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AVRADCOM Technical Report 80-A-7

A Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics

Part III: Program Manual

Wayne Johnson

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A Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics
Part III: Program Manual

Wayne Johnson, Aeromechanics Laboratory
AVRADCOM Research and Technology Laboratories
Ames Research Center, Moffett Field, California

NASA
National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035

United States Army
Aviation Research and
Development Command
St Louis, Missouri 63166

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A COMPREHENSIVE ANALYTICAL MODEL OF
ROTORCRAFT AERODYNAMICS AND DYNAMICS

Part III: Program Manual

Wayne Johnson

Ames Research Center
and
Aeromechanics Laboratory
AVRADCOM Research and Technology Laboratories

SUMMARY

The computer program for a comprehensive analytical model of rotorcraft aerodynamics and dynamics is described. This analysis is designed to calculate rotor performance, loads, and noise; the helicopter vibration and gust response; the flight dynamics and handling qualities; and the system aeroelastic stability. The analysis is a combination of structural, inertial, and aerodynamic models, that is applicable to a wide range of problems and a wide class of vehicles. The analysis is intended for use in the design, testing, and evaluation of rotors and rotorcraft, and to be a basis for further development of rotary wing theories. This report documents the computer program that implements the analysis.

1. COMMON BLOCK CONTENTS

This section describes the contents of the common blocks used by the program. Each description begins with the common block label. The total length of the block is given in parentheses after the label. Then all variables in the block are listed. The left-hand column gives the variable name, and the right-hand column gives the location of the variable in the common block. Finally, a description of the variable is provided (except for variables in blocks with labels of the form xxDATA, which are input parameters). Only the common blocks for rotor #1 are described; the common blocks for rotor #2 have an identical structure.

TMDATA(182)

FILEID(4)	input file identification (alphanumeric date and time; BLOCK DATA if input file is neither read nor written)	1
TITLE(20)		5
CODE		25
ANTYPE(3)		26
OPREAD(10)		29
NPRNTI		39
DEBUG(25)		40
OPUNIT		65
NROTOR		66
ALTMSL		67
TEMP		68
VKTS		69
VEL		70
VTIP		71
RPM		72
OPGRND		73
HAGL		74
OPENGN		75
AFLAP		76
MPSI		77
DENSE		78
OPDENS		79
COLL		80
LATCYC		81
LNGCYC		82
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APITCH		84
AROLL		85
ACLIMB		86
AYAW		87
RTURN		88
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MREV		90
ITERM		91
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ITERC		93
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ITERF		161
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CTTRIM	167
CPTRIM	168
CYTRIM	169
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MTRIM	172
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FACTOR	175
EPTRIM	176
OPGOVT	177
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TITLE(20)	1
TYPE	21
VTIPN	22
RADIUS	23
SIGMA	24
GAMMA	25
NBLADE	26
TDAMPO	27
TDAMPC	28
TDAMPR	29
NUGC	30
NUGS	31
GDAMPC	32
GDAMPS	33
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FACTNW	1
OPVXVY	2
KNW	3
KRW	4
KFW	5
KDW	6
RRU	7
[illegible]RU	8
PRU	9
FNW	10
DVS	11
DLS	12
CORE(5)	13
OPCORE(2)	18
WKMODL(13)	20
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LHW	35
OPHW	36
OPRTS	37
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FWGSO(2)	113
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KWGSI(4)	119
KWGSO(4)	123

G1DATA(55)

KFWG	1
OPFWG	2
ITERWG	3
FACTWG	4
WGMODL(2)	5
RTWG(2)	7
COREWG(4)	9
MRVBWG	13
LDMWG	14
NDMWG(36)	15
IPWGDB(2)	51
QWGDB	53
DQWG(2)	54

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TITLE(20)	2
WEIGHT	21
IXX	22
IYY	23
IZZ	24
IXY	25
IXZ	26
IYZ	27
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WLR2	40
FSWB	41
BLWB	42
WLWB	43
FSHT	44
BLHT	45
WLHT	46
FSVT	47
BLVT	48
WLVT	49
FSOFF	50
BLOFF	51
WLOFF	52
FSCG	53
BLCG	54
WLCG	55
HMAST	56
DPSI21	57
CANTHT	58
CANTVT	59
KOCFE	60
KCCFE	61
KSCFE	62
KPCFE	63
PCCFE	64
PSCFE	65
PPCFE	66
KFOCFE	67
KROCFE	68
KFCCFE	69

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KRCCFE	70
KFSCFE	71
KRSCFE	72
KFPCFE	73
KRPCFE	74
PFCCFE	75
PRCCFE	76
PFPCFE	77
PRPCFE	78
KFCFE	79
KTCFE	80
KACFE	81
KECFE	82
KRCFE	83
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BADATA(37)

LFTAW	1
IWB	2
LFTDW	3
LFTFW	4
DRGOW	5
DRGVW	6
DRGIW	7
DRGDW	8
DRGFW	9
AMAXW	10
MOMOW	11
MOMAW	12
MOMDW	13
MOMFW	14
SIDEB	15
SIDEP	16
SIDER	17
ROLLB	18
ROLLP	19
ROLLR	20
ROLLA	21
YAWB	22
YAWP	23
YAWR	24
YAWA	25
LFTAH	26
LFTEH	27
AMAXH	28
IHT	29
LFTAV	30
LFTRV	31
AMAXV	32
IVT	33
FETAIL	34
LHTAIL	35
HVTAIL	36
OPTINT	37

ENDATA(22)

ENGPOS	1
THRTLC	2
IENG	3
KMAST1	4
KMAST2	5
KICS	6
KENG	7
KPGOVE	8
KPGOV1	9
KPGOV2	10
KIGOVE	11
KIGOV1	12
KIGOV2	13
T1GOVE	14
T1GOV1	15
T1GOV2	16
T2GOVE	17
T2GOV1	18
T2GOV2	19
GSE	20
GSI	21
KEDAMP	22

L1DATA(239)

MHARML	1
MHLOAD	2
MALOAD	3
MRLOAD	4
RLOAD(20)	5
NPOLAR	25
NWKGMP(4)	26
MWKGMP	30
JWKGMP(8)	31
MHARMN(3)	39
MTIMEN(3)	42
MNOISE	45
RANGE(10)	46
ELVATN(10)	56
AZMUTH(10)	66
KFATIG	76
SENDUR(18)	77
CMAT(18)	95
EXMAT(18)	113
NPLOT(75)	131
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OPNOIS(4)	236

LADATA(331)

MVIB	1
FSVIB(10)	2
WLVIB(10)	12
BLVIB(10)	22
ZETAV(3,10,10)	32

GCDATA(18)

OPTRAN	1
OPGUST(3)	2
VELG	5
PSIG	6
GDIST(2)	7
GTIME	9
CTIME	10
GMAG(3)	11
CMAG(5)	14

TNDATA(42)

NPRNTT	1
NPRNTP	2
NPRNTL	3
NRSTRT	4
TMAX	5
TSTEP	6
OPPLOT	7
DOFPLT(21)	8
DOF(7)	29
OPSAS	36
KCSAS	37
KSSAS	38
TCSAS	39
TSSAS	40
ITERT	41
OPLMDA	42

STDATA(251)

NPRNTP	1
NPRNTL	2
ITERS	3
CPLMDA	4
DELTA	5
DOF(7)	6
CCN(16)	13
GUS(3)	29
CPPRNT(4)	32
KCSAS	36
KSSAS	37
TCSAS	38
TSSAS	39
EQTYPE(12)	40
NPRNTT	52
ANTYPE(5)	53
NSYSAN	58
NSTEP	59
NFREQ	60
FREQ(100)	61
NBPLOT	161
NAMEXP(7)	162
NAMEVP(19)	169
NXPLT	188
NVPLT	189
NDPLT	190
NF0PLT	191
NF1PLT	192
MSPLT	193
NTPLOT	194
PERPLT	195
DTPLT	196
TMXPLT	197
LGUST(3)	198
MGUST(3)	201
NAMEXA(10)	204
FREQA(10)	214
MACC	224
FSACC	225
BLACC	226
WLACC	227
TSTEP	228
TMAX	229
OPPLOT	230
DOFPLT(21)	231

FLDATA(566)

OPFLOW	1
OPSYMM	2
OPFDAN	3
MPSIPC	4
NINTPC	5
NBLDFL	6
OPSAS	7
KCSAS	8
KSSAS	9
TCSAS	10
TSSAS	11
OPTORS(2)	12
OPGRND	14
KASGE	15
DOF(80)	16
CON(26)	96
GUS(3)	122
DELTA	125
OPRINT	126
MPSICC	127
DALPHA	128
DMACH	129
OPUSLD	130
ANTYPE(4)	131
NSYSAN	135
NSTEP	136
NFREQ	137
FREQ(100)	138
NBPLOT	238
NAMEXP(80)	239
NAMEVP(29)	319
NXPLT	348
NVPLT	349
NDPLT	350
NFOPLT	351
NF1PLT	352
MSPLT	353
NTPLOT	354
PERPLT	355
DTPLT	356
TMXPLT	357
LGUST(3)	358
MGUST(3)	361
NAMEXA(83)	364
FREQA(83)	447
MACC	530
FSACC	531

BLACC	532
WLACC	533
ZETACC(3,10)	534
NAMEXR(3)	564

A1TABL(15119)

TITLE(20)	title for airfoil data (80 characters)	1
IDENT(4)	identification (alphanumeric date and time)	21
NMAX	$n_{N_a} * n_{N_m} * N_r$	25
	angle of attack boundaries	
NAB	N_a	26
NA(20)	n_k, k = 1 to N_a	27
A(20)	α_k (deg), k = 1 to N_a	47
	Mach number boundaries	
NMB	N_m	67
NM(20)	n_k, k = 1 to N_m	68
M(20)	M_k, k = 1 to N_m	88
	radial stations	
NRB	N_r	108
R(11)	r_k, k = 1 to N_r+1	109
	airfoil characteristics	
CLT(5000)	c_{ℓ_j}, j = 1 to NMAX	120
CDT(5000)	c_{d_j}, j = 1 to NMAX	5120
CMT(5000)	c_{m_j}, j = 1 to NMAX	10120

CASECM(9)

RESTRT	restart code: 1 for trim, 2 for flutter, 3 for flight dynamics, 4 for transient	1
JCASE	case number	2
TASK	task code: 1 for trim, 2 for flutter, 3 for flight dynamics, 4 for transient	3
JOB		4
RSWRT		5
NCASES		6
BLKDAT		7
RDFILE		8
START		9

UNITNO(11)

NFDAT	1
NFAF1	2
NFAF2	3
NFRS	4
NFEIG	5
NFSCR	6
NUDB	7
NUOUT	8
NUPP	9
NULIN	10
NUIN	11

TRIMCM(1604)

IDENT(4)	identification code for case and restart file (alphanumeric date and time)	1
DRATIO	density ratio, ρ/ρ_0	5
DENSE	air density ρ	6
CSOUND	speed of sound	7
ALTD	density altitude	8
GRAV	gravity, $g/\Omega^2 R$	9
CXTARG	target C_X/σ for trim	10
OPRTR2	integer parameter: 0 to skip rotor #2 calculations	11
DPSI	$\Delta\psi$ (rad)	12
COUNTT	integer parameter: number of trim iterations	13
FSCALE	Ω (reference rotor)	14
RSCALE	R	15
NSCALE	N	16
ISCALE	I_b	17
GSCALE	γ	18
SSCALE	σ	19
CSCALE	c_m	20
COSPSI(36)	$\cos \psi_j$, j = 1 to MPSI	21
SINPSI(36)	$\sin \psi_j$, j = 1 to MPSI	57
KEPSI(21,36)	complex parameter: $(K_n/J)e^{-in\psi_j}$ j = 1 to MPSI, n = 1 to max(MHARM,MHARMF*NBLADE)	93

RTR1CM(1070)

OMEGA	rotor speed Ω (rad/sec)	1
MTIP	tip Mach number $\Omega R/c_s$	2
GAMMA	Lock number γ	3
CMEAN	mean chord c_m	4
IB	characteristic inertia I_b	5
NBM	number of bending modes	6
NTM	number of torsion modes	7
NGM	zero if no gimbal or teeter mode	8
NBMT	number of mean bending deflection modes	9
GLAG	g_{lag}	10
MLD	$M_{LD}/I_b\Omega^2$	11
DZLD	$\dot{\zeta}_{LD}/\Omega$	12
CGC	$C^*_{GC} = C_{GC}/\frac{1}{2}NI_b\Omega$ (or $C^*_T = C_{GC}/2I_b\Omega$)	13
CGS	$C^*_{GS} = C_{GS}/\frac{1}{2}NI_b\Omega$	14
NUGC	ν_{GC} (or ν_T)	15
NUGS	ν_{GS}	16
CTO	collective control damping $C_\theta/I_b\Omega$	17
CTC	cyclic control damping $C_\theta/I_b\Omega$	18
CTR	rotating control damping $C_\theta/I_b\Omega$	19
RA(30)	aerodynamic radial stations, r_i, i = 1 to MRA	20
DRA(30)	aerodynamic segment length Δr_i, i = 1 to MRA	50
FTIP(30)	tip loss multiplicative factor f_i, i = 1 to MRA	80
PSI21M	$\Delta\psi_{21}$ (rad), 0. for rotor #1 (for BODYM, MOTNH, WAKEN, ENGNM)	110
PSI21W	$\Delta\psi_{21}$ (rad), $-\Delta\psi_{21}$ for rotor #2 (for WAKEN, WAKEC)	111
MUX	μ_x	112
MUY	μ_y	113
MUZ	μ_z	114
RGUST(3,3)	R_G	115
CHUB(6,16)	c	124
CBHUB(3,3)	$\bar{c}$ (including factor Ω_{ref}/Ω)	220
CHUBT(16,6)	c^T	229

		RTR1CM
ALFHP	α_{HP} (deg)	325
PSIHP	ψ_{HP} (deg)	326
MAT	M_{at}	327
CD(2)	C_D for drive train H_n^{-1}	328
CPSI(2)	C_ψ for drive train motion	330
	burst tip vortex in wake model	
PINTER(36)	ϕ_{inter} (rad) at ψ_j, j = 1 to MPSI	332
PBURST(36)	ϕ_b (rad) at ψ_j, j = 1 to MPSI	368
	inertial and structural data at $r = e + (j-1)\Delta r$, j = 1 to MRB+1	
EIXXB(51)	$\Omega^2 R^4/EI_{xx}$	404
EIZZB(51)	$\Omega^2 R^4/EI_{zz}$	455
MASSB(51)	m	506
TWISTB(51)	θ_{tw} (rad)	557
CENT(51)	$\int_r^1 m\rho\, d\rho$	608
	inertial and structural data at $r = r_{FA} + (j-1)\Delta r$, j = 1 to MRB+1	
ITHETB(51)	I_θ	659
GJB(51)	$\Omega^2 R^4/GJ$	710
	inertial data at $r = (j-1)\Delta r$, j = 1 to MRM+1	
MASSI(51)	mR^3/I_b	761
ITHETI(51)	$I_\theta R/I_b$	812
XII(51)	x_I/R	863
XCI(51)	x_C/R	914
TWISTI(51)	θ_{tw} (rad)	965
KP2I(51)	k_P^2/R^2	1016
IPITCH	blade pitch inertia (slug-ft^2 or kg-m^2)	1067
	control system stiffness K_θ (ft-lb/rad or m-N/rad)	
KTO	collective	1068
KTC	cyclic	1069
KTR	reactionless	1070

RH1CM(12792)

HRTR(16,16,21)	complex rotor transfer function matrix, H_n^{-1}; size NBM+NTM+NGM; n = 0 to MHARM	1
HBODY(16,6,10)	complex airframe transfer function matrix, $H_n^{-1} C^T e^{in\Delta\psi_{21}}$; $n = pN\Omega/\Omega_{ref}$, p = 1 to MHARMF	10753
HENG(6,10)	complex drive train transfer function matrix, $H_n^{-1} C_D e^{in\Delta\psi_{21}}$; $n = pN\Omega/\Omega_{ref}$, p = 1 to MHARMF	12673

BODYCM(446)

AMODE1(6,16)	$(\vec{\xi}_k, \vec{\gamma}_k)$ at rotor #1 hub (dimensionless)	1
AMODE2(6,16)	$(\vec{\xi}_k, \vec{\gamma}_k)$ at rotor #2 hub (dimensionless)	61
	pitch/mast-bending coupling (dimensionless)	
KMSTC1(10)	K_{MC_k} for rotor #1	121
KMSTS1(10)	K_{MS_k} for rotor #1	131
KMSTC2(10)	K_{MC_k} for rotor #2	141
KMSTS2(10)	K_{MS_k} for rotor #2	151
ADAMPA(10)	aerodynamic damping $(2\gamma/\sigma aA)(q/V)F_{q_k \dot{q}_k}$	161
ACNTRL(4,10)	control derivatives $(2\gamma/\sigma aA)\, q\, F_{q_k \delta}$	171
AMASS(10)	M_k^*	211
ADAMPS(10)	$M_k^* g_s \omega_k$	221
ASPRNG(10)	$M_k^* \omega_k^2$	231
MSTAR	M^*	241
MSTARG	$M^* g$	242
ISTAR(3,3)	I^*	243
CWS	$C_W/\sigma = (a/2\gamma)\, M^* g$	252
HMASS	aircraft mass (slug or kg)	253
NAM	number of airframe modes	254
	aircraft description ($\theta_T = \psi_T = 0$)	
RSF10(3,3)	R_{SF} for rotor #1	255
RSF20(3,3)	R_{SF} for rotor #2	264
RHUB10(3)	$\vec{r}$ at rotor #1 hub	273
RHUB20(3)	$\vec{r}$ at rotor #2 hub	276
RWBO(3)	$\vec{r}$ at wing/body	279
RHTO(3)	$\vec{r}$ at horizontal tail	282
RVTO(3)	$\vec{r}$ at vertical tail	285
ROFFO(3)	$\vec{r}$ off rotor	288

BODYCM

	aircraft description	
RSF1(3,3)	R_{SF} for rotor #1	291
RSF2(3,3)	R_{SF} for rotor #2	300
RHUB1(3)	$\vec{r}$ at rotor #1 hub	309
RHUB2(3)	$\vec{r}$ at rotor #2 hub	312
RWB(3)	$\vec{r}$ at wing/body	315
RHT(3)	$\vec{r}$ at horizontal tail	318
RVT(3)	$\vec{r}$ at vertical tail	321
ROFF(3)	$\vec{r}$ off rotor	324
TCFE(11,5)	T_{CFE}	327
VXREKF(3)	$(\vec{V} \times) R_e \vec{k}_F$	382
MVXRE(3,3)	$-M^* (\vec{V} \times) R_e$	385
GMTRX(3,3)	G	394
IBODY(3,3)	$R_e^T I^* R_e$	403
REULER(3,3)	R_e	412
RFV(3,3)	R_{FV}	421
RFE(3,3)	R_{FE}	430
KE(3)	$\vec{k}_E$	439
VELF(3)	$\vec{V}$	442
VCLIMB	V_{climb}	445
VSIDE	V_{side}	446

ENGNCM(131)

QTHRTL	$r_E Q_t^*$	1
IENG	$r_E^2 I_E^*$	2
KMI1	K_{MI_1}	3
KMI2	$K_{MI_2}^*$	4
KMR	K_{MR}	5
KME1	$K_{ME_1}^*$	6
KME2	$K_{ME_2}^*$	7
	governor proportional gains, $K_p * \Omega$	
KPGOVE	engine	8
KPGOV1	rotor #1	9
KPGOV2	rotor #2	10
NDM	number of drive train modes	11
	governor time lag, $\tau_1 * \Omega$	
T1GOVE	engine	12
T1GOV1	rotor #1	13
T1GOV2	rotor #2	14
	governor time lag, $\tau_2 * \Omega^2$	
T2GOVE	engine	15
T2GOV1	rotor #1	16
T2GOV2	rotor #2	17
QEDAMP	$r_E^2 \; Q_\Omega^*$	18
IRSTAR	I_R^*	19
MENG(6,6)	mass matrix for H_n^{-1}	20
SENG(6,6)	spring matrix for H_n^{-1}	56
DENG(6,6)	damping matrix for H_n^{-1}	92
HENGO(2,2)	H_0^{-1} for static elastic motion	128

GUSTCM(12989)

	gust components, velocity axes	
VGWBV(3)	at wing/body, $\vec{g}_W$	1
VGHTV(3)	at horizontal tail, $\vec{g}_H$	4
VGVTV(3)	at vertical tail, $\vec{g}_V$	7
VGR1V(3,30,36)	at rotor #1, $\vec{g}(r_i, \psi_j)$	10
VGR2V(3,30,36)	at rotor #2, $\vec{g}(r_i, \psi_j)$	3250
VGHUB1(3)	at rotor #1 hub, $\vec{g}$ (for wake geometry)	6490
VGHUB2(3)	at rotor #2 hub, $\vec{g}$ (for wake geometry)	6493
	gust components, F axes	
VGWBF(3)	at wing/body, $\vec{g}_W$	6496
VGHTF(3)	at horizontal tail, $\vec{g}_H$	6499
VGVTF(3)	at vertical tail, $\vec{g}_V$	6502
	gust components, S axes	
VGR1S(3,30,36)	at rotor #1, $\vec{g}(r_i, \psi_j)$	6505
VGR2S(3,30,36)	at rotor #2, $\vec{g}(r_i, \psi_j)$	9745
	transient control	
VPTRAN(5)	$\Delta\vec{v}_P = (\delta_0 \;\; \delta_c \;\; \delta_s \;\; \delta_p \;\; \delta_t)^T$	12985

CONTCM(32)

VCNTRL(11)	control vector (rad): $\vec{v} = (\theta_{75}\ \theta_{1c}\ \theta_{1s}\ \theta_{75}\ \theta_{1c}\ \theta_{1s}\ \delta_s\ \delta_e\ \delta_a\ \delta_r\ \theta_t)^T$ rotor#1 rotor#2 airframe	1
THETFT	θ_{FT} (rad)	12
PHIFT	ϕ_{FT} (rad)	13
THETFP	θ_{FP} (rad)	14
PSIFP	ψ_{FP} (rad)	15
THETAT	θ_T (rad)	16
PSIT	ψ_T (rad)	17
DVBODY(6)	airframe motion (dimensionless) $(\dot{\phi}_F\ \dot{\theta}_F\ \dot{\psi}_F\ \dot{x}_F\ \dot{y}_F\ \dot{z}_F)$	18
DOMEGA	$\dot{\psi}_s$ (static; dimensionless)	24
DDZF	$\ddot{z}_F$ (dimensionless)	25
VPILOT(5)	pilot control vector (rad): $\vec{v}_P = (\delta_0\ \delta_c\ \delta_s\ \delta_p\ \delta_t)^T$	26
TGOVR1	$(\Delta\theta_{govr})_{rotor\#1}$ (rad)	31
TGOVR2	$(\Delta\theta_{govr})_{rotor\#2}$ (rad)	32

