES)
      ROTCR =  -(OMEGA(AINTL*SILAML+AINTR*SILAMR )
      ROTCL =  -(OMEGA(AINTL*CILAML+AINTR*CILAMR )
      C
      IF (ITIME .NE. 1) GOTO
```

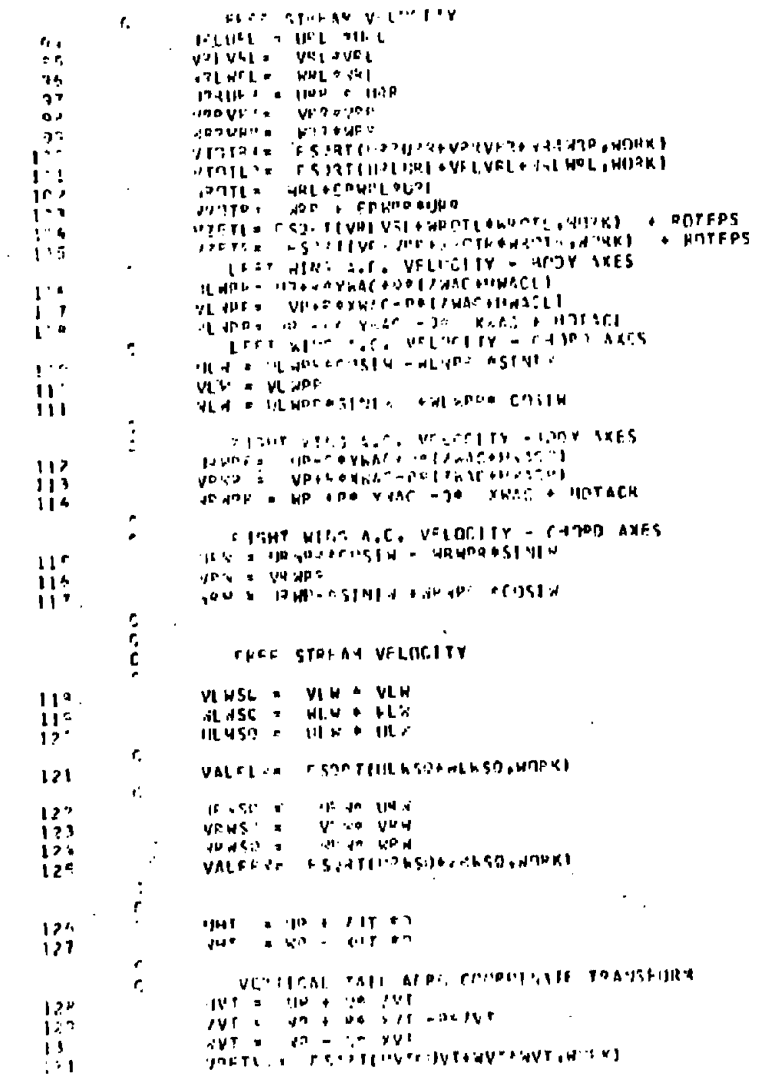
Figure G.6. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

```
      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= RHOQV2 *(USQ+VSQ+WSQ)
      IF(SQF.GT.SQFPRM) GO TO 130
      NCLOSE = 0
      SQFPRM= QHRK1A*QHRK19
      GO TO 140
  130 NCLOSE= 1
      SQFPRM= QHRK14-QHRK19
  140 CONTINUE
C        GLASS SYSTEM
      CALL LINT(CKEY,GMEM,GMEM,ISTG,SQF,GAATAB,GAIALF,GBATAB,GBIALF,
     )           ALFTAB,ALEREF)
      GAIBET = GBIALF
      ALFGLS= ALPHF*RDTODG
      BETGLS = BETAF*RDTODG
      AIGLOS= ALFGLS*GAIALF+BETGLS*GAIBET
      AIGBGS= BETGLS*GAIBET-ALFGLS*GAIALF
      BIGGLS= ALFGLS*GBIALF
C        FUSELAGE PIVOT VELOCITY
      UP =  U - Q*ZCG - XDTCG
      VP =  V + P*ZCG-R* XCG
      WP =  W + Q*XCG -ZDTCG
C
C
C        LEFT ROTOR HUB VELOCITY - BODY AXES
      UPLPP = UP +PRYN -RLS*SININL*(Q*AINDTL)+Q* HIL
      VRLPP = VP +RLS*(P*COSINL+P*SININL) -P* HIL
      WPLPP = WP -P*YN-RLS*(Q*AINDTL)*COSINL +HIDTL
C
C        RIGHT ROTOR HUB VELOCITY - BODY AXES
      URRPP =UP-P*YN -RLS*SININR*(Q*AINDTR) +Q* HIR
      VRRPP =VP +RLS*(P*COSINR +P*SININR) -P* HIR
      WRRPP = WP +P*YN -RLS*(Q*AINDTP)*COSINR +HIDTP
C
C        LEFT ROTOR HUB VELOCITY - SHAFT AXES
      UPL= UPLPP*COSINL -WRLPP*SININL
      VRL=  VRLPP
      WRL=  UPLPP*SININL +WRLPP*COSINL
C
C        RIGHT ROTOR HUB VELOCITY - SHAFT AXES
      URR =  URRPP*COSINR -WRRPP*SININR
      VRR =  VRRPP
      WRR=   URRPP*SININR +WRPPP*COSINR
C
```

Figure G.6. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.



```
C
C     FREE STREAM VELOCITY
C
      VLWSL =  VLW * VLW
      WLWSC =  WLW * WLW
      ULWSQ =  ULW * ULW
C
      VALFL =  FSQRT(ULWSQ+WLWSQ,WORK)
C
      UBWSQ =  UB * UBW
      VBWSQ =  VB * VBW
      WBWSQ =  WB * WBW
      VALBSQ =  FSQRT(UBWSQ+VBWSQ+WBWSQ,WORK)
C
      QBAT  =  QB + QIT *Q
      QWT   =  QW - QIT *Q
C
C     VERTICAL TAIL AERO COMPONENTS TRANSFORM
      UVT =  UB + QB *ZVT
      VVT =  VB + PB *ZVT -RB*XVT
      WVT =  WB - QB *XVT
      VORTVT =  FSQRT(UVT*UVT+VVT*VVT+WVT*WVT)
```

Figure G.6. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

```
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 )
*****************************  S Y N T A X   E R R O R  ***********************      6  ))
      C
      C       ROTOR INPUT EQUATIONS (AERO)
      C         NOTE ALPHRR AND ALPHLR ARE DEFINED BETWEEN 0 AND 180 DEGREES
      C              I.E.  90 +OR- 90 DEGREES
133         ALPHLR=  ATAN2(VZETL,URL)  + EPSRL
134         ZETHL=  ATAN2(VPL,WROTL)
135         CALL SINCOS(ZETHL,SINZHL,COSZHL)
      C
136         ALPHRR=  ATAN2(VZETR,URR)  + EPSLR
137         ZETHR=  ATAN2(VRR,WROTR)
138         CALL SINCOS(ZETHR,SINZHR,COSZHR)
      C       VELOCITIES
      C
      C       ROTOR ANGULAR RATE TRANSFORMS
      C
      C       LEFT ROTOR - NACELLE AXES
139         PNLN=  P*COSINL - R*SININL
140         QNLN=  Q*AIRDTL
141         RNLN=  P*SININL +R*COSINL
      C       LEFT ROTOR - WIND AXES
142         PNLR=  PNLN
143         QNLR= QNLN*COSZHL -RNLN*SINZHL
144         RNLR= QNLN*COSZHL +RNLN*SINZHL
      C
      C       RIGHT ROTOR - NACELLE AXES
145         PNRN=  -P*COSINR +R*SININR
146         QNRN= Q*AIRDTR
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)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

```
C
C
C       ENTER CONTROL COORDINATE AXIS TRANSFORM
C         LEFT MOTOR
C
      AICLP  =  AICLPR*CPHIP+BICLDP*SPHIP
      BICLP  = -AICLDP*SPHIP+BICLDP*CPHIP
C
      AICL   =  AICLP*CPSIZHL-BICLDP*SPSIZHL
      BICL   =  AICLP*SPSIZHL+BICLDP*CPSIZHL
C
C       RIGHT MOTOR
      AICRP  =  AICRPR*CPHIP+BICRPR*SPHIP
      BICRP  = -AICRPR*SPHIP+BICRPR*CPHIP
C
      AICR   =  AICRP*CPSIZHR+BICRDP*SPSIZHR
      BICR   = -AICRP*SPSIZHR+BICRDP*CPSIZHR
C
C       ENTER EQUATIONS
C
      ENEA1  =  ENF1*CT1+ENSF2*AMUR5Q+ENSF3*AMUR   +ENF4
      DNEA1  =  DNF1*CT1+DNSF2*AMUR5Q+DNSF3*AMUR   +DNF4
      ESEA1  =  ESF1*CT1+ESSF2*AMUR5Q+ESSF3*AMUR   +ESF4
      DSEA1  =  DSF1*CT1+DNSF2*AMUR5Q+DNSF3*AMUR   +DSF4
      IF(AMUR.GT.0.0001) GO TO 150
      EPYP1A =  EPY1*CT1+EPM2*AMUR5Q+EPM3*AMUR   +EPM4
      DPM1A  =  DPM1*CT1+DPM2*AMUR5Q+DPM3*AMUR   +DPM4
      EYM1A  =  EYM1*CT1+EYM2*AMUR5Q+EYM3*AMUR   +EYM4
      DYM1A  =  DYM1*CT1+DYM2*AMUR5Q+DYM3*AMUR   +DYM4
      GO TO 151
  150 CONTINUE
      EPM1A  =  EPM1*CT1+EPM5*AMUR5Q+EPM6*AMUR   +EPM7
      DPM1A  =  DPM1*CT1+DPM5*AMUR5Q+DPM6*AMUR   +DPM7
      EYM1A  =  EYM1*CT1+EYM5*AMUR5Q+EYM6*AMUR   +EYM7
      DYM1A  =  DYM1*CT1+DYM5*AMUR5Q+DYM6*AMUR   +DYM7
  151 CONTINUE
C
      ENEA   =  ENF1*(ENSF2*AICR+ENSF3*AICL)+ENF4
      DNEA   =  DNF1*(DNSF2*AICR+DNSF3*AICL)+DNF4
      ESEA   =  ESF1*(ESSF2*AICR+ESSF3*AICL)+ESF4
      DSEA   =  DSF1*(DNSF2*AICR+DNSF3*AICL)+DSF4
C
      ENEAL  =  ENF1*CT1+ENSF2*AMULS0+ENSF3*AMUL   +ENF4
      DNEAL  =  DNF1*CT1+DNSF2*AMULS0+DNSF3*AMUL   +DNF4
      ESEAL  =  ESF1*CT1+ESSF2*AMULS0+ESSF3*AMUL   +ESF4
      DSEAL  =  DSF1*CT1+DNSF2*AMULS0+DNSF3*AMUL   +DSF4
      IF(AMUL.GT.0.0001) GO TO 152
      EPM1AL =  EPM1*CT1+EPM2*AMULS0+EPM3*AMUL   +EPM4
      DPM1AL =  DPM1*CT1+DPM2*AMULS0+DPM3*AMUL   +DPM4
```

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

Figure G.6. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

Figure G.6. (Continued)

PRECEDING PAGE BLANK NOT FILMED

```
                                        ( 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 ************************      G  +L
  270           SQWING =  SQF + 0.5*QQVDSK*(TR +TL )
  271           SQLW   =     RDEOV2 *(ULWSQ+VLWSQ+WLWSQ)) TL * QQVDSK
  272           SQRW   =    RDEOV2*(URWSQ+VRWSQ+WRWSQ)  + TR * QQVDSK
  273           IF(INCLOSE.EQ.1)  GO TO 420
  274           FINPR=   FINDEG-QBRKLT
                C        EQUATIONS FOR DOORS OPEN
  275           SGNULW= 1.0
  276           IF(ULW.LT.0.) SGNULW= -1.0
  277           SGNURW= 1.0
  278           IF(URW.LT.0.0) SGNURW= -1.0
  279           XAERLW=  -SGNULW*FFU*SQLW*(1.-CTSLR)
  280           XAERRW=  -SGNURW*FFU*SQRW*(1.-CTSPR)
  281           YAERLW =  0.
  282           YAERRW=  0.
  283           ZAERLW =  QQVTL*TL
  284           ZAERRW =  QQVTR*TR
  285           RMARLW=  -XWC2*ZAERLW + RMQVTL * TL
  286           RMARRW =  -XWC2*ZAERRW + RMQVTR*TR
  287           ALAPRG=  .5*SPAN*(ZAERRW*(1.-0.5*S(RW)-ZAERLW*(1.-0.5*S(LW))
  288           ANARMS =  1.
                C        SET WING DYNAMIC PRESSURE = TO HARD 2.5  FOR THETA TWIST EQ
  289           SQWING = 6.0
  290           SQLW=  0.0
  291           SQRW=  0.0
                C
  292           AVELW=  0.0
  293           GO TO 430
  294     420   CONTINUE
                C        EQUATIONS FOR DOORS CLOSED
  295           FINPR=  FINDEG + QBRKLT
                C
                C
                C        ANGLE OF ATTACK AND SIDESLIP
  296           ALPHLW=  ATAN2(WLW,ULW)  +THTLAC
  297           BETALW=  ATAN2(VLW,VALFLW)
                C
  298           ALPHRW=  ATAN2(WRW,URW)  + THTRAC
  299           BETARW=  ATAN2(VRW,VALFRW)
                C
  300           ALWSSQ  =  ALPHLW  - EPSLR
  301           ARWSSQ  =  ALPHRW  - EPSRR
  302           ALRSLW  =  ALWSSQ  - THTLAC
  303           ALRSRW  =  ARWSSQ  - THTRAC
```

Figure G.6. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

```
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 AILSPI  (DFLAIL     ,DELSPL,DCLLDA,DCDLDA,DCMLDA,DCLLSP,DCDLSP,
            * DCMLSPI
306          CALL AILSPI  (DFLAIR     ,DELSPR,DCLRDA,DCDRDA,DCMRDA,DCLRSP,DCDRSP,
            * DCMRSPI
             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,2.0,CLAVE)
             C
             C
317          ALLWPR= ALPHLW - AINW -THTLAC
318          ALRWPR=  ALPHRW - AINW - THTLAC
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)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

```
      IF(ALWSSN.GT.DEG20) IWARN1( 7)=  .TRUE.
      IF(ARWSSN.GT.DEG20) IWARN1( 8)=  .TRUE.
      IF(ALPHLW.GT.DEG20) IWARN1( 9)=  .TRUE.
      IF(AL*HRW.GT.DEG20) IWARN1(10)=  .TRUE.
      CALL SINCOS(EPPLR,SEPLW,CEPLW)
      CALL SINCOS(EPPRR,SEPRW,CEPRW)
C
C
      TRMWG5 =  (1.-GTSLR)*(1.-SILW)
      TRMWG6 =  (1.-GTSRR)*(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)*
     *  BKARPP
      CDSRW =  (SIRW*(CLRWSS*SEPRW +CDRWSS*CEPRW)+ CDRWAO* TRMWG6)*
     *  BKARPP
      CMSRW =  (SIRW*CMRWSS + CMRWAO *TRMWG6 )*BKARPR
C
      DCLSPW= .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*(SK22+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
      AMARLW =  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.-AVECTS)
   41  CONTINUE
      XAERWG =  XAERLW + XAERRW
      YAERWG =  YAERLW + YAERRW
      ZAERWG=  ZAERLW + ZAERRW
      ALARWG =  CLSW * SCWING * COEF15
```

Figure G.6. (Continued)

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REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

Figure G.6. (Continued)

```
      244   CONTINUE
            EPTL1 =  EPZERO*DEPDAL*(AVEALH- SLAC*WDOT/(U*U+0.01))
            IF(AVEPP.LT.EPTL1 ) GO TO 261
            EPTAIL=  AVEPP*(1.-GEF)*DOVESM
            GO TO 265
      261   CONTINUE
            EPTAIL=  EPTL1*(1.-GEF)*DOVESM
      265   CONTINUE
      253   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,SALHT,CALHT)
      C
      C        TAIL REVISION   9/6/72
      C
            ALHTPR   = TAUHT *DELELV
            ALHTC    = ALPHHT + ALHTPR
            ALHTP    = HTSTLL + ALHTPR
            ALHTM    = -HTSTLL + ALHTPR
            CLAT     = CLALHT *CLTCOR
            TRMHT2   = 0.5 * ALHTP
            TRMHT3   = 0.5 * ALHTM
            IWARNII(5)=  .TRUE.
            IF(ALHTE) 270,277,276
      271   IF(ALHTE.GT.(-PI +TRMHT2)) GO TO 272
      C        REGION 7
            CLHT =  CLAT *( ALHTE +PI)
            CDHT =  CDOHT + CLHT*CLHT *COEF2I
            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 *COEF2I
            CDHT = CDHTST -(1.1-CDHTST)*(ALHTE+PI-TRMHT2)/(TRMHT2 -PIOV2)
            GO TO 289
      274      IF(ALHTE .GT.ALHTM) GO TO 276
      C        REGION 5
            CLHTST =  CLAT * ALHTM
            CLHT   =  CLHTST *(PIOV2+ALHTE)/(PIOV2+ALHTM)
            CDHTST = CDOHT *CLHTST*CLHTST *COEF2I
            CDHT   = CDHTST +(1.1-CDHTST)*(ALHTE-ALHTM)/(-PIOV2 -ALHTM)
            GO TO 289
      276   IF(ALHTE .GT.ALHTP) GO TO 278
      C        REGION 4
      277   CLHT   =  CLAT * ALHTE
            CDHT   =  CDOHT + CLHT*CLHT *COEF2I
            IWARNII(5)=  .FALSE.
            GO TO 289
      278   IF(ALHTE.GT.PIOV2)  GO TO 280
      C        REGION 2
            CLHTST =  CLAT *ALHTP
            CLHT   =  CLHTST*(PIOV2-ALHTE)/(PIOV2-ALHTP)
```

Figure G.6. (Continued)

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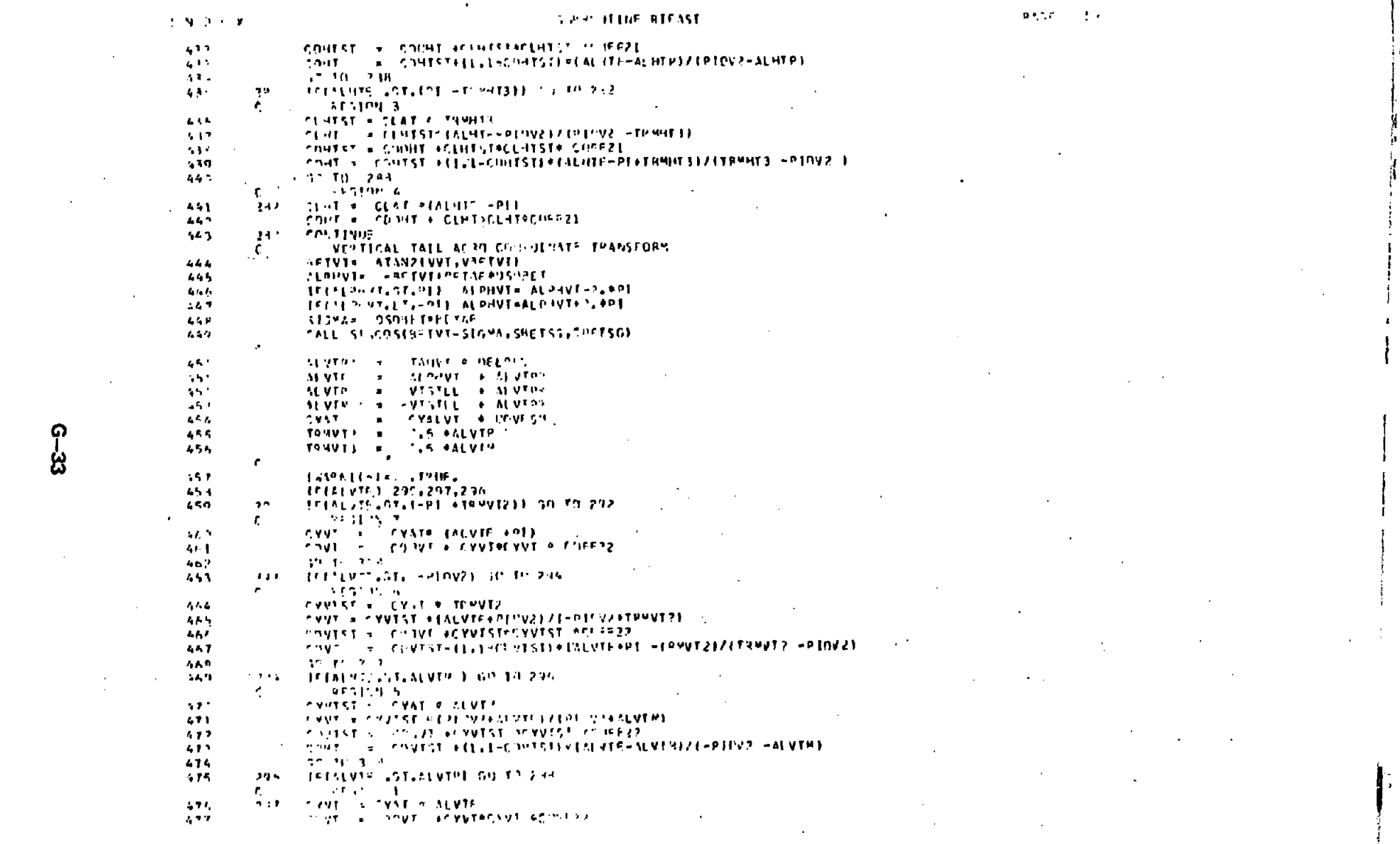


Figure G.6. (Continued)

```
      IWARN1(6)=  .FALSE.
      GO TO 308
  299 IF(ALVTE .GT.PIOV2) GO TO 302
C        REGION 2
      CYVTST  =  CYAT * ALVTP
      CYVT    =  CYVTST *(PIOV2 -ALVTE)/(PIOV2 -ALVTP)
      CDVTST  =  CDOVT +CYVTST*CYVTST * COEF22
      CDVT    =  CDVTST +(1.-CDVTST)*(ALVTE -ALVTP)/(PIOV2-ALVTP)
      GO TO 308
  301 IF(ALVTE .GT.(PI -TRMVT3)) GO TO 302
C        REGION 3
      CYVTST  =  CYAT * TRMVT3
      CYVT    =  CYVTST *(ALVTE -PIOV2)/(PIOV2 -TRMVT3)
      CDVTST  =  CDOVT + CYVTST*CYVTST* COEF22
      CDVT = CDVTST+(1.-CDVTST)*(ALVTE-PI+TRMVT3)/(TRMVT3-PIOV2)
      GO TO 308
C        REGION 4
  302 CYVT =  CYAT *(ALVTE -PI)
      CDVT =  CDOVT + CYVT *CYVT * COEF22
  308 CONTINUE
C
C        TOTAL TAIL FORCE AND MOMENT RESOLUTION
C
C
C
C
C
      TRMHT =  SQF* COEF23
C
C        CHANGE MADE TO HALVE EFFHT FOR T NAC  GT  PINDEG
      IF(INCLDSF.EQ.0.AND.UPRIME.GT.0.) TRMHT= TRMHT*0.5
C
C
      XAPHT =  TRMHT*(CLHT*SALIHT -CDHT*CALIHT *CBETSG)
      YAPHT = -TRMHT* SBETSG *CDHT
      ZAPHT = -TRMHT *(CLHT*CALIHT +CDHT*CBETSG*SALIHT )
      ALAPHT=  -YAPHT *(ZHT- ZCG)
      AMAPHT=   ZAPHT*(XCG-XHT) +XAPHT*(ZHT-ZCG)
      ANAPHT=   -YAPHT *(XCG -XHT )
C
C
      TRMVT =   SQF* COEF24
C
      XAPVT = -TRMVT*CALIHT*(CDVT*CBETSG +CYVT*SBETSG)
      YAPVT =  TRMVT*(CYVT*CBETSG -CDVT*SBETSG )
      ZAPVT = -TRMVT*SALIHT*(CDVT*CBETSG + CYVT*SBETSG )
      ALAPVT=   - YAPVT *(ZVT -ZCG)
      AMAPVT =  ZAPVT *(XCG-XVT)+XAPVT *(ZVT-ZCG)
      ANAPVT =  -YAPVT *(XCG -XVT)
C
      XAPRT  =  XAPHT + XAPVT
      YAPRT  =  YAPHT + YAPVT
      ZAPRT  =  ZAPHT + ZAPVT
      ALAPRT =  ALAPHT + ALAPVT
      AMAPRT =  AMAPHT + AMAPVT
```

Figure G.6. (Continued)

```
J . S E K                          SUBROUTINE REFAST                          PAGE  21

  515           YDAFY  =  YDSVOIT + AYDARVT
                C
  514
                                    ( 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 *************************      E  **
                C
  517           IF(S>LS.NE.1.0) GO TO 85
  518           CALL .EAC
  519     85    CONTINUE
                C
  520           XAERR= XBXER + DXLG
  521           YAERR= YAXER + DYLG
  522           ZAERR= ZAXER + DZLG
  523           ALARR= ALARER + LLLG
  524           AMARR= AMARER + DMLG
  525           ANARR= ANARER+ DNLG
                C
                C
                C     PLASTIC AXES TO C.G. TRANSFORM
                C       AERODYNAMIC FORCES AND MOMENTS RESOLVED TO THE
                C         TOTAL CENTER OF GRAVITY
                C
  526           XAERC =  XAERRG +XAERF +YAERT +XAERWG
  527           YAERC =  YAERRG +YAERF +YAERT +YAERWG
                C     ZAERO BROKEN INTO TERMS  1) FOR VERTICAL BENDING
                C                              2) NOT FOR VERTICAL BENDING
  528           ZAERVB=  ZAERRG + ZAERWG
  529           ZAERG=   ZAERF + ZAERT
  530           ZAERO=   ZAERVB + ZAERG
                C
                C
                C     LAERO BROKEN INTO TERMS  1) FOR VERTICAL BENDING
                C                              2) NOT FOR VERTICAL BENDING
  531           ALAERG=  ALARER+YMF(ZAERVB-ZAERWG)
  532           ALAERO=  ALARER+ALAERT+ALARRG+ZCG*YAERRG
  533           ALAERB=  ALARVB+ALAERG
                C
                C     MAERO BROKEN INTO TERMS  1) FOR VERTICAL BENDING
                C                              2) NOT FOR VERTICAL BENDING
  534           AMARVB=  XCG*ZAERRG
  535           AMAERO=  AMARER+AMAERT+AMARRG-ZCG*XAERRG
  536           AMAERB=  AMARVB+AMARWG
                C
  537           ANAERO=  ANARER+ANAERT+ANARRG+
```

Figure G.6. (Continued)

```
     * +YN*(XAERNL-XAERNR)-XCG*YAERNC
538           RQ =       R*Q
539           PQ =       P*Q
540           QR =       Q*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           TERM13 =  COEF4*COEF2*( PR*(1.-2.*SILAMR*SILAMR)- (RR-PP)*SILAMR*
     *  CILAMR )
548           TERM2R =  -(RR -PP)* FIZZPR*SININR *COSINR *COEF1*(XAERQ*SILAMR
     *  + ZAERQ*CILAMR )
549           TERM3R =   COEF9*(PQ*SILAMR +RQ*CILAMR)
      C
      C       AINDDL EQUATION  CROSS TERMS
550           TERM1L =  COEF4*COEF2*( PR*(1.-2.*SILAML*SILAML)-(RR-PP)*SILAML *
     *  CILAML )
551           TERM2L =  -(RR-PP)* FIZZPR *SININL*COSINL +COEF1*(XAERQ*SILAML
     * +  ZAERQ*CILAML )
552           TERM3L =  -COEF9*(PQ* SILAML + RQ*CILAML )
553           IF(NVQ.EQ.1) GO TO 60
554           HIR=  0.
555           HIDTR= 0.
556           HIL= 0.
557           HIDTL= 0.
558           HWACR= 0.
559           HDTACR= 0.
560           HWACL= 0.
561           HDTACL= 0.
562           GO TO 70
563     60    CONTINUE
564           TRMHIS=  COEF10*ZAERQ
565           HIR=SKW1*ZAERNP+SKW2*ZAERRW*SKW3*ALARNR-TRMHIS*(SKW4+SKW5)
566           HIDTR= OVDTIM*(HIR-HIROLD)
567           HIROLD=  HIR
568           HIL=SKW1*ZAERNL+SKW2*ZAERLW-SKW3*ALARNL-TRMHIS*(SKW4+SKW5)
569           HIDTL= OVDTIM*(HIL-HILOLD)
570           HILOLD=  HIL
571           HWACR= SKW6*ZAERNR+SKW7*ZAERRW+SKW8*ALARNP-TRMHIS*(SKW9+SKW10)
572           HDTACR=  OVDTIM*(HWACR-HACROD)
573           HACROD=  HWACR
574           HWACL= SKW6*ZAERNL+SKW7*ZAERLW-SKW8*ALARAL-TRMHIS*(SKW9+SKW10)
575           HDTACL=  OVDTIM*(HWACL-HACLOD)
576           HACLOD=  HWACL
577     70    CONTINUE
      C       TERMS FOR THETA TWIST EQUATION
578           CHOW=  SC1 + SC2*DELFLP
      C
579           TRMTL1=  SOLW*(1.-CTSLP)
```

Figure G.6. (Continued)

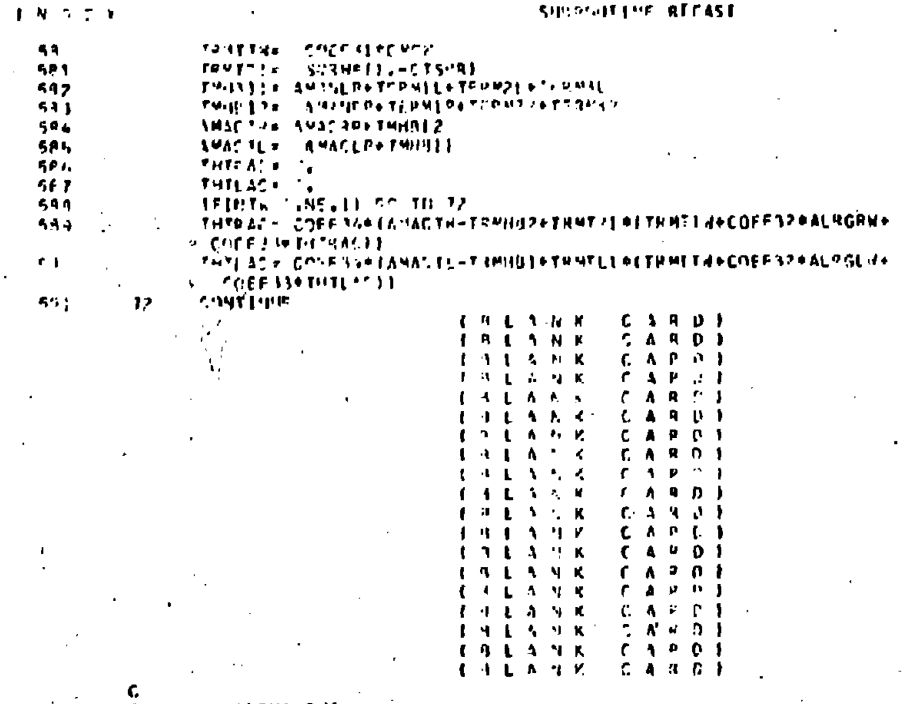
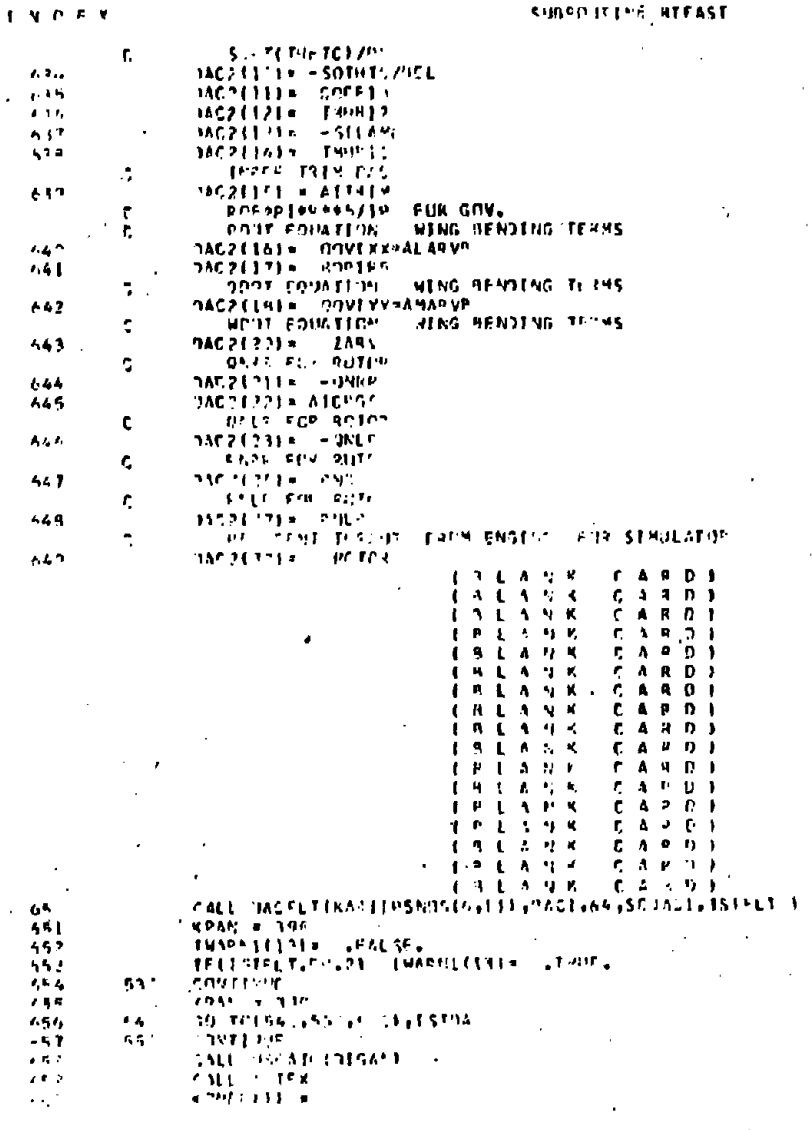


Figure G.6. (Continued)

```
602          DAC1(11) = VTRIM
             C   HDOT EQUATION  NON-WING BENDING TERMS
603          DAC1(12)=   ZARRO
             C   HTRIM DAC
604          DAC1(13) = -HTRIM
             C   SQRT(ROE/ROEO)*VTOTAL FOR QCA FUNCTIONS
605          DAC1(14)=  FSQRT(ROE/ROEO,MARK)  * U
             C   COEFFICIENT OF AINDOR IN THE QDOT EQUATION
606          DAC1(15)=  (FIYYPR+COEF4*(XRCOS-ZRSIN)) * QQVIYY
             C   VTOTLR FOR MU CALC ON ANALOG
607          DAC1(16)=  VTOTLR
             C   COEFFICIENT OF AINDOL IN THE QDOT EQUATION
608          DAC1(17)=  (FIYYPR+COEF4*(XLCOS-ZLSIN)) * QQVIYY
             C   LEFT ROTOR ALPHA FOR QCA
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 QCA
613          DAC1(22)=  -ALPHRR
             C   COEFFICIENT OF RDOT IN THE RDOT EQUATION
614          DAC1(23)=   FIXZR * QQVIZZ
             C   PNLR FOR MU CALC ON ANALOG
615          DAC1(24)=  PNLR
             C   COEFFICIENT OF AINDOR IN THE RDOT EQUATION
616          DAC1(25)=   SILAMR * QQVIZZ
             C   PNRR FOR MU CALC ON ANALOG
617          DAC1(26)=  PNRR
             C   COEFFICIENT OF AINDOL IN THE RDOT EQUATION
618          DAC1(27)=   SILAML * QQVIZZ
             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) = BIGLS
627          DAC2( 3)=  COEF13
628          DAC2(04)=  -AIGLGS
629          DAC2( 5)=  SILAMP
             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)



```
INDEX                                SUBROUTINE MTFAST                                PAGE  11

      C        $...T(THETC)/R
 634            DAC2(1)1)= -SOTHTS/ICL
 635            DAC2(11)=  COSF)\
 636            DAC2(12)=  FAOR)2
 637            DAC2(13)=  -SI(AM(
 638            DAC2(14)=  TMPF(:
      C           [PSF TRIM D/S
 639            DAC2(15) = AIT4(M
      C           RDS9P[**9**5/1P  FOR GDV.
      C           PDIF EQUATION   WING BENDING TERMS
 640            DAC2(16)=  DDVEXX*ALARVP
 641            DAC2(17)=  RDP1RS
      C           DDIF EQUATION   WING BENDING TERMS
 642            DAC2(18)=  DDVEYY*AMARVP
      C           MDIF EQUATION   WING BENDING TERMS
 643            DAC2(20)=   ZARS\
      C           DAIS FLY RUTIN
 644            DAC2(21)=  -DNRP
 645            DAC2(22)= AIRPS(
      C           DELS FOR RDIP
 646            DAC2(23)=  -DNLP
      C           ERDR FDV RUTP
 647            DAC2(24)=  PNP
      C           $*LP FOR RDTP
 648            DAC2(25)=  PNLP
      C           DF  TFMI T(S)P  FROM ENGINE  FOR SIMULATOR
 649            DAC2(26)=  RCFDR
                                    ( A L A N K   C A R D )
                                    ( A L A N K   C A R D )
                                    ( A 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 DACFLT(KAS(IPSNDS(6,1)),DAC(,64,SCDA(,1,ISIFLT )
 651            KPAR = 196
 652            IMAP(1)1)=  .FALSE.
 653            IF(ISELT.EQ.21  IMAP(L(1)1=  .TRUE.
 654       53'  CONTINUE
 655            KPAR = 31P
 656       54   DO 55(54,55),( 1),ESTDA
 657       55'  CONTINUE
 658            CALL (SCAD(IDEGA1)
 659            CALL  TFK
 660            CONTINUE
```

Figure G.6. (Continued)

```
 661           CALL TRACK('RTFAST  ',21)
 662           RETURN
 663      500  DO 510 J=1,32
 664      510  CALL DISABL(J-1)
 665      520  IPAN= KPAN
 666           RETURN
 667           END
```


Figure G.6. (Continued)

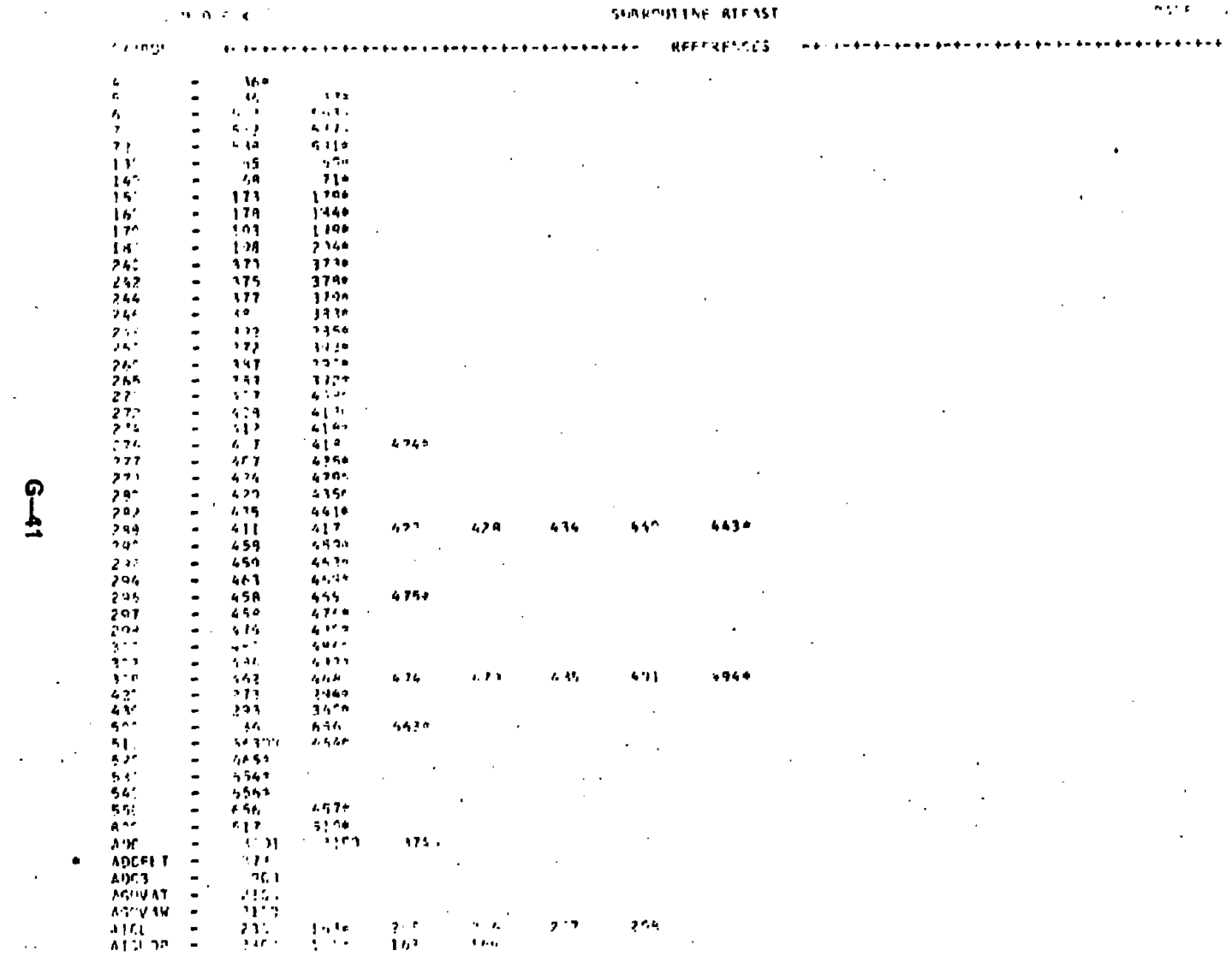


Figure G.6. (Continued)

AICLGS - 76* 628
AICLPR - 900 161 162
AICR - 2300 167* 185 186 187 188
AICRDP - 2300 165* 167 168
AICRGS - 77* 645
AICRPR - 900 165 166
AILSP - 3050 3760
AINDTL - 900 49 50 82 84 140
AINDTR - 900 49 50 85 87 146
AINHT - 1100 395 398AG
AINL - 900 41AG 42
AINR - 900 40AG 42
AINREF - 900
AINRLM - 1500
AIN4 - 1100 316AG 317 318 348
AITRIM - 2800 639
AKEY - 1300
ALAERR - 2700 533*
ALAMDA - 1100
ALARF - 2300 523* 532
ALARFP - 2000 523
ALARHT - 2600 500* 513
ALARIC - 2300 264* 531
ALARNL - 2300 251* 266 568 574
ALARNP - 2300 259* 266 565 571
ALARRG - 532* 533 593
ALART - 2600 513* 532
ALARVB - 531* 533 640
ALARVT - 2600 537* 513
ALARWG - 2400 287* 364* 532
ALBBK - 1100
ALEGLS - 74* 76 77 78
ALFREF - 72AG
ALFSQ - 2000
ALFTAB - 1400 72AG
ALHTE - 2600 430* 407 408 409 412 414 416 418 420 422 424 425
429 431 433 435 437 439 441
ALHTV - 2600 402* 405 418 419 420 422
ALHTP - 2600 431* 404 424 430 431 433
ALHTPR - 2600 399* 400 401 402
ALHTST - 1100
ALIM - 1500
ALLNSQ - 2200
ALLRH - 2300 235* 251 254
ALLWPP - 2400 317* 319
ALNCBK - 1100
ALPHF - 2000 61* 74 316AG 502
ALPHHT - 2600 395* 396 397 398AG 402
ALPHLN - 2200
ALPHLP - 2300 133* 600
ALPHLW - 2400 296* 300 304 313AG 317 333 348
ALPHPR - 2200
ALPHPW - 2300 136* 613
ALPHRA - 2400 298* 301 314 314AG 318 334 348
ALPHVT - 2400 445* 446 447 451

Figure G.6. (Continued)

ALPSLW - 2403 312* 540
ALPSLW - 2403 313* 540
ALPWSQ - 2200
ALPWH - 2303 239* 260 262
ALPWPP - 2403 318* 321
ALVTE - 2403 451* 458 454 455 463 465 467 471 473 475 476
467 442 484 485 488 492 493
ALVTH - 2403 453* 456 460 470 471 473
ALVTP - 2403 452* 455 475 491 482 484
ALVTPP - 2403 453* 451 452 453
ALVTST - 1103
ALWSSD - 2400 300* 302 311A5 331
AMACH - 1803
AMACLP - 903 585
AMACRP - 903 594
AMACSQ - 1803
AMACTL - 2503 545* 587
AMACTP - 2503 594* 599
AMAERD - 2701 536*
AMARE - 2703 524* 525
AMAREP - 2703 524
AMAPHT - 2403 511* 514
AMARLP - 2403 345* 364* 365
AMARNC - 2401 247* 535
AMARVL - 2303 253* 267
AMARVP - 2300 241* 267
AMARRS - 535* 536 595
AMAWSW - 2403 236* 358* 365
AMART - 2603 514* 535
AMARVP - 534* 536 642
AMAPVT - 2603 5.8* 514
AMARWS - 2403 345* 535
AMEM - 1303
AMLRH - 2303 236* 252
AMPNLP - 2301 252* 253 592
AMRNPP - 2303 243* 261 543
AMPUTL - 2303 215* 231 232
AMPUTP - 2303 222* 233 234
AMTRH - 2303 219* 235
AMUL - 1903 157* 159 1.5 19? 191 192 193 194 195 196 197 200
201 212 223
AMULSQ - 1903 159* 189 19? 191 192 194 195 196 197 209 211 212
223
AMUR - 1903 158* 162 163 1.1 171 172 173 174 175 176 177 182
181 142 183
AMUESC - 1303 160* 169 17? 171 172 174 175 176 177 183 181 182
183
AMAETP - 2703 537* 597
AMARE - 2703 525* 537
AMAREP - 2603 525
AMASHT - 2403 512* 515
AMAWSC - 2303 268* 537
AMAPHS - 2403 254* 268
AMAPVP - 2303 242* 268
AMAVE - 2703 515* 537

Figure G.6. (Continued)

ANARVT - 2400 539* 515
ANARWG - 2400 238* 366* 577
ANDIG - 600 344G
ANDIG2 - 600
ANLRW - 2300 237* 250
ANROTL - 2300 216* 231 232
ANROTR - 2300 223* 233 234
ANRRW - 2300 240* 258
AREAHT - 1100
AREAVT - 1100
AREAW - 1100
ARHT - 1100
ARILW - 2400
ARIRW - 2400
* ARTEX - 659*
ARVT - 1100
ARWING - 900
ARWSSD - 2400 331* 303 31245 332
ASLP - 1500
* ATAN2 - 61 62 133 134 136 137 296 297 298 299 395 444
ATAULP - 2400
ATAURP - 2400
AVFALR - 2400
AVFALW - 2400 304* 386 612
AVFGLW - 2400 292* 359* 367
AVFGTS - 2400 345 346 347 348 359
AVFFPP - 2400 371 397 399
AVEIN - 1600 42* 367
AVEYAC - 1100
AVEYCS - 1100
AVFZFT - 2400
AX - 1500
COSOS - 600
BETAF - 2000 62* 75 347 349 445 448 624
BETALN - 2200
BETALW - 2400 297* 323
BETARN - 2200
BETARW - 2400 319* 325
BETESC - 2000
BEIGLS - 75* 76 77
BIFVT - 2001 444* 445 449AG
BIGGLS - 78* 626
BICL - 2300 164* 205 206 207 208
BICLOP - 2300 162* 163 164
BICLPP - 900 161 162
BICR - 2300 168* 185 196 197 198
BICROP - 2300 164* 167 169
BICRPP - 900 165 166
BIGK - 2100
BKALPP - 2400 339 340 341
BKARPP - 2400 342 343 344
BKD1T - 1100
BKD2T - 1100
BKD3T - 1100
BKFY - 1100

Figure G.6. (Continued)

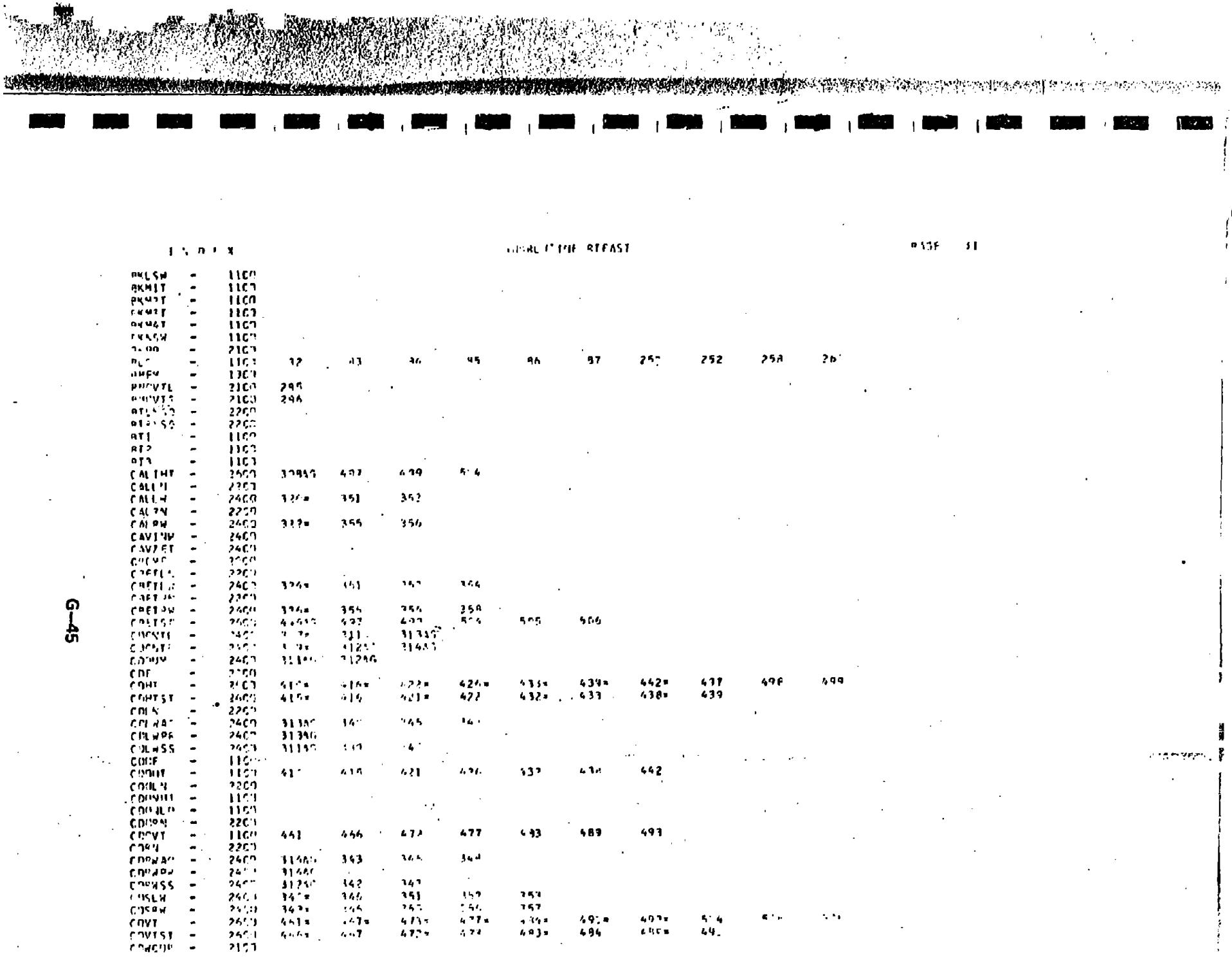


Figure G.6. (Continued)

CEPLW - 2400 335AG 339 340
CEPRW - 2400 336AG 342 343
* CGGTVR - 119
CMORD - 1100 354 358
CTLAML - 1600 44= 50 550 551 552 598 633
CTLAMR - 1600 43= 50 547 548 549 596 625
CLALHT - 1100 403
CLALPH - 1100
CLAT - 2600 403= 409 413 419 425 430 436 441
CLAVE - 2400 316AG 347 348
* CLCOCH - 311* 312* 313* 314*
CLCNTL - 2400
CLCNTR - 2400
CLDUM - 2400 311AG 312AG
CLF - 2000
* CLF1 - 315*
* CLF2 - 316*
CLHT - 2600 409= 410 414= 415= 425= 426 431= 437= 441= 447 497 499
CLHTST - 2600 413= 414 415 419= 420 421 430= 431 432 436= 437 438
CLILW - 2400
CLIRW - 2400
CLLN - 2200
CLLWAD - 2400 313AG 339 345 347 348
CLLWPR - 2400 313AG
CLLWSS - 2400 311AG 339 340
CLMAX - 1100
CLOAL - 1100
CLRN - 2200
CLRWAD - 2400 314AG 342 345 347 348
CLRWPR - 2400 314AG
CLRWSS - 2400 312AG 342 343
CLSLW - 2400 339= 345 351 352 359
CLSRW - 2400 342= 345 355 356 359
CLSW - 2400 347= 364
CLTCOR - 2100 433
CLWCOR - 2100
CLZERO - 2400 315AG 316AG
CMCNTL - 2400 309= 311AG 313AG
CMCNTR - 2400 310= 312AG 314AG
CMF - 2000
CMLN - 2200
CMLWAD - 2400 313AG 341
CMLWSS - 2400 311AG 341
CMOF - 1100
CMON - 1100
CMOW - 2700 578= 580
CMRN - 2200
CMRWAD - 2400 314AG 344
CMRWSS - 2400 312AG 344
CMSLW - 2400 341= 354
CMSRW - 2400 344= 358
CNF - 2000
CNFAIL - 2300 179= 205
CNFAIR - 2300 179= 185
CNFOIL - 2300 199= 205

Figure G.6. (Continued)

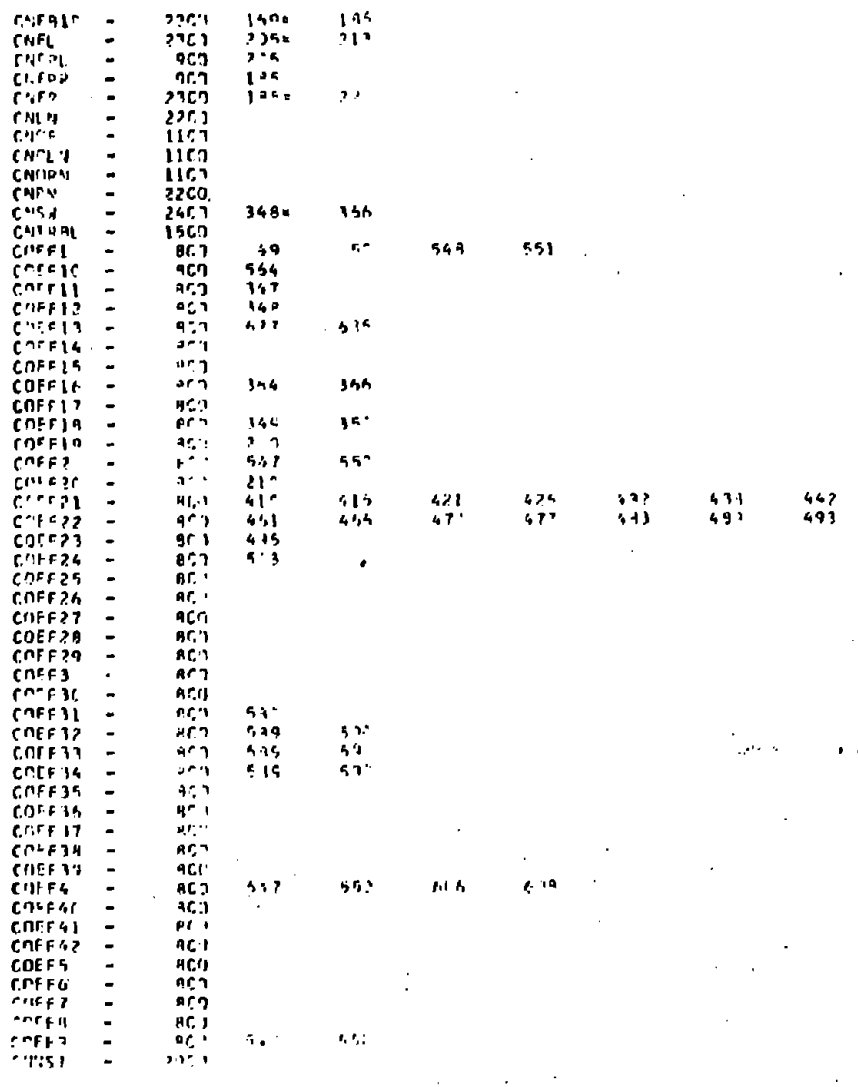


Figure G.6. (Continued)

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)

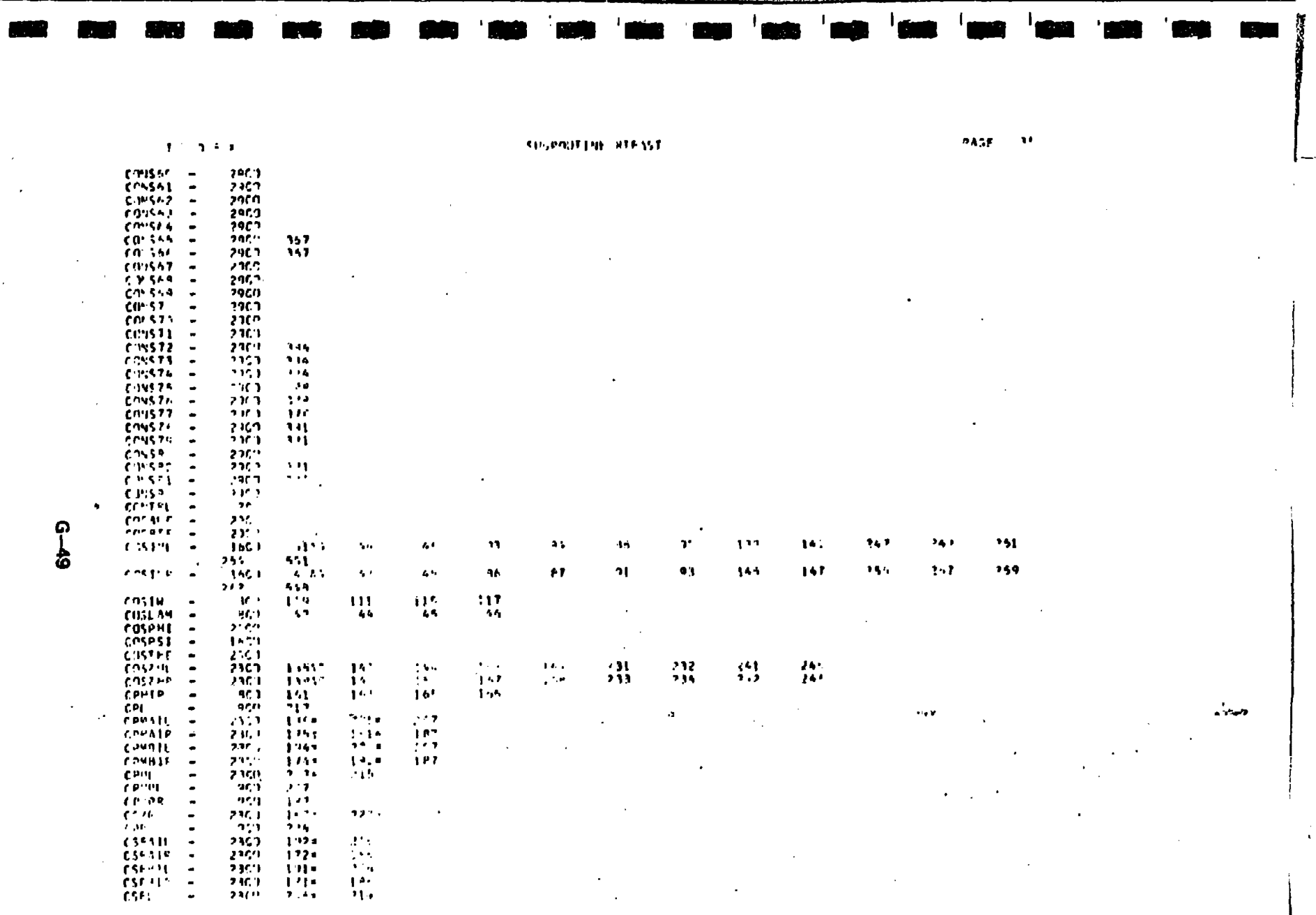


Figure G.6. (Continued)

CSFPL - 900 204
CSFPR - 900 186
CSFR - 2300 186= 221
CTAULR - 2400
CTAURR - 2400
CTL - 2300 189 190 191 192 194 195 196 197 200 201 202 203
211= 212
CTLPRN - 900 211
CTR - 2300 169 170 171 172 174 175 176 177 180 181 182 183
218= 219
CTRPRN - 900 218
CTSLR - 2400 279 337 479
CTSRR - 2400 280 338 581
CVALVT - 1100 454
CVAT - 2600 454= 460 464 470 476 481 487 492
CVF - 2000
CVLN - 2200
CVMAIL - 2300 197= 203= 208
CVMALR - 2300 177= 183= 189
CVMBIL - 2300 196= 202= 209
CVMBIR - 2300 176= 182= 188
CVML - 2300 208= 216
CVMPL - 900 209
CVMPR - 900 188
CVMR - 2300 198= 223
CVRN - 2200
CVVT - 2600 460= 461 465= 471= 476= 477 482= 488= 492= 493 504 505
506
CVVTST - 2600 464= 465 466 470= 471 472 481= 482 483 487= 488 489
C2INL - 1600
C2INR - 1600
• DACFLT - 690*
• DACIO - 12*
DAC1 - 1200 592= 593= 594= 595= 596= 597= 598= 599= 600= 601= 602= 603=
604= 615= 606= 607= 608= 609= 610= 611= 612= 613= 614= 615= 616=
617= 618= 619= 622= 623= 624= 690A0
DAC2 - 1200 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 - 2900 375
DBRK10 - 2900
DBRK11 - 2900
DBRK12 - 2900
DBRK13 - 2900
DBRK14 - 2900
DBRK15 - 2900
DBRK16 - 2900
DBRK17 - 2900 274 295
DBRK18 - 2900 67 76
DBRK19 - 2900 67 78
DBRK2 - 2900
DBRK20 - 2900
DBRK21 - 2900
DBRK3 - 2900
DBRK4 - 2900
DBRK5 - 2900

Figure G.6. (Continued)