CONVCM(80)

	mean square motion (rotor #1)	
B1MS(10)	β	1
T1MS(5)	θ	11
BG1MS	β_G	16
P1MS(16)	ϕ	17
PS1MS(6)	ψ	33
	mean square motion (rotor #2)	
B2MS(10)	β	39
T2MS(5)	θ	49
BG2MS	β_G	54
P2MS(16)	ϕ	55
PS2MS(6)	ψ	71
G1MS	mean square circulation (rotor #1)	77
G2MS	mean square circulation (rotor #2)	78
COUNTM	integer parameter: number of motion iterations	79
COUNTC	integer parameter: number of circulation iterations	80

MD1CM(6773)

T75OLD	old θ_{75} (initialized to 1000.)	1
NBMOLD	old NBM (initialized to 0)	2
NTMOLD	old NTM (initialized to 0)	3
NU(20)	bending frequency ν_i, i = 1 to NCOLB (per rev)	4
NUNR(20)	nonrotating bending frequency ν_{NR_i}, i = 1 to NCOLB (rad/sec)	24
	bending mode displacement $\vec{\eta}_i$, i = 1 to NBM, at radial station r =	
ETA(2,10)	r_{FA}	44
ETA(2,10)	r_{PB}	64
ETA(2,10)	r_{ROOT}	84
ETA(2,10)	1	104
ETA(2,10,11)	(j-1)0.1, j = 1 to 11	124
ETA(2,10,51)	(j-1)Δr, j = 1 to MRM+1	344
ETA(2,10,30)	r_j, j = 1 to MRA	1364
	bending mode slope $\vec{\eta}_i'$, i = 1 to NBM, at radial station r =	
ETAP(2,10)	r_{FA}	1964
ETAP(2,10)	r_{PB}	1984
ETAP(2,10)	r_{ROOT}	2004
ETAP(2,10)	1	2024
ETAP(2,10,11)	(j-1)0.1, j = 1 to 11	2044
ETAP(2,10,51)	(j-1)Δr, j = 1 to MRM+1	2264
ETAP(2,10,30)	r_j, j = 1 to MRA	3284
	bending mode curvature $\vec{\eta}_i''$, i = 1 to NBM, at radial station r =	
ETAPP(2,10)	r_{FA}	3884
ETAPP(2,10)	r_{PB}	3904
ETAPP(2,10)	r_{ROOT}	3924
ETAPP(2,10)	1	3944
ETAPP(2,10,11)	(j-1)0.1, j = 1 to 11	3964
ETAPP(2,10,51)	(j-1)Δr, j = 1 to MRM+1	4184
ETAPP(2,10,30)	r_j, j = 1 to MRA	5204

		MD1CM
ETAPH(2,10)	bending mode slope at hinge, $\vec{\eta}'(e)$	5804
WT(11)	torsion frequency ω_i, i = 1 to NCOLT+1, (per rev)	5824
	control system frequency (per rev)	
WTO	collective	5835
WTC	cyclic	5836
WTR	reactionless	5837
	torsion mode displacement ξ_i, i = 1 to NTM, at radial station r =	
ZETA(5,11)	(j-1)0.1, j = 1 to 11	5838
ZETA(5,51)	$(j-1)\Delta r$, j = 1 to MRM+1	5893
ZETA(5,30)	r_j, j = 1 to MRA	6148
	torsion mode slope ξ_i', i = 1 to NTM, at radial station r =	
ZETAP(5,11)	(j-1)0.1, j = 1 to 11	6298
ZETAP(5,51)	$(j-1)\Delta r$, j = 1 to MRM+1	6353
ZETAP(5,30)	r_j, j = 1 to MRA	6608
KPB(10)	pitch/bending coupling K_{P_i}, i = 1 to NBM	6758
KPG	pitch/gimbal coupling K_{P_G}	6768
DEL1	δ_{FA_1} (rad)	6769
DEL2	δ_{FA_2} (rad)	6770
DEL3	δ_{FA_3} (rad)	6771
DEL4	δ_{FA_4} (rad)	6772
DEL5	δ_{FA_5} (rad)	6773

WKV1CM(8165)

CTOLD	old C_T	1
CMXOLD	old C_{M_x}	2
CMYOLD	old C_{M_y}	3
GAMOLD(30,36)	old Γ_{ij} (i = 1 to MRA, j = 1 to MPSI)	4
CRCOLD(36)	old max Γ_j (j = 1 to MPSI)	1084
VIND(3,30,36)	$\vec{\lambda}(r_i, \psi_j)$ (i = 1 to MRA, j = 1 to MPSI)	1120
LAMBDA	mean λ_{tpp}	4360
FGE	$f_{GE} = v/v_\infty = 1-(\cos\epsilon/4z)^2$ (1. if OGE)	4361
COSE	$\cos\epsilon$	4362
ZAGL	z_{AGL}	4363
VINT(3,30,36)	$\vec{\lambda}_{int}(r_i, \psi_j)$ (i = 1 to MRA, j = 1 to MPSI) at other rotor	4364
VORH(3,36)	$\vec{\lambda}_{int}(\psi_j)$ (j = 1 to MPSI), at other rotor hub	7604
LAMBDI	mean λ_{int}, at other rotor	7712
VWB(3,36)	$\vec{\lambda}_W(\psi_j)$ (j = 1 to MPSI), at wing/body	7713
VHT(3,36)	$\vec{\lambda}_H(\psi_j)$ (j = 1 to MPSI), at horizontal tail	7821
VVT(3,36)	$\vec{\lambda}_V(\psi_j)$ (j = 1 to MPSI), at vertical tail	7929
VOFF(3,36)	$\vec{\lambda}_O(\psi_j)$ (j = 1 to MPSI), off rotor disk	8037
LAMBDW(3)	mean $\vec{\lambda}_W$, at wing/body	8145
LAMBDH(3)	mean $\vec{\lambda}_H$, at horizontal tail	8148
LAMBDV(3)	mean $\vec{\lambda}_V$, at vertical tail	8151
LAMBDO(3)	mean $\vec{\lambda}_O$, off rotor disk	8154
EINTW(3)	$\vec{e}_W = K_W C_W R_{SF}^T (-\vec{k}_S)(\Omega R)/(\Omega R)_{ref}$	8157
EINTH(3)	$\vec{e}_H = K_H C_H R_{SF}^T (-\vec{k}_S)(\Omega R)/(\Omega R)_{ref}$	8160
EINTV(3)	$\vec{e}_V = K_V C_V R_{SF}^T (-\vec{k}_S)(\Omega R)/(\Omega R)_{ref}$	8163

INC1CM(4365)

MB	Inertia coefficients	1
SB		2
I0		3
IQ(10)		4
SQ(2,10)		14
IQA(2,10)		34
IQDQ(10,10)		54
IQDQT(10,10,4)		154
IQDP(10)		554
IQDPT(10,4)		564
IQDB(10)		604
IQDBT(10,4)		614
SQDDP(10,5)		654
SQDDPT(10,5,4)		704
SQP(10,5)		904
SQPT(10,5,4)		954
IQ0(10)		1154
IQ0DQ(2,10)		1164
IQ0DQT(2,10,4)		1184
IQ0DP		1264
IQ0DPT(4)		1265
IQ0DB		1269
IQ0DBT(4)		1270
SQ0DDP(2,5)		1274
SQ0DDT(2,5,4)		1284
IFX0		1324
IMX0		1325
IP(5)		1326
IPA(2,5)		1331
IPAT(2,5,4)		1341
SP(2,5)		1381
SPT(2,5,4)		1391
IPDDP(5,5)		1431
IPDDPT(5,5,4)		1456
IPDDTT(5,5,4,4)		1556
IFP(5,5)		1956
SPDDQ(5,10)		1981
SPDDQT(5,10,4)		2031
IP0(5)		2231
SPQ(5,10)		2236
SPQT(5,10,4)		2286
XAPQ(2,5,4,30)	$\vec{X}_{kj}$ at r_i, i = 1 to MRA	2486
MQDQ(10,10)	Aerodynamic spring and damping	3686
MQDB(10)		3786
MQP(10,5)		3796
MDQ(10)		3846
MDB		3856
MP(5)		3857

		INC1CM
QDZ		3862
QT		3863
MPDQ(5,10)		3864
MPDB(5)		3914
MPDP(5,5)		3919
MPP(5,5)		3944
IQDQS(10,10)	Inertia coefficients, summed over q_j	3969
IQDPS(10)		4069
IQDBS(10)		4079
SQDDPS(10,5)		4089
SQPS(10,5)		4139
IQODQS(2,10)		4189
IQODPS		4209
IQODBS		4210
SQODDS(2,5)		4211
IPAS(2,5)		4221
SPS(2,5)		4231
IPDDPS(5,5)		4241
SPDDQS(5,10)		4266
SPQS(5,10)		4316

(NBM=10, NTM=5, NBMT=4, MRA=30)

WKV1CM(8165)

CTOLD	old C_T	1
CMXOLD	old C_{M_x}	2
CMYOLD	old C_{M_y}	3
GAMOLD(30,36)	old Γ_{ij} (i = 1 to MRA, j = 1 to MPSI)	4
CRCOLD(36)	old max Γ_j (j = 1 to MPSI)	1084
VIND(3,30,36)	$\vec{\lambda}(r_i, \psi_j)$ (i = 1 to MRA, j = 1 to MPSI)	1120
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VVT(3,36)	$\vec{\lambda}_V(\psi_j)$ (j = 1 to MPSI), at vertical tail	7929
VOFF(3,36)	$\vec{\lambda}_0(\psi_j)$ (j = 1 to MPSI), off rotor disk	8037
LAMBDW(3)	mean $\vec{\lambda}_W$, at wing/body	8145
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EINTH(3)	$\vec{e}_H = K_H C_H R_{SF}^T (-\vec{k}_S)(\Omega R)/(\Omega R)_{ref}$	8160
EINTV(3)	$\vec{e}_V = K_V C_V R_{SF}^T (-\vec{k}_S)(\Omega R)/(\Omega R)_{ref}$	8163

MNH1CM(462)

ALF(10,6)	complex α_{pN} (p = 1 to MHARMF), without Euler angle contributions	1
DALF(10,6)	complex $\dot{\alpha}_{pN}$ (p = 1 to MHARMF)	121
DDALF(10,6)	complex $\ddot{\alpha}_{pN}$ (p = 1 to MHARMF)	241
PSIS(10)	complex $\Psi_{s_{pN}}$ (p = 1 to MHARMF)	361
TGOVR(10)	complex $(\Delta\Theta_{govr})_{pN}$ (p = 1 to MHARMF)	381
TMAST(21)	complex $(\Delta\Theta_{mast\text{-}bend})_n$ (n = 1 to MHARM)	401
ALFO(6)	α_{static}	443
DDALO(6)	$\dot{\alpha}_{static}$	449
DDALFO(6)	$\ddot{\alpha}_{static}$	455
PSISO	$(\Psi_s)_{static}$	461
DPSISO	$(\dot{\Psi}_s)_{static}$	462

$$\alpha = (x_h \; y_h \; z_h \; \alpha_x \; \alpha_y \; \alpha_z)^T$$

AES1CM(36720)

STATE(30,36,3)	integer parameter defining stall state for lift, drag, moment (initialized to zero)	1
	peak dynamic stall vortex loads (initialized to zero)	
DCLMAX(30,36)	$c_{\ell_{max}}$	3241
DCDMAX(30,36)	$c_{d_{max}}$	4321
DCMMAX(30,36)	$c_{m_{max}}$	5401
	effective environment for lift, drag, moment	
MEFF(30,36,3)	Mach number M_{eff}	6481
AEFF(30,36,3)	angle of attack α_{eff}	9721
	dynamic stall vortex load	
DCLDS(30,36)	$c_{\ell_{ds}}$	12961
DCDDS(30,36)	$c_{d_{ds}}$	14041
DCMDS(30,36)	$c_{m_{ds}}$	15121
SAVE(30,36,19)	section aerodynamic data	16201

(1)	u_P	(11)	c_ℓ
(2)	u_T	(12)	c_d
(3)	u_R	(13)	c_m
(4)	U	(14)	$c_{d_{radial}}$
(5)	θ (deg)	(15)	F_x/ac_m
(6)	ϕ (deg)	(16)	F_r/ac_m
(7)	α (deg)	(17)	F_z/ac_m
(8)	M	(18)	$\underset{\sim}{M}_a/ac_m$
(9)	$\cos\Lambda$	(19)	$\tilde{F}_r/ac_m$
(10)	$\dot{\alpha}c/V$		

aerodynamic data at (r_i, ψ_j) on disk, $i = 1$ to MRA, $j = 1$ to MPSI

MNR1CM(1112)

BETA(21,10)	complex $\beta_n^{(i)}$ (i = 1 to NBM, n = 0 to MHARM)	1
THETA(21,5)	complex $\theta_n^{(i)}$ (i = 1 to NTM, n = 0 to MHARM)	421
BETAG(21)	complex β_{G_n} (n = 0 to MHARM)	631
PHI(10,16)	complex $\phi_{pN}^{(i)}$ (i = 1 to NAM, p = 1 to MHARMF)	673
PSID(10,6)	complex $(\psi_s \ \psi_I \ \psi_e \ \Delta\theta_t \ \Delta\theta_{g_1} \ \Delta\theta_{g_2})_{pN}$ (p = 1 to MHARMF)	993

MNSCM(12)

QSSTAT(10)	$(q_{s_k})_{\substack{static\\elastic}}$	(k = 7 to NAM)	1
PISTAT	$(\Psi_I)_{\substack{static\\elastic}}$		11
PESTAT	$(\Psi_e)_{\substack{static\\elastic}}$		12

AEF1CM(1548)

FORCE(16,36)	$(\vec{F}_j)_{\text{last rev}}$, j = 1 to MPSI (dimension NBM+NTM+NGM)	1
FHUB(6,36)	hub reactions (without rotor mass terms) $F = (\gamma 2C_H/\sigma a,\ \gamma 2C_Y/\sigma a,\ \gamma 2C_T/\sigma a,$ $\gamma 2C_{M_x}/\sigma a,\ \gamma 2C_{M_y}/\sigma a,\ -\gamma 2C_Q/\sigma a)$	577
TORQUE(36)	$\gamma \tilde{C}_Q/\sigma a$	793
SAVE(36,20)	integrated aerodynamic forces (1)-(10) $M_{q_k}\text{aero}/ac$ (11)-(15) $M_{p_k}\text{aero}/ac$ (16) $C_{m_x}/\sigma a$ (17) $C_{m_z}/\sigma a$ (18) $C_{f_x}/\sigma a$ (19) $C_{f_z}/\sigma a$ (20) $C_{f_r}/\sigma a$	829

QR1CM(1139)

QRTR(6)	rotor generalized force, $\vec{Q} = C^T F$	1
FHUBM(6)	mean hub reaction $F = (\gamma 2C_H/\sigma a,\ \gamma 2C_Y/\sigma a,\ \gamma 2C_T/\sigma a,\ \gamma 2C_{M_x}/\sigma a,\ \gamma 2C_{M_y}/\sigma a,\ -\gamma 2C_Q/\sigma a)$	7
	for trim	
CLS	C_L/σ (wind axes)	13
CXS	C_X/σ (wind axes)	14
CTS	C_T/σ	15
CYS	C_Y/σ	16
CPS	C_P/σ	17
	for inflow	
CT	C_T	18
CMX	C_{M_x}	19
CMY	C_{M_y}	20
	for trim	
BETA0	β_0	21
BETAC	β_c	22
BETAS	β_s	23
	for inflow	
GAM(30,36)	circulation Γ_{ij} (i = 1 to MRA, j = 1 to MPSI)	24
CIRC(36)	maximum circulation Γ_j (j = 1 to MPSI)	1104

QBDCM(49)

QWB(6)	wing-body generalized forces	1
QHT(6)	horizontal tail generalized forces	7
QVT(6)	vertical tail generalized forces	13
SAVE(31)	airframe aerodynamic data	19

(1)	$(D/q)_{WB}$	ft^2 or m^2
(2)	$(Y/q)_{WB}$	↓
(3)	$(L/q)_{WB}$	↓
(4)	$(M_x/q)_{WB}$	ft^3 or m^3
(5)	$(M_y/q)_{WB}$	↓
(6)	$(M_z/q)_{WB}$	↓
(7)	$(D/q)_{HT}$	ft^2 or m^2
(8)	$(L/q)_{HT}$	↓
(9)	$(D/q)_{VT}$	↓
(10)	$(L/q)_{VT}$	↓
(11)	α_{WB}	deg
(12)	β_{WB}	↓
(13)	α_{HT}	↓
(14)	α_{VT}	↓
(15)	ϵ	↓
(16)	σ	↓
(17-19)	$\vec{V}_{WB}$	ft/sec or m/sec
(20-22)	$\vec{V}_{HT}$	↓
(23-25)	$\vec{V}_{VT}$	↓
(26-28)	$\vec{\omega}$	rad/sec
(29)	q_{WB}	dimensionless
(30)	q_{HT}	↓
(31)	q_{VT}	↓

WG1CM(7998)

RBR(3,36)	$\vec{r}_b(r_{ROOT}, \Psi_j)$	1
RBT(3,36)	$\vec{r}_b(1, \Psi_j)$	109
MUTPP(3)	$\vec{\mu}_{tpp}$	217
	prescribed wake, tip vortices	
DZT(144)	$D_z(k)$, k = 1 to KRWG	220
DRT(144)	$D_r(k)$, k = 1 to KRWG	364
K2T	K_2	508
	prescribed wake, sheet inside edge	
DZSI(144)	$D_z(k)$, k = 1 to KRWG	509
DRSI(144)	$D_r(k)$, k = 1 to KRWG	653
K2SI	K_2	797
	prescribed wake, sheet outside edge	
DZSO(144)	$D_z(k)$, k = 1 to KRWG	798
DRSO(144)	$D_r(k)$, k = 1 to KRWG	942
K2SO	K_2	1086
	free wake, tip vortices	
DFWG(3,2304)	$\vec{D}(n)$, n = 1 to KRWG*MPSI	1087

$$n = (\ell - 1)KFWG + k$$

$$((k = 1 \text{ to } KFWG),\ \ell = 1 \text{ to } MPSI)$$

WKC1CM(120007)

MR	total number of points in flow field at which nonuniform induced velocity calculated for each azimuth (ML+MI+MW+MH+MV+MO)	1
ML	number of points on this rotor (MRL if INFLOW(1) = 1; zero otherwise)	2
MI	number of points on other rotor (MRL of other rotor if INFLOW(2) = 3; 1 if INFLOW(2) = 2; zero otherwise)	3
MW	number of points on wing-body (1 if INFLOW(3) = 2; zero otherwise)	4
MH	number of points on horizontal tail (1 if INFLOW(4) = 2; zero otherwise)	5
MV	number of points on vertical tail (1 if INFLOW(5) = 2; zero otherwise)	6
MO	number of points off rotor disk (1 if INFLOW(6) = 1; zero otherwise)	7
C(3,20000)	$\vec{C}(n)$, n = 1 to MPSI*MR*MPSI	8
CNW(3,20000)	$\vec{C}_{NW}(n_{NW})$, n_{NW} = 1 to MRG*(KNW+1)*MRL*MPSI	60008

$$\vec{v}(r_k, \psi_\ell) = \sum_{j=1}^{J} \Gamma_j \vec{C}(n) + \sum_{j=\ell-K_{NW}}^{\ell} \sum_{i=1}^{M} \Gamma_{ij} \vec{C}_{NW}(n_{NW})$$

n = ((ℓ - 1)*MR + k - 1)*MPSI + j
(((j = 1 to MPSI), k = 1 to MR), ℓ = 1 to MPSI)

n_{NW} = (((ℓ - 1)*MRL + k - 1)*(KNW+1) + j - ℓ + KNW)*MRG + i
((((i = 1 to MRG), j = ℓ - KNW to ℓ),
k = 1 to MRL), ℓ = 1 to MPSI)

AEMNCM(78)

Q(10)	q_k k = 1 to NBM	1
DQ(10)	$\dot{q}_k$	11
DDQ(10)	$\ddot{q}_k$	21
P(5)	p_k, k = 1 to NTM ($p_0 = p_d + p_r$)	31
DP(5)	$\dot{p}_k$	36
DDP(5)	$\ddot{p}_k$	41
PD	p_d	46
DPD	$\dot{p}_d$	47
DDPD	$\ddot{p}_d$	48
PR	p_r	49
DPR	$\dot{p}_r$	50
DDPR	$\ddot{p}_r$	51
BG	β_G	52
DBG	$\dot{\beta}_G$	53
DDBG	$\ddot{\beta}_G$	54
AHUB(6)	$\alpha = (x_h\ y_h\ z_h\ \alpha_x\ \alpha_y\ \alpha_z)$ (without Euler angle contributions to $\alpha_x \alpha_y \alpha_z$)	55
DAHUB(6)	$\dot{\alpha} = (\dot{x}_h\ \dot{y}_h\ \dot{z}_h\ \dot{\alpha}_x \dot{\alpha}_y \dot{\alpha}_z)$	61
DDAHUB(6)	$\ddot{\alpha} = (\ddot{x}_h\ \ddot{y}_h\ \ddot{z}_h\ \ddot{\alpha}_x \ddot{\alpha}_y \ddot{\alpha}_z)$	67
PS	ψ_s	73
DPS	$\dot{\psi}_s$	74
DDPS	$\ddot{\psi}_s$	75
TM	$\Delta\theta_{mast\text{-}bend}$	76
TG	$\Delta\theta_{govr}$	77
DTT	$\ddot{\theta}_G - \theta_G + 2\dot{\beta}_G$	78

LDMNCM(2932)

SAVEM(36,78)	motion at Ψ_j, j = 1 to MPSI (refer to common block AEMNCM for contents)	1
MB	inertial coefficients for section loads	2809
SB		2810
IO		2811
SQ(2,10)		2812
IQA(2,10)		2832
IQDQ(2,10)		2852
IQDB		2872
IQDP(2)		2873
SQDDP(2,5)		2875
SQP(2,5)		2885
IFXO		2895
IMXO(2)		2896
IPDDP(5)		2898
IPP(5)		2903
IPA(2)		2908
SPDDQ(10)		2910
SPQ(10)		2920
SP(2)		2930
IPO		2932

FLMCM(21928)

A2(6400)		1
A1(6400)		6401
A0(6400)		12801
B(2320)		19201
DOF1(80)		21521
NAMEX(80)		21601
NAMEV(29)		21681
MX		21710
MX1		21711
MV		21712
MG		21713
DOF1S(46)	symmetric matrices	21714
NAMEXS(46)		21760
NAMEVS(16)		21806
MXS		21822
MX1S		21823
MVS		21824
MGS		21825
DOF1A(43)	antisymmetric matrices	21826
NAMEXA(43)		21869
NAMEVA(13)		21912
MXA		21925
MX1A		21926
MVA		21927
MGA		21928

variables (80)

$$x = (x_{R1}\ x_{R2}\ x_S\ \Psi_e\ \ \Delta\theta_t\ \Delta\theta_{govr_1}\ \Delta\theta_{govr_2})$$

controls (29)

$$v = (v_{R1}\ v_{R2}\ v_S\ \Theta_t\ \ v_P\ g)$$

FLM1CM(4236)