DRPKA - 2900
DRPKT - 2900
DRPKR - 2900
DRPKR - 2900 173 193
DCDDF - 2400
DCDLDA - 2400 3154G 317
DCDLG - 1100
DCDLSP - 2400 3154G 317
DCDRDA - 2400 3164G 318
DCDRSP - 2400 3164G 318
DCLDF - 2400
DCLLDA - 2400 3154G 3114G 3134G
DCLLSP - 2400 3154G 3114G 3134G
DCLRDA - 2400 3164G 3124G 3144G
DCLRSP - 2400 3164G 3124G 3144G
DCLSPW - 2400 345* 347
DCMDCL - 1500
DCMDF - 2400
DCMLDA - 2400 3154G 318
DCMLG - 1100
DCMLSP - 2400 3154G 318
DCMRDA - 2400 3164G 319
DCMRSP - 2400 3164G 31
DCMSPW - 2400 346* 347
DCYCLM - 1500
DEGZC - 1100 331 337 339 336
DEL - 1800 514
DELALM - 1500
DELAS - 900
DELBT - 900
DELELV - 900 339
DELEPZ - 374* 376 376 378 390 381 384
DELFLP - 900 47 3151G 478
DELRS - 900
DELRT - 900
DELRUP - 900 45
DELSPL - 900 3151G
DELSPR - 900 3161G
DELSS - 900
DELST - 900
DELTH - 900
DEPZAL - 381* 384* 384
DFLAIL - 900 3 154G 3114G 3134G 374
DFLAIP - 900 3 154G 3124G 3144G 374
DGTORC - 1100 376 378
DIGAM - 600 46416
DIGAM2 - 600
DISABL - 4644
DLALM - 1500
DLFLPC - 1500
DLFPSP - 1600 47*
DLLG - 2200 538
DLLMC - 2200 251 254
DLPLM - 1500
DLRNC - 2200 249 252

G-51

Figure G.6. (Continued)

DLSL4	=	1500				
DMLG	=	2000	524			
DMLNC	=	2200	242			
DMRNC	=	2200	245			
DNF1	=	1000	170	197		
DNF2	=	1000	170	190		
DNF3	=	1000	170	197		
DNF4	=	1000	170	190		
DNLG	=	2000	525			
DNLNC	=	2200	250			
DNRNC	=	2200	258			
DOVF	=	1100				
DOVTL	=	2100	283			
DOVTR	=	2100	284			
DPM1	=	1000	175	181	195	201
DPM2	=	1000	175	195		
DPM3	=	1000	175	195		
DPM4	=	1000	175	195		
DPM5	=	1000	191	201		
DPM6	=	1000	191	201		
DPM7	=	1000	191	201		
DRLM	=	1500				
DSDBFT	=	1100	449	449		
DSF1	=	1000	172	192		
DSF2	=	1000	172	192		
DSF3	=	1000	172	192		
DSF4	=	1000	172	192		
DTIM	=	600				
DUM12	=	900				
DUM13	=	900				
DUM14	=	900				
DUM15	=	900				
DUM43	=	900				
DUM44	=	900				
DUM45	=	900				
DUM46	=	900				
DUM47	=	900				
DUV49	=	900				
DXLG	=	2000	529			
DXLNC	=	2200	247	249		
DXRNC	=	2200	255	257		
DYLG	=	2000	521			
DYLNC	=	2200	248			
DYM1	=	1000	177	183	197	203
DYM2	=	1000	177	197		
DYM3	=	1000	177	197		
DYM4	=	1000	177	197		
DYM5	=	1000	183	203		
DYM6	=	1000	183	203		
DYM7	=	1000	183	203		
DYRNC	=	2200	256			
DZLG	=	2000	522			
DZLNC	=	2200	243			
DZRNC	=	2200	244			
EFFHT	=	1100				

Figure G.6. (Continued)

	EFFVT	-	1150					
	EN4XN1	-	1400					
	EN4XN2	-	1400					
	EN4XP1	-	1400					
	ENEL	-	900					
	ENER	-	900					
	ENF1	-	1300	149	189			
	ENF2	-	1300	149	189			
	ENF3	-	1300	149	189			
	ENF4	-	1300	149	189			
*	ENG	-	90					
*	ENGVAR	-	190					
	EN1VX	-	300					
	EN1STP	-	100					
	EN1TVP	-	300					
	EN2VX	-	30[illegible]					
	EN2REF	-	110					
	EN2STP	-	100					
*	ENMVAR	-	270					
	EPIL1	-	2400	134				
	EPIPL	-	2400	133				
	EPM1	-	1300	174	182	194	2[illegible]	
	EPM2	-	1300	174	194			
	EPM3	-	1300	174	194			
	EPM4	-	1300	174	194			
	EPM5	-	1300	140	230			
	EPM6	-	1300	180	230			
	EPM7	-	1300	180	230			
	EPULR	-	2400	330	335A5			
	EPUPM	-	2100					
	EPUR	-	2400	331	336A6			
	EPTABL	-	2400	378*	388*	391*	394*	395
	EPTL1	-	2400	396*	397	391		
	EPWBL	-	2400	132	347*	368		
	EPWRP	-	2400	132	368*			
	EPZERO	-	2400	376*	378*	396		
	EQNE	-	100					
	ESE1	-	1300	171	191			
	ESE2	-	1300	171	191			
	ESE3	-	1300	171	191			
	ESE4	-	1300	171	191			
	ETA1	-	1500					
	ETA1RF	-	1500					
	ETAR0	-	1500					
	ETAW0	-	1500					
	EVDTMV	-	300					
	EVDTPP	-	300					
	EVM1	-	1300	174	182	194	2[illegible]2	
	EVM2	-	1300	174	194			
	EVM3	-	1300	174	174			
	EVM4	-	1300	174	196			
	EVM5	-	1300	132	202			
	EVM6	-	1300	142	202			
	EVM7	-	1300	182	202			
	EX1	-	1100	276	280			

Figure G.6. (Continued)

FIC - 11C0 229 230 254 242
FINDEG - 11C0 274 295
FINPR - 11C0 274* 295*
FIP - 11C0 227 228 235 238
FIPDHL - 23C0 227* 236 237
FIPDHR - 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 548 641
FIZZW - 11C0
FJXX - 27C0 544
FJYY - 27C0 545
FJZZ - 27C0 546
* FLAGS - 40
FNORHL - 23C0 213* 241 245
FNORHR - 23C0 220* 242 246
FSIDEL - 23C0 214* 241 245
FSIDER - 23C0 221* 242 246
FSMACH - 18C0
THE VARIABLE- FSORT -IS USED BEFORE IT IS DEFINED
FSORT - 6C 53 100 121 124 125 128 131 605
* FUSVAR - 20*
GAATAB - 14C0 724G
GAIALF - 72G6 76 77
GAIBET - 73* 76 77
GBATAB - 14C0 724G
GBETOR - 15C0
GBETP - 14C0
GBETP - 15C0
GBUTOK - 4C7
GBIALF - 72G6 73 78
GDR1 - 15C0
GDR2 - 15C0
GDLTH - 15C0
* GFA* - 5184*
GEF - 2103 171 389 391
* GEFVAP - 21*
GGUST - 15C0
GICLM - 15C0
GINRC - 15C0
GKEY - 13C0 724G

Figure G.6. (Continued)

```
I N D E X                                   SUBROUTINE HTFAST                                   PAGE   41

GLPSLP   -    15C0
GLPP     -    15C0
GLSLM    -    15C0
GNEM     -    13C0    77AG
GOMG     -    15C0
GP       -    15C0
GPHS     -    15C0
GPHI     -    15C0
GPRI     -    15C0
GPSI     -    15C0
GPSIOP   -    15C0
GQ       -    15C0
GR       -    15C0
GPHR     -    15C0
GTH      -    15C0
GTHF     -    15C0
GTHGHV   -    15C0
H        -    3C0
         THE VARIABLE= HACL D  -IS USED BEFORE IT IS DEFINED
HACLID   -    575     576=
         THE VARIABLE= HACL D  -IS USED BEFORE IT IS DEFINED
HACRID   -    577     578=
HOUT     -    3C0
HOTAGL   -    25C0    1 8     561=    575=
HOTAGF   -    25C0    115     559=    172=
HOTRIM   -    25C0    611
HSEPLR   -    21C0
HSEFRP   -    21C0
HLMJR    -    21C0
HOLD     -    6C0
HOLD2    -    6C0
HP       -    11C0
HRHJR    -    21C0
HSO      -    16C0
HTC4     -    21C0
HTRIM    -    28C0
HTSTLOW  -    [illegible]    611
HTU      -    21C0
H[illegible]L   -    25C0    116     117     561=    574=    575     576
HUACR    -    25C0    117     117     554=    571=    572     573
HWC4     -    21C0
• HYBCUN -    6P
• HYRID  -    7=
HIOTL    -    25C0    46      557=    560=
HIOTR    -    25C0    47      555=    556=
HIL      -    25C0    82      83      554=    559=    540     57
         THE VARIABLE= HILOLD  -IS USED BEFORE IT IS DEFINED
HILOLD   -    549     572=
HIP      -    25C0    45      46      554=    555=    566     567
         THE VARIABLE= HIRPLD  -IS USED BEFORE IT IS DEFINED
HIROLD   -    566     557=
IAP      -    5C0
IC       -    6C0
ICNSPC   -    2C0
ICLP     -    5C0
```

Figure G.6. (Continued)

ICONOP - 4C0
IC2 - 6C0
IDURC - 6C0
IFC - 6C7
IFCHAN - 6C0
IFLAG - 2C0
IFRAME - 6C7
IGN - 6C0
IHJB - 6C0
ILEX - 6C0
INITVP - 16*
INC - 4C0
INC21 - 4C0
IPAN - 2C0 664*
IPHASE - 4C0
IPSNDS - 4C0 37A0 6598G
IPCTS - 4C0
IRCR - 6C0
IRUNIT - 4C0
ISCOPE - 2C0
ISENCE - 4C7
ISETC - 6C0
ISHRC - 6C0
ISLOW - 4C0
ISTA - 4C0
ISTAD - 4C7 16
ISTAD2 - 4C0
ISTB - 4C0
ISTDA - 6C7 656
ISTDA2 - 6C7
ISTFLT - 6598G 653
ISTG - 72A0
ISTGD - 6C0
ISTGD2 - 6C0
ISTHD - 6C0
ISTHD2 - 6C0
ISTIC - 6C0
ISTIC2 - 6C7
ISTPIT - 6C0
ISTR4 - 6C0
ISTR42 - 6C0
ISYNC - 6C0
ITRIM - 4C0
ITSC - 6C7
IWARN1 - 4C0 9L6 327* 328* 329* 330* 331* 332* 333* 334* 406* 427* 457* 478* 642* 653*
IWARN2 - 4C0 9L6
IWREVT - 4C0
J - 66307 66410
JTRIM - 4C0
KAR - 7C0 -.37A0 6598G
KONER - 2C0 640*
KPAN - 14* 651* 659* 665
KTRIM - 4C0
LFIR - 6C0

Figure G.6. (Continued)

• EINT - 72*
MIEMT - 200
MIECR - 200
MONDIG - 400
• NACVAR - 22*
NADCS - 601
NCHAIN - 601
NCLOSE - 64* 599 273 373 476
NCOV - 600
NCONSL - 600
NDACS - 603
NERAME - 201
NGFF - 401
NIDS - 600
NOSIM - 200
NPCS - 601
NPLOT - 401
NPLOT2 - 401
NSIMID - 300
NTMST - 599 644
NVR - 401 599
PHOTIP - 3[illegible]
PLTM - 3[illegible]
PLTMID - 3[illegible]
NZERO - 3[illegible]
RMA - 1503
RMDT - 823 225 226
RMDTL - 1203 235* 235
RMDTS - 1203 236* 239
RMEGA - 1203 161 162
RMEGAL - 1203 151* 153 155 227
RMEGAS - 1203 152* 154 156 228
RMEGEL - 1203 230 264
RMEGES - 1203 231 262
RMGS - 1503
RMIRF - 1503
RMLM - 1503
RMSD - 1503
RMSFF - 1503
RMSLP - 1503
RMSOL - 1503 143* 212 213 214 215 216 217
RMSS - 1503 144* 212 [illegible] 221 222 223 224
RMSA - 1503
RMVTC - 1503
RMVDSP - 803 271 272 273
RMVESN - 1403 571 [illegible] 591 594
RMVIXP - 2303 593 594 596 598 [illegible]
RMVIYY - 2303 615 616 [illegible] 642
RMVIZZ - 2303 617 614 [illegible] 613
RPSMA - 403
RPSMA2 - 403
RVFFIP - 303 644 [illegible] [illegible] [illegible]
RVSOTH - 1403
RVTIDL - 1403

Figure G.6. (Continued)

P - 2700 54* 80 83 94 96 97 107 108 113 114 129 139
141 145 147 539 541 542
PC - 1100
PCTOL - 1800
PCTOR - 1900 449
PGUST - 900 64
PHI - 900
PHIPH - 1100
PI - 1100 396 397 438 439 416 435 439 441 446 447 459 460
467 486 490 497
PILMSK - 200
PIOV2 - 1100 417 414 416 420 427 429 431 433 437 439 463 465
467 471 473 480 482 484 488 490
PNLN - 2300 139* 142
PNLR - 2300 142* 151 615
PNRN - 2300 145* 148
PNRR - 2300 148* 152 617
PP - 2700 542* 545 547 549 550 551
PPRIME - 900 3180 54
PQ - 2700 539* 544 546 549 552
PR - 2700 541* 545 547 550
PROJ - 600
PST - 900
Q - 2700 55* 79 81 82 94 85 97 106 108 112 114 126
127 128 130 143 145 254 262 538 539 543
QFSW - 2200
QGUST - 900 65
QNLN - 2300 140* 143 144 217
QNLR - 2300 143* 646
QNRN - 2300 146* 149 150 240
QNRR - 2300 149* 644
QPRIME - 900 55
R - 2700 56* 80 82 83 85 86 106 107 112 113 129 139
141 145 147 229 230 538 540 541 543
ROTOOG - 1100 74 75
RESLR - 2400
RESRR - 2400
* RETURN - 662* 6660
RGUST - 900 66
RLH - 1500
RNLN - 2300 141* 143 144 216
RNLR - 2300 144* 648
RNRN - 2300 147* 149 152 239
RNRR - 2300 150* 647
ROF - 1800 209 210 805
ROFOV2 - 1900 64 271 272
ROIED - 300 695
ROPIR4 - 2300 2.0* 212 213 214 219 221 221
ROPIR5 - 2300 210* 215 216 217 222 223 224 641
ROTFPS - 1100 134 135
ROTRAD - 1100 155 156
* ROTVAR - 239
RPRIME - 900 56
RQ - 2700 538* 543* 544 546 549 552
RR - 2700 540* 545 547 548 550 551

Figure G.6. (Continued)

RR11 - 2100
RR12 - 2100
* RTFAST - 1*
* RTPASS - 80
SALIHT - 2400 398AG 497 499 51A
SALIN - 2200
SALLW - 2400 313* 351 352
SALRN - 2200
SALRW - 2400 321* 355 356
SAVINW - 2400
SAVZET - 2400
SBETLN - 2200
SBETLW - 2400 323* 353
SBETRN - 2200
SBETRW - 2400 325* 357
SBETSG - 2600 449AG 49B 5?4 535 55A
SDECAF - 2200
SDFRN - 1100
SBESAF - 2?00
SBWPR - 110?
SCI - 2101
SCADC1 - 900 3?1?
SCADC2 - 90?
SCADC3 - 90?
SCADC4 - 90?
SCDAC1 - 90? 45046
SCDAC2 - 90?
SCDAC3 - 90?
SCDAC4 - 90?
SC1 - 1503 578
SC2 - 1500 47R
SEPLW - 2400 33546 339 343
SEPRW - 2400 33A4G 342 343
SFHEL - 2?0?
SFHER - 2?0?
SFPL - 2?0?
SFPWL - 2?00
SFPWR - 2?0?
SFPW - 2?00
SFOL - 2?0?
SFOR - 2?0?
SFSEL - 2?0?
SFSER - 2?0?
SFTI - 2?0?
SFTR - 2?0?
SFVHL - 2?0?
SFVHR - 2?0?
SG - 110?
SGNSIF - 42?* 421* 422
SGNJLW - 2?0? 27?* 27A* 279
SGNJOW - 2?0? 27?* 27B* 2A?
SHI - 1100
SHPLW - 1502
SHPRTL - 13??
SHPRTR - 1?0? 547

Figure G.6. (Continued)

SHPRQL - 23C0
SHPRQP - 23C0
SHPSTP - 3C0
SHW - 11C0
SHW2 - 15C0
SHW3 - 15C0
SIGMA - 26C0 448= 449AG
SIL - 24C0
SILAML - 16C0 46= 49 550 551 552 618 637
SILAMR - 16C0 45= 49 547 548 549 616 629
SILW - 24C0 297 337 339 340 341 345 346
SINALF - 23C0
SINRTF - 20C0
SINCOS - 40* 41* 135* 138* 335* 336* 398* 449* 139 141 247 249 251
SININL - 16C0 41AG 44 46 92 83 88 90
254 551
SININR - 16C0 42AG 43 45 95 86 91 93 145 147 255 257 259
262 548
SININ - 8C0 109 111 115 117
SINLAM - 8C0 43 44 45 46
SINPHI - 20C0
SINPSI - 16C0
SINTHE - 20C0
SINZHL - 21C0 135AG 143 144 163 164 231 232 241 245
SINZHR - 23C0 138AG 149 151 167 168 233 234 242 246
SIR - 24C0
SIRW - 24C0 287 338 342 343 344 345 346
SIT - 24C0
SKDA - 15C0
SKDCOL - 15C0
SKOLB - 15C0
SKOLE - 15C0
SKOLR - 15C0
SKOLRD - 15C0
SKOLS - 15C0
SKEPS - 11C0
SKTHTH - 15C0
SKTRIM - 29C0
SKW1 - 15C0 565 568
SKW10 - 15C0 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 - 15C0 565 568
SKW5 - 15C0 565 568
SKW6 - 15C0 571 574
SKW7 - 15C0 571 574
SKW8 - 15C0 571 574
SKW9 - 15C0 571 574
SK0 - 11C0
SK1 - 11C0
SK10 - 11C0
SK2 - 11C0
SK20 - 11C0 347

Figure G.6. (Continued)

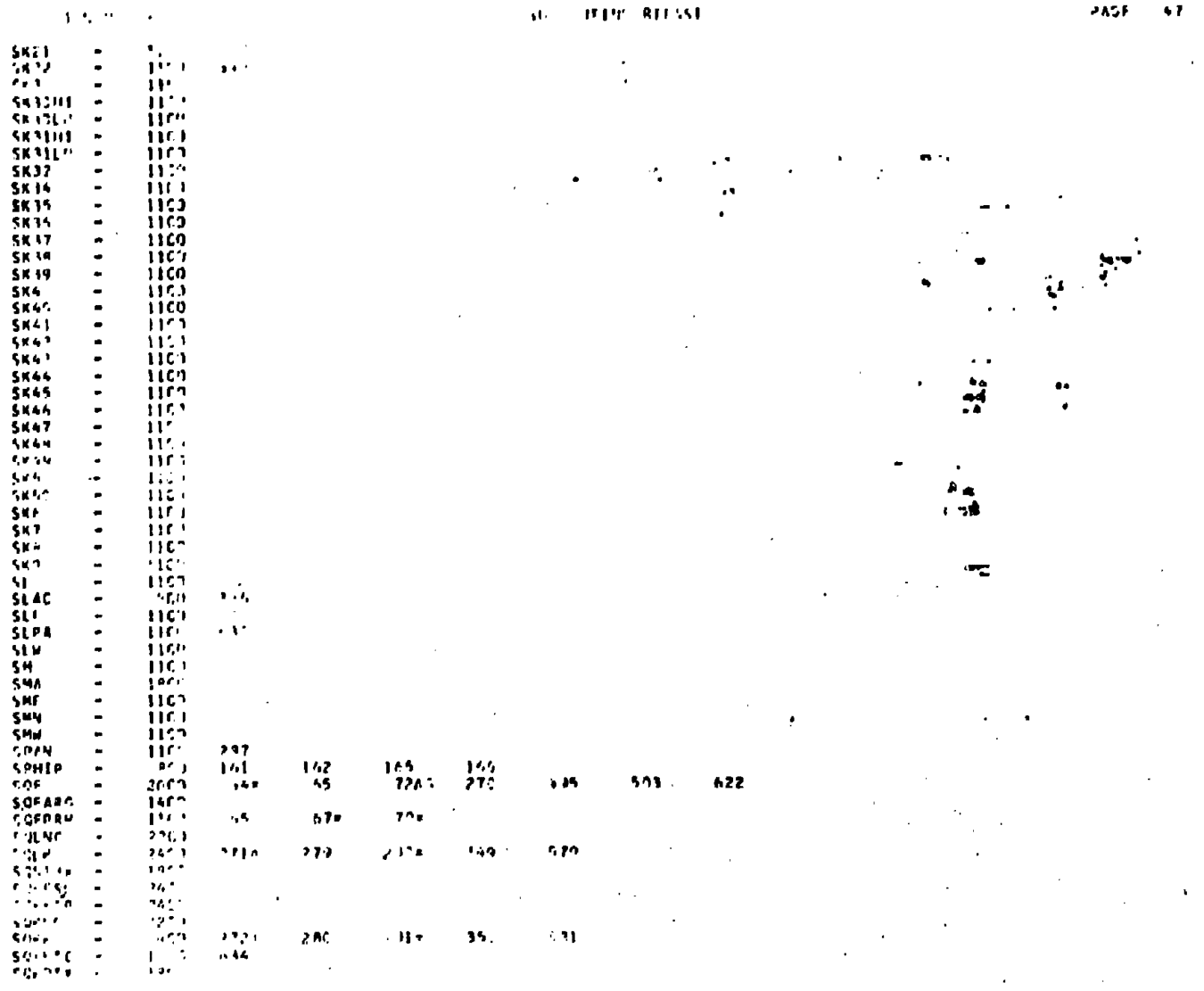


Figure G.6. (Continued)

SSSING - 2400 [illegible] 2489* 3A4 346
SSSINL - 1600
SSSINR - 1400
STAILR - 2400
STAIRR - 2400
SUMIXX - 800
SUMIXZ - 800
SUMIYY - 800
SUMIZZ - 800
SVSTAB - 1400
SVSTAR - 2400
SVSTRL - 2400
SWLG - 400 517
SWLG2 - 900
S2INL - 1600
S2INR - 1600
TAILVP - 240*
TAUAG - 1400
TAUHGT - 1500
TAUCYR - 1500
TAUDB - 1500
TAUDR - 1500
TAUEE - 1500
TAUGIC - 1500
TAUGLS - 1500
TAUGST - 1500
TAUHT - 1100 318
TAUL - 800
TAULR - 2400
TAUP - 1500
TAUPDS - 1500
TAUPHI - 1500
TAUPR - 1500
TAUPRI - 1500
TAUPSI - 1500
TAUQ1 - 1500
TAUQ2 - 1500
TAURQ1 - 1500
TAURQ2 - 1500
TAURR - 2400
TAURT1 - 1100
TAURT2 - 1100
TAUR1 - 1500
TAUR2 - 1500
TAUR3 - 1500
TAUSHP - 1500
TAUTH - 1500
TAUTHE - 1500
TAUVT - 1100 490
TAVAEP - 2400
TCOLF - 300
TDEGF - 1800
TEAL - 1800
TEAR - 1800
TEMPI - 2700 [illegible] 533

Figure G.6. (Continued)

TERM01 - 2700 545* 595
TERM01 - 2700 545* 597
TERM1 - 2700
TERM1L - 2700 595* 597
TERM1R - 2700 547* 583
TERM2 - 2700
TERM2L - 2700 551* 582
TERM2R - 2700 568* 583
TERM3 - 2700
TERM3L - 2700 552* 582
TERM3R - 2700 549* 583
TERM4 - 2700
TERM5 - 2700
TERM6 - 2700
THCDEL - 1900
THS - 100
THETC - 1300
THFMEM - 1900
THMMIP - 1900
THPTEM - 1900
THTLAC - 2900 [illegible]
THTR2C - 2900 [illegible]
THTRIC - 2900 61*
TH75L - 3500
TH75LC - 1900
TH7SR - 1900
TIGFI - 2100 211
TIGFR - 2100 213
TI - 2100 213* 247 247 271 281 285
TMHR1C - 244* 244
TMHR11 - 582* 595 639
TMHR12 - 583* 596 636
TMHR1C - 2500
TMHR11 - 2500
TMAC1 - 2200
TMAC2 - 2200
TMMDIM - 1900
TOP3L - 2300 [illegible]
TOR09 - 2300 [illegible]
TR59 - 400
TR - 2900 210* 245 247 271 272 286 296
* TRACE - 33* 661*
TRIM - 600
TRIM2 - 600
TRMAR1 - 2300 243* 247 254 252
TRMAR2 - 2300 244* 245 257 [illegible]
TRMAR3 - 2300 [illegible] 251 [illegible]
TRMAR4 - 2300 250* 250 253
* TRMCOM - 200
TRMHR1 - 2300 230* 253 [illegible]
TRMHR2 - 2300 [illegible] 241 549
TRMH33 - 231* 234
TRMH44 - 232* 237
TRMH45 - 233* 239

Figure G.6. (Continued)

TRNHR6 - 234* 240
TRNHBT - 241* 243
TRNHR8 - 242* 244
TRNHR9 - 245* 244
TRNHT - 26C0 495* 496* 497 498 499
TRNHT2 - 26C0 414* 408 413 414 416
TRNHT3 - 26C0 425* 435 436 437 439
TRNHIS - 564* 565 568 571 574
TRNIL1 - 579* 590
TRNTR1 - 581* 589
TRNTTI - 27C0
TRNTTP - 27C0
TRNTTW - 580* 589 590
TRNVT - 24C0 503* 504 505 506
TRNVT2 - 24C0 445* 459 464 465 467
TRNVT3 - 24C0 456* 486 487 488 490
TRNWG1 - 24C0
TRNWG4 - 25C0
TRNWG5 - 24C0 337* 339 341 341
TRNWG6 - 24C0 339* 342 343 344
TRNWGT - 24C0 349* 351 352 353 354
TRNWGA - 24C0 350* 355 356 357 358
TRNWG9 - 25C0
TSRASE - 6C0
TSREOD - 6C0
* TSTRTF - 39*
TTMSLN - 15C0
TTMSLP - 15C0
TZERO - 3C0
TZET1 - 24C0
TZET2 - 24C0
TZET3 - 24C0
TZET4 - 24C0
TZET5 - 24C0
TZET6 - 24C0
U - 27C0 51* 57 61 79 386 605 621
UGUST - 9C0 51
UHT - 19C0 126* 395
ULN - 19C0 119* 120 276 298
ULNPR - 19C0 106* 109 111
ULNSQ - 19C0 120* 121 271
UP - 19C0 79* 82 85 105 112 126 128
UPRIME - 9C0 51 394 496
URL - 19C0 88* 94 132 133
URLPR - 19C0 82* 88 90
URLURL - 19C0 94* 101
UPR - 19C0 91* 97 103 136
URPPR - 19C0 85* 91 93
UPRURR - 19C0 97* 100
URW - 19C0 115* 122 278 299
URWPR - 19C0 112* 115 117
URWSQ - 19C0 122* 125 272
* USEATO - 349 6598
USQ - 19C0 57* 60 63 64
UTRIM - 28C0 630

Figure G.6. (Continued)

UVT - 1900 128* 131
V - 2700 52* 59 62 63
VALFLM - 1900 121* 237
VALFRM - 1900 125* 239
VALFS - 1900 60* 62
VALNCL - 1900
VALNCO - 1900
VBETVT - 1900 131* 444
VEAST - 1700 623
* VELVAP - 194*
VGUST - 900 52
VLM - 1900 110* 118 207
VLMPO - 1900 107* 110
VLMSQ - 1900 119* 271
VNORTH - 1700 619
VP - 1900 93* 83 84 107 111 129
VPRIME - 900 52
VRL - 1900 48* 95 134
VRLPR - 1900 43* 89
VRLVRL - 1900 95* 101 104
VRV - 1900 93* 93 137
VRVPO - 1900 44* 92
VRVVRC - 1900 98* 100 105
VRW - 1900 114* 127 201
VRWPO - 1900 111* 114
VRWSQ - 1900 121* 272
VSQ - 1900 54* 63 64
VSTAR - 2400
VSTARG - 1400
VSTARL - 2400
VTIPL - 1900 155* 157
VTIPP - 1900 154* 159
VTOTAL - 1900 53*
VTOTLR - 1900 111* 157 627
VTCTOR - 1900 107* 148 611
VTPLW - 2800 452
VTSTLL - 400 452 453
VVT - 1900 130* 444
VZFTL - 1900 104* 133
VZFTR - 1900 105* 136
W - 2700 53* 60 61 111
WDOT - 900 114
WGUST - 900 53
WHT - 1900 127* 135
WLM - 1900 111* 119 204
WLMPR - 1900 1 9* 120 111
WLMSQ - 1900 119* 121 271
* WNGVAP - 24*
* WNGV92 - 25*

THE VARIABLE- WORK -IS USED BEFORE IT IS DEFINED

WORK - 60 59 100 101 104 105 121 125 131 625
WP - 1900 91* 84 87 108 114 127 138
WPRIME - 900 53
WRL - 1900 97* 96 111
WRLPR - 1900 94* 98 99

Figure G.6. (Continued)

WRLWRL - 1900 94* 121
WRNTL - 1900 112* 104 134
WRNTR - 1900* 115 137
WPR - 1900 93* 99 103
WRRPR - 1900 87* 91 93
WRRWPR - 1900 99* 100
WRW - 1900 117* 124 298
WRWPR - 1900 114* 115 117
WPWSQ - 1900 124* 125 272
WSQ - 1900 59* 60 63 64
WVT - 1900 130* 131
XAERF - 2000 522* 526
XAERLW - 2400 279* 352* 356 361
XAERNC - 2300 263* 526 535
XAERNL - 2300 247* 263 537
XAERNR - 2300 255* 263 537
XAERO - 2700 526* 548 551 599
XAERRW - 2400 290* 356* 359 341
XAERT - 2600 513* 526
XAERWG - 2400 361* 365 526
* XAIO - 9*
XAREP - 2000 520
XARHT - 2600 497* 501 513
XARVT - 2600 514* 518 519
XCG - 1700 80 81 365 521 532 508 539 534 537 630
* XCNTRL - 15*
XDTCG - 1700 49* 79
XF - 2700
XFAC - 1100
XFCON - 800
XFMFLF - 2700
* XFUNC - 14*
XHT - 1100 127 521 522
XL - 2700
XLCOS - 2700 618
* XLINTP - 13*
XLSIN - 2700
* XMAP - 10*
* XPAR1 - 11*
* XPAR3 - 29*
XR - 2700
XRCOS - 2700 618
XRLCON - 900
XRSIN - 2700
XVT - 1100 129 130 528 539
XW - 2700
XWAC - 1100 127 108 113 114 354 358
XWCON - ACO
XWC2 - 1100 285 286
XWWLW - 2700
XXICON - 800
XXJCON - ACO
XYICON - ACO
YAERF - 2700 521* 527
YAERLW - 2400 281* 353* 362

Figure G.6. (Continued)

YAERNC	-	2300	244*	527	537	547					
YAERNL	-	2300	248*	245	264						
YAERNP	-	2300	256*	258	266						
YAERO	-	2700	527*	531							
YAERRW	-	2400	342*	347*	362						
YAERT	-	2600	511*	527							
YAERWG	-	2400	342*	527							
YAPEP	-	2700	521								
YAPHT	-	2600	498*	503	532	511					
YARVT	-	2600	526*	507	509	511					
YN	-	1100	82	86	85	87	531	537			
YPA	-	1100									
YWAC	-	1100	106	108	112	114					
YYICON	-	800									
YYJCON	-	800									
ZAERC	-	2300	522*	529							
ZAERLW	-	2400	248*	286	287	351*	356	364	566	574	
ZAERNC	-	2300	265*	528	534						
ZAERNL	-	2300	248*	268	531	548	575				
ZAERNR	-	2300	257*	245	571	565	571				
ZAERO	-	2700	531*	543	551	564					
ZAERRW	-	2400	344*	236	287	356*	365	363	565	571	
ZAERT	-	2600	512*	526							
ZAERWG	-	2400	343*	365	534						
ZAPEP	-	2700	522								
ZAPHT	-	2600	499*	531	512						
ZAPRG	-	8200	533	535							
ZARVT	-	2600	514*	528	513						
ZCG	-	1700	79	81	365	533	541	537	538	532	535
ZDTCG	-	1700	91*	91							
ZETHL	-	2300	134*	13586							
ZETHR	-	2300	137*	13403							
ZETR1	-	2400									
ZETR2	-	2400									
ZETR3	-	2400									
ZETR4	-	2400									
ZF	-	2700									
ZFAC	-	1100									
ZFCON	-	800									
ZFHFHF	-	2700									
ZHT	-	1100	126	504	531						
ZL	-	2700									
ZLCOS	-	2700									
ZLSIN	-	2700	538								
ZPA	-	1100									
ZR	-	2700									
ZRCOS	-	2700									
ZRLCON	-	800									
ZRSIN	-	2700	536								
ZVT	-	1100	128	129	537	538					
ZW	-	2700									
ZWAC	-	1100	116	117	112	113	356	358			
ZWCON	-	800									
ZWHHW	-	2700									

Figure G.6. (Continued)

ZZICON - 8CO
ZZJCON - 8CO

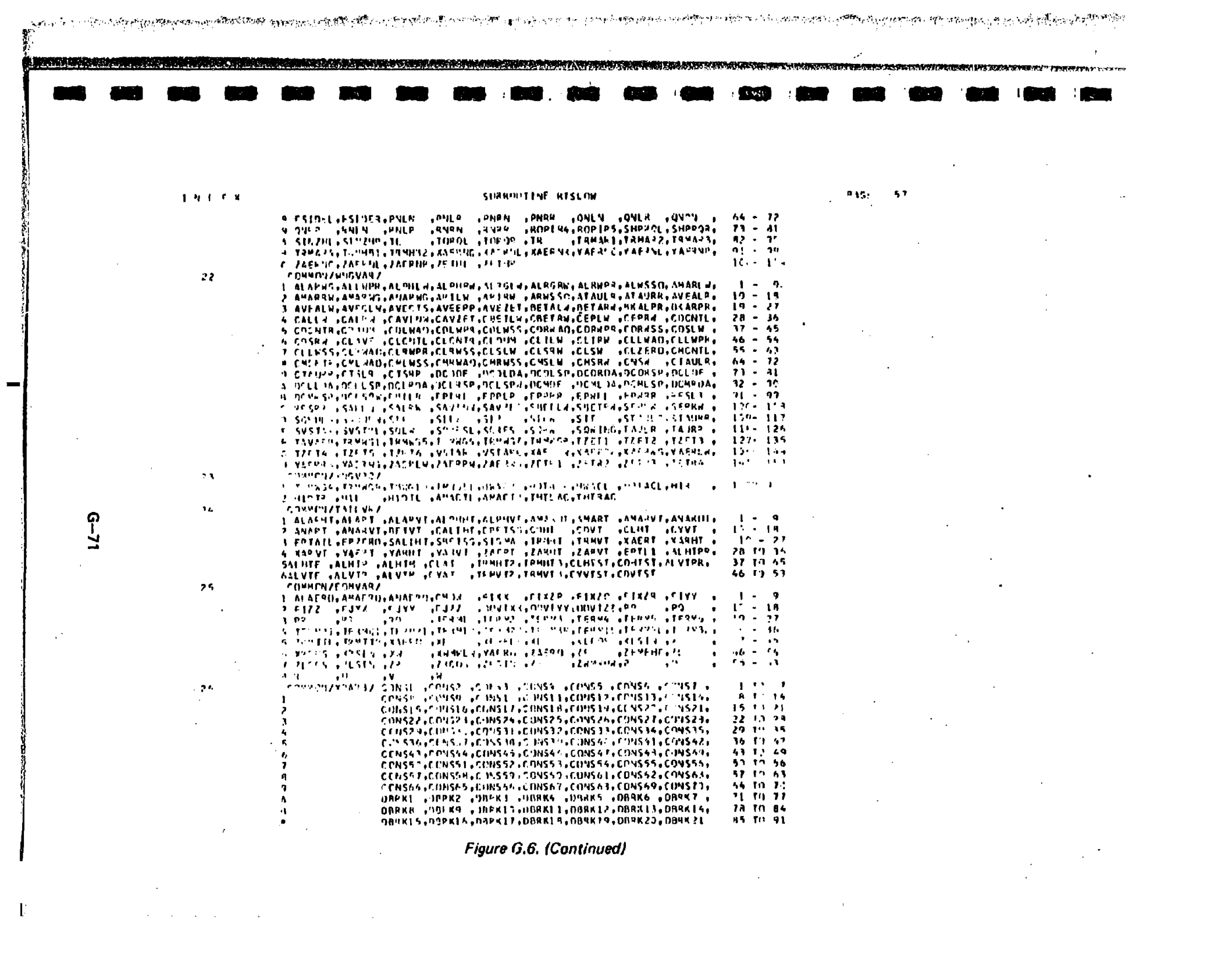
Figure G.6. (Continued)

```
      1          SUBROUTINE RTSLOW
      2          COMMON/CONTRL/ ISCOM,IFLAG(10),ICDSPC(4,4),NIECOM(2),NIGNT(2),
     *                NOSIM ,IPAN      ,PELMSK      ,NFRAME(2),KONFN(2)
      3          COMMON/DVRCOM/PROJ  ,NCINSL,N2CS(2),NCHAIN(2),IFRAME(2),NADCS(2),
     *               NDNOS(4),NDACS(4),IRCV(4),IEC(4),NCON(4) ,LETR(4) ,
     *               IC(10)  ,ISTIC   ,IOLD(10),ISTHO,OPERA(10),
     *               ISTIC   ,DIGAN(10),ISTDA  ,ANDIG(10),ISTAD,
     *               IC2(10) ,ISTIC2  ,IOLD2(10),ISTHO2 ,OPERA2(10),
     *               ISTIC2  ,DIGAN2(10),ISTDA2  ,ANDIG2(10),ISTAD2, IGN,
     *               ISTPIT  ,IQUNIT,IAD,IDC,IDC21,ICLP,ITSC,ILEX,ISETC ,
     *               MONDIG  ,IOURC(4)  ,ISHRC(4) ,ISYNC(4) , NIOS  ,
     *               IHJR    ,IECHAN    ,TSOASF(2),TSREQD(2), IRCTS(4),
     *                TSOL(4) ,IPSNOS(13),7),OTEM(2) ,TPIM(10) ,ISTRM ,
     *                TRIM2(10),ISTRM2
      4          COMMON/HYDIO/ KAR(256)
      5          COMMON/ENG/  NREFID,NUIND ,NETHID,N2IND ,NOIND ,NRNDED ,
     *               ENGTMX,ENEMX ,FUELMX,ENDMX ,EDMX  ,SHPSTR
     *               ERRTPS,ESLIST,RJET  ,IZERO ,ICOEF
      6          COMMON/ELASS/ IAASS(10),IWASS(10),ISENCE(2),IOREVT(2),ICOMP,
     1  ITRIM,JTRIM,KTRIM,NPLOT,NPLOT2,IPHASE,ISLOW,SPLG,CRUISE,
     2  ISTE,ISTP,NGCE,NVP,NTWIT
      7          LOGICAL*1  IWARE1,IWARN2
      8          COMMON/ATTSS/ ATSIN ,ATSEC ,SINCAM,COSCAM,SUMIXK,SUMIXZ,SUMIYY,
     *               SUMIZZ,SUMIXZ,XPICON,XWCON ,XRICON,XSICON,XPICON,
     *               YYICON,YYJCON,YCGCON,ZRICON,ZWCON ,ZZICON,ZZJCON,
     *               SLAC  ,ATSTEL,ZTSTEL,DONTSK,AWAING,CPHIC ,SPHIC ,
     *               EVOTIM,
     *               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/KALM/ SCADC1(32),SCADC2(32),SCADC3(32),SCADC4(32),
     *               SCADC5(32),SCADC6(32),SCADC7(32),SCADC8(32),
     1         PPRIME,QPRIME,RPRIME,UPRIME,VPRIME,WPRIME,THE    ,PHI    ,  40  41
     *         PSI    ,HDOT   ,H      ,DUM12 ,DUM13 ,DUM14 ,DUM15 ,HDIF   ,
     *         DELSIE,DELAIR,DELSPD,DELSPL,GILPRM,GNFPL ,GSFPL ,GPMPL ,
     *         GYMPL ,GPL    ,LTZPRM,GNFP4 ,GSFP4 ,GPMPP ,GYMPA ,GPP    ,
     *         AINDTP,AINDP  ,AINDTL,AINDL ,AICLPR,AICLP4,AICRPP,AICRPP,
     2         DELHDP,AINDSF,DUM43 ,DUM44 ,DUM45 ,DUM46 ,DUM47 ,DUM48 ,  48  49
     *         SNLST ,ESLOST ,VDUST ,HDIST ,PGUST ,QGUST ,RGUST ,UAUST ,  50  51
     *         DHDT  ,PPSP   ,AMICRP,AMACLP,ENFL  ,ENFA  ,DELELV,DELELP
     *       , DELAT ,DELST ,DELPT ,DELTH ,DELPS ,DELSS ,DELRS ,THTSP ,
     *         THTSL ,ADCS(32)
     11          COMMON/XAXIS/ AIRUT ,AINT  ,ALAMDA,ALHTST,ALVTST,AREAMI,AREAM ,   1  TO   7
     *APEAVT,AXHF  ,AXVF  ,AXVEAS,AXVEYG,CLS   ,CDDF  ,CDDHF ,CDDVT ,   8  TO  16
     *CHORD ,CLALUT,CLSLOW,CMDF  ,CMDN  ,CSDF  ,CNDLN ,CNDPN ,CYALVT,  17  TO  25
     *DDOLG ,DDMLG ,DIDDM ,DDVT  ,DSDACT,EFFMF ,EFFVT ,EIF   ,EINDRS,  26  TO  34
     *EJP   ,EJXXF ,EJXAPP,EJXXM ,EJXZF ,EJXZPP,EJXTM ,EJYYF ,EJYYPP,  35  TO  43
     *EJYYM ,EJZZF ,EJZZPP,EJZZM ,HP    ,QMPFF ,PC    ,PI    ,POTRAD,  44  TO  52
     *SHEPP ,SHPPP ,SC    ,SHF   ,SHM   ,SK0   ,SK1   ,SK2   ,SK3   ,  53  TO  61
     *SK4   ,SK5   ,SK6   ,SK7   ,SK8   ,SK9   ,SK10  ,SK20  ,SK21  ,  62  TO  70
     *SK22  ,SK30  ,SK31  ,SK32  ,SK33  ,SK34  ,SK35  ,SK36  ,SK37  ,  71  TO  79
     *SK38  ,SK39  ,SK40  ,SK41  ,SK42  ,SK43  ,SK44  ,SK45  ,      ,  80  TO  86
```

Figure G.6. (Continued)

```
     *SK44  ,SK47  ,SK48  ,SK49  ,SK5   ,SL    ,SLF   ,SLPA  ,SLW   ,    89 TO 97
     *SM    ,SMF   ,SMN   ,SMW   ,SPAN  ,TAUHT ,TAUVT ,XFAC  ,XMT   ,    98 TO106
     *XWAC  ,XVT   ,YN    ,YPA   ,YWAC  ,ZFAC  ,ZHT   ,ZPA   ,ZWAC  ,
     *ZVT   ,CLOAL ,PHIPH ,SK33HI,EN2REF,XWC2  ,BT1   ,BT2   ,BT3   ,
     *BKDIT ,BKD2T ,BK23T ,BK41T ,BKM2T ,BKM3T ,BKM4T ,SK33HI,
     *FEU   ,CLMAX ,ALARK ,BKLSW ,BKNSW ,SQFPRM,DEG20 ,DGTORD,HTVTKT,   133TO141
     *PIOV2 ,RDTODG,RDTFPS,SKFPS ,ALNCBK,TAURT1,TAURT2
11   COMMON/SPIN/ RCBI(19),ISTRBI,TADC3(32)
12   COMMON/XLINIP/ AKEY(16),AMEM(2),BKEY(16),BMEM(2),GKEY(10),GMEM
13   COMMON/XFUNC / VSTARG(33), TAUAS(9),SVSTAB(13,9),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,EMXMDT,EN2STR,FSMACH,OMEGEL,    1 -  9
     2 OMEGER,ONOVTC,ONOVFS,OVSQTH,OVTHDL,ROE   ,ROEOV2,SHPPRL,SHPPRR,   10 - 18
     3 SMA   ,SQNIMX,SQTHTC,SQWDTX,TDEGF ,TEAL  ,TEAR  ,THCDEL,THETC    19 - 27
     4,PCTDL,PCTOR                                                      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 URLWL ,URP   ,URPPR ,URRURR,URW   ,URWPR ,URWSQ ,USQ   ,UVT   ,   19 - 27
     4 VALFLW,VALFRW,VALFS ,VALNDL,VALNDR,VBETVT,VLW   ,VLWPR ,VLWSQ ,   28 - 36
     5 VP    ,VRL   ,VRLPR ,VRLVRL,VPR   ,VRRPR ,VRRVRR,VRW   ,VRWPR ,   37 - 45
     6 VRWSQ ,VSQ   ,VTIPL ,VTIPR ,VTOTAL,VTOTLR,VTOTPR,VVT   ,VZETL ,   46 - 54
     7 WJETR ,WHT   ,WLW   ,WLWPR ,WLWSQ ,WP    ,WRL   ,WRLPR ,WRLWRL,   55 - 63
     9 WRW   ,WRWPR ,WRWSQ ,WPR   ,WRRPR ,WRRWRR,WSQ   ,WVT             64 - 71
18   COMMON/FUSVAR/
     1 ALARF ,ALARFP,ALFSQ ,ALPHF ,AMAPF ,AMARFP,ANARF ,ANARFP,BETAF ,    1 -  9
     2 BETFSQ,CBCHF ,COF   ,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 ,XARFP ,YAERF ,YARFP ,ZAERF ,ZARFP    28 - 36
     *   ,SINTHF,COSTHF,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  ,PP11  ,PP12  ,SB1   ,TTGEL ,TTGER                         19 - 24
20   COMMON/NACVAR/
     1 ALLNSQ,ALPHLN,ALPHRN,ALPNSQ,BETALN,BETARN,BTLNSQ,BTRNSQ,CALLV ,    1 -  9
     2 CALPV ,CBETLN,CBETRN,CDLN  ,CDSLN ,CDSRN ,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 SALL2 ,SALRN ,SBETLN,SBETRN,SQLNC ,SQRNC ,TNAC1 ,TNAC2           36 - 44
21   COMMON/ROTVAR/
     1 AICL  ,AICLOP,AICR  ,AICROP,ALARNC,ALLRH ,ALARNL,ALARNR,ALRRH ,    1 -  9
     2 ALPHLN,ALPHRN,ANARNC,ANARNL,ANARNR,ANLRH ,ANRNLP,ANRNRP,ANROTL,   10 - 18
     3 ANROTR,ANRRH ,ANARNC,ANARNL,ANARNR,ANLRH ,ANROTL,ANROTR,ANRRH ,   19 - 27
     4 BICL  ,BICLOP,BICR  ,BICROP,CNFAIL,CNFAIR,CNFBIL,CNFBIR,CNFL  ,   28 - 36
     5 CNFR  ,COSZHL,COSZHR,CPNAIL,CPNAIR,CPNBIL,CPNRIR,CPNL  ,CPNR  ,   37 - 45
     6 CSFAIL,CSFAIP,CSFBIL,CSFBIR,CSFL  ,CSFR  ,CTL   ,CTR   ,CYNAIL,   46 - 54
     7 CYNAIP,CYNBIL,CYNBIR,CYNL  ,CYNR  ,FIPONL,FIPONR,FNORNL,FNORNR,   55 - 63
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Figure G.6. (Continued)



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I N I C X                          SUBROUTINE RTSLOW                          PAGE   57

      COMMON/MSGVAR/
     1 ALAPHG,ALLMPR,ALPHLW,ALPHRW,ALRGLW,ALRGRW,ALRWPR,ALWSSQ,AMARLW,    1 -  9
     2 AMARRW,AMAPWG,AMAPWQ,APTLW ,APTRW ,ARWSSQ,ATAULR,ATAURR,AVEALR,   10 - 18
     3 AVEALW,AVEGLW,AVEGTS,AVEEPP,AVEZET,BETALW,BETARW,BKALPR,BKARPR,   19 - 27
     4 CALLW ,CALRW ,CAVIPW,CAVZET,CBETLW,CBETRW,CEPLW ,CEPRW ,CDCNTL,   28 - 36
     5 CDCNTR,CDLIPW,CDLWAQ,CDLWPR,CDLWSS,CDRWAQ,CDRWPR,CDRWSS,CDSLW ,   37 - 45
     6 CDSRW ,CLSLW ,CLCPTL,CLCNTR,CLDIPW,CLILW ,CLIRW ,CLLWAQ,CLLWPR,   46 - 54
     7 CLLWSS,CLRWAQ,CLRWPR,CLRWSS,CLSLW ,CLSRW ,CLSW  ,CLZERO,CMCNTL,   55 - 63
     8 CMCNTR,CMLWAQ,CMLWSS,CMRWAQ,CMRWSS,CMSLW ,CMSRW ,CMSW  ,CTAULR,   64 - 72
     9 CTAURR,CTILR ,CTISHP,DCIOPF,DCOLDA,DCOLSP,DCORDA,DCORSP,DCLIPF,   73 - 81
     A DCLLDA,DCLLSP,DCLRDA,DCLRSP,DCLSPD,DCMOPF,DCMLDA,DCMLSP,DCMRDA,   82 - 90
     B DCMRSP,DCLSPW,EPILW ,EPIRW ,EPPLP ,EPPRP ,EPWIL ,EPWIR ,FESLT ,   91 - 99
     C FESRT ,SALT  ,SALRW ,SAZERO,SAVZET,SHFTLW,SHFTRW,SIGMA ,SIGRW ,  100 - 108
     D SQRTL ,SQRTR ,SSL   ,SSLW  ,SSP   ,SSRW  ,SSF   ,STAULR,STAURR,  109 - 117
     E SVSTSL,SVSTSR,SWLW  ,SWRW  ,SWSLW ,SWSRW ,SQRTRG,TAULR ,TAURR ,  118 - 126
     F TAVERG,TRMHT1,TRMHS5,TRMHT2,TRMHT3,TZET1 ,TZET2 ,TZET3 ,TZET4 ,  127 - 135
     G TZET5 ,TZET6 ,VELAB ,VSTAPL,XAE   ,XAERTG,XAERWG,XAERWL,YAERLW,  136 - 144
     H YAERRW,YAERWG,ZAEPLW,ZAEPRW,ZAERTG,ZETA1 ,ZETA2 ,ZETA3 ,ZETA4    145 - 153

      COMMON/DGVAR/
     1 A0GSG,A0MGG,A0GGL,A0MJL,A0GSL,A0DTL,A0GCL,A0MCL,A0L   ,    1 -  9
     2 A0DTR ,A0L   ,A0DTL,AMAGTL,AMAGTR,TMTLAG,TMTRAG

      COMMON/TAILVAR/
     1 ALAGMT,ALAPT ,ALAPVT,ALPHMT,ALPHVT,AMART ,AMARVT,ANAGMT,ANAPT ,   1 -  9
     2 ANAPVT,ANAGVT,BETVT ,CALTMT,CBETST,CDMT  ,CDVT  ,CLMT  ,CYVT  ,  10 - 18
     3 EPTAIL,EPZERO,SALTMT,SHFTSQ,SIGMA ,TRMMT ,TRMVT ,XAERT ,YAERMT,  19 - 27
     4 YAPVT ,YAPRT ,YAWMT ,YAWVT ,ZAPRT ,ZAWMT ,ZAPVT ,EPTLT ,ALMIPP,  28 TO 36
     SALMTF ,ALMIP ,ALMIM ,CLAT  ,TRMMT2,TRMMT3,CLMTST,CDMTST,ALVIPR,  37 TO 45
     ALVTF ,ALVIP ,ALVIM ,CYAT  ,TRMVT2,TRMVT3,CYVTST,CDVTST           46 TO 53

      COMMON/FORVAR/
     1 ALAERD,AMAERD,ANAERD,CMJX  ,CFIXX ,CFIXZP,CFIXZD,CFIXZ9,CIYY  ,   1 -  9
     2 CJZZ  ,CJYY  ,CJXX  ,CJZZ  ,XMIXX,ONMIYY,ONMIZZ,PD    ,PQ    ,  10 - 18
     3 PR    ,PP    ,PD    ,TERM1 ,TERM2 ,TERM3 ,TERM4 ,TERM5 ,TERM6 ,  19 - 27
     4 TERM7 ,TERM8 ,TERM9 ,TERM10,TERM11,TERM12,TERM13,TERM14,TERM15,  28 - 36
     5 TERM16,TERM17,XMIXZ ,XI    ,CLIXX ,CLIXZ ,XI    ,      ,      ,  37 - 45
     6 XMIYY ,CMIXZ ,XJ    ,XAERLW,YAERLW,ZAERLW,ZI    ,ZEMFHF,ZI    ,  46 - 54
     7 ZLCGS ,CLIZZ ,ZJ    ,ZAERLW,ZAERRW,ZAERWG,ZJ    ,      ,      ,  55 - 63
     8 XMIZZ ,      ,XI    ,      ,      ,      ,      ,      ,      ,  64 - 72
     9 ZLCGS ,CLIZZ ,ZJ    ,ZAERLW,ZAERRW,ZAERWG,ZJ    ,      ,      ,  73 - 81
     A XMIZZ ,      ,XI    ,      ,      ,      ,      ,      ,      ,  82 - 90
     B ZLCGS ,CLIZZ ,ZJ    ,ZAERLW,ZAERRW,ZAERWG,ZJ    ,      ,      ,  91 - 99
     C XMIZZ ,      ,XI    ,      ,      ,      ,      ,      ,      ,  100 - 108
     D ZLCGS ,CLIZZ ,ZJ    ,ZAERLW,ZAERRW,ZAERWG,ZJ    ,      ,      ,  109 - 117
     E XMIZZ ,      ,XI    ,      ,      ,      ,      ,      ,      ,  118 - 126
     F ZLCGS ,CLIZZ ,ZJ    ,ZAERLW,ZAERRW,ZAERWG,ZJ    ,      ,      ,  127 - 135
     G XMIZZ ,      ,XI    ,      ,      ,      ,      ,      ,      ,  136 - 144
     H ZLCGS ,CLIZZ ,ZJ    ,ZAERLW,ZAERRW,ZAERWG,ZJ    ,      ,      ,  145 - 153
     I XMIZZ ,      ,XI    ,      ,      ,      ,      ,      ,      ,  154 - 162
     J ZLCGS ,CLIZZ ,ZJ    ,ZAERLW,ZAERRW,ZAERWG,ZJ    ,      ,      ,  163 - 171
     K XMIZZ ,      ,XI    ,      ,      ,      ,      ,      ,      ,  172 - 180
     L ZLCGS ,CLIZZ ,ZJ    ,ZAERLW,ZAERRW,ZAERWG,ZJ    ,      ,      ,  181 - 189
     M XMIZZ ,      ,XI    ,      ,      ,      ,      ,      ,      ,  190 - 198
     N ZLCGS ,CLIZZ ,ZJ    ,ZAERLW,ZAERRW,ZAERWG,ZJ    ,      ,      ,  199 - 207
     O XMIZZ ,      ,XI    ,      ,      ,      ,      ,      ,      ,  208 - 216
     P ZLCGS ,CLIZZ ,ZJ    ,ZAERLW,ZAERRW,ZAERWG,ZJ    ,      ,      ,  217 - 225
     Q XMIZZ ,      ,XI    ,      ,      ,      ,      ,      ,      ,  226 - 234
     R ZLCGS ,CLIZZ ,ZJ    ,ZAERLW,ZAERRW,ZAERWG,ZJ    ,      ,      ,  235 - 243
     S XMIZZ ,      ,XI    ,      ,      ,      ,      ,      ,      ,  244 - 252
     T ZLCGS ,CLIZZ ,ZJ    ,ZAERLW,ZAERRW,ZAERWG,ZJ    ,      ,      ,  253 - 261
     U XMIZZ ,      ,XI    ,      ,      ,      ,      ,      ,      ,  262 - 270
     V ZLCGS ,CLIZZ ,ZJ    ,ZAERLW,ZAERRW,ZAERWG,ZJ    ,      ,      ,  271 - 279
     W XMIZZ ,      ,XI    ,      ,      ,      ,      ,      ,      ,  280 - 288
     X ZLCGS ,CLIZZ ,ZJ    ,ZAERLW,ZAERRW,ZAERWG,ZJ    ,      ,      ,  289 - 297
     Y XMIZZ ,      ,XI    ,      ,      ,      ,      ,      ,      ,  298 - 306
     Z ZLCGS ,CLIZZ ,ZJ    ,ZAERLW,ZAERRW,ZAERWG,ZJ    ,      ,      ,  307 - 315

      COMMON/XMAT/ CONST ,CONST2 ,CONST3 ,CONST4 ,CONST5 ,CONST6 ,CONST7 ,   1 -  7
     1             CONST8 ,CONST9 ,CONST10,CONST11,CONST12,CONST13,CONST14,   8 - 14
     2             CONST15,CONST16,CONST17,CONST18,CONST19,CONST20,CONST21,  15 - 21
     3             CONST22,CONST23,CONST24,CONST25,CONST26,CONST27,CONST28,  22 - 28
     4             CONST29,CONST30,CONST31,CONST32,CONST33,CONST34,CONST35,  29 - 35
     5             CONST36,CONST37,CONST38,CONST39,CONST40,CONST41,CONST42,  36 - 42
     6             CONST43,CONST44,CONST45,CONST46,CONST47,CONST48,CONST49,  43 - 49
     7             CONST50,CONST51,CONST52,CONST53,CONST54,CONST55,CONST56,  50 - 56
     8             CONST57,CONST58,CONST59,CONST60,CONST61,CONST62,CONST63,  57 - 63
     9             CONST64,CONST65,CONST66,CONST67,CONST68,CONST69,CONST70,  64 - 70
     A             DBRK1 ,DBRK2 ,DBRK3 ,DBRK4 ,DBRK5 ,DBRK6 ,DBRK7 ,   71 - 77
     B             DBRK8 ,DBRK9 ,DBRK10,DBRK11,DBRK12,DBRK13,DBRK14,  78 - 84
     C             DBRK15,DBRK16,DBRK17,DBRK18,DBRK19,DBRK20,DBRK21   85 - 91
```

Figure G.6. (Continued)

```
      D             ,SFTL   ,SFNFL ,SFSFL ,SFPHL ,SFYHL ,SFQL   ,SFPL   ,
      E              SFTR   ,SFNFR ,SFSFR ,SFPHR ,SFYHR ,SFQR   ,SFPR
      F             ,CONS71,CONS72,CONS73,CONS74,CONS75,CONS76,CONS77     10ATO112
      G             ,CONS78,CONS79,CONS80,CONS81                          11370116
C        TABLE OF PRE-COOKED COEFFICIENTS DEFINITION D
C     XFCON =   SLF*(1.-SHF/SH) -SLW*SHW/SH
C     ZFCON =   SHF*(1.-SHF/SH) -SHW*SHW/SH
C     XWCON =   SLW*(1.-SHW/SH) -SLF*SHF/SH
C     ZWCON =   SHW*(1.-SHW/SH) -SHF*SHF/SH
C     XRLCON=  -(SHF*SLF +SHW*SLW)/SH
C     ZRLCON=  -(SHF*SHF +SHW*SHW)/SH
C     XXICON=   SUMIXX + 2.*SHN*YN*YN
C     YYICON=   SUMIYY
C     ZZICON=   SUMIZZ + 2.*SHN* YN*YN
C     XZICON=   FIXZF + FIXZW
C     XXJCON=   SUMIZZ -SUMIYY +2.*SHN*YN*YN
C     YYJCON=  (FIXXF -FIZZFI+(FIXXW-FIZZWI
C     ZZJCON=  (SUMIYY-SUMIXX) -2.*SHN* YN*YN
C     COEF1 =   SL*SHN/SH
C     COEF2 =   SL*(1. -SHN/SH)
C     COEF3 =   FIXXPR -FIZZPR
C     COEF4 =   SL*SHN
C     COEF5 =   SHF * SHF
C     COEF6 =   SHW * SHW
C     COEF7 =   SHF * SLF
C     COEF8 =   SHW * SLW
C     COEF9 =   SL*SHN*YN
C        COEF10=  1. / SH
C     COEF11= RKLSW*AVEYAC/2./SPAN
C     COEF12= RKNSW*AVEYAC/2./SPAN
C     COEF13=       (FIYYPR+SL*SL*SHN*(1.-SHN/SH))
C     COEF16= AREAW*SPAN          (S * B )   .
C     COEF17= CHORD/SPAN          (C / B )    . WING CHARACTERISTICS
C        COEF18=  S / 2
C     COEF19 =  PI*ROTRAD*ROTRAD*ROTPAD*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 T+ 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      XRCLS=   XR* COS(INR-LAMDA)
C      RLSIN =  ZL* SIN(INL-LAMDA)
C      ZLCOS =  ZL* COS(INL-LAMDA)
C      XLSIN =  XL* SIN(INL-LAMDA)
C      XLCOS =  XL* COS(INL-LAMDA)
C      ZFMHF=    SHF* SHF * ZF
C      ZWMHW=    SHW* SHW * ZW
C      XFMFLF=   SHF* SLF * XF
C      XWMXLW=   SHW* SLW * XW
C      TERM1 =  (IXXPR-IZZPR)*(SSQINR + SSQINL)
C      TERM2 =  (IXZPR)* S2INR +S2INL)
C      TERM3 =  (SL *SHN)*(ZRSIN +ZLSIN)
C      TERM4 =  (IXXPR-IZZPR)*(S2INR +S2INL) * 0.5
C      TERM5 =   IXZPR *(C2INR+C2INL)
C      TERMA =  (SL *SHN) *(XRCOS + XLCOS)
C      ROVIXX=  1./FIXX
C      ROVIYY=  1./FIYY
C      ROVIZZ=  1./FIZZ
C      RQ =     Q*Q
C      PQ =     P*Q
C      RR =     R*R
C      PR =     P*R
C      PP =     P*P
C         FOR BIT 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  1
C
C         BIT NUMBER   DSS 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 5: FT.   GFF = 3.
C           2. IF  V  LE  30 KT   TAIL AERO = 2.
C           3. IF  DEL FLAP GT  75 DEG    EPSILON TAIL = 0.
C           4. IF  GTS 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)

```
      27          CALL TRACK('RTSLOW  *',1)
      28     10   CALL REVENT(IFC(1),NCON(1),ISENCE(1),IREVNT,0)
      29          KPAN = 300
      30          CALL GETBIT(ISENCE(2),ICINOP,29)
      31          CALL GETBIT(ISENCE(2),KTRIM,30)
      32          IF((JTRIM.EQ.0.AND.KTRIM.EQ.0).OR.(ITRIM.NE.0) GO TO 36
      33          CALL USEAIO(RC81)
      34          KPAN= 302
      35          ITRIM= 1
      36     35   GO TO(35,36,500),ISTRBL
      37     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  )
      38          ENTRY TSTRTS
      39          CALL SINCOS(PSI,SINPSI,COSPSI)
      40           CALL SINCOS(THE,SINTHE,COSTHE)
      41          CALL SINCOS(PHI,SINPHI,COSPHI)
      42          SSQINR = SININR*SININR
      43          SSQINL = SININL*SININL
      44          C2INL  =  1.- 2.*SSQINL
      45          C2INR  =  1.- 2.*SSQINR
      46          S2INL  =  2.*SININL*COSINL
      47          S2INR  =  2.*SININR*COSINR
      48          HSQ=  H**2
      49          QFSW= SQF*AREAW
      50          VALNCR=  FSQRT(URRURR+WRRWRR,WORK)
      51          VALNCL=    FSQRT(URLURL+WRLWRL,WORK)
                  C
                  C     CENTER OF GRAVITY CALCULATION
                  C
                  C     CG LOCATION W.R.T. PIVOT
      52          XCG= -XRLCON *COEFI*(CILAML+CILAMR)
      53          ZCG= -ZRLCON -COEFI*(SILAML+SILAMR)
                  C
                  C
                  C     AIRCRAFT CONDITION CALCULATIONS
                  C
                  C     GROUND TRACK
                  C     NORTHWARD VELOCITY
                  C
      54          VNORTH= UPRIME*COSTHE*COSPSI+VPRIME*(SINPHI*SINTHE*COSPSI-
```

Figure G.6. (Continued)