A2(30,30)	A_2	1
A1(30,30)	A_1	901
A0(30,30)	A_0	1801
AA2(30,6)	$\tilde{A}_2$	2701
AA1(30,6)	$\tilde{A}_1$	2881
AA0(30,6)	$\tilde{A}_0$	3061
B(30,8)	B	3241
BG(30,3)	B_G	3481
C2(6,30)	C_2	3571
C1(6,30)	C_1	3751
C0(6,30)	C_0	3931
CA2(6,6)	$\tilde{C}_2$	4111
CA1(6,6)	$\tilde{C}_1$	4147
CA0(6,6)	$\tilde{C}_0$	4183
DG(6,3)	D_G	4219

variables (30): x_R

controls (8): v_R

gust(3): g

hub motion (6): α

hub forces (6): F

FLMACM(912)

A2(16,16)	a_2	1
A1(16,16)	a_1	257
A0(16,16)	a_0	513
B(16,4)	b	769
BG(16,3)	b_G	833
BL(16,2)	b_λ	881

variables (16): x_S

controls (4): v_S

gust (3): g

inflow(2): $(\lambda_{u_1}, \lambda_{u_2})$

<u>FLINCM(477)</u>

MASSB	
IO	1
IQ(10)	2
SQ(10,2)	3
IQA(10,2)	13
IQDQ(10,10)	33
IQDP(10)	53
IQDB(10)	153
SQDDP(10,5)	163
SQP(10,5)	173
IQODQ(10,2)	223
SQODDP(5,2)	273
IP(5)	293
IPA(5,2)	303
SP(5,2)	308
IPDDP(5,5)	318
IPP(5,5)	328
SPDDQ(5,10)	353
SPQ(5,10)	378
	428

FLAECM(646)

MQU(10)	1
MQDZ(10)	11
MQZ(10)	21
MQL(10)	31
MQDB(10)	41
MQB(10)	51
MQDQ(10,10)	61
MQQ(10,10)	161
MQP(10,5)	261
MMU	311
MDZ	312
MZ	313
ML	314
MDB	315
MB	316
MDQ(10)	317
MQ(10)	327
MP(5)	337
TU	342
TDZ	343
TZ	344
TL	345
TDB	346
TB	347
TDQ(10)	348
TQ(10)	358
TP(5)	368
HU	373
HDZ	374
HZ	375
HL	376
HDB	377
HB	378
HDQ(10)	379
HQ(10)	389
HP(5)	399
QU	404
QDZ	405
QZ	406
QL	407
QDB	408
QB	409
QDQ(10)	410
QQ(10)	420
QP(5)	430
RR	435
RU	436
RDZ	437
RZ	438

	FLAECM
RL	439
RDB	440
RB	441
RDQ(10)	442
RQ(10)	452
RP(5)	462
MPU(5)	467
MPDZ(5)	472
MPZ(5)	477
MPL(5)	482
MPDB(5)	487
MPB(5)	492
MPDQ(5,10)	497
MPQ(5,10)	547
MPP(5,5)	597
MPDP(5,5)	622

STDCM(882)

DERIV(7,21)		1
DRVR1(7,21)	(both rotors for flutter case)	148
DRVR2(7,21)		295
DRVWB(7,21)		442
DRVHT(7,21)		589
DRVVT(7,21)		736

variables (21):

$(\ddot{z}_F \;\; \dot{\phi}_F \;\; \dot{\theta}_F \;\; \dot{\psi}_F \;\; \dot{x}_F \;\; \dot{y}_F \;\; \dot{z}_F \;\; \dot{\psi}_s$

$\vartheta_0 \;\; \vartheta_{1c} \;\; \vartheta_{1s} \;\; \theta_0 \;\; \theta_{1c} \;\; \theta_{1s} \;\; \delta_f \;\; \delta_e \;\; \delta_a \;\; \delta_r$

$u_G \;\; v_G \;\; w_G)$

equations (7):

(L M N X Y Z Q)

STMCM(340)

A2FD(7,7)	1
A1FD(7,7)	50
A0FD(7,7)	99
BFD(7,19)	148
DOFFD(7)	281
CONFD(16)	288
GUSFD(3)	304
DOF1FD(7)	307
NAMXFD(7)	314
NAMVFD(19)	321
MXFD	340

variables (7):

$(\phi_F \;\; \theta_F \;\; \psi_F \;\; x_F \; y_F \; z_F \;\; \psi_s)$

controls (19):

$(\theta_0 \;\; \theta_{1c} \;\; \theta_{1s} \;\; \theta_0 \;\; \theta_{1c} \;\; \theta_{1s}$

$\delta_f \;\; \delta_e \;\; \delta_a \;\; \delta_r \;\; \theta_t \;\; \delta_0 \;\; \delta_c \;\; \delta_s \;\; \delta_p \;\; \delta_t$

$u_G \;\; v_G \;\; w_G)$

gust components in wind axes

TRANCM(62)

QTRIM(6)	trim generalized force (total)	1
CQST1	trim $-\gamma 2C_Q/\sigma a$ (rotor #1)	7
CQST2	trim $-\gamma 2C_Q/\sigma a$ (rotor #2)	8
IBODYI(7,7)	inverse of body inertia	9
DCSAS	SAS δ_c	58
DSSAS	SAS δ_s	59
TTGOV	transient governor $\Delta\theta_t$	60
T1GOV	transient governor $(\Delta\theta_{govr})_{rotor\#1}$	61
T2GOV	transient governor $(\Delta\theta_{govr})_{rotor\#2}$	62

2. SUBPROGRAM FUNCTION AND COMMUNICATION

This section describes the functions of the subprograms that constitute the computer program. The communication of the subprograms with each other is also described, in terms of the input and output variables. The description begins with the subprogram name, and its arguments. Next there is a statement of the principal function of the subprogram, and usually a general reference to a section in the analysis development. Then notes about the program content are given, including references to sections in the analysis development as appropriate. Finally all the input and output variables of the subprogram are listed. The left-hand column gives the variable name in the subprogram, and the right-hand column gives the label of the common block in which the variable is located. Some description of the variable may be given as well. Only the subprograms for rotor #1 are described; the subprograms for rotor #2 have identical functions and structure.

MAIN

Name: MAIN

Function: primary job and analysis control

General reference: section 5.3.5

CPRTR2 IDENT(4)	TRIMCM
ANTYPE(3) FILEID(4)	TMDATA
RESTRT JCASE TASK JOB RSWRT NCASES BLKDAT RDFILE START	CASECM

TIMER

Name: TIMER(N,I,T)

Function: program timer

N	integer parameter controlling timing calculations		
		0	initialize
		1	start timer
		2	stop timer
		3	print times
		other	return present time
I	timer number		
		1	case
		2	TRIM
		3	FLUT
		4	STAB
		5	TRAN
		6	STABL
		7	FLUTL
		8	WAKEC1,WAKEC2
		9	GEOMR1,GEOMR2
		10	RAMF
		11	MODE1,MODE2
		12	MOTNR1,MOTNR2
		13	PERF
		14	LOAD
T	elapsed CPU time (sec)		

DEBUG ITDB IDB(23)	integer parameter: print time T if GE 1	TMDATA

INPTN

Name: INPTN

Function: input for new job

JCASE		CASECM
BLKDAT		
RDFILE		
DEBUGI	integer parameter: debug print control	TMDATA
OPREAD(10)		
NROTOR		
IXX		BDDATA
IYY		
IZZ		
IXY		
IXZ		
IYZ		
ATILT		
FSCG		
BLCG		
WLCG		
WEIGHT		
FILEID(4)		TMDATA
:		
MHARMF		

INPTO

Name: INPTO

Function: input for old job

RESTRT		CASECM
DEBUGI	integer parameter: debug print control	TMDATA
NROTOR		
ANTYPE(3)		
OPREAD(10)		
DEBUG(25)		
NPRNTI		

INPTA1

Name: INPTA1

Function: read airfoil table file

DEBUG	
TITLE(20)	TMDATA
IDENT(4)	A1TABL
NMAX	
NAB	
NA(20)	
A(20)	
NMB	
NM(20)	
M(20)	
NRB	
R(11)	
CLT(5000)	
CDT(5000)	
CMT(5000)	

INPTR1

Name: INPTR1

Function: read rotor anmelist

DEBUG	TMDATA
TITLE(20)	R1DATA
⋮	
TWISTI(51)	

INPTW1

Name: INPTW1

Function: read wake namelist

DEBUG	TMDATA
FACTWU	W1DATA
⋮	
KWGSO(4)	
KFWG	G1DATA
⋮	
DQWG(2)	

INPTB

Name: INPTB

Function: read body namelist

DEBUG	TMDATA
TITLE(20) ⋮ DOFSYM(10)	BDDATA
LFTAW ⋮ OPTINT	BADATA
ENGPOS ⋮ KEDAMP	ENDATA

INPTL1

Name: INPTL1

Function: read loads namelist

DEBUG	TMDATA
MHARML	L1DATA
⋮	
OPNOIS(4)	
MVIB	LADATA
⋮	
ZETAV(3,10,10)	

INPTF

Name: INPTF

Function: read flutter namelist for new job

DEBUG	TMDATA
OPFLOW	FLDATA
:	
NAMEXR(3)	

INPTS

Name: INPTS

Function: read flight dynamics namelist for new job

DEBUG	TMDATA
NPRNTP	STDATA
⋮	
DOFPLT(21)	
OPTRAN	GCDATA
⋮	
CMAG(5)	

INPTT

Name: INPTT

Function: read transient namelist for new job

DEBUG	TMDATA
NPRNTT	TNDATA
⋮	
OPLMDA	
OPTRAN	GCDATA
⋮	
CMAG(5)	

INPTG

Name: INPTG

Function: read flutter namelist for old job

DEBUG

ANTYPE(4)

:

NAMEXR(3)

TMDATA

FLDATA

INPTU

Name: INPTU

Function: read flight dynamics namelist for old job

DEBUG	TMDATA
OPPRNT(4)	STDATA
⋮	
DOFPLT(21)	
OPTRAN	GCDATA
⋮	
CMAG(5)	

INPTV

Name: INPTV

Function: read transient namelist for old job

DEBUG

NPRNTT
NPRNTP
NPRNTL
NRSTRT
TMAX

TMDATA

TNDATA

FILEI

Name: FILEI(NFILE,RDWRT)

Function: read or write input file

NFILE file unit number

RDWRT integer parameter: 0 to read file, 1 to write file

TITLBD(20)	BDDATA
TITLR1(20)	R1DATA
TITLR2(20)	R2DATA
TITLCS(20)	TMDATA
FILEID(4)	
all	TMDATA
all	BDDATA
all	BADATA
all	ENDATA
all	LADATA
all	GCDATA
all	TNDATA
all	STDATA
all	FLDATA
all	R1DATA
all	W1DATA
all	G1DATA
all	L1DATA
all	R2DATA
all	W2DATA
all	G2DATA
all	L2DATA

FILEJ

Name: FILEJ(NFILE,RDWRT)

Function: read or write trim data file

NFILE	file unit number	
RDWRT	integer parameter: 0 to read file, 1 to write file	
MPSI		TMDATA
LEVEL1		
LEVEL2		
KNW1		W1DATA
MRG1		
MRL1		
KFWG1		G1DATA
KNW2		W2DATA
MRG2		
MRL2		
KFWG2		G2DATA
all		TRIMCM
all		BODYCM
all		ENGNCM
all		GUSTCM
all		CONTCM
all		CONVCM
all		MNSCM
all		QBDCM
all		RTR1CM
all		RH1CM
all		MD1CM
all		INC1CM
all		WKV1CM
all		MNH1CM
all		AES1CM
all		MNR1CM
all		AEF1CM
all		QR1CM
all		RTR2CM
all		RH2CM
all		MD2CM
all		INC2CM
all		WKV2CM
all		MNH2CM
all		AES2CM
all		MNR2CM
all		AEF2CM
all		QR2CM

FILER

Name: FILER(RDWRT)

Function: read or write restart file

Restart file structure:

1) case header record
2) input, trim, airfoil data
3) task header record -- ID,NREC
   (ID = 2 for flutter, 3 for flight dynamics, 4 for transient)
4) task data (NREC records)
5) repeat #3 and #4 as necessary
6) end record -- ID = 0, NREC = 0

RDWRT	integer parameter: 0 to read file, 1 to write file	
RESTRT		
		CASECM
TITLCS(20)		
FILEID(4)		TMDATA
NROTOR		
CODE		
IDENT(4)		
		TRIMCM
TITLR1(20)		
TITLR2(20)		R1DATA
TITLBD(20)		R2DATA
		BDDATA
TITLA1(20)		
AF1ID(4)		A1TABL
NMAX1		
CLT1(5000)		
CDT1(5000)		
CMT1(5000)		
TITLA2(20)		
AF2ID(4)		A2TABL
NMAX2		
CLT2(5000)		
CDT2(5000)		
CMT2(5000)		

FILEF

Name: FILEF(RDWRT)

Function: read or write flutter restart file

RDWRT	integer parameter: 0 to read file, 1 to write file	
NRCTOR		TMDATA
OPFDAN		FLDATA
NBM1 NTM1 NGM1		RTR1CM
NBM2 NTM2 NGM2		RTR2CM
all		FLMCM
all		STDCM
all		STMCM
all		MD1CM
all		MD2CM
all		STDATA
all		GCDATA

FILES

Name: FILES(RDWRT)

Function: read or write flight dynamics restart file

RDWRT	integer parameter: 0 to read file, 1 to write file	
all		STDCM
all		STMCM
all		STDATA
all		GCDATA

FILET

Name: FILET(RDWRT,ENDREC)

Function: read or write transient restart file

RDWRT	integer parameter: 0 to read file, 1 to write file
ENDREC	integer parameter: 0 if at start of transient record, 1 if at end of record (required for file write only)

IT	WORK
YN(7)	
DYN(7)	
DDYN(7)	
MTRACE	
TRACE(14377)	
LEVEL1	TMDATA
LEVEL2	
all	TRANCM
all	TNDATA
all	GCDATA
all	L1DATA
all	L2DATA
all	LADATA

FILEE

Name: FILEE(KEY)

Function: write eigenvalue file

KEY	integer parameter defining case	
	0 start file	
	flutter, const. coeff. (FLUTL)	
	1 complete	
	2 symmetric	
	3 antisymmetric	
	flutter, periodic coeff. (FLUT)	
	4 complete	
	5 symmetric	
	6 antisymmetric	
	flight dynamics (STABL)	
	7-18 6+IEQ (IEQ = equation type)	
TASK JCASE		CASECM
IDENT(4) CODE		TRIMCM
		TMDATA
LAMDA(60) MX2	λ (constant coefficients)	EIGVC
LMDAP(60) LMDACP(60) MX2P	λ (periodic coefficients) λ_c (periodic coefficients)	EIGVP

INIT

Name: INIT

Function: initialization

NROTOR TMDATA

INITA

Name: INITA

Function: initialize environment parameters

General reference: section 2.5

OPUNIT	TMDATA
ALTMSL	
TEMP	
DENSEI	
OPDENS	
DENSE	TRIMCM
ALTD	
DRATIO	
CSOUND	

INITC

Name: INITC

Function: initialize case parameters

OPUNIT	TMDATA
DEBUG	
MPSI	
MHARM(2)	
MHARMF(2)	
OPTRIM	
OPGOVT	
LEVEL2	
DOF(54)	
DOFT(8)	
VKTS	
VEL	
VTIP	
RPM	
COLL	
LATCYC	
LNGCYC	
PEDAL	
APITCH	
AROLL	
ACLIMB	
AYAW	
RTURN	
NROTOR	
XTRIM	
CXTRIM	
THETFT	CONTCM
PHIFT	
THETFP	
PSIFP	
THETAT	
PSIT	
DVBODY(6)	
DOMEGA	
DDZF	
VPILOT(5)	
TGOVR1	
TGOVR2	
NBLD1	R1DATA
VTIPN	
RADIUS	
SIGMA	
GAMMA0	

OMEGA1	RTR1CM
OMEGA2	RTR2CM
HMASS	BODYCM
TRATIO	BDDATA
CONFIG	
WEIGHT	
NBLD2	R2DATA
DRATIO	TRIMCM
DENSE	
GRAV	
CXTARG	
OPRTR2	
DPSI	
FSCALE	
RSCALE	
NSCALE	
ISCALE	
GSCALE	
SSCALE	
CSCALE	
COSPSI(36)	
SINPSI(36)	
KEPSI(21,36)	

INITR1

Name: INITR1

Function: initialize rotor parameters

Normalization parameters: section 2.6
Aerodynamic r, Δr: section 2.4.1
Tip loss factor: section 2.4.5
Linear twist: section 2.3.5
Control system damping: section 5.1.3
Gimbal/teeter spring and damping: sections 2.2.12, 2.2.13
Lag damper: section 2.2.16

DEBUG		
MPSI		TMDATA
DOF(16)	rotor degrees of freedom	
DOFT(4)		
LEVEL		
TRATIO		BDDATA
DENSE		TRIMCM
CSOUND		
DRATIO		
QRTR(6)		QR1CM
FHUBM(6)		
CLS		
CXS		
CTS		
CYS		
CPS		
CT		
CMX		
CMY		
BO		
BC		
BS		
CIRC(36)		
K2T		WG1CM
K2SI		
K2SO		
GAMMAO		R1DATA
SIGMA		
NBLADE		
RADIUS		
VTIPN		
TDAMPO		
TDAMPC		
TDAMPR		

INITR1

NUGCO	R1DATA
NUGSO	
GDAMPC	
GDAMPS	
LDAMPC	
LDAMPM	
LDAMPR	
MRB	
MRM	
RAE(31)	
MRA	
BTIP	
CPTIP	
TWISTA(30)	
TWISTI(51)	
RI(51)	
MRI	
INFLOW(6)	
LINTW	
TWISTL	
OMEGA	RTR1CM
GLAG	
MLD	
DZLD	
CGS	
CGC	
NUGC	
NUGS	
CTO	
CTC	
CTR	
MTIP	
GAMMA	
CMEAN	
IB	
NBM	
NTM	
NGM	
NBMT	
RA(30)	
DRA(30)	
FTIP(30)	
CTOLD	WKV1CM
CMXOLD	
CMYOLD	
VIND(3,30,36)	
LAMBDA	

VINT(3,30,36)	WKV1CM
VORH(3,36)	
LAMBDI	
VWB(3,36)	
VHT(3,36)	
VVT(3,36)	
VOFF(3,36)	
LAMBDW(3)	
LAMBDH(3)	
LAMBDV(3)	
LAMBDO(3)	
EINTW(3)	
EINTH(3)	
EINTV(3)	
STATE(30,36,3)	AES1CM
DCLMAX(30,36)	
DCDMAX(30,36)	
DCMMAX(30,36)	
ALPHA(30,36)	
BETA(21,10)	MNR1CM
THETA(21,5)	
BETAG(21)	
PHI(10,16)	
PSID(10,6)	
QSSTAT(10)	MNSCM
PISTAT	
PESTAT	
FORCE(16,36)	AEF1CM
FHUB(6,36)	
TORQUE(36)	
T750LD	MD1CM
NBMOLD	
NTMOLD	
VGUST(3,30,36)	GUSTCM
GUSTH(3)	

INITB

Name: INITB

Function: initialize airframe parameters

Position of aircraft components: section 4.1.5
Rotation matrix R_{SF}: section 4.1.2
$\vec{r}$, R_{SF} without θ_T/ψ_T rotations: sections 4.1.3, 4.1.5
(for wind tunnel trim case)
Control matrix T_{CFE}: section 4.1.6
Aircraft inertia: section 4.2.4
Airframe elastic modes:
a) pitch/mast-bending coupling (KMST): section 4.2.3
b) mode shape at hub (AMODE): section 4.2.2
c) mass, spring, damping: section 4.2.4
d) aerodynamic damping and control: section 4.2.7

Initialization (for wind tunnel case)

$$R_{FV} = R_e = R_{FE} = I, \quad R_e^T I^* R_e = I^*$$

$$\vec{V} = V\,\vec{i}_F, \quad \vec{k}_E = \vec{i}_F$$

$$-M^*(\vec{V}\times)R_e = -M^* V(\vec{i}_F \times)$$

$$(\vec{V}\wedge)R_e\,\vec{k}_F = -V\,\vec{j}_F$$

$$G = -M^* g\,(\vec{k}_F \times)$$

DEBUG		TMDATA
VEL		
DOF(16)	airframe degrees of freedom	
GRAV		TRIMCM
GAMMA	reference rotor	
SIGMA		
IB		
OMEGA		
NBLADE		
RADIUS		
P21MR1	0.	RTR1CM
P21WR1	$\Delta\psi_{z1}$ (rad)	
P21MR2	$\Delta\psi_{z1}$ (rad)	RTR2CM
P21WR2	$-\Delta\psi_{z1}$ (rad)	
ROTAT1		R1DATA
OPHVB1(3)		

INITB

ROTAT2 OPHVB2(3)		R2DATA
VGWBV(3) VGHTV(3) VGVTV(3)	gust in velocity axes	GUSTCM
QWB(6) QHT(6) QVT(6)		QBDCM
AMODE1(6,10) : VSIDE		BODYCM
TITLE(20) : DOFSYM(10)		BDDATA
DRGIW		BADATA

INITE

Name: INITE

Function: initialize drive train parameters

Engine inertia and control: sections 4.3.1, 4.3.2
Governor parameters (dimensionless): section 4.3.3
Drive train spring constants: section 4.3.2

DEBUG		TMDATA
OPENGN		
DOF(6)	drive train degrees of freedom	
TRATIO		BDDATA
NBLADE	reference rotor	TRIMCM
IB		
OMEGA		
ENGPOS		ENDATA
THRTLC		
IENG		
KMAST1		
KMAST2		
KICS		
KENG		
KPE		
KP1		
KP2		
T1E		
T11		
T12		
T2E		
T21		
T22		
QTHRTL		ENGNCM
IENGS		
KMI1		
KMI2		
KMR		
KME1		
KME2		
KPGOVE		
KPGOV1		
KPGOV2		
T1GOVE		
T1GOV1		
T1GOV2		
T2GOVE		
T2GOV1		
T2GOV2		
NDM		

CHEKR1

Name: CHEKR1

Function: check for fatal errors

TMDATA

MPSI
LEVEL

R1DATA

NBLADE
MRA
RAE(31)
MRI
RI(51)
RROOT
INFLOW(6)

W1DATA

MRG
NG(30)
MRL
NL(30)
KNW

RTR1CM

RA(30)

R2DATA

MRLO other rotor

PRNTJ

Name: PRNTJ

Function: print job input data

FILEID(4)	TMDATA
all	CASECM
all	UNITNO

PRNTC

Name: PRNTC

Function: print case input data

JCASE	CASECM
JOB	
START	
FILEID(4)	TMDATA
TITLCS(20)	
CODE	
ANTYPE(3)	
OPUNIT	
OPTRIM	
NROTOR	
VKTS	
VEL	
RPM	
VTIP	
ALTMSL	
TEMP	
OPGRND	
HAGL	
AFLAP	
OPENGN	
OPGOVT	
RTURN	
LEVEL1	
LEVEL2	
DOF(54)	
DOFT(8)	
MPSI	
MHARM	
MHARMF	
OPDENS	
IDENT(4)	TRIMCM
DENSE	
DRATIO	
CSOUND	
ALTD	
TITLBD(20)	BDDATA
WEIGHT	
FSCG	
WLCG	
BLCG	
CONFIG	
ATILT	

	PRNTC
CWS	BODYCM
NAM	
NDM	ENGNCM
TITLA1(20)	A1TABL
AF1ID(4)	
TITLA2(20)	A2TABL
AF2ID(4)	
TITLR1(20)	R1DATA
TYPE1	
RADUS1	
NBLD1	
SIGMA1	
INFLW1(6)	
OPHVB1(3)	
OPSTL1	
OPYAW1	
OPCMP1	
OPUSL1	
ROTAT1	
HINGE1	
ELAG1	
EFLAP1	
GAMMA1	RTR1CM
OMEGA1	
MTIP1	
CMEAN1	
IB1	
NBM1	
NTM1	
NGM1	
NBMT1	
TITLR2(20)	R2DATA
⋮	
EFLAP2	
GAMMA2	RTR2CM
⋮	
NBMT2	

PRNT

Name: PRNT

Function: print trim input data

FILEID(4) TMDATA

:

MHARMF(2)

PRNTR1

Name: PRNTR1

Function: print rotor input data

NBM NTM NGM RA(30) DRA(30) FTIP(30)	RTR1CM
TITLE(20) : TWISTI(51)	R1DATA

PRNTW1

Name: PRNTW1

Function: print wake input data

MPSI LEVEL	TMDATA
FACTOR ⋮ KWGSO(4)	W1DATA
KFWG ⋮ DQWG(2)	G1DATA

PRNTB

Name: PRNTB

Function: print body input data

NROTOR	TMDATA
TITLE(20) ⋮ DOFSYM(10)	BDDATA
LFTAW ⋮ OPTINT	BADATA
ENGPOS ⋮ KEDAMP	ENDATA

PRNTF

Name: PRNTF

Function: print flutter input data

IDENT(4)

CONFIG

CPFLCW

:

CPUSLD

TRIMCM

BDDATA

FLDATA

PRNTS

Name: PRNTS

Function: print flight dynamics input data

IDENT(4)	TRIMCM
NPRNTP	STDATA
⋮	
GUS(3)	

PRNTT

Name: PRNTT

Function: print transient input data

IDENT(4)	TRIMCM
NPRNTT	TNDATA
⋮	
OPLMDA	

PRNTG

Name: PRNTG

Function: print transient gust and control input data

NROTOR

OPTRAN

:

CMAG(5)

TMDATA

GCDATA

TRIM

Name: TRIM

Function: trim

General reference: sections 5.3.5, 5.3.1

RESTRT RSWRT	CASECM
OPRTR2	TRIMCM
LEVEL1 LEVEL2 ITERU ITERR ITERF NPRNTT NPRNTP NPRNTL	TMDATA

TRIMI

Name: TRIMI(LEVEL1,LEVEL2)

Function: calculate trim solution by iteration

General reference: section 5.3.1

Codes:

control number (C) =	1	2	3	4	5	6	7	8	9
control =	δ_0	δ_c	δ_s	δ_p	θ_{FT}	ϕ_{FT}	ψ_{FP}	θ_{FP}	θ_T

test number (T) =	1	2	3	4	5	6	7	8	9	10	11
test =	none	$\vec{F}$	$\vec{M}$	$F_x F_z$	M_y	C_P	C_T	β_c	β_s	$C_L C_X$	$C_L C_X C_Y$

(i = 1 to MT)

OPTRIM	MT	C(i)	T(i)
0	0		
1	6	1 2 3 4 5 6	2 1 1 3 1 1
2	6	1 2 3 4 5 7	2 1 1 3 1 1
3	7	1 2 3 4 5 6 8	2 1 1 3 1 1 6
4	7	1 2 3 4 5 7 8	2 1 1 3 1 1 6
5	3	1 3 5	4 1 5
6	4	1 3 5 8	4 1 5 6
7	0		
8	0		
9	0		
10	0		
11	1	1	7
12	1	9	7
13	1	1	6
14	2	2 3	8 9
15	3	1 2 3	7 8 9
16	3	1 2 3	11 1 1
17	3	1 2 9	11 1 1
18	4	1 2 3 9	10 1 8 9
19	3	1 2 3	11 1 1
20	3	1 2 9	11 1 1
21	4	1 2 3 9	10 1 8 9
22	1	3	8
23	2	1 3	7 8
24	2	1 3	10 1
25	2	1 9	10 1
26	3	1 3 9	10 1 8
27	2	1 3	10 1
28	2	1 9	10 1
29	3	1 3 9	10 1 8

LEVEL1	wake analysis for rotor #1 and rotor #2:	TRIMI
LEVEL2	0 for uniform inflow, 1 for prescribed wake, 2 for free wake	
DEBUG		TMDATA
CPTRIM		
CTTRIM		
CYTRIM		
BSTRIM		
BCTRIM		
OPTRIM		
MTRIM		
MTRIMD		
FACTOR		
ITERM		
ITERC		
DELTA		
EPTRIM		
OPGOVT		
CXTARG		TRIMCM
GRAV		
COUNTT		
CNTRLZ(11)		BDDATA
CWS		BODYCM
KE(3)		
VXREKF(3)		
TCFE(11,5)		
COUNTM		CONVCM
COUNTC		
NBLD1		R1DATA
ROTATE		
NBLD2		R2DATA
GAMMA1		RTR1CM
OMEGA1		
IB1		
GAMMA2		RTR2CM
OMEGA2		
IB2		
VCNTRL(11)		CONTCM
THETFT		
PHIFT		
THETFP		
PSIFP		
THETAT		
DPSIF	$\dot{\psi}_F$	
VPILOT(5)		
TGOVR1		
TGOVR2		

TRIMI

QRTR1(6)		QR1CM
CLS		
CXS		
CTS		
CYS		
CPS		
BETAC		
BETAS		
CQS1	$C_Q/\sigma = C_P/\sigma$	
QRTR2(6)		QR2CM
CQS2	$C_Q/\sigma = C_P/\sigma$	
QWB(6)		QBDCM
QHT(6)		
QVT(6)		

TRIMP

Name: TRIMP(LEVEL1,LEVEL2,ITER,ITERM)

Function: print trim solution

LEVEL1 LEVEL2	wake analysis for rotor #1 and rotor #2: 0 for uniform inflow, 1 for prescribed wake, 2 for free wake	
ITER	iteration number	
ITERM	maximum number of iterations	
CPTRIM		
CTTRIM		TMDATA
CYTRIM		
BCTRIM		
BSTRIM		
OPTRIM		
MTRIM		
EPTRIM		
CPGOVT		
COLL		
LATCYC		
LNGCYC		
PEDAL		
APITCH		
AYAW		
AROLL		
ACLIMB		
CXTARG		
GRAV		TRIMCM
COUNTT		
CPRTR2		
NBLD1		
TYPE1		R1DATA
NBLD2		
TYPE2		R2DATA
GAMMA1		
OMEGA1		RTR1CM
IB1		
GAMMA2		
OMEGA2		RTR2CM
IB2		
CWS		
KE(3)		BODYCM
VXREKF(3)		

TRIMP

VCNTRL(11)		CCNTCM
THETFT		
PHIFT		
THETFP		
PSIFP		
THETAT		
PSIT		
DPSIF	$\dot{\psi}_F$	
VPILOT(5)		
TGOVR1		
TGOVR2		
QRTR1(6)		QR1CM
CLS		
CXS		
CTS		
CYS		
CPS		
BETAC		
BETAS		
CQS1	$C_Q/\sigma = C_P/\sigma$	
QRTR2(6)		QR2CM
CQS2	$C_Q/\sigma = C_P/\sigma$	
QWB(6)		QBDCM
QHT(6)		
QVT(6)		

FLUT

Name: FLUT

Function: flutter

General reference: sections 5.3.5, 5.3.6

RSWRT RESTRT	CASECM
OPRTR2 NBLADE	TRIMCM
OPFLOW OPSYMM OPFDAN MPSIPC NINTPC NBLDFL	FLDATA
A2(6400) ⋮ MGA	FLMCM
MXFD	STMCM

FLUTM

Name: FLUTM(PSI)

Function: calculate flutter matrices

General reference: section 6.3.1

Inflow dynamics: sections 6.1.5, 2.4.3

$$DLDT = \frac{\sigma a}{2\gamma}\frac{\partial\lambda}{\partial T}$$

$$DLDM = \frac{\sigma a}{2\gamma}\frac{\partial\lambda}{\partial M}$$

$$TT = \tau_T$$

$$TM = \tau_M$$

$$DLDZ = \frac{\partial\lambda}{\partial z}$$

$$ZK = \vec{k}_E \cdot \vec{\xi}_k$$

Drive train equations: section 6.2.3
Construct flight dynamics matrices: section 5.3.3 also
(only if rigid body degrees of freedom present)
Symmetric/antisymmetric matrices: section 6.3.3

PSI	ψ (for periodic coefficients)	
DEBUG		TMDATA
OPENGN		
OPRTR2		TRIMCM
DOFSYM(10)		BDDATA
TRATIO		
CONFIG		
NEM		
REULER(3,3)		BODYCM
KE(3)		
RHUB1(3)		
RHUB2(3)		
AMODE1(6,10)		
AMODE2(6,10)		
KMSTC1(10)		
KMSTS1(10)		
KMSTC2(10)		
KMSTS2(10)		
MVXRE(3,3)		
TCFE(11,5)		
KIGOVE		ENDATA
KIGOV1		
KIGOV2		

	FLUTM
GSE	
GSI	ENDATA
QTHRTL	
IENG	ENGNCM
QEDAMP	
KMI1	
KMI2	
KMR	
KME1	
KME2	
KPGOVE	
KPGOV1	
KPGOV2	
T1GOVE	
T1GOV1	
T1GOV2	
T2GOVE	
T2GOV1	
T2GOV2	
MENG22	
MENG33	
SENG22	
SENG33	
RADUS1	
NBLD1	R1DATA
KFLMD1	
KHLMD1	
SIGMA1	
FXLMD1	
FYLMD1	
KINTH1	
KINTF1	
FMLMD1	
OMEGA1	
NTM1	RTR1CM
NBM1	
NGM1	
MUX1	
MUY1	
MUZ1	
GAMMA1	
IB1	
RGUST1(3,3)	
CHUB1(6,16)	
CBHUB1(3,3)	
CHUBT1(16,6)	

		FLUTM
RADUS2 : FMLMD2		R2DATA
OMEGA2 : CHUBT2(16,6)		RTR2CM
KPB1(10) KPG1		MD1CM
KPB2(10) KPG2		MD2CM
T1C1 T1S1 T1C2 T1S2		CONTCM
LAMBD1 COSE1 ZAGL1		WKV1CM
LAMBD2 COSE2 LAMBD2		WKV2CM
CTS1	$\gamma 2C_T/\sigma a$	QR1CM
CTS2	$\gamma 2C_T/\sigma a$	QR2CM
DERIV(7,21) DRVR1(7,21) DRVWB(7,21) DRVHT(7,21) DRVVT(7,21)		STDCM
A2FD(7,7) : MXFD		STMCM
OPFLOW OPSYMM NBLADE OPSAS KCSAS KSSAS TCSAS TSSAS OPTCRS(2) OPGRND KASGE		FLDATA

	FLUTM
DOF(80) CON(26) GUS(3)	FLDATA
A2(6400) ⋮ MGA	FLMCM
A2A(16,16) ⋮ BLA(16,2)	FLMACM
A2R1(30,30) ⋮ DGR1(6,3)	FLM1CM
A2R2(30,30) ⋮ DGR2(6,3)	FLM2CM

FLUTB

Name: FLUTB

Function: calculate flutter aircraft matrices

General reference: section 6.2.2

OPRTR2		TRIMCM
NEM		BDDATA
IBODY(3,3) MSTAR MVXRE(3,3) GMTRX(3,3) RFV(3,3) AMASS(10) ADAMPS(10) ASPRNG(10) ADAMPA(10) ACNTRL(4,10)		BODYCM
DELTA OPRINT		FLDATA
DVBODY(6) DDZF CNTRL(4)	 $(\delta_f \; \delta_e \; \delta_a \; \delta_r)$	CONTCM
GWB(3) GHT(3) GVT(3)	gust in F axes	GUSTCM
QWB(6) QHT(6) QVT(6)		QBDCM
A2(16,16) : BL(16,2)		FLMACM
DRVWB(7,21) DRVHT(7,21) DRVVT(7,21)		STDCM
LMDAW1(3) LMDAH1(3) LMDAV1(3) EINTW1(3) EINTH1(3) EINTV1(3)		WKV1CM
LMDAW2(3) : EINTV2(3)		WKV2CM

FLUTR1

Name: FLUTR1(PSI)

Function: calculate flutter rotor matrices

General reference: sections 6.1.6, 6.4

Azimuthal summations:

$\frac{1}{N}\sum_{m=1}^{N}$	at	$\psi_m = \psi + m\frac{2\pi}{N}$	for periodic coefficients
$\frac{1}{J}\sum_{j=1}^{J}$	at	$\psi_j = j\frac{2\pi}{J}$	for constant coefficient approximation (section 6.1.7)

Reorder hub reactions: Λ_u equation multiplied by 2 to get $(-\gamma 2C_T/\sigma a)$

Inflow dynamics due to velocity perturbations: sections 6.1.4, 6.1.6

PSI ψ (periodic coefficients only)

CPFLOW MPSICC NBLDFL	FLDATA
KBM KTM NGM GAMMA NUGC NUGS CGC CGS CT0 CTC CTR MUX MUY MUZ	RTR1CM
NBLD GSB(10) GST(5) KHLMDA KFLMDA	R1DATA
NU(10) WT(5) WT0 WTC WTR KPB(10) KPG	MD1CM

		FLUTR1
LAMBDA		WKV1CM
CTS	$\gamma 2C_T/\sigma a$	QR1CM
T1C		CONTCM
T1S		
A2(30,30)		FLM1CM
⋮		
DG(6,3)		
MASSB		FLINCM
⋮		
SPQ(5,10)		
MQU(10)		FLAECM
⋮		
MPDP(5,5)		

FLUTI1

Name: FLUTI1(PSI)

Function: calculate flutter inertia coefficients

General reference: section 6.1.3

PSI ψ

DEBUG DCFT(4)	TMDATA
GLAG KBM KTM NBMT	RTR1CM
BETA(21,10)	MNR1CM
ETAPH(2,10)	MD1CM
MB : SPQT(5,10,4)	INC1CM
MASSBL : SPQL(5,10)	FLINCM

FLUTA1

Name: FLUTA1(PSI)

Function: calculate flutter aerodynamic coefficients

General reference: section 6.1.4

Perturbation section forces: without c/c_m factor

Aerodynamic coefficients: $FZO = C_T/\sigma$, $FXO = C_Q/\sigma$

PSI	ψ	
DEBUG		TMDATA
DOFT(4)		
MPSI		
DPSI		TRIMCM
MRA		R1DATA
CHORD(30)		
XA(30)		
XAC(30)		
CPCOMP		
OPYAW		
CPSTLL		
RFA		
RA(30)		RTR1CM
DRA(30)		
CMEAN		
FTIP(30)		
NBMT		
KBM		
KTM		
MTIP		
MUX		
MUY		
MUZ		
ETA(2,10,30)	bending modes at r_i, i = 1 to MRA	MD1CM
ETAP(2,10,30)		
ETAPP(2,10,30)		
ZETA(5,30)	torsion modes at r_i, i = 1 to MRA	
ZETAP(5,30)		
DEL1		
DEL2		
DEL3		
DEL4		
DEL5		
DALPHA		FLDATA
DMACH		
OPUSLD		

FLUTA1

BETA(21,10)	MNR1CM
DCLDS(30,36) DCDDS(30,36) DCMDS(30,36) SAVE(30,36,19)	AES1CM
XAPQ(2,5,4,30)	INC1CM
MQU(10) : MPDP(5,5)	FLAECM

FLUTL

Name: FLUTL(ID,A2,A1,A0,B,MX,MX1,MV,MG,DOF1,NAMEX,NAMEV)

Function: analyze flutter constant coefficient linear equations

Vibration point location: sections 4.1.3, 4.1.5

ID	problem identification: 1 for complete dynamics, 2 for symmetric, 3 for antisymmetric	
A2(MX*MX) A1(MX*MX) A0(MX*MX)	coefficient matrices	
B(MX*MV)	control matrix	
MX	number of degrees of freedom	
MX1	number of first order degrees of freedom	
MV	number of controls	
MG	number of gust components	
DOF1(MX)	integer vector designating first order degrees of freedom	
NAMEX(MX)	vector of variable names	
NAMEV(MV)	vector of control names	
VELB(3)		BODYCM
GRAV OMEGA RADIUS	 reference rotor reference rotor	TRIMCM
FSCG BLCG WLCG NEM		BDDATA
THETFT PHIFT THETAT PSIT		CONTCM
ANTYPE(4) : NAMEXR(3)		FLDATA

STAB

Name: STAB

Function: flight dynamics

General reference: sections 5.3.5, 5.3.3

RESTRT
RSWRT

CASECM

STABM

Name: STABM

Function: calculate flight dynamics stability derivatives and matrices

General reference: section 5.3.3

Print during stability derivative calculations:

a) increment: 1st number dimensionless, 2nd number dimensional
b) motion and controls: 1st number dimensionless, 2nd number dimensional

1) angular velocity = deg/sec
2) linear velocity, gust velocity = ft/sec or m/sec
3) $\dot{\psi}_s$ = rpm
4) $\ddot{z}_F$ = ft/sec^2 or m/sec^2
5) controls = deg

c) generalized forces: moments and forces in $\delta 2C/\sigma a$ form (rotor #1 parameters, body axes); torque in $-\delta C_Q/\sigma a$ form (rotor #1 parameters)

MPSI LEVEL1 LEVEL2 DEBUG	TMDATA
OPRTR2 LSCALE FSCALE	TRIMCM
NBLD1 MRA1 TYPE1	R1DATA
IB1 CHUB1(6,16) CHUBT1(16,6) OMEGA1	RTR1CM
NBLD2 MRA2 TYPE2	R2DATA
IB2 CHUB2(6,16) CHUBT2(16,6) OMEGA2	RTR2CM
IBODY(3,3) MSTAR MVXRE(3,3) GMTRX(3,3) TCFE(11,5)	BODYCM

		STABM
CONFIG		BDDATA
QRTR1(6)		QR1CM
CQS1	$-\gamma 2C_Q/\sigma a$	
QRTR2(6)		QR2CM
CQS2	$-\gamma 2C_Q/\sigma a$	
I01		INC1CM
I02		INC2CM
IRSTAR		ENGNCM
QTHRTL		
QEDAMP		
KPGOVE		
KPGOV1		
KPGOV2		
KIGOVE		ENDATA
KIGOV1		
KIGOV2		
NPRNTP		STDATA
NPRNTL		
ITERS		
OPLMDA		
DELTA		
DOF(7)		
CON(16)		
GUS(3)		
VGWBV(3)		GUSTCM
VGHTV(3)		
VGVTV(3)		
VGRTR1(3,30,36)		
VGRTR2(3,30,36)		
VGHUB1(3)		
VGHUB2(3)		
VCNTRl(11)		CONTCM
DVBODY(6)		
DOMEGA		
D[illegible]		
QWB(6)		QBDCM
QHT(6)		
QVT(6)		
DERIV(7,21)		STDCM
⋮		
DRVVT(7,21)		
A2FD(7,7)		STMCM
⋮		
MXFD		

STABD

Name: STABD

Function: print stability derivatives

General reference: section 5.3.3

Options:
- a) rotor coefficient form, $M^*X = \gamma 2C/\sigma a$
- b) stability derivative form, X (acceleration)
- c) dimensionless or dimensional

Dimensions:

a) force or moment

	forces(FF)	moments (FM)	torque (FQ)
M^*X form	$\frac{1}{2}NI_b\Omega^2/R$	$\frac{1}{2}NI_b\Omega^2$	$NI_b\Omega^2$
X form	Ω^2R	Ω^2	Ω^2

b) subscripts

acceleration ($\ddot{z}$)	$= \Omega^2R$	(FA)
angular velocity	$= \Omega$	
linear velocity	$= \Omega R$	(FV)
controls	= 57.3	
gust velocity	$= \Omega R$	(FV)

TASK		CASECM
DOFFD(7) CONFD(16) GUSFD(3) NAMEV(19)		STMCM
ISTAR(3,3) MSTAR		BODYCM
IRSTAR		ENGNCM
NBLADE IB OMEGA RADIUS	reference rotor	TRIMCM
OPPRNT(4)		STDATA
DRVR1(7,21) DRVR2(7,21) DRVWB(7,21) DRVHT(7,21) DRVVT(7,21)		STDCM

STABE

Name: STABE

Function: calculate flight dynamics equations

DEBUG		TMDATA
OMEGA	reference rotor	TRIMCM
EQTYPE(12) KCSAS KSSAS TCSAS TSSAS		STDATA
A2FD(49) : MXFD		STMCM
CPSYMM CPSASF		FLDATA
TASK		CASECM

STABL

Name: STABL(IEQ,A2,A1,A0,B,MX,MX1,MV,MG,DOF1,NAMEX,NAMEV,DOF,CON)

Function: analyze flight dynamics linear equations

Vibration point location: sections 4.1.3, 4.1.5
Numerical integration of transient: sections 5.3.2, 5.3.3
(see also program TRAN)

IEQ	equation type identifier	
A2(MX*MX) A1(MX*MX) A0(MX*MX)	coefficient matrices	
B(MX*MV)	control matrix	
MX	number of degrees of freedom	
MX1	number of first order degrees of freedom	
MV	number of controls	
MG	number of gust components	
DOF1(MX)	integer vector designating first order degrees of freedom	
NAMEX(MX)	vector of variable names	
NAMEV(MV)	vector of control names	
DOF(7)	integer vector designating degrees of freedom used	
CON(19)	integer vector designating controls used	
OMEGA RADIUS GRAV	reference rotor	TRIMCM
VELF(3)		BODYCM
VGHUB1(3) VPTRAN(5)		GUSTCM
FSCG WLCG BLCG		BDDATA
THETFT PHIFT THETAT PSIT DVBODY(6) DOMEGA		CONTCM
NPRNTT : DOFPLT(21)		STDATA

STABP

Name: STABP(TIM,IT,YN,DYN,DDYN,DOF)