```
     *  COSPHI*SINPSI)+WPRIME*(COSPHI*SINTHE*COSPSI*SINPHI*SINPSI)
C        EASTWARD  VELOCITY
     VEAST= UPRIME*COSTHE*SINPSI+VPRIME*(SINPHI*SINTHE*SINPSI+
    *COSPHI*COSPSI)+WPRIME*(COSPHI*SINTHE*SINPSI-SINPHI*COSPSI)
C        DOWNWARD VELOCITY ON ANALOG
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  )
     (  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        DENSITY CALCULATIONS
C        EQUATION FOR 1962 HIGH CURVE FIT PROGRAM
     RHO = .4009838367E-03 -.3023432996E-04 * H
    *  +.5430091731E-09 *H**3 -.3725338648E-14 *H**4 * H
C
     OMEGA=  TZERO -ICOMEGA*H
     THETA=  .0019279339*(TOMEGA+459.69)
     SQTHTA=  SQRT(THETA,WORK)
     OVTHTA = 1. / THETA
     RHO = RHO*DEL*OVTHTA
     DENSTY=  RHO * 1.0
     SMACH=  1116.*SQTHTA
     AMACH=  VTOTAL /SMA
     AMACSQ= AMACH * AMACH
     RGMACH=  SQRT(1.0+AMACSQ,WORK)
     OVRSMA =  1./SMACH
     THDEL=  SQTHTA*DEL
     OVTHDL= 1./THDEL
     OVSQTH=  1./SQTHTA
C
     RGAS= TRSP*OVTVTC
      EMACHT = EMACHX * EMDTDR * OVTHDL
     EMAXN1=  EN1MX*OVSQTH
     EMAXN2 = EN2REF*OMEGA /OMREF
     EN2STR=  EMAXN2*EN2MX
     SQRDTX = EMXMDT * EMXMDT
     SQRIMX=  EMAXN1 * EMAXN1
     CALL ENGINE(TCAL,SHPRR,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
      TEAL=  TPSL*ONOVTC
      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 )
                                  ( B L A N K   C A R D )
**** ********************** S Y N T A X   E R R O R ********************** C *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.+SK6*BETAFP*BETAFP*ABS(BETAFP))+SK2*ALPHFP*ALPHFP
     *   +SK1*ABS(ALPHFP)+DCDLG*SWLG2
 9C     CYF=  BETAFP*(SK7+SK8*ABS(BETAFP))
```

Figure G.6. (Continued)

```
      91          CNF= CNF+ALPHEP*(SK4+SK6*SH$(ALPHEP))*QCHLG*SWLG2
      92          CNFD= CNDF*ALPHEP*(SK5*SK6*ABS(BETAEP))
                  C
                  C       BODY AXES FORCES AND MOMENTS (ABOUT CG)
      93          SBFSAF= SINBTF*SINALF
      94          SBFCAF= SINBTF*COSALF
      95          CNFCNF= COEF17 * CNF
      96          XAREP= QFSW*(-CLF*COSALF-CDF*COSBTF*SINALF-CYF*SBFSAF)
      97          YAREP= QFSW*(-CDF*COSALF+CLF*SINALF-CYF*SBFCAF)
      98          YAREP= QFSW*(CYF*COSBTF-CDF*SINBTF)
      99          ZNAREP= QFSW*CHORD*CNF*COSBTF+ZAREP*(XCG-XFAC)-XAREP*(ZCG-ZFAC)
     100          ZN4REP= QFSW*SPAN *(CNF*COSALF-CNCNF*SBFSAF) -YAREP*(XCG-XFAC)
     101          ZL4REP= QFSW*SPAN *(-CDCNF*SBFCAF-CNF*SINALF)  +YAREP*(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 R D )
                                          ( B L A N K   C A R D )
                  C         ADDS AND RATE ALTITUDE EFFECTS ON DAMPING DERIVS
     102          HXC4 = H +(XNAC-XCG)*SINTHE +(ZCG-ZNAC)*COSTHE
     103          HTC4 = H +(XHT -XCG)*SINTHE +(ZCG-ZHT) *COSTHE
                  C
     104          AGOVAT = 1.0
     105          IF(NGEF.NE.1)  GO TO 430
     106          IF(HTC4 .GT. DBRK14 ) GO TO 420
     107          AGOVAT = CONS59 +HTC4*(CONS60 +CONS61*HTC4)
     108          GO TO 430
     109     420  IF(HTC4 .GE. DBRK15) GO TO 63
     110          AGOVAT = CONS62 +HTC4*(CONS63 +CONS64*HTC4)
     111     430  CONTINUE
     112          CLTCDA= AGOVAT*DQVFSM
     113          AGOVAW = 1.0
     114          BK29= 1.0
     115          IF(NGEF.NE.1) GO TO 650
     116          IF(HNC4.GT.DBRK16) GO TO 640
     117          AGOVAW= CONS644+HNC4*(CONS45+CONS46*HNC4)
     118          BK29= -1.0
     119          GO TO 650
     120     640  IF(HNC4.GE.DBRK11) GO TO 650
     121          AGOVAW= CONS47+HNC4*(CONS48+CONS49*HNC4)
     122          BK29= -1.0
     123     650  CONTINUE
     124          CLDCDR=    AGOVAW * DQVFSM
     125          CNDCDR=  BK29*COEF17
     126          HDHUB= H+(RLSPCOSINP-XCG)*SINTHE+((ULS*SINEGR+ZCG)*COSPHI-
                 *   YN *SINPHI)*COSTHE
     127          IF(AMUP.GE.DBRK12) GO TO 412
     128          DEEP3 = HDHUB/(2.*RTDRAD*(CONS50+BK5*(COSPHI*(SINTHE*COSINR +
                 *   COSTHE*SINENR))))
     129          IF(NGEF.NE.1)  GO TO 412
```

Figure G.6. (Continued)

```
      IF(HGEFRR.GE.OBRK13) GO TO 412
      TIGER  =(HGEFRR*HGEFRR*(CONS51+CONS52*AMUR)+HGEFRR*(CONS53*AMUR
     * +CONS541 +CONS55 +CONS56*AMUR )
      DDVTR= BKD1T*HGEFRR*HGEFRR+BKD2T*HGEFRR+BKD3T
      BKDVTR= BKM1T*HGEFRR*HGEFRR+BKM2T*HGEFRR+BKM3T
      GO TO 413
412   TIGER= 1.0
      DDVTR= DDVT
      BKDVTR=  BKM4T
413   CONTINUE
      IF(AMUL.GE.OBRK12 )  GO TO 414
      HLHUB= HRHUB *2.0*YN*SIN941*COSTHE
      HGEFLR = HLHUB/(2.*RDTRAD*(CONS50+ABS(COSPHI*(SINTHE*COSINL +
     *  COSTHE*SIN(INL))))
      IF(HGEF.NE.1) GO TO 414
      IF(HGEFLR.GE.OBRK13) GO TO 415
      TIGEL  =(HGEFLR*HGEFLR*(CONS51+CONS52*AMUL)+HGEFLR*(CONS53*AMJL
     * +CONS541 +CONS55 +CONS56*AMUL )
      DDVTL= BKD1T*HGEFL*HGEFLR+BKD2T*HGEFLR+BKD3T
      BKDVTL=  BKM1T*HGEFLR*HGEFLR+BKM2T*HGEFLR+BKM3T
      GO TO 415
414   TIGEL= 1.0
      DDVTL= DDVT
      BKDVTL=  BKM4T
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 )
C
C       NACELLE AERODYNAMICS
C
C
      ALPHLN=  ATAN2(WRL,U9L)
      ALPHRN=  ATAN2(WRR,U9R)
C
      BETALN=  ATAN2(V9L,VALNCL)
      BETARN=  ATAN2(V9R,VALNCR)
C
      CALL  SINCOS(ALPHLN,SALLN,CALLN)
      CALL  SINCOS(ALPHRN,SALRN,CALRN)
      CALL  SINCOS(BETALN,SBETLN,CBETLN)
      CALL  SINCOS(BETARN,SBETRN,CBETRN)
C
      TRANCL=  SALLN*CALLN
```

Figure G.8. (Continued)

```
      TRMNC2=  SALPHN*CALPN
      TRMNC3=  SBETLN*CBETLN
      TRMNC4=  SBETPN*CBETPH
C
C        WIND AXES
      IF(ABS(ALPHLN).GT.ALMCRK) GO TO 720
      CDCLN=  CDCNLO
      SK32L=  SK32LO
      SK33L=  SK33LO
      GO TO 730
  720 CDCLN=  CDCNHI
      SK32L=  SK32HI
      SK33L=  SK33HI
  730 CONTINUE
      CDLN=  CDCLN*SK32L*ABS(ALPHLN)+SK33L*ALPHLN*ALPHLN
      CLLN=  SK32*TRMNC1
      CMLN=  CMPL*TRMNC1*(SK34+SK35*ABS(TRMNC1))
      CYLN=  TRMNC3*(SK43+SK44*ABS(TRMNC3))
      CNLN=  CDCLN*TRMNC3*(SK40+SK41*ABS(TRMNC3))
C
C
      IF(ABS(ALPHRN).GT.ALMCRK)  GO TO 740
      CDCRN=  CDCNLO
      SK32R=  SK32LO
      SK33R=  SK33LO
      GO TO 750
  740 CDCRN=  CDCNHI
      SK32R=  SK32HI
      SK33R=  SK33HI
  750 CONTINUE
      CDRN=  CDCRN*SK32R*ABS(ALPHRN)+SK33R*ALPHRN*ALPHRN
      CLRN=  SK32*TRMNC2
      CMRN=  CMPL*TRMNC2*(SK34+SK35*ABS(TRMNC2))
      CYRN=  TRMNC4*(SK36+SK37*ABS(TRMNC4))
      CNRN=  CDCRN*TRMNC4*(SK40+SK39*ABS(TRMNC4))
C
C        LIFT NACELLE AERO FORCES -  BODY AXES
C
      SQLNC=   RQ*SURV2*(CLFLDRL+VPLV*WKNORL)
      SQRNC=   RQ*SURV2*(CLRDDRR+VPRVR2*WRNORR)
      TNAC1 = SQRNC * COEFF1
      TNAC2 =  SQLNC * COEFF1
C
      DRAGC = -TNAC1*( CLRN*CALRN +SALRN*(CDRN*CBETRN +CYRN*SBETRN ) )
      SIDEC =  TNAC1*( CLRN*SALRN -CALRN*(CDRN +CYRN*SBETRN) )
      DVORC =  TNAC1*( CYRN*CBETRN -CDRN*SBETRN )
      DMOMC =  TNAC1*CHORD * CMRN *CBETRN
      DNORC =  TNAC1*SPAN  *CALRN*(CMRN -COEFF2*CYRN*SBETRN )
      ELRNC = -TNAC1*SPAN  *( COEFF2*CMRN*SBETRN*CALRN +CNRN*SALRN )
C
C        LEFT  NACELL AERO FORCES  -  BODY AXES
C
C
      DZLNC = -TNAC2*( CLLN*CALLN +SALLN*(CDLN*CBETLN +CYLN* SBETLN ) )
      DYLNC =  TNAC2*(CLLN*SALLN -CALLN*(CDLN +CYLN* SBETLN ) )
```

Figure G.6. (Continued)

```
      DYLNC =  TMAC2*(CVLN*CRETLN -CDLN* SRETLN )
      DMLNC =  TMAC2*CHORD * CMLN * CRETLN
      DNLNC =  TMAC2*SPAN  * CALLN*(CNLN -COEF17*CMLN* SRETLN )
      DLLNC = -TMAC2*SPAN  *( COEF17*CMLN*SRETLN*CALLN +CNLN*SALLN )
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 )
**** ********************** S Y N T A X   E R R O R ********************** 6 11
C
C     WING AERODYNAMICS
C
C        PRELIMINARY CALCULATIONS
C          RIGHT ROTOR
C
      TAURR =  ALPHRR  +  ATAN2(FNORMR,TR )
      RESRR=  FSQRT(TR*TR+FNORMR*FNORMR+FSIDER*FSIDER,WORK)
      TRMWG1 =  COEF25 / ROF
      SQRESR=  FSQRT((RESRR+1.)*TRMWG1,WORK)
      VSTAR = VTOTRR/SQRESR
C
      ATAURR =  ABS(TAURR)
      CALL LINT (AKEY, AMEM,AMEM ,ISTA,VSTAR ,ATAURR,SVSTAB ,SVSTAR  )
      NPAN = 32
      IWARN(11)=  .FALSE.
      IF(ISTA.EQ.2) IWARN(11)= .TRUE.
C
C
      CALL SINCOS(TAURR,STAURR,CTAURR)
C
      TMWG11=  SVSTAR*STAURR
      TMWG11=  VSTAR*SVSTAR*CTAURR
      EPSRR=  ATAN2(TMWG10,TMWG11)
      CTSRR= 4./(4.+      VSTAR*VSTAR)
C
C           LEFT ROTOR
      TAULR =  ALPHLR  +  ATAN2(FNORML,TL )
      RESLR=  FSQRT(TL*TL+FNORML*FNORML+FSIDEL*FSIDEL,WORK)
      SQRESL=  FSQRT((RESLR+1.)*TRMWG1,WORK)
      VSTARL=  VTOTLR/SQRESL
C
      CALL SINCOS(TAULR,STAULR,CTAULR)
C
```

Figure G.6. (Continued)

```
      STAULR = ABS(TAULR)
      CALL LINT (XKEY, XMEM,AMEM ,ISEG,VSTARL,ATAULR,SVSTAB ,SVSTPL  )
      LMARK(12)=  .FALSE.
      KPAN = 321
       IF(ISTR.EQ.2) LMARK(12)= .TRUE.
C
C
      TRMHG4=  SVSTPL*STAULR
      TRMHG9=  VSTARE*SVSTPL*CTAULR
      EPPLR=  ATAN2(TRMHG4,TRMHG9)
      CTSLR=  4.7E4.4      VSTARL*VSTARLI
C
C     CALCULATE THE EFFECTIVE AMOUNT OF WING AREA IN DOWNWASH - USES AVERAGES
C
      AVEZET =   .5 *(ZETHR + ZETHL )
      AVEALP =  .5 *(ALPHRP + ALPHLP)
      AVEEPS =  .5 *(EPSRR + EPSLR )
      AVECTS =  .5 *(CTSRP + CTSLR )
C
C
      CALL SINCOS(AVEZET,SAVZET,CAVZET)
      CALL SINCOS(AVEINW- AINW , SAVINW,CAVINW )
C
      TAVAEP =  TAN(AVEALR -AVEEPS )
C
      TZET1 = (RLS-PC*CAVINW*HP( SAVINW ) * TAVAEP
      TZET2 =  TZET1*CAVZET +PC*SAVINW *HP*CAVINW
      TZET3 =  ROOT2D*SQRT(AR  - TZET2*TZET2
C
      IF(TZET3) 360,30 ,350
  350 CONTINUE
      ZETA2=  ASIN(TZET3,WORK)
      ZETA1  =  TZET1 * SAVZET
C
      TZET4 = (RLS -(PC-CHORD)*CAVINW *HP*SAVINW )* TAVAEP
      TZET5 =  TZET4* SAVZET +(PC-CHORD)*SAVINW *HP*CAVINW
      TZET6 =  ROOT2D*SQRT(AR  - TZET5*TZET5
C
      ZETA3 =  TZETA + SAVZET
      IF(TZET6) 360,360,355
  355 CONTINUE
      ZETA4=  ASIN(TZETA,WORK)
C
      GO TO 370
  360 ZETA1=  0.
      ZETA2=  0.
      ZETA3=  0.
      ZETA4=  0.
   37 CONTINUE
      SIR =   COEF24*(ZETA1+ ZETA2 +ZETA3 +ZETA4 )
      SIRW =  COEF24 * SIR
      SIT  =  CHORD *(ZETA2 +ZETA4 )
      SIL  =  SIT - SIR
      SILW =  COEF24 * SIL
      EPSILW= 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))
      HKALPR= (VSTARL*CLILW*SVSTRL)/(VSTARL*SVSTRL)
      HKARPR=  (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 )
      C
      C       ROTOR/ROTOR INTERFERENCE
      IF(V) 400,400,390
  390 BIGX = CONS57  -EPPRP
      RR11   =  RT1 + BT2* BIGX *RT1 + BIGX *BIGX
      RR12= RR11*SVSTAN*SQRESR
      EPPRM=  -ATAN2(RR12,VTOTLR+1.E-)
      EPILR =  0.
      EPIPL = ABS(BETAF)* AINL * EPPRM  * CONS58
      GO TO 410
  400 BIGX = CONS57  - EPPLR
      RR11   =  RT1 + BT2*BIGX *RT1 + BIGX*BIGX
      RR12   =  RR11 *SVSTRL * SQRESL
      EPPRM=  -ATAN2(RR12,VTOTRR+1.E-)
      EPILR = ABS(BETAF)* AINR * EPPRM  * CONS58
      EPIRL =  0.
  410 CONTINUE
      DEF  =  0.
      IF(NDEF.NE.1)  GO TO 220
      IF(HMC4.GE..09PK16) GO TO 205
      DEF= (COEF35*4.*(HTC4-HMC4)*(HTC4-HMC4))/(COEF35*4.*(HTC4+
     *  HMC4)*(HTC4+HMC4))
  205 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 )
( B L A N K   C A R D )
C        FUSELAGE
294         XF = SLF - XCG
295         ZF = SHF - ZCG
C        WING
296         XW = SLW - XCG
297         ZW = SHW - ZCG
C        NACELLES
298         XR = SL* CILAMR -XCG
299         ZR = -SL* SILAMR -ZCG
C
300         XL = -SL* CILAML -XCG
301         ZL = -SL* SILAML -ZCG
C
C           INTERMEDIATE CALCULATIONS
302         RSIN   =   ZR* SILAMR
303         RCOS   =   ZR* CILAMR
304         XRSIN  =   XR* SILAMR
305         XRCOS  =   XR* CILAMR
306         ZLSIN  =   ZL* SILAML
307         ZLCOS  =   ZL* CILAML
308         XLSIN  =   XL* SILAML
309         XLCOS  =   XL* CILAML
310         ZFSIN  =   ZF* COSFA
311         ZWSINA =   ZW* COSFA
312         XFSIN  =   XF* COSFA
313         XWSINA =   XW* COSFA
314         TERM1  =   COSFA *(SSOINR*SSOINL)
315         TERM2  =   SINFA *(SSINR + SSINL)
316         TERM3  =   COSFA *(ZRSIN +ZLSIN)
317         TERM4  =   COSFA *(SSINR *SSINL) * .5
318         TERM5  =   SINFA*(RSIN +RSINL)
319         TERM6  =   COSFA *(XRCOS + XLCOS )
C
C           INERTIAS
320         FIXX = XXICON -TERM1 -TERM2 +ZFSINA+ZWSINA -TERM3
321         FIXZ= XZICON +TERM4  -TERM5+ZFCOSFA+ZWCOSFA+COSFA*(ZRCOS+ZLCOS)
322         FIYY = YYICON+XFSINF+ZFSINF+XWSINW+ZWSINW+TERM6 -TERM3
323         FIXZP = FIXZ
324         FIZZ  = ZZICON +TERM1 +TERM2+XFSINF+XWSINW +TERM4
325         FJXX = FIZZ-FIYY
326         FJYY = FIXX-FIZZ
327         FJZZ = FIYY-FIXX
328         FIXZM = FIXZP
```

Figure G.6. (Continued)

```
                      DOVFXX=   1./FIXX
                      DOVFYY=   1./FIYY
                      DOVFZZ=   1./FIZZ
                      ISLOW= 0
                      CALL TRACK('RTSLOW  ',21
                      RETURN
                 500  DO 510 J=1,12
                 510   CALL DISABL(J-1)
                 520  IPAN = KPAN
                      RETURN
                      END
```


Figure G.6. (Continued)

```
SYMBOL                 REFERENCES

I                 -    280*
J                 -    360*
26                -    32      36      370
2C                -    292     293     2950
35                -    248     1600
355               -    256     2570
345               -    248     256     2610
372               -    259     3560
39                -    2760*
395               -    276     2770
40                -    276     2760
41                -    283     290*
412               -    121     129     135     1450
413               -    134     138*
414               -    132     142     143     1460
415               -    147     151*
42                -    36      1370
51                -    1330    1360
52                -    1390*
62                -    106     1 1*
63                -    105     1 0     1 2     1110*
64                -    116     117*
65                -    114     122     12      1210*
72                -    164     1690*
73                -    168     1730
76                -    178     1830
77                -    182     1860*
ABS               -    88      90      3       91      93      125     151     164     173     175     176     177     178
                       197     199     17      110     214     220     282     288
ADC1              -    900*
AGIVAT            -    1900    114*    117*    119*    112
AGIVAW            -    1900    113*    117*    121*    124
AICL              -    2100
AICLOP            -    2100
AICLSP            -    2100
AICP              -    2100
AICPOP            -    2100
AICPSP            -    900*
AINITI            -    900*
AINITP            -    900*
AINIT             -    1900
AINL              -    900     142
AINP              -    900     218
AINPREF           -    900
AINW              -    1900    2130*
AKEY              -    1200    2150*
ALAFPD            -    2500
ALAMDA            -    1300
ALARR             -    1800
ALARRP            -    1800    131*
ALARHE            -    2400
ALARNC            -    2100
ALARNL            -    2100
```

Figure G.6. (Continued)

ALAFNR - 21C0
ALART - 24C0
ALARVT - 24C0
ALARWG - 22C0
ALBRK - 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 84AG
ALPHFP - 86* 18 89 91
ALPHHT - 24C0
ALPHLN - 20C0 152* 156AG 164 173
ALPHLW - 21C0 224 239
ALPHLW - 22C0
ALPHPN - 20C0 153* 157AG 179 111
ALPHRR - 21C0 2 6 239
ALPHSH - 22C0
ALPHVT - 24C0
ALRGLW - 22C0
ALRGRW - 22C0
ALPNSQ - 20C0
ALRRH - 21C0
ALRWPR - 22C0
ALVTE - 24C0
ALVTM - 24C0
ALVTP - 24C0
ALVTPR - 24C0
ALVTST - 10C0
ALWSSQ - 22C0
AMACH - 16C0 46* 48
AMACLP - 90
AMACRP - 90
AMACSQ - 16C0 66* 67
AMACTL - 23C0
AMACTR - 23C0
AMAERQ - 25C0
AMARF - 18C0
AMARFP - 18C0 99*
AMARHT - 24C0
AMARLW - 22C0
AMARNC - 21C0
AMARNL - 21C0
AMARNR - 21C0
AMARRW - 22C0
AMART - 24C0
AMARVT - 24C0
AMARWG - 22C0

Figure G.6. (Continued)

AMEM - 1200 2154G
AMLRH - 21C0
AMRNLP - 21C0
AMRNRP - 21C0
AMROTL - 21C0
AMROTR - 21C0
AMRRH - 21C0
AMUL - 17C0 139 144
AMULSQ - 17C0
AMUR - 17C0 127 131
AMURSQ - 17C0
ANAERO - 25C0
ANARF - 18C0
ANARFP - 18C0 13?*
ANARHT - 24C0
ANARNC - 21C0
ANARNL - 21C0
ANARNR - 21C0
ANART - 24C0
ANARVT - 24C0
ANARWC - 22C0
ANDEG - 3C0
ANDEG2 - 3C0
ARLRH - 21C0
ARROTL - 21C0
ARROTR - 21C0
ARRRH - 21C0
ARRAHT - 19C0
ARRAVT - 19C0
ARCSW - 19C0 49
ARHT - 10C0
ARILW - 22C0 27?* 272
ARIRW - 22C0 27?* 273
ARVT - 10C0
ARWING - 9C0 272 273
ARWSSQ - 22C0
ATAN2 - 1?? 153 144 15? ??? ??? ??? ??? ??? ???
ATAULP - 22C0 23?* 215AG
ATAURP - 22C0 214* 215AG
AVEALR - 22C0 ?39* 244
AVEALW - 22C0
AVECLW - 22C0
AVECTS - 22C0 241*
AVEEPP - 22C0 24?* 244
AVEIN - 14C0 243AG
AVEYAC - 19C0
AVEYCS - 19C0
AVEZET - 22C0 23?* 24?1G
BONOS - 3C0
BETAF - 18C0 85AG 292 288
BETAFP - 8?* 89 9C 92
BETALW - 22C0 154* 158AG
BETALW - 22C0
BETARW - 22C0 145* 149?G
BETARW - 22C0

Figure G.6. (Continued)

BETFSQ - 18C0
BETVT - 21C0
BICL - 21C0
BICLOP - 21C0
BICLPR - 9C0
BICR - 21C0
BICROP - 21C0
BICRPR - 9C0
BIGX - 19C0 277* 278 284* 285
BKALPR - 22C0 274*
BKARPR - 22C0 275*
BKD1T - 10C0 132 145
BKD2T - 10C0 132 145
BKD3T - 10C0 132 145
BKEY - 12C0 230AG
BKLSW - 10C0
BKM1T - 10C0 133 146
BKM2T - 10C0 133 146
BKM3T - 10C0 133 146
BKM4T - 10C0 137 150
BKNSW - 10C0
BK99 - 19C0 114* 118* 122* 125
BLS - 10C0 126 245 252
BMEM - 12C0 230AG
BMOVTL - 19C0 146* 150*
BMOVTR - 19C0 113* 137*
BTLNSQ - 20C0
BTRNSQ - 20C0
BT1 - 10C0 278 285
BT2 - 10C0 278 285
BT3 - 10C0 278 285
CALIHT - 24C0
CALLN - 21C0 156AG 160 202 203 206 207
CALLH - 22C0
CALRN - 20C0 157AG 161 196 197 200 201
CALRH - 22C0
CAVINH - 22C0 243AG 245 246 252 253
CAVZET - 22C0 242AG 246 253
CBCMF - 18C0 95* 100 121
CBFTLN - 20C0 158AG 162 202 204 205
CBFTLH - 22C0
CBETRN - 20C0 159AG 163 196 198 199
CBETRH - 22C0
CBETSG - 24C0
CDCNTL - 22C0
CDCNTR - 22C0
CDDUM - 22C0
CDF - 18C0 99* 96 97 98
CDHT - 24C0
CDHTST - 24C0
CDLN - 20C0 173* 202 203 204
CDLWAD - 22C0
CDLWPR - 22C0
CDLWSS - 22C0
CDDF - 10C0 99

Figure G.6. (Continued)

CDOUT	-	1200						
CDCLN	-	2200	166*	169*	173			
CDDNHI	-	1000	159	163				
CDDNLO	-	1000	165	179				
CDDRN	-	2000	179*	183*	187			
CDDVT	-	1000						
CDRN	-	2200	187*	196	197	198		
CDRWAD	-	2200						
CDR4PP	-	2200						
CDR4SS	-	2200						
CDSLW	-	2200						
CDSRW	-	2200						
CDVT	-	2400						
CDVTST	-	2400						
CDWCDP	-	1900	125*					
CEPLW	-	2200						
CEPRW	-	2200						
CGGTVP	-	150						
CHORD	-	1001	19	199	206	252	253	267
CILAHL	-	1400	52	332	309	311		
CILAHR	-	1400	52	312	316	307		
CLALHT	-	1200						
CLALPH	-	1001	272	273				
CLAT	-	2400						
CLAVE	-	2200						
CLCNTL	-	2200						
CLCNTR	-	2200						
CLDUM	-	2200						
CLF	-	1800	48*	96	97			
CLHT	-	2400						
CLHTST	-	2400						
CLILW	-	2200	277*	274				
CLIRW	-	2200	278*	275				
CLLN	-	2200	194*	202	203			
CLLWAD	-	2200						
CLLWPP	-	2200						
CLLWSS	-	2200						
CLMAX	-	1001						
CLOAL	-	1000						
CLRN	-	2200	199*	196	197			
CLRWAD	-	2200						
CLR4PP	-	2200						
CLR4SS	-	2200						
CLSLW	-	2200						
CLSRW	-	2200						
CLSW	-	2200						
CLTCDR	-	1900	112*					
CLWCDF	-	1900	124*					
CLZERC	-	2200						
CMCNTL	-	2200						
CMCNTR	-	2200						
CMF	-	1800	91*	95	99			
CMLN	-	2200	179*	275	276	277		
CMLWAD	-	2200						
CMLWSS	-	2200						

Figure G.6. (Continued)

CHOF - 1900 91
CHON - 1900 175 189
CHOW - 2500
CHRN - 2500 199* 199 200 201
CHRWAD - 2200
CHRWSS - 2200
CHSLW - 2200
CHSRW - 2200
CNF - 1800 92* 100 101
CNFAIL - 2100
CNFAIR - 2100
CNFBIL - 2100
CNFBIR - 2100
CNFL - 2100
CNFPL - 900
CNFPR - 900
CNFR - 2100
CNLN - 2200 177* 206 207
CNOF - 1000 92
CNOLN - 1000 177
CNORN - 1000 191
CNRN - 2200 191* 201 201
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 - 800 268 269
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 319
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 129 141
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
CONS60 - 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
CONS70 - 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 97 103
COSDTF - 19C0 95AG 97 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
CPMA1L - 21C0
CPMA1R - 21C0
CPMB1L - 21C0
CPMB1R - 21C0
CPML - 21C0

Figure G.6. (Continued)

CPMPL - 900
CPMPR - 900
CPMP - 2100
CPR - 900
CSFAIL - 2100
CSFAIR - 2100
CSFBIL - 2100
CSFBIR - 2100
CSFL - 2100
CSFPL - 900
CSFPP - 900
CSFR - 2100
CTAULA - 2200 229AG 235
CTAURA - 2200 219AG 221
CTL - 2100
CTLPPM - 900
CTP - 2100
CTPPRM - 900
CTSLP - 2200 237= 241
CTSRR - 2200 223= 241
CYALVT - 1000
CYAT - 2400
CYF - 1800 92= 96 97 98
CYLM - 2200 176= 202 203 204
CYMAIL - 2100
CYMAIR - 2100
CYMBIL - 2100
CYMBIR - 2100
CYML - 2100
CYMPL - 900
CYMPR - 900
CYMR - 2100
CYRN - 2100 193= 196 197 198
CYVT - 2400
CYVTST - 2400
C2INL - 1400 44= 320
C2INR - 1400 45= 320
DBRK1 - 2600
DBRK10 - 2601 114
DBRK11 - 2600 115
DBRK12 - 2600 137 139
DBRK13 - 2600 135 143
DBRK14 - 2600 136
DBRK15 - 2600 139
DBRK16 - 2600 293
DBRK17 - 2600
DBRK18 - 2600
DBRK19 - 2600
DBRK2 - 2600
DBRK20 - 2600
DBRK21 - 2600
DBRK3 - 2600
DBRK4 - 2600
DBRK5 - 2600
DBRK6 - 2600

Figure G.6. (Continued)

DBRK7 - 26C0
DBRK8 - 26C0
DBRK9 - 26C0
DCODF - 22C0
DCOLDA - 22C0
DCOLG - 10C0 89
DCOLSP - 22C0
DCORDA - 22C0
DCORSP - 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
DEG2O - 10C0
DEL - 16C0 57* 62 69
DELAS - 9C0
DELAT - 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
DGTORO - 10C0
DIGAN - 3C0
DIGAN2 - 3C0
DISABL - 338*
DLFPSQ - 14C0
DLLG - 18C0
DLLNC - 20C0 197*
DLRNC - 20C0 201*
DMLG - 18C0
DMLNC - 20C0 215*
DMRNC - 20C0 199*
DNLG - 18C0
DNLNC - 23C0 206*
DNRNC - 20C0 210*
DOVT - 19C0 136 149
DOVTL - 19C0 145 149
DOVTR - 19C0 132 136

Figure G.6. (Continued)

CSORET - 1000
DTIM - 300
DUM12 - 900
DUM13 - 900
DUM14 - 900
DUM15 - 900
DUM43 - 900
DUM44 - 900
DUM45 - 900
DUM46 - 900
DUM47 - 900
DUM48 - 900
DXLG - 1400
DXLNG - 2000 233*
DXRNG - 2000 197*
DYLG - 1800
DYLNG - 2000 214*
DYRNG - 2000 178*
DZLG - 1900
DZLNG - 2000 212*
DZRNG - 2000 176*
EFFHT - 1000
EFFVT - 1000
EMAXN1 - 1400 74* 78
EMAXN2 - 1600 76* 74
EMXRDT - 1600 77* 77
ENFL - 900 91
ENFR - 900 92
* ENG - 5*
* ENGPIE - 700
* ENGVAR - 16*
ENIMX - 500 74
ENISTP - 500
ENITMX - 500
EN2MX - 500 76
EN2REF - 1000 75
EN2STR - 1600 76*
* EQNVAR - 25*
EPILR - 2200 291* 298*
EPIRL - 2200 292* 299*
EPPLR - 2200 234* 240 284
EPPRM - 1000 293* 292 287* 288
EPPRR - 2200 232* 240 277
EPTAIL - 2400
EPTLI - 2400
EPWRL - 2200
EPWPR - 2200
EPZERO - 2400
EQMX - 500
EWDTMX - 500 73
EWDTRR - 500 73
FEU - 1000
FIE - 1000
FIMDED - 1000
FIMPR - 1000

Figure G.6. (Continued)

FIP - 19C0
FIPONL - 21C0
FIPONR - 21C0
FIXX - 25C0 322* 328 329 331
FIXXF - 19C0
FIXXPR - 10C0
FIXXW - 10C0
FIYZF - 10C0
FIYZP - 25C0 323* 325 330
FIYZPR - 10C0 317 320
FIYZQ - 25C0 325*
FIYZR - 25C0 330*
FIYZW - 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
FSHACH - 16C0 67* 68
THE VARIABLE FSORT IS USED BEFORE IT IS DEFINED
FSORT - 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 48 57 58 102 103 126
HDOT - 9C0
HDTACL - 23C0
HDTACR - 23C0
HGEFLR - 19C0 141* 143 144 145 146
HGEFRR - 19C0 128* 130 131 132 133
HLIUB - 19C0 140* 141
HOLD - 3C0
HOLD2 - 3C0
HP - 10C0 245 246 252 253
HRIUB - 19C0 126* 128 140
HSO - 14C0 48* 57
HTC4 - 19C0 103* 106 107 109 110 294
HYSTLL - 8C0

Figure G.6. (Continued)

HTVTKT - 13C0
HWACL - 23C0
HWAC9 - 23C0
HWC4 - 19C0 1.2# 114 117 130 121 293 294
* HYBCON - 3#
* HYBIO - 4#
HIOTL - 23C0
HIOTR - 23C0
HIL - 23C0
HIR - 23C0
IAD - 3C0
IADC3 - 11C0
IC - 3C0
ICDSPC - 2C0
ICLR - 3C0
ICONDP - 6C0 1CAG
IC2 - 3C0
IDUPC - 3C0
IEC - 1C0 29AG
IECHAN - 3C0
IFLAG - 2C0
IFRAME - 3C0
IGN - 3C0
IHJR - 3C0
ILEX - 3C0
* INITVR - 14#
IOC - 3C0
IOCPI - 3C0
IPAN - 2C0 339#
IPHASE - 6C0
IPSNOS - 1C0
IRCTS - 3C0
IRCX - 3C0
IREVNT - 29AG
IRUNIT - 3C0
ISCNPF - 2C0
ISENCF - 4C0 29AG 3CAG 31AG
ISETC - 3C0
ISHRC - 3C0
ISLOW - 6C0 314#
ISTA - 6C0 215AG 21#
ISTAD - 3C0
ISTAD2 - 3C0
ISTA - 6C0 23CAG 23J
ISTDA - 3C0
ISTDA2 - 3C0
ISTGO - 1C0
ISTGO2 - 1C0
ISTHO - 3C0
ISTHO2 - 3C0
ISTIC - 3C0
ISTIC2 - 3C0
ISTPIT - 1C0
ISTRRI - 11C0 3A
ISTRW - 3C0

Figure G.6. (Continued)

	ISTAR2	-	3C0					
	ISYNC	-	3C0					
	ITRIM	-	6C0	12	35*			
	ITSC	-	3C0					
	IWARN1	-	6C0	7LG	217*	218*	231*	233*
	IWARN2	-	6C0	7LG				
	IWREVT	-	6C0					
	J	-	33700	338AG				
	JTRIM	-	6C0	32				
	KAR	-	4C0					
	KONFR	-	2C0					
	KPAN	-	29*	34*	216*	232*	339	
	KTRIM	-	6C0	31AG	32			
	LETR	-	3C0					
*	LINT	-	215*	230*				
	MICNT	-	2C0					
	MIECR	-	2C0					
	MONDIG	-	3C0					
*	NACVAR	-	20*					
	NADCS	-	3C0					
	NCHAIN	-	3C0					
	NCON	-	3C0	28AG				
	NCONSL	-	3C0					
	NDACS	-	3C0					
	NFRAME	-	2C0					
	NGEF	-	6C0	105	115	129	147	292
	NIOS	-	3C0					
	NOSIM	-	2C0					
	NPCS	-	3C0					
	NPLOT	-	6C0					
	NPLOT2	-	6C0					
	NQIND	-	5C0					
	NRNOID	-	5C0					
	NTWST	-	6C0					
	NVB	-	6C0					
	NWOFID	-	5C0					
	N1IND	-	5C0					
	N1THID	-	5C0					
	N2IND	-	5C0					
	OMDOT	-	9C0					
	OMDTL	-	17C0					
	OMDTR	-	17C0					
	OMEGA	-	9C0	75				
	OMEGAL	-	17C0					
	OMEGAR	-	17C0					
	OMEGEL	-	16C0	91*				
	OMEGER	-	16C0	79AG	81	92*		
	OMREF	-	10C0	75				
	OMSOL	-	17C0					
	OMSOR	-	17C0					
	OMOVTC	-	16C0	61*	62	72		
	OOVDSK	-	8C0					
	OOVFSH	-	16C0	68*	112	124		
	OOVIXX	-	25C0	331*				
	OOVIYY	-	25C0	332*				

Figure G.6. (Continued)

	OVI77	-	2900	313*						
	OPERA	-	300							
	OPERA2	-	300							
	OVDFIN	-	900							
	OVSOTH	-	1600	71*	74					
	OVSOTL	-	1400	72*	73					
	P	-	2500							
	PC	-	1900	245	246	252	253			
	PCTOL	-	1600							
	PCTOR	-	1600	79AG						
	PGUST	-	900							
	PHI	-	900	41AG						
	PHIPH	-	1000							
	PI	-	1300							
	PILMSK	-	200							
	PIOV2	-	1300							
	PNLN	-	2100							
	PNLR	-	2100							
	PNRN	-	2100							
	PNRR	-	2100							
	PP	-	2500							
	PPRIME	-	900							
	PQ	-	2500							
	PR	-	2500							
	PROJ	-	300							
	PSI	-	900	19AG						
	Q	-	2500							
	QFSW	-	1800	49*	96	97	98	99	100	101
	QGUST	-	900							
	QNLN	-	2100							
	QNLR	-	2100							
	QNRN	-	2100							
	QNRR	-	2100							
	QPRIME	-	900							
	R	-	2500							
	RCPL	-	1100	33AG						
	RDTHOG	-	1900							
	RESLR	-	2200	229*	226					
	RESRR	-	2200	213*	212					
*	RETURN	-	336*	341*						
*	REVENT	-	28*							
	RGUST	-	900							
	RNLN	-	2100							
	RNLR	-	2100							
	RNRN	-	2100							
	RNRR	-	2100							
	ROE	-	1600	62*	63	211				
	ROEOV2	-	1600	63*	192	193				
	ROFO	-	500	62						
	ROPTR4	-	2100							
	ROPTR5	-	2100							
	ROTFPS	-	1900							
	ROTRAD	-	1900	128	141	247	256			
*	ROTVAR	-	21*							
	RPRIME	-	900							

Figure G.6. (Continued)

RQ - 25C0
RR - 25C0
RR11 - 19C0 278= 279 285= 286
RR12 - 19C0 279= 280 286= 287
* RTPASS - 8*
* RTSLOW - 1*
SALIHT - 24C0
SALLN - 20C0 156AG 160 202 203 207
SALLW - 22C0
SALRN - 20C0 157AG 161 196 197 201
SALRW - 22C0
SAVINW - 22C0 243AG 245 246 252 253
SAVPET - 22C0 242AG 251 255
SBETLN - 20C3 158AG 162 207 233 234 206 207
SBFTLW - 22C3
SBFTRN - 20C3 159AG 163 196 197 198 200 201
SBFTRW - 22C0
SBETSG - 24C3
SBFCAF - 19C0 94= 97 101
SBFPR - 10C0
SBFSAF - 18C0 93= 96 100
SBWPR - 10C0
SP1 - 19C0
SCADC1 - 9C0
SCADC2 - 9C0
SCADC3 - 9C0
SCADC4 - 9C0
SCDAC1 - 9C0
SCDAC2 - 9C0
SCDAC3 - 9C0
SCDAC4 - 9C0
SFPLW - 22C0
SFPRW - 22C0
SFNFL - 26C0
SFNFR - 26C0
SFPL - 26C0
SFPHL - 26C0
SFPHR - 26C0
SFPR - 26C0
SFQL - 26C0
SFQR - 26C0
SFSFL - 26C0
SFSFR - 26C0
SFTL - 26C0
SFTR - 26C0
SFYHL - 26C0
SFYHR - 26C0
SG - 10C0
SGNULW - 22C0
SGNURW - 22C0
SHF - 19C0 277
SHPPRL - 16C0 80=
SHPPRR - 16C0 79AG 80
SHPRQL - 21C0
SHPRQR - 21C0

Figure G.6. (Continued)

SHPSTR - 5C0
SHW - 10C0 239
SIGMA - 24C0
SIL - 22C0 268* 269 270
SILAML - 14C0 53 303 308 310
SILAMR - 14C0 53 301 304 306
SILW - 22C0 259*
SINALF - 18C0 84AG 86 93 96 97 101
SINBTF - 18C0 85AG 87 93 94 98
SINCOS - 39* 40* 41* 84* 85* 156* 157* 158* 159* 219* 228* 242* 243*
SININL - 14C0 43 46 141
SININR - 14C0 42 47 126 128
SINIW - 8C0
SINLAM - 9C0
SINPHI - 18C0 41AG 54 55 126 140
SINPSI - 14C0 39AG 54 55
SINTHE - 18C0 40AG 54 55 102 109 126 128* 141
SINZNL - 21C0
SINZNP - 21C0
SIR - 22C0 265* 266 268 271
SIRW - 22C0 266*
SIT - 22C0 267* 268
SKEPS - 10C0
SK' - 10C0 87
SK1 - 10C0 90
SK10 - 10C0 92
SK2 - 10C0 89
SK20 - 10C0
SK21 - 10C0
SK22 - 10C0
SK3 - 10C0 88
SK30HI - 10C0 170 194
SK30L - 166* 170* 173
SK30LO - 10C0 156 180
SK30R - 180* 194* 197
SK31HI - 10C0 171 195
SK31L - 167* 171* 173
SK31LO - 10C0 157 181
SK31R - 181* 195* 197
SK32 - 10C0 174 188
SK34 - 10C0 175 189
SK35 - 10C0 175 189
SK36 - 10C0 190
SK37 - 10C0 190
SK38 - 10C0 191
SK39 - 10C0 191
SK4 - 10C0 93
SK40 - 10C0 177
SK41 - 10C0 177
SK42 - 10C0 99
SK43 - 10C0 176
SK44 - 10C0 176
SK45 - 10C0
SK46 - 10C0
SK47 - 10C0

Figure G.6. (Continued)

SK48 - 10CD
SK49 - 10CD
SK5 - 10CD 91
SK50 - 10CD
SK6 - 10CD 91
SK7 - 10CD 90
SK8 - 10CD 90
SK9 - 10CD 92
SL - 10CD 300 301 302 303
SLAC - 8CD
SLF - 10CD 296
SLPA - 10CD
SLW - 10CD 298
SM - 10CD
SMA - 16CD 64= 65
SMF - 10CD
SMH - 10CD
SMW - 10CD
SPAN - 10CD 100 101 200 201 206 207
SPHIP - 8CD
* SPIO - 11*
SQF - 18CD 49
SQFARG - 13CD
SQFPRM - 10CD
SQLNG - 20CD 192= 195
SQLW - 22CD
SQN1MX - 16CD 78=
SQRESL - 22CD 226= 227 286
SQRESR - 22CD 212= 213 279
SQRNG - 20CD 193= 194
SQRW - 22CD
SQTHTC - 16CD 60= 64 69 71
SQWDTX - 16CD 77=
SQWING - 22CD
SSQINL - 14CD 43= 44 315
SSQINR - 14CD 42= 45 316
STAULR - 22CD 228AG 234
STAURR - 22CD 219AG 220
SUMIXX - 8CD
SUMIXZ - 8CD
SUMIYY - 8CD
SUMIZZ - 8CD
SVSTAB - 13CD 215AG 230AG
SVSTAR - 22CD 215AG 220 221 275 279
SVSTRL - 22CD 230AG 234 235 274 286
SWLG - 6CD
SWLG2 - 9CD 89 91
SZINL - 14CD 46= 317 319
SZINR - 14CD 47= 317 319
* TAILVR - 24*
* TAN - 244
TAUAG - 13CD
TAUHT - 10CD
TAUL - 3CD
TAULR - 22CD 224= 228AG 229

Figure G.6. (Continued)

TAURR - 2200 209* 214 219AG
TAURT1 - 1000
TAURT2 - 1000
TAUVT - 1000
TAVAEP - 2200 244* 245 252
TDEEF - 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 318* 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 42AG
THETC - 1600 50* 60 61
THTLAC - 2300
THTRAC - 2300
TH75L - 900
TH75R - 900
TIGFL - 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
TOPOL - 2100
TORQR - 2100
TPS* - 900 72
TR - 2100 209 210
TRACK - 27* 135*
TRIM - 300
TRIM2 - 300
TRMAR1 - 2100
TRMAR2 - 2100
TRMAP3 - 2100
TRMAP4 - 2100
TRMHR1 - 2100
TRMHR2 - 2100
TRMHT - 2400
TRMHT2 - 2400
TRMHT3 - 2400
TRMNC1 - 1600 174 175

Figure G.6. (Continued)

TRMNC2 - 161* 198 199
TRMNC3 - 162* 176 177
TRMNC4 - 163* 190 191
TRMTTL - 25C0
TRMTTR - 25C0
TR4VT - 24C0
TR4VT2 - 24C0
TR4VT3 - 24C0
TR4WG1 - 22C0 211* 212 226
TR4WG4 - 23C0 234* 236
TR4WG5 - 22C0
TR4WG6 - 22C0
TR4WG7 - 22C0
TR4WG8 - 22C0
TR4WG9 - 23C0 235* 236
TSBASE - 3C0
TSREQD - 3C0
* TSTRTS - 3A*
TZERO - 5C0 58
TZET1 - 22C0 245* 246 251
TZET2 - 22C0 246* 247
TZET3 - 22C0 247* 248 250
TZET4 - 22C0 252* 253 255
TZET5 - 22C0 253* 254
TZET6 - 22C0 254* 256 258
U - 25C0
UGUST - 9C0
UMT - 17C0
ULW - 17C0
ULWPR - 17C0
ULWSQ - 17C0
UP - 17C0
UPRIME - 9C0 54 55
URL - 17C0 152
URLPR - 17C0
URLURL - 17C0 51 192
URR - 17C0 153
URRPR - 17C0
URRURR - 17C0 50 193
URW - 17C0
URWPR - 17C0
URWSQ - 17C0
* USEAID - 33*
USQ - 17C0
UVT - 17C0
V - 25C0 276
VALFLW - 17C0
VALFRW - 17C0
VALFS - 17C0
VALNCL - 17C0 51* 154
VALNCR - 17C0 50* 155
VBETVT - 17C0
VEAST - 15C0 55*
* VELVAR - 17*
VGUST - 9C0

Figure G.6. (Continued)

```
      VLW      -    17C0
      VLWPR    -    17C0
      VLWSQ    -    17C0
      VNORTH   -    15C0    94*
      VP       -    17C0
      VPRIMF   -     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*    231AG   235     237     274
      VTIPL    -    17C0
      VTIPR    -    17C0
      VTOTAL   -    17C0    65
      VTOTLR   -    17C0   227     280
      VTOTRR   -    17C0   213     297
      VTSTLL   -     AC0
      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      211     212     225     226     257     258
      WP       -    17C0
      WPRIME   -     9C0    54       55
      WRL      -    17C0   192
      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 - 21C0
* XAIO - 9#
XAREF - 18C0 97# 99
XARHT - 24C0
XARVT - 24C0
XCG - 15C0 52# 99 100 102 123 126 296 298 300 302
XDTCG - 15C0
XF - 25C0 296# 314
XFAC - 10C0 99 100
XFCON - 8C0
XFNFLF - 25C0 314# 324 326
* XFUNC - 13#
XHT - 10C0 123
XL - 25C0 302# 310 311
XLCOS - 25C0 311# 321
* XLINTP - 12#
XLSIN - 25C0 310#
* XPAP1 - 10#
* XPAP3 - 26#
XR - 25C0 3[illegible]# 306 307
XRCOS - 25C0 307# 321
XRLCON - 8C0 42
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
YAREF - 18C0 99# 100 101
YARHT - 24C0
YARVT - 24C0
YN - 10C0 126 140
YPA - 10C0
YWAC - 10C0
YYICON - 8C0 324
YYJCON - 8C0

Figure G.6. (Continued)

ZAFRF - 18C0
ZAERLW - 22C0
ZAERNC - 21C0
ZAFRNL - 21C0
ZAERNR - 21C0
ZAERO - 25C0
ZAERRH - 22C0
ZAERT - 24C0
ZAERWG - 22C0
ZARFP - 18C0 96= 99
ZARHT - 24C0
ZARVT - 24C0
ZCG - 15C0 93= 99 131 172 103 126 297 299 351 303
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
ZFHFHF - 25C0 312= 322 324
ZHT - 10C0 133
ZL - 25C0 333= 338 309
ZLCOS - 25C0 329= 323
ZLSIN - 25C0 334= 318
ZPA - 10C0
ZR - 25C0 331= 304 305
ZRCOS - 25C0 314= 323
ZRLCON - 9C0 53
ZRSIN - 25C0 304= 318
ZVT - 10C0
ZW - 25C0 299= 313 323
ZWAC - 10C0 102
ZWCON - 9C0
ZWWHW - 25C0 313= 322 324
ZZICON - 8C0 326
ZZJCON - 8C0

Figure G.6. (Continued)

```
INDEX          SUBROUTINE ATLSP(DEL,SPOIL,DCLA,DCOA,DCMA,DCLS,DCOS,DCMS)

      1        SUBROUTINE ATLSP(DEL,SPOIL,DCLA,DCOA,DCMA,DCLS,DCOS,DCMS)
      2        COMMON/XPARM1/ XPAR1(320),
     *PIOV2  ,CLMAX ,ALPO  ,RKFSW ,RKSSW ,SCFPRM,DEG2D ,DGTORD,HTVTKT,   1337D141
     *PIOV2 ,RDTODG,ROTFPS,SKFPS ,ALNCBK,TAURT1,TAURT2
      3        COMMON/XPAR1/ 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  ,SFYFL ,SFSFL ,SFPHL ,SFYHL ,SFQL  ,SFPL  ,
     E              SFTR  ,SFSFR ,SFSFR ,SFPHR ,SFYHR ,SFQR  ,SFPR
     F             ,CONS71,CONS72,CONS73,CONS74,CONS75,CONS76,CONS77   1067D311
     G             ,CONS78,CONS79,CONS80,CONS81                        1338
              C
      4        NOPT= 2
      5        GO TO 5
      6        ENTRY CLF1(DEL,CLZ)
      7        NOPT= 1
      8    5   CONTINUE
              C
      9         IF(DEL.GT.DBRK7) GO TO 30
     10        DCLA= CONS27*DEL
     11        GO TO 45
     12   30   IF(DEL.GT.DBRK8) GO TO 40
     13        DCLA= CONS28*DEL*(CONS29+CONS30*DEL)
     14        GO TO 45
     15   40   DCLA= CONS31*DEL*(CONS32+CONS33*DEL)
     16   45   CONTINUE
     17        IF(NOPT.NE.1) GO TO 48
     18        CLZ= DCLA
     19        RETURN
     20   48   CONTINUE
              C
     21        DCOA= 0.
              C
     22        IF(DEL.GT.DBRK21) GO TO 55
     23        DCMA= DEL*(CONS34+DEL*CONS35)
     24        GO TO 65
     25   50   DCMA= DEL*(CONS36+DEL*CONS37)  *CONS38
     26   55   CONTINUE
              C
     27        IF(SPOIL.GT.DBRK20) GO TO 60
     28        DCLS= CONS39*SPOIL
     29        GO TO 65
     30   60   DCLS= CONS40+SPOIL*(CONS67+CONS68*SPOIL)
     31   65   CONTINUE
              C
```

Figure G.6. (Continued)

```
I N D E X          SUBROUTINE AILSPIDEL,SPOIL,DCLA,DCJA,DCMA,DCLS,DCOS,DCMS)          PAGE   95

   32          DCOS= CONS69*SPOIL*(CONST0+CONST1*SPOIL)
               C
   33          DCMS= 0.
               C
   34          RETURN
   35          END
```


Figure G.6. (Continued)

SYMBOL REFERENCES

5	5	8*	
30	9	12*	
40	12	15*	
45	11	14	16*
49	17	20*	
50	22	25*	
55	24	26*	
60	27	10*	
65	29	11*	
* AILSP	1*		
AIRRK	200		
ALNGAK	200		
RKLSW	200		
RKNSW	200		
* CLFL	6*		
CLMAK	200		
CLF	445	18*	
CNST	100		
CONSI0	300		
CONSI1	300		
CONSI2	300		
CONSI3	300		
CONSI4	300		
CONSI5	300		
CONSI6	300		
CONSI7	300		
CONSI8	300		
CONSI9	300		
CONS2	100		
CONS20	300		
CONS21	300		
CONS22	300		
CONS23	300		
CONS24	300		
CONS25	300		
CONS26	300		
CONS27	300	10	
CONS28	300	13	
CONS29	300	13	
CONS3	100		
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	100		
CONS40	300	30	
CONS41	300		

Figure G.6. (Continued)

CONS42 - 3C0
CONS43 - 3C0
CONS44 - 3C0
CONS45 - 3C0
CONS46 - 3C0
CONS47 - 3C0
CONS48 - 3C0
CONS49 - 3C0
CONS5 - 3C0
CONS50 - 3C0
CONS51 - 3C0
CONS52 - 3C0
CONS53 - 3C0
CONS54 - 3C0
CONS55 - 3C0
CONS56 - 3C0
CONS57 - 3C0
CONS58 - 3C0
CONS59 - 3C0
CONS6 - 3C0
CONS60 - 3C0
CONS61 - 3C0
CONS62 - 3C0
CONS63 - 3C0
CONS64 - 3C0
CONS65 - 3C0
CONS66 - 3C0
CONS67 - 3C0 33
CONS68 - 3C0 34
CONS69 - 3C0 37
CONS7 - 3C0
CONS70 - 3C0 32
CONS71 - 3C0 32
CONS72 - 3C0
CONS73 - 3C0
CONS74 - 3C0
CONS75 - 3C0
CONS76 - 3C0
CONS77 - 3C0
CONS78 - 3C0
CONS79 - 3C0
CONS8 - 3C0
CONS80 - 3C0
CONS81 - 3C0
CONS9 - 3C0
DBPK1 - 3C0
DBPK10 - 3C0
DBPK11 - 3C0
DBPK12 - 3C0
DBPK13 - 3C0
DBPK14 - 3C0
DBPK15 - 3C0
DBPK16 - 3C0
DBPK17 - 3C0
DBPK18 - 3C0

Figure G.6. (Continued)

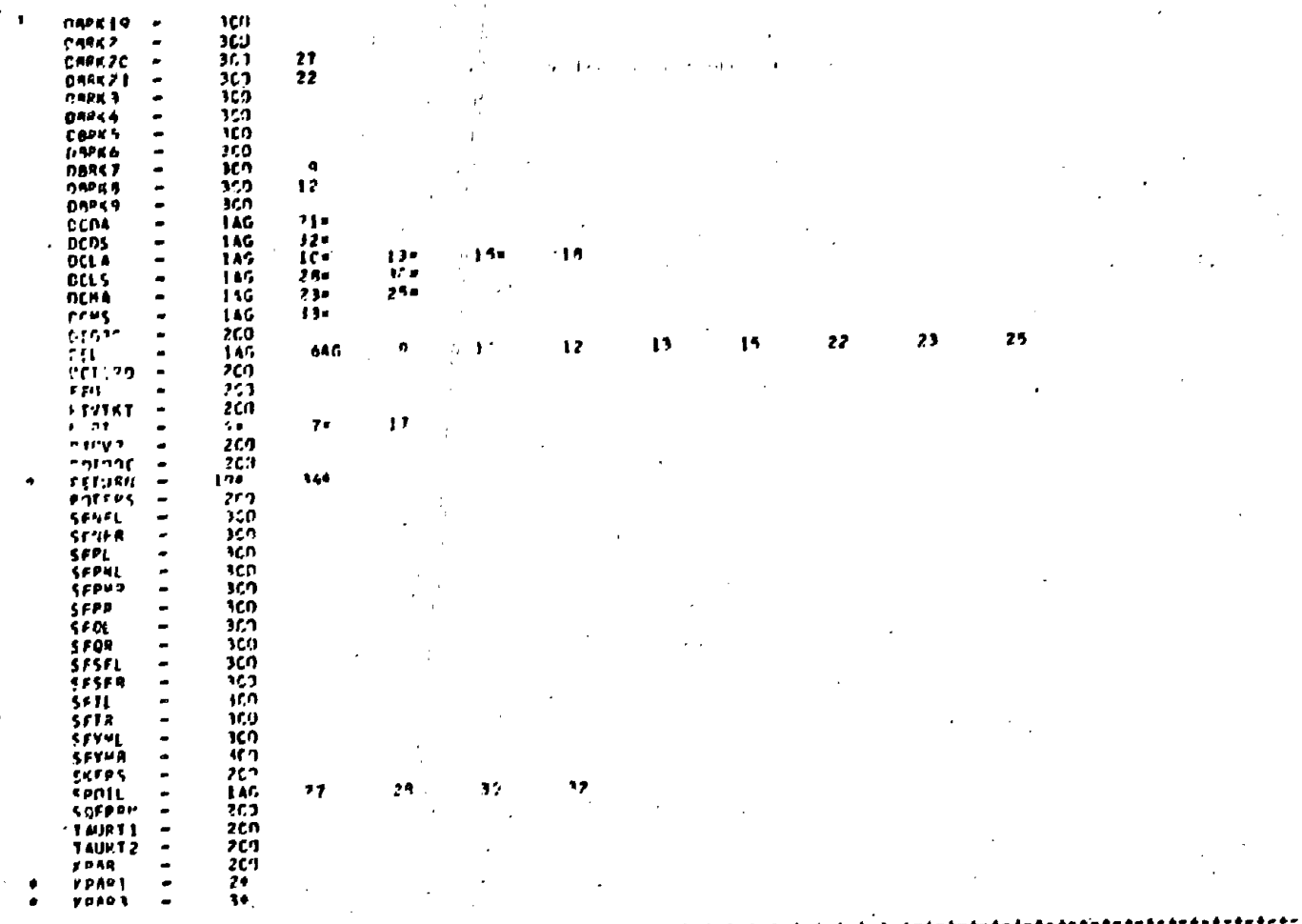


Figure G.6. (Continued)

```
      1          SUBROUTINE CLCDCM(ALPHA,DEL,CLDEL,CLSP,CDFASP,CMFASP,CL,CD,CM,
     *  CLP,CDP)
      2          COMMON/XACDEF/ 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
     *DCOLG ,DCMLG ,FINPR ,GOVT  ,GSOBET,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    ,RDTRAD,  44 TO 52
     *SBFPR ,SBWPP ,SG    ,SHF   ,SHN   ,SK0   ,SK1   ,SK2   ,SK3   ,  53 TO 61
     *SK4   ,SK5   ,SK6   ,SK7   ,SK8   ,SK9   ,SK10  ,SK20  ,SK21  ,  62 TO 70
     *SK22  ,COONLO,SK30LO,SK31LO,SK32  ,COONHI,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 ,SK30H1,CN2REF,KWC2  ,DT1   ,BT2   ,BT3   ,
     *DK01T ,DK02T ,DK03T ,DKM1T ,DKM2T ,DKM3T ,DKM4T ,SK31H1,
     *FFU   ,CLMAX ,ALPHK ,PKLSW ,DKNSW ,SQFPHM,DCG25 ,DGTORD,HTVTKT,  133T0141
     *PIOV2 ,ROTORG,RDTEPS,SKEPS ,ALNGAK,TAURT1,TAURT2
      4          COMMON/GEEVAR/
     1 AGOVAT,AGOVAW,AIGX  ,AK30  ,BMOVTL,BMOVTS,COWCOR,CLTCOR,CLWCOR,   1 -  9
     2 DOVTL ,DOVTR ,EPPRM ,GFF   ,HGEFFM,HGEFRR,HLHUB ,HRHUB ,HTC4  ,  10 - 18
     3 HXC4  ,RR11  ,RR12  ,SBL   ,TIGEL ,TIGER                         19 - 24
      5          COMMON/FLAGS/ IWARN1(16),IWARN2(16),ISENCE(2),IWREVT(2),ICONTP,
     1 ITRIM,JTRIM,KTRIM,NPLOT,NPLOT2,IPHASE,ISLOW,SWLG,GRUTON,
     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             ,CONST1,CONST2,CONST3,CONST4,CONST5,CONST6,CONST7   106T7112
     G             ,CONST8,CONST9,CONS10,CONSP1                       113T0116
      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 * RDTOD
      CLALDG= CLALPH*DGTORD
C
      IF(DEL.GT.DARK2) GO TO 1
      ALNLP= CONS1 +CONS2*DEL
      ALNLM= CONS3+CONS4*DEL
      GO TO 20
   10 ALNLP=  CONS5
      ALNLM=  CONS6
   20 CONTINUE
      ALARK1= ALNLP+DARK3
      ALARK2=  ALNLM-DARK3
C
      IF(DEL.GT.DARK6)  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
      IWARN(4)=  .FALSE.
      IF(ALDEG.GE.ALARK2) GO TO 102
      CLNLP=  CL1+CLALDG*ALNLP
      CLP= CLNLP*(CONS7+ALDEG)/(CONS7+ALARK2)
      IWARN(4)=  .TRUE.
      GO TO 140
  101 IF(ALDEG.GE.ALNLM) GO TO 110
      CLNLP=  CL1+CLALDG*ALNLM
      ALDUM= ALNLM-ALDEG*CONS1
      DCLNL= ALDUM*(CONS8*ALDUM+CONS9 +CONS10
      CLP= CLNLP-DCLNL
      IWARN(4)=  .TRUE.
      GO TO 140
  110 IF(ALDEG.GT.ALNLP) GO TO 120
      CLP=  CLALDG*ALDEG+CL1
      GO TO 140
  120 IF(ALDEG.GT.ALARK1) GO TO 130
      CLNLP=  CL1+CLALDG*ALNLP
      ALDUM=  ALDEG-ALNLP+CONS1
      DCLNL = ALDUM*(CONS8*ALDUM+CONS9)+CONS10
      CLP=  CLNLP+DCLNL
      IWARN(4)=  .TRUE.
      GO TO 140
  130 CONTINUE
      CLNLP=  CL1+CLALDG*ALNLP
      CLP= CLNLP*(CONS7-ALDEG)/(CONS7-ALARK1)
  140 CONTINUE
      IF(NDOT.NE.1) GO TO 150
      CL2=  CLP*CLWOOR
      RETURN
  150 CONTINUE
C
      CLPMX= CLMAX*CLDEL*CLSP
      CLIGE=  CLP*CLWOOR
      IF(CLIGE.LT.CLPMX) GO TO 160
      DODIGE= 1.
```