Function: print flight dynamics transient solution

General reference: section 5.3.3

Print during numerical integration (in STABL):

a) controls in deg
b) gust velocity: 1st number dimensionless, 2nd number dimensional
c) aircraft motion: 1st number dimensionless, 2nd number dimensional
   1) displacement = deg, ft or m
   2) velocity = deg/sec, ft/sec or m/sec
   3) acceleration = deg/sec^2, g
   4) inertial axes = deg/sec, g

$$\text{AANG} = \vec{\omega} = R_e \begin{pmatrix} \dot{\phi}_F \\ \dot{\theta}_F \\ \dot{\psi}_F \end{pmatrix}$$

$$\text{ALIN} = \vec{a}_{body} = \begin{pmatrix} \ddot{x}_F \\ \ddot{y}_F \\ \ddot{z}_F \end{pmatrix} - (\vec{V} \times) R_e \begin{pmatrix} \dot{\phi}_F \\ \dot{\theta}_F \\ \dot{\psi}_F \end{pmatrix}$$

TIM	time (dimensionless)
IT	time count
YN(7)	$(\phi_F\ \theta_F\ \psi_F\ x_F\ y_F\ z_F\ \psi_s)$
DYN(7)	$(\dot{\phi}_F\ \dot{\theta}_F\ \dot{\psi}_F\ \dot{x}_F\ \dot{y}_F\ \dot{z}_F\ \dot{\psi}_s)$
DDYN(7)	$(\ddot{\phi}_F\ \ddot{\theta}_F\ \ddot{\psi}_F\ \ddot{x}_F\ \ddot{y}_F\ \ddot{z}_F\ \ddot{\psi}_s)$
DOF(7)	integer vector: 0 if degree of freedom not used

GRAV
LSCALE
FSCALE — TRIMCM

TSTEP
TMAX
NPRNTT — STDATA

	STABP
VGHUB1(3) VPTRAN(5)	GUSTCM
MSTAR MVXRE(3,3) REULER(3,3)	BODYCM

TRAN

Name: TRAN

Function: transient

General reference: sections 5.3.5, 5.3.2

RESTRT		CASECM
RSWRT		
LEVEL1		TMDATA
LEVEL2		
DVBODY(6)		CONTCM
DOMEGA		
MVXRE(3,3)		BODYCM
MSTAR		
IBODY(3,3)		
OMEGA	reference rotor	TRIMCM
QRTR1(6)		QR1CM
CQS1	$-\gamma 2C_Q/\sigma a$	
QRTR2(6)		QR2CM
CQS2	$-\gamma 2C_Q/\sigma a$	
QWB(6)		QBDCM
QHT(6)		
QVT(6)		
QTRIM(6)		TRANCM
CQST1		
CQST2		
IBODYI(7,7)		
NPRNTT		TNDATA
NPRNTP		
NPRNTL		
NRSTRT		
TMAX		
TSTEP		
OPPLOT		
DOFPLT(21)		
DOF(7)		
I01		INC1CM
I02		INC2CM
CHUB1(6,16)		RTR1CM
CHUBT1(16,6)		
OMEGA1		
IB1		

	TRAN
CHUB2(6,16)	RTR2CM
CHUBT2(16,6)	
OMEGA2	
IB2	
NBLD1	R1DATA
NBLD2	R2DATA
IRSTAR	ENGNCM

TRANI

Name: TRANI(Y,DY,DDY)

Function: calculate transient acceleration for numerical integration

General reference: section 5.3.2

Y(7)	$(\phi_F \; \theta_F \; \psi_F \; x_F \; y_F \; z_F \; \psi_s)$	
DY(7)	$(\dot{\phi}_F \; \dot{\theta}_F \; \dot{\psi}_F \; \dot{x}_F \; \dot{y}_F \; \dot{z}_F \; \dot{\psi}_s)$	
DDY(7)	$(\ddot{\phi}_F \; \ddot{\theta}_F \; \ddot{\psi}_F \; \ddot{x}_F \; \ddot{y}_F \; \ddot{z}_F \; \psi_s)$	
LEVEL1		TMDATA
LEVEL2		
DEBUG		
OPRTR2		TRIMCM
MVXRE(3,3)		BODYCM
GMTRX(3,3)		
TCFE(11,5)		
CNTRLZ(11)		RDDATA
QTHRTL		ENGNCM
QEDAMP		
KPGOVE		
KPGOV1		
KPGOV2		
KIGOVE		ENDATA
KIGOV1		
KIGOV2		
IB1		RTR1CM
OMEGA1		
NBLD1		R1DATA
IB2		RTR2CM
OMEGA2		
NBLD2		R2DATA
QRTR1(6)		QR1CM
CQS1	$-\gamma 2C_Q/\sigma a$	
QRTR2(6)		QR2CM
CQS2	$-\gamma 2C_Q/\sigma a$	
QWB(6)		QBDCM
QHT(6)		
QVT(6)		

DOF(7)	TNDATA
OPSAS	
KCSAS	
KSSAS	
TCSAS	
TSSAS	
ITERT	
OPLMDA	
QTRIM(6)	TRANCM
CQST1	
CQST2	
IBODYI(7,7)	
DCSAS	
DSSAS	
TTGOV	
T1GOV	
T2GOV	
VITRAN(5)	GUSTCM
VCNTRL(11)	CONTCM
DVBODY(6)	
DOMEGA	
DDZF	
VPILOT(5)	
TGOVR1	
TGOVR2	

TRANP

Name: TRANP(TIM,IT,YN,DYN,DDYN)

Function: print transient solution

General reference: section 5.3.2

Print notes:

a) controls in deg
b) gust velocity dimensionsal
c) aircraft motion: 1st number dimensionless, 2nd number dimensional
   1) displacement = deg, ft or m
   2) velocity = deg/sec, ft/sec or m/sec
   3) acceleration = deg/sec^2, g
   4) inertial axes = deg/sec, g
d) generalized forces: moments and forces in $\gamma 2C/\sigma a$ form (rotor #1 parameters, body axes); torque in $-\gamma c_Q/\sigma a$ form (rotor #1 parameters)

$$\text{AANG} = \vec{\omega} = R_e \begin{pmatrix} \dot{\phi}_F \\ \dot{\theta}_F \\ \dot{\psi}_F \end{pmatrix}$$

$$\text{ALIN} = \vec{a}_{body} = \begin{pmatrix} \ddot{x}_F \\ \ddot{y}_F \\ \ddot{z}_F \end{pmatrix} - (\vec{V} \times) R_e \begin{pmatrix} \dot{\phi}_F \\ \dot{\theta}_F \\ \dot{\psi}_F \end{pmatrix}$$

TIM	time (dimensionless)
IT	time count
YN(7)	$(\phi_F \ \theta_F \ \psi_F \ x_F \ y_F \ z_F \ \psi_s)$
DYN(7)	$(\dot{\phi}_F \ \dot{\theta}_F \ \dot{\psi}_F \ \dot{x}_F \ \dot{y}_F \ \dot{z}_F \ \dot{\psi}_s)$
DDYN(7)	$(\ddot{\phi}_F \ \ddot{\theta}_F \ \ddot{\psi}_F \ \ddot{x}_F \ \ddot{y}_F \ \ddot{z}_F \ \ddot{\psi}_s)$

LEVEL1
LEVEL2 — TMDATA

FSCALE
LSCALE
GRAV
OPRTR2 — TRIMCM

		TRANP
ITERT		TNDATA
OPLMDA		
TSTEP		
TMAX		
MSTAR		BODYCM
REULER(3,3)		
MVXRE(3,3)		
GMTRX(3,3)		
QTHRTL		ENGNCM
QEDAMP		
VGWBV(3)		CUSTCM
VGHTV(3)		
VGVTV(3)		
VGHUB1(3)		
VGHUB2(3)		
VPTRAN(5)		
NBLD1		R1DATA
TYPE1		
IB1		RTR1CM
OMEGA1		
NBLD2		R2DATA
TYPE2		
IB2		RTR2CM
OMEGA2		
QRTR1(6)		QR1CM
CQS1	$-\gamma 2C_Q/\sigma a$	
QRTR2(6)		QR2CM
CQS2	$-\gamma 2C_Q/\sigma a$	
QWB(6)		
QHT(6)		
QVT(6)		
VCNTRL(11)		CONTCM
VPILOT(5)		
TGOVR1		
TGOVR2		
QTRIM(6)		TRANCM
CQST1		
CQST2		
DCSAS		
DSSAS		
TTGOV		
T1GOV		
T2GOV		

TRANC

Name: TRANC(TIM)

Function: calculate transient gust and control

General reference: section 5.3.4

TIM	time (dimensionless)	
VELF MPSI	$V/\Omega R$	TMDATA
OMEGA RADIUS COSPSI(36) SINPSI(36) OPRTR2	reference rotor	TRIMCM
RA1(30) RA2(30)		RTR1CM RTR2CM
RWB(3) RHT(3) RVT(3) RFV(3,3) RSF1(3,3) RSF2(3,3) RHUB1(3) RHUB2(3)		BODYCM
MRA1 ROTAT1		R1DATA
MRA2 ROTAT2		R2DATA
VGWBV(3) VGHTV(3) VGVTV(3) VGRTR1(3,30,36) VGRTR2(3,30,36) VGHUB1(3) VGHUB2(3) VPTRAN(5)	gust in wind axes	GUSTCM
OPTRAN ⋮ CMAG(5)		GCDATA

CONTRL

Name: CONTRL(T,PERIOD,C)

Function: calculate transient control time history

General reference: section 5.3.4

Calculates: $C(t) = \frac{1}{2}(1 - \cos 2\pi t/T)$

T	time(sec)
PERIOD	period T (sec)
C	control C

GUSTU

Name: GUSTU(T,PERIOD,G)

Function: calculate uniform gust time history

General reference: section 5.3.4

Calculates: $G(t) = \frac{1}{2}(1 - \cos 2\pi t/T)$

T	time (sec)
PERIOD	period T (sec)
G	gust G

GUSTC

Name: GUSTC(XG,L,L0,G)

Function: calculate convected gust wave shape

General reference: section 5.3.4

Calculates: $G(x_g) = \frac{1}{2}(1 - \cos 2\pi(x_g - L_0)/L\ )$

XG	distance x_g (ft or m)
L	wavelength L (ft or m)
L0	starting position L_0 (ft or m)
G	gust G

PERF

Name: PERF

Function: Performance

General reference: section 5.2.1

Operating condition:

a) motion: 1st number dimensionless, 2nd number dimensional

1) velocity = ft/sec or m/sec

2) dynamic pressure, q = lb/ft^2 or N/m^2

3) weight, C_W/σ = lb or N

4) body motion = deg/sec, ft/sec or m/sec

5) $\ddot{z}$ = ft/sec^2 or m/sec^2

6) Ψ_s = rpm

b) body orientation and controls in deg

Circulation convergence:

a) tolerance, CG/S in C_T/σ form

b) G/E = ratio error to tolerance (≤ 1 if converged)

Motion convergence:

a) tolerance, BETA (etc) in deg

b) BETA/E (etc) = ratio error to tolerance (≤ 1 if converged)

Airframe performance: section 4.2.6

a) aerodynamic loads: dimensional

b) components:

1) angles in deg

2) loads, q dimensional

3) induced velocity, total velocity dimensionless

Gust velocity: dimensionless

System power: dimensional (HP); number in parentheses is percent total power

a) climb power = $V_c W$

System efficiency parameters:

a) gross weight, W = lb or N

b) drag-rotor = $D_r = (P_i + P_o)/V$; D/q-rotor = $D_r/\frac{1}{2}\rho V^2$;
L/D-rotor = W/D_r

c) drag-total = $D_{total} = P_{total}/V$; D/q-total = $D_{total}/\frac{1}{2}\rho V^2$;
L/D-total = W/D_{total}

d) figure of merit = $M = 1 - P_{nonideal}/P_{total}$

		PERF
VEL		TMDATA
ITERM		
EPMOTN		
ITERC		
EPCIRC		
AFLAP		
OPRTR2		TRIMCM
GRAV		
SIGMA		
RADIUS		
OMEGA		
DENSE		
VELF(3)		BODYCM
VCLIMB		
VSIDE		
CWS		
HMASS		
NAM		
NDM		ENGNCM
NBM1		RTR1CM
NTM1		
NGM1		
NBM2		RTR2CM
NTM2		
NGM2		
VGWB(3)	gust in wind axes	GUSTCM
VGHT(3)		
VGVT(3)		
VGHUB1(3)		
VGHUB2(3)		
VCNTRL(11)		CONTCM
THETFT		
PHIFT		
THETFP		
PSIFP		
THETAT		
PSIT		
DVBODY(6)		
DOMEGA		
DDZF		
SAVE(31)		QBDCM

	PERF
LMDAW1(3) LMDAH1(3) LMDAV1(3)	WKV1CM
LMDAW2(3) LMDAH2(3) LMDAV2(3)	WKV2CM
B1MS(10) ⋮ COUNTC	CONVCM

PERFR1

Name: PERFR1(P,PCPP,PI,PINT,PO,PN)

Function: calculate and print rotor performance

General reference: section 5.2.1

Operating condition:

$$\begin{pmatrix} -\mu_x \\ \mu_y \\ \mu_z \end{pmatrix}_{TPP} = \begin{bmatrix} 1 & 0 & \beta_c \\ 0 & 1 & \beta_s \\ -\beta_c & -\beta_s & 1 \end{bmatrix} \begin{pmatrix} -\mu_x \\ \mu_y \\ \mu_z \end{pmatrix}_{HP}$$

$$\alpha_{HP} = \alpha_{CP} + \theta_{1s} = \alpha_{TPP} - \beta_c$$

$$(\beta_c)_{CP} = (\beta_c + \theta_{1s})_{HP}$$

$$(\beta_s)_{CP} = (\beta_s - \theta_{1c})_{HP}$$

Harmonics of gimbal motion: section 5.1.2

Rotor forces and motion:
shaft axes (-S), tip path plane axes (-T), wind axes (L or X)
coefficient (Cx-), coefficient/solidity (Cx6-), dimensional (x-)

Rotor power: LIDEAL = λ_{ideal} (see also section 2.4.3)

P	total power	
PCPP	climb and parasite power	
PI	induced power	
PINT	interference power	
PO	profile power	
PN	non-ideal power	
OPUNIT		TMDATA
VEL		
MPSI		
MHARM		
MHARMF		
DENSE		TRIMCM
NAM		BODYCM
NDM		ENGNCM
T75		CONTCM
T1C		
T1S		
FZ(30,36)	F_z/ac	AES1CM
ALPHA(30,36)		

PERFR1

VIND(3,30,36)		WKV1CM
LAMBDA		
VINT(3,30,36)	λ_{int} (due to other rotor)	WKV2CM
LAMBDI		
RADIUS		R1DATA
SIGMA		
MRA		
TYPE		
NBLADE		
HINGE		
MUX		RTR1CM
MUY		
MUZ		
OMEGA		
DRA(30)		
RA(30)		
ALFHP		
PSIHP		
MTIP		
MAT		
NBM		
NTM		
NGM		
NUGC		
NUGS		
T75OLD		MD1CM
NU(20)		
ETA(2,10)	bending mode at tip	
WT(11)		
WTO		
WTC		
WTR		
FHUB(6)		QR1CM
CLS		
CXS		
BETAO		
BETAC		
BETAS		
CIRC(36)		
BETA(21,10)		MNR1CM
THETA(21,5)		
BETAG(21)		
PHI(10,16)		
PSID(10,6)		
QSSTAT(10)		MNSCM
PISTAT		
PESTAT		

LOAD

Name: LOAD(LEVEL1,LEVEL2)

Function: loads, vibration, and noise

Airframe vibration: section 5.2.8

Vibration point location: sections 4.1.3, 4.1.5

LEVEL1	wake analysis level for rotor #1	
LEVEL2	wake analysis level for rotor #2	
MHARMF(2)		TMDATA
OPRTR2		TRIMCM
FSCALE		
LSCALE		
GRAV		
TRATIO		BDDATA
FSCG		
WLCG		
BLCG		
NBLD1		R1DATA
OMEGA1		RTR1CM
NBLD2		R2DATA
OMEGA2		RTR2CM
MVXRE(3,3)		BODYCM
MSTAR		
REULER(3,3)		
VELF(3)		
NAM		
THETAT		CONTCM
PSIT		
PHI1(10,16)		MNR1CM
PHI2(10,16)		MNR2CM
MVIB		LADATA
FSVIB(10)		
WLVIB(10)		
BLVIB(10)		
ZETA(3,10,10)		

LOADR1

Name: LOADR1(LEVEL)

Function: calculate and print rotor loads

Print aerodynamics (function r and Ψ):

a) dimensionless quantities generally, angles in deg
b) induced velocity in nonrotating shaft axes
c) interference induced velocity is that due to other rotor
d) gust components in velocity axes

Force/c_{mean} (dimensionless):

L/C $= \frac{1}{2}U^2(c/c_{mean})c_\ell = L/c_{mean}$

D/C $= \frac{1}{2}U^2(c/c_{mean})c_d = D/c_{mean}$

M/C $= \frac{1}{2}U^2(c^2/c_{mean})c_m = M/c_{mean}$

DR/C $= \frac{1}{2}U^2(c/c_{mean})c_{d_{radial}} = D_{radial}/c_{mean}$

FZ/C = CT/S $= F_z/c_{mean} = d(C_T/\sigma)/dr$

FX/C $= F_x/c_{mean}$

MA/C $= M_a/c_{mean}$

FR/C $= F_r/c_{mean}$

FRT/C $= \tilde{F}_r/c_{mean}$

Forces (dimensional)

L	= section lift	lb/ft or N/m
D	= section drag	lb/ft or N/m
M	= section pitch moment	ft-lb/ft or m-N/m
DR	= section radial drag	lb/ft or N/m
FZ	$= F_z = dT/dr$	lb/ft or N/m
FX	$= F_x$	lb/ft or N/m
MA	$= M_a$	ft-lb/ft or m-N/m
FR	$= F_r$	lb/ft or N/m
FRT	$= \tilde{F}_r$	lb/ft or N/m

Blade section power: section 5.2.1

CP/S $= d(C_P/\sigma)/dr$

P = section power HP/ft or HP/m

LEVEL level of wake analysis

OPUNIT
MPSI TMDATA

LOADR1

DENSE		TRIMCM
DPSI		
COSPSI(36)		
SINPSI(36)		
TYPE		R1DATA
RADIUS		
NBLADE		
OPSTLL		
CHORD(30)		
INFLOW(6)		
MRA		
OMEGA		RTR1CM
CMEAN		
RA(30)		
MUX		
MUY		
MUZ		
NBM		
NTM		
NGM		
PINTER(36)		
PBURST(36)		
ETAT(2,10)	bending mode at tip	MD1CM
ETA(2,10,30)	bending mode at r_i, i = 1 to MRA	
DBV		W1DATA
VGUST(3,30,36)		GUSTCM
GAM(30,36)		QR1CM
CIRC(36)		
MHLOAD		L1DATA
MALOAD		
MRLOAD		
RLOAD(20)		
NPOLAR		
MWKGMP		
MNOISE		
RANGE(10)		
ELVATN(10)		
AZMUTH(10)		
NPLOT(75)		
SAVEM(36,78)		LDMNCM
MOTION(78)		AEMNCM

STATE(30,36,3)	AES1CM
DCLMAX(30,36)	
DCDMAX(30,36)	
DCMMAX(30,36)	
MEFF(30,36,3)	
AEFF(30,36,3)	
DCLDS(30,36)	
DCDDS(30,36)	
DCMDS(30,36)	
SAVE(30,36,19)	
VIND(3,30,36)	WKV1CM
LAMBDA	
VWB(3,36)	
VHT(3,36)	
VVT(3,36)	
VOFF(3,36)	
LAMBDW(3)	
LAMBDH(3)	
LAMBDV(3)	
LAMBDO(3)	
VORH(3,36)	
VINT(3,30,36)	WKV2CM
LAMBDI	

LOADH1

Name: LOADH1

Function: calculate and print hub and control loads

Root loads:

$MCON = C_{m_{con}}/\sigma$

$MHUBX = C_{m_x}/\sigma$

$MHUBZ = C_{m_z}/\sigma$

$FHUBX = C_{f_x}/\sigma$

$FHUBY = C_{f_y}/\sigma$

$FHUBZ = C_{f_z}/\sigma$

$CENT = C_{f_{cent}}/\sigma$

Hub loads:

$FHUBH = C_H/\sigma$

$FHUBY = C_Y/\sigma$

$FHUBT = C_T/\sigma$

$FHUBMX = C_{M_x}/\sigma$

$FHUBMY = C_{M_y}/\sigma$

$FHUBQ = C_Q/\sigma$

Harmonic analysis: $$F_n = \frac{1}{J}\sum_{j=1}^{J} F_j e^{-in\psi_j} X_n$$

Dimensional loads:

root force $= \rho\Omega^2 R^4 (c/R)$

root moment $= \rho\Omega^2 R^5 (c/R)$

hub force $= N\rho\Omega^2 R^4 (c/R) = \rho(\Omega R)^2 \pi R^2 \sigma$

hub moment $= N\rho\Omega^2 R^5 (c/R) = \rho(\Omega R)^2 \pi R^3 \sigma$

MHARM MPSI		TMDATA
NBLADE RADIUS TYPE		R1DATA
CMEAN GAMMA OMEGA NBM NTM		RTR1CM
DENSE DPSI COSPSI(36) SINPSI(36)		TRIMCM
MHARML NPLOT(75) SENDUR(12) CMAT(12) EXMAT(12) KFATIG	for hub and control loads	L1DATA

MPAERO(36)	$(M_{p_o}/ac)_{aero}$	AEF1CM
CMXA(36)		
CMZA(36)		
CFXA(36)		
CFZA(36)		
CFRA(36)		
SAVEM(36,78)		LDMNCM
MB		INC1CM
SB		
I0		
SQ(2,10)		
IQA(2,10)		
IFX0		
IMX0		
IP(5)		
IPP(5,5)		
IP0(5)		
IQ0DQ(2,10)	summed over q_j	
⋮		
SPQ(5,10)		

LOADS1

Name: LOADS1(R)

Function: calculate and print blade section loads

General reference: sections 5.2.2, 5.2.3, 5.2.4

Azimuth loop: PHIX = $\vec{\phi} \cdot \vec{i}_B$

PHIZ = $\vec{\phi} \cdot \vec{k}_B$

T = θ

FXS-X = C_{f_x}/σ

FXS-R = C_{f_r}/σ

FXS-Z = C_{f_z}/σ

CENT = $C_{f_{cent}}/\sigma$

MXS-X = C_{m_x}/σ

MXS-Z = C_{m_z}/σ

MTOR = $C_{m_{tors}}/\sigma$

(- = B for shaft axes, P for principal axes)

Harmonic analysis: $F_n = \frac{1}{J} \sum_{j=1}^{J} F_j \, e^{-in\psi_j} \; K_n$

Dimensional loads:

forces = $(\gamma/a)\, I_b \Omega^2/R = \rho \Omega^2 R^4 (c/R)$

moments = $(\gamma/a)\, I_b \Omega^2 = \rho \Omega^2 R^5 (c/R)$

R radial station r/R

MPSI
MHARM TMDATA
DOFT(4)

DENSE
DPSI TRIMCM
COSPSI(36)
SINPSI(36)

TYPE
NBLADE R1DATA
RADIUS
MRA

OMEGA
CMEAN RTR1CM
GAMMA
RA(30)
DRA(30)
NBMT
NBM
NTM

MHARML		L1DATA
SENDUR(6)	for section loads	
CMAT(6)		
EXMAT(6)		
KFATIG		
NPLOT(75)		
ETA(2,10,30)	bending modes at r_i, i = 1 to MRA	MD1CM
DEL1		
DEL2		
DEL3		
DEL4		
DEL5		
FXAERO(30,36)	F_x/ac	AES1CM
FZAERO(30,36)	F_z/ac	
MAAERO(30,36)	M_a/ac	
FRAERO(30,36)	$\tilde{F}_r$/ac	
BETA(21,10)		MNR1CM
MB		LDMNCM
⋮		
IPO		
SAVEM(36,78)		

LOADI1

Name: LOADI1(R,Q,TR,ZR,EPR,ER)

Function: calculate inertia coefficients for section loads

General reference: sections 5.2.2, 5.2.3, 5.2.4

Blade pitch: section 2.3.5

$$CS = \cos\theta,\ SN = \sin\theta,\ TR = \theta(r)$$

$$W = (z_o\vec{i} - x_o\vec{k}),\quad WP = (z_o\vec{i} - x_o\vec{k})',\quad WPP = (z_o\vec{i} - x_o\vec{k})''$$

$$WXI = (z_o\vec{i} - x_o\vec{k} - x_I\vec{k})$$

$$ZR = \xi_i(r),\ ER = \vec{\eta}_i(r),\ EPR = \vec{\eta}_i'(r)$$

$$WR = (z_o\vec{i} - x_o\vec{k})_{trim},\ WPR = (z_o\vec{i} - x_o\vec{k})'_{trim},\ \text{at } r$$

$$WRXC = (z_o\vec{i} - x_o\vec{k} - x_C\vec{k}),\ \text{at } r$$

$$EPXIO(NBM) = (\vec{\eta}'\cdot\vec{k}\ x_I)\ \text{ at } r = e$$

$$CE(NBM) = \int_0^r \vec{\eta}_i'' \cdot (z_o\vec{i} - x_o\vec{k} - x_I\vec{k})\, d\rho$$

$$CMR(MRM+1) = \int_\rho^1 (\rho^* - r)\, m\, d\rho^*$$

$$WFA = (z_o\vec{i} - x_o\vec{k}),\ WPFA = (z_o\vec{i} - x_o\vec{k})' \ \text{ at } r_{FA}$$

$$X = \vec{X}_k(\rho),\ XR = \vec{X}_k(r)$$

R	radial station r/R	
Q(4)	mean deflection q_j	
TR	pitch θ_m at r	
ZR(5)	ξ_k at r	
EPR(2,10)	$\vec{\eta}_k'$ at r	
ER(2,10)	$\vec{\eta}_k$ at r	
DEBUG		TMDATA
T75		CONTCM
EFLAP		R1DATA
ELAG		
XFA		
RFA		
ZFA		
RCPL		
NOPB		
MRM		

LOADI1

NBM		RTR1CM
NTM		
NGM		
NBMT		
MASS(51)		
ITHETA(51)		
XI(51)		
TWIST(51)		
ETA(2,10,51)	bending modes at $r=(j-1)\Delta r$, $j=1$ to MRM+1	MD1CM
ETAP(2,10,51)		
ETAPP(2,10,51)		
ZETA(5,51)	torsion modes at $r=(j-1)\Delta r$, $j=1$ to MRM+1	
ETAPH(2,10)		
EFA(2,10)	bending modes at $r = r_{FA}$	
EFAP(2,10)		
DEL1		
DEL2		
DEL3		
DEL4		
DEL5		
MB		LDMNCM
⋮		
IPO		

LOADF

Name: LOADF(S,MPSI,K,SE,C,M,DAMAGE,SEQ)

Function: calculate fatigue damage

General reference: section 5.2.9

Input:

S(MPSI)	vector of load S_j, j = 1 to MPSI; dimensional
MPSI	number of azimuthal stations; maximum 36
K	parameter K in fatigue damage calculation
SE	endurance limit S_E (dimensional)
M	material exponent
C	material constant

S-N curve approximated by $N = \dfrac{C}{(S/S_E - 1)^M}$

Output:

DAMAGE	damage fraction per rev (only calculated if $S_E > 0$, $C > 0$, and $M \neq 0$)
SEQ	equivalent $\frac{1}{2}$ peak-to-peak load (only calculated if $M \neq 0$)

LOADM

Name: LOADM(F,MPSI,FMEAN,FHPP)

Function: calculate mean and half peak-to-peak

Input:

F(MPSI)	load F_j, j = 1 to MPSI
MPSI	number of azimuthal stations

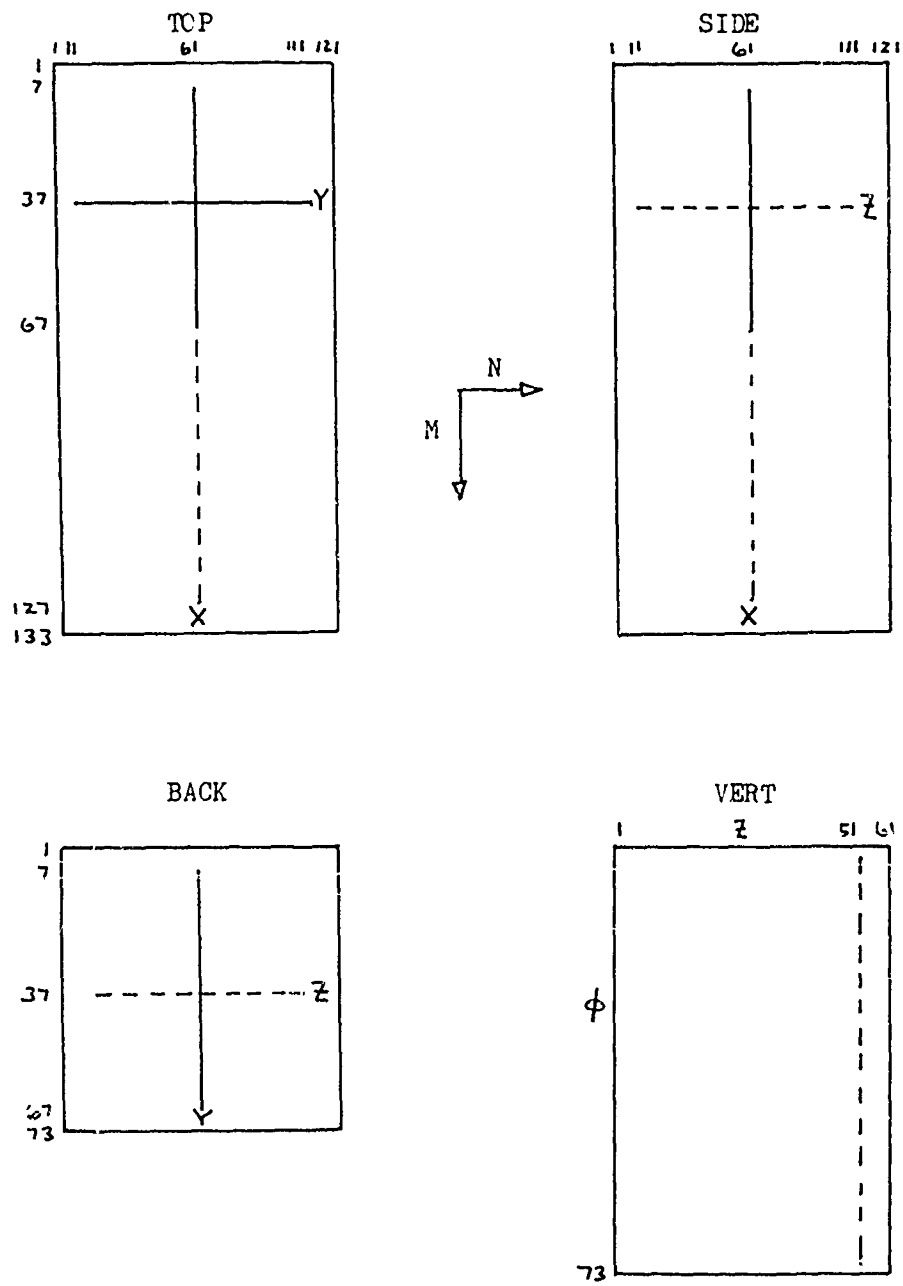
Output:

FMEAN	mean load
FHPP	$\frac{1}{2}$ peak-to-peak load

GEOMP1

Name: GEOMP1(LEVEL)

Function: printer-plot of wake geometry

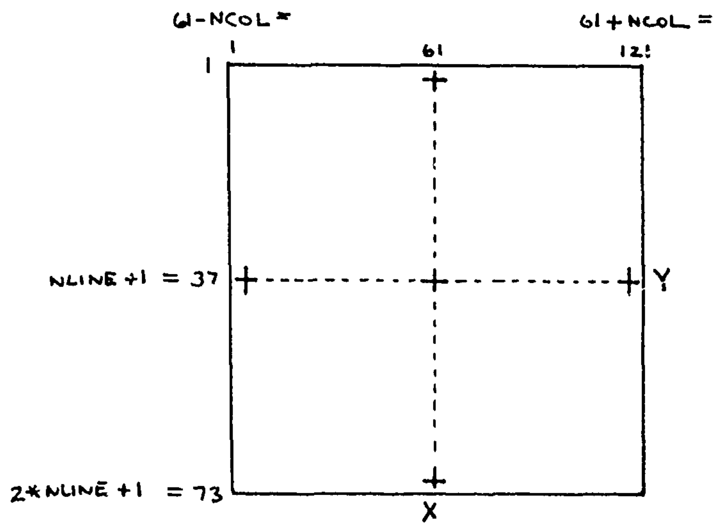


LEVEL	wake analysis: 1 for prescribed wake, 2 for free wake geometry	
MPSI		TMDATA
TYPE		R1DATA
MWKGMP		L1DATA
JWKGMP(8)		
NWKGMP(4)		
KFW		W1DATA
KDW		
KNW		
KRW		
KRWG		
KFWG		G1DATA

POLRPP

Name: POLRPP(A,MRA,RA,MPSI,ISUB,NPLOT,DA,NUPP)

Function: printer-plot of polar plot



A	array to be plotted
MRA	number of radial stations
RA(MRA)	radial stations r_i, i = 1 to MRA
MPSI	number of azimuthal stations $\Psi_j = j\Delta\Psi$, j = 1 to MPSI, $\Delta\Psi$= 360/MPSI
ISUB	first dimension of array A; positive if first subscript is r_i, negative if first subscript is Ψ_j
NPLOT	n; data plotted every n-th step
DA	plot increment: last digit of integer part of A/DA is plotted (if multiple of NPLOT)
NUPP	unit number for printed output

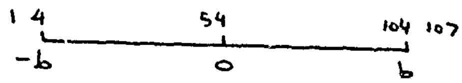
HISTPP

Name: HISTPP(A,MRA,RA,MPSI,ISUB,NPLOT,NAME,NUPP)

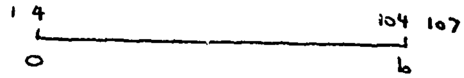
Function: printer-plot of azimuthal time history

let c = minimum, d = maximum values over azimuth

1) $d > 0,\ c < -.03d$ or $c < 0,\ d > .03|c|$
   use $b = [\max(d, |c|)]$

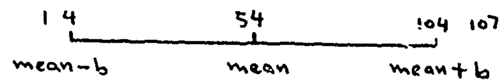


2) $d > 2|c|,\ c > -.03d$
   use $b = [d]$



3) $c < -2|d|,\ d < .03c$
   use $b = [|c|]$

4) otherwise, use $\text{mean} = [\frac{1}{2}(c+d)]$
   and $b = [\max(\text{mean}-c,\ d-\text{mean})]$



mean = AM = KM * 10**NM

b = B = K * 10**N

to convert F to $K*10^N$ (K = 1 to 9)

a) if F = 0, then F = .99

b) $N = [\log|F|]$
   if $F < 1.$, then $N = N - 1$

c) $K = [|F|/10^{**}N] + 1$
   if K = 10, then N = N + 1 and K = 1
   if $F < 0$, then $K = -K$

d) F = K * 10**N

A	array to be plotted
MRA	secondary variable: number of values (minimum 1)
RA(MRA)	secondary variable: values r_i, i = 1 to MRA; alphanumeric labels if NPLOT LT 0; not used if MRA EQ 1
MPSI	number of azimuthal stations $\Psi_j = j\Delta\Psi$, j = 1 to MPSI, $\Delta\Psi = 360/\text{MPSI}$
ISUB	first dimension of array A; positive if first subscript is r_i, negative if first subscript is Ψ_j
NPLOT	number of values of secondary variable per plot; minimum 1 and maximum 3; negative for alphanumeric labels; not used if MRA EQ 1
NAME	name of secondary variable, 4 characters; not used if MRA EQ 1
NUPP	unit number for printed output

NOISR1

Name: NOISR1(RANGE,ELVATN,AZMUTH)

Function: calculate and print far field rotational noise

General reference: section 5.2.10

Calculate constants: $CSTR = \cos\theta_r/(1 - M_r)$

$$FT = -N^3\Omega^2 \xi/4\pi\sigma_0(1 - M_r)^2$$
$$FD = N^2/4\pi\sigma_0(1 - M_r)$$
$$FL = -N^2\Omega\sin\theta_r/4\pi c_s\sigma_0(1 - M_r)^2$$
$$FR = -N^2\Omega\cos\theta_r/4\pi c_s\sigma_0(1 - M_r)^2$$
$$FB = N\Omega\cos\theta_r/c_s(1 - M_r)$$
$$FS = N\Omega\sigma_0/c_s$$

Harmonic analysis of loads: $F_n = \frac{1}{J}\sum_{j=1}^{J} F_j\, e^{-in\psi_j}\, K_n$

RANGE	range s_o (dimensional)	
ELVATN	elevation θ_o (deg)	
AZMUTH	azimuth ψ_o (deg)	
MPSI		TMDATA
OPUNIT		
DPSI		TRIMCM
DENSE		
CSOUND		
COSPSI(36)		
SINPSI(36)		
OMEGA		RTR1CM
CMEAN		
MUX		
MUY		
MUZ		
RA(30)		
DRA(30)		
NBLADE		R1DATA
CHORD(30)		
SIGMA		
RADIUS		
MRA		
TYPE		
AXS(30)	A_{xs}/c^2	L1DATA
OPNOIS(4)		
MHARMN(3)		
MTIMEN(3)		

NCISR1

FXA(30,36)	F_x/ac	AES1CM
FZA(30,36)	$\underset{\sim}{F}_z$/ac	
FRA(30,36)	$\tilde{F}_r$/ac	
BETAC		QR1CM
BETAS		

BESSEL

Name: BESSEL(NB,XB,BJ)

Function: calculate J Bessel function

Input:

NB	order of Bessel function, n
XB	argument of Bessel function, x

Output:

BJ	Bessel function $J_n(x)$

RAMF

Name: RAMF(LEVEL1,LEVEL2,OPLMDA)

Function: calculate rotor/airframe periodic motion and forces

General reference: section 5.1.13

Test motion convergence: section 5.1.4
Test circulation convergence: section 5.1.12

LEVEL1 LEVEL2	integer parameter specifying rotor #1 and rotor #2 wake analysis: 0 for uniform inflow, 1 or 2 for nonuniform inflow
OPLMDA	integer parameter: 0 to suppress inflow update

MPSI	TMDATA
MHARM(2)	
MHARMF(2)	
ITERM	
EPMOTN	
ITERC	
EPCIRC	
DEBUG	
MREV	
MPSIR	
OPRTR2	TRIMCM
NAM	BODYCM
NDM	ENGNCM
CMEAN1	RTR1CM
NBM1	
NTM1	
NGM1	
CMEAN2	RTR2CM
NBM2	
NTM2	
NGM2	
B1(21,10)	MNR1CM
T1(21,5)	
BG1(21)	
P1(10,16)	
PS1(10,6)	
B2(21,10)	MNR2CM
T2(21,5)	
BG2(21)	
P2(10,16)	
PS2(10,6)	

	RAMF
B1MS(10) : : COUNTC	CONVCM
CIRC1(36) CT1 CMX1 CMY1	QR1CM
CIRC2(36) CT2 CMX2 CMY2	QR2CM
SIGMA1	R1DATA
SIGMA2	R2DATA

MODE1

Name: MODE1

Function: blade modes

T750LD NBMOLD NTMOLD	MD1CM
DEBUG	TMDATA
HINGE EPMODE	R1DATA
NBM NTM	RTR1CM
T75	CONTCM

MODEC1

Name: MODEC1

Function: initialize blade mode parameters

Linearly interpolate data for bending mode calculation: section 2.3.1
Tip mass: section 2.2.19
Evaluate centrifugal force for bending mode calculation: section 2.3.1

$$CENT = \int_r^1 \rho m \, d\rho$$

Linearly interpolate data for torsion mode calculation: section 2.3.3
Evaluate pitch inertia and control system stiffness: sections 2.2.9, 5.1.3

MRB MTIP XITIP EFLAP ELAG RFA RADIUS MRM FTO FTC FTR WTIN VTIPN KTOI KTCI KTRI MRI RI(51) XI(51) XC(51) KP2(51) MASS(51) ITHETA(51) GJ(51) EIXX(51) EIZZ(51) TWIST(51)	R1DATA
DEBUG	TMDATA

RTR1CM

IB
OMEGA
EIXXB(51)
EIZZB(51)
MASSB(51)
TWISTB(51)
CENT(51)
ITHETB(51)
GJB(51)
MASSI(51)
ITHETI(51)
XII(51)
XCI(51)
TWISTI(51)
KP2I(51)
IPITCH
KTO
KTC
KTR

MODEB1

Name: MODEB1

Function: calculate blade bending modes

General reference: section 2.3.1

Blade pitch: section 2.3.5

Calculate:

$$DS = \xi_k'(e)\, K_\xi / \Omega^2 R^3\, \xi_i'(e)$$

$$C = \int_e^1 \xi_k'' \cdot \xi_i''\, dr$$

$$DC = \int_e^1 \left[\int_r^1 \rho m\, d\rho\, \xi_i' \cdot \xi_k' - m\, k_\theta \cdot \xi_k\, k_\theta \cdot \xi_i \right] dr$$

$$B = \int_e^1 \xi_k \cdot \xi_i\, m\, dr$$

$$A = \int_e^1 \xi_k'' \left(EI / \Omega^2 R^4 \right)^{-1} \xi_i''\, dr$$

Normalize eigenvector solution: using Galerkin modes from last call, which was at r = 1

T75 DEBUG	CONTCM TMDATA
NOPB RCPL KFLAP KLAG EFLAP ELAG RADIUS RCPLS TSPRNG RFA RPB NCOLB MRB NONROT HINGE MRA RROOT MRM	R1DATA
NU(20) NUNR(20) ETA(2,10,96) ETAP(2,10,96) ETAPP(2,10,96) ETAPH(2,10)	MD1CM

MASS(51) EIXX(51) EIZZ(51) TWIST(51) CENT(51) OMEGA NBM RA(30)	inertial and structural data at $r = e + (j-1)\Delta r$, r = 1 to MRB + 1	RTR1CM

MODEG

Name: MODEG(R,EFLAP.ELAG,NCOLB,HINGE,F,DF,DDF)

Function: calculate Galerkin functions for bending modes

General reference: section 2.3.1

R	radial station r/R
EFLAP	flap hinge offset e_f/R
ELAG	lag hinge offset ϵ_l/R
NCOLB	number of functions
HINGE	integer parameter: 0 for hinged blade, 1 for cantilever blade
F(NCOLB)	Galerkin functions f_i
DF(NCOLB)	Galerkin functions f_i'
DDF(NCOLB)	Galerkin functions f_i''

MODEA1

Name: MODEA1

Function: calculate articulated blade flap and lag modes

General reference: section 2.3.2

Calculate: $F = \int_e^1 \eta m \, dr$, $G = \int_e^1 \eta^2 m \, dr$

DEBUG		TMDATA
MRB EFLAP ELAG KFLAP KLAG RADIUS MRM RFA RPB MRA RROOT		R1DATA
RA(30) OMEGA NBM MASS(51)	 section mass at $r = e + (j-1)\Delta r$, $j = 1$ to MRB+1	RTR1CM
NU(20) NUNR(20) ETA(2,10,96) ETAP(2,10,96) ETAPP(2,10,96) ETAPH(2,10)		MD1CM

MODET1

Name: MODET1

Function: calculate blade torsion modes

General reference: section 2.3.3

Evaluate Galerkin functions at r: $x = \pi(r - r_{FA})/(1 - r_{FA})$

Calculate:

$$A = \int_0^1 \xi_k' (GJ/\Omega^2 R^2)^{-1} \xi_i' \, dr$$

$$B = \int_0^1 I_\theta \xi_k \xi_i \, dr$$

$$C = \int_0^1 \xi_k' \xi_i' \, dr$$

Normalize eigenvector solution: using Galerkin functions from last iteration, which was at r = 1

DEBUG		TMDATA
MRB		R1DATA
RFA		
RADIUS		
MRM		
NCOLT		
MRA		
IPITCH		RTR1CM
KTO		
KTC		
KTR		
OMETA		
NTM		
RA(30)		
ITHETA(51)	I_θ at $r = r_{FA} + (j-1)\Delta r$, j = 1 to MRB+1	
GJ(51)	GJ at $r = r_{FA} + (j-1)\Delta r$, j = 1 to MRB+1	
WT(11)		MD1CM
WTO		
WTC		
WTR		
ZETA(5,92)		
ZETAP(5,92)		

MODEK1

Name: MODEK1

Function: calculate kinematic pitch-bending coupling

General reference: section 2.3.4

DEBUG		TMDATA
T75		CONTCM
PHIPL		R1DATA
PHIPH		
RPH		
RPB		
XPH		
KPIN		
DEL3G		
ATANKP(10)		
ETA(2,10)	bending modes at r_{FB}	MD1CM
ETAP(2,10)		
KPB(10)		
KPG		
NBM		RTR1CM