Figure G.6. (Continued)

```
I N D E X          SUBROUTINE CLCDE(ALPHA,DEL,CLDEL,CLSP,CDFASP,CMFASP,CL,CD,CM,
     C
      85            CLIGE= CLPHX
      86            GO TO 170
      87      140   CDDIGE= CDMC*P*(CLIGE-CL0)*(CLIGE-CL0)
      88      170   CONTINUE
     C
      89            ALDUM= DBRK4
      70            IF(ALDEG.LT.DBRK4) ALDUM=DBRK4
      71            IF(ALDEG.GE.DBRK4.AND.ALDEG.LE.DBRK5) ALDUM= ALDEG
     C
      72            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)
      73            IF(ALDEG.GE.DBRK4) GO TO 180
      74            CDM= CONS11+CD1+CDFASP
      75            CDB= CLM-(CL-CDM)*(ALDEG-DBRK4)*CONS12
      76            CMB= (CONS17+CMFASP)*(CONS7+ALDEG)*CONS12
      77            GO TO 200
      78      180   IF(ALDEG.GT.DBRK5) GO TO 190
      79            CDB= ALDEG*(CONS13+ALDEG*CONS14) +CONS15+CD1+CDFASP
      80            CMB= CONS16+CONS18*ALDEG+CMFASP
      81            GO TO 200
      82      190   CDPLUS= CONS11+CD1+CDFASP
      83            CDB= CDPLUS+(1.-FDPLUS)*(ALDEG-DBRK5)*CONS12
      84            CMB= (CONS20+CMFASP)*(CONS7-ALDEG)*CONS12
      85      200   CONTINUE
     C
     C
      86            CL= CLIGE
      87            CD= CDP+DCDIGE
      88            CM= CMP
     C
      89            RETURN
      90            END
```

Figure G.6. (Continued)

PAGE

SYMBOL		REFERENCES												
5	-	9	12*											
10	-	15	19*											
20	-	19	21*											
100	-	31	36*											
115	-	36	43*											
112	-	24	27*											
114	-	26	28*											
120	-	43	46*											
130	-	46	53*											
140	-	35	42	45	52	55*								
150	-	57	59*											
160	-	63	67*											
170	-	66	68*											
180	-	73	78*											
190	-	78	82*											
200	-	77	81	[illegible]										
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												
AGOVAM	-	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)

ALNG9K - 300
ALNL9 - 17* 29* 31 32 36 37 38
AL*L2 - 16* 19* 22 43 47 48 54
ALPHA - 140 1730 13
ALVTST - 300
AREAHT - 300
AREAVT - 300
AREAW - 300
ARHT - 300
ARVT - 300
AVEYAC - 300
AVEYCS - 300
BIGX - 400
BKD1T - 300
BKD2T - 300
BKD3T - 300
BKLSW - 300
BKM1T - 300
BKM2T - 300
BKM3T - 300
BKM4T - 300
BKNSW - 300
BKQQ - 400
BLS - 300
BMOVTL - 400
BMOVTR - 400
BT1 - 300
BT2 - 300
BT3 - 300
CD - 140 47*
CDFASP - 140 74 79 92
CDV - 74* 75
CDDF - 300
CDDHT - 300
CDDVHI - 300
CDDVLO - 300
CDDVT - 300
CDP - 140 75* 79* 83* 87
CDPLUS - 92* 93
CDWCDF - 400 67
CDI - 72* 74 79 82
CHORD - 300
CL - 140 85*
CLALDD - 14* 37 37 44 47 54
CLALHT - 300
CLALPH - 300 14
CLCDCM - 1*
CLDEL - 140 1740 20 61
CLF2 - 13*
CLIGE - 62* 63 65* 67 86
CLMAX - 300 61
CLNLP - 32* 33 37* 43 47* 53 54* 55
CLOAL - 300 29
CLP - 140 33* 40* 44* 50* 55* 58 62 67
CLPMX - 61* 63 65

Figure G.6. (Continued)

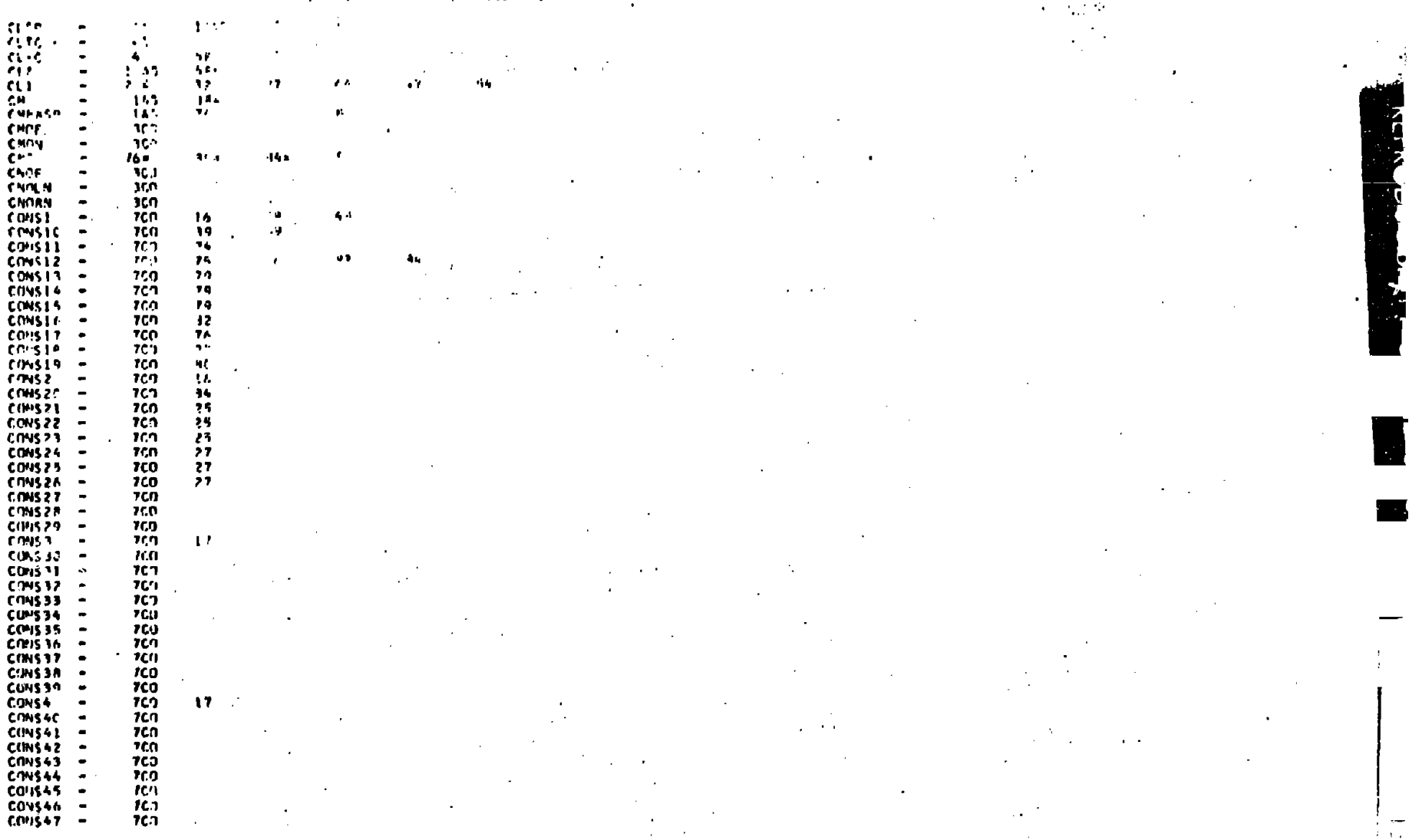


Figure G.6. (Continued)

CONS48 - TCO
CONS49 - TCO
CONS5 - TCO 19
CONS50 - TCO
CONS51 - TCO
CONS52 - TCO
CONS53 - TCO
CONS54 - TCO
CONS55 - TCO
CONS56 - TCO
CONS57 - TCO
CONS58 - TCO
CONS59 - TCO
CONS6 - TCO 20
CONS60 - TCO
CONS61 - TCO
CONS62 - TCO
CONS63 - TCO
CONS64 - TCO
CONS65 - TCO
CONS66 - TCO
CONS67 - TCO
CONS68 - TCO
CONS69 - TCO
CONS7 - TCO 13 55 76 94
CONS70 - TCO
CONS71 - TCO
CONS72 - TCO
CONS73 - TCO
CONS74 - TCO
CONS75 - TCO
CONS76 - TCO
CONS77 - TCO
CONS78 - TCO
CONS79 - TCO
CONS8 - TCO 39 49
CONS80 - TCO
CONS81 - TCO
CONS9 - TCO 39 49
CYALVT - TCO
DARK1 - TCO
DARK10 - TCO
DARK11 - TCO
DARK12 - TCO
DARK13 - TCO
DARK14 - TCO
DARK15 - TCO
DARK16 - TCO
DARK17 - TCO
DARK18 - TCO
DARK19 - TCO
DARK2 - TCO 19
DARK2C - TCO
DARK21 - TCO
DARK3 - TCO 22 23

Figure G.6. (Continued)

DBRK4 - 7C0 70 71 73 75
DBRK5 - 7C0 69 71 78 83
DBRK6 - 7C0 24
DBRK7 - 7C0
DBRKA - 7C0
DBRK9 - 7C0
DCOIGE - 44= 67= 87
DCOLG - 3C0
DCLNL - 39= 40 49= 50
DCMLG - 3C0
DEG20 - 3C0
DEL - 1A0 15 16 17 24 25 27 72
DGTORD - 3C0 14
DOVT - 3C0
DOVTL - 4C0
DOVTR - 4C0
DSOBET - 3C0
EFFHT - 3C0
EFFVT - 3C0
EN2REF - 3C0
EPPRM - 4C0
F - 25= 27= 29
FEU - 3C0
FIE - 3C0
FINDEG - 3C0
FINPR - 3C0
FIP - 3C0
FIXXF - 3C0
FIXXPR - 3C0
FIXXW - 3C0
FIXZF - 3C0
FIXZPR - 3C0
FIXZW - 3C0
FIYYF - 3C0
FIYYPR - 3C0
FIYYW - 3C0
FIZZF - 3C0
FIZZPR - 3C0
FIZZW - 3C0
• FLAGS - 5=
GBUTON - 5C0
GEF - 4C0
• GEFVAR - 4=
HGEFLR - 4C0
HGEFRR - 4C0
HLHUB - 4C0
HP - 3C0
HRHUB - 4C0
HTC4 - 4C0
HTVTRT - 3C0
HWC4 - 4C0
ICONDP - 5C0
IPHASE - 5C0
ISENCE - 5C0
ISLOW - 5C0

Figure C.6. (Continued)

ISTA	-	5C0					
ISTR	-	5C0					
ITRIM	-	5C0					
IWARN1	-	5C0	ALG	32*	34*	41*	51*
IWARN2	-	5C0	6LG				
IWREVT	-	5C0					
JTRIM	-	5C0					
KTRIM	-	5C0					
NGEF	-	5C0					
NOPT	-	8*	11*	57			
NPLOT	-	5C0					
NPLOT2	-	5C0					
NTWST	-	5C0					
NVB	-	5C0					
OMREF	-	3C0					
PC	-	3C0					
PHIPH	-	3C0					
PI	-	3C0					
PIOV2	-	3C0					
ROTODG	-	3C0	13				
* RETURN	-	4**	8**				
ROTFPS	-	3C0					
ROTRAD	-	3C0					
RR11	-	4C0					
RR12	-	4C0					
SBFPR	-	3C0					
SBMPR	-	3C0					
SB1	-	4C0					
SFNFL	-	7C0					
SFNFR	-	7C0					
SFPL	-	7C0					
SFPML	-	7C0					
SFPMR	-	7C0					
SFPR	-	7C0					
SFQL	-	7C0					
SFQR	-	7C0					
SFSFL	-	7C0					
SFSFR	-	7C0					
SFTL	-	7C0					
SFTR	-	7C0					
SFYML	-	7C0					
SFYMR	-	7C0					
SG	-	3C0					
SHF	-	3C0					
SHN	-	3C0					
SKFPS	-	3C0					
SKO	-	3C0					
SKI	-	3C0					
SKIO	-	3C0					
SK2	-	3C0					
SK20	-	3C0					
SK21	-	3C0					
SK22	-	3C0					
SK3	-	3C0					
SK30HI	-	3C0					

Figure G.6. (Continued)

SK9CLD - 3C0
SK9IN1 - 3C0
SK9ILD - 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
SMM - 3C0
SMW - 3C0
SPAN - 3C0
SQFPRM - 3C0
SWLG - 3C0
TAUHT - 3C0
TAURT1 - 3C0
TAURT2 - 3C0
TAUVT - 3C0
TIGEL - 4C0
TIGER - 4C0
* XACDEF - 2*
XFAC - 3C0
XHT - 3C0
* XPAR1 - 3*
* XPAR3 - 7*
XVT - 3C0
XWAC - 3C0
XWC2 - 3C0
YM - 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 ,NDEND ,NRNOID ,
     *                       FWDTMX,EN1MX ,EN1TMX,EN2MX ,EQMX  ,SHPSTR
     *                     ,  EWDTPR,EN1STR,ROE0  ,ZERO ,TCOEF
      3          COMMON/ENGVAR/
                 1 AMACH ,AMACSQ,OFL   ,EMAXN1,EMAXN2,EMXWDT,EN2STR,FSMACH,OMEGEL,   1 -  9
                 2 OMEGFR,ONUVTC,ONVFSM,OVSQTH,OVTHOL,ROE   ,ROEOV2,SHPPRL,SHPPR,   10 - 18
                 3 SMA   ,SONIMX,SQTHTC,SQWDTX,TOEGF ,TEAL  ,TEAR  ,THCDEL,THETC    19 - 27
                 4,PCTQL,PCTQR                                                      28 TO 29
      4          COMMON/FLAGS/ IWARN1(16),IWARN2(16),ISENCE(2),IWREVT(2),ICOMOP,
                 1 ITRIM,JTRIM,KTRIM,NPLOT,NPLOT2,IPHASE,ISLOW,SWLG,GBUTON,
                 2 ISTA,ISTR,NGEF,NVB,NTHST
      5          LOGICAL*1  IWARN1,IWARN2
                 C
                 C     ENGINE CHARACTERISTICS USED
                 C     NWDTID = 1     FUEL FLOW CUTOFF
                 C     N1IND  = 1     N1 CUTOFF
                 C     N1THID = 2     NO REFERRED N1 CUTOFF
                 C     N2IND  = 2     N2 CUTOFF - NON-OPTIMUM N2 VARIATION
                 C     NQIND  = 1     TORQUE CUTOFF
                 C     NRNOID = 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-.2594440650E-05*TEASQ
                *+.1010425181E-08*TEACUB-.1444138416E-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 = 1587.5624254308-1375.3423740741*EMXWDT+12872.399602814*
                *  SQWDTX-22742.789871054*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.1) 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 = -2.262254383 +1.251288659*AMACH+.9621240231*AMACSQ
```

Figure G.6. (Continued)

```
     *  *(.351959542HE-02-.1439742133E-02*AMACH+.1308445977E-02*AMACSQ)*
     *   TEA +
     *  (-.1316093319E-05+.6259988594E-06*AMACH+.6664941537E-06*AMACSQ)*
     *   TEASQ +
     *  (.1766923983E-09-.8357295710E-10*AMACH-.9332102725E-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= 4555.7525996C754266.635140C7463*AMACH-10962.24966689*AMACSQ
     **(-10591.1062235G1-14C0A.747444625*AMACH+34472.65375921?*AMACSQ)*
     *   EMAXN1 +
     *  (13876.68452344?+151C0.9688113098*AMACH-36112.607870716*AMACSQ)*
     *   SQN1MX +
     *  (-2621.662341542-5179.?8?822431*AMAC4+12502.1731364?8*AMACSQ)*
     *   SQN1MX*EMAXN1
   24          TEASQ = TEA * TEA
   25          TEACUB = TEASQ * TEA
   26          TEA4TH = TEACUB * TEA
   27          SN1 = 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 END 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 = -5.587478?552-2.6697228923*AMACH+1.126341937?*AMACSQ
     **(.7055C66994E-C2+.3351714914E-02*AMACH+.1235[91608E-03*AMACSQ)*
     *   TEA +
     *  (-.2593416699E-05-.1287459451E-05*AMACH-.4369359301E-06*AMACSQ)*
     *   TEASQ +
     *  (.3395936162E-(9+.1505373914E-?9*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(NRNDID.EQ.C)  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)

```
      ESHP  = 2.9433431215-.2571902618*AMACH+1.3604785868*AMACSQ
     **(-.6857620248E-02+.7364753977E-03*AMACH-.1979318276E-02*AMACSQ)*
     *  TEA +
     * (.4348718891E-05-.3926992714E-06*AMACH+.1001305662E-05*AMACSQ)*
     *  TEASQ +
     * (-.7408074668E-09+.6969538123E-10*AMACH-.1674167095E-09*AMACSQ)*
     *  TEACUB
C
      ENGSHP= SKPN*SKPR*ESHP
C        END OF ENG 1 SUBR BLOCK
      IF(N1IND.EQ.1) GO TO 6000
      IF(N2IND.NE.1)  GO TO 8000
C        THIS OPTION WILL BE LEFT BLANK UNTIL NEEDED
      GO TO 8000
 6000 IF(N2IND.EQ.2) GO TO 7000
C        THIS OPTION WILL BE LEFT BLANK UNTIL NEEDED
 7000 SHPMAX=  FOMX*EN2STR*DVTHDL
      IWARNI( 3)=  .FALSE.
      IF(ENGSHP.LT.SHPMAX)  GO TO 8000
      IWARNI( 3)=  .TRUE.
      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
      TEA= 1550.0865704333-170.1403074660*AMACH-242.7678229176*AMACSQ
     **(1145.2371955474+149.9327819876*AMACH+706.5669321644*AMACSQ)*
     *  SHPMAX +
     * (-1125.4640744348+74.2124463353*AMACH-792.5722367991*AMACSQ)*
     *  SHPMAX * SHPMAX +
     * (656.3876664477-226.4415181282*AMACH+311.0886620534*AMACSQ)*
     *  SHPMAX*SHPMAX*SHPMAX
      TEASQ = TEA * TEA
      TEACUB = TEASQ * TEA
      TEA4TH = TEACUB * TEA
C
C        SINCE TORQUE LIMIT HIT CAUSING A LOWER TEA TO BE REQ , THE
C           N1 CALCULATION MUST BE RE-CALCULATED
      EN1 = -2.242254353 +1.251248655*AMACH+.9621240231*AMACSQ
     * +(.3519585429E-02-.1539742133E-02*AMACH-.1308445977E-02*AMACSQ)*
     *  TEA +
     * (-.1316C9331BE-05+.6259888594E-06*AMACH+.6364941537E-06*AMACSQ)*
     *  TEASQ +
     * (.1765905983E-09-.8357285710E-10*AMACH-.9302102725E-10*AMACSQ)*
     *  TEACUB
C
 8000 IF(N2IND.NE.1) GO TO 9000
C        THIS OPTION WILL BE LEFT BLANK UNTIL NEEDED
 9000 SHPOUT=  ENGSHP*SHPSTR*THCOEL
      OMENG= EN1*SQTHTC * EN1STR*0.10471966
      PCTORQ  =  100. *THCOEL *EN3SHP /EN2STR
      RETURN
      END
```

Figure G.6. (Continued)

SYMBOL REFERENCES

1000	-	9	12	18*					
2000	-	19	21	28*					
3000	-	29	29*						
4000	-	31	35*						
5000	-	37	38*						
6000	-	41	44*						
7000	-	44	45*						
8000	-	42	43	47	55*				
9000	-	55	56*						
AMACH	-	300	19	23	32	39	50	54	
AMACSQ	-	300	19	23	32	39	50	54	
DEL	-	300							
EMAKN1	-	300	21	33	27				
EMAKN2	-	300							
EMXNDT	-	300	12	14					
* ENG	-	2*							
* ENGINE	-	1*							
ENGSHP	-	41*	47	49*	56	58			
* ENGVAR	-	1*							
EN1	-	19*	31	27*	54*	57			
EN1MX	-	200							
EN1STR	-	200	47						
EN1T4X	-	200							
EN2	-	32*	33						
EN2MX	-	200							
EN2OPT	-	33*	34						
EN2STR	-	300	33	45	54				
EQMX	-	200	45						
ESHP	-	39*	40						
EWDOT	-	10*	12						
EWDTMX	-	200							
EWDTPP	-	200							
* FLAGS	-	4*							
FSMACH	-	300							
GRUTCH	-	400							
ICONDP	-	400							
IPHASE	-	400							
ISPACE	-	400							
ISLOW	-	400							
ISTA	-	400							
ISTB	-	400							
ITRIM	-	400							
IWARN1	-	400	5LG	11*	13*	20*	22*	46*	48*
IWARN2	-	400	5LG						
IWREVT	-	400							
JTRIM	-	400							
KTRIM	-	400							
NGEF	-	400							
NPLOT	-	400							
NPLOT2	-	400							
NQIND	-	200	41						
NRPMID	-	200	37						
NTWST	-	400							

Figure G.6. (Continued)

NVR - 4C0
NWDTTD - 2C0 9
N1IND - 2C0 18
N1THID - 2C0 38
N2IND - 2C0 31 42 44 55
OMEGFL - 3C0
OMEGER - 3C0
OMENG - 1AG 57=
ONOVTC - 3C0
OOVFSM - 3C0
OVSOTH - 3C0 33
OVTHOL - 3C0 45
PCTORQ - 1AG 58=
PCTOL - 3C0
PCTOR - 3C0
* RETURN - 59=
ROE - 3C0
ROEOV2 - 3C0
ROEO - 2C0
SHPMAX - 45= 47 49 53
SHPOUT - 1AG 56=
SHPPRL - 3C0
SHPPRR - 3C0
SHPSTR - 2C0 56
SKPN - 35= 36= 40
SKPR - 36= 40
SMA - 3C0
SONIMX - 3C0 13
SQTHTC - 3C0 67
SQWDTK - 3C0 14
SWLG - 4C0
TCOEF - 2C0
TOFGF - 3C0
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 18 25= 26 32 39 52= 53 54
TEAL - 3C0
TEAR - 3C0
TEASQ - 6= 7 10 15= 16 18 24= 25 32 39 51= 52 54
TEA4TH - 8= 10 17= 26= 53=
THCOEL - 3C0 56 58
THETC - 3C0
TZERO - 2C0

Figure G.6. (Continued)

```
      1           SUBROUTINE GEAR
      2           COMMON/KAIO/ SCADC1(32),SCADC2(32),SCADC3(32),SCADC4(32),
     *                        SCDAC1(32),SCDAC2(32),SCDAC3(32),SCDAC4(32),
     1          PPRIME,QPRIME,RPRIME,UPRIME,VPRIME,WPRIME,TME    ,PHI    ,  80  16
     *          PSI    ,WDOT   ,      ,DUM12 ,DUM13 ,DUM14 ,DUM15 ,HDOT   ,
     *          DELAIL,DELAIR,DELSPR,DELSPL,CYLPRM,CNFPL ,CSFPL ,CPMPL  ,
     *          CYMPL ,CPL    ,CYMPRM,CNFPP ,CSFPR ,CPMPR ,CYMPR ,CPR    ,
     *   ADC(62) ,
     *   ADC(63)
      3           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,FRICTO,FRICT1,FRICTS
     *                       , BRK1   ,BRK2   ,BRK3   ,BRKDUM
      4           COMMON/GGGTVR/
     1 VEAST ,VNORTH,XCG    ,XDTCG  ,ZCG    ,ZDTCG                                  1 -  6
      5           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 DLLG  ,DMLG  ,DNLG   ,DXLG   ,DYLG   ,DZLG   ,QFSW   ,SBFCAF,SQFSAF,  19 - 27
     4 SINALF,SINBTF,SQF    ,XARPF  ,XARFP  ,YARRF  ,YARFP  ,ZARRF  ,ZARFP    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
      6           DIMENSION DX(4),DY(4),DZ(4),DL(4),DM(4),DN(4)
      7           DIMENSION XG(4),YG(4),ZG(4),RAD(4),SKST(4) ,SDST(4)
      8           DIMENSION BG(4)
      9           EQUIVALENCE (XG(1),XG1),(YG(1),YG1),(ZG(1),ZG1  ),(RAD(1),RAD1  )
     *   ,(SKST(1),SKST1 ) ,(SDST(1),SDST1)
     1            EQUIVALENCE (BG(1),BRK1)
     11           N= 1
     12           IF(UPRIME) 75,110,120
     13      75   SIGNL= -1.0
     14           GO TO 125
     15     110   SIGNL= 0.0
     16           GO TO 125
     17     120   SIGNL= 1.0
     18     125   CONTINUE
     19           IF(VPRIME) 130,140,150
     20     130   SIGNV= -1.0
     21           GO TO 155
     22     140   SIGNV= 0.0
     23           GO TO 155
     24     150   SIGNV= 1.0
     25     155   CONTINUE
C            LANDING GEAR  - A/C LOCATION
     26     50    XN= XG(N)-XCG
     27           YN=  YG(N)
     28           ZN= ZG(N)-ZCG
C
C            STRUT DEFLECTION
     29           HGTHEN=  XN*SINTHE -ZN*COSTHE -RAD(N)
```

Figure G.6. (Continued)

```
      HGPHI(N)=  COSTHE*(YN*SINPHI+(ZN*RAD(N))*(COSPHI-1.))
      DOVCTP=  1./(COSTHE*COSPHI)
      HTN=  (H+HGTHEN-HGPHI(N) * DOVCTP
C
      IF(HTN.LT.0.) GO TO 100
      DX(N)= 0.
      DY(N)= 0.
      DZ(N)= 0.
      DL(N)= 0.
      DM(N)= 0.
      DN(N)= 0.
      GO TO 200
C        RATE OF STRUT DEFLECTION
100   HTDTN= HDOT+ DOVCTP*QPRIME*XN-PPRIME*YN
C
C        VERTICAL FORCE
      FGZN=  SKST(N)*HTN +SDST(N)*HTDTN
C        LONGITUDINAL FORCE
      FMUN=  (FRICTO+FRICTI*RG(N))*FGZN*SIGNU
C
C        SIDE FORCE
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
      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
      DX(N) =  FMUN  - FGZN * THE
      DY(N)= FSN+FGZN*PHI
      DZ(N)= FMUN*THE-FSN*PHI+FGZN
      DM(N)= -DZ(N)*XN+DX(N)*(ZN+RAD(N)+HTN )
      DL(N)= DZ(N)*YN -DY(N)*(ZN+RAD(N)+HTN)
      DN(N)= -DX(N)*YN +XN*DY(N)
200    N= N+1
      IF(N.LE.3) GO TO 50
      DXLG= DX(1)+DX(2)+DX(3)
      DYLG= DY(1)+DY(2)+DY(3)
      DZLG= DZ(1)+DZ(2)+DZ(3)
      DLLG =  DL(1)+DL(2) +DL(3)
      DMLG =  DM(1)+DM(2) +DM(3)
      DNLG =  DN(1)+DN(2) +DN(3)
      RETURN
       END
```

Figure G.6. (Continued)

SYMBOL REFERENCES

[illegible]	=	246	92	
75	=	12	136	
1	=	31	61*	
11	=	12	154	
12	=	12	17*	
125	=	14	14	186
130	=	19	20*	
14[illegible]	=	19	22*	
150	=	19	24*	
155	=	21	23	25*
2[illegible]	=	6[illegible]	51*	
ADC	=	200		
ADC3	=	200		
ALARF	=	500		
ALARFP	=	500		
ALFSP	=	500		
ALPHF	=	500		
AMARF	=	500		
AMARFP	=	500		
AMAXF	=	500		
AMAXFP	=	500		
BETAF	=	500		
BETAFP	=	500		
BG	=	401	1[illegible]	43
BRKDIM	=	100		
BRAT	=	303	1[illegible]	
BRX	=	300		
BRX3	=	303		
CBCAF	=	500		
CDF	=	500		
CGGTVP	=	40		
CLF	=	500		
CMF	=	500		
CRF	=	500		
CNFPL	=	200		
CNFPP	=	200		
COSALF	=	500		
COSBTF	=	500		
COSPHI	=	500	1[illegible]	31
COSTHE	=	500	29	1[illegible] 31
CPL	=	200		
CPMPL	=	200		
CPMPP	=	200		
CPP	=	200		
CSFPL	=	200		
CSFPP	=	200		
CTLPRM	=	200		
CTPPRM	=	200		
CVF	=	500		
CVMPL	=	200		
CVMPP	=	200		
DELSPL	=	200		
DELSPP	=	200		

Figure G.6. (Continued)

DELAIL - 2CD
DELAIR - 2CD
DL - 5DI 17= 49= 56
DLLG - 5CD 56=
DY - 6DI 18= 48= 57
DYLG - 5CD 57=
DN - 6DI 19= 50= 58
DNLG - 5CD 58=
DUM12 - 2CD
DUM13 - 2CD
DUM14 - 2CD
DUM19 - 2CD
DX - 6DI 34= 45= 48 50 53
DXLG - 5CD 53=
DY - 6DI 35= 46= 49 50 54
DYLG - 5CD 54=
DZ - 6DI 36= 47= 49 49 55
DZLG - 5CD 55=
FGN - 42= 43 44 45 46 47
FMIN - 43= 45 47
FRICTO - 3CD 43
FRICTS - 3CD 44
FRICTL - 3CD 43
FSN - 44= 46 47
* FUSVAR - 5*
* GEAR - 1*
H - 2CD 37
HDOT - 2CD 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
ONVCTP - 31= 32 41
PHI - 2CD 46 47
* PPRIME - 2CD 41
PSI - 2CD
QFSW - 5CD
QPRIME - 2CD 41
RAD - 7DI 9E0 29 33 48 49
RADDUM - 3CD
RAD1 - 3CD 9F0
RAD2 - 3CD
RAD3 - 3CD
* RETURN - 50*
RPRIME - 2CD
SBFCAF - 5CD
SDFSAF - 5CD
SCADC1 - 2CD
SCADC2 - 2CD
SCADC3 - 2CD
SCADC4 - 2CD
SCDAC1 - 2CD
SCDAC2 - 2CD

Figure G.6. (Continued)

SCOAC3 - 2C0
SCOAC4 - 2C0
SDST - 7D1 9E0 42
SDSTOM - 3C0
SDSTI - 3C0 9E1
SDST2 - 3C0
SDST3 - 3C0
SIGNU - 13* 15* 17* 43
SIGNV - 2?* ?2* 24* 44
SINALF - 5C0
SINBTF - 5C0
SINPHI - 5C0 1?
SINTHE - 5C0 29
SKST - 7D1 9E0 42
SKSTOM - 3C0
SKSTI - 3C0 9E?
SKST2 - 3C0
SKST3 - 3C0
SQF - 5C0
THF - 2C0 45 47
UPRIMF - 2C0 12
VEAST - 4C0
VNORTH - 4C0
VPRIMF - 2C0 10
WDOT - 2C0
WPRIMF - 2C0
XAERF - 5C0
XAIO - 2*
XAREF - 5C0
XCG - 4C0 26
XDTCG - 4C0
XG - 7D1 9E0 26
XGDUM - 3C0
XGEAR - 3*
XG1 - 3C0 9E?
XG2 - 3C0
XG3 - 3C0
XN - 24* 29 41 49 5?
YAERF - 5C0
YAREF - 5C0
YG - 7D1 9E0 ??
YGDUM - 3C0
YG1 - 3C0 9E0
YG2 - 3C0
YG3 - 3C0
YN - 27* 30 41 49 5?
ZAERF - 5C0
ZAREF - 5C0
ZCG - 4C0 ?8
ZDTCG - 4C0
ZG - 7D1 9E0 ?9
ZGDUM - 3C0
ZG1 - 3C0 9E0
ZG2 - 3C0
ZG3 - 3C0

Figure G.6. (Continued)

ZN - 28= 29 30 48 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
AGDVAT - RTSLOW
AGDVAW - RTSLOW
AICL - RTFAST
AICLDP - RTFAST
AICLGS - RTFAST
AICLPP - RTFAST
AICP - RTFAST
AICPDP - RTFAST
AICPGS - RTFAST
AICPPP - RTFAST
AILSP - RTFAST
AINDTL - RTFAST
AINDTR - RTFAST
AINHT - RTFAST
AINL - RTFAST RTSLOW
AINR - RTFAST RTSLOW
AINW - RTFAST RTSLOW
AITRIM - RTFAST
AKEY - RTSLOW
ALAERC - RTFAST
ALART - RTFAST
ALARFP - RTFAST RTSLOW
ALARHT - RTFAST
ALARNG - RTFAST
ALAFNL - RTFAST
ALARAP - RTFAST
ALARPG - RTFAST

Figure G.6. (Continued)

ALART - RTFAST
ALARVB - RTFAST
ALARVT - RTFAST
ALARWG - RTFAST
ALBRK1 - CLCOCM
ALBRK2 - CLCOCM
ALDEG - CLCOCM
ALDUM - CLCOCM
ALFGLS - RTFAST
ALFREF - RTFAST
ALFTAB - RTFAST
ALHTF - RTFAST
ALHTM - RTFAST
ALHTP - RTFAST
ALHTPR - RTFAST
ALLRH - RTFAST
ALLVPP - RTFAST
ALNCPK - RTSLOW
ALNLM - CLCOCM
ALNLP - CLCOCM
ALPHA - CLCOCM
ALPHF - RTFAST RTSLOW
ALPHFP - RTSLOW
ALPHHT - RTFAST
ALPHLM - RTSLOW
ALPHLP - RTFAST RTSLOW
ALPHLW - RTFAST
ALPHPM - RTSLOW
ALPHPP - RTFAST RTSLOW
ALPHPW - RTFAST
ALPHVT - RTFAST
ALRGLW - RTFAST
ALRGRW - RTFAST
ALRRH - RTFAST
ALRWPF - RTFAST
ALVTF - RTFAST
ALVTM - RTFAST
ALVTP - RTFAST
ALVTPP - RTFAST
ALWSSO - RTFAST
AMACH - ENGINE RTSLOW
AMACLP - RTFAST
AMACRP - RTFAST
AMACSO - ENGINE RTSLOW
AMACTL - RTFAST
AMACTR - RTFAST
AMAFPO - RTFAST
AMARF - RTFAST
AMARFP - RTFAST RTSLOW
AMARHT - RTFAST
AMARLW - RTFAST
AMARNC - RTFAST
AMARTL - RTFAST
AMARWP - RTFAST
AMARRG - RTFAST

Figure G.6. (Continued)

AMARPW - RTFAST
AMART - RTFAST
AMARVE - RTFAST
AMARVT - RTFAST
AMARWG - RTFAST
AMEM - RTSLOW
AMLRH - RTFAST
AMRNLP - RTFAST
AMRVPP - RTFAST
AMROTL - RTFAST
AMROTP - RTFAST
AMRRH - RTFAST
AMUL - RTFAST RTSLOW
AMULSQ - RTFAST
AMUR - RTFAST RTSLOW
AMURSQ - RTFAST
ANAEPP - RTFAST
ANARF - RTFAST
ANARFP - RTFAST RTSLOW
ANARHT - RTFAST
ANARNG - RTFAST
ANAPPL - RTFAST
ANAPRP - RTFAST
ANART - RTFAST
ANARVT - RTFAST
ANARWG - RTFAST
ANDTG - RTFAST
ANLRH - RTFAST
ANROTL - RTFAST
ANPOTR - RTFAST
ANPRH - RTFAST
APEAM - RTSLOW
APILM - RTSLOW
APIRH - RTSLOW
APTEX - RTFAST
APWING - RTSLOW
APWSSQ - RTFAST
ATAN2 - RTFAST RTSLOW
ATAULP - RTSLOW
ATAURP - RTSLOW
AVEALR - RTSLOW
AVEALW - RTFAST
AVECLW - RTFAST
AVECTS - RTFAST RTSLOW
AVEFPP - RTFAST RTSLOW
AVEIH - RTFAST RTSLOW
AVEZET - RTSLOW
BETAC - RTFAST RTSLOW
BETAFP - RTSLOW
BETAIN - RTSLOW
BETALW - RTFAST
BETARN - RTSLOW
BETAPW - RTFAST
BETGLS - RTFAST
BETVT - RTFAST

Figure G.6. (Continued)

```
AG      - GEAR
AICGLS  - RTFAST
AICL    - RTFAST
AICLOP  - RTFAST
AICLPP  - RTFAST
AICR    - RTFAST
AICROP  - RTFAST
AICRPR  - RTFAST
AIGX    - RTSLOW
AKALPR  - RTFAST   RTSLOW
AKARPP  - RTFAST   RTSLOW
AK01T   - RTSLOW
AK02T   - RTSLOW
AK03T   - RTSLOW
AKEY    - RTSLOW
AKM1T   - RTSLOW
AKM2T   - RTSLOW
AKM3T   - RTSLOW
AKM4T   - RTSLOW
AK99    - RTSLOW
ALS     - RTFAST   RTSLOW
ANEN    - RTSLOW
ANOVTL  - RTFAST   RTSLOW
ANOVTR  - RTFAST   RTSLOW
ARK1    - GEAR
AT1     - RTSLOW
AT2     - RTSLOW
AT3     - RTSLOW
CALIHT  - RTFAST
CALLN   - RTSLOW
CALLW   - RTFAST
CALRN   - RTSLOW
CALRW   - RTFAST
CAVINW  - RTSLOW
CAYZET  - RTSLOW
CBCHF   - RTSLOW
CBETLN  - RTSLOW
CBETLW  - RTFAST
CBETRN  - RTSLOW
CBETRW  - RTFAST
CRETSC  - RTFAST
CD      - CLCDCW
CDCNTL  - RTFAST
CDCNTR  - RTFAST
CDDIW   - RTFAST
CDF     - RTSLOW
CDFASP  - CLCDCW
CDHT    - RTFAST
CDHTST  - RTFAST
CDLN    - RTSLOW
CDLWAD  - RTFAST
CDLWPR  - RTFAST
CDLWSS  - RTFAST
CDM     - CLCDCW
CDOF    - RTSLOW
```

Figure G.6. (Continued)

CDNHT - RTFAST
CDOLN - RTSLOW
CDONHT - RTSLOW
CDONLG - RTSLOW
CDORN - RTSLOW
CDOVT - RTFAST
COP - CLCOCM
COPLUS - CLCOCM
CORN - RTSLOW
CORNAD - RTFAST
CORWPR - RTFAST
CORWSS - RTFAST
CDSLW - RTFAST
CDSRW - RTFAST
CDVT - RTFAST
CDVTST - RTFAST
CONCOR - CLCOCM RTSLOW
COS - CLCOCM
CFPLW - RTFAST
CFPRW - RTFAST
CGGTVR - GEAR RTFAST RTSLOW
CHORD - RTFAST RTSLOW
CILAML - RTFAST RTSLOW
CILAMS - RTFAST RTSLOW
CL - CLCOCM
CLALDG - CLCOCM
CLALHT - RTFAST
CLALPH - CLCOCM RTSLOW
CLAT - RTFAST
CLAVE - RTFAST
CLCOCM - RTFAST
CLDEL - CLCOCM
CLDUP - RTFAST
CLF - RTSLOW
CLF1 - AILSW RTFAST
CLF2 - CLCOCM RTFAST
CLHT - RTFAST
CLHTST - RTFAST
CLIGE - CLCOCM
CLILW - RTSLOW
CLIRW - RTSLOW
CLLN - RTSLOW
CLLWAD - RTFAST
CLLWPR - RTFAST
CLLWSS - RTFAST
CLMAX - CLCOCM
CLNLP - CLCOCM
CLOAL - CLCOCM
CLP - CLCOCM
CLPMX - CLCOCM
CLRN - RTSLOW
CLRWAD - RTFAST
CLRWPR - RTFAST
CLRWSS - RTFAST
CLSLW - RTFAST

Figure G.6. (Continued)

CLSP - CLCDC4
CLSRW - RTFAST
CLSW - RTFAST
CLTCDR - RTFAST RTSLOW
CLWCDR - CLCDC4 RTSLOW
CLZ - AILSP CLCDC4
CLZERO - RTFAST
CLI - CLCDC4
CM - CLCDC4
CMCNTL - RTFAST
CMCNTR - RTFAST
CMF - RTSLOW
CMFASP - CLCDC4
CMLN - RTSLOW
CMLWAD - RTFAST
CMLWSS - RTFAST
CMOF - RTSLOW
CMON - RTSLOW
CMOW - RTFAST
CMP - CLCDCH
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
CDEF1 - RTFAST RTSLOW
CDEF10 - RTFAST
CDEF11 - RTFAST
CDEF12 - RTFAST
CDEF13 - RTFAST
CDEF16 - RTFAST
CDEF17 - RTSLOW
CDEF18 - RTFAST RTSLOW
CDEF19 - RTFAST
CDEF2 - RTFAST
CDEF20 - RTFAST
CDEF21 - RTFAST
CDEF22 - RTFAST
CDEF23 - RTFAST
CDEF24 - RTFAST

Figure G.8. (Continued)

COEF25 - RTSLOW
COEF26 - RTSLOW
COEF27 - RTSLOW
COEF28 - RTSLOW
COEF29 - RTSLOW
COEF3 - RTSLOW
COEF3C - 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
CONS1C - CLCDCM
CONS11 - CLCDCM
CONS12 - CLCDCM
CONS13 - CLCDCM
CONS14 - CLCDCM
CONS15 - CLCDCM
CONS16 - CLCDCM
CONS17 - CLCDCM
CONS18 - CLCDCM
CONS19 - CLCDCM
CONS2 - CLCDCM
CONS2C - CLCDCM
CONS21 - CLCDCM
CONS22 - CLCDCM
CONS23 - CLCDCM
CONS24 - CLCDCM
CONS25 - CLCDCM
CONS26 - CLCDCM
CONS27 - AILSP
CONS28 - AILSP
CONS29 - AILSP
CONS3 - CLCDCM
CONS3C - AILSP
CONS31 - AILSP
CONS32 - AILSP
CONS33 - AILSP
CONS34 - AILSP
CONS35 - AILSP
CONS36 - AILSP
CONS37 - AILSP
CONS38 - AILSP
CONS39 - AILSP
CONS4 - CLCDCM
CONS4C - AILSP
CONS41 - RTFAST
CONS42 - RTFAST

Figure G.6. (Continued)

CONS43 - RTFAST
CONS44 - RTSLOW
CONS45 - RTSLOW
CONS46 - RTSLOW
CONS47 - RTSLOW
CONS48 - RTSLOW
CONS49 - RTSLOW
CONS5 - CLCOCM
CONS5C - RTSLOW
CONS51 - RTSLOW
CONS52 - RTSLOW
CONS53 - RTSLOW
CONS54 - RTSLOW
CONS55 - RTSLOW
CONS56 - RTSLOW
CONS57 - RTSLOW
CONS5P - RTSLOW
CONS59 - RTSLOW
CONSA - CLCOCM
CONS60 - RTSLOW
CONS61 - RTSLOW
CONS62 - RTSLOW
CONS63 - RTSLOW
CONS64 - RTSLOW
CONS65 - RTFAST
CONS66 - RTFAST
CONS67 - AILSP
CONS68 - AILSP
CONS69 - AILSP
CONS7 - CLCOCM
CONS7C - AILSP
CONS71 - AILSP
CONS72 - RTFAST
CONS73 - RTFAST
CONS74 - RTFAST
CONS75 - RTFAST
CONS76 - RTFAST
CONS77 - RTFAST
CONS78 - RTFAST
CONS79 - RTFAST
CONS8 - CLCOCM
CONS80 - RTFAST
CONS81 - RTFAST
CONS9 - CLCOCM
CONTRL - RTFAST RTSLOW
COSALF - RTSLOW
COSATF - RTSLOW
COSINL - RTFAST RTSLOW
COSINR - RTFAST RTSLOW
COSIN - RTFAST
COSLAM - RTFAST
COSPHI - GEAR RTSLOW
COSPSI - RTSLOW
COSTHF - 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
CTAULP - RTSLOW
CTAURR - RTSLOW
CTL - RTFAST
CTLPRP - RTFAST
CTR - RTFAST
CTRPRM - RTFAST
CTSLP - RTFAST RTSLOW
CTSRP - 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
C2INP - RTSLOW
DACFLT - RTFAST
DACID - RTFAST
DAC1 - RTFAST
DAC2 - RTFAST
DBRK1 - RTFAST
DBRK10 - RTSLOW
DBRK11 - RTSLOW
DBRK12 - RTSLOW
DBRK13 - RTSLOW
DBRK14 - RTSLOW

Figure G.6. (Continued)

DBRK15 - RTSLOW
DBRK16 - RTSLOW
DBRK17 - RTFAST
DBRK18 - RTFAST
DBRK19 - RTFAST
DBRK2 - CLCDCM
DBRK20 - AILSP
DBRK21 - AILSP
DBRK3 - CLCDCM
DBRK4 - CLCDCM
DBRK5 - CLCDCM
DBRK6 - CLCDCM
DBRK7 - AILSP
DBRK8 - AILSP
DBRK9 - RTFAST
DCDA - AILSP
DCDIGE - CLCDCM
DCDLDA - RTFAST
DCDLG - RTSLOW
DCDLSP - RTFAST
DCDRDA - RTFAST
DCDRSP - RTFAST
DCDS - AILSP
DCLA - AILSP
DCLLDA - RTFAST
DCLLSP - RTFAST
DCLNL - CLCDCM
DCLRDA - RTFAST
DCLRSP - RTFAST
DCLS - AILSP
DCLSPW - RTFAST
DCMA - AILSP
DCMLDA - RTFAST
DCMLG - RTSLOW
DCMLSP - RTFAST
DCMRDA - RTFAST
DCMRSP - RTFAST
DCMS - AILSP
DCNSPW - RTFAST
DEG20 - RTFAST
DEL - AILSP CLCDCM RTFAST RTSLOW
DELELV - RTFAST
DELEPZ - RTFAST
DELFLP - RTFAST
DELRUD - RTFAST
DELSPL - RTFAST
DELSPR - RTFAST
DEPCAL - RTFAST
DFLAIL - RTFAST
DFLAIR - RTFAST
DGTORD - CLCDCM RTFAST
DIGAN - RTFAST
DISADI - RTFAST RTSLOW
DL - GEAR
DLFPSD - RTFAST

DLLG - GEAR RTFAST
DLLNC - RTFAST RTSLOW
DLRNC - RTFAST RTSLOW
DP - GEAR
DPLG - GEAR RTFAST
DPLNC - RTFAST RTSLOW
DPRNC - RTFAST RTSLOW
DR - GEAR
DRF1 - RTFAST
DRF2 - RTFAST
DRF3 - RTFAST
DRF4 - RTFAST
DRLG - GEAR RTFAST
DRLNC - RTFAST RTSLOW
DRRNC - RTFAST RTSLOW
DDVT - RTSLOW
DDVTL - RTFAST RTSLOW
DDVTR - RTFAST RTSLOW
DPM1 - RTFAST
DPM2 - RTFAST
DPM3 - RTFAST
DPM4 - RTFAST
DPM5 - RTFAST
DPM6 - RTFAST
DPMT - RTFAST
DSDRFT - RTFAST
DSF1 - RTFAST
DSF2 - RTFAST
DSF3 - RTFAST
DSF4 - RTFAST
DX - GEAR
DXLG - GEAR RTFAST
DXLNC - RTFAST RTSLOW
DXRNC - RTFAST RTSLOW
DY - GEAR
DYLG - GEAR RTFAST
DYLNC - RTFAST RTSLOW
DYM1 - RTFAST
DYM2 - RTFAST
DYM3 - RTFAST
DYM4 - RTFAST
DYM5 - RTFAST
DYM6 - RTFAST
DYMT - RTFAST
DYRNC - RTFAST RTSLOW
DZ - GEAR
DZLG - GEAR RTFAST
DZLNC - RTFAST RTSLOW
DZRNC - RTFAST RTSLOW
EMAXN1 - ENGINE RTSLOW
EMAXN2 - RTSLOW
EMXNDT - ENGINE RTSLOW
ENFL - RTSLOW
ENFR - RTSLOW
ENFI - RTFAST

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
EQMVAR - 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
EPTLI - RTFAST
EPWRL - RTFAST
EPWRR - RTFAST
EPZERO - 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
FINDFG - RTFAST
FINPR - RTFAST

Figure G.6. (Continued)

```
FIP     - RTFAST
FIPDM   - RTFAST
FIPDMP  - RTFAST
FIXX    - RTSLOW
FIXEP   - RTFAST    RTSLOW
FIXEPP  - RTSLOW
FIXEQ   - RTFAST    RTSLOW
FIXEP.  - RTFAST    RTSLOW
FIYY    - RTSLOW
FIYYPR  - RTFAST
FIZZ    - RTSLOW
FIZZPR  - RTFAST
FJXX    - RTFAST    RTSLOW
FJYY    - RTFAST    RTSLOW
FJZZ    - RTFAST    RTSLOW
FLAGS   - CLOCK4    ENGINE    RTFAST    RTSLOW
FMUN    - GEAR
FNORMI  - RTFAST    RTSLOW
FNORMP  - RTFAST    RTSLOW
FRICTC  - GEAR
FRICTS  - GEAR
FRICTI  - GEAR
FSTOEL  - RTFAST    RTSLOW
FSTOER  - RTFAST    RTSLOW
FSMACH  - RTSLOW
FSN     - GEAR
FSQRT   - RTFAST    RTSLOW
FUSVAR  - GEAR      RTFAST    RTSLOW
GAATAP  - RTFAST
GAIALF  - RTFAST
GAIRET  - RTFAST
GRATAP  - RTFAST
GRIALF  - RTFAST
GEAR    - RTFAST
GFF     - RTFAST    RTSLOW
GFFVAR  - CLOCK4    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)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

HTDTN - GEAR
HTN - GEAR
HTRIM - RTFAST
HTSTLL - RTFAST
HWACL - RTFAST
HWACR - RTFAST
HWG4 - RTSLOW
HYBCON - RTFAST RTSLOW
HYBID - RTFAST RTSLOW
HIDTL - RTFAST
HIDTR - RTFAST
HIL - RTFAST
HILOLD - RTFAST
HIR - RTFAST
HIROLD - RTFAST
ICONOP - RTSLOW
IFC - RTSLOW
INITVR - RTFAST RTSLOW
IPAN - RTFAST RTSLOW
IPSNOS - RTFAST
IREVNT - RTSLOW
ISENCE - RTSLOW
ISLOW - RTSLOW
IST4 - RTSLOW
ISTAD - RTFAST
ISTB - RTSLOW
ISTDA - RTFAST
ISTFLT - RTFAST
ISTG - RTFAST
ISTRBL - 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
NDEF - RTSLOW
NOPT - AILSP CLCDCM
NOIND - ENGINE
NRNOID - ENGINE
NTWST - RTFAST
NVB - RTFAST
NWDTID - ENGINE
N1IND - ENGINE
N1THID - ENGINE
N2IND - ENGINE
OMDOT - RTFAST
OMDTL - RTFAST

Figure G.6. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
OMOTR   - RTFAST
OMEGA   - RTFAST   RTSLOW
OMEGAL  - RTFAST
OMEGAR  - RTFAST
OMEGFL  - RTFAST   RTSLOW
OMEGFP  - RTFAST   RTSLOW
OMENG   - ENGINE
OMREF.  - RTSLOW
OMSQL   - RTFAST
OMSQR   - RTFAST
ONOVTC  - RTSLOW
OOVCTP  - GEAR
OOVOSK  - RTFAST
OOVFSH  - RTFAST   RTSLOW
OOVIXX  - RTFAST   RTSLOW
OOVIYY  - RTFAST   RTSLOW
OOVIZZ  - RTFAST   RTSLOW
OVDTIM  - RTFAST
OVSOTH  - ENGINE   RTSLOW
OVTHOL  - 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
RADL    - GEAR
RCBI    - RTSLOW
ROTOOG  - CLCDCM   RTFAST
RESLR   - RTSLOW
RESRR   - RTSLOW
RETURN  - AILSP    CLCDCM   ENGINE   GEAR     RTFAST   RTSLOW
REVENT  - RTSLOW
RGUST   - RTFAST
```

Figure G.6. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

RNLN - RTFAST
RNLR - RTFAST
RNRN - RTFAST
RNRR - RTFAST
ROE - RTFAST RTSLOW
ROEDV2 - RTFAST RTSLOW
ROEO - RTFAST RTSLOW.
ROPIR& - RTFAST
ROPIR9 - RTFAST
ROTFPS - RTFAST
ROTRAD - RTFAST RTSLOW
ROTVAR - RTFAST RTSLOW
PPRIME - RTFAST
RO - RTFAST
RR - RTFAST
RRII - RTSLOW
RRI2 - RTSLOW
RTPASS - RTFAST RTSLOW
SALIHT - RTFAST
SALLN - RTSLOW
SALLW - RTFAST
SALRN - RTSLOW
SALRW - RTFAST
SAVINH - RTSLOW
SAVZET - RTSLOW
SBETLN - RTSLOW
SBETLW - RTFAST
SBETRN - 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
SGNSOF - RTFAST
SGNULW - RTFAST
SGNURW - RTFAST
SHF - RTSLOW
SHPMAX - ENGINE
SHPOUT - ENGINE
SHPPRL - RTSLOW
SHPPRP - RTFAST RTSLOW
SHPSTR - ENGINE
SHW - RTSLOW
SIGMA - RTFAST
SIGNU - GEAR
SIGNV - GEAR
SIL - RTSLOW
SILAMI - 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
SKSTL   - GEAR
SKW1    - RTFAST
SKW1C   - RTFAST
SKW2    - RTFAST
SKW3    - RTFAST
SKW4    - RTFAST
SKW5    - RTFAST
SKW6    - RTFAST
SKW7    - RTFAST
SKW8    - RTFAST
SKW9    - RTFAST
SK0     - RTSLOW
SK1     - RTSLOW
SK10    - RTSLOW
SK2     - RTSLOW
SK2C    - RTFAST
SK21    - RTFAST
SK22    - RTFAST
SK3     - RTSLOW
SK3CHI  - RTSLOW
SK3CL   - RTSLOW
SK3CLO  - RTSLOW
SK3CP   - RTSLOW
SK31HI  - RTSLOW
SK31I   - 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
SLAG    - RTFAST
SLF     - RTSLOW
SLPA    - RTFAST
SLW     - RTSLOW
SMA     - RTSLOW
SPAN    - RTFAST    RTSLOW
SPHIP   - RTFAST
SPIO    - RTSLOW
SPOIL   - AILSP
SQF     - RTFAST    RTSLOW
SQFPRM  - RTFAST
SQLNC   - RTSLOW
SQLW    - RTFAST
SQNIMX  - 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
SVSTAR  - RTSLOW
SVSTAR  - RTSLOW
SVSTRL  - RTSLOW
SWLG    - RTFAST
SWLG2   - RTSLOW
SZINL   - RTSLOW
SZINR   - RTSLOW
TAILVR  - RTFAST    RTSLOW
TAN     - RTSLOW
TAUHT   - RTFAST
TAULR   - RTSLOW
TAURR   - RTSLOW
TAUVT   - RTFAST
TAVAEP  - RTSLOW
TCOEF   - RTSLOW
TDEGF   - RTSLOW
TEA     - ENGINE
TEACUR  - ENGINE
TEAR    - RTSLOW
```

Figure G.6. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

TFASO - ENGINE
TFA4TH - ENGINE
TERMP1 - RTFAST
TERM01 - RTFAST
TERMP1 - RTFAST
TERM1 - RTSLOW
TERM1L - RTFAST
TERM1R - RTFAST
TERM2 - RTSLOW
TERM2L - RTFAST
TERM2R - RTFAST
TERM3 - RTSLOW
TERM3L - RTFAST
TERM3R - RTFAST
TERM4 - RTSLOW
TERM5 - RTSLOW
TERMA - RTSLOW
THCOEL - ENGINE RTSLOW
THE - GEAR RTSLOW
THETC - RTSLOW
THTLAC - RTFAST
THTRAC - RTFAST
THYRIR - RTFAST
TIGEL - RTFAST RTSLOW
TIGER - RTFAST RTSLOW
TL - RTFAST RTSLOW
TMHB1C - RTFAST
TMHB11 - RTFAST
TMHB12 - RTFAST
TMWG1C - 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
TRMCCA - 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)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

TRMHLS - RTFAST
TRMNC1 - RTSLOW
TRMNC2 - RTSLOW
TRMNC3 - RTSLOW
TRMNC4 - RTSLOW
TRMTL1 - RTFAST
TRMTR1 - RTFAST
TRMTTW - RTFAST
TRMVT - RTFAST
TRMVT2 - RTFAST
TRMVT3 - RTFAST
TRMWG1 - RTSLOW
TRMWG4 - RTSLOW
TRMWG5 - RTFAST
TRMWG6 - RTFAST
TRMWG7 - RTFAST
TRMWG8 - RTFAST
TRMWG9 - RTSLOW
TSTRTF - RTFAST
TSTRTS - RTSLOW
TZERO - RTSLOW
TZET1 - RTSLOW
TZET2 - RTSLOW
TZET3 - RTSLOW
TZET4 - RTSLOW
TZET5 - RTSLOW
TZET6 - RTSLOW
U - RTFAST
UGUST - RTFAST
UHT - RTFAST
ULW - RTFAST
ULWPR - RTFAST
ULWSQ - RTFAST
UP - RTFAST
UPRIMF - GEAR RTFAST RTSLOW
URL - RTFAST RTSLOW
URLPR - RTFAST
URLURL - RTFAST RTSLOW
URR - RTFAST RTSLOW
URRPR - RTFAST
URRURR - RTFAST RTSLOW
URW - RTFAST
URWPR - RTFAST
URWSQ - RTFAST
USEA10 - RTFAST RTSLOW
USQ - RTFAST
UTRIM - RTFAST
UVT - RTFAST
V - RTFAST RTSLOW
VALFLW - RTFAST
VALFRW - RTFAST
VALFS - RTFAST
VALNCL - RTSLOW
VALNCR - RTSLOW
VRCTVT - RTFAST

Figure G.6. (Continued)

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VEAST - RTFAST RTSLOW
VELVAP - RTFAST RTSLOW
VGUST - RTFAST
VLW - RTFAST
VLWPP - RTFAST
VLWSO - RTFAST
VNORTH - RTFAST RTSLOW
VP - RTFAST
VPRIME - GEAR RTFAST PTSLOW
VRL - RTFAST RTSLOW
VRLPR - RTFAST
VRLVPL - RTFAST RTSLOW
VRR - RTFAST RTSLOW
VRRPR - RTFAST
VRRVPP - RTFAST RTSLOW
VRW - RTFAST
VRWPR - RTFAST
VRWSO - RTFAST
VSQ - RTFAST
VSTAR - RTSLOW
VSTARL - RTSLOW
VTIPL - RTFAST
VTIPR - RTFAST
VTOTAL - RTFAST RTSLOW
VTOTLR - RTFAST RTSLOW
VTOTRR - RTFAST RTSLOW
VTRIM - RTFAST
VTSTLL - RTFAST
VVT - RTFAST
VZETL - RTFAST
VZETP - RTFAST
W - RTFAST
WDOT - RTFAST
WGUST - RTFAST
WHT - RTFAST
WLW - RTFAST
WLWPR - RTFAST
WLWSQ - RTFAST
WNGVAR - RTFAST RTSLOW
WNGVR2 - RTFAST RTSLOW
WORK - RTFAST RTSLOW
WP - RTFAST
WPRIME - RTFAST RTSLOW
WRL - RTFAST RTSLOW
WRLPR - RTFAST
WRLWPL - RTFAST RTSLOW
WROTL - RTFAST
WROTR - RTFAST
WRR - RTFAST RTSLOW
WRRPR - RTFAST
WRRWRP - RTFAST RTSLOW
WRW - RTFAST
WRWPR - RTFAST
WRWSO - RTFAST
WSQ - RTFAST

Figure G.6. (Continued)

WVT - RTFAST
XACOEF - CLCOCM
XAERF - RTFAST
XAERLW - RTFAST
XAERNC - RTFAST
XAERNL - RTFAST
XAERNR - RTFAST
XAERO - RTFAST
XAERRW - RTFAST
XAERT - RTFAST
XAERWG - RTFAST
XAIO - GEAR RTFAST RTSLOW
XAREP - 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
XGI - GEAR
XHT - RTFAST RTSLOW
XL - RTSLOW
XLCOS - RTFAST RTSLOW
XLINTP - RTFAST RTSLOW
XLSIN - RTSLOW
XMAP - RTFAST
XN - GEAR
XPAR1 - AILSP CLCOCM RTFAST RTSLOW
XPAR3 - AILSP CLCOCM RTFAST RTSLOW
XR - RTSLOW
XRCOS - RTFAST RTSLOW
XRLCON - RTSLOW
XRSIN - RTSLOW
XVT - RTFAST
XW - RTSLOW
XWAC - RTFAST RTSLOW
XWG2 - RTFAST
XWHWLW - RTSLOW
XXICON - RTSLOW
XZICON - RTSLOW
YAERF - RTFAST
YAERLW - RTFAST
YAERNC - RTFAST
YAERNL - RTFAST
YAERNR - RTFAST
YAERO - RTFAST
YAERRW - RTFAST
YAERT - RTFAST
YAERWG - RTFAST
YAREP - RTFAST RTSLOW

Figure G.6. (Continued)

YARHT - RTFAST
YARVT - RTFAST
YG - GEAR
YGI - 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
ZARIG - RTFAST
ZARVB - RTFAST
ZARVT - RTFAST
ZCG - GEAR RTFAST RTSLOW
ZDTCG - RTFAST
ZFTHL - RTFAST RTSLOW
ZFTHR - RTFAST RTSLOW
ZETR1 - RTSLOW
ZETR2 - RTSLOW
ZETR3 - RTSLOW
ZETR4 - RTSLOW
ZF - RTSLOW
ZFAC - RTSLOW
ZFMFHF - RTSLOW
ZG - GEAR
ZGI - GEAR
ZHT - RTFAST RTSLOW
ZL - RTSLOW
ZLCOS - RTSLOW
ZLSIN - RTFAST RTSLOW
ZN - GEAR
ZR - RTSLOW
ZRCOS - RTSLOW
ZRLCOM - RTSLOW
ZRSIN - RTFAST RTSLOW