MODED1

Name: MODED1

Function: calculate blade root geometry

General reference: section 2.2.1

DEBUG	TMDATA
T75	CONTCM
CONE	R1DATA
DROOP	
SWEEP	
FDROOP	
FSWEEP	
DEL1	MD1CM
DEL2	
DEL3	
DEL4	
DEL5	

INRTC1

Name: INRTC1

Function: calculate blade inertia coefficients

General reference: section 2.2.19

Blade pitch: section 2.3.5

Calculate: CS(MRM+1) = $\cos\theta$, SN(MRM+1) = $\sin\theta$

CM(MRM+1) = $\int_r^1 m\,d\rho$

CMR(MRM+1) = $\int_r^1 \rho m\,d\rho$

CMRR(MRM+1) = $\int_r^1 \rho^2 m\,d\rho$

CXIM(MRM+1) = $\int_r^1 x_I \cos\theta\, m\,d\rho$

CXIRM(MRM+1) = $\int_r^1 x_I \sin\theta\, \rho m\,d\rho$

DEM(NBM,MRM+1) = $\int_r^1 \vec{k}_B\cdot\vec{\eta}_i\, m\,d\rho$

DERM(NBM,MRM+1) = $\int_r^1 \vec{i}_B\cdot\vec{\eta}_i\, \rho m\,d\rho$

CEPEP(NBM,NBMT,MRM+1) = $\int_0^r \vec{\eta}_i{}'\cdot\vec{\eta}_j{}'\,d\rho$

X(2,NTM,NBMT,MRM+1) = $\vec{X}_{kj}$

a) X = $\int_{r_{FA}}^r \xi_k'\,(\vec{\eta}_j - \rho\vec{\eta}_j{}')\,d\rho$

b) XH = $\int_{r_{FA}}^r \xi_k'\,\vec{\eta}_j{}'\,d\rho$

c) X = $\vec{X}_{kj}$ for $k \geq 1$ and $k = 0$

XCFA = x_C at r_{FA}

XCE = x_C at e

XIE = x_I at e

KP2TWP = $k_P^2\ \theta_{tw}'$

DEBUG
T75

MRM
NOPB
RCPL
RFA
ZFA
XFA
ELAG

TMDATA
CONTCM

R1DATA

INRTC1

RADIUS		R1DATA
MBLADE		
MRA		
EFLAP		
IB		RTP1CM
NBM		
NTM		
NGM		
NBMT		
RA(30)		
IPITCH		
MASS(51)	inertial data at $r = (j-1)\Delta r$, j = 1 to MRM+1	
ITHETA(51)		
XI(51)		
XC(51)		
KP2(51)		
TWIST(51)		
ETA(2,10,51)	bending modes at $r = (j-1)\Delta r$, j = 1 to MRM+1	
ETAP(2,10,51)		
ETAPP(2,10,51)		
ZETA(5,51)	torsion modes at $r = (j-1)\Delta r$, j = 1 to MRM+1	
ZETAP(5,51)		
EFA(2,10)		
EFAP(2,10)	bending modes at r_{FA}	
ETAPH(2,10)		
DEL1		
DEL2		
DEL3		
DEL4		
DEL5		
MB		INC1CM
⋮		
XAPQ(2,5,4,30)		

MODEP1

Name: MODEP1

Function: print blade modes

TYPE		R1DATA
HINGE		
NCOLB		
NONROT		
NCOLT		
RCPL		
EFLAP		
ELAG		
KFLAP		
KLAG		
RCPLS		
TSPRNG		
RADIUS		
OMEGA		RTR1CM
NBM		
NTM		
NGM		
NUGC		
NUGS		
KTO		
KTC		
KTR		
IB		
MB		INC1CM
SB		
IO		
IP(5)		
T75OLD		MD1CM
NU(20)		
NUNR(20)		
ETA(2,10,11)	bending modes at r = (j-1).1, j = 1 to 11	
ETAP(2,10,11)		
ETAPP(2,10,11)		
WT(11)		
WTO		
WTC		
WTR		
ZETA(5,11)	torsion modes at r = (j-1).1, j = 1 to 11	
ZETAP(5,11)		
ETAPH(2,10)		
KPB(10)		
KPG		

MODEP1

DEL1
DEL2
DEL3
DEL4
DEL5

MD1CM

BODYC

Name: BODYC

Function: initialize airframe parameters at trim

Wind tunnel trim case: section 4.1.3
$\vec{r}$, R_{SF} with Θ_T/Ψ_T rotations: sections 4.1.3, 4.1.5
Free flight trim case: section 4.1.1
Calculate R_e: section 4.2.1
Calculate $R_e^T I^* R_e$, $-M^*(\vec{V}\times)R_e$, G, $(\vec{V}\times)R_e\vec{k}_F$: section 4.2.4
Airframe gust velocity in body axes: section 4.1.4

THETFT	CONTCM
PHIFT	
PSIFP	
THETFP	
THETAT	
PSIT	
DEBUG	TMDATA
VEL	
OPTRIM	
MSTAR	BODYCM
MSTARG	
ISTAR(3,3)	
RSF10(3,3)	
RSF20(3,3)	
RHUB10(3)	
RHUB20(3)	
RWB0(3)	
RHT0(3)	
RVT0(3)	
ROFF0(3)	
RSF1(3,3)	
RSF2(3,3)	
RHUB1(3)	
RHUB2(3)	
RWB(3)	
RHT(3)	
RVT(3)	
ROFF(3)	
VXREKF(3)	
MVXRE(3,3)	
GMTRX(3,3)	
IBODY(3,3)	
REULER(3,3)	
RFV(3,3)	

	BODYC
RFE(3,3) KE(3) VELF(3) VCLIMB VSIDE	BODYCM
VGWBV(3) VGHTV(3) VGVTV(3) VGWBF(3) VGHTF(3) VGVTF(3)	GUSTCM

<u>ENGNC</u>

Name: ENGNC

Function: initialize drive train parameters at trim

Engine damping: section 4.3.1
Drive system inertia: section 5.3
Drive system spring, damping, mass matrices: section 5.1.9
Drive system static elastic matrix: section 5.1.10
Calculate C_ψ : section 5.1.5
Calculate C_D: section 5.1.9

DEBUG		TMDATA
OPENGN		
OPRTR2		TRIMCM
NBLD1		R1DATA
NBLD2		R2DATA
IB1		RTR1CM
OMEGA1		
GAMMA1		
CD1(2)		
CPSI1(2)		
IB2		RTR2CM
OMEGA2		
GAMMA2		
CD2(2)		
CPSI2(2)		
I01		INC1CM
QT1		
QDZ1		
I02		INC2CM
QT2		
QDZ2		
CQS1	$-\gamma 2C_Q/\sigma a$	QR1CM
CQS2	$-\gamma 2C_Q/\sigma a$	
KIGOVE		ENDATA
KIGOV1		
KIGOV2		
GSE		
GSI		
KEDAMP		

ENGNC

ENGNCM

QTHRTL
IENG
IMI1
KMI2
KMR
MKE1
KME2
KPGOVE
KPGOV1
KPGOV2
T1GOVE
T1GOV1
T1GOV2
T2GOVE
T2GOV1
T2GOV2
QEDAMP
IRSTAR
MENG(6,6)
SENG(6,6)
DENG(6,6)
HENGO(2,2)

MOTNC1

Name: MOTNC1

Function: initialize rotor parameters at trim

Calculate α_{HP}, ψ_{HP}, M_{at}: sections 2.4.2, 4.1.2

Calculate R_G: section 4.1.4

Rotor gust velocity in shaft axes: section 4.1.4

Calculate c, $\overline{c}$: section 4.2.2

Calculate c^T: section 4.2.5

Calculate μ_x, μ_y, μ_z: section 4.1.2

DEBUG MPSI		TMDATA
NSCALE ISCALE FSCALE LSCALE		TRIMCM
IB OMEGA MTIP MUX MUY MUZ ALFHP PSIHP MAT RGUST(3,3) CHUB(6,16) CBHUB(3,3) CHUBT(16,6)		RTR1CM
ROTATE NBLADE RADIUS MRA		R1DATA
NEM		BDDATA
DVBODY(6)		CONTCM
VGUSTV(3,30,36)	gust at rotor disk, velocity axes	GUSTCM
VGUSTS(3,30,36)	gust at rotor disk, shaft axes	
VGUSTH(3)	gust at rotor hub, velocity axes	

VELF(3)
RFV(3,3)
REULER(3,3)
RSF(3,3)
RHUB(3)
AMODE(6,10)

BODYM1

Name: BODYM1

Function: calculate airframe transfer function matrix

General reference: section 5.1.8

DEBUG DOF(16) MHARMF	 airframe degrees of freedom	TMDATA
FSCALE		TRIMCM
NBLADE		R1DATA
OMEGA DPSI21 CHUBT(16,6)	 $\Delta\Psi_{21}$ (rad); 0. for rotor #1	RTR1CM
AMASS(10) ADAMPS(10) ASPRNG(10) ADAMPA(10) IBODY(3,3) MVXRE(3,3) GMTRX(3,3) MSTAR NAM		BODYCM
HBODY(16,6,10)		RH1CM

ENGNM1

Name: ENGNM1

Function: calculate drive train transfer function matrix

General reference: section 5.1.9

DEBUG MHARMF DOF(6)	 drive train degrees of freedom	TMDATA
FSCALE		TRIMCM
NBLADE		R1DATA
OMEGA DPSI21 CD(2)	 $\Delta\Psi_{21}$ (rad); 0. for rotor #1	RTR1CM
MENG(6,6) SENG(6,6) DENG(6,6) NDM		ENGNCM
HENG(6,10)		RH1CM

WAKEU1

Name: WAKEU1

Function: calculate uniform wake-induced velocity

General reference: section 2.4.3

Lagged thrust and moment: section 5.1.12
Vectors for aerodynamic interference: section 4.2.6
Interference induced velocity: section 4.2.6

DEBUG	TMDATA
OPGRND	
HAGL	
MPSI	
DPSI	TRIMCM
COSPSI(36)	
SINPSI(36)	
LSCALE	
FSCALE	
MRA	R1DATA
RADIUS	
ROTATE	
FACTOR	
KHLMDA	
KFLMDA	
FXLMDA	
FYLMDA	
FMLMDA	
KINTH	
KINTF	
KINTWB	
KINTHT	
KINTVT	
INFLOW(6)	
RA(30)	RTR1CM
OMEGA	
MUX	
MUY	
MUZ	
MRAO	R2DATA
RADUSO	
OMEGAO	RTR2CM
RSF(3,3)	BODYCM
RHUB(3)	
RWB(3)	
RHT(3)	
RVT(3)	
KE(3)	

CT	C_T	QR1CM
CMY	C_{M_y}	
CMX	C_{M_x}	
CTOLD		WKV1CM
CMXOLD		
CMYOLD		
VIND(3,30,36)		
LAMBDA		
FGE		
COSE		
ZAGL		
VINT(3,30,36)		
LAMBDI		
LAMBDW(3)		
LAMBDH(3)		
LAMBDV(3)		
LAMBDO(3)		
EINTW(3)		
EINTH(3)		
EINTV(3)		

WAKEN1

Name: WAKEN1(LEVEL)

Function: calculate non-uniform wake induced velocity

General reference: section 3.1.4

Calculate R_{TF}: section 3.1.3

$$R_{TF} = R_{TS}R_{SF}$$

$$R_{21} = (R_{SF})_{\text{other rotor}} R_{TF}^{T}$$

Lagged circulation: section 5.1.12

Interpolate induced velocity: linear interpolation between inflow points, constant beyond first or last point

Calculate mean induced velocity: TPP normal component, area-weighted mean

LEVEL	rotor wake level: 0 for uniform inflow (only replace old circulation)	
DEBUG MPSI		TMDATA
DPSI		TRIMCM
MRA ROTATE INFLOW(6)		R1DATA
RA(30) DRA(30) DP21M DPSI21	 $\Delta\Psi_{21}$ (rad); 0. for rotor #1 $\Delta\Psi_{21}$ (rad); $-\Delta\Psi_{21}$ for rotor #2	RTR1CM
MRAO ROTATO	other rotor	R2DATA
RAO(30) DRAO(30)		RTR2CM
NG(30) MRG NL(30) MRL FACTOR OPVXVY KNW OPRTS		W2DATA
NLO(30) MRLO	other rotor	W2DATA
RSF(3,3) RSFO(3,3)	 other rotor	BODYCM

WAKEN1

GAM(30,36)		QR1CM
CRC(36)		
BETAC		
BETAS		
BETACO	other rotor	QR2CM
BETASO		
GAMOLD(30,36)		WKV1CM
CRCOLD(36)		
VIND(3,30,36)		
LAMBDA		
VINT(3,30,36)		
VORH(3,36)		
LAMBDI		
VWB(3,36)		
VHT(3,36)		
VVT(3,36)		
VOFF(3,36)		
LAMBDW(3)		
LAMBDH(3)		
LAMBDV(3)		
LAMBDO(3)		
MR		WKC1CM
ML		
MI		
MW		
MH		
MV		
MO		
C(3,20000)		
CNW(3,20000)		

INRTM1

Name: INRTM1

Function: calculate rotor transfer function matrix

General reference: section 5.1.6

Aerodynamic spring and damping: section 2.2.20

DEBUG		TMDATA
DOF(15)	rotor bending and torsion degrees of freedom	
DOFT(4)		
MPSI		
MHARM		
RA(30)		RTR1CM
DRA(30)		
CMEAN		
MUZ		
NUGC		
NUGS		
CGC		
CGS		
GLAG		
CTO		
CTC		
CTR		
NBM		
NTM		
NGM		
NBMT		
GAMA	γ	
KEPSI(21,36)		TRIMCM
HRTR(16,16,21)		RH1CM
CT	C_T	QR1CM
LAMBDA		WKV1CM
BETA(21,10)		MNR1CM
THETA(21,5)		
BETAG(21)		
FORCE(16,36)		AEF1CM
NBLADE		R1DATA
GSB(10)		
GST(5)		
MRA		
CHORD(30)		
SIGMA		
XA(30)		
XAC(30)		

INTRM1

NU(20)

ETAPH(2,10) MD1CM

KPG

KFB(10)

AETA(2,10,3) bending modes at r_i, $i = 1$ to MRA

AZETA(5,30) torsion modes at r_i, $i = 1$ to MRA

WT(11)

WTO

WTC

WTR

MB

⋮ INC1CM

XAPQ(2,5,4,30)

MQDQ(10,10)

⋮

MPP(5,5)

IQDQS(10,10)

⋮

SPQS(5,10)

INRTI

Name: INRTI(MX,H,KEEP,LMINV,MMINV)

Function: calculate inverse of transfer function matrix

MX	dimension of H_n
H(MX*MX)	complex matrix H_n to be inverted
KEEP(MX)	integer vector designating degrees of freedom to be retained; 0 for unused degrees of freedom
LMINV(MX+1)	scratch vector
MMINV(MX+1)	scratch vector

MOTNH1

Name: MOTNH1

Function: calculate harmonics of hub motion

General reference: sections 5.1.5, 5.1.11

DEBUG		TMDATA
MHARM		
MHARMF		
GRAV		TRIMCM
FSCALE		
LSCALE		
RADIUS		R1DATA
ROTATE		
NBLADE		
OPHVIB(3)		
OMEGA		RTR1CM
CHUB(6,16)		
CBHUB(3,3)		
CPSI(2)		
DPSI21	$\Delta\psi_u$ (rad); 0. for rotor#1	
KMASTC(10)		BODYCM
KMASTS(10)		
RSF(3,3)		
KE(3)		
NAM		
NDM		ENGNCM
DVBODY(6)		CONTCM
DOMEGA		
QSSTAT(10)		MNSCM
PISTAT		
PHI(10,16)		MNR1CM
PSID(10,2)	(ψ_s, ψ_I)	
THTG(10)	$(\Delta\theta_{g1})$	
PHIO(10,16)	(due to other rotor)	MNR2CM
PSIDO(10,2)	(ψ_s, ψ_I)	
THTGO(10)	$(\Delta\theta_{g1})$	
ALF(10,6)		MNH1CM
⋮		
DPSISO		

MOTNR1

Name: MOTNR1(JSTART)

Function: calculate harmonics of rotor motion

General reference: sections 5.1.6, 5.1.13

Lag damper moment: section 2.2.16
Calculate coning and tip-path plane tilt: section 3.1.3
Calculate hub reactions: section 5.1.7

JSTART	azimuth index j_{start}	
MPSI		TMDATA
MPSIR		
DEBUG		
MHARM		
MHARMF		
DOFT(4)		
NBLADE		R1DATA
GAMMA		NTR1CM
NBM		
NTM		
NGM		
NBMT		
GLAG		
MLD		
DZLD		
CGC		
CGS		
NUGS		
NUGC		
KPB(10)		MD1CM
KPG		
ETAPH(2,10)		
ETATIP(2,10)	bending mode at r = 1	
B0		QR1CM
BC		
BS		
BETA(21,10)		MNR1CM
THETA(21,5)		
BETAG(21)		
DPSI		TRIMCM
COSPSI(36)		
SINPSI(36)		
KEPSI(21,36)		
HRTR(16,16,21)		RH1CM

MOTNR1

FORCE(16,36) FHUB(6,36) TORQUE(36) SAVE(36,20)		AEF1CM
Q(10) : DTT		AEMNCM
MB SB IO IQ(10) SQ(2,10) IQA(2,10) IQO(10) IFXO IMXO IP(5) IPP(5,5) IPO(5) XAPQ(2,5,4,30) MQDQ(10,10) : MPP(5,5) IQDQ(10,10) : SPQ(5,10)	summed over q_j (IQDQ)	INC1CM

MOTNB1

Name: MOTNB1(PS1)

Function: calculate blade and hub motion

General reference: section 5.1.5

Rigid pitch p_r: section 5.1.3

PSI	ψ	
Q(10) : DTT		AEMNCM
MHARM MHARFM		TMDATA
NBLADE NBM NTM NGM		R1DATA RTR1CM
KPB(10) KPG		MD1CM
T75 T1C T1S		CONTCM
BETA(21,10) THETA(21,5) BETAG(21)		MNR1CM
ALF(10,6) : DPSIS0		MNH1CM

AEROF1

Name: AEROF1(JPSI,QT,MQ,MP,CMX,CMZ,CFX,CFZ,CFR)

Function: calculate blade aerodynamic forces

Calculate XAP = $\vec{X}_{A_k}$: section 2.2.19

Section velocity components: section 2.4.2
Calculate U, M, ϕ, α: section 2.4.1

ϕ in rad, α in deg

Calculate $\dot{\alpha}c/V$: section 2.4.7
Calculate $\cos\Lambda$: section 2.4.6

REVFLW = 1 if just crossed reverse flow boundary

Tip loss correction: section 2.4.5
Section forces and pitch moment: section 2.4.1

FZ = F_z/ac_m, FX = F_x/ac_m, FR = F_r/ac_m, MA = M_a/ac_m

Circulation: section 2.4.9
Unsteady lift, moment, and circulation: sections 2.4.8, 2.4.9

LUS = L_{us}/ac, MUS = M_{us}/ac, GUS = Γ_{us}/ac

Maximum circulation outboard $r_{G_{max}}$: section 3.1.4

JPSI	azimuth index j
QT(4)	q_{jtrim}
MQ(10)	$M_{q_k aero}/ac$
MP(5)	$M_{p_k aero}/ac$
CMX	$C_{m_x}/\sigma a$
CMZ	$C_{m_z}/\sigma a$
CFX	$C_{f_x}/\sigma a$
CFZ	$C_{f_z}/\sigma a$
CFR	$C_{f_r}/\sigma a$

Q(10) AEMNCM
DQ(10)
DDQ(10)
P(5)
DP(5)
DDP(5)
BG
DBG
DDBG
AHUB(6)
DAHUB(6)
DDAHUB(6)

PS DPS DDPS		AEMNCM
DEBUG MPSI		TMDATA
DPSI FSCALE COSPSI(36) SINPSI(36)		TRIMCM
MRA CHORD(30) TWIST(30) THETZL(30) XA(30) XAC(30) RGMAX RFA XFA OPUSLD		R1DATA
RA(30) DRA(30) MTIP OMEGA CMEAN FTIP(30) MUX MUY MUZ NBM NTM NBMT RGUST(3,3) CHUB(6,16)		RTR1CM
XAPQ(2,4,5,30)		INC1CM
T75 DVBODY(6)		CONTCM
VIND(3,30,36)		WKV1CM
VINT(3,30,36)	interference velocity from other rotor	WKV2CM
GAM(30,36) CIRC(36)		QR1CM
SAVE(30,36,19)		AES1CM
VGUST(3,30,36) VGUSTH(3)	gust at rotor disk, shaft axes gust at rotor hub, velocity axes	GUSTCM

ETA(2,10,30)	bending modes at r_i, i = 1 to MRA	MD1CM
ETAP(2,10,30)		
ETAPP(2,10,20)		
ZETA(5,30)	torsion modes at r_i, i = 1 to MRA	
ZETAP(5,30)		
DEL1		
DEL2		
DEL3		
DEL4		
DEL5		

AEROS1

Name: AEROS1(ALPHA,DALPHA,COSYAW,MACH,JPSI,IR,REVFLW,CL,CD,CM,CDR,OPTION)

Function: calculate blade section aerodynamic coefficients

Corrected Mach number: section 2.4.5
Stall model, delayed α: section 2.4.7
Yawed flow, effective α: section 2.4.6
Calculate 2-D airfoil characteristics at effective α and M: section 2.4.7
Section characteristics corrected for yawed flow and stall delay: sections 2.4.6, 2.4.7
Dynamic stall vortex loads: section 2.4.7

ALPHA	angle of attack α (deg)
DALPHA	$\dot{\alpha}c/V$
COSYAW	cos Λ
MACH	Mach number M
JPSI	azimuth index j
IR	radial station index i
REVFLW	integer parameter: 1 if just crossed reverse flow boundary
CL	c_ℓ
CD	c_d
CM	c_m
CDR	$c_{d_{radial}}$
OPTION	integer parameter: 0 for derivatives of coefficients in flutter analysis (no dynamic stall vortex loads, and calculated data not saved)

STATE(30,36,3) AES1CM
DCLMAX(30,36)
DCDMAX(30,36)
DCMMAX(30,36)
MEFF(30,36,3)
AEFF(30,36,3)
DCLDS(30,36)
DCDDS(30,36)
DCMDS(30,36)

MRA R1DATA
MCORRL(30)
MCORRD(30)
MCORRM(30)

AEROS1

TAUL TAUD TAUM ADELAY AMAXNS PSIDS(3) ALFDS(3) ALFRE(3) CLDSP CDDSP CMDSP OPYAW OPSTLL OPCOMP	R1DATA
DEBUG MPSI	TMDATA

AEROT1

Name: AEROT1(ALPHA,MACH,RADIAL,OPTION,CL,CD,CM)

Function: interpolate airfoil tables

General reference: section 2.4.4

ALPHA	angle of attack α (deg)
MACH	Mach number M
RADIAL	radial station r/R
OPTION	integer parameter: if 1 calculate c_ℓ, if 2 calculate c_d, if 3 calculate c_m, if 4 calculate all three coefficients
CL	$c_{\ell_{2D}}$
CD	$c_{d_{2D}}$
CM	$c_{m_{2D}}$

NAB
NA(20)
A(20)
NMB
NM(20)
M(20)
NRB
R(11)
CLT(5000)
CDT(5000)
CMT(5000)