ZVT - RTFAST
ZW - RTSLOW
ZWAC - RTFAST RTSLOW
ZWNWIM - RTSLOW
ZZICON - RTSLOW

****

Figure G.6. (Continued)

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AILSP 94
CLCDCM 99
CLF1 ..... -94
CLF2 ..... -99
ENGINE 110
GEAR 115
RTFAST 1
RTSLOW 55
TSTRTF ..... -1
TSTRTS ..... -55
SUPER INDEX 120

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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

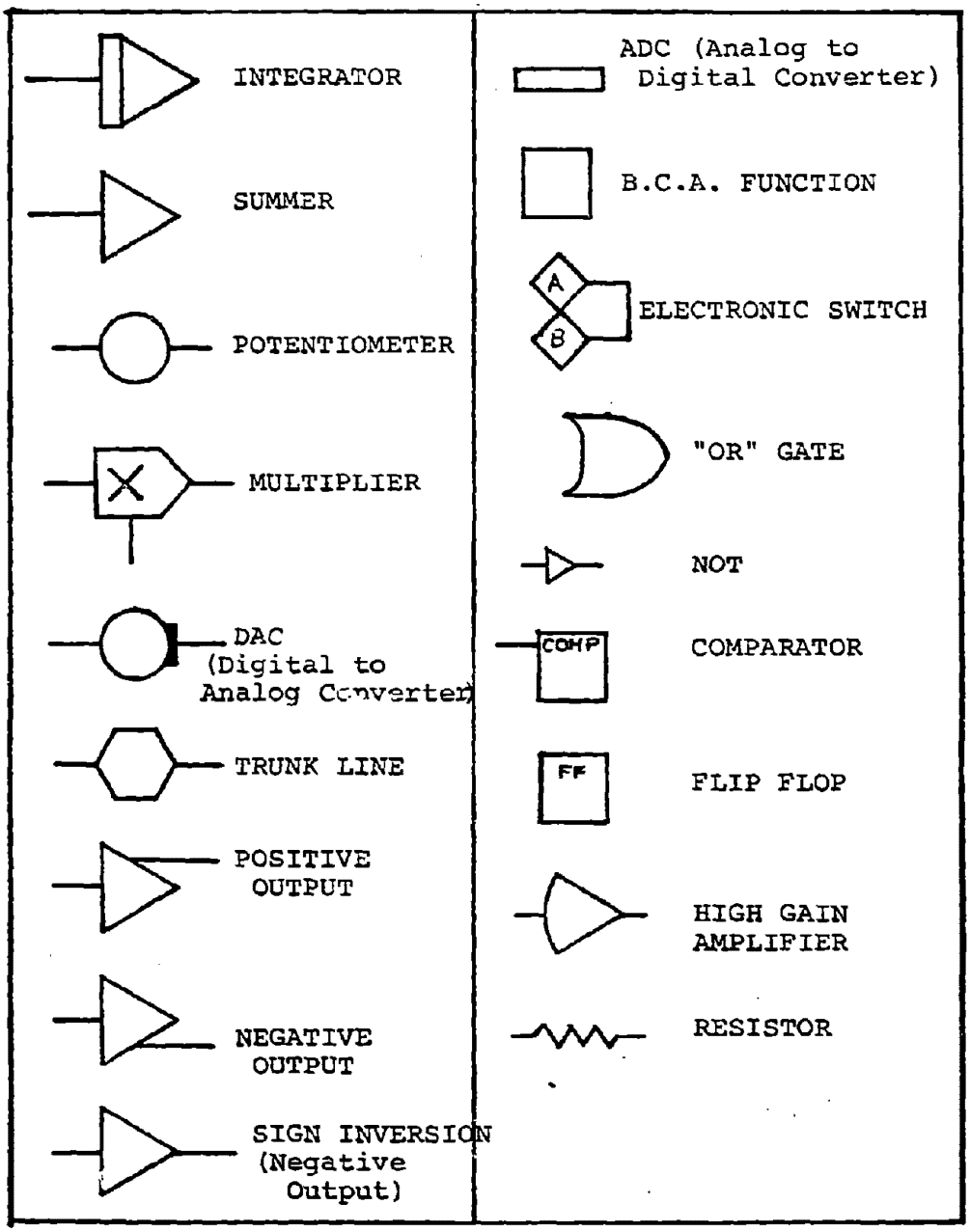


Figure G.7. Analog Symbols

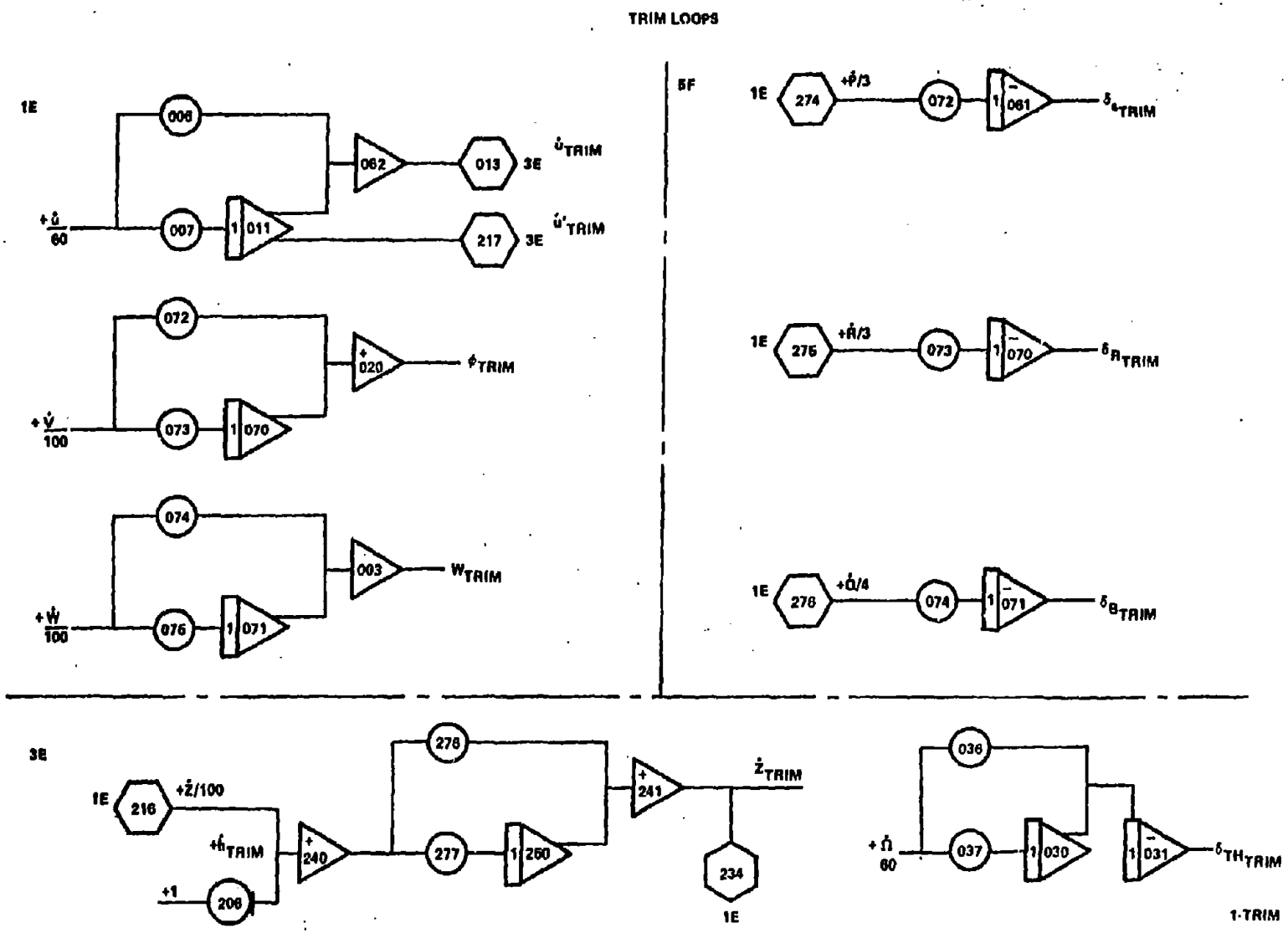


Figure G.8. Analog Diagrams for Model 222 Simulation

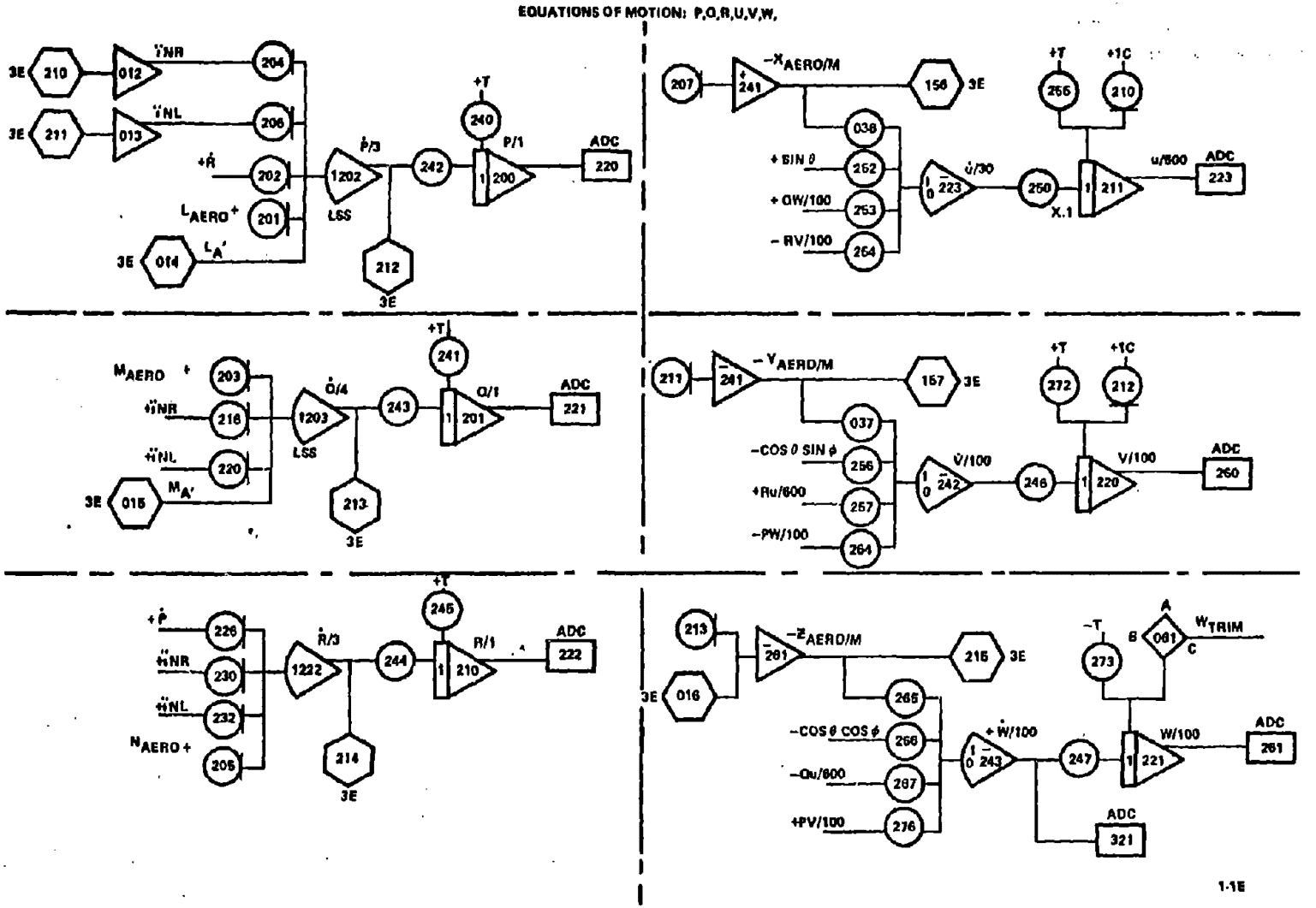


Figure G.8. (Continued)

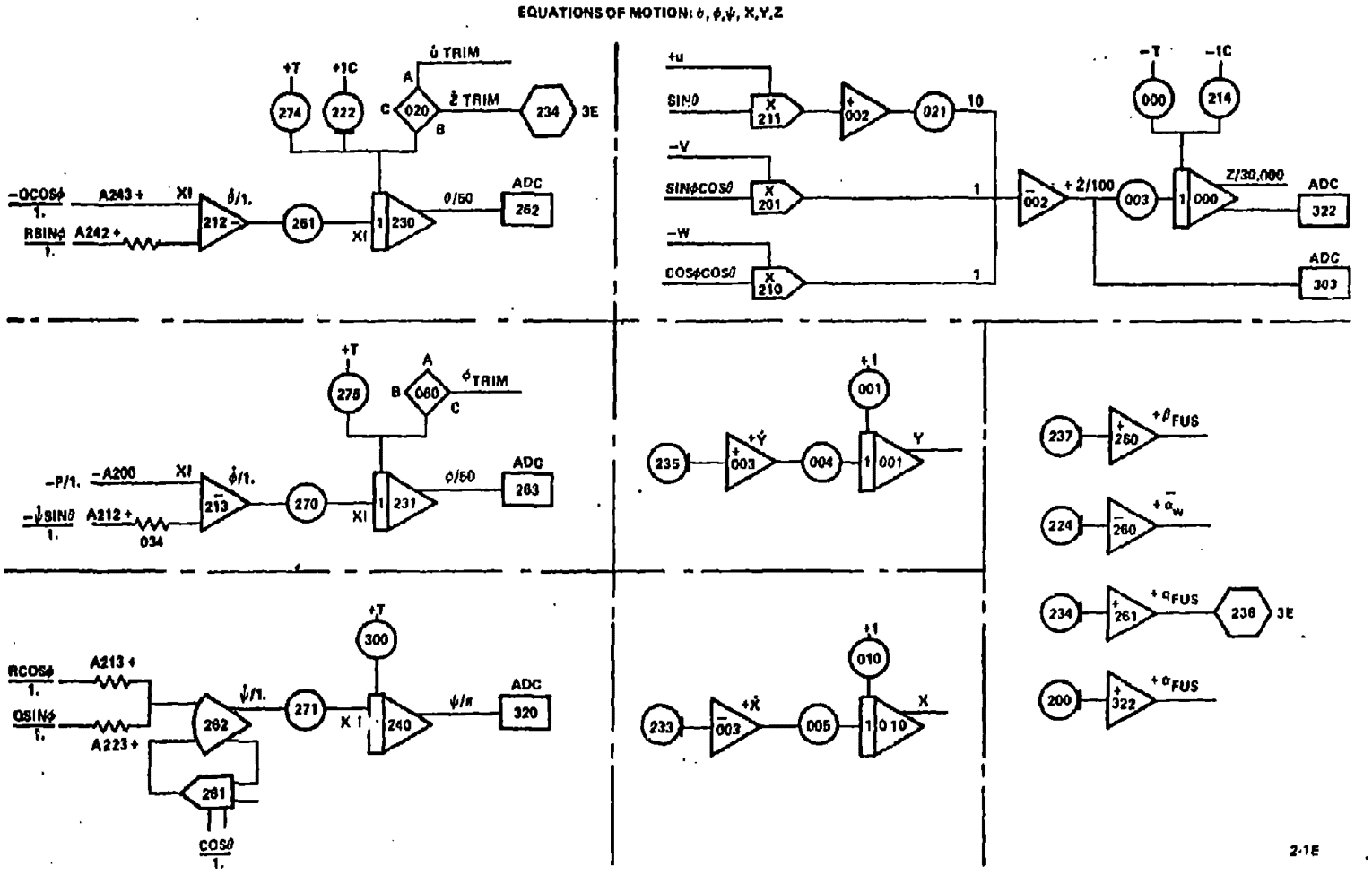


Figure G.8. (Continued)

EQUATIONS OF MOTION MULTIPLICATIONS

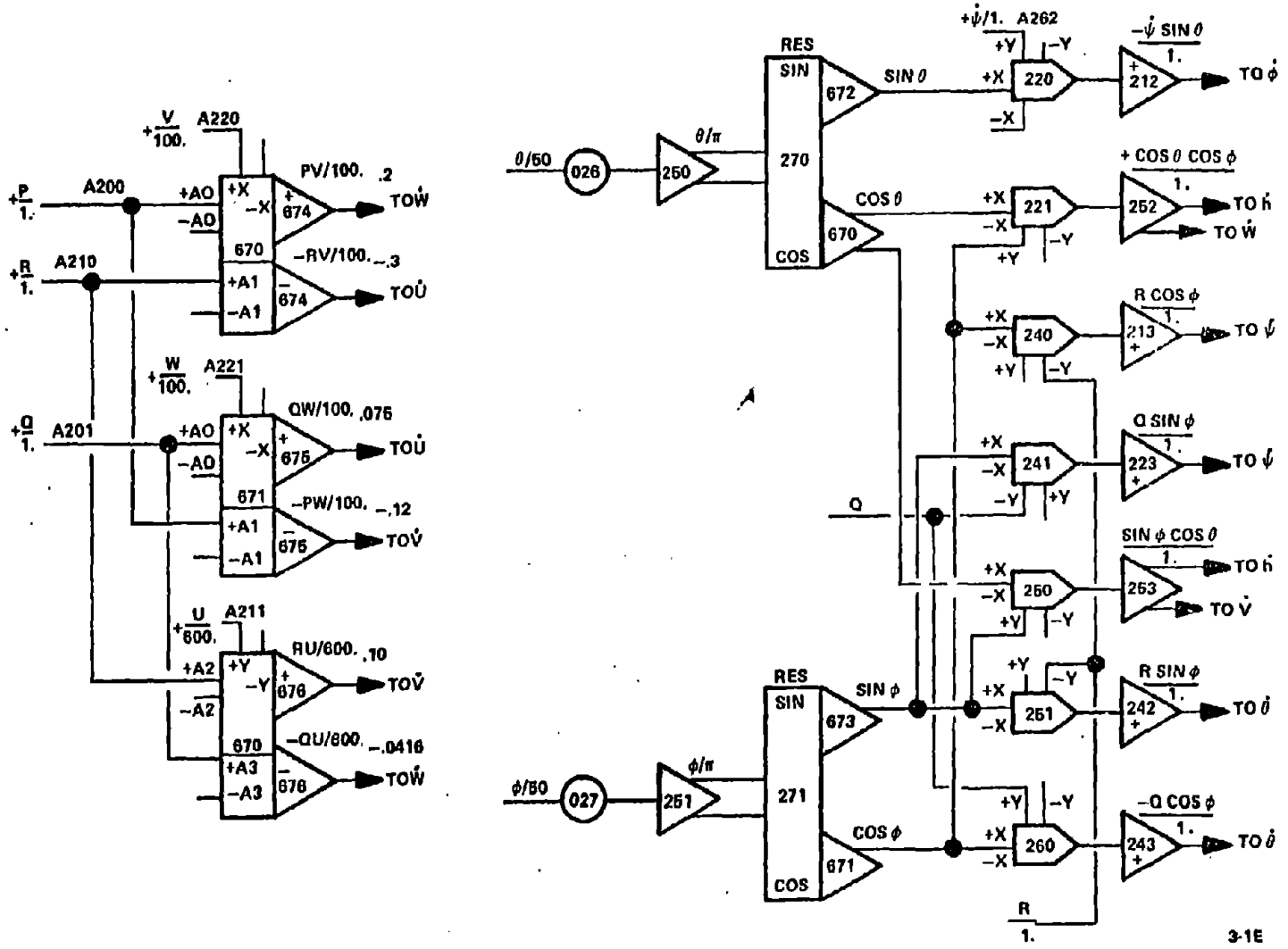


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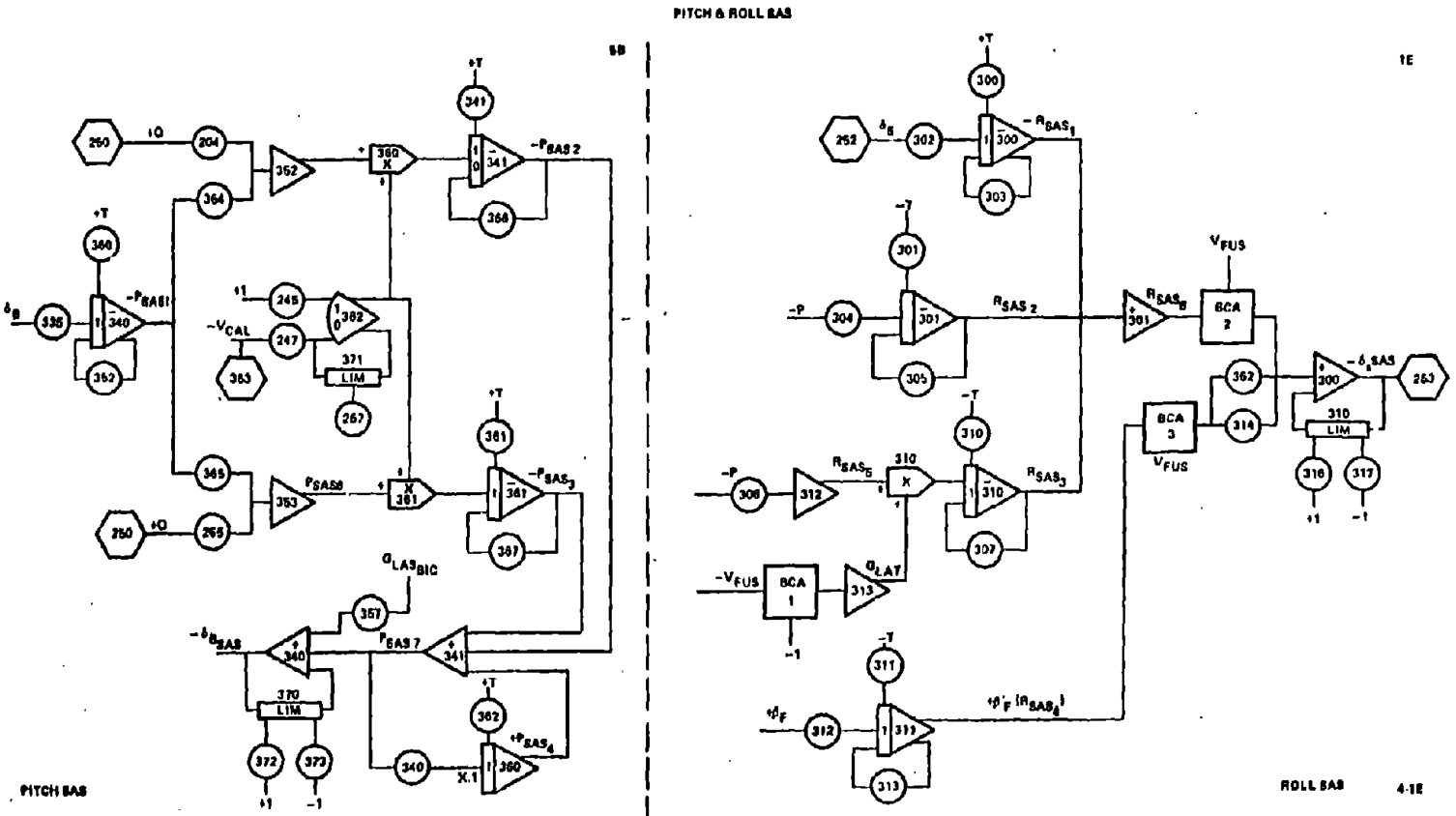


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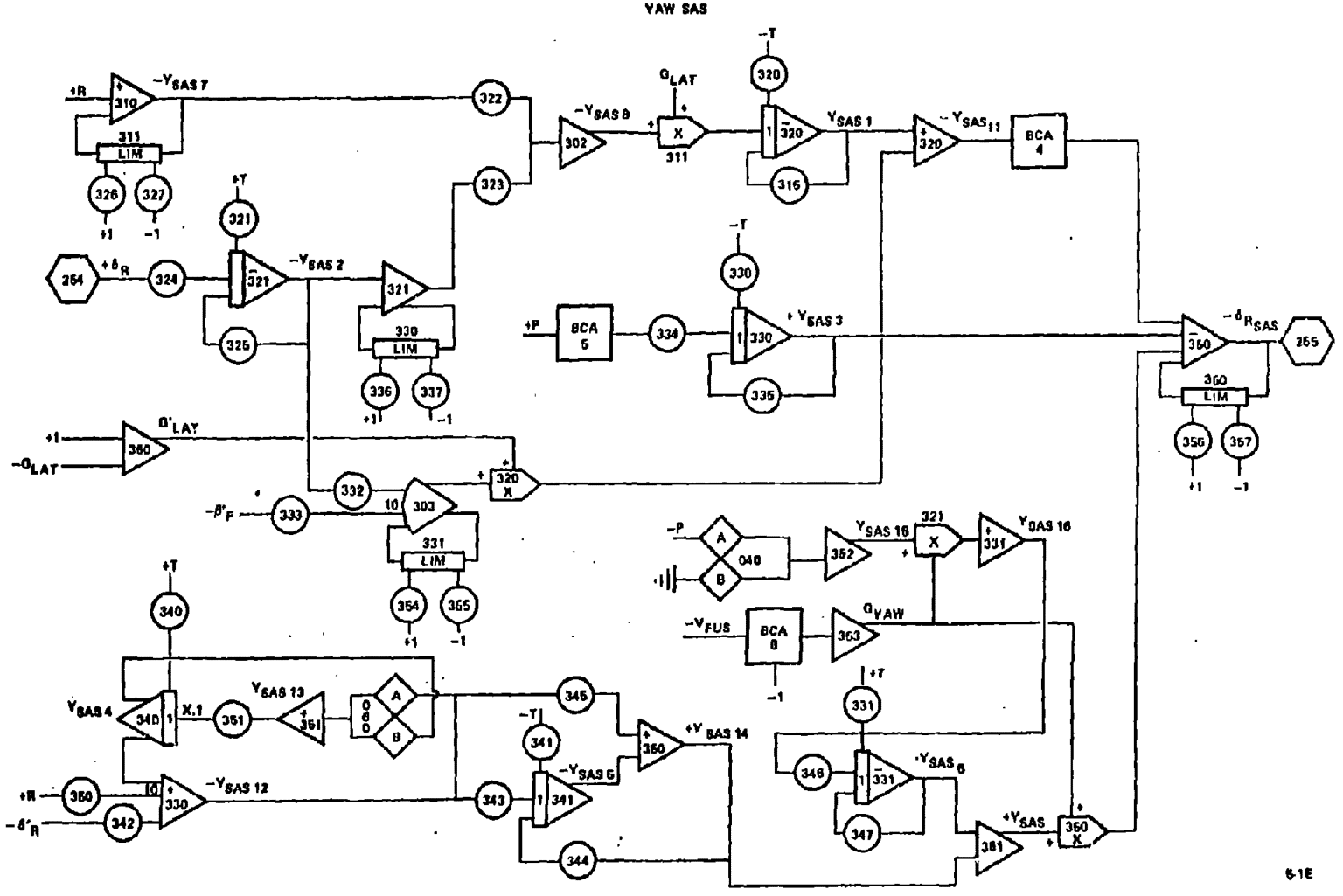


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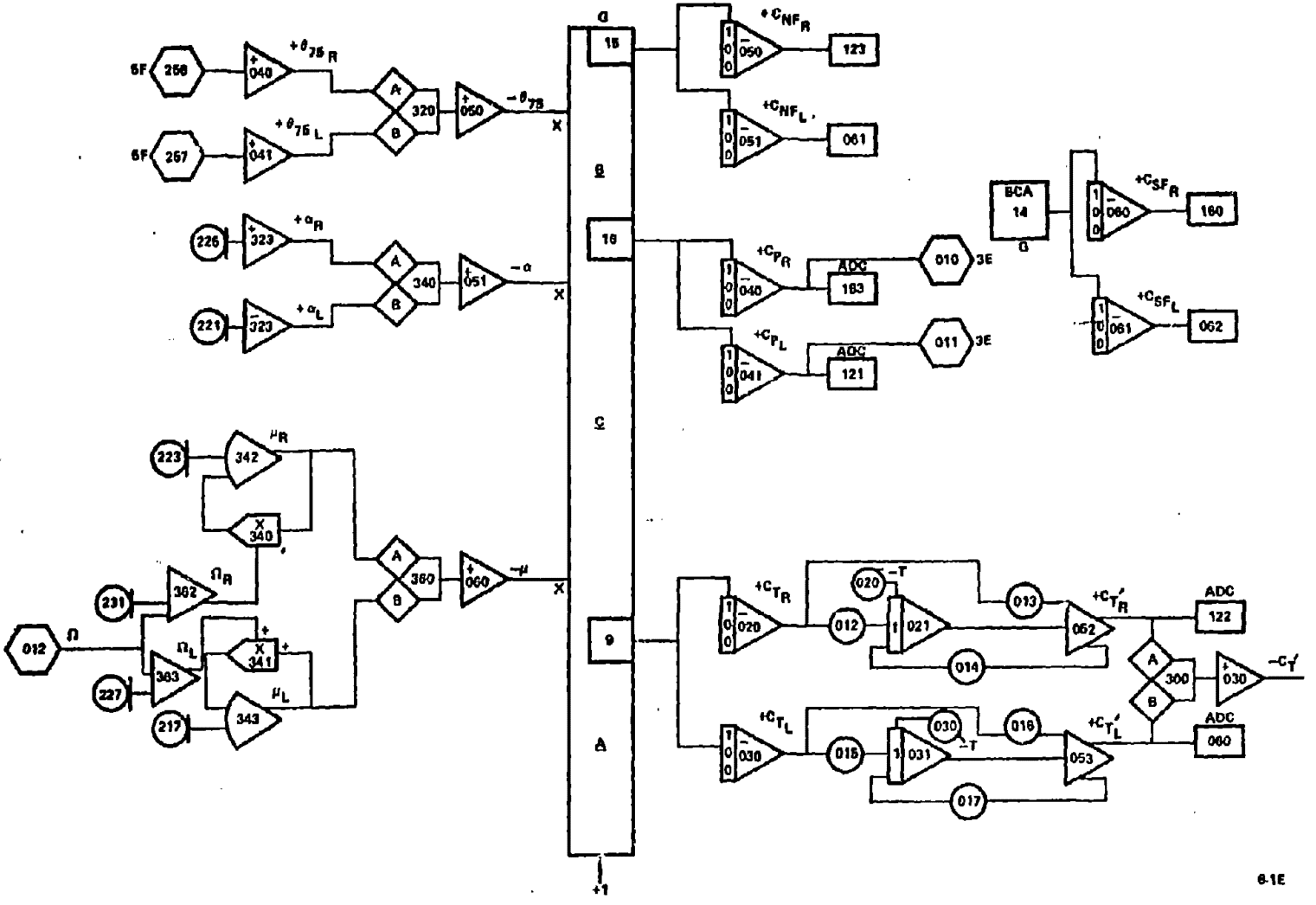


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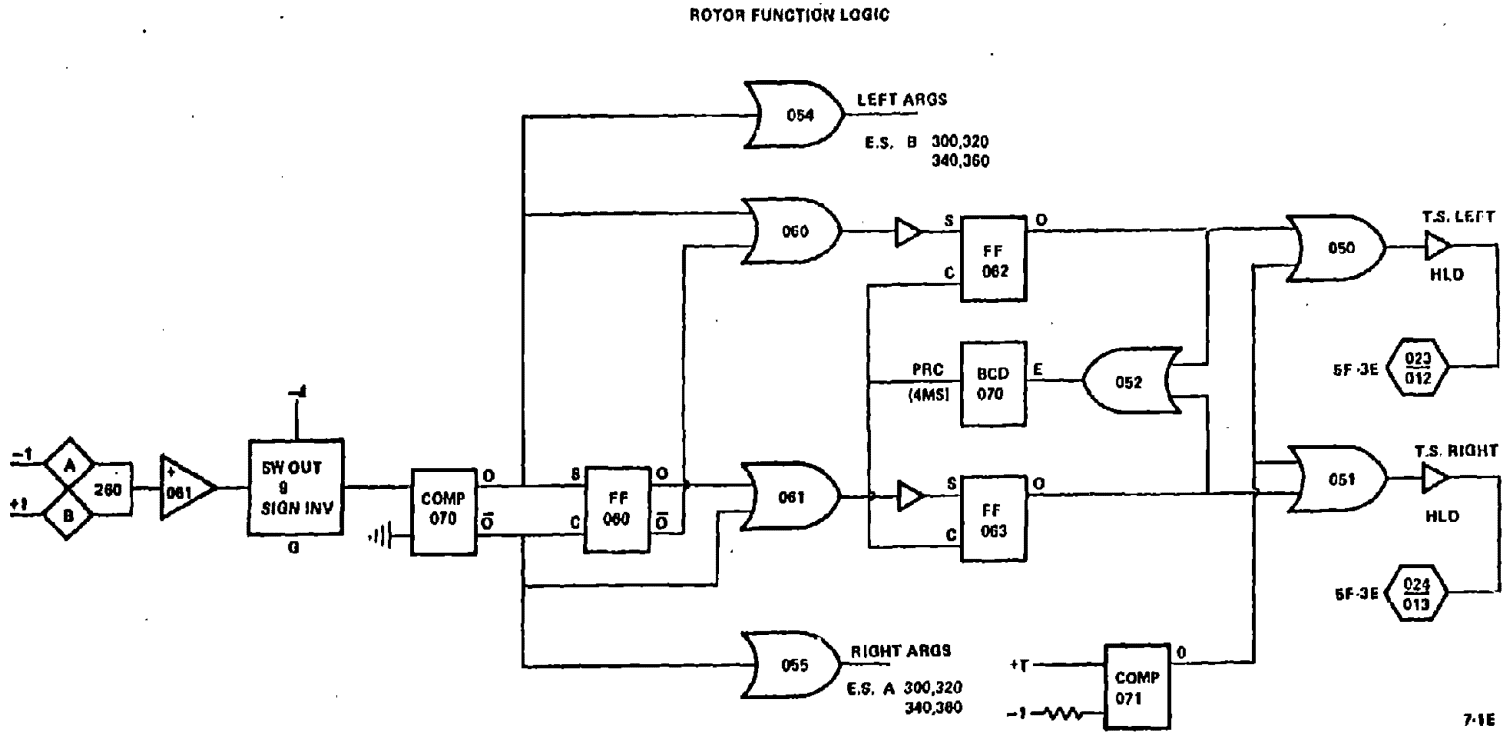


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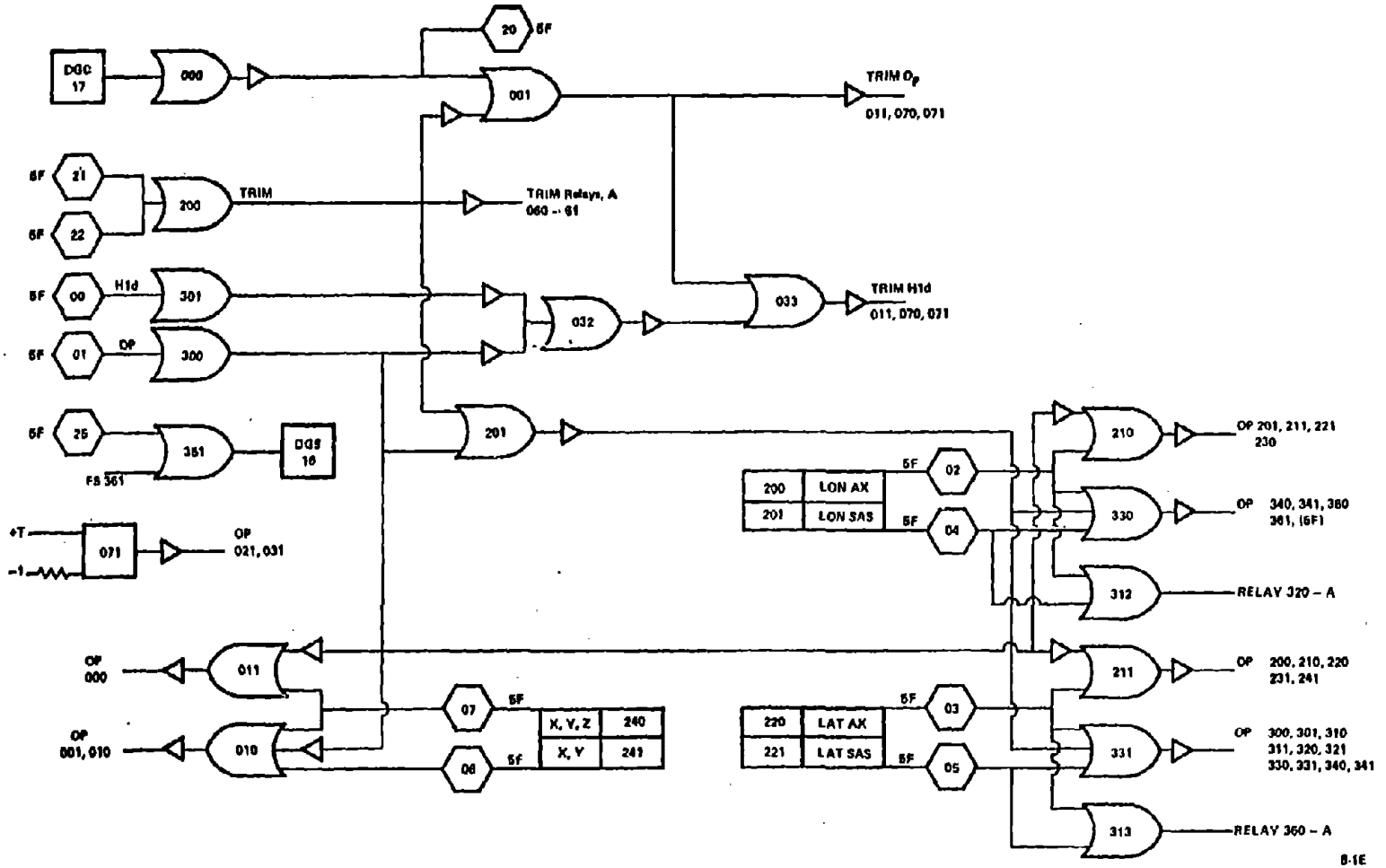


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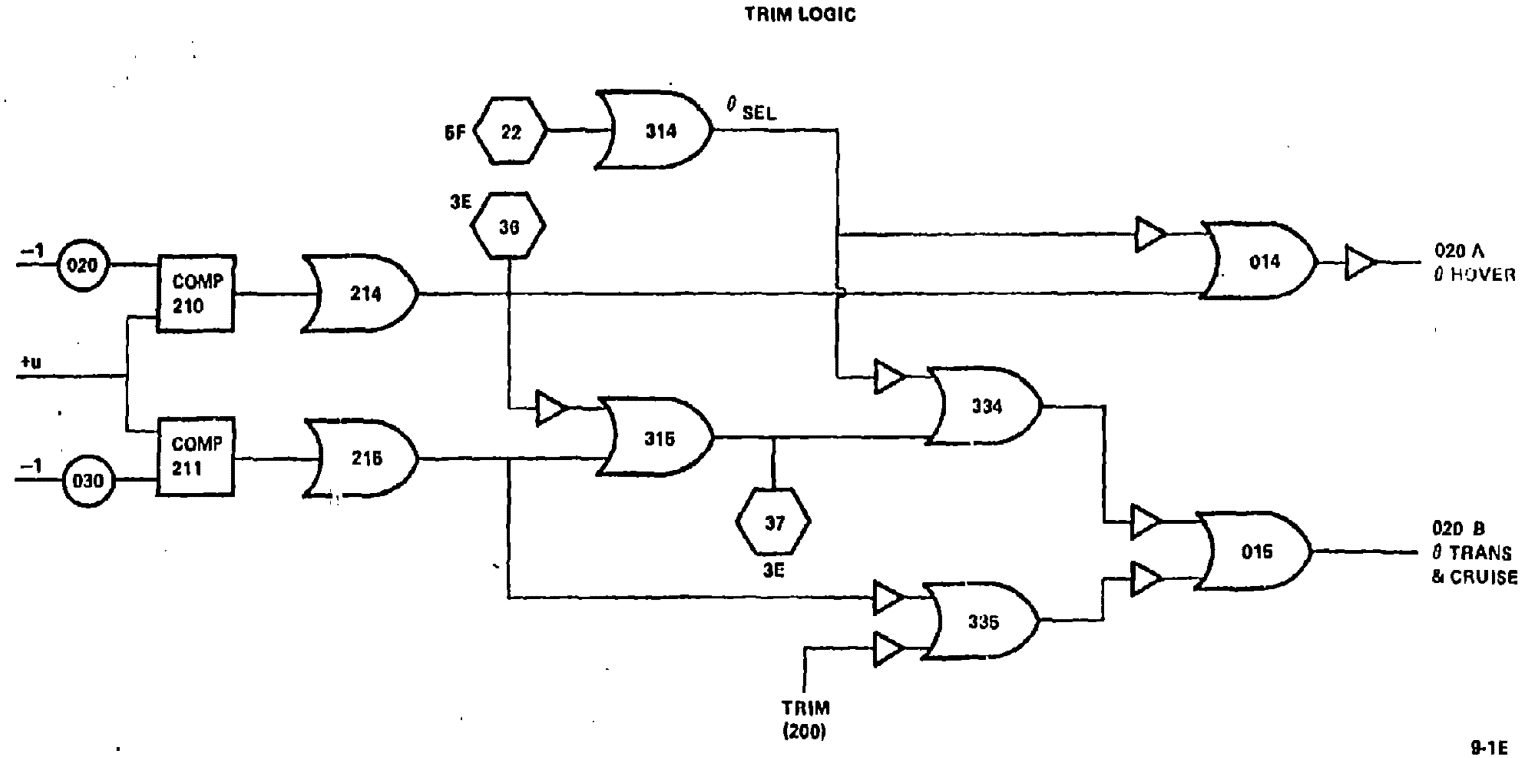


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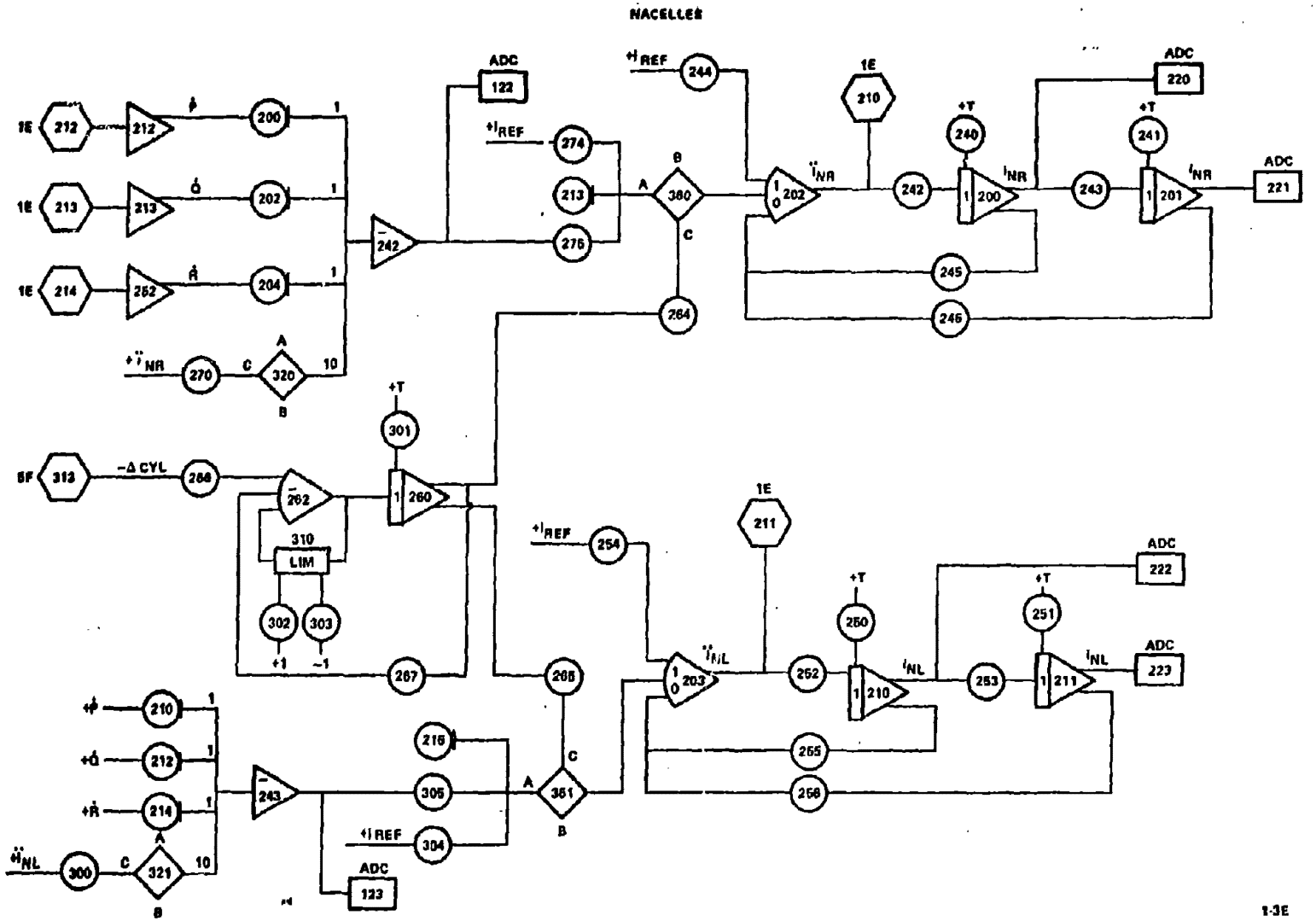


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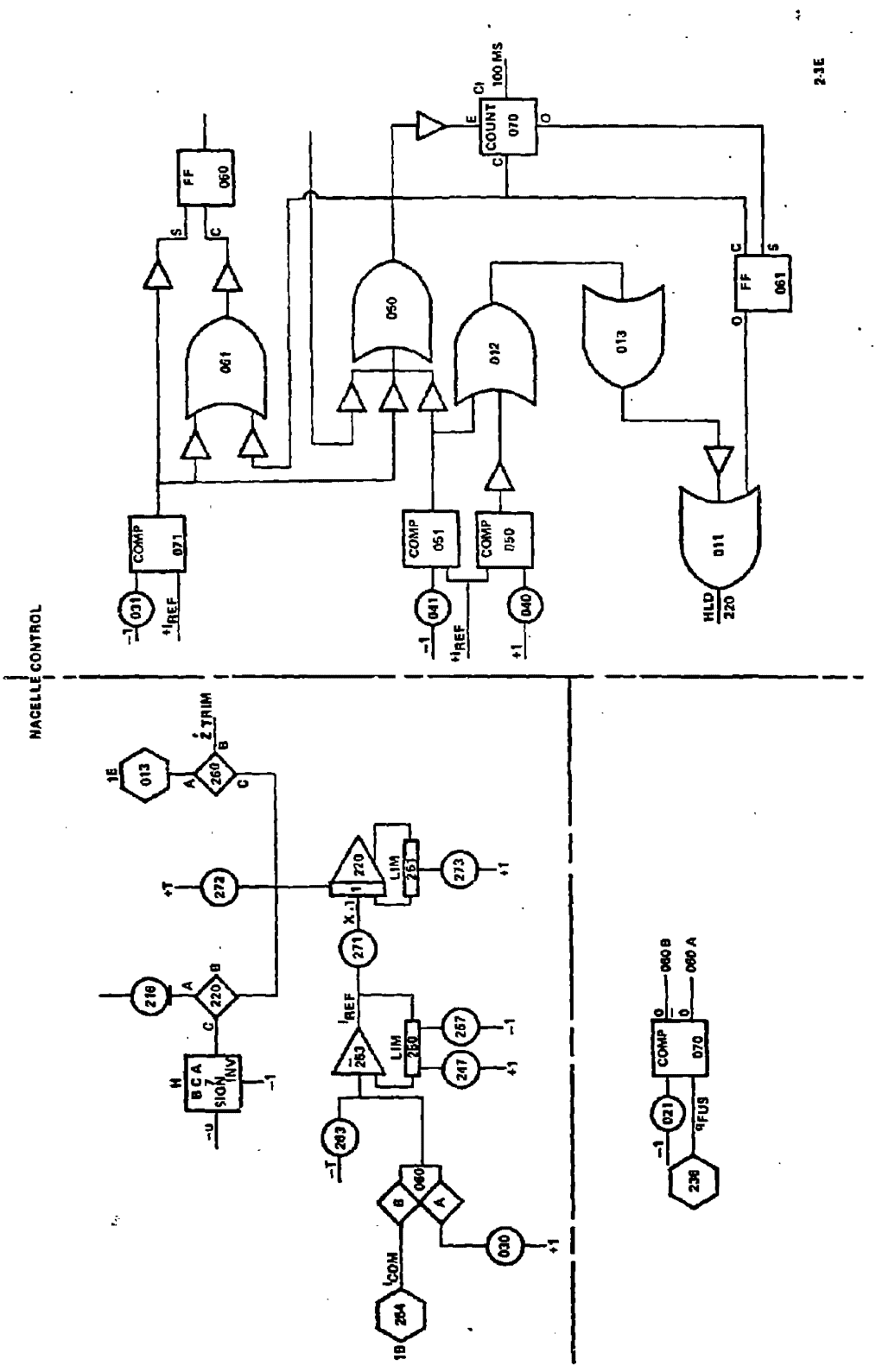


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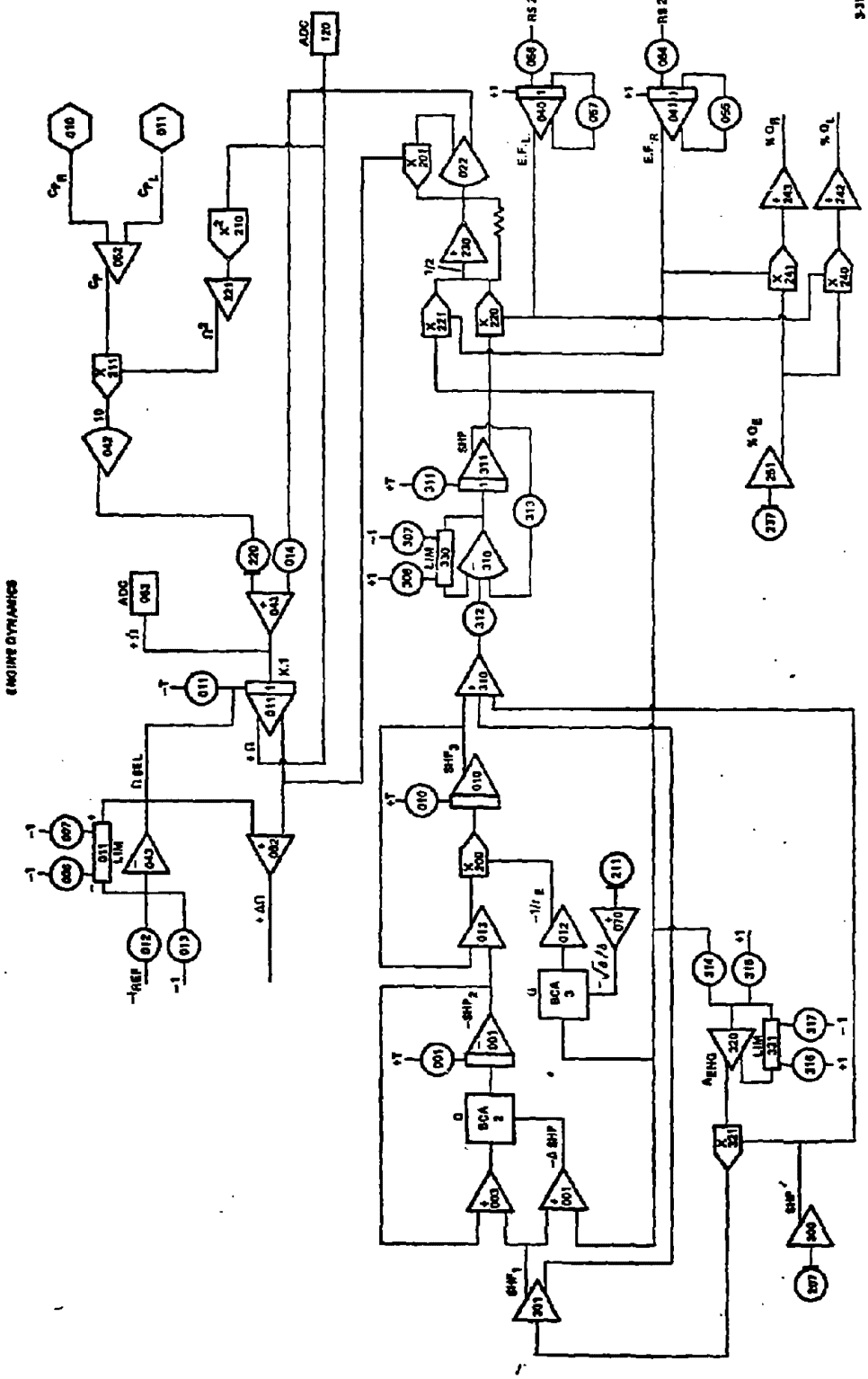


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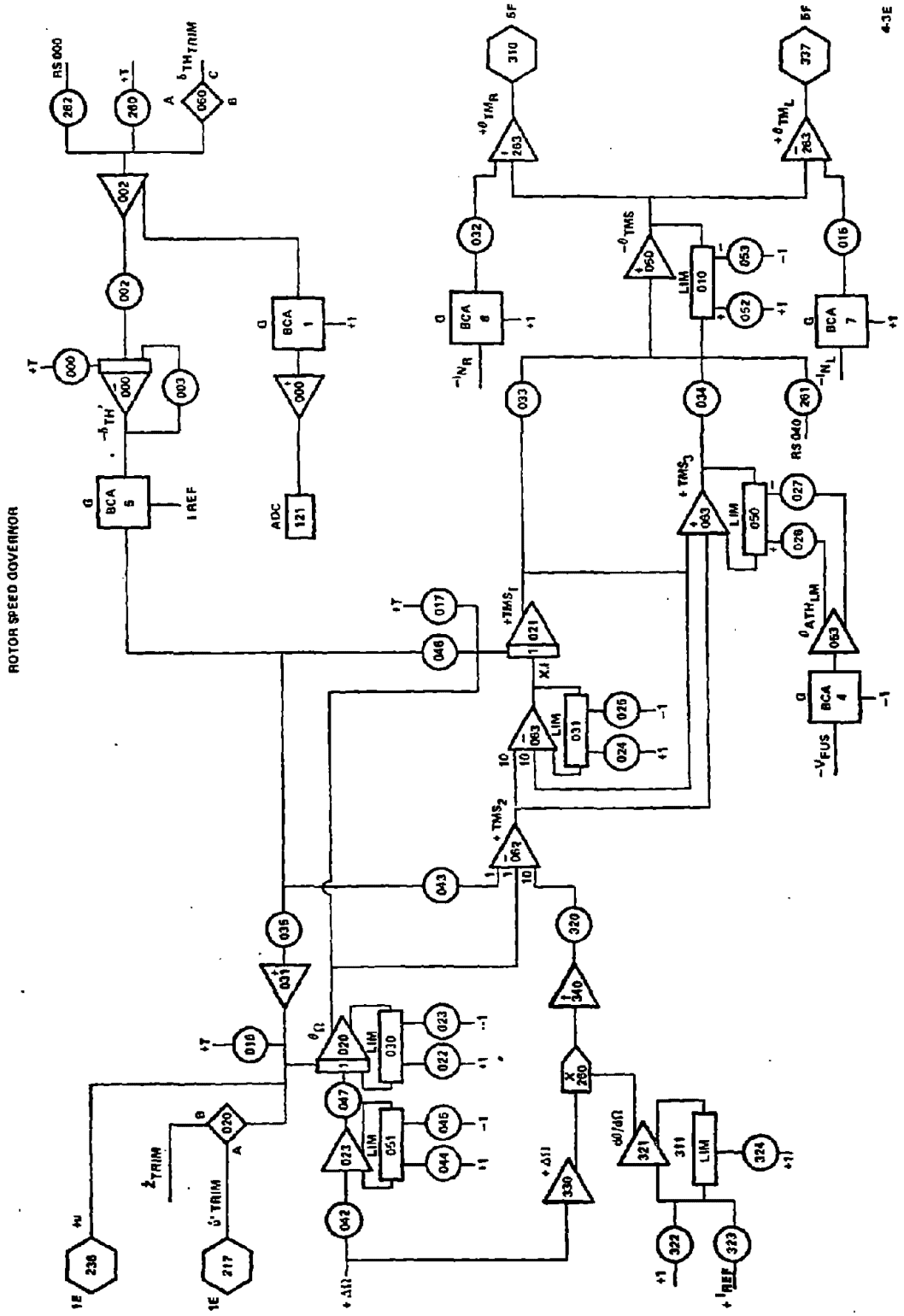


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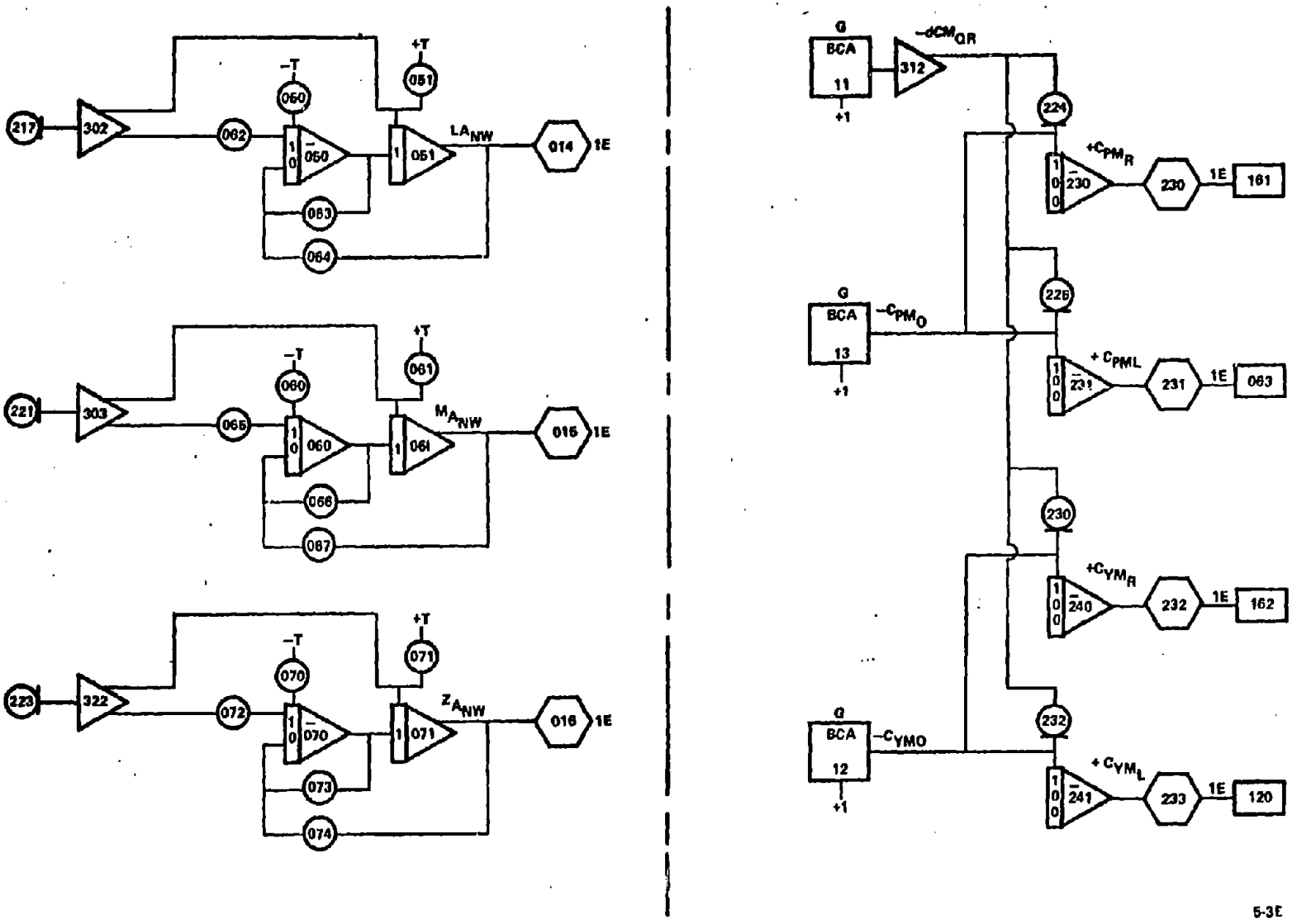


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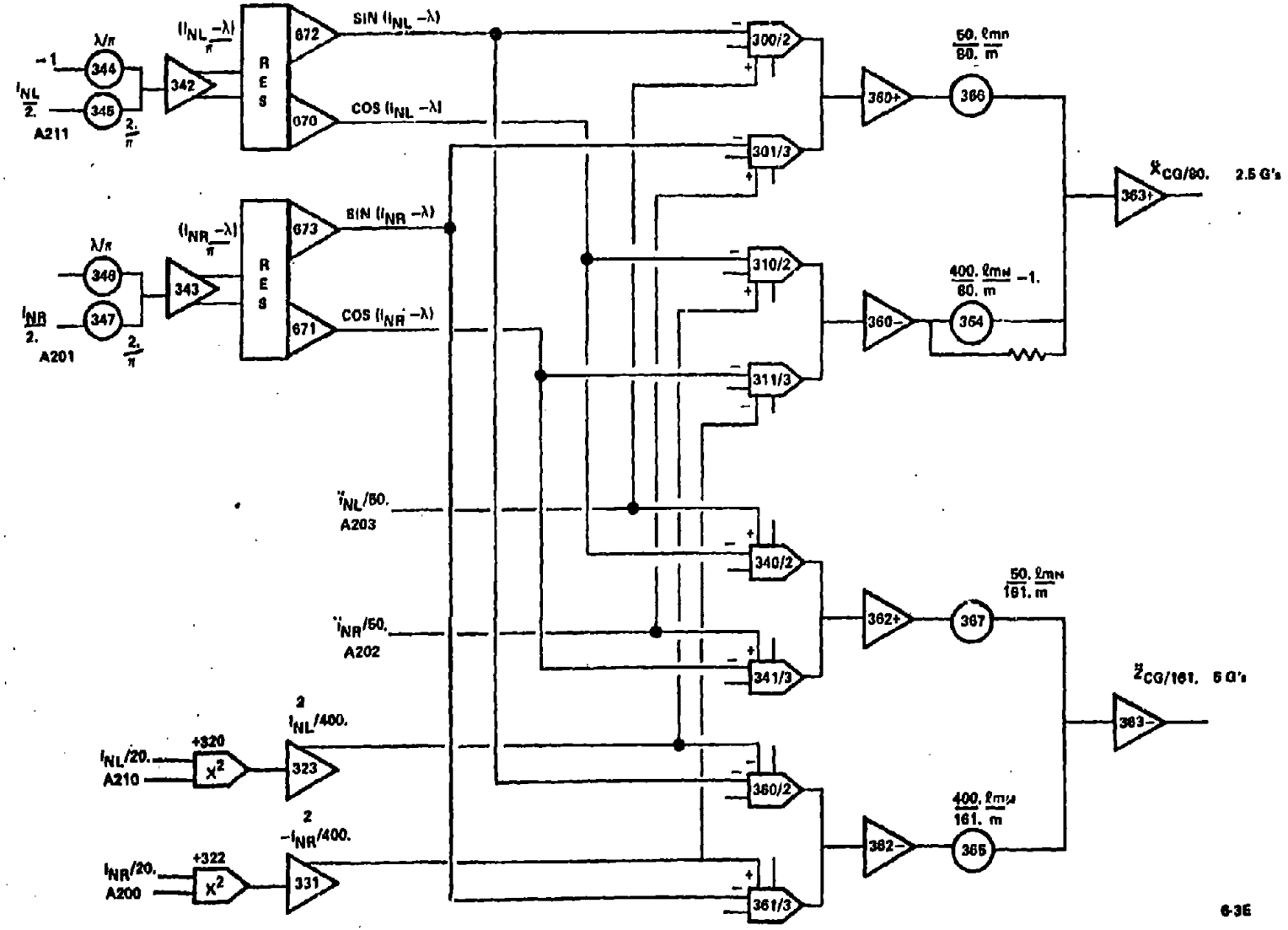
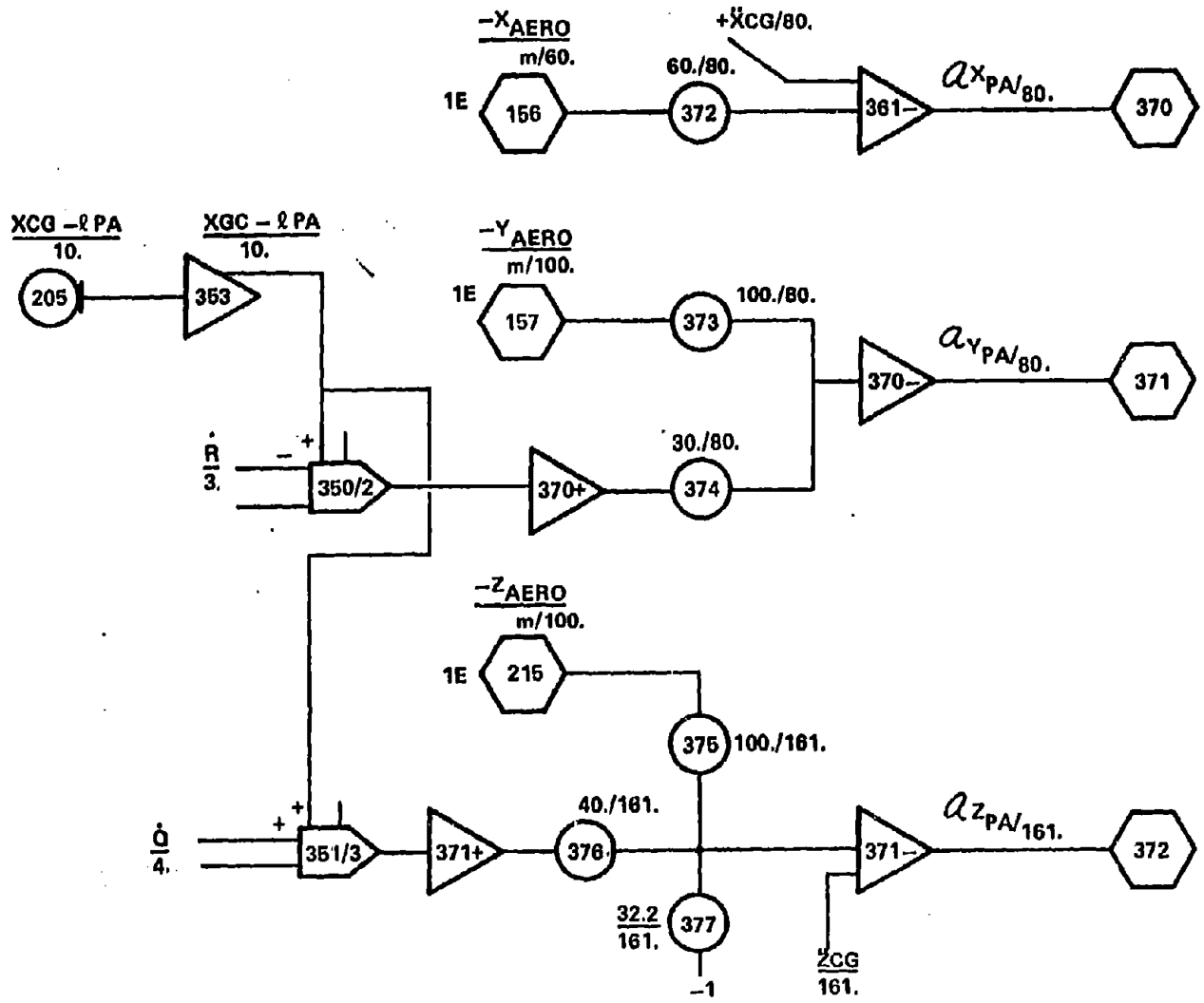


Figure G.8. (Continued)



7-3E

Figure G.8. (Continued)

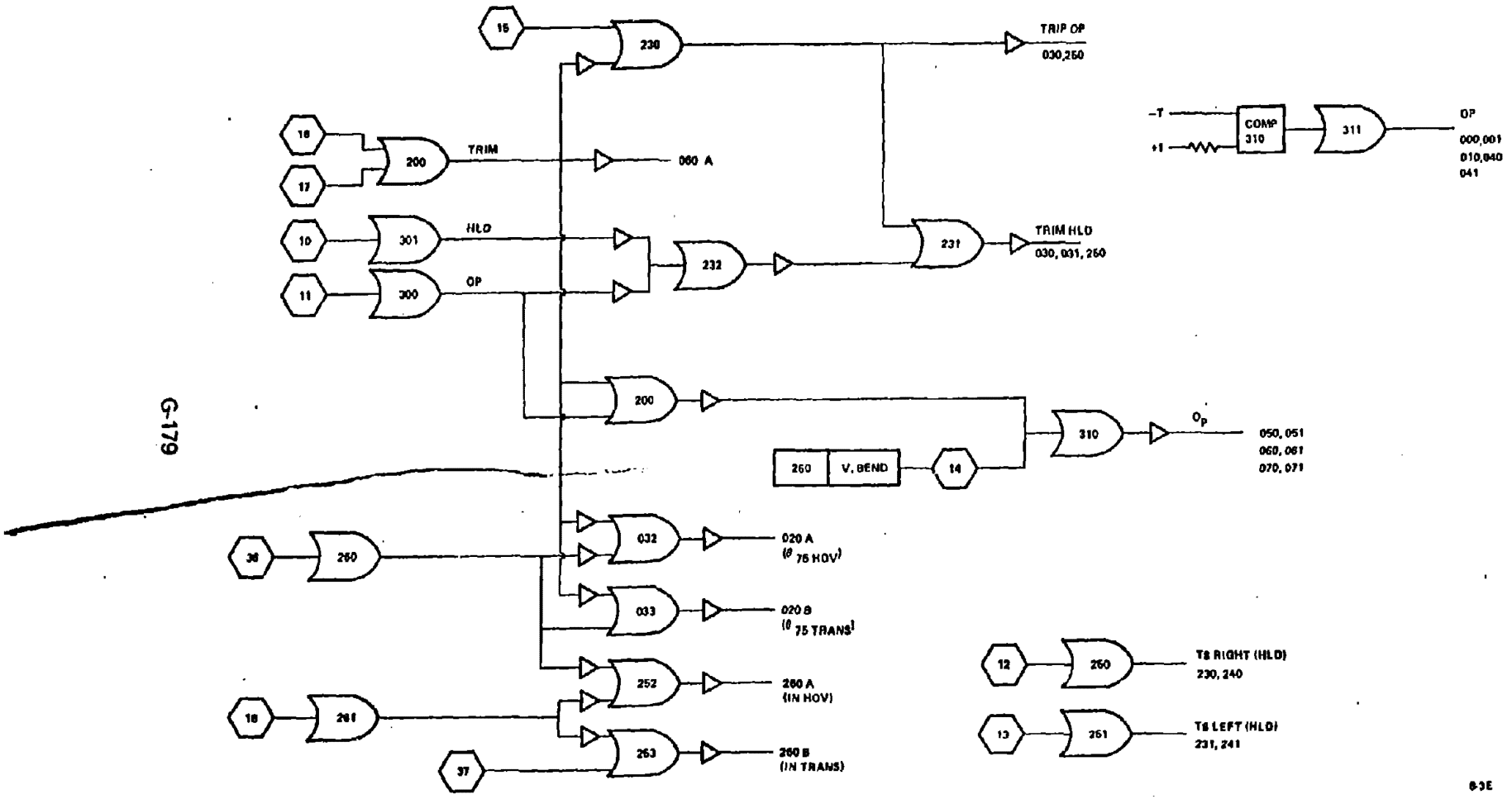


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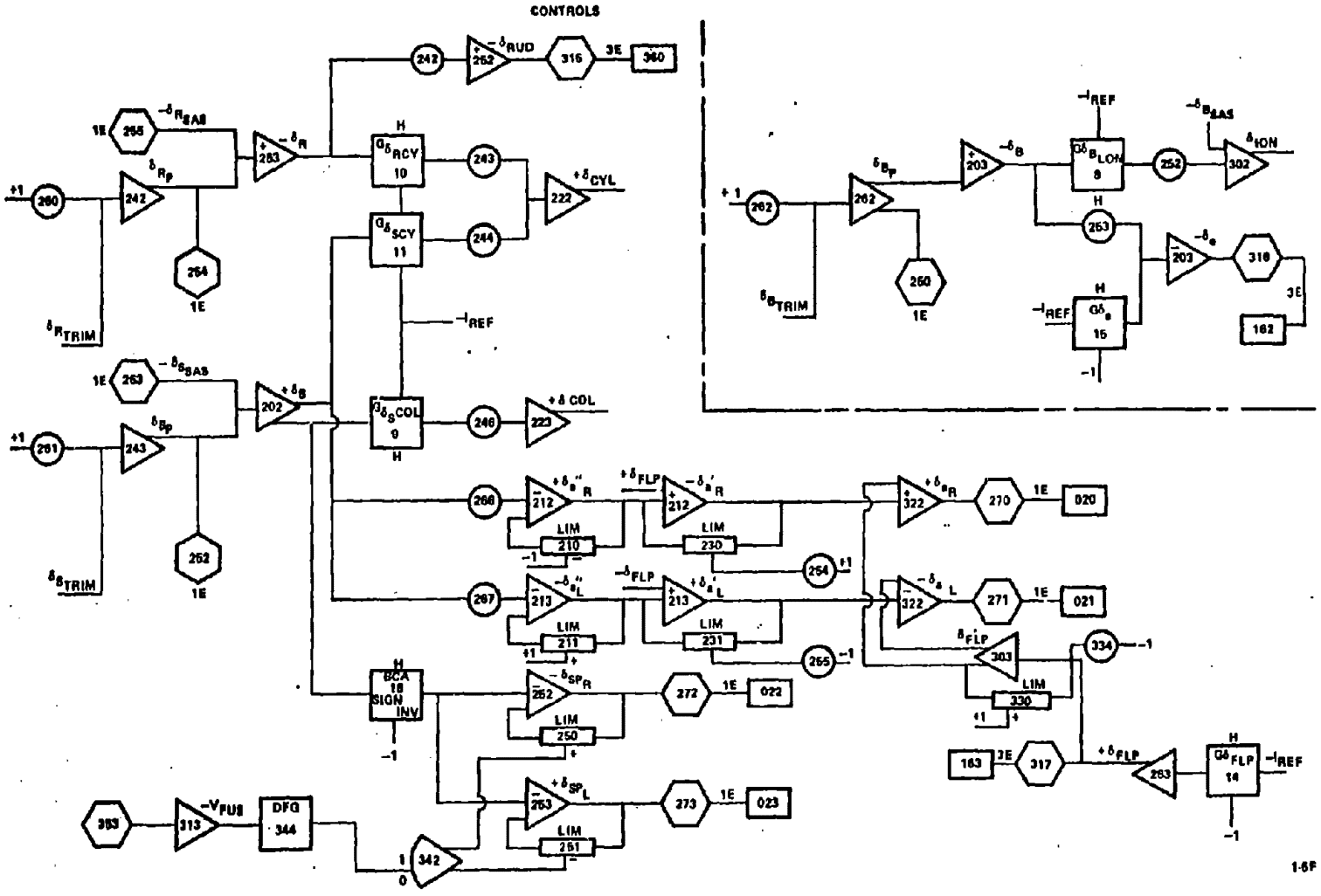


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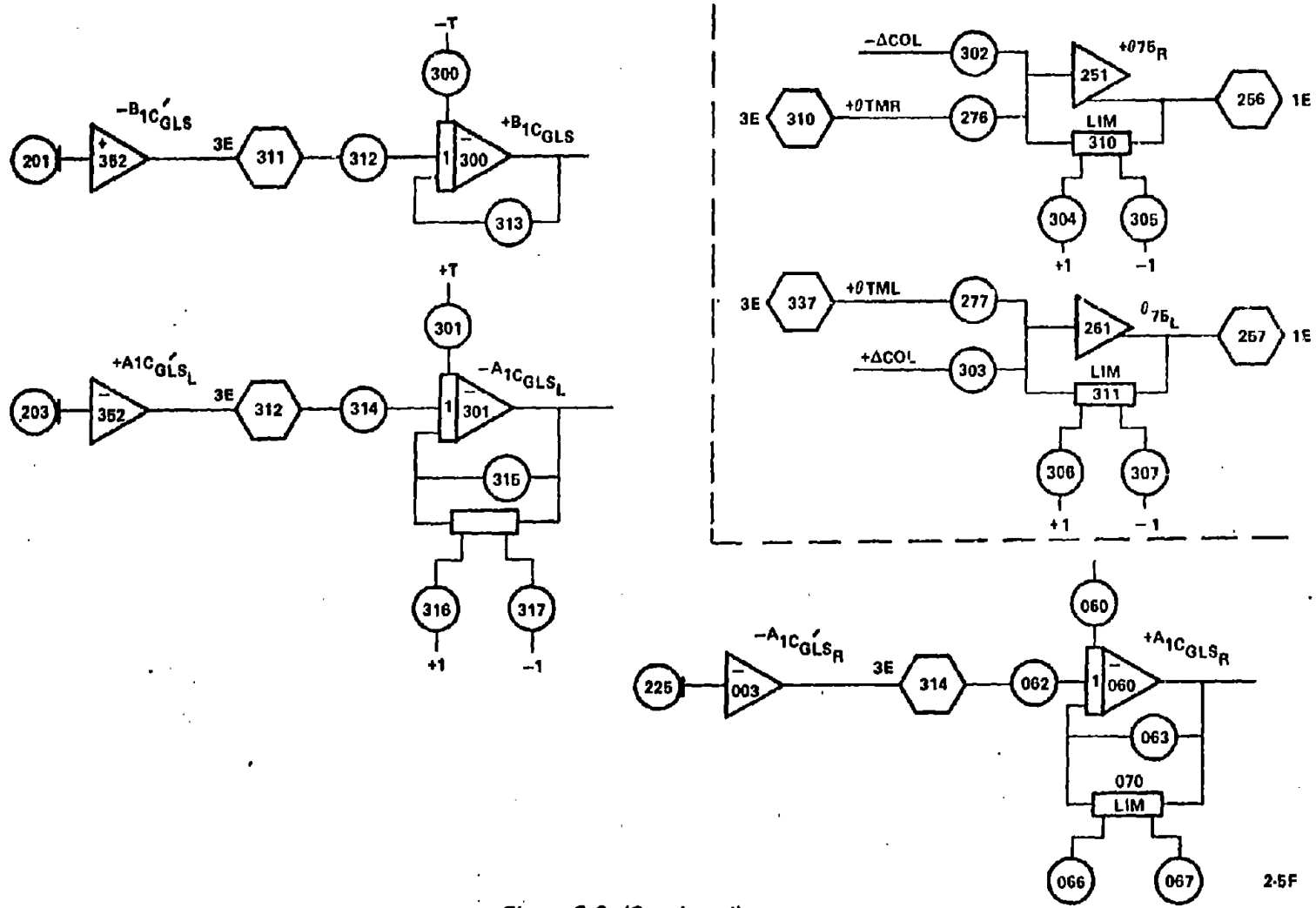
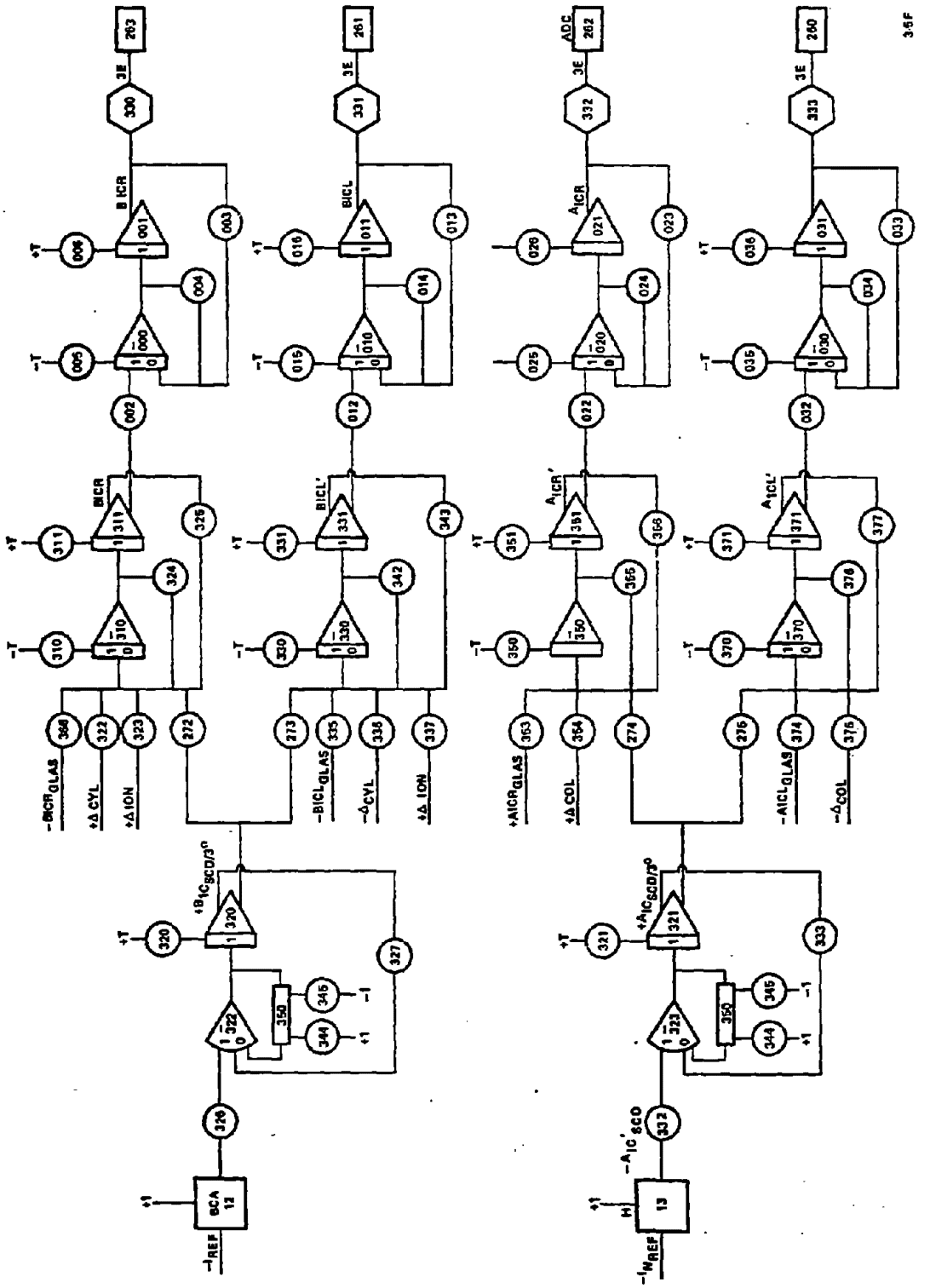


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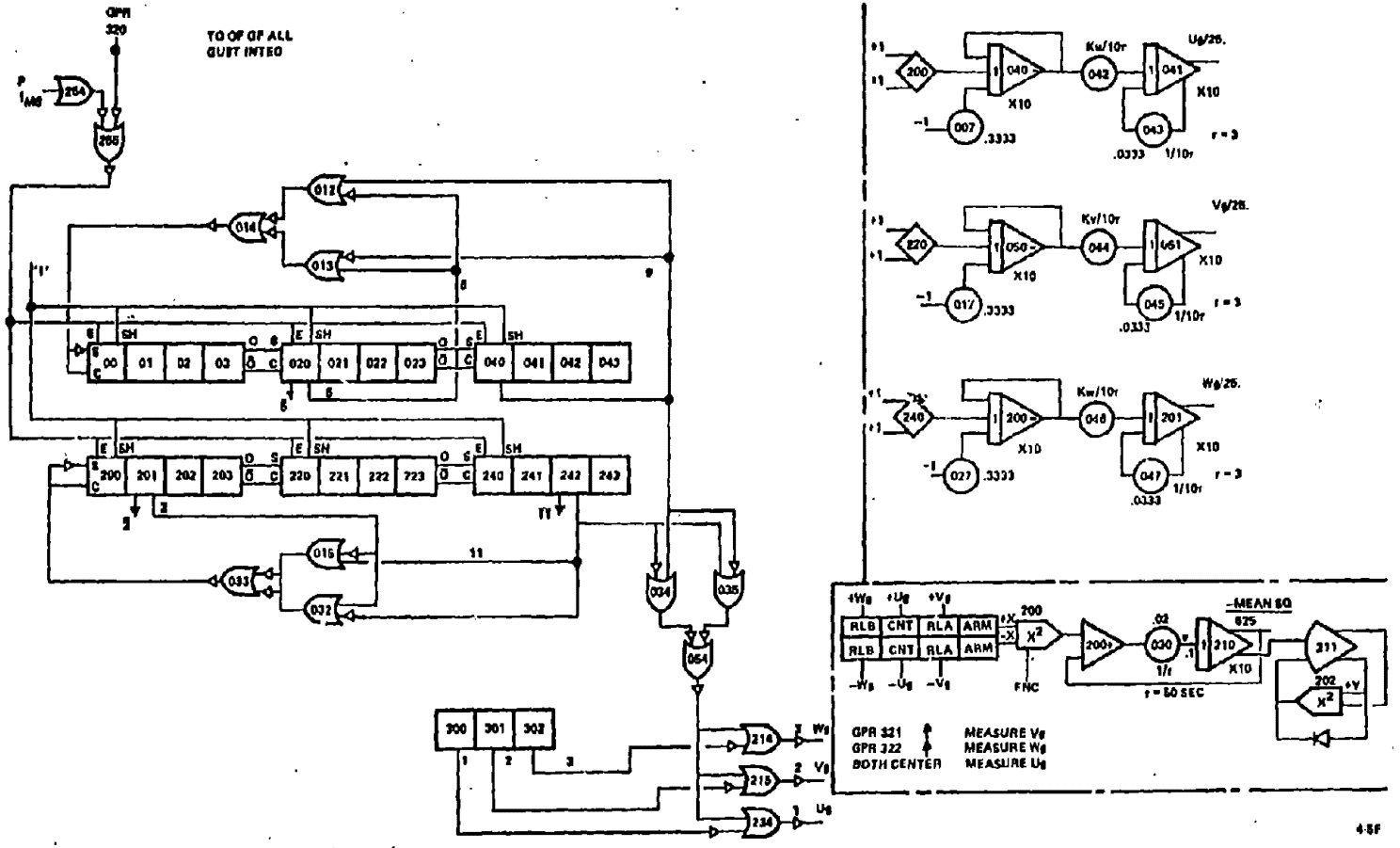


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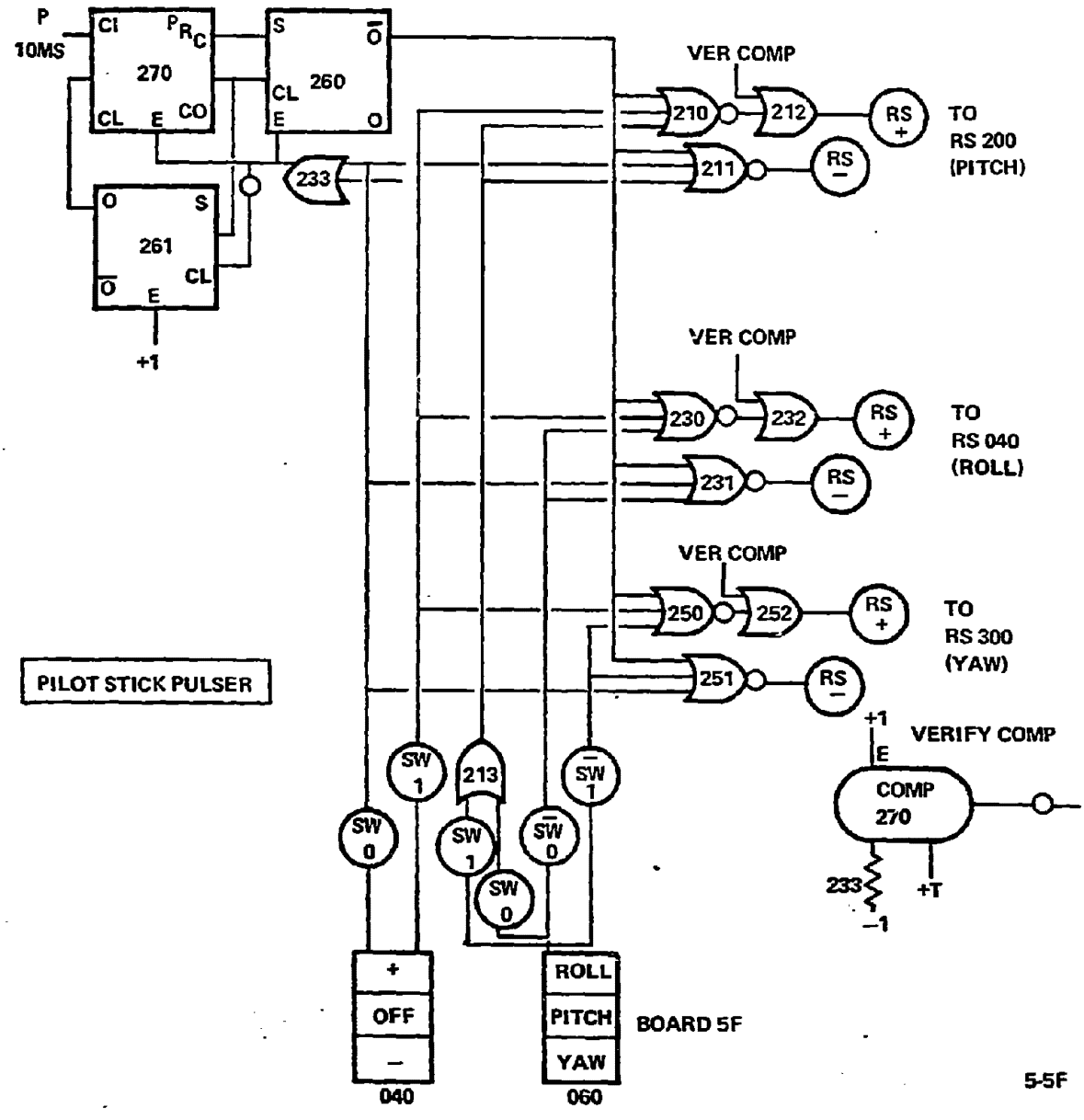


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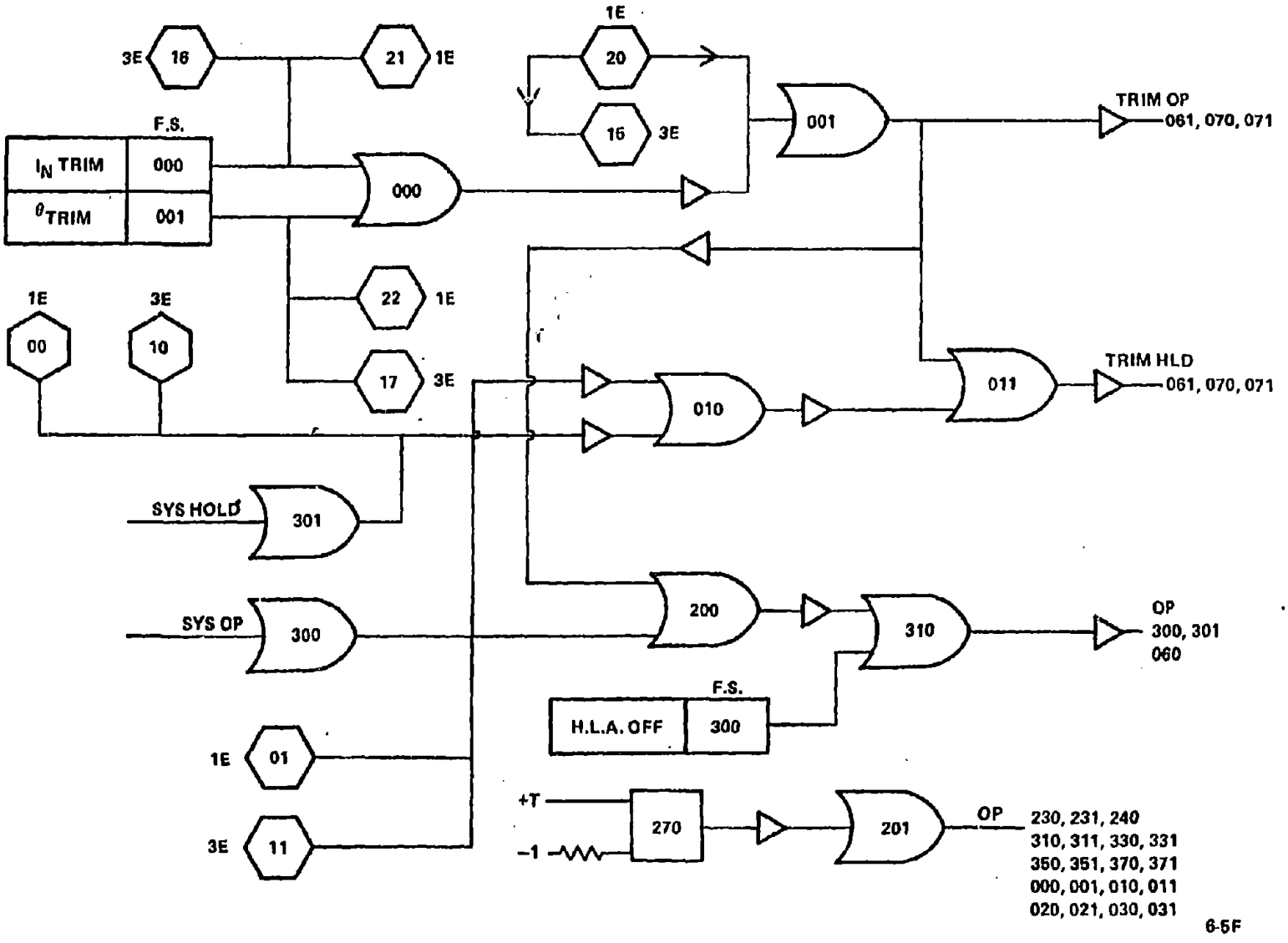


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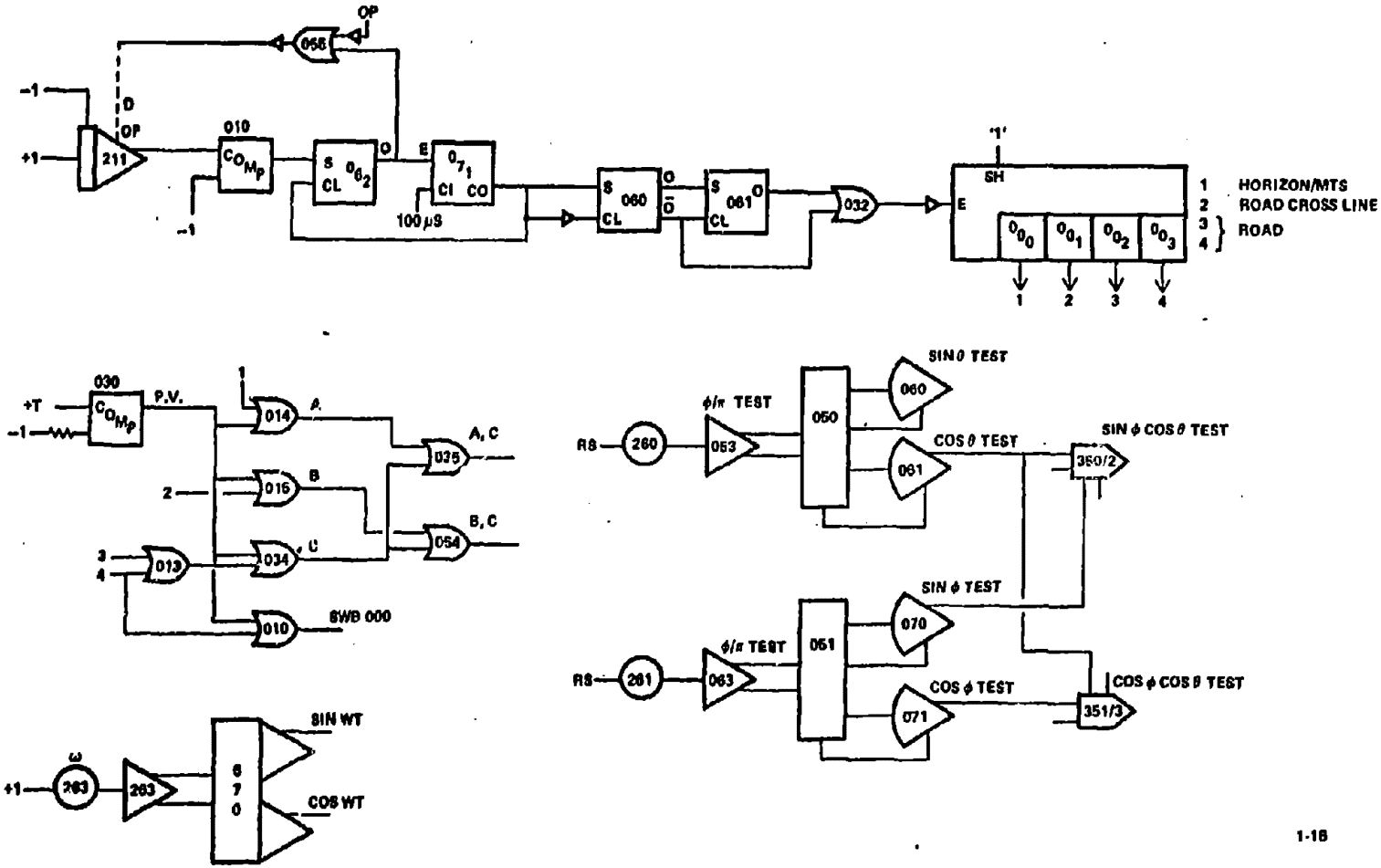


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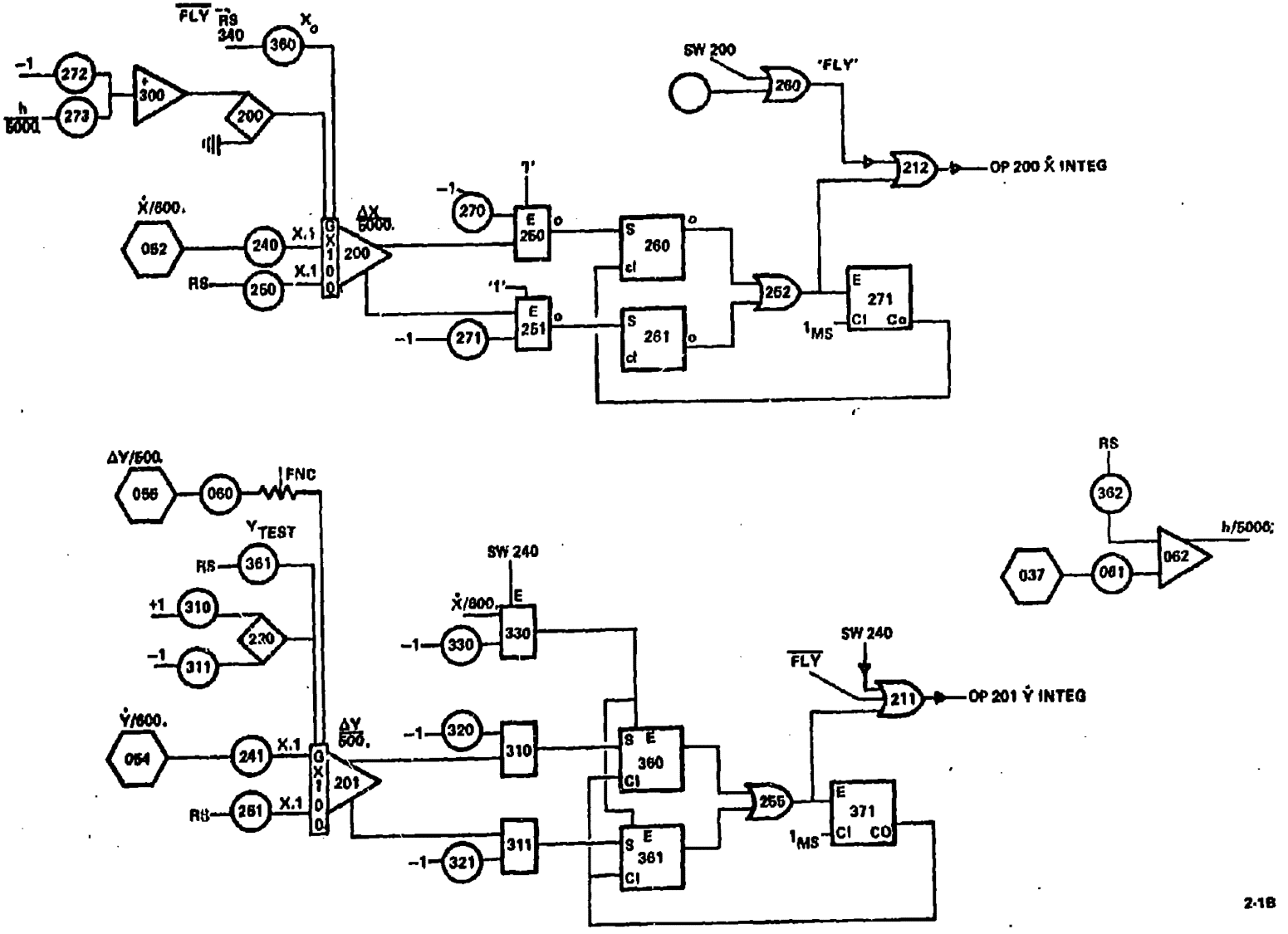


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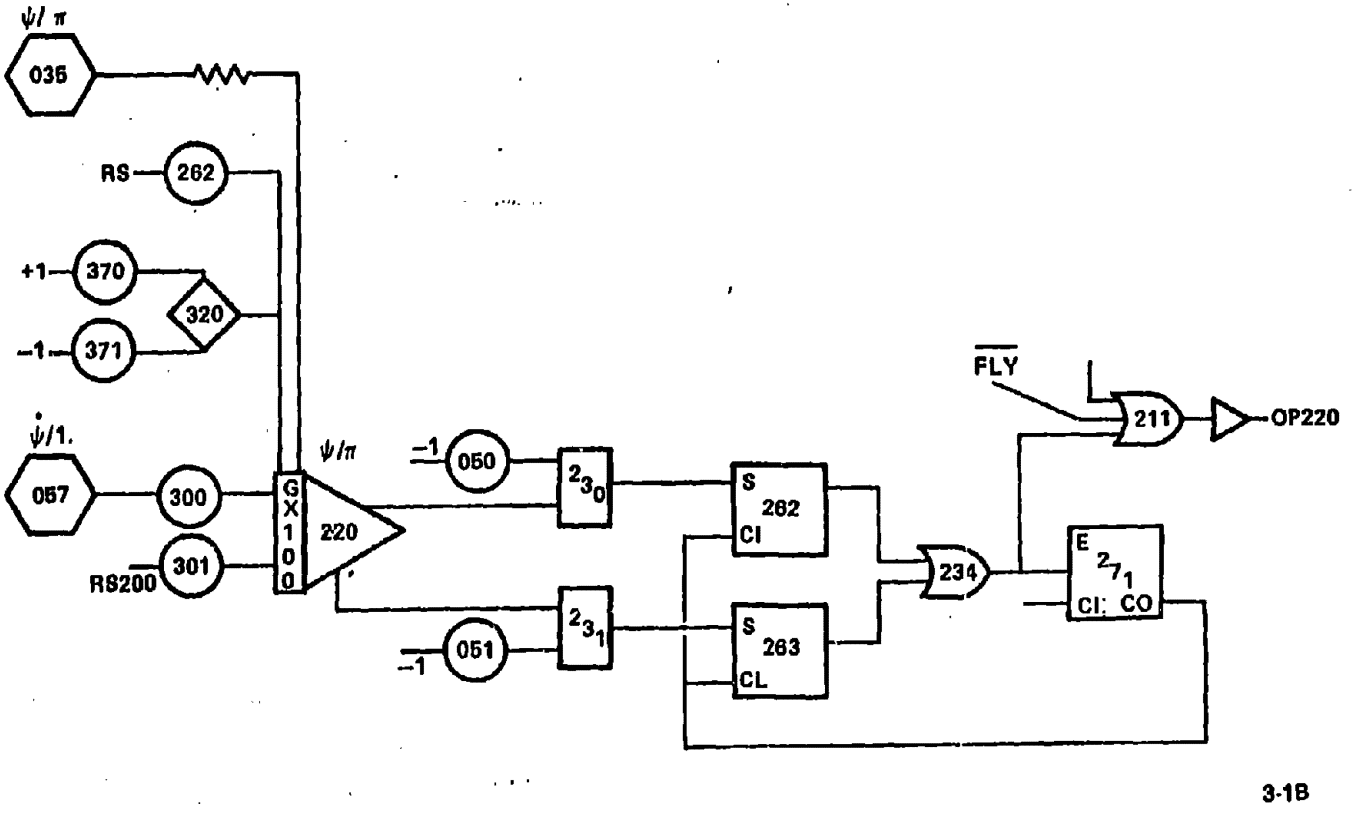


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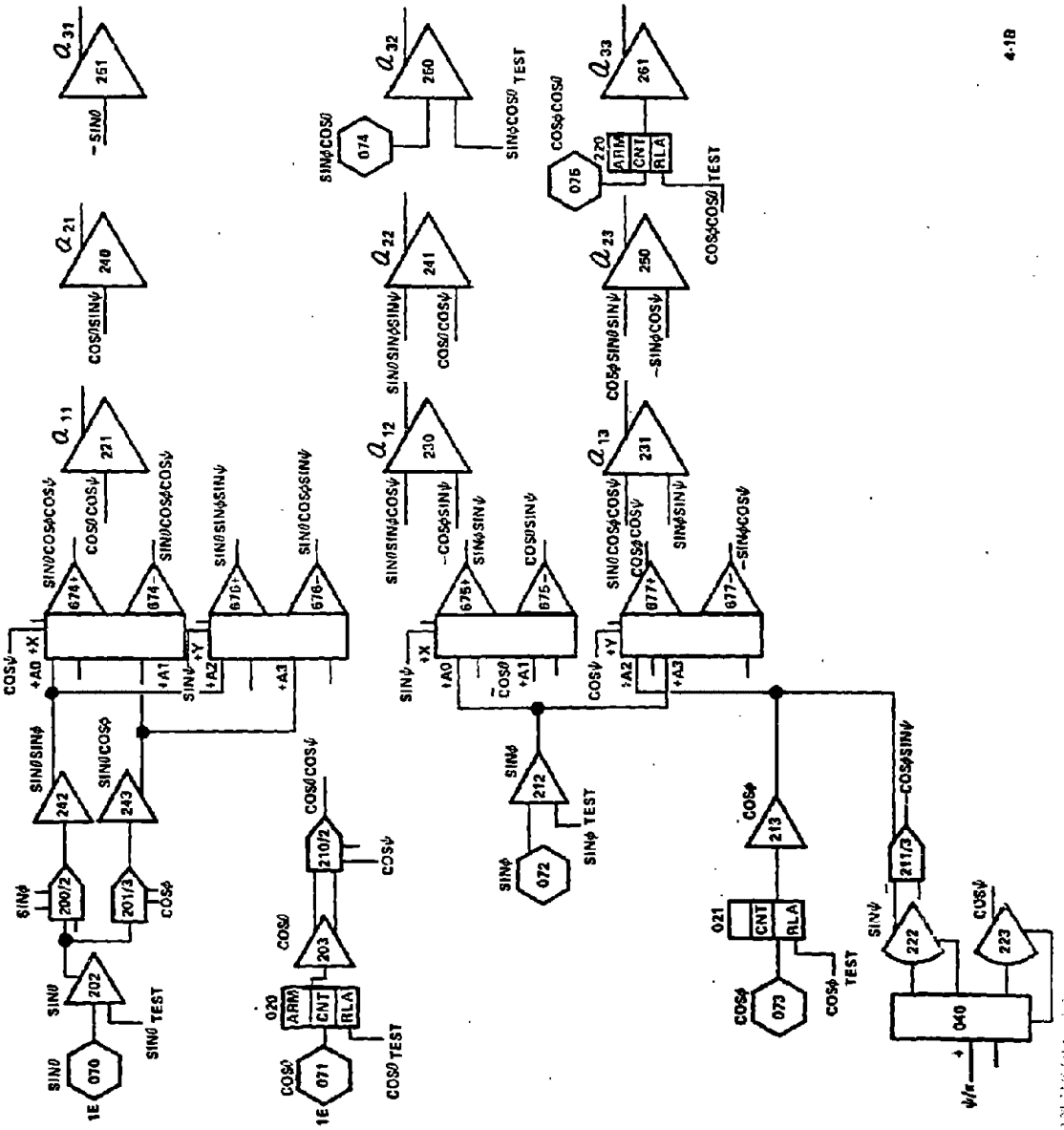


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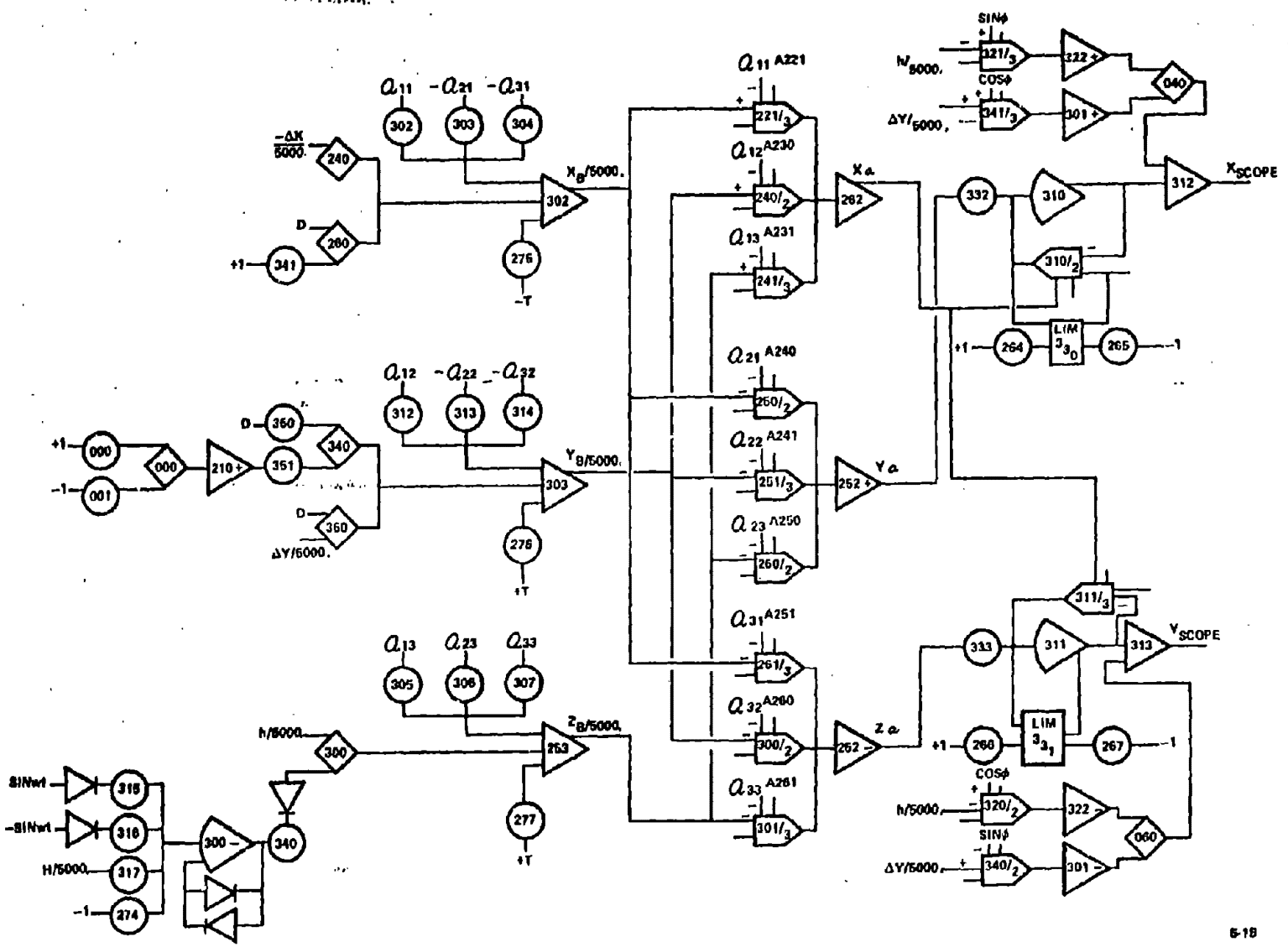


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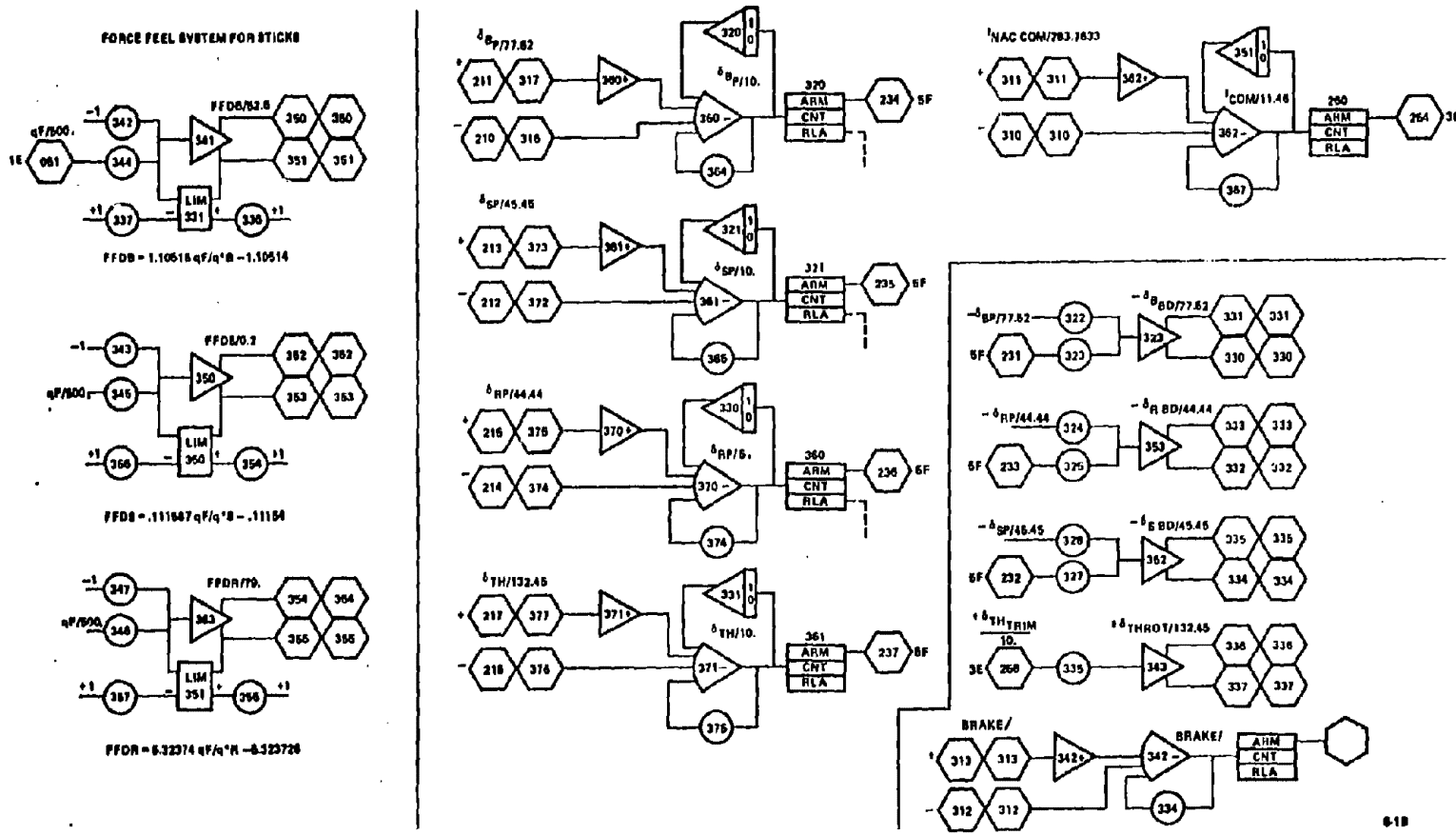


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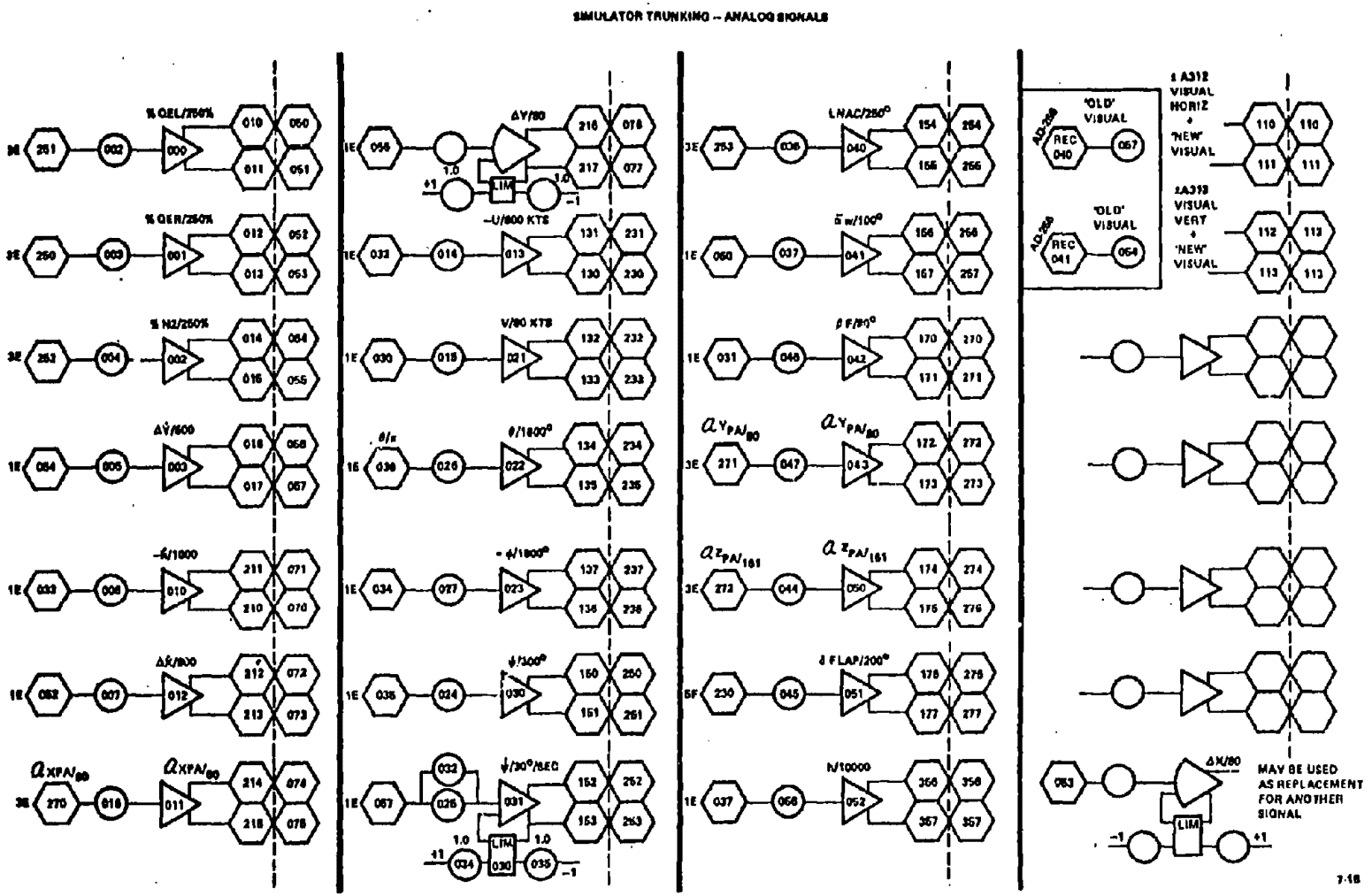


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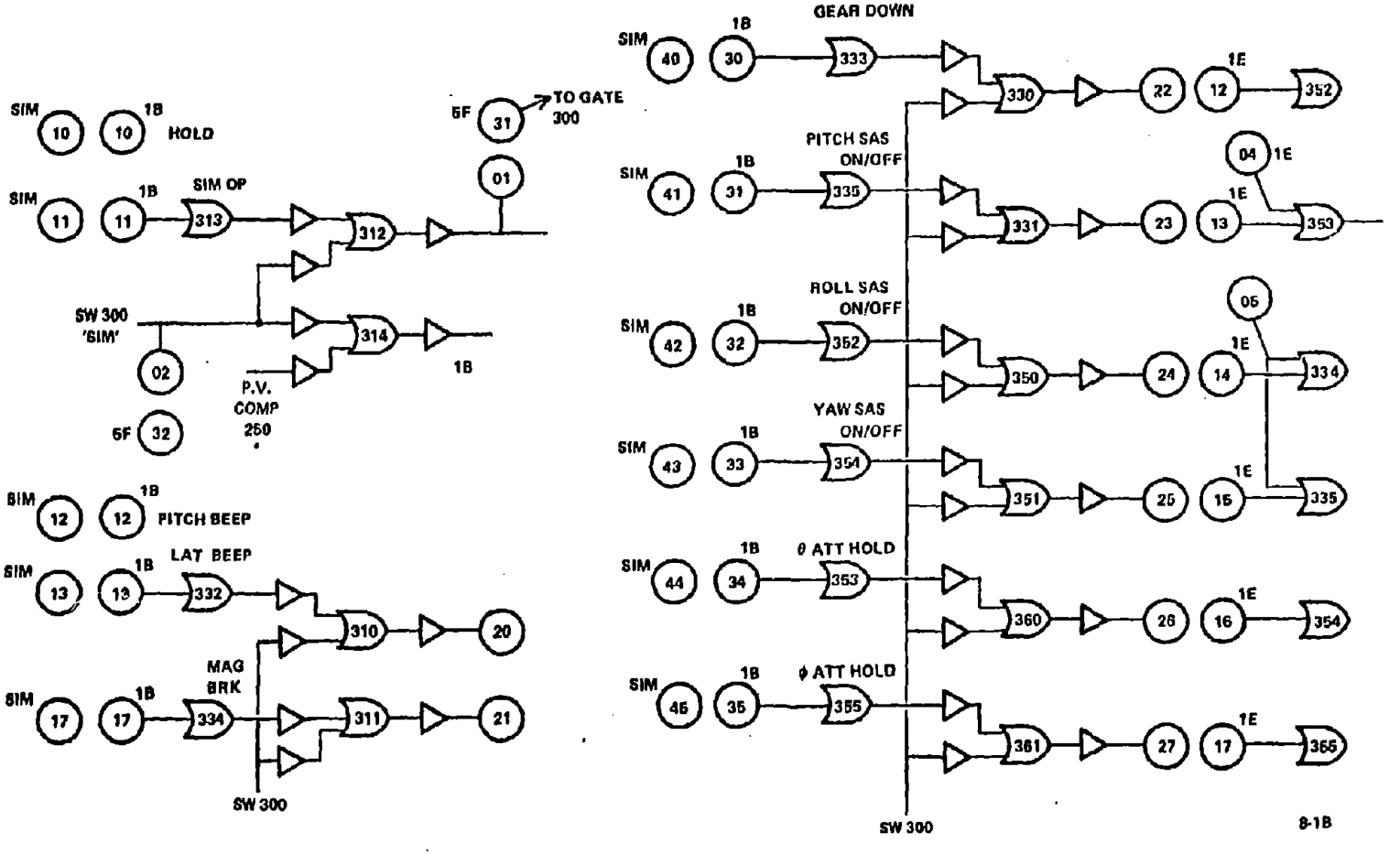


Figure G.8. (Continued)

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0001            SUBROUTINE STATIC
0002            REAL *8  MATA(5,5),MATB(5),MT
0003            REAL*8 MZTSAV(5,5),MAPSAV(5)
0004            COMMON/COMTA/ T1(250),P1(10 ),P3(10),P4(10),A10(10),A11(32),
*                    SJI(50),TR1(250)
0005            COMMON/FLAGS/ IMAIN(16),IMAIN2(16),ISENSE(2),IWHEVT(3),ICONDP,
1  ITRIM,JTRIM,KTRIM,MPLOT,NPLOT2,IPHASE,ISLOW,SWLG,OPSTRM,
2  IST1,IST2,NGLE,NVB,MFAST
0006            LOGICAL*1  IMAIN1,IWARN2
0007            COMMON/HYBCOM/PROJ   ,NCONSL,NPCS(2),NCHAIN(2),IFRAME(2),NADCS(2),
*                    NONOS(4),NDACS(4),IRCK(4),IFC(4),NCON(4) ,LSTR(4) ,
*                    IC(19)  ,ISTIC   ,HOLD(19),ISTHO,OPERA(19),
*                    ISTGO   ,DIGAN(19),ISTOA  ,ANDIG(19),ISTAO,
*                    IC2(19) ,ISTIC2  ,HOLD2(19),ISTHO2 ,OPERA2(19),
*                    ISTGO2  ,DIGAN2(19),ISTOA2  ,ANDIG2(19),ISTAO2, IGN,
*                    ISTPIT  ,IPUNIT,IAD,IDC,IDC2,ICLR,ITSC,ILEN,ISETC ,
*                    MONDIG  ,IDUPC(4)  ,ISHRC(4) ,ISYNC(4) , NIOS  ,
*                    IHUB    ,IECHAN    ,TSBASE(2),TSREQD(2), IRCTS(4),
*                     TAUL(4) ,IPSNCS(10,2),DTIN(2) ,TRIM(19) ,ISTRS ,
*                     TRIM2(19),ISTPM2
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0008            COMMON/XIC/    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       IVS1,SHPIC,SHPDIC,OLTHP,OMGSIC,
3       TLTPIC,AILSIC,AINDOT,AITRIC,AILDOT,AILSIC,PDOT,YDOT,GLSSIC,
4       GLSSIC,GLSAIC,VISPL(2),GAICP,GAICP ,AICPDT,AICPIC,AICLPT,
5       AICLIC,PICPRT,PICRIC,PICLDT,PICLIC,AICRPD,AICRP,AICLPD,
6       AICLP,PICRPD,AICRP,PICLPD,PICLP,ALARDT,ALARIC,AMARDT,
7       AMARIC,ZAPDIC,ZARIC,DCYIC,SHPIC
0009            COMMON/DIGICS/ XAERO,YAERO,ZAERP,ZAPP,ALAERP,ALARP,AMAERP,AMARP,
1       AMAERD,GLSR,GLSAR,GLSAL,SHPPAR
0010            COMMON/XIC1/   DELR,DELS,DELR,DELTH,AINGEN,GMGSEL,
1       GLATPH,SPDEL,GJETPH,GPSIPH,SPRP4,GYAW,AINREF,SUMLON,GJSCDL,
2       GDRCYL,GDSCYL,GAIC,GDIC,GDELP,GDE,GDSP,TPS,DVTAUD,DVTAUF,
3       THATLM,SDTURT,RCABLK,THGTVL,THGTVR,SWDIT,GTC,GMCOR,GYMC,
4       CPM1,CSE  ,CNE1,CP),DLSPLM
0011            COMMON/TRMCOM/ UTRIM,VTRIM,WTRIM,HDOTLM,THTRIM,AITRIM,
1       SKTRIM(13)
0012            COMMON/XMAX/   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
0013            COMMON/XMAX/   PDOTMX,QDOTMX,RDOTMX,UDOTMX,VDOTMX,WDOTMX,THMX,VWMX,
1       ZARMX,YDOTMX,XDOTMX,ZMX,YMX,XMX,DELBMX,DELSMX,DELRMX,
2       DLTHMX,DELAMX,DELEMX,DLSPMX,DLTHMX,DLSHMX ,TPSMX,THATMX,
```

Figure G.9. Analog Static Check Routine (Digital)

REPRODUCIBILITY OF THE

```
                3       SHPMX,THDMMX,TCMDMX,OMEGMX,TT4SMX,DCYLMX,DCOLMX,DLONMX,
                4       XMKCL,AICMX,BICMX,TH75MX,ALEPMX,AMUPMX,CFMX,CPMX,CNFMX,
                5       CSFMX,CPMMX,CYMMX,CPMDMX,CYMDMX,ASFSMX,AIDDMX,AIDDMX,
                6       AIAMX,AINDMX,AMACMX,THFMX,PHIMX,PSIMX,DSCYMX,DECYMX,
                7       GSCDMX,GACDMX,TAUFMX,DICDX,ALMGMX,SOFMX,ACGMX,PCTDMX,
                8       DLFLMX,GUSTMX,
                9       PMX,QMX,RMX,THDMX,PHDMX,PSDMX
0014            COMMON/XPART/ AINHT ,AINW  ,ALAMDA,ALHTST,ALVTST,AREAHT,AREAW ,    1 TO  7
               *AZEAVT,ARHT  ,ARVT  ,AVEYAC,AVEYCS,BLS   ,CDOF  ,CDOHT ,CDOVT ,    8 TO 16
               *CHORD ,CLALHT,CLALPH,CMOF  ,CMOI  ,CMOF  ,CNOLN ,CHORN ,CYALVT,   17 TO 25
                3DCDLG ,DCMLG ,FINPR ,DDVT  ,DSDDET,FEEHT ,FEEVT ,FIE   ,FINDEG,   26 TO 34
               *FIP   ,FIXXF ,FIXXPR,FIXXW ,FIXZF ,FIXZPR,FIXZW ,FIYYF ,FIYYPR,   35 TO 43
               *FIYYW ,FIZZF ,FIZZPR,FIZZW ,HP    ,OMREF ,PG    ,PI    ,RDTRAD,   44 TO 52
               *SBEPR ,SBWPR ,SG    ,SHF   ,SHW   ,SK0   ,SK1   ,SK2   ,SK3   ,   53 TO 61
               *SK4   ,SK5   ,SK6   ,SK7   ,SK8   ,SK9   ,SK10  ,SK20  ,SK21  ,   62 TO 7.
               *SK22  ,SK30LO,SK31LO,SK32  ,SKDOWN,SK34  ,SK35  ,SK36  ,       71 TO 79
               *SK37  ,SK38  ,SK39  ,SK40  ,SK41  ,SK42  ,SK43  ,SK44  ,SK45  ,    1 TO 61
               *SK46  ,SK47  ,SK48  ,SK49  ,SK50  ,SL    ,SLF   ,SLPA  ,SLW   ,   89 TO 97
               *SM    ,SMF   ,SMN   ,SMW   ,SPAN  ,TAUHT ,TAUVT ,XFAC  ,XHT   ,   98 TO
               *YMAC  ,XVT   ,YN    ,YPA   ,YWAC  ,ZFAC  ,ZHT   ,ZPA   ,ZWAC  ,
               *ZVT   ,CLJAL ,PHIDH ,SK30HI,SK30PT,KMC2  ,DT1   ,DT2   ,DT3   ,
               *DKDIT ,DKD2T ,DKDDT ,DKVLT ,DKM2T ,DKMDT ,DKM4T ,SK31HI,
               *FCU   ,CLMAX ,ALBMX ,DKLSW ,DKNSW ,SOFPRM,DEG2R ,DGTORD,HTVTST,  133TO141
               *PIOV2 ,PITODG,RDTFPS,SKFPS ,ALNCW ,TAURT1,TAURT2
0015            COMMON/XCNTRL/ SKOLP ,SKOLS ,SKOLI ,SKOLE ,SKOLRD,TH75LP,TH75LN,
                1       TAUOLS,GLSLP,TAUSLC,DELTM,TPMC,TQ4SLP,TQ4LM,GTCM,QMA,ETAA,
                2       SKDA  ,GTH,TAUTH,DMGC,QMSLP,QMLM,GQMG,SKOCOL,THETLM,THDMLP,
                3       THDMLM,SHPLM,GTHDDY,DMRD,ETARD,TTPSLP,TTMSLN,GDR1,GDR2,
                4       TAUDR,GQ,GTHE,TAUQ1,TAUQ2,TAUTHE,GLPD,GLPSLP,GPDS,TAUPDS,
                5       GP,TAUP,GBETP,TAUBET,GPHI,TAUPHI,GPSIDR,GBETDR,GRDR,TAUDR,
                6       GPSI,TAUPSI,GBETR,TAUPP,GDRL,TAUPRI,GR,TAUR1,TAUR2,TAUR3,
                6       RLM,DRLM,DLDLM,DLSLM,DLPLM,
                7       TDMDLM,GDLTH,SKW1,SKW2,SKW3,SKW4,SKW5,
                8       SKW6,SKW7,SKW8,SKW9,SKW10,GGUST,TAUGST,DMWB,ETAWB,GMWBF,
                9       DMIPF,ETAIPF,SKTHTW,SC1,SC2,DCMDCL,AINRLM,TAUR01,TAUR02,
                A       TAUFF,TAUCYR,DCYRL1,AP,ASLP,ALIM,TAUSHP,DELALM,
                B       DLELP
0016            COMMON/SIMMAT/ AXPAMX,AYPAMX,AZPAMX,XDDMX ,ZDDMX ,FEBMX ,FESMX ,
                1               FERMX ,VSIMX ,WTSIMX,USIMX ,HDTSMX,PHISMX,PSISMX,
                2               THESMX,TDSIMX,PPMSMX,AINSMX,AIDSMX,ALWSMX,DEPSMX,
                3               DBDDMX,DSBDMX,DRBDMX,THBDMX,DBPSMX,DSPSMX,DRPSMX,
                4               DTPSMX,XDTSMX,YDTSMX,DXSIMX,DYSIMX,HSIMX ,PSDTSX
                5              ,BRKMX ,BRKSMX,XVISMX,YVISMX,ZVISMX,SCDPMX
0017            COMMON/SIMPAR/ VISIC ,VCALI ,VCALD ,XHORIZ,YRDAD ,QSTAR3,QSTAR5,
                1       QSTARR,BDB   ,BDS   ,BDR   ,HSLOPE,SSLOPE,HSLOPF
                2       ,FELAIO,COMIDT,COMDTH,COMDLB,COMDLS,COMDLP,BRAKE ,
                3       VISVER,VISHOR,SCOPLM,FREQNT,BIASMT,PKMT1 ,PKMT2 ,
                4       GZMTS1,GZMTS2,SLX   ,SLY   ,SLZ   ,XDIC  ,YDIC  ,
                5       ZDIC  ,XDTEST,YDTEST
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
FORTRAN IV    MODEL 44  PS       VERSION 3,  LEVEL 3   DATE  73032                    PAGE  0002

0019              COMMON/XPAR3/ XP3(91)
                 1              ,SFTL   ,SFIEL  ,SFSEL  ,SFPAL  ,SFYAL  ,SFQL   ,SFPL   ,
                 2               SFTm   ,SFNER  ,SFSEP  ,SFPAR  ,SFYAR  ,SFQ    ,SFPR
0019              DIMENSION A2P(39),A2N(39),SJ2(39),T32(39),A3P(39),A3N(39),
                 *          SJ3(39),T33(39)
0020              DIMENSION A4P(39),A4N(39),SJ4(39),T34(39)
0021              EQUIVALENCE (A1P,A2P),(A1N,A2N),(SJ1,SJ2),(TR1,T32)
0022              EQUIVALENCE (A1P,A3P),(A1N,A3N),(SJ1,SJ3),(TR1,T33)
0023              EQUIVALENCE (A1P,A4P),(A1N,A4N),(SJ1,SJ4),(TR1,T34)
0024              DATA PD4/*15   */,IT4/*7    */
                  C
                  C
0025              DATA VDEIL/55./
0026              DATA THPCTU/0.6/
0027              DATA AINDET/0.25/
0028              DATA  QINRF/85.9/,ANRATE/2.1/
0029              DATA GBAIS/0.3333/,TAUGMN/50./
                  C     DEFINE VALUES TO CERTAIN VARIABLES FOR CHECKOUT PURPOSES
0030              DATA PCTQ/64./,AVEALM/0.4/
0031              DATA RCEL/*,0.3378/
                  C
                  C                    COEFFICIENT
                  C     PDOT      QDOT      RDOT      AINDOR    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       AINDOR .
                  C                                                              .
                  C     5,1       5,2       5,3       5,4       5,5       AINDDL.
                  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)

```
FORTRAN IV    MODEL 44  PS       VERSION 3,  LEVEL 3   DATE  73092                    PAGE  0014

0045                AINDTL = AINLDI
0046                AINDTR = AINRDI
0047                OMEGON = XLIM(OMLM,OMGC,OMGC+OMGSEL*OMSLP*AINAF)
0048                OMEGA = OMEGIC+OMGCON
0049                THTM = THTMIC+UIC*THTMMX/UMX*THPCTU-GDTHRT*DLTUP*GDLTH
0050                CPMDD = CMDDR
0051                CYMDR = CMDDR
0052                CPL     = CPC
0053                CPR     = CPC
0054                CNFPL =  CNFC                                          STK(2487
0055                CNFPR =  CNFC                                          STK(2492
0056                CSFPL =  CSFC                                          STK(2514
0057                CSFPR =  CSFC                                          STK(2519
0058                CPMDL   = CPMC
0059                CPMDR   = CPMC
0060                CPMDL   = CPMDD
0061                CPMDL   = CPMDD
0062                CYMDL   = CYMC
0063                CYMDL   = CYMC
0064                CYMDL =  CYMDR
0065                CYMDR   = CYMDR
0066                RCTDL = RCTC
0067                RCTDL = RCTC
                C
0068                CONI = SMN*SL*SL*(1.-SMN/SM)*PI*YYPI
                C
0069                CALL SINCOS(PHSLS*DGTORD,SPHSLS,CPHSLS)
0070                CALL SINCOS(THE,SINTHE,COSTHE)
0071                CALL SINCOS(PHI,SINPHI,COSPHI)
0072                CALL SINCOS(PSI,SINPSI,COSPSI)
0073                CALL SINCOS(AINR,SINAINR,COSAINR)
0074                CALL SINCOS(AINL,SINAINL,COSAINL)
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 =  SINAINR * SINAINR
0082                SSQINL =  SINAINL * SINAINL
0083                CALL SINCOS(AINW,SINAINW,COSAINW)
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)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
C        EASTWARD VELOCITY
0087          VEAST= U*COSTHE*SINPSI+V*(SINPHI*SINTHE*SINPSI+COSPHI*COSPSI)
             *  +W*(COSPHI*SINTHE*SINPSI-SINPHI*COSPSI)
C        DOWNWARD VELOCITY
0090          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
C           CENTER OF GRAVITY CALCULATION
C
C
C
C           CG LOCATION,W.R.T. PIVOT
0094          XCG = (SMF*SLF+SMV*SLW)/SM+SL*SMN/SM*(CILAML+CILAMR)
0095          ZCG = (SMF*SHF+SMV*SHW)/SM-SL*SMN/SM*(SILAML+SILAMR)
C           CG VELOCITY W.R.T. PIVOT( NON-ROTATING AXES)
0096          XDTCG= -SL*SMN/SM*(ALPDTL*SILAML+ALPDTR*SILAMR)
0097          ZDTCG= -SL*SMN/SM*(ALPDTL*CILAML+ ALPDTR*CILAMR)
C
C           DENSITY CALCULATIONS
C           EQUATION FOR DEL FROM CURVE FIT PROGRAM
C
0098          DEL = .999588346E7 -.362343259E-6 * H
             * +.543995170E-09 *HSQ -.372041334E-14 *HSQ * H
C
0099          TDEGC=  TZERO -TODEF*H
0100          THETC=  .3519279E3*(TDEGF+459.69)
0101          SQTHTC= SQRT(THETC)
0102          ONOVTC = 1. / THETC
0103          ROE = ROEF*DEL*ONOVTC
0104          RORPSS= ROE*PI*ROTRAD**5
0105          VTOTAL= SQRT(U*U+V*V+W*W)
0106          VCALIB = VTOTAL*SQRT(ROE/ROSL)
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)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
FORTRAN IV    MODEL 44  PS       VERSION 3,  LEVEL 3   DATE  73092                    PAGE  0004
0111                ALPHE=  ATAN2(W,U)
0112                BETAE=  ATAN2(V,VALES)
0113                QOE= 0.5*RHOE*VTOTAL*VTOTAL
                C      LEFT ROTOR HUB VELOCITY - BODY AXES
0114                URLPR = UP +R*YN -BLS*SININL*(Q+AINDTL) + Q*HIL
0115                VRLPR = VP +BLS*(P*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* HIP
0118                VRRPR = VP + BLS*IR*COSINR*P*SININR -P* HIP
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                VTOTR = 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(VRL*VRL+WROTL*WROTL)
0131                VZETR =  SQRT(VRR*VRR+ 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)  + EPSRL
0133                ZETHL=  ATAN2(VRL,WROTL)
0134                CALL SINCOS(ZETHL,SINZHL,COSZHL)
0135                ALPHRR=  ATAN2(VZETR,URR)  + EPSLR
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)

```
0142              ONLP  =  ONLN*COSZHL -RNLN*SINZHL
0143              RNLP  =  RNLN*COSZHL +ONLN*SINZHL
                  C        RIGHT ROTOR - NACELLE AXES
0144              PNRN = -P*COSIHR + R*SINIHR
0145              QNRN =   Q+ AIRDTA
0146              RNRN = - P*SINIHR -R*COSIHR
                  C        RIGHT ROTOR - WIND AXES
0147              PWRS =  PNRN
0148              QNRR =  QNRN*COSZHR +RNRN*SINZHR
0149              RNRR = -PNRN*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              CPNRR = CPHOR -CPMOR*QNRR                                  ST
0157              CYNRR = CYMOR +CYMRR*RNRR
0158              CPNRL = CPMOL -CPMRL *QNLR                                 ST
0159              CYNRL = 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)*(SSOINP*SSOINL1-FIXZPR*(S2INR+S2INL1
                 *       +2.*SMN*YN*YN +SHF*SHF*ZF +SMW*SHK*ZW -SL*SMN*ZR*SILAMR +
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
     *       ZL* SILAML )
      C
0173          FIXX = (SUMIZZ-SUMIYY)+(FIXXPR-FIZZPR)*(SS2INR+SS2INL)-FIXZPR *(
     *         S2INR +S2INL )+2.*SMN*YN*YM -(SAF*SHF*ZF+SMW*SHW*ZW) +
     *         SL*SMN*(ZR * SILAMR +ZL*SILAML)
      C
0174          FIXZ = 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*
     *         (XR *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          FIXZ = FIXZF+FIXZW+0.5*(FIXXPR-FIZZPR)*(S2INR+S2INL) +FIXZPR*
     *         (C2INR+C2INL)-SMN*SL*(XR*SILAMR +XL* SILAML )
      C
0178          FIZZ  = SUMIZZ +(FIXXPR-FIZZPR)*(SS2INR+SS2INL)+FIXZPR*(S2INR+
     *          S2INL)+2.*SMN* YN*YM+SMF*SLF*XF+SMW*SLW*XW+SMF*SL*(XR*
     *          CILAMR +XL*CILAML)
      C
0179          FJZZ = SUMIYY-SUMIXX +(FIXXPR-FIZZPR)*(SS2INR+SS2INL)+FIXZPR*(
     *         S2INR+S2INL) -2.*SMN* YN*YM+SHF*SLF*XF+SMW*SLW*XW +SMN*SL*
     *        (XR*CILAMR +XL*CILAML)
      C
0180          FIXZ = 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          ALARMN = ALARP+ALARIC*FIXX
0182          AMARMN = AMARP+AMARIC*FIYY
0183          ZARMN = ZARP+ZARIC*SM
0184          ALAERO = ALAERP+ALARMN
0185          AMAERO = AMAERP+AMARMN
0186          ZAERO = ZAERP+ZARMN
      C
      C       ROOT EQUATION   CROSS TERMS
      C
0187          TERMR1 = -FJXX*R*D*P*Q*FIXZP
      C
      C       ROOT EQUATION   CROSS TERMS
0188          TERMQ1 = -FJYY*Q*R -FIXZQ*(P**2 -R**2)
      C
      C
      C       ROOT EQUATION  CROSS TERMS
0189          TERMR1 = -FJZZ*P*Q -FIXZR*R*Q
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
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) =  TERMRL + .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)=  FIYYRP*SL*SMN*(-ZR*SILAMR +XR*CILAMR )
C       ROOT EQUATION   AINDOL COEFFICIENT
0200          MATA(2,5)=  FIYYRP*SL*SMN*(-ZL*SILAML +XL*CILAML )
C       ROOT EQUATION   FORCING FUNCTION
0201          MATB(2)    =  TERMRL  + ANAERO
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 )   =  TERMRL  + 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)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
FORTRAN IV    MODEL 44  PS       VERSION 3,  LEVEL 3   DATE  73/?2                    PAGE  ??1

0211                MATA(4,4)=  1.?
                C      AINDDR EQUATION AINDDL COEFFICIENT
0212                MATA(4,5) =  ?.
                C      AINDDR EQUATION FORCING FUNCTION
0213                MATB(4)= QMIRE**2*(AINRE*GINRE*DCYIC-AINR)-2.*ETAIRE*OMIRE*AINDTS
                C
                C      AINDDL EQUATION PDOT COEFFICIENT
0214                MATA(5,1) = ?.
                C      AINDDL EQUATION QDOT COEFFICIENT
0215                MATA(5,2) = 0.
                C      AINDDL EQUATION RDOT COEFFICIENT
0216                MATA(5,3) = ?.
                C      AINDDL EQUATION AINDDR COEFFICIENT
0217                MATA(5,4) =  ?.
                C      AINDDL EQUATION AINDDL COEFFICIENT
0218                MATA(5,5)=  1.?
                C      AINDDL EQUATION FORCING FUNCTION
0219                MATB(5)= QMIRE**2*(AINRE-GINRE*DCYIC-AINDL)-2.*ETAIRE*OMIRE*AINDTI
                C      SAVE MATA ARRAY
0220                DO 1? JJ=1,5
0221                 MABSAV(JJ)=  MATB(JJ)
0222                DO 2? KK=1,5
0223                MATSAV(JJ,KK)= MATA(JJ,KK)
0224             2? CONTINUE
0225             1? 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                AINDDR= MATB(4)
0231                AINDDL= MATB(5)
                C      RESTORE MATA ARRAY
0232                DO 3? JJ=1,5
0233                 MATB(JJ)= MABSAV(JJ)
0234                DO 4? KK=1,5
0235                MATA(JJ,KK)= MATSAV(JJ,KK)
0236             4? CONTINUE
0237             3? 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)

REPRODUCIBILITY OF THE

```
FORTRAN IV    MODEL 44  P5       VERSION 3,  LEVEL 3   DATE  73/12                    PAGE  011

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              AMAGP = ( SMN*SL*YN*CILAMR*PDOT-(SMN*SL*SL*(1.-SMN/SM)+CIYYDR)
                 1          *(QDOT+AINDDR)-SMN*SL*YN*SILAMR*PDOT)
0254              AMAGL = (-SMN*SL*YN*CILAML*PDOT-(SMN*SL*SL*(1.-SMN/SM)+CIYYDR)
                 1          *(QDOT+AINDDL)+SMN*SL*YN*SILAML*PDOT)
0255              AIRCO = XLIM(AINRLM,-AINRLM,ATNCOM)
                  C
                  C       THRUST MANAGEMENT SYSTEM
                  C
0256              DLTHPD = GTH/TAUTH*DELTH - DLTHP/TAUTH
0257              AENG = XLIM(ALIM,-1.2,AO-ASLP*SHPIC)
0258              SHP1 = SHPRP*AENG
0259              DSHP = SHP1-SHPIC
0260              DSHPP = SHP1-SHP2IC
0261              SHP2D = DVTAUD*DSHPP
0262              DSHPPP = SHP2IC-SHP3IC
0263              SHP3D = DVTAUE*SQTHTC/DEL*DSHPPP
0264              SHP4 = SHPRP*SHP3IC-SHP1
0265              SHPD = XLIM(SHPLM,-SHPLM,(SHP4-SHPIC)/TAUSHP)
0266              JAVL = SHPIC/OMEGA
0267              CPRO = 0.5 *(CPL+CPL)
0268              OMEGA = CPRO*OMEGA**2
0269              THDOT = (550.*QAVL-R )P[R5*QR)DI/*IP
0270              DLTHG = OMEGA - DHGDM
0271              THDM = XLIM(TCMDLM,-TCMDLM,GCMS*DLTHG)
0272              DTHDM = XLIM(IOMLM,-.,TCMC*TCMSLP*AINRF)
0273              TMS2 = THDM + DTHDO*GTOM*DLOMG+GDTHPT*DLTHP*COLTH
0274              TMSD = XLIM(THRTLM,-THRTLM,1./.1*(TMS2-TMS1-THDM-GDTHPT*DLTHP*
                 1          COLTH))
```

Figure G.9. (Continued)

```
FORTRAN IV    MODEL 44  PS       VERSION 3,  LEVEL 3   DATE  730 2                    PAGE  212

0275                THMS3=  XLIM(THATLM,-THATLM,THMS2-THMS1-THDM-GDTHRT*DLTHP*GDLTH)
0276                THTMS = XLIM(ETMSLP,TTMSLM,THMS1+THDM+THMS3+GDTHRT*DLTHP*GDLTH)
0277                THTMSR = THTMS*GTHGDV*THGDVR
0278                THTMSL = THTMS*GTHGDV*THGDVL
                C
                C
                C       ROTOR THRUST
                C
0279                CTRPRM = ROT1 + CTC*TAUR01/TAUR02*SETR
0280                ROTTD = CTC/TAUR02*SETR-CTRPRM/TAUR02
0281                CTLPRM = ROT2+CTC*TAUR01/TAUR02*SETL
0282                ROT2D = CTC/TAUR02*SETL-CTLPRM/TAUR02
                C
                C       SAS (LATERAL, LONGITUDINAL)
                C
                C       PITCH SAS
0283                PSAS1D = (DELR-PSAS11)/TAUDR
0284                PSAS5 = (GQ*Q-GDB2*PSAS11)/TAUC1
0285                PSAS4 = (GTHE*Q-GDB1*PSAS11)*TAUTHE/TAUTHE
0286                GLONPH = XLIM(1.,1.,GLPC-GLPSLP*VCAL(6))
0287                PSAS2D = PSAS5*GLONPH-PSAS2/TAUQ1
0288                PSAS3D = PSAS6*GLONPH-PSAS3/TAUTHE
0289                PSAS7 = PSAS2*PSAS3-PSAS4
0290                PSAS4D = PSAS7/TAUQ2
0291                DELDS = XLIM(DLALM,-DLDLM,PSAS7*GLSD(C)
                C       ROLL SAS
0292                RSAS1D = (GPDS*DELS-PSAS1)/TAUPDS
0293                PSAS2D = (GP*P-PSAS21)/TAUP
0294                RSAS4D = (BETAF-RSAS41)/TAUBET
0295                RSAS5=GPHI*P*TAUPHI/TAUPHI
0296                RSAS3D = PSAS5*GLATPH-RSAS3/TAUPHI
0297                RSAS4 = RSAS2*PSAS3-RSAS1
0298                DELSS = XLIM(DLSLM,-DLSLM,RSAS6*GWDLL-RSAS4*GBETP*GBETDH)
                C       YAW SAS
0299                YSAS2D = (DELR-YSAS2)/TAUDR
0300                YSAS7 = XLIM(RLM,-RLM,R)
0301                YSAS9 = XLIM(DRLM,-DRLM,YSAS7)
0302                YSAS1 = (GPSI*YSAS7-GPSIDR*YSAS21*TAUPSI/TAUPSI
0303                YSAS1D = YSAS5*GLATPH-YSAS1/TAUPSI
0304                YSAS1D = XLIM(DELRMX,-DELRMX,-GBETP*RSAS4-GBETDR*YSAS2)
0305                GLATPR = 1.-GLATPH
0306                YSAS11 = YSAS1+YSAS12*GLATPR
0307                YSAS4D = (P*GPPPH-YSAS3)/TAUPR
0308                YSAS12 = GP*R-GPDR*YSAS2-YSAS4
0309                YSAS13 = YSAS12
0310                IF(VCALIB.LT.VDEFI*SKEPSI YSAS13 = -YSAS4
0311                YSAS4D = YSAS13/TAUR1
0312                YSAS14 = YSAS12*TAUR2/TAU23+YSAS5
0313                YSAS5D = (YSAS12-YSAS14)/TAUR3
```

Figure G.9. (Continued)

```
FORTRAN IV    MODEL 44  PS       VERSION 3,  LEVEL 1   DATE  73292                    PAGE  219

0314                YSAS15 = P
0315                IF(VCALIP.LT.VSETIA*SKEPSI) YSAS15 = 1.
0316                YSAS16 = YSAS15*YAW
0317                YSAS17 = (GPPI*YSAS16*TAUPPI-YSAS16)/TAUPPI
0318                YSAS18 = YSAS16-YSAS6
0319                DELRS = XLIM(DLRLM,-DLRLM,YSAS11*GPSIPH*YSAS3+YSAS17*GYAW)
                    C
                    C       CONTROL EQUATIONS
                    C
0320                DELRT = DELR
0321                DELST = DELS - DELSS
0322                DELRT = DELR - DELRS
0323                DELRJD = -SKDLRD*DELRT
0324                DELELV = -SKDLE*DELRT + GDE*DGTRI
0325                DELELP  = GDELP
0326                DELAI2 =-XLIM(0.,-DELAMX,SKDA*DELST)
0327                DELAL2 = XLIM(DELAMX,0.,SKDA*DELST)
0328                DELAP1= XLIM(DELAL4,0.,DELAR2+DELELP)
0329                DELALI= XLIM(DELAL4,0.,DELAL2+DELELP)
0330                DELAR = DELAP1 + DELELP
0331                DELAL = DELALI + DELELP
0332                DELSPR = XLIM(DLSPLM,0.0,GDSP)
0333                DELSPL = -XLIM(0.,-DLSPLM,GDSP)
0334                DCYI =  DELRT*SKDLR*GDSCYL-DELST*SKDLS*GDSCYI
0335                DCOL = DELST*SKDLS*GDSCOL
0336                DLCYI = DELRT*SKDLR*GDAILDA-DELRS
0337                DCYPD = XLIM(DCYRLM,-DCYRLM,(DCYL-DCYIC)/TAICYP)
0338                GAICI = XLIM(GICLM,-GICLM,(GAIC-GAICPI)/TAUGIC)
0339                GAICI = XLIM(GICLM,-GICLM,(GAIC-GAICPI)/TAUGIC)
                    C
0340                GLSBD = GLSB/TAUGLS-GLSBIC/TAUGLS
0341                GLSARD = GLSAR/TAUGLS-GLSAIR/TAUGLS
0342                GLSALD = GLSAL/TAUGLS-GLSAIL/TAUGLS
                    C
0343                DIRPDD = DMA**2*(GRICP-DCYL-DLONI-2.*ETAA*DMA*BICRDD
                   1       - DMA**2*BICPP
0344                AILPDD = DMA**2*(GAICP*DCYL-DLCDI-2.*ETAA*DMA*BIGLPD
                   1       - DMA**2*BICLP
0345                AIRPDD = DMA**2*(-GLSAIR-SKDCOL*DCOL+GAICPI-2.*ETAA*DMA*AICLPD-
                   1         DMA**2*AICRP
0346                AILPDD = DMA**2*(GLSAIL+SKDCOL*DCOL+GAICPI-2.*ETAA*DMA*AICLPD-
                   1         DMA**2*AICLP
0347                BICRDD = (DMRD**2*AICRP-2.*ETARD*DMRD*BICRDI-DMRD**2*BICRIC
0348                BICLDD = DMRD**2*GICLP-2.*ETARD*DMRD*BICLDI-DMRD**2*BICLIC
0349                AICRDD = (DMRD**2*AICRP-2.*ETARD*DMRD*AICRDI-DMRD**2*AICRIC
0350                AICLDD = (DMRD**2*AICLP-2.*ETARD*DMRD*AICLDI-DMRD**2*AICLIC
0351                TH75I = XLIM(TH75LP,TH75LN,THTMSR-DCOL)
0352                TH75I = XLIM(TH75LP,TH75LN,THTMSL+DCOL)
                    C
```

Figure G.9. (Continued)

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```
FORTRAN IV    MODEL 44  PS       VERSION 3,  LEVEL 1   DATE  73092                    PAGE  0014

C        WING VERTICAL BENDING
C
0353          ALAPRP = DMWR**2*(ALAPR-ALAPWN)/(EIXX-2.*ETA*B*DMWR**ALAPWN)
0354          AMAPRP = DMWR**2*(AMAPR-AMAPWN)/(EIYY-2.*ETA*B*DMWR**AMAPWN)
0355          ZAPRP = (DMWR**2*(ZAPR-ZAPWN)/SM-2.*ETA*B*DMWR**2*ZAPWIN
C
0356          CALL ANDAIN(PROJ,BONDS(1),LETR(1),IEC(1),NCON(1),P1,3,3)
0357          CALL ANDAIN(PROJ,BONDS(2),LETR(2),IEC(2),NCON(2),P2,3,3)
0358          CALL ANDAIN(PROJ,BONDS(3),LETR(3),IEC(3),NCON(3),P3,3,3)
0359          CALL ANDAIN(PROJ,'IP','RB',IEC(1,3,P4,3,3)
C          DAC CALCULATION SECTION
0360          P1(2 2) = -ALPHF/ABFSMX
0361          P1(2 11) = (ALAPRP*TERMP1)/EIXX/RDOTMX
0362          P1(2 12)= -MATA(1,3)/EIXX*RDOTMX/RDOTMX
0363          P1(2 13) = (AMAPRP*TERMQ1)/EIYY/QDOTMX
0364          P1(2 14)= -MATA(1,4)/EIXX*ADOTMX/RDOTMX
0365          P1(2 15) =  MATA(3) /EIZZ / RDOTMX
0366          P1(2 16)= -MATA(1,5)/EIXX*ADOTMX/RDOTMX
0367          P1(2 17) =  XAPRP/ SM /QDOTMX
0368          P1(2 18) = VTRIM*SKEPS/QMX
0369          P1(2 11) =  YAPRP/ SM /VDOTMX
0370          P1(2 12)= VTRIM*SKEPS/VMX
0371          P1(2 13) =   ZAPRP / SM / ZAPMX
0372          P1(2 14)= -HTRIM/ZMX
0373          P1(2 15) = VCALIB/UMX
0374          P1(2 16)= -MATA(2,4)/EIYY*ADOTMX/QDOTMX
0375          P1(2 17) =  VTOTLR/RGTRAD/AMURMX/QMEGMX
0376          P1(2 20)= -MATA(2,5)/EIYY*ADOTMX/QDOTMX
0377          P1(2 21) =  -ALPHLR / ALFGMX
0378          P1(2 22) = THTRIM/THEMX/RDTODG
0379          P1(2 23) =  VTOTPR/PGTRAD/AMURMX/QMEGMX
0380          P1(2 24)  = -AVEALW/ ALWGMX
0381          P1(2 25) =  -ALPHRR / ALFGMX
0382          P1(2 26)= -MATA(3,1)/EIZZ*RDOTMX/RDOTMX
0383          P1(2 27) = PNLN/QMEGMX
0384          P1(2 30)= -MATA(3,4)/EIZZ*ADOTMX/RDOTMX
0385          P1(2 31) = PNRN/QMEGMX
0386          P1(2 32)= -MATA(3,5)/EIZZ*ADOTMX/RDOTMX
0387          P1(2 33)=  -VNORTH/XDOTMX
0388           SGNSQF = 1.0
0389          IF(U.LT.0.) SGNSQF  = -1.
0390          P1(2 34)=  -SQF*SGNSQF/SQFMX
0391          P1(2 35)=  -VEAST/YDOTMX
0392          P1(2 37)  =- BETAF / ABFSMX
0393          P2(2 10) =-SMN*SL*YN*CLAMR*RDOTMX/AMACMX
0394          P2(2 11) = GLSQ/GLSMX
0395          P2(2 12) = (SMN*SL*SL*(1.-SMN/SM)+EIYYPR)*QDOTMX/AMACMX
0396          P2(2 13) =-GLSAL/GLSMX
0397          P2(2 14) = SMN*SL*YN*SCLAMR*RDOTMX/AMACMX
```

Figure G.9. (Continued)

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```
0398              P2(2051) =  (XCG-SLPA)/XCGMX
0399              P2(2054) = UDTP14/VMMX/A0.
0400              P2(2057) = SWPP02/SWPMX
0401              P2(2101) = SMN*SL*YN*CILAML*PP01T44/AMACMX
0402              P2(2111) =-SITHTC/DEL*TAUEMX/GBUTON
0403              P2(2112) = (SMN*SL*SL*(1.-SMN/SM)*EYYP01*PP01TMX/AMACMX
0404              P2(2114) =-SMN*SL*YN*SILAML*PP01TMX/AMACMX
0405              P2(2116)= VITP14/AINMX /PP1000
0406              P2(2117) =  ALAPP/EIXX/PP01MX
0407              P2(2220) = MOPIPS/EIP*OMEGMX*CPMX   /2.*12.
0408              P2(2221) =  AMARP/EIYY/PP01MX
0409              P2(2223) =  ZARP/SM/ZARMX
0410              P2(2224) = -QNRR / QMX * CPMOMX / CPMMX
0411              P2(2234) = GLSAR/GLSMX
0412              P2(2236) = -QNLR / QMX * CPMOMX / CPMMX
0413              P2(2240) =  RNRR / RMX * CYMPMX / CYMMX
0414              P2(2242) =  RNLR / RMX * CYMLMX / CYMMX
0415              P2(2247) =   PCTDR / PCTDMX
                  C
                  C     PHASE 1B    (CONSOLE 1)    POT. CALCULATION SECTION
                  C
0416              P1(3402) =-ZIC/ZMX
0417              P1(3411) = YIC/YMX
0418              P1(3423) = VMMX/ZMX/GBUTON
0419              P1(3434) = YDOTMX/YMX/GBUTON
0420              P1(3435) = XDOTMX/XMX/GBUTON
0421              P1(3436) = SKTRIM(01)
0422              P1(3437) = SKTRIM(02)
0423              P1(3810) = XIC/XMX
0424              P1(3812) = 1./TAUR02/GBUTON*SFTP
0425              P1(3813) = TAUR01/TAUR02*SFTR
0426              P1(3814) = 1./TAUR02/GBUTON
0427              P1(3815) = 1./TAUR02/GBUTON*SFTL
0428              P1(3816) = TAUR01/TAUR02*SFTL
0429              P1(3817) = 1./TAUR02/GBUTON
0430              P1(3820) = P7.*SKEPS/UMX
0431              P1(3841) = UMX/VMMX/10.
0432              P1(3926) = THEMX/PI
0433              P1(3927) = PHIMX/PI
0434              P1(3930) = 141.*SKEPS/UMX
0435              P1(3932) =  ROT1 / CTMX
0436              P1(3933) =  ROT2 / CTMX
0437              P1 (3936) =   1./ 10.
0438              P1 (3937) =   1./ 10.
0439              P1(3950)=     YDFT1 *SKEPS  / UMX
0440              P1(3972) = SKTRIM(03)
0441              P1(3973) = SKTRIM(04)
0442              P1(3974) = SKTRIM(05)
0443              P1(3975) = SKTRIM(06)
```

Figure G.9. (Continued)

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```
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/VMMX/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*VMMX/UDOTMX/10.
0456          P1(254) = PMX*VMMX/UDOTMX/10.
0457          P1(255) = UIC/UMX
0458          P1(256) = SG*1.0/VDOTMX/10.
0459          P1(257) = PMX*UMX/VDOTMX/10.
0460          P1(264) = PMX*VMMX/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/VMMX
0467          P1(273) = WIC/VMMX
0468          P1(274) = THEIC/THEMX
0469          P1(275) = PHEIC/PHIMX
0470          P1(276) = PMX*VMMX/WDOTMX/10.
0471          P1(277) = PSIIC/PSIMX
0472          P1(300) = RSAS1/DELSMX
0473          P1(301) = RSAS2/DELSMX
0474          P1(302) = GPQS/TAUPQS*DELSMX/DELSMX/GBUTON
0475          P1(303) = 1./TAUPQS/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/ABESMX
0482          P1(312) = 1./TAUBET/GBUTON
0483          P1(313) = 1./TAUBET/GBUTON
0484          P1(314) = GBETA*ABESMX/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) = GPSID*/GBUTON
0492          P1(324) = 1./TAUDP*DELRMX/DELRMX/GBUTON
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THE

```
0493          P1(335) = 1./TAUDK/GBUTON
0494          P1(336) = DLM/RMX
0495          P1(337) = RLM/RMX
0496          P1(338) = YSAS3/DELRMX
0497          P1(339) = YSAS6/DELRMX
0498          P1(340) = GBETOP/1.
0499          P1(341) = GBETP*AUESMX/DELRMX/1.
0500          P1(342) = ?./TAUPR*RMX/DELRMX/GBUTON
0501          P1(343) = 1./TAUPR/GBUTON
0502          P1(344) = DRLM/DELRMX
0503          P1(345) = DRLM/DELRMX
0504          P1(346) = YSAS4/DELRMX
0505          P1(347) = YSAS5/DELRMX
0506          P1(348) = GROR
0507          P1(349) = 1./TAUR3/GBUTON
0508          P1(350) = 1./TAUR3/GBUTON
0509          P1(351) = TAUR2/TAUR3
0510          P1(352) = GRRL*RMX/DELRMX/GBUTON
0511          P1(353) = 1./TAUPR1/GBUTON
0512          P1(354) = GR*RMX/DELRMX/1.
0513          P1(355) = 1./TAUR1/GBUTON/2.1
0514          P1(356) = GBETR*2.+1.
0515          P1(357) = 1.0
0516          P1(358) = 1.0
0517          P1(359) = DLRLM/DELRMX
0518          P1(360) = DLRLM/DELRMX
C
C     BOARD 3F      (SOCKET 2)      POT. CALCULATION SECTION
C
0519          P2(001) = DLTHR/DLTHMX
0520          P2(002) = SHR2IC/SHPMX
0521          P2(003) = GTH/TAUTH/GBUTON
0522          P2(004) = 1.0/TAUTH/GBUTON
0523          P2(005) = DMLM/OMEGMX
0524          P2(006) = OMGO/OMEGMX
0525          P2(007) = SHP3IC/SHPMX
0526          P2(008) = -OMEGIC/OMEGMX
0527          P2(009) = OMSL*AINMX /OMEGMX
0528          P2(010) = OMGO/OMEGMX
0529          P2(011) = 550./E[0*SHPMX/OMEGMX/TAUSMX
0530          P2(012) = GTHGOV/TAUSMX
0531          P2(013) = THOMIC/THOMMX
0532          P2(014) = TMSL/THOMMX
0533          P2(015) = THRCTU
0534          P2(016) = QIWRF/SOFMX
0535          P2(017) = THOMLP/THOMMX
0536          P2(018) = -THOMLN/THOMMX
0537          P2(019) = THRTLM/THOMMX
0538          P2(020) = THRTLM/THOMMX
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
0539          P2(0236) = THATMX/THDMMX
0540          P2(0237) = THATMX/THDMMX
0541          P2(0238) = AMRATE/AINRMX**DSIDB0
0542          P2(0311) = P0.5*EGDIB/AINMX
0543          P2(0232) = GTHGDV/TTMSMX
0544          P2(0233) = THDMMX/TTMSMX
0545          P2(0234) = THDMMX/TTMSMX
0546          P2(0235) = GDLTH *DLTHMX/THDMMX
0547          P2(0236) = SKTRIM(12)
0548          P2(0237) = SKTRIM(13)
0549          P2(0240) = AINDET*DGTORD/AINRMX
0550          P2(0241) = AINDET*DGTORD/AINRMX
0551          P2(0242) = GDLTH *DLTHMX/THDMMX
0552          P2(0243) = GDDG*DMEGMX/TDMDMX
0553          P2(0244) = TDMDLM/TDMDMX
0554          P2(0245) = TDMDLM/TDMDMX
0555          P2(0246) = GDLTH *DLTHMX/THDMMX
0556          P2(0247) = TDMDMX/THDMMX/GBUTON
0557          P2(0250) = ALARDI/PDCTMX/1.
0558          P2(0251) = ALARIC/PDCTMX
0559          P2(0252) = TTMSLM/TTMSMX
0560          P2(0253) =-TTMSLM/TTMSMX
0561          P2(0254) = 1./TAUEF/GDLTON
0562          P2(0255) = 1./TAUEF/GBUTON
0563          P2(0256) = 1./TAUEF/GBUTON
0564          P2(0257) = 1./TAUEF/GBUTON
0565          P2(0260) = AMARDI/PDCTMX/1.
0566          P2(0261) = AMARIC/PDCTMX
0567          P2(0262) = DMWB**2/1C./GBUTON/1C.
0568          P2(0263) = 2.*BETAWB*DMWB/GBUTON /1C.
0569          P2(0264) = DMWB**2/1C./GBUTON/1C.
0570          P2(0265) = DMWB**2/1C./GBUTON/1C.
0571          P2(0266) = 2.*BETAWB*DMWB/GBUTON /1C.
0572          P2(0267) = DMWB**2/1C./GBUTON/1C.
0573          P2(0270) = ZARDIC/ZARMX/10.
0574          P2(0271) = ZARIC/ZARMX
0575          P2(0272) = DMWB**2/1C./GBUTON/1C.
0576          P2(0273) = 2.*BETAWB*DMWB/GBUTON /1C.
0577          P2(0274) = DMWB**2/1C./GBUTON/1C.
0578          P2(0240) = AINRDI/AIRDMX
0579          P2(0241) = AINRIC/AINMX
0580          P2(0242) = AIDDMX/AINDMX/GBUTON
0581          P2(0243) = AINDMX/AINMX/GBUTON
0582          P2(0244) = DMIRE**2*AINMX/AIDDMX/1C.
0583          P2(0245) = 2.*BETAIR*DMIRE*AINDMX/AIDDMX/1C.
0584          P2(0246) = DMIRE**2*AINMX/AIDDMX/1C.
0585          P2(0247) = AINRLM/AINRMX
0586          P2(0250) = AINLDI/AINDMX
0587          P2(0251) = AINLIC/AINMX
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
0588          P2(252) = AIDDMX/AINDMX /GRUTON
0589          P2(253) = AINDMX/AINMX/GRUTON
0590          P2(254) = (MIRE**2*AINMX/AIDDMX/1.
0591          P2(255) = 2.*BETAIRE**2*MIRE*AINMX/AIDDMX/1.
0592          P2(256) = (MIRE**2*AINMX/AIDDMX/1.
0593          P2(257) = AINPLM/AIRDMX
0594          P2(258) = DELTM /DLTMMX
0595          P2(261) = 1.
0596          P2(262) = 0.
0597          P2(263) = AINSION/AINSMX
0598          P2(264) = GINRE*DMIRE**2*DCYLMX/AIDDMX/1.
0599          P2(265) = GINRE*DMIRE**2*DCYLMX/AIDDMX/1.
0600          P2(266) = 1./TAUCYR/1.*/GRUTON
0601          P2(267) = 1./TAUCYR/1.*/GRUTON
0602          P2(270) = CONI*AIDDMX/AMACMX  /1.
0603          P2(271) = AINRMX/AIRMX
0604          P2(272) = AIRFIC/AINMX
0605          P2(273) = 105.*DGTORD/AIDDMX
0606          P2(274) = 2.*BETAIRE*DMIRE*AINMX/AIDDMX/1.
0607          P2(275) = AMACMX/CONI/AIDDMX/1.
0608          P2(276) = SKTSIM(7)
0609          P2(277) = SKTSIM( 8)
0610          P2(310) = CONI*AIDDMX/AMACMX /1.
0611          P2(311) = DCYIC/DCYLMX
0612          P2(312) = DCYCLM/DCYLMX/GRUTON
0613          P2(313) = DCYCLM/DCYLMX/GRUTON
0614          P2(314) = 2.*BETAIRE*DMIRE*AINMX/AIDDMX/1.
0615          P2(315) = AMACMX/CONI/AIDDMX/1.
0616          P2(316) = SHPLM/SHPMX/GRUTON
0617          P2(317) = SHPLM/SHPMX/GRUTON
0618          P2(311) = SHPIC/SHPMX
0619          P2(312) = 1./TAUSHP/GRUTON/1.
0620          P2(313) = 1./TAUSHP/GRUTON/1.
0621          P2(314) = ASLP*SHPMX
0622          P2(315) = AO ,
0623          P2(316) = ALIM
0624          P2(317) = 1.0
0625          P2(320) = TTDM*DGMX/TTMSMX/1.
0626          P2(321) = TOMC/1.
0627          P2(322) = TOMSLP*AINMX/1.
0628          P2(324) = TOPLM/1.
0629          P2(344)= ALAMDA/PI
0630          P2(345)= /TMMX/PI
0631          P2(346)= ALAMDA/PI
0632          P2(347)= AINMX/PI
0633          P2(364)= AINMX**2//DDMX*SL*SMN/SM -1.
0634          P2(365)= AINMX**2//DDMX*SL*SMN/SM
0635          P2(366)= AIDDMX/DDMX*SL*SMN/SM
0636          P2(367)= AIDDMX/ZDDMX*SL*SMN/SM
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

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FORTRAN IV   MODEL 44  PS       VERSION 3,  LEVEL 1   DATE  73092                    PAGE  [illegible]
0637                P2(372)=  UDOTMX/AXPAMX
0639                P2(373)=  VDOTMX/AYPAMX
0639                P2(374)=  WDOTMX*XCOSX/AYPAMX
0640                P2(375)=  WDOTMX/AZPAMX
0641                P2(376)=  UDOTMX*XCOSX/AZPAMX
0642                P2(377)=  SG/AZPAMX
                C
                C     BEGIN SECOND (CONSOLE 3)        POT. CALCULATION SECTION
                C
0643                P3(032) = DMRD**2/1C./GBUTON/1C.
0644                P3(033) = DMRD**2/1C./GBUTON/1C.
0645                P3(034) = 2.0*ETARD*DMRD/GBUTON/1D.
0646                P3(035) = RICRDI/RICMX/1D.
0647                P3(036) = RICRIC/RICMX
0648                P3(037) = GBAIS
0649                P3(212) = DMRD**2/1C./GBUTON/1C.
0650                P3(213) = DMRD**2/1C./GBUTON/1C.
0651                P3(214) = 2.0*ETARD*DMRD/GBUTON/1D.
0652                P3(215) = AICLDI/AICMX/1D.
0653                P3(216) = AICLIC/AICMX
0654                P3(217) = GBAIS
0655                P3(232) = DMRD**2/1C./GBUTON/1C.
0656                P3(233) = DMRD**2/1C./GBUTON/1C.
0657                P3(234) = 2.0*ETARD*DMRD/GBUTON/1D.
0658                P3(235) = AICRDI/AICMX/1D.
0659                P3(236) = AICRIC/AICMX
0660                P3(237) = GBAIS
0661                P3(241) = 1./TAUSMN
0662                P3(242) = DMRD**2/1C./GBUTON/1C.
0663                P3(243) = DMRD**2/1C./GBUTON/1C.
0664                P3(234) = 2.0*ETARD*DMRD/GBUTON/1C.
0665                P3(245) = AICLDI/AICMX/1D.
0666                P3(236) = AICLIC/AICMX
0667                P3(242) = GGUST/TAUGST/GBUTON/GUSTMX
0668                P3(243) = 1./TAUGST/GBUTON
0669                P3(244) = GGUST/TAUGST/GBUTON/GUSTMX
0670                P3(245) = 1./TAUGST/GBUTON
0671                P3(246) = GGUST/TAUGST/GBUTON/GUSTMX
0672                P3(247) = 1./TAUGST/GBUTON
0673                P3(060) = GLSATA/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(9)
0679                P3(073) = SKTRIM(10)
0680                P3(074) = SKTRIM(11)
0681                P3(242) = SKDLRD*DELRMX/DLRDMX
0682                P3(243) = SKDLR*DELRMX/DLRYLMX*GRCYMX
```

Figure G.9. (Continued)

```
0683          P3(244) = SKOLS*DELSMX/DCYLMX*GSCYMX
0684          P3(245) = GLPS/LO.
0685          P3(246) = SKOLS*DELSMX/DCYLMX*GSCOMX
0686          P3(247) = GLPSLP*QMX/LO.
0687          P3(252) = SKOLB*DELBMX/DLONMX
0688          P3(253) = SKOLB*DELBMX/DELBMX
0689          P3(254) = DELALM/DELAMX
0690          P3(255) = DELALM/DELAMX
0691          P3(257) = 1.E
0692          P3(260) = DELR  /DELRMX
0693          P3(261) = DELS  /DELSMX
0694          P3(262) = DELB  /DELBMX
0695          P3(264) = GQ/TAUQL*QMX/DLONMX/GBUTON/LO.
0696          P3(265) = GTHE*QMX/DLONMX/GBUTON
0697          P3(266) = SKOA*DELSMX/DELAMX
0698          P3(267) = SKOA*DELSMX/DELAMX
0699          P3(272) = OMA**2*GICMX/AICMX/IC./GBUTON/LO.
0700          P3(273) = OMA**2*GICMX/AICMX/IC./GBUTON/LO.
0701          P3(274) = OMA**2*GICMX/AICMX/IC./GBUTON/LO.
0702          P3(275) = OMA**2*GICMX/AICMX/IC./GBUTON/LO.
0703          P3(276) = TT4SMX/TH754X
0704          P3(277) = TT4SMX/TH754X
0705          P3(300) = GLSHIC/GLSMX
0706          P3(311) = GLSAIL/GLSMX
0707          P3(312) = DCOLMX/TH75MX
0708          P3(313) = DCOLMX/TH75MX
0709          P3(304) = TH75LP/TH75MX
0710          P3(305) = -TH75LN/TH75MX
0711          P3(306) = TH75LP/TH75MX
0712          P3(307) = -TH75LN/TH75MX
0713          P3(310) = AICRPD/AICMX/IC.
0714          P3(311) = AICRP /AICMX
0715          P3(312) = 1./TAUGLS/GBUTON
0716          P3(313) = 1./TAUGLS/GBUTON
0717          P3(314) = 1./TAUGLS/GBUTON
0718          P3(315) = 1./TAUGLS/GBUTON
0719          P3(316) = GLSLM/GLSMX
0720          P3(317) = GLSLM/GLSMX
0721          P3(320) = -GBICP/GICMX
0722          P3(321) = -GAICP/GICMX
0723          P3(322) = OMA**2*DCYLMX/AICMX/IO./GBUTON/LO.
0724          P3(323) = OMA**2*PLONMX/AICMX/IO./GBUTON/LO.
0725          P3(324) = 2.0*ETAA*OMA/GBUTON/LO.
0726          P3(325) = OMA**2/IO./GBUTON/LO.
0727          P3(326) = 1./TAUGIC/GBUTON/LO.
0728          P3(327) = 1./TAUGIC/GBUTON/LO.
0729          P3(330) = AICLPD/AICMX/LO.
0730          P3(331) = AICLP /AICMX
0731          P3(332) = 1./TAUGIC/GBUTON/LO.
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
0732              P3(313) = 1./TAUGIC/GBUTON/1.
0733              P3(314) = DLELPC/DLELMX
0734              P3(335) = 1./TAUDR*DELBMX/DLONMX/GBUTON
0735              P3(336) = DMA**2*GLSMX/AICMX/1.,/GBUTON/1.
0736              P3(337) = DMA**2*DLONMX/BICMX/1.,/GBUTON/1.
0737              P3(340) = 1./TAUDZ/GBUTON/C.1
0738              P3(341) = PSAS2/DLONMX
0739              P3(342) = 2.0*ETAA*DMA/GBUTON/1.
0740              P3(343) = DMA**2/1.,/GBUTON/1.
0741              P3(344) = GICLM/GICMX/GBUTON
0742              P3(345) = GICLM/GICMX/GBUTON
0743              P3(346) = GICLM/GICMX/GBUTON
0744              P3(347) = GICLM/GICMX/GBUTON
0745              P3(350) = AICRPD/ AICMX/1.
0746              P3(351) = AICRP /AICMX
0747              P3(352) = 1./TAUDR/GBUTON
0748              P3(353) = DMA**2*GLSMX/AICMX/GBUTON/1.,/1.
0749              P3(354) =SKOCOL*DMA**2*DCOLMX/AICMX/1.,/GBUTON/1.
0750              P3(355) = 2.0*ETAA*DMA/GBUTON/1.
0751              P3(356) = DMA**2/1.,/GBUTON/1.
0752              P3(357) = GLSMX/DLONMX
0753              P3(360) = PSAS1/DLONMX
0754              P3(361) = PSAS3/DLONMX
0755              P3(362) = PSAS4/DLONMX
0756              P3(364) = GDB2/TAUD1/GBUTON/1.
0757              P3(365) = GDB1/GBUTON
0758              P3(366) = 1./TAUD1/GBUTON/1.
0759              P3(367) = 1./TAUTHE/GBUTON
0760              P3(370) = AICLPD/AICMX/1.
0761              P3(371) = AICLP /AICMX
0762              P3(372) = DLELM/DLONMX
0763              P3(373) = DLELM/DLONMX
0764              P3(374) = DMA**2*GLSMX/AICMX/GBUTON/1.,/1.
0765              P3(375) =SKOCOL*DMA**2*DCOLMX/AICMX/1.,/GBUTON/1.
0766              P3(376) = 2.0*ETAA*DMA/GBUTON/1.
0767              P3(377) = DMA**2/1.,/GBUTON/1.
                  C
                  C
0768              XBODY = -XIC+VISIC+RHORIZ*XBIC
0769              YBODY= YROAD+YPOAD+VISIC+YIC+YBIC
0770              ZBODY=  H+ZBIC
                  C
0771              SA11 =  COSTHE * COSPSI
0772              SA12 =  SINPHI *SINTHE *COSPSI - COSPHI * SINPSI
0773              SA13 =  COSPHI *SINTHE *COSPSI + SINPHI * SINPSI
                  C
0774              SA21 =  COSTHE * SINPSI
0775              SA22 =  SINPHI *SINTHE*SINPSI + COSPHI * COSPSI
0776              SA23 =  COSPHI *SINTHE *SINPSI -SINPHI * COSPSI
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
C
      SA31 =   - SINTHE
      SA32 =     SINPHI * COSTHE
      SA33 =   COSPHI * COSTHE
C
      XACVIS =  -(SA11*XBODY +SA12*YBODY +SA13 *ZBODY)
      YACVIS =  -(SA21*XBODY +SA22*YBODY +SA23 *ZBODY)
      ZACVIS= -(-SA31*XBODY+SA32*YBODY+SA33*ZBODY)
C
      YSCOPE= ZACVIS/XACVIS*VCAL1*XVISMX/ZVISMX
      XSCOPE= YACVIS/XACVIS*VCAL2*XVISMX/YVISMX
C
      FFDO=  XLIM(FFDMX,FFLMLO,BSLOPE*SQF/QSTARB +BOB)
      FFDS=  XLIM(FFSMX,FFLMLO,SSLOPE*SQF/QSTARS + BOS)
      FFDK=  XLIM(FFPMX,FFLMLO,PSLOPE*SQF/QSTARR + BOR)
      OMEGA= OMEGA/OMREF*100.
      DRAKBB=  COMDLO-DELP
      DRAKBR=  COMDLR-DELP
      DSAKBS=  COMDLS-DELS
      THAKBR =  -SKTRIM(12)*CMDOT/CMLGMX*DLTMAX
      PSDSIM= XLIM(PSDTSX,-PSDTSX,PSIDOT*PDT*100)
      XSIM=  XLIM(DXSIMX,-DXSIMX,XIC)
      YSIM=  XLIM(DYSIMX,-DYSIMX,YIC)
      IF(NPLOT.EQ.2) GO TO 975
      COMDLO= 0.0
      COMDLS= 0.0
      COMDLR= 0.0
      COMLOT= 0.0
      BRAKE= 0.0
975   CONTINUE     BOARD 1B (CONSOLE 4) SIMULATOR BOARD
C
      P4(000) =   1.0000
      P4(001) =   1.0000
      P4(002)=  PCTQMX/TQSIMX
      P4(003)=  PCTQMX/TQSIMX
      P4(004)=  CAEGMX/OMREF*100./PPMS4K
      P4(005)= YDOTMX/YDTSMX
      P4(006)=  VWMX/WDTSMX
      P4(007)=  XDOTMX/XDTSMX
      P4(014)=  UMX/SKEPS/USIMX
      P4(015)=  VMMX/SKEPS/VSIMX
      P4(016)=  AXPAMX/AXPAMX
      P4(024)=  PSIMX*RDTODG/PSISMX
      P4(025)=  PSDMX*RDTODG/PSDTSX/2.0
      P4(026)= PI*RDTODG/THESMX
      P4(027)=  PI*RDTODG/PHISMX
      P4(032)=  PSDMX*RDTODG/PSDTSX/2.0
      P4(034)=  PSDTSX/PSDTSX
      P4(035)=  PSDTSX/PSDTSX
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
0821          P4(315)= AINMX*RDTODG/ALMSMX
0822          P4(317)= ALWGMX*RDTODG/ALWSMX
0823          P4(344)= AZPAMX/AZPAMX
0824          P4(345)= DLEIMX/DEPSMX
0825          P4(346)= ABESMX*RDTODG/RESIMX
0826          P4(347)= AYPAMX/AYPAMX
0827          P4(350)= .1475
0828          P4(351)= 0.1475
0829          P4(352)= DXSIMX/DXSIMX
0830          P4(353)= DXSIMX/DXSIMX
0831          P4(354)= 1.0000
0832          P4(355)= XMK/DXSIMX/10.
0833          P4(356)= ZMX/HSIMX
0834          P4(357)= 1.0000
0835          P4(358)= YMX/YVISMX
0836          P4(359)= ZMX//VISMX
0837          P4(240) =  XDOTMX / XVISMX  /10.
0838          P4(241) =  YDOTMX / YVISMX / 10.
0839          P4(250)= XDOTST/XVISMX/10.
0840          P4(251)= YDOTST/YVISMX/10.
0841          P4(260) =  THE / PI
0842          P4(261) =  PHI / PI
0843          P4(262) =  PSI / PI
0844          P4(263) =  FREQMT / 100.
0845          P4(264) =  SCOPLX
0846          P4(265) =  SCOPLY
0847          P4(266) =  SCOPLY
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) =  YDIC / XVISMX
0855          P4(276) =  YDIC / YVISMX
0856          P4(277) =  ZDIC / ZVISMX
0857          P4(310)= PSDMX/PI/10.
0858          P4(311)= 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)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
0870              P4(315) =    PKMTL / ZVISMX
0871              P4(316) =    PKMTZ / ZVISMX
0872              P4(317) =    GZMTSI
0873              P4(320) =   3.6572
0874              P4(321) =   3.6572
0875              P4(322)=  QBPSMX/QBBDMX
0876              P4(323)=  DELBMX/QBBDMX
0877              P4(324)=  DBPSMX/QBSDMX
0878              P4(325)=  DELBMX/QBBDMX
0879              P4(326)=  QSPSMX/QSPDMX
0880              P4(327)=  DELSMX/QSBDMX
0881              P4(330) =   10.* SKEPS / XDOTMX
0882              P4(332) =   VCALI * XVISMX / YVISMX
0883              P4(333) =   VCALJ * XVISMX / ZVISMX
0884              P4(334)=  2.*PAKSMX/BRKSMX
0885              P4(335)=  DLTHMX/THDDMX
0886              P4(336)=  FFBMX/FFBMX
0887              P4(337)=  FFLHLD/FFBMX
0888              P4(340) =   GZMTSZ
0889              P4(341) =   XMMTIZ / XVISMX
0890              P4(342)=  -FMS/FFBMX
0891              P4(343)=  -FMS/FFSMX
0892              P4(344)=  ESLOPE/QSTSMX*SQFMX/FFBMX
0893              P4(345)=  ESLOPE/QSTSMX*SQFMX/FFSMX
0894              P4(346)=  ESLOPE/QSTSMX*SQFMX/FFZMX
0895              P4(347)=  -HDF/FFBMX
0896              P4(350) =   YMTGD / YVISMX
0897              P4(351) =   YFDAD / YVISMX
0898              P4(354)=  FFSMX/FFSMX
0899              P4(355)=  FFBMX/FFBMX
0900              P4(356)=  FFLMLI/FFSMX
0901              P4(357)=  FFLHLD/FFBMX
0902              P4(360) =   XIC    / XVISMX
0903              P4(361) =   YIC    / YVISMX
0904              P4(362)=  H/ZMX
0905              P4(364)=  2.*QELBMX/QBPSMX
0906              P4(365)=  2.*QELSMX/QSPSMX
0907              P4(367)=  2.*AINSMX/AIDSMX**QDT2DG
0908              P4(370)=  3.1416
0909              P4(371)=  3.1416
0910              P4(374)=  2.*FLRMX/QPPSMX
0911              P4(375)=  2.*QLTHMX/QTPSMX
                  C
0912              RETURN
0913              ENTRY STG2N1          BOARD 32 (CONSOLE I) AMPLIFIER SCALE FACTOR CALCULATION; P DENOTES POSITIVE OUTPUT,
0914              CALL ANDAIN(ABOU,BONDS(1),LSTR(11,IFC(1),NCIN(1),AIP,1,5,3PM,1,5, N DENOTES NEGATIVE OUTPUT
                 *            SJ1,4,5,TR1,6,5)
                  C
0915              AIP(380) = ZIC/ZMX
```

Figure G.9. (Continued)

REPRODUCIBILITY

```
0916                AIP(  71) = YIC/YMX
0917                AIP( 172) = UIC*SIN(PHI)/UMX
0918                AIP( 173) = ZDOT/VMAX
0919                AIP( 208) = YDOT/YDOTMX
0920                AIP( 209) = XDOT/XDOTMX
0921                AIP( 210) = XIC/XMX
0922                AIP(  11) = 0.0
0923                AIP(  12) = AINDOR/AIDOMX
0924                AIP(  13) = AINDDL/AIDDMX
0925                AIP( 220) = -SKTRIM(3)*VDOT/VDOTMX
0926                AIN( 320) = CTO/CTMX
0927                AIP( 321) = ROT1/CTMX
0928                AIP( 336) = -CTRPRM/CTMX
0929                AIN( 330) = CTC/CTMX
0930                AIP( 331) = ROT2/CTMX
0931                AIP(  42) = TH75R/TH75MX
0932                AIN(  42) = CPR/CPMX
0933                AIP( 341) = TH75L/TH75MX
0934                AIN(  41) = CPL/CPMX
0935                AIP(  33) = -TH75S/TH75MX
0936                AIN(  55) = CNEPL/CNEMX
0937                AIP(  51) = -ALPHA*/ALPHMX
0938                AIP(  61) = CNEPR/CNEMX
0939                AIP(  52) = CTRPRM/CTMX
0940                AIP(  53) = CTLPRM/CTMX
0941                AIP( 162) = -AMU/AMUMX
0942                AIP( 164) = CSPDR/CSPMX
0943                AIP(  71) = -1.0
0944                AIP( 241) = CSPPL/CSPMX
0945                AIP( 162) = SKTRIM(11)*UDOT/UDOTMX
0946                AIP( 163) = SKTRIM(15)*VDOT/VDOTMX
0947                AIP( 170) = 0.0
0948                AIP( 171) = 0.0
0949                AIP( 200) = PIC/PMX
0950                AIP( 201) = QIC/QMX
0951                AIP( 202) = PDOT/PDOTMX
0952                AIP( 203) = QDOT/QDOTMX
0953                AIP( 210) = RIC/RMX
0954                AIP( 211) = UIC/UMX
0955                AIP( 212) = -PSIDOT*SIN(PHI)/PSIMX
0956                AIN( 212) = THEDOT/THDMX
0957                AIP( 213) = S*COS(PHI)/RMX
0958                AIN( 213) = THEDOT/DHDMX
0959                AIP( 221) = VIC/VMAX
0960                AIP( 221) = WIC/VMAX
0961                AIP( 222) = WDOT/WDOTMX
0962                AIP( 223) = Q*SIN(PHI)/QMX
0963                AIN( 223) = UDOT/UDOTMX
0964                AIP( 230) = THEIC/THEMX
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
0965          AIP(231) = PHILC/PHILMX
0966          AIP(240) = PSILC/PSILMX
0967          AIP(241) =  -XAERO1 /SM / COCTMX
0968          AIN(241) =  -YAERO1 /SM / VDOTMX
0969          AIP(242) = R*SINPHI/RMX
0970          AIN(242) = VDOT/VDOTMX
0971          AIP(243) =-Q*COSPHI/QMX
0972          AIN(243) = WDOT/WDOTMX
0973          AIP(250) = THE/PI
0974          AIP(251) = PHI/PI
0975          AIP(252) = COSTHE*COSPHI
0976          AIP(253) = COSTHE*SINPHI
0977          AIP(260) =  DETAF / ABFSMX
0978          AIN(260) =  AVEALH / ALWGMX
0979          AIP(261) =  SOF    / SDFMX
0980          AIN(261)= -ZAERO/SM/ZACMX
0981          AIP(262) = PSIDOT/PSDMX
0982          AIP(300) =-DELSS/DELSMX
0983          AIN(300) =-RSAS1/DELSMX
0984          AIP(301) =-RSAS6/DELSMX
0985          AIN(301) = RSAS2/DELSMX
0986          AIP(302) =-YSAS3/DELRMX/GAUTOP
0987          AIP(303) = YSAS12/DELRMX
0988          AIP(310) =-YSAS7/RMX
0989          AIN(310) = RSAS3/DELSMX
0990          AIP(311) = RSAS4/ABFSMX
0991          AIP(312) =-RSAS5/DELSMX/GAUTOP
0992          AIP(313) =GLATPH/1.
0993          AIP(320) =-YSAS11/DELRMX
0994          AIN(320) = YSAS1/DELRMX
0995          AIP(321) = YSAS9/DELRMX
0996          AIP(321) =-YSAS2/DELRMX
0997          AIP(322) = ALPHF/ABFSMX
0998          AIN(322) =-VCALIB/UMX
0999          AIP(323) = ALPHR3/ALFRMX
1000          AIN(323) = ALPHLP/ALFRMX
1001          AIP(330) =-YSAS12/DELRMX
1002          AIN(330) = YSAS3/DELRMX
1003          AIP(331) = YSAS16/PMX
1004          AIN(331) =-YSAS6/DELRMX
1005          AIP(340) = YSAS4/DELRMX
1006          AIP(341) =-YSAS5/DELRMX
1007          AIP(342) = AMUR/AMURMX
1008          AIP(343) = AMUL/AMUPMX
1009          AIP(350) = YSAS14/DELRMX
1010          AIN(350) =-DELRS/DELRMX
1011          AIP(351) = YSAS10/DELRMX
1012          AIP(352) =-YSAS15/PMX
1013          AIP(353) = GYAW/1.
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
1014                SJ1(4[illegible]) = GLATCH/1,
1015                SJ1(3[illegible]) = YSAS1Z/[illegible]MX
1016                SJ1(3[illegible]) = OMEGAR/OMEGMX
1017                SJ1(3[illegible]) = OMEGAL/OMEGMX
                C   VALUES AT SUMMING JUNCTIONS OF AMPLIFIERS: BOARD 1E (CONSOLE 1)
1018                SJ1(3[illegible]) = /DOUT/ZMX/GROUTON
1019                SJ1(3[illegible]) = YDOUT/YMX/GROUTON
1020                SJ1(3[illegible]) = XDOUT/XMX/GROUTON
1021                SJ1(3[illegible]) = SKTH1*(0.2)*YDOT/HDOTMX
1022                SJ1(3[illegible]) = 0.0
1023                SJ1(3[illegible]) = ROT1D/CTMX/GROUTON
1024                SJ1(3[illegible]) = 0.0
1025                SJ1(3[illegible]) = ROT2D/CTMX/GROUTON
1026                SJ2(3[illegible]) = 0.0
1027                SJ2(3[illegible]) = 0.0
1028                SJ1(3[illegible]) = 0.0
1029                SJ1(3[illegible]) = 0.0
1030                SJ1(3[illegible]) = 0.0
1031                SJ1(3[illegible]) = 0.0
1032                SJ1(3[illegible]) = SKT[illegible]*(0.4)*YDOT/YDOTMX
1033                SJ1(3[illegible]) = SKT[illegible]*(0.4)*XDOT/XDOTMX
1034                SJ1(3[illegible]) = PDOT/PMX/GROUTON
1035                SJ1(3[illegible]) = QDOT/QMX/GROUTON
1036                SJ1(2[illegible]) = RDOT/RMX/GROUTON
1037                SJ1(2[illegible]) = UDOT/UMX/GROUTON
1038                SJ1(2[illegible]) = VDOT/VMX/GROUTON
1039                SJ1(2[illegible]) = WDOT/WMX/GROUTON
1040                SJ1(2[illegible]) = THEDOT/THEMX/GROUTON
1041                SJ1(2[illegible]) = PHIDOT/PHIMX/GROUTON
1042                SJ1(2[illegible]) = PSIDOT/PSIMX/GROUTON
1043                SJ1(3[illegible]) = RSAS1D/DELSMX/GROUTON
1044                SJ1(3[illegible]) =-RSAS2D/DELSMX/GROUTON
1045                SJ1(3[illegible]) =-RSAS3D/DELSMX/GROUTON
1046                SJ1(3[illegible]) = RSAS4D/DELSMX/GROUTON
1047                SJ1(3[illegible]) =-YSAS1D/DELRMX/GROUTON
1048                SJ1(3[illegible]) = YSAS2D/DELRMX/GROUTON
1049                SJ1(3[illegible]) =-YSAS3D/DELRMX/GROUTON
1050                SJ1(3[illegible]) = YSAS4D/DELRMX/GROUTON
1051                SJ1(3[illegible]) = YSAS5D/DELRMX/GROUTON
1052                SJ1(3[illegible]) =-YSAS6D/DELRMX/GROUTON
                C   BOARD 1E (CONSOLE 1) VALUES OF TRUNK LINES AND ADC'S (FIRST 32 TR'S ARE ADC'S)
1053                TR1(2[illegible]) = P/PMX
1054                TR1(2[illegible]) = Q/QMX
1055                TR1(2[illegible]) = R/RMX
1056                TR1(2[illegible]) = U/UMX
1057                TR1(2[illegible]) = V/VMX
1058                TR1(2[illegible]) = W/WMX
1059                TR1(2[illegible]) = THE/THEMX
1060                TR1(2[illegible]) = PHI/PHIMX
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
1061                TR1(120) = PSI/PSIMX
1062                TR1(121) = HDOT/HDOTMX
1063                TR1(122) = -THE/THEMX
1064                TR1(123) = ZDOT/VSMX
1065                TR1(124) =-DELAL/DELAMX
1066                TR1(125) =  DELAR/DELAMX
1067                TR1(126) = -DELSPA/DLSPMX
1068                TR1(127) = DELSPL/DLSPMX
1069                TR1(128) = CTLPSI/CTMX
1070                TR1(129) = CNEPL/CNEMX
1071                TR1(130) = CSEPL/CSEMX
1072                TR1(131) = CPMPL/CPMMX
1073                TR1(132)=  SINTHE
1074                TR1(133)=  COSTHE
1075                TR1(134)=  SINPHI
1076                TR1(135)=  COSPHI
1077                TR1(136)=  SINPHI*COSTHE
1078                TR1(137)=  COSPHI*COSTHE
1079                TR1(138) = CYMPL/CYMMX
1080                TR1(139) = CPL/CPMX
1081                TR1(140) = CTRPRP/CTMX
1082                TR1(141) = CNEPP/CNEMX
1083                TR1(142) = CSEPP/CSEMX
1084                TR1(143) =  CPMPP/CPMMX
1085                TR1(144) = CYMPP/CYMMX
1086                TR1(145) = CPP/CPMX
C
1087                TR1(146) = CPR/CPMX
1088                TR1(147) = CPL/CPMX
1089                TR1(148) = OMEGA/OMEGMX
1090                TR1(149) = SKTWIND(1)*COSPT/UWDTMX
1091                TR1(150) = ALARWN/FIXX/SPDTMX
1092                TR1(151) = AMRPWN/CTYY/SPDTMX
1093                TR1(152) = ZARWN/SM/787.0X
1094                TR1(153) =-DELTH/DLTHMX
1095                TR1(154) = -DSHP/SHPMX
1096                TR1(155) =-SHPIC/SHPMX
1097                TR1(156) =-ATMRF/ATMMX
1098                TR1(157) =-TPS/TPSMX
1099                TR1(158) = SHPSD/SHPMX/GRUTON
1100                TR1(159) =-DSHPP/SHPMX
1101                TR1(160) =-DVTAUF*SQTHTC/DEL/GRUTON
1102                TR1(161) = SQTHTC/DEL*TAUFMX/GRUTON
1103                TR1(162) = THATL*/THATMX
1104                TR1(163) = SQTHGT*DLTHP/DLTHMX
1105                TR1(164) =-DLTHP/DLTHMX
1106                TR1(165) = DTHOOM*DLONG/THDMMX/1.
1107                TR1(166) = DLONG/OMEGMX
1108                TR1(167) =-THGOVL/1.
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
FCPTRAN IV    MODEL 44  DS       VERSION 3, LEVEL 7   DATE 77/07                    PAGE 014

1149                TR1(150) =-CMPDR/CMPDMX
1150                TR1(151) =-CVM /CVMMX
1151                TR1(152) =-CPVP/CPVPMX
1152                TR1(153) = AINPRE/AINPMX
1153                TR1(154) =  ACC/PA/AZPAMX
1154                TR1(155) =  ACCYPA/AYPAMX
1155                TR1(156) =  -XAERR/SM/UDOTMX
1156                TR1(157) =  -YAERR/SM/VDOTMX
1157                TR1(170) =-AINP/AINPMX
1158                TR1(171) =-AINL/AINMX
1159                TR1(172) =-THCOVR/I.
1160                TR1(210) = AINDDR/AIDDMX
1161                TR1(211) = AINDDL/AIDDMX
1162                TR1(212) = PDOT/PDOTMX
1163                TR1(213) = QDOT/QDOTMX
1164                TR1(214) = RDOT/RDOTMX
1165                TR1(215) = -ZAERR/SM/WDOTMX
1166                TR1(216) = ZDOT/VMMX
1167                TR1(217) = 0.0
1168                TR1(220) = CPMDR/CPDMX
1169                TR1(221) = CPMDL/CPDMX
1170                TR1(232) = CYMDR/CYMMX
1171                TR1(233) = CYMDL/CYMMX
1172                TR1(234) =-SKTRIM(71*(DOOT-DOTRIM)/VDMX
1173                TR1(235) = DIS/DT
1174                TR1(250) = P/GMX
1175                TR1(251) = DELR/DELRMX
1176                TR1(252) =  DELS/DELSMX
1177                TR1(253) =-DELS/DELSMX
1178                TR1(254) = DELR/DELRMX
1179                TR1(255) =-DELRS/DELRMX
1180                TR1(256) = -TH75R/TH75MX
1181                TR1(257) = -TH75L/TH75MX
1182                TR1(270) =  DELAR/DELAMX
1183                TR1(271) =-DELAL/DELAMX
1184                TR1(272) = -DELSR/DELSRMX
1185                TR1(273) = DELSL/DELSRMX
1186                TR1(274) = PDOT/PDOTMX
1187                TR1(275) = RDOT/RDOTMX
1188                TR1(276) = QDOT/QDOTMX
1189                TR1(350) =-DELST/DELSMX
1190                TR1(351) = GOBLOW*DELST/DELSMX
1191                TR1(352) =-DELNT/DELNMX
1192                TR1(353) =-VCALL/VMX
1193                TR1(354) =-DELT/DELTMX
1194                TR1(355) = GOSCJLA*DELST/GSCCMX/DELSMX
1195                TR1(356) = GOSCYL*DELST/GSCYMX/DELSMX
1196                TR1(357) =-GOSCYL*DELST/GSCYMX/DELSMX
1197                TR1(370) = DELST/DELSMX
```

Figure G.9. (Continued)

```
1158            TR1(371) =-GAIC/GICMX
1159            TR1(372) =-GDIC/GICMX
1160            TR1(373) = GDELP/DELMX
1161            TR1(374) = GDC/(DELMX*COS(THR))
1162            TR1(375) = GDSP/DLSPMX
C
1163            TR1(330) =   V  / VWMX
1164            TR1(331) =  DETAF / ABFSMX
1165            TR1(332) =  -VCALEB / UMX
1166            TR1(333) =  - HDOT / VWMX
1167            TR1(334) =  - PHI / PI
1168            TR1(335) =    PSI / PSIMX
1169            TR1(336) =    THE / PI
1170            TR1(337) =    H / ZMX
1171            TR1(350) =    AVEALA / ALNGMX
1172            TR1(351) =    SOF / SOFMX
1173            TR1(352) =    XDOT / XDOTMX
1174            TR1(353) =    XIC  / XMX
1175            TR1(354) =    YDOT / YDOTMX
1176            TR1(355) =    YIC  / YMX
1177            TR1(357) =  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 AUDATA(P3OU,HDNOS(2),LETR(2),IEGL(2),NGDN(2),A2P(1,3),A2N(1,5),
     *                  SJ2,4,5,TR2,5,5)
C
1189            A2P(380) = TPS/TPSMX
1190            A2N(382) =-DELTHP/DLTHMX
1191            A2P(381) =   -DSHP/SHPMX
1192            A2N(381) = -SHP2IC/SHPMX
1193            A2P(382) = DELTH/DLTHMX
1194            A2P(383) =-DSHPP/SHPMX
1195            A2N(383) = -GLSAP/GLSMX
1196            A2N(310) = SHP3IC/SHPMX
1197            A2P(311) = OMEGA/OMEGMX
1198            A2P(312) =-SQTHTC/DEL*GVTAUE/GRAVITON
1199            A2P(313) =-DSHPPP/SHPMX
1200            A2P(320) =  THDM/THDMX
1201            A2P(321) = (THDM+THS1+GDTHRT*DLTHP*GDLTH)/THDMX
1202            A2P(322) = DAVL*OMEGMX/SHPMX
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
FORTRAN IV    MODEL 44, OS      VERSION 3,  LEVEL 1    DATE  73 142
1203            A2P(231) = THUMD/TDMDMX
1204            A2P( 30) = 0.
1205            A2P(231) = -GDTHC[**(1.0/3.0)]/THDMX
1206            A2P(231) =-SQTF[X(12)*DTDCT/CVMDMX
1207            A2P( 37) = 1.0
1208            A2P(241) = 1.0
1209            A2P(242)=  SQRD/CPMX/OMEGA**2   *1.92.
1210            A2P( 43) = TMDOT/CMEGMX
1211            A2P( 43) = OMEGDM/CMEGMX
1212            A2P(250)=  -THTMS/TTMSMX
1213            A2N(250) = ALARDI/PDOTMX/1.
1214            A2P(251) = ALARMN/FIXX/PDOTMX
1215            A2P(252) = CPRD/CPMX      *2.0                    STK2341.
1216            A2P(253) = THATLM/THATMX
1217            A2N(262) = AMARDI/PDOTMX/1.
1218            A2P(261) = AMARMN/FIXX/PDOTMX
1219            A2P(262) = OLOMG/OMEGMX
1220            A2N(262) =-TMS2/THDOMX
1221            A2P(263) = TMS2/THDMX
1222            A2N(263) = TMSID/THDMX
1223            A2P(270) =  SQTF[X/FLOAT(JMAX/2)]*N
1224            A2N(270) = ZARDI/ZDMX/1.
1225            A2P( 71) = ZARMN/ZMX/ZDMX
1226            A2P(272) = AINDOT/AINDMX
1227            A2P(231) = AINP  /AINMX
1228            A2P(232) = AINDD/AINDMX
1229            A2P(233) = AINDOL/AINDMX
1230            A2P(215) = AINLDI/AINDMX
1231            A2P(211) = AINL  /AINMX
1232            A2P(213) = PDOT/PDOTMX
1233            A2P(213) = QDOT/QDOTMX
1234            A2P(222) = AINSE /AINMX
1235            A2P(221) = OMEGA**2/OMEGA**2
1236            A2P(233) = SHPIC/SHPMX
1237            A2N(237) = CPMDR/CPMMX
1238            A2N(241) = CPMPL/CPMMX
1239            A2P(243) = (UDOT-UDTD[V])/VMMX
1240            A2N(240) = CVMDR/CVMMX
1241            A2P(241) =-SQTF[M(-7)*(HDOT-HDTD[V])/VMMX
1242            A2N(241) = CVMPL/CVMMX
1243            A2P(242) = PCTDL/PCTDMX
1244            A2N(242) = AMACDR/AMACMX
1245            A2P(243) = PCTDR/PCTDMX
1246            A2N(243) = AMACLR/AMACMX
1247            A2P(250) = 0.0
1248            A2P(251) =   PCTDR / PCTDMX
1249            A2P(252) = RDOT/RDOTMX
1250            A2N(253) = AIRTD/AIRDMX
1251            A2P(260) = DCYIC/DCYLMX
```

Figure G.9. (Continued)

```
1292              A2N(262) = DCV90/DCYL4X/GBUTON
1293              A2P(263) = THTMSP/TTMSMX
1294              A2N(263) = THTMSL/TTMSMX
1295              A2P(300) = SHPPRR/SHPMX
1296              A2P(301) = SHP1/SHPMX
1297              A2P(302) = ALARP/FLXX/PDOTMX
1298              A2P(303) = AMARP/FLYY/QDOTMX
1299              A2P(310) = -SHP4/SHPMX
1300              A2N(310) = SHP0/SHPMX/GBUTON
1301              A2P(311) = SHP1C/SHPMX
1302              A2P(312) = -CMDQR/CPMOMX
1303              A2P(320) = AENG
1304              A2P(321) = DTHOOM/1.
1305              A2P(322) = ZARP/SM/ZAPMX
1306              A2P(323) =  AINLDI**2/AINDMX**2
1307              A2P(330) = DLONG/OMEGMX
1308              A2P(331) = -AINRDI**2/AINDMX**2
1309              A2P(340) = DTHOOM*DLONG/OMEGMX
1310              A2P(342) =  (AINL-ALAMDA)/PI
1311              A2P(343) =  (AINR-ALAMDA)/PI
1312              A2P(352) = -GLS0/GLSMX
1313              A2P(352) = GLSAL/GLSMX
1314              A2P(353) =  (XCG-SLPA)/XCGMX
1315              A2P(360) =  (AINDDL*SILAML+AINDDR*SILAMR)/AIDDMX
1316              A2N(360) =  (AINLDI**2*SILAML+AINRDI**2*SILAMR)/AINDMX**2
1317              A2P(361) =  ACCXPA/AXPAMX
1318              A2P(367) =  (AINDDL*SILAML+AINDDR*SILAMR)/AIDDMX
1319              A2N(362) =  (-AINLDI**2*SILAML-AINRDI**2*SILAMR)/AINDMX**2
1320              A2P(363) =  XDDCG/XDDMX
1321              A2N(363) =  ZDDCG/ZDDMX
1322              A2P(370) =  RDOT*(XCG-SLPA)/(RDOTMX*XCGMX)
1323              A2N(370) =  ACCYPA/AYPAMX
1324              A2P(371) =  -QDOT*(XCG-SLPA)/(QDOTMX*XCGMX)
1325              A2N(371) =  ACCZPA/AZPAMX
```

C. BOARD 3E (CONSOLE 2) VALUES AT SUMMING JUNCTIONS OF AMPLIFIERS

```
1326              SJ2(300) = DLTHPD/DLTHMX/GBUTON
1327              SJ2(301) = SHPPD/SHPMX/GBUTON
1328              SJ2(310) = SHP3D/SHPMX/GBUTON
1329              SJ2(311) = QMDOT/OMEGMX/GBUTON
1330              SJ2(320) = THOMD/THOMMX/GBUTON
1331              SJ2(321) = THS1D/THDMMX/GBUTON
1332              SJ2(330) = SKTR(4,13)*QMDOT/OMEGMX
1333              SJ2(331) = 0.
1334              SJ2(340) = 0.0
1335              SJ2(341) = 0.
1336              SJ2(350) = -ALARDD/PDOTMX/10./GBUTON/10.
1337              SJ2(351) = ALARDI/PDOTMX/GBUTON
1338              SJ2(360) = -AMARDD/QDOTMX/10./GBUTON/10.
1339              SJ2(361) = AMARDI/QDOTMX/GBUTON
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
1300              SJ2(   ) =-ZAR00/ZAR0X/1.0/GROUTON/12.
1301              SJ2(   ) = ZAR01C/ZZR0X/GROUTON
1302              SJ2(   ) = AIR002/AIR0XX/GROUTON
1303              SJ2(   ) = AIR001/AIR0XX/GROUTON
1304              SJ2(231) = AIR00L/AIR0XX/GROUTON
1305              SJ2(241) = AIRL01/AIRXX/GROUTON
1306              SJ2(251) = AIRR0/AIR0X /GROUTON
1307              SJ2(260) = 0.
1308              SJ2(261) = 0.
1309              SJ2(262) = 0.
1310              SJ2(263) = 0.
1311              SJ2(264) = -(ZOUT+HOTRIM)*SKTRIM(8)/VVMX
1312              SJ2(265) = OCYR0/OCYLMX/GROUTON
1313              SJ2(266) = SHR0/SHRMX/GROUTON
                C BOARD 3E (CONSOLE 2) VALUES OF TRUNK LINES AND ADC'S (FIRST 32 TR'S ARE ADC'S)
1314              TR2(   ) =AIR001/AIRMX
1315              TR2(221) = AIR0   /AIRMX
1316              TR2(222) = AIRL01/AIR0MX
1317              TR2(223) = AIR    /AIRMX
1318              TR2(260) = VICLIC/AICMX
1319              TR2(261) = VICLIC/AICMX
1320              TR2(262) = VICRIC/AICMX
1321              TR2(263) = RICRIC/AICMX
1322              TR2(225)=-DELMOD/DLRDMX
1323              TR2(121) = AIRRF/AIRMX
1324              TR2(221) = 0.
1325              TR2(222) = 0.
1326              TR2(223) = 0.
1327              TR2(260) = 0.
1328              TR2(261) = 0.
1329              TR2(262) = 0.
1330              TR2(263) = OMDOT/OMEGMX
1331              TR2(120) = OMEGA/OMEGMX
1332              TR2(121) = TPS/TPSMX
1333              TR2(122) = AMACRP/AMACMX
1334              TR2(123) = AMACLP/AMACMX
1335              TR2(164) = 1.0
1336              TR2(161) = 1.
1337              TR2(162) =-DLLLV/DLELMX
1338              TR2(163) = DLELP/DLELMX

1339              TR2(110) = CPL/CPMX
1340              TR2(111) = CPL/CPMX
1341              TR2(112) = OMEGA/OMEGMX
1342              TR2(113) = SKTRIM(11)*OUT/DOCTMX
1343              TR2(114) = SLARMN/FLYX/DOCTMX
1344              TR2(115) = ALARMN/FLYX/DOCTMX
1345              TR2(116) = ZARMN/SM//ARMX
1346              TR2(130) = 0.
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THIS

```
1347          TR2(331) = 0.
1348          TR2(332) = 0.
1349          TR2(110) =-DELTH/DLTHMX
1350          TR2(111) = -DSHP/SHPMX
1351          TR2(112) =-SHPIC/SHPMX
1352          TR2(113) =-AINRF/AINMX
1353          TR2(114) =-TPS/TPSMX
1354          TR2(115) = SHPPD/SHPMX/GBUTON
1355          TR2(116) =-DSHPP/SHPMX
1356          TR2(117) =-DVTAUE*SQTHTC/DEL/GBUTON
1357          TR2(130) = SQTHTC/DEL*TAUEMX/GBUTON
1358          TR2(131) = THATLM/THATMX
1359          TR2(132) = GDTHRT*DLTHP/DLTHMX
1360          TR2(133) =-DLTHP/DLTHMX
1361          TR2(134) = DTHDOM*DLOMG/THDMMX/1.
1362          TR2(135) = DLOMG/OMEGMX
1363          TR2(136) =-THGOVL/1.
1364          TR2(150) =-CYDOR/CPPGMX
1365          TR2(151) =-CYMD/CYMPX
1366          TR2(152) =-CPMC/CPMPX
1367          TR2(153) = AINDEF/AINMX
1368          TR2(154)=  ACC/PA/AZPAMX
1369          TR2(155)=  ACCYPA/AYPAMX
1370          TR2(156)=  -XAERD/SM/UDOTMX
1371          TR2(157)=  -YAERD/SM/VDOTMX
1372          TR2(170) =-AINP/AINMX
1373          TR2(171) =-AINL/AINMX
1374          TR2(172) =-THGOVR/1.
1375          TR2(210) = AINDOR/AIDDMX
1376          TR2(211) = AINDDL/AIDDMX
1377          TR2(212) = PDOT/PDOTMX
1378          TR2(213) = QDOT/QDOTMX
1379          TR2(214) = RDOT/RDOTMX
1380          TR2(215)= -ZAERD/SM/WDOTMX
1381          TR2(216) = ZDOT/VMMX
1382          TR2(217) = 0.0
1383          TR2(230) = CPMPR/CPMMX
1384          TR2(231) = CPMEL/CPMMX
1385          TR2(232) = CYMDR/CYMMX
1386          TR2(233) = CYMDL/CYMMX
1387          TR2(234) =-SKTRIM(7)*(UDOT-RDTCTM)/VMMX
1388          TR2(235) = UIC/UMX
1389          TR2(310) = THTMSR/TTMSMX
1390          TR2(311) =-GLSR/GLSMX
1391          TR2(312) = GLSAL/GLSMX
1392          TR2(313) =-DCYL/DCYLMX
1393          TR2(314) = -GLSAR/GLSMX
1394          TR2(315) =-DELRUD/DLRDMX
1395          TR2(316) =-DELELV/DELEMX
```

Figure G.9. (Continued)

```
1396              TR2(317) = DELPLR/DELPMX
1397              TR2(318) = BICPIC/BICPX
1398              TR2(319) = BICLIC/BICPX
1399              TR2(320) = AICPIC/AICPX
1400              TR2(321) = AICLIC/AICPX
1401              TR2(322) = DELTH/DLTHMX
1402              TR2(323) = THTMSL/TTPSMX
C
1403              TR2(324) =  PCTOL/PCTPMX
1404              TR2(325) =  PCTOR/PCTPMX
1405              TR2(326) =  OMEGA/ OMEGMX
1406              TR2(327) =  AINPF / AIPRX
1407              TR2(328) =  COMDOT/AISPMX
1408              TR2(329) =  COMDTH/ DLTHMX
1409              TR2(330) = -SKTRIM(12)*COMDOT/OMEGMX
1410              TR2(331) =  AVAIL
1411              TR2(332) =  ACCXPA/AXPAMX
1412              TR2(333) =  ACCYPA/AYPAMX
1413              TR2(334) =  ACCZPA/AZPAMX
C  BOARD 6F (CONSOLE 3); AMPLIFIER SCALE FACTOR CALCULATION; P DENOTES POSITIVE OUTPUT
1414              DETUPS                                    N DENOTES NEGATIVE OUTPUT
1415              ENTRY STCP13
1416              CALL ANDAIS(PHOJ,20PCS(2),LCTR(3),IFC(2),NCL(31,A3P(  ,5,A3N(  ,5,
                 *          5J3,4,5,T23,4,5)
C
1417              A3P(  ) = AICPOI/AICPX/1.
1418              A3P(  ) = AICPIC/AICPX
1419              A3P(  ) = AICLOI/AICPX/1.
1420              A3P(  ) = AICLIC/AICPX
1421              A3N(  ) = AICPOI/AICPX/1.
1422              A3P(  ) = AICPIC/AICPX
1423              A3P(  ) = AICLOI/AICPX/1.
1424              A3P(  ) = AICLIC/AICPX
1425              A3N(  ) = 1.
1426              A3P(  ) = 1.
1427              A3P(  ) = 1.
1428              A3P(  ) = 1.
1429              A3P(  ) = GLSAI*/GLSMX
1430              A3N(  ) = 1.
1431              A3N(  ) = 1.
1432              A3N(  ) = 1.
1433              A3P(  ) = 1.
1434              A3P(  ) = 1.
1435              A3P(  ) =  .
1436              A3P(  ) = DELST/DLTSMX
1437              A3P(  ) = -DELST/DLTSMX
1438              A3N(  ) = -DELELV/ELEMX
1439              A3P(  ) = 1.
1440              A3P(  ) = 1.
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
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) = DELD/DELDMX
1456              A3P(263) = DELELP/DLELMX
1457              A3N(3001) = GLSAIG/GLSMX
1458              A3N(3011) =-GLSAIL/GLSMX
1459              A3P(3021) = DLON/DLONMX
1460              A3P(3031) = DLELPP/DLELMX
1461              A3N(311) = AICRPD/AICMX/1.
1462              A3P(311) = AICRP /AICMX
1463              A3P(312) = DELAR/DELAMX
1464              A3N(312) =-DELAL/DELAMX
1465              A3P(313) = -VCALIB/UMX
1466              A3P(320) = GAICP/GAICMX
1467              A3P(321) = GAICP/GAICMX
1468              A3N(322) = GAICD/GAICMX/GAUTON
1469              A3N(323) = GAICD/GAICMX/GAUTON
1470              A3N(3301) = AICLPD/AICMX/1.
1471              A3P(331) = AICLP /AICMX
1472              A3P(3401) =-DELRS/DLONMX
1473              A3N(3401) =-PSAS1/DLONMX
1474              A3N(341) = PSAS7/DLONMX
1475              A3N(3411) =-PSAS2/DLONMX
1476              A3P(342) = DLSPLM/DLSPMX
1477              A3N(350) = AICRPD/AICMX/1.
1478              A3P(351) = AICRP /AICMX
1479              A3P(352) = PSAS5/DLONMX/GAUTON/1.
1480              A3P(353) = PSAS6/DLONMX/GAUTON
1481              A3P(360) = PSAS4/DLONMX
1482              A3N(361) =-PSAS3/DLONMX
1483              A3P(362) = GLONPH/1.
1484              A3N(370) = AICLPD/AICMX/1.
1485              A3P(371) = AICLP /AICMX
C BOARD 6F (CONSOLE 3) VALUES AT SUMMING JUNCTIONS OF AMPLIFIERS
1486              SJ3(380) =-BICRDD/BICMX/1./GAUTON/1.
1487              SJ3(381) = BICRD1/BICMX/GAUTON
1488              SJ3(390) =-BICLDD/BICMX/1./GAUTON/1.
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
1489                SJ3(  11) = BICLPD/BICMX/GBUTON
1490                SJ3(  21) =-AICRPD/AICMX/...
1491                SJ3(  31) = AICLPD/AICMX/GBUTON
1492                SJ3(  41) =-AICLPD/AICMX/...
1493                SJ3(  51) = AICLPD/AICMX/GBUTON
1494                SJ3(  61) =-GLSARD/GLSMX/GBUTON
1495                SJ3(  71) = PDFTWS_BIM(29)/PDFTMX
1496                SJ3(  81) = PDFTWS_BIM(13)/PDFTMX
1497                SJ3(  91) =PDFTWS_BIM(11)/PDFTMX
1498                SJ3( 101) = -GLSBD/GLSMX/GBUTON
1499                SJ3( 111) =  GLSALD/GLSMX/GBUTON
1500                SJ3( 121) =-BIRPDD/BICMX/...
1501                SJ3( 131) = BICRPD/BICMX/GBUTON
1502                SJ3( 141) = GAICD/GICMX/GBUTON
1503                SJ3( 151) = GAICD/GICMX/GBUTON
1504                SJ3( 161) =-BILPDD/BICMX/...
1505                SJ3( 171) = BICLPD/BICMX/GBUTON
1506                SJ3( 181) = PSAS1D/DLOAMX/GBUTON
1507                SJ3( 191) = PSAS2D/DLOAMX/GBUTON
1508                SJ3( 201) =-AIRPDD/AICMX/...
1509                SJ3( 211) = AICRPD/AICMX/GBUTON
1510                SJ3( 221) = PSAS4D/DLOAMX/GBUTON
1511                SJ3( 231) = PSAS3D/DLOAMX/GBUTON
1512                SJ3( 241) =-AILPD/AICMX/...
1513                SJ3( 251) = AICLPD/AICMX/GBUTON
C   BOARD 6F (CONSOLE 3) VALUES OF TRUNK LINES AND ADC'S (FIRST 32 TR'S ARE ADC'S)
1514                TR3(  11) =-DELRT/DELMX
1515                TR3(  21) = DELST/DELMX
1516                TR3(  31) =-DELRT/DELMX
1517                TR3(  41) = DELTH/DELMX
1518                TR3(  51) =-DELRS/DELMX
1519                TR3(  61) =-DELSS/DELMX
1520                TR3(  71) =-DELSS/DELMX
1521                TR3(  81) =  TH75R/TH75MX
1522                TR3(  91) =  TH75L/TH75MX
C
1523                TR3( 101) = 0.
1524                TR3( 111) = 0.
1525                TR3( 121) = 0.
1526                TR3( 131) = 0/0DX
1527                TR3( 141) = DELR/DELMX
1528                TR3( 151) =  DELS/DELMX
1529                TR3( 161) =-DELSS/DELMX
1530                TR3( 171) = DELR/DELMX
1531                TR3( 181) =-DELSS/DELMX
1532                TR3( 191) = -TH75R/TH75MX
1533                TR3( 201) = -TH75L/TH75MX
1534                TR3( 211) =  DELAR/DELAMX
1535                TR3( 221) =-DELAL/DELAMX
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THE

```
      TR3(272) = -DELSPR/DLSPMX
      TR3(273) = DELSPL/DLSPMX
      TR3(274) = PDOT/PDOTMX
      TR3(275) = RDOT/RDOTMX
      TR3(276) = QDOT/QDOTMX
      TR3(311) = THTMSR/TTMSMX
      TR3(311) =-GLSB/GLSMX
      TR3(312) = GLSAL/GLSMX
      TR3(313) =-DCYL/DCYLMX
      TR3(314) = -GLSAR/GLSMX
      TR3(315) =-DELRUD/DLRDMX
      TR3(316) =-DELELV/DELEMX
      TR3(317) = DELELP/DLELMX
      TR3(330) = BICBIC/BICMX
      TR3(331) = BICLIC/BICMX
      TR3(332) = AICBIC/AICMX
      TR3(333) = AICLIC/AICMX
      TR3(334) = DELTH/DLTHMX
      TR3(337) = THTMSL/TTMSMX
      TR3(350) =-DELST/DELSMX
      TR3(351) = GORLCN*DELRT/DELRMX
      TR3(352) =-DELRT/DELRMX
      TR3(353) =-VCALIB/UMX
      TR3(354) =-DELRT/DELRMX
      TR3(355) = GDSCOL*DELST/GSCOMX/DELSMX
      TR3(356) = GORCYL*DELRT/GRCYMX/DELRMX
      TR3(357) =-GDSCYL*DELST/GSCYMX/DELSMX
      TR3(370) = DELST/DELSMX
      TR3(371) =-GAIC/GICMX
      TR3(372) =-GBIC/GICMX
      TR3(373) = GDELP/DLELMX
      TR3(374) = GDE/DELEMX*DGTORD
      TR3(375) = GDSP/DLSPMX
C
      TR3(230)=  DELELP/DLELMX
      TR3(231) =   DELR / DELRMX
      TR3(232) =   DELS / DELSMX
      TR3(233) =   DELR / DELRMX
      TR3(234) =   COMDLR / DELRMX
      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
      BONDS(4) = BD4
      LETR(4) = LT4
      CALL ANDAIN(PROJ,'1B','B',IFC(1),3,A4P,2,5,A4N,1,5,SJW,3,5,IR4,5,
     *5)
```

Figure G.9. (Continued)

```
      C
      A4P(307) = PQTSL/TQSIMX
      A4P(311) = PQTSR/TQSIMX
      A4P(322) = PQM2/RPYSMX
      A4P(323) = YDOT/YDTSMX
      A4P(213) = -HDOT/HDTSMX
      A4P(311) = ACCXPA/AXPAMX
      A4P(312) = XDOT/XDTSMX
      A4P(313) = -VCALIB/SKEWS/VSIMX
      A4P(321) = V/SKEWS/VSIMX
      A4P(322) = THE*RDTODG/THESMX
      A4P(323) = -PHI*RDTODG/PHISMX
      A4P(330) = PSI*RDTODG/PSISMX
      A4P(331) = PSDSIM/PSDTSX
      A4P(340) = AINRE*RDTODG/AINSMX
      A4P(341) = AVEALR*RDTODG/ALNSMX
      A4P(342) = BETAE*RDTODG/BTSIMX
      A4P(343) = ACCYPA/AYPAMX
      A4P(350) = ACCZPA/AZPAMX
      A4P(351) = DELELP/DCPSMX
      A4P(362) = H/HSIMX
      A4P(363) = 0.
      A4P(370) = 0.
      A4P(371) = 1.0E+3
      A4P(372) = H/ZMX
      A4P(373) = 0.
      A4P(377) = 0.
      A4P(378) = 1.0E+3
      A4P(200) =  XIC    / XVISMX
      A4P(201) =  YIC    / YVISMX
      A4P(202) =  SINTHE
      A4P(203) =  COSTHE
      A4P(210) =  1.0D+3
      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 C.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) =   FRCOMT / 100.
1636            A4P(300)= (XHCPIT-H)/XVISMX
1637            A4P(301)=  (PIASMT-H*GZMTSI)/ZVISMX
1638            A4P(302) =   X30DY / 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)=  0.3000
1645            A4P(321)=  0.0000
1646            A4P(329)=  -BRKDOR/DORDMX
1647            A4P(330)=  0.3000
1648            A4P(331)=  0.0000
1649            A4P(341)=    FEDS   / FEDMX
1650            A4P(342)=  -BRAKE/BRKSMX
1651            A4N(342)=   BRAKE/BRKMX
1652            A4P(343)=   THBKDR/THRDMX
1653            A4P(350)=    FEDS   / FESMX
1654            A4P(351) =  0.0
1655            A4P(352)=  -DSTKDR/CSADMX
1656            A4P(353)=  -DEAKDR/DRADMX
1657            A4P(362)=  -COMDL3/DBPSMX
1658            A4N(360)=   COMDL3/DELBMX
1659            A4P(361)=    -COMDLS/DSPSMX
1660            A4N(361)=  COMDLS/DELSMX
1661            A4P(362)=  -COMIDT/AIDSMX
1662            A4N(362)=  COMIDT/AISBMX
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(330) =    V / VWMX
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
1677              TR4(131) =  BETAF / ABFSMX
1678              TR4(132) = -VCALIB / VMX
1679              TR4(133) = -HDOT / VWYX
1680              TR4(134) = -PHI  / PI
1681              TR4(135) =  PSI  / PSIMX
1682              TR4(136) =  THE  / PI
1683              TR4(137) =  H / ZMX
1684              TR4(150) =  AVEALW /ALWSMX
1685              TR4(151) =  SQF  / SQFMX
1686              TR4(152) =  XDOT / XDOTMX
1687              TR4(153) =  XIC  / XMX
1688              TR4(154) =  YDOT / YDOTMX
1689              TR4(155) =  YIC  / YMX
1690              TR4(157)=  PSIDOT/PSDMX
1691              TR4(170)=  SINTHE
1692              TR4(171)=  COSTHE
1693              TR4(172)=  SINPHI
1694              TR4(173)=  COSPHI
1695              TR4(174)=  SINPHI*COSTHE
1696              TR4(175)=  COSPHI*COSTHE
1697              TR4(110)=  VISMOR
1698              TR4(111)=  -TR4(110)
1699              TR4(112)=  VISVER
1700              TR4(113)=  -TR4(112)
1701              TR4(130)=  VCALIB/SKEPS/VSIMX
1702              TR4(131)=  -TR4(130)
1703              TR4(132)=  V/SKEPS/VSIMX
1704              TR4(133)=  -TR4(132)
1705              TR4(134)=  THE*RDTODG/THESMX
1706              TR4(135)=  -TR4(134)
1707              TR4(136)=  PHI*RDTODG/PHISMX
1708              TR4(137)=  -TR4(136)
1709              TR4(150)=  PSI*RDTODG/PSISMX
1710              TR4(151)=  -TR4(150)
1711              TR4(152)=  PSDSIM/PSDISX
1712              TR4(153)=  -TR4(152)
1713              TR4(154)=  AINPF*RDTODG/AINSMX
1714              TR4(155)=  -TR4(154)
1715              TR4(156)=  AVEALW*RDTODG/ALWSMX
1716              TR4(157)=  -TR4(156)
1717              TR4(170)=  BETAF*RDTODG/BTSIMX
1718              TR4(171)=  -TR4(170)
1719              TR4(172)=  ACCYPA/AYPAMX
1720              TR4(173)=  -TR4(172)
1721              TR4(174)=  ACCZPA/AZPAMX
1722              TR4(175)=  -TR4(174)
1723              TR4(176)=  DELFLP/DFPSMX
1724              TR4(177)=  -TR4(176)
1725              TR4(210)=  HDOT/HDTSMX
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
1726          TR4(211) =  -TR4(210)
1727          TR4(212) =  XDOT/XDTSMX
1728          TR4(213) =  -TR4(212)
1729          TR4(214) =  ACCXPA/AXPAMX
1730          TR4(215) =  -TR4(214)
1731          TR4(230) =  DELELB/DLELMX
1732          TR4(231) =    DELB / DELBMX
1733          TR4(232) =    DELS / DELSMX
1734          TR4(233) =    DELR / DELRMX
1735          TR4(234) =    COMDLB / DELBMX
1736          TR4(235) =    COMDLS / DELSMX
1737          TR4(236) =    COMDLR / DELRMX
1738          TR4(237) =    AVAIL
1739          TR4(250) =  PCTOL/PCTOMX
1740          TR4(251) =  PCTOR/PCTOMX
1741          TR4(252) =    OMEGA / OMEGMX
1742          TR4(253) =  AINRF/AINMX
1743          TR4(254) =  COMIDT/AINRMX
1744          TR4(255) =    COMDTH / DLTHMX
1745          TR4(256) = -SKTRIM(12)*OMDOT/OMESMX
1746          TR4(257) =    AVAIL
1747          TR4(270) =  ACCXPA/AXPAMX
1748          TR4(271) =  ACCYPA/AYPAMX
1749          TR4(272) =  ACCZPA/AZPAMX
1750          TR4(310) =  -COMIDT/AIDSMX
1751          TR4(311) =  -TR4(310)
1752          TR4(312) =  -BRAKE/BRKSMX
1753          TR4(313) =  -TR4(312)
1754          TR4(330) =  DBRKDR/DBBDMX
1755          TR4(331) =  -TR4(330)
1756          TR4(332) =  DRBKDP/DRBDMX
1757          TR4(333) =  -TR4(332)
1758          TR4(334) =  DSBKDR/DSBDMX
1759          TR4(335) =  -TR4(334)
1760          TR4(336) =  THBKDR/THBDMX
1761          TR4(337) =  -TR4(336)
1762          TR4(350) =  FFDB/FFBMX
1763          TR4(351) =  -TR4(350)
1764          TR4(352) =  FFDS/FFSMX
1765          TR4(353) =  -TR4(352)
1766          TR4(354) =  FFDR/FFRMX
1767          TR4(355) =  -TR4(354)
1768          TR4(356) =  H/HSIMX
1769          TR4(357) =  -TR4(356)
1770          TR4(370) =  -COMDLB/DBPSMX
1771          TR4(371) =  -TR4(370)
1772          TR4(372) =  -COMDLS/DSPSMX
1773          TR4(373) =  -TR4(372)
1774          TR4(374) =  -COMDLR/DRPSMX
```

Figure G.9. (Continued)

REPRODUCIBILITY OF THE

```
1775                TR4(376) = -TR4(374)
1776                TR4(375) = -CONJG(TH/C*TPSMX
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.

TILT ROTOR TRIM DATA

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	RDE	TH75 L	TH75 R
-0.44000E 00	0.24500E 01	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	AICL	AICR
-0.12590E 01	-0.70000E-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	BICL	BICR
0.23835E 01	0.0	0.63000E-01	0.11700E 00	0.85500E-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	0.98021E 03	0.50275E 05	0.14168E 05	0.60628E 05	0.21152E 03
NU 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
NU 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	-0.95239E 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	-0.54087E 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 00	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 01	-0.55187E 04	-0.56095E 04	0.23065E 02	0.19979E 02	0.82739E 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 03	-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	-0.14729E 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	HI L
-0.44233E 00	-0.18792E 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	HI 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 FUSE	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	0.25526E 00	0.26346E 00	-0.92932E-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 FUSE	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 3.10. Typical Model 222 Trim Sheet

REPRODUCIBILITY OF THE ORIGINAL PAGE

TOTAL VELOCITY ~ KTS.	"u" COMPONENT OF VELOCITY ~KTS.	"v" COMPONENT OF VELOCITY ~ KTS.	"w" COMPONENT OF VELOCITY ~ KTS	GROSS WEIGHT ~LBS~	ROTOR RPM	ALT (h)
PITCH ATTITUDE (θ) ~DEG.	ROLL ATTITUDE ϕ ~ DEG.	YAW ANGLE (ψ) DEG	REFERENCE NACELLE ANGLE ($i_{N_{REF}}$) ~DEG	LEFT WING TWIST AT TIP - ($\theta_{T_{LW}}$) ~DEG~	RIGHT WING TWIST AT TIP ($\theta_{T_{RW}}$) ~ ~DEG~	ATT... DEVI... ~SLU...
TOTAL LONG. STICK POSITION (δ_B) ~IN.	TOTAL LATERAL STICK POSITION (δ_S) ~ IN.	TOTAL RUDDER PEDAL POSITION (δ_P) ~IN.~	THROTTLE POSITION (δ_{TH}) ~IN.~	LONG. SAS INPUT ($\delta_{B_{SAS}}$) ~IN~	LATERAL SAS INPUT ($\delta_{S_{SAS}}$) ~IN~	DIFF... INPU...
ELEVATOR DEFLECTION (δ_e) ~ DEG	RUDDER DEFLECTION (δ_{RUD}) ~DEG	LEFT WING FLAPERON DEFLECTION (δ_{F_L}) ~ DEG	RIGHT WING FLAPERON DEFLECTION (δ_{a}) ~ DEG.	LEFT WING SPOILER DEFLECTION (δ_{SD_L}) ~ DEG	RIGHT WING SPOILER DEFLECTION (δ_{SD_R}) ~ DEG.	FLA... (δ_F)
ENGINE TURBINE INLET TEMP. (T_{BS}) ~ DEG.~	ENGINE SPEED (Ω_E) ~ RPM	ENGINE SHAFT POWER AVAILABLE (SHP_A)	LEFT ROTOR POWER REQUIRED ($SHP_{R_{LR}}$)	RIGHT ROTOR POWER REQUIRED ($SHP_{R_{RR}}$)	TOTAL ROLL INERTIA (I_{xx}) ~ SLUG-FT²~	TOTA... (I_{yy})
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 AT ~F
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	TOTA... AT ~
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~	LEF... LONG... ~
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~	LEF... FOR... ~L
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~	LEF... VER... (Z'_N)
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_{ACT}) ~FT-LB~	LEFT NACELLE ROLLING MOMENT ($\Delta\mathcal{L}'_{LN}$) ~FT-LB~	RIGHT NACELLE ROLLING MOMENT ($\Delta\mathcal{L}'_{RN}$) ~FT-LB~	LEF... POW... ($\mathcal{L}'$
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_{ACT}) ~FT-LB~	LEFT NACELLE PITCHING MOMENT ($\Delta m'_{LN}$) ~FT-LB~	RIGHT NACELLE PITCHING MOMENT ($\Delta m'_{RN}$) ~FT-LB~	LEF... PITC... (m
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~	LEF... YAW... (
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.	LE... AN... (α_{L}
FUSELAGE ATTITUDE (θ_F) ~DEG~	VERTICAL TAIL ANGLE OF ATTACK (α_{VT}) ~ DEG.	LEFT WING ANGLE OF ATTACK (α_{LW_G}) ~ DEG ~	RIGHT WING ANGLE OF ATTACK (α_{RW_G}) ~ DEG~	LEFT NACELLE SIDEFORCE COEFF (C_{YLN})	RIGHT NACELLE SIDEFORCE COEFF. (C_{YRN})	LE... AN...
FUSELAGE LIFT COEFF. (C_{LF})	HORIZONTAL TAIL LIFT COEFF. (C_{LH})	LEFT WING SLIPSTREAM LIFT COEFF. ($C_{LS_{LW}}$)	RIGHT WING SLIPSTREAM LIFT COEFF. ($C_{LS_{RW}}$)	LEFT NACELLE LIFT COEFF (C_{LLN})	RIGHT NACELLE LIFT COEFF. (C_{LRN})	LS CO...
FUSELAGE DRAG COEFF. (C_{DF})	HORIZONTAL TAIL DRAG COEFF (C_{DH})	LEFT WING SLIPSTREAM DRAG COEFF. ($C_{D_{SLW}}$)	RIGHT WING SLIPSTREAM DRAG COEFFICIENT ($C_{D_{SRW}}$)	LEFT NACELLE DRAG. COEFF (C_{CLN})	RIGHT NACELLE DRAG COEFF ($C_{D_{RN}}$)	LI... FI...
FUSELAGE PITCHING MOMENT COEFF. (C_{MF})	VERTICAL TAIL LIFT COEFF. (C_{YVT})	LEFT WING SLIPSTREAM PITCHING MOMENT COEFF. ($C_{M'_{SLW}}$)	RIGHT WING SLIPSTREAM PITCHING MOMENT COEFF. ($C_{M_{SRW}}$)	LEFT NACELLE PITCHING MOMENT COEFF. (C_{MLN})	RIGHT NACELLE PITCHING MOMENT COEFF. (C_{MRN})	R... C...
FUSELAGE YAWING MOMENT COEFF. (C_{NF})	VERTICAL TAIL DRAG COEFF. (C_{DVT})	WING SLIPSTREAM ROLLING MOMENT COEFF. ($C_{\mathcal{L}_{SW}}$)	WING SLIPSTREAM YAWING MOMENT COEFF. (C_{NS_W})	LEFT NACELLE YAWING MOMENT COEFF. (C_{YLN})	RIGHT NACELLE YAWING MOMENT COEFF. (C_{YRN})	RI... FU...
HOR. TAIL DOWNWASH AT α = ZERO. (ϵ_0) ~DEG.~	HORIZONTAL TAIL DOWNWASH ANGLE (ϵ) ~ DEG.	LEFT ROTOR DOWNWASH ANGLE (ϵ_{PRE}) ~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~	I... R... RO...

Figure G.11. Definition of Trim Sheet Parameters

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

...TUDE ~ FT.	LONG. LOCATION OF C.G WITH RESPECT TO PIVOT ~ IN.	VERTICAL LOCATION OF CG WITH RESPECT TO PIVOT ~ IN
...SPHERIC. ...TY (ρ) ...S/FT^3 ~	LEFT ROTOR COLL. PITCH AT .75 R. ($\theta_{.75_L}$) ~ DEG ~	RIGHT ROTOR COLL. PITCH AT .75 R ($\theta_{.75_R}$) ~ DEG ~
...ICAL SAS ...T ($\delta_{T_{SAS}}$) ~ IN. ~	LEFT ROTOR LATERAL CYCLIC PITCH (A_{1C_L}) ~ DEG ~	RIGHT ROTOR LATERAL CYCLIC PITCH (A_{1C_R}) ~ DEG ~
...DEFLECTION ~ DEG.	LEFT ROTOR LONG. CYCLIC PITCH (B_{1C_L}) ~ DEG ~	RIGHT ROTOR LONG. CYCLIC PITCH (B_{1C_R}) ~ DEG ~
...PITCH INERTIA) ~ SLUG-FT^2	TOTAL YAW INERTIA (I_{zz}) ~ SLUG-FT^2 ~	DYNAMIC PRESSURE (q_∞) ~ LB/FT^2 ~
...ROLL MOMENT ...EFT HUB ($\mathcal{L}_{LRH}$) ...-LB ~	TOTAL PITCH MOMENT AT LEFT HUB ($\mathcal{M}_{LRH}$) ~ FT-LB ~	TOTAL YAW MOMENT AT LEFT HUB ($\mathcal{N}_{LRH}$) ~ FT-LB ~
...L ROLL MOMENT ...IGHT HUB ($\mathcal{L}_{RRH}$) ...T-LB ~	TOTAL PITCH MOMENT AT RIGHT HUB ($\mathcal{M}_{RRH}$) ~ FT-LB ~	TOTAL YAW MOMENT AT RIGHT HUB ($\mathcal{N}_{RRH}$) ~ FT-LB ~
...TIP PIVOT ...FORCE (X^{NL}_{AERO}) ...S ~	RIGHT TIP PIVOT LONG FORCE (X^{NR}_{AERO})	LONG. ACCELERATION AT C.G (X_{AERO}/m) ~ FT/SEC^2 ~
...TIP PIVOT SIDE ...E (Y^{NL}_{AERO}) ...S ~	RIGHT TIP PIVOT SIDE FORCE (Y^{NR}_{AERO}) ~ LB ~	LATERAL ACCELERATION AT CG (Y_{AERO}/m) ~ FT/SEC^2 ~
...T TIP PIVOT ...TICAL FORCE ...$_{AERO}$) ~ LB ~	RIGHT TIP PIVOT VERTICAL FORCE (Z^{NR}_{AERO}) ~ LB ~	VERTICAL ACCELERATION AT CG. (Z_{AERO}/m) ~ FT/SEC^2 ~
...T TIP PIVOT ...NG MOMENT ...$_{AERO}$) ~ 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 ~
...T TIP PIVOT ...NING MOMENT ...$^{NL}_{AERO}$) ~ FT-LB ~	RIGHT TIP PIVOT PITCHING MOMENT ($\mathcal{M}^{NL}_{AERO}$) ~ FT-LB ~	PITCH ACCELERATION AT CG ($\mathcal{M}_{AERO}/I_{yy}$) ~ RAD/SEC^2 ~
...T TIP PIVOT ...ING MOMENT ...$^{NL}_{AERO}$) ~ FT-LB ~	RIGHT TIP PIVOT YAWING MOMENT ($\mathcal{N}^{NL}_{AERO}$) ~ FT-LB	YAW ACCELERATION AT CG ($\mathcal{N}_{AERO}/I_{zz}$) ~ RAD/SEC^2 ~
...T ROTOR RESOLVED ...LES OF ATTACK ...) ~ DEG ~	RIGHT ROTOR RESOLVED ANGLE OF ATTACK (α_{LR}) ~ DEG ~	LEFT TIP DEFLECTION (h_{i_L}) ~ IN. ~
...T ROTOR SIDESLIP ...LE (β_{HL}) ~ DEG	RIGHT ROTOR SIDESLIP ANGLE (β_{HR}) ~ DEG ~	RIGHT TIP DEFLECTION (h_{i_R}) ~ IN. ~
...T ROTOR POWER ...F. ($C_{P_{LR}}$)	LEFT ROTOR THRUST COEFF ($C_{T_{LR}}$)	LEFT ROTOR NORMAL FORCE COEFF. ($C_{NF_{LR}}$)
...T ROTOR SIDE- ...E COEFF. ($C_{SF_{LR}}$)	LEFT ROTOR PITCHING MOMENT COEFF. ($C_{PM_{LR}}$)	LEFT ROTOR YAWING MOMENT COEFF. ($C_{YM_{LR}}$)
...T ROTOR POWER- ...OEFF. ($C_{P_{RR}}$)	RIGHT ROTOR THRUST COEFF. ($C_{T_{RR}}$)	RIGHT ROTOR NORMAL FORCE COEFF. ($C_{NF_{RR}}$)
...HT ROTOR SIDE- ...CE COEFF. ($C_{SF_{RR}}$)	RIGHT ROTOR PITCHING MOMENT COEFF. ($C_{PM_{RR}}$)	LEFT ROTOR YAWING MOMENT COEFF. ($C_{YM_{RR}}$)
...RFERENCE ANGLE ...T WING C/L) ...E (ϵ_{WING}) ~ DEG. ~	INTERFERENCE ANGLE LEFT WING ON ROTOR (ϵ_{WRL}) ~ DEG.	ROTOR ACCEL. ($\dot{\Omega}$) ~ RAD/SEC^2

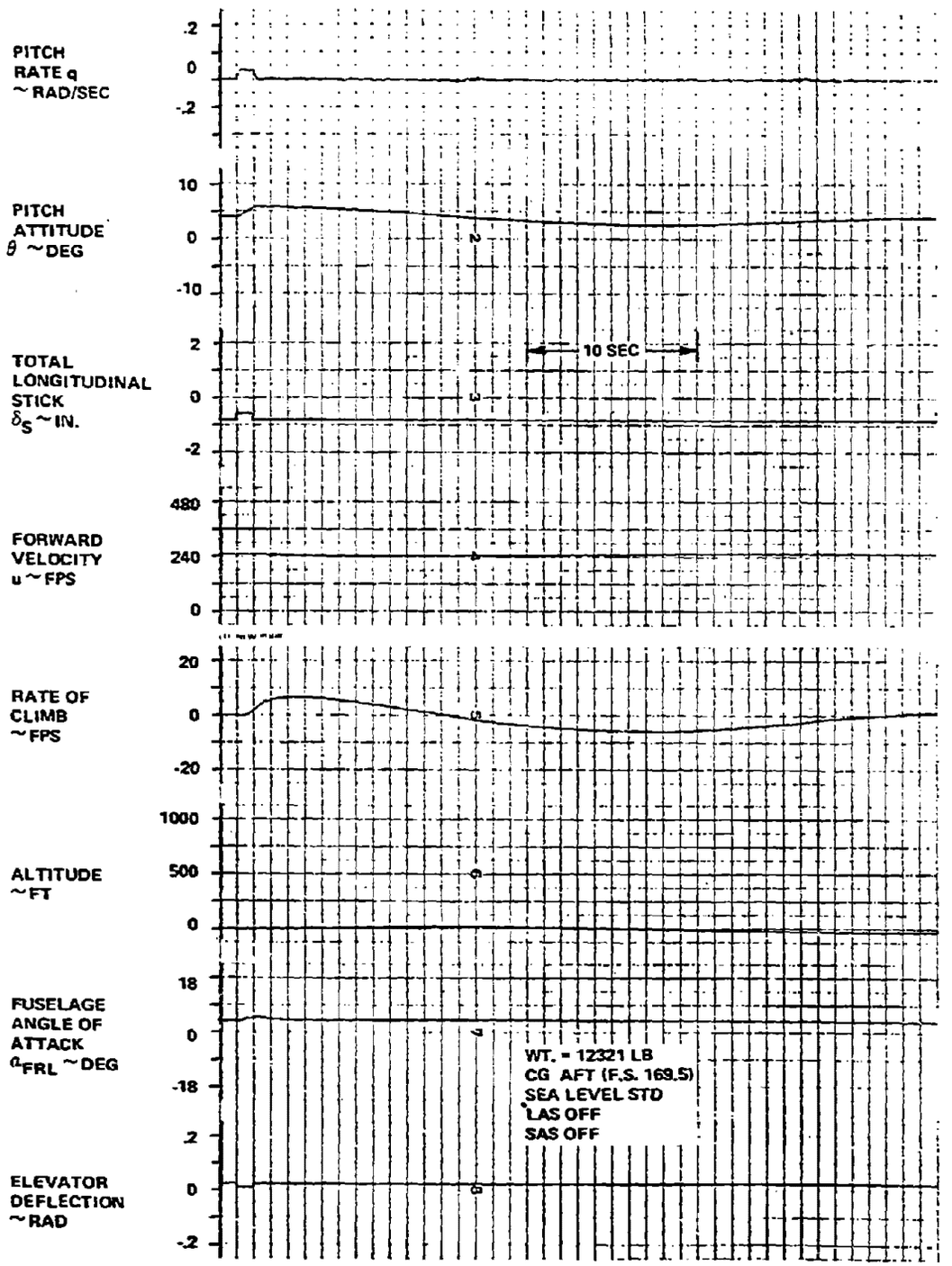


Figure G.12. Typical Time History Response to A .25 Inch Longitudinal Stick Pulse at 150 Knots

VALIDATION OF THE MODEL 222 SIMULATION AT AMES RESEARCH CENTER

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.

- Dynamic Responses (Response to control pulses)
  - 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	±10%
Time to double (or half) amplitude	±10%

  - Stability Derivative Checks
    - 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_u, M_w, M_q, Z_w,

L_{δ_s}, N_{δ_s}, L_{δ_r}, N_{δ_r}, M_{δ_B}, M_{i_N}, $Z_{\delta_{TH}}$) ±10%

  - Validation of Time Frame

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 ±10%.

  - Transport Lag Checks

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)

- Pilot acceptance 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.