A1TABL

BODYV1

Name: BODYV1

Function: calculate harmonics of airframe motion

General reference: section 5.1.8

DEBUG MPSI MHARMF	TMDATA
NBLADE	R1DATA
NAM	BODYCM
HBODY(16,6,10)	RH1CM
FHUB(6,36)	AEF1CM
PHI(10,16)	MNR1CM
KEPSI(21,36)	TRIMCM

ENGNV1

Name: ENGNV1

Function: calculate harmonics of drive train motion

General reference: section 5.1.9

DEBUG MHARMF MPSI	TMDATA
NBLADE	R1DATA
NDM	ENGNCM
TORQUE(36)	AEF1CM
PSID(10,6)	MNR1CM
HENG(6,10)	RH1CM
KEPSI(21,36)	TRIMCM

MOTNF1

Name: MOTNF1

Function: calculate rotor generalized forces

General reference: section 5.1.7

C_L/σ and C_X/σ for trim: section 5.2.1

DEBUG MPSI	TMDATA
SIGMA	R1DATA
GAMMA MUX MUY MUZ CHUBT(16,6)	RTR1CM
FHUB(6,36)	AEF1CM
FHUBM(6) QRTR(6) CLS CXS CTS CYS CPS CT CMX CMY	QR1CM

MOTNS

Name: MOTNS

Function: calculate static elastic motion

General reference: section 5.1.10

DEBUG		TMDATA
DOFA(16)	airframe degrees of freedom	
DOFD(6)	drive train degrees of freedom	
CPRTR2		TRIMCM
CHUBT1(16,6)		RTR1CM
CHUBT2(16,6)		RTR2CM
DDALF1(6)		MNH1CM
DDALF2(6)		MNH2CM
FHUBM1(6)		QR1CM
FHUBM2(6)		QR2CM
ASPRNG(10)		BODYCM
ACNTRL(4,10)		
NAM		
HENGO(2,2)		ENGNCM
NDM		
DELF		CONTCM
DELE		
DELA		
DELR		
MB1		INC1CM
MB2		INC2CM
QSSTAT(10)		MNSCM
PISTAT		
PESTAT		

BODYF

Name: BODYF(LEVEL1,LEVEL2)

Function: calculate airframe generalized forces

General reference: section 4.2.6

LEVEL1 LEVEL2	wake level for rotor #1 and rotor #2: 0 for uniform inflow	
DEBUG MPSI AFLAP		TMDATA
GAMMA SIGMA RADIUS OMEGA OPRTR2	reference rotor	TRIMCM
VBODY(3)	$(\dot{x}_F \; \dot{y}_F \; \dot{z}_F)$	CONTCM
WBODY(3)	$(\dot{\phi}_F \; \dot{\theta}_F \; \dot{\psi}_F)$	
DELF DELE DELA DELR DDZF		
CANTHT CANTVT		BDDATA
REULER(3,3) RWB(3) RHT(3) RVT(3) VELF(3)		BODYCM
QWB(6) QHT(6) QVT(6) SAVE(31)		QBDCM
VIW1(3,36) VIH1(3,36) VIV1(3,36) LMDAW1(3) LMDAH1(3) LMDAV1(3)		WKV1CM

VIW2(3,36) VIH2(3,36) VIV2(3,36) LMDAW2(3) LMDAH2(3) LMDAV2(3)		WKV2CM
GWB(3) GHT(3) GVT(3)	gust in F axes	GUSTCM

BODYA

Name: BODYA(VWB,VHT,VVT,WWB,AFLAP,DELF,DELE,DELA,DELR,DAWB, FWB,MWB,FHT,FVT,ANGLES)

Function: calculate body aerodynamic forces

General reference: section 4.2.6

VWB(3) VHT(3) VVT(3)	velocity (u, v, w) at wing-body, horizontal tail, and vertical tail; F axes; ft/sec or m/sec
WWB(3)	angular velocity (p, q, r); rad/sec
AFLAP	flap angle δ_F (deg)
DELF	flaperon control δ_f (rad)
DELE	elevator control δ_e (rad)
DELA	aileron control δ_a (rad)
DELR	rudder control δ_r (rad)
DAWB	$\dot{\alpha}_{WB}$ (rad/sec)
FWB(3)	$(D/q,\ Y/q,\ L/q)_{WB}$; ft^2 or m^2
MWB(3)	$(M_x/q,\ M_y/q,\ M_z/q)_{WB}$; ft^3 or m^3
FHT(2)	$(D/q,\ L/q)_{HT}$, ft^2 or m^2
FVT(2)	$(D/q,\ L/q)_{VT}$; ft^2 or m^2
ANGLES(6)	$(\alpha_{WB},\ \beta_{WB},\ \alpha_{HT},\ \alpha_{VT},\ \epsilon,\ \sigma)$; deg

CANTHT CANTVT	BDDATA
LFTAW : OPTINT	BADATA

WAKEC1

Name: WAKEC1(LEVEL)

Function: calculate influence coefficients for nonuniform inflow

General reference: sections 3.1.3, 3.1.4

Calculate h for axisymmetric wake: section 3.1.6
Ground effect parameters: sections 2.4.3, 3.1.5
Calculate first blade/vortex intersection age and core bursting age: section 3.1.7
Wake age loop:

$$LANDJ = (\ell - 1) * MR * MPSI + j$$

$$JTEMJ = j_{te} - j$$

Burst/unburst core radius: section 3.1.7
Axisymmetric far wake: section 3.1.6
Complete C and C_{NW} for axisymmetric geometry: section 3.1.6

LEVEL	wake analysis: 0 for uniform inflow, 1 for prescribed wake, 2 for free wake geometry	
NBLADE		R1DATA
RADIUS		
ROTATE		
RROOT		
CHORD(30)		
MRA		
INFLOW(6)		
ROTATO	other rotor	R2DATA
RADUSO		
OMEGA		RTR1CM
CMEAN		
RA(30)		
PINTER(36)		
PBURST(36)		
DPSI21	$\Delta\Psi_{21}$ (rad); $-\Delta\Psi_{21}$ for rotor #2	
OMEGAO	other rotor	RTR2CM
BETAC		QR1CM
BETAS		
BETASO		QR2CM
BETASO		
MPSI		TMDATA
DEBUG		
DEBUGV	debug print control for VTXL and VTXS	
OPGRND		
HAGL		

		WAKEC1
DPSI		
LSCALE		TRIMCM
FSCALE		
RWB(3)		
RHT(3)		BODYCM
RVT(3)		
RHUB(3)		
RHUBO(3)	other rotor	
ROFF(3)		
RSF(3,3)		
RSFO(3,3)	other rotor	
KE(3)		
RFE(3,3)		
K2T		
MUTPP(3)		WG1CM
KNW		
KRW		W1DATA
KFW		
KDW		
RRU		
FRU		
PRU		
FNW		
DVS		
DLS		
CORE(5)		
OPCORE(2)		
WKMODL(13)		
OPNWS(2)		
LHW		
OPHW		
OPRTS		
VELB		
DPHIB		
DBV		
QDEBUG		
MRG		
NG(30)		
MRL		
NL(30)		
MRLO	other rotor	
		W2DATA

```
MR
ML
MI
MW
MH
MV
MO
C(3,20000)
CNW(3,20000)
```

WAKEB1

Name: WAKEB1(PSI,OPTION,RBR,RBT,RB)

Function: calculate blade position

General reference: section 3.1.3

PSI	ψ (rad)	
OPTION	integer parameter controlling calculation of $\vec{r}_b$: if 1, at r_{ROOT} and 1; if 2, at circulation stations; if 3, at inflow stations	
RBR(3)	$\vec{r}_b$ at r_{ROOT}	
RBT(3)	$\vec{r}_b$ at tip ($r = 1$)	
RB(3,30)	$\vec{r}_b$ at inflow or circulation stations	
MPSI		TMDATA
MHARMF		
MHARM		
RFA		R1DATA
ZFA		
XFA		
NBLADE		
RROOT		
NBM		RTR1CM
RA(30)		
OPWKBP(3)		W1DATA
MRG		
NG(30)		
MRL		
NL(30)		
BETA(21,10)		MNR1CM
BETAG(21)		
PSIS(10)		MNH1CM
PSIS0		
ETA(2,10,30)	bending modes at r_i, i = 1 to MRA	MD1CM
ETAR(2,10)	bending modes at r_{ROOT}	
ETAT(2,10)	bending modes at tip ($r = 1$)	
DEL1		
DEL2		
DEL3		

VTXL

Name: VTXL(R1,R2,RP,MODEL,OPCORE,CORE,DLS,CHORD,PSI,OPGRND,ZAGL,RTE,
V1,V2,DEBUG)

Function: calculate vortex line segment induced velocity

General reference: section 3.1.7

Calculate: S1 = s_1/s, S2 = s_2/s, RMSQ = r_m^2

Lifting surface correction:

ANGLS = Λ (deg)

HLS = h (-1.0 for no correction)

RSINL = $r \sin\Lambda$, COSL = $\cos\Lambda$, SINL = $\sin\Lambda$

LLL = L_{ll}, LLS = L_{ls}, FACTLS = L_{ls}/L_{ll}

Image element in ground effect: section 3.1.5

R1(3)	$\vec{r}_1$ (at ϕ)
R2(3)	$\vec{r}_2$ (at $\phi+\Delta\Psi$)
RP(3)	$\vec{r}_P$ (at P)
MODEL	integer parameter: 1 for stepped vorticity distribution, 2 for linear vorticity distribution
OPCORE	integer parameter defining vortex core type: 0 for distributed, 1 for concentrated vorticity
CORE	vortex core radius r_c
DLS	d_{ls} for lifting surface correction, LT 0. to suppress
PSI	Ψ; required for $d_{ls} \geq 0$ only
CHORD	chord c at P; required for $d_{ls} \geq 0$ only
OPGRND	integer parameter: 0 for out of ground effect
ZAGL	z_{AGL}; required in ground effect only
RTE(3,3)	R_{TE}; required in ground effect only
DEBUG	integer parameter: debug print if GE 3
V1(3)	$\Delta\vec{v}$ due to Γ_1 (at ϕ)
V2(3)	$\Delta\vec{v}$ due to Γ_2 (at $\phi+\Delta\Psi$)

VTXS

Name: VTXS(R1,R2,R3,R4,RP,MODELT,MODELS,OPCORE,CORET,CORES,DVS,
OPGRND,ZAGL,RTE,MDLT,MDLS,VT1,VT2,VS1,VS3,DEBUG)

Function: calculate vortex sheet segment induced velocity

General reference: section 3.1.8

Image element in ground effect: section 3.1.5

R1(3)	$\vec{r}_1$
R2(3)	$\vec{r}_2$
R3(3)	$\vec{r}_3$
R4(3)	$\vec{r}_4$
RP(3)	$\vec{r}_P$
MODELT MODELS	integer parameters defining trailed and shed vorticity model: 0 to omit, 1 for stepped line, 2 for linear line, 3 for sheet
OPCORE	integer parameter defining vortex core type: 0 for distributed, 1 for concentrated vorticity
CORET	r_c for trailed vorticity (LT 0. for s/2)
CORES	r_c for shed vorticity (LT 0. for t/2)
DVS	d_{vs} for sheet edge test; LT 0. to suppress
OPGRND	integer parameter: 0 for out of ground effect
ZAGL	z_{AGL}; required in ground effect only
RTE(3,3)	R_{TE}; required in ground effect only
DEBUG	integer parameter: debug print if GE 3
MDLT MDLS	integer parameters specifying trailed and shed vorticity model used
VT1(3)	$\Delta\vec{v}_t$ due to Γ_1 (at ϕ, outside edge)
VT2(3)	$\Delta\vec{v}_t$ due to Γ_2 (at $\phi+\Delta\Psi$, outside edge)
VS1(3)	$\Delta\vec{v}_s$ due to Γ_1 (at ϕ, outside edge)
VS3(3)	$\Delta\vec{v}_s$ due to Γ_3 (at ϕ, inside edge)

$$(\Delta v_{t_3} = -\Delta v_{t_1},\ \Delta v_{t_4} = -\Delta v_{t_2})$$
$$(\Delta v_{s_2} = -\Delta v_{s_1},\ \Delta v_{s_4} = -\Delta v_{s_3})$$

GEOME1

Name: GEOME1(K,L,LEVEL,RWT,RWSO,RWSI)

Function: evaluate wake geometry

General reference: section 3.1.3

K	k ($\phi = k\Delta\psi$)
L	ℓ ($\psi = \ell\Delta\psi$)
LEVEL	wake analysis: 1 for prescribed wake geometry, 2 for free wake geometry
RWT(3)	$\vec{r}_w$ at tip vortex
RWSO(3)	$\vec{r}_w$ at sheet inside edge
RWSI(3)	$\vec{r}_w$ at sheet outside edge

MPSI	TMDATA
DPSI	TRIMCM
KRWG	W1DATA
KFWG	G1DATA
RBR(3,36)	WG1CM
RBT(3,36)	
MUTPP(3)	
DZT(144)	
DRT(144)	
K2T	
DZSI(144)	
DRSI(144)	
K2SI	
DZSO(144)	
DRSO(144)	
K2SO	
DFWG(3,2304)	

GEOMR1

Name: GEOMR1(LEVEL)

Function: calculate wake geometry distortion

General reference: section 3.1.3

Prescribed wake geometry: CTG = C_T, CTOS = C_T/σ, TW = θ_{tw} (deg)

LEVEL	wake analysis: 1 for prescribed wake geometry, 2 for free wake geometry	
DEBUG		TMDATA
MPSI		
DPSI		TRIMCM
NBLADE		R1DATA
SIGMA		
TWIST(30)	θ_{tw} at r_i, i = 1 to MRA	
KHLMDA		
RROOT		
MRA		
LAMBDA		WKV1CM
LAMBDI	interference velocity, due to other rotor	WKV2CM
KRWG		W1DATA
OPRWG		
FWGT(2)		
FWGSI(2)		
FWGSO(2)		
KWGT(4)		
KWGSI(4)		
KWGSO(4)		
CT	C_T	QR1CM
CIRC(36)		
BETAC		
BETAS		
RA(30)		RTR1CM
MUX		
MUY		
MUZ		
RBR(3,36)		WG1CM
⋮		
K2SO		

GEOMF1

Name: GEOMF1

Function: calculate free wake geometry distortion

General reference: section 3.2

Subprograms required: WGAM, DCALC, NWCAL, WQCAL, VSCAL, QSVL, QCVL, QVS

DEBUG	integer parameter controlling debug print: GE 1, print D at $\phi = 2\pi/N$ each iteration; GE 2, allow printing; GE 3, controlled by IPWGDB and QWGDB	TMDATA
MPSI	(maximum 24, multiple NBLADE)	
SIGMA NBLADE		R1DATA
PHIBWG(36)	core burst age $\phi_b(\psi)$ (rad)	RTR1CM
DBV		W1DATA
MUTPP(3) DFWG(3,2304)		WG1CM
LAMBDA FACTGE		WKV1CM
LAMBDI	interference velocity, due to other rotor	WKV2CM
CONING	β_0 (rad)	QR1CM
CIRC(36)	Γ/Ω^2R	
KFWG OPFWG ITERWG FACTWG WGMODL(2) RTWG(2) COREWG(4) MRVBWG LDMWG NDMWG(36) IPWGDB(2) QWGDB DQWG(2)		G1DATA
DEL1 DEL2		MD1CM

MINV

Name: MINV(A,N,D,L,M)

Function: calculate inverse of matrix

Input:

A(N*N)	matrix (destroyed)
N	dimension
L(N+1)	scratch vector
M(N+1)	scratch vector

Output:

A(N*N)	A - inverse
D	determinant of A; 0. if A is singular

MINVC

Name: MINVC(A,N,D,L,M)

Function: calculate inverse of complex matrix

Input:

A(N*N)	complex matrix
N	dimension
L(N+1)	scratch vector
M(N+1)	scratch vector

Output:

A(N*N)	complex A - inverse
D	complex determinant of A; 0. if A is singular

EIGENJ

Name: EIGENJ(N,NM,A,T,EVR,EVI,VECR,VECI,INDIC,NEI)

Function: calculate eigenvalues and eigenvectors of matrix

Subprograms required: SCALEM, HESQR, REALVE, COMPVE

Input:

A(N*N)	matrix A (destroyed)
N	order of matrix
NM	actual first dimension of arrays; maximum 100
NEI	0 to calculate only eigenvalues
T	dummy argument (set to 24. in EIGENJ)

Output:

EVR(N)	real part of eigenvalues of A
EVI(N)	imaginary part of eigenvalues of A
VECR(N*N)	real part of eigenvectors of A
VECI(N*N)	imaginary part of eigenvectors of A
INDIC(N)	if 2, no error; if 1, eigenvector not found; if 0, neither eigenvector nor eigenvalue found

DERED

Name: DERED(NX,NV,DOF,CON,A2,A1,A0,B,DOF1,DOF0,NAMEX,NAMEV)

Function: eliminate equations and variables from system of differential equations

Input:

NX	dimension of matrices
NV	dimension of matrices
DOF(NX)	integer vector designating degrees of freedom to be eliminated: DOF = 0 if variable not used
CON(NV)	integer vector designating controls to be eliminated: CON = 0 if variable not used
A2(NX*NX) A1(NX*NX) A0(NX*NX)	coefficient matrices
B(NX*NV)	control matrix
DOF0(NX)	integer vector
DOF1(NX)	integer vector
NAMEX(NX)	vector of variable names
NAMEV(NV)	vector of control names

Output:

A2 A1 A0 B DOF0 DOF1 NAMEX NAMEV	reconstructed matrices and vectors

QSTRAN

Name: QSTRAN(MX,MX0,MX1,MV,A2,A1,A0,B0,DOF1,DOF0,NAMEX)

Function: quasistatic reduction of system of linear differential equations

General reference: section 6.3.2

Input:

A2(MX*MX) A1(MX*MX) A0(MX*MX)	coefficient matrices
B0(MX*MV)	control matrix
DOF1(MX)	integer vector designating first order degrees of freedom: DOF1(I) = 0 for x_i first order
DOF0(MX)	integer vector designating quasistatic variables: DOF0(I) = 0 for x_i quasistatic
MX	number of degrees of freedom, maximum 60
MX0	number of quasistatic degrees of freedom
MX1	number of first order degrees of freedom
MV	number of controls, maximum 60
NAMEX(MX)	vector of variables names

Output:

A2 A1 A0 B0 DOF1 NAMEX	reconstructed matrices and vectors
MX	number of remaining degrees of freedom (MX-MX0)
MX1	number of remaining first order degrees of freedom

CSYSAN

Name: CSYSAN(N,MX,MX1,MV,A2,A1,A0,B0,NFREQ,FREQ,NSTEP,DOF1,FSCALE,
NAMEX,NAMEV,NFOUT)

Function: analyze system of constant coefficient linear differential equations

General reference: sections 7.2, 7.2.1

N — calculation control

	N = 0	1	2	10	11	12
eigenvalues	x	x	x	x	x	x
eigenvectors		x	x		x	x
check sums			x			x
zeros				x	x	x

A2(MX*MX) A1(MX*MX) A0(MX*MX)	coefficient matrices
B0(MX*MV)	control matrix
MX	number of degrees of freedom
MX1	number of first order degrees of freedom
MV	number of controls (maximum MX2 = 2*MX - MX1 = 60; maximum MV = 60)
DOF1(MX)	integer vector designating first order degrees of freedom (zero columns in A0); DOF1(I) = 0 for x_i first order
FSCALE	frequency scale factor Ω (in rad/sec to obtain frequencies in Hz and times in sec); there is no print of dimensional eigenvalues if FSCALE $\leq$ 0.
NAMEX(MX)	vector of variables names
NAMEV(MV)	vector of control names
NSTEP	static response calculated if NSTEP $\neq$ 0
NFREQ	number of frequencies for which frequency response calculated; none if NFREQ $\leq$ 0
FREQ(NFREQ)	vector of frequencies (dimensionless) for calculation of frequency response
NFOUT	unit number for printed output

Output:

LAMDA(MX2)	eigenvalues
MX2	number of eigenvalues

available in following common block:

```
COMMON /EIGVC/LAMDA(60),MX2
COMPLEX LAMDA
```

DETRAN

Name: DETRAN(A,MX,MX1,MV,A2,A1,A0,B0,DOF1,NAMEX,NAME,NFOUT)

Function: transform equations to state variable form

General reference: section 7.1

Input:

A2(MX*MX) A1(MX*MX) A0(MX*MX)	coefficient matrices
B0(MX*MV)	control matrix
MX	number of degrees of freedom, maximum 60
MX1	number of first order degrees of freedom
MV	number of controls, maximum 60
DOF1(MX)	integer vector designating first order degrees of freedom; DOF1(I) = 0 for x_i first order
NAMEX(MX)	vector of variable names
NFOUT	unit number for printed output

Output:

A(MX2*MX2)	coefficient matrix
B0(MX*MV)	control matrix
NAME(MX2)	vector of variable names

(MX2 = 2 * MX - MX1)

SINE

Name: SINE(W,A,ASQ,BO,MX,MX1,MV,NAME,NAMEV,NFCUT)

Function: calculate frequency response from matrices

General reference 7.2.3

Response calculation: for last MX states only

W	frequency (dimensionless)
A(MX2*MX2)	coefficient matrix A
ASQ(MX2*MX2)	coefficient matrix squared, A^2
BO(MX*MV)	control matrix
MX	number of degrees of freedom
MX1	number of first order degrees of freedom
MV	number of controls (maximum MX2 = 2*MX - MX1 = 60; maximum MV = 60)
NAME(MX2)	vector of variable names
NAMEV(MV)	vector of control names
NFOUT	unit number for printed output

STATIC

Name: STATIC(A,BO,MX,MX1,MV,NAME,NAMEV,NFOUT)

Function: calculate static response from matrices

General reference: section 7.2.2

Response calculation: for last MX states only

A(MX2*MX2)	coefficient matrix
BO(MX*MV)	control matrix
MX	number of degrees of freedom
MX1	number of first order degrees of freedom
MV	number of controls (maximum MX2 = 2*MX - MX1 = 60; maximum MV = 60)
NAME(MX2)	vector of variable names
NAMEV(MV)	vector of control names
NFOUT	unit number for printed output

ZERO

Name: ZERO(A,BO,MX2,MX,MV,NX,NV)

Function: calculate zeros

General reference: section 7.2.4

A(MX2*MX2)	coefficient matrix
BO(MX*MV)	control matrix
MX2	number of states, maximum 60
MX	number of degrees of freedom
MV	number of controls
NX	state number i for which zeros to be calculated
NV	control number j for which zeros to be calculated

Output:

LAMDAZ(MZ)	zeros of x_i/v_j
K1	factor K_1: $x_i/v_j = K_1 \frac{\prod(z-s)}{\prod(p-s)}$
MZ	number of zeros

available in the following common block:

```
COMMON /EIGVZ/LAMDAZ(60),K1,MZ
COMPLEX LAMDAZ
REAL K1
```

ZETRAN

Name: ZETRAN(Z,MZ)

Function: transform matrix for zero calculation

General reference: section 7.2.4

Input:

Z(MZ*MZ)	matrix A^* (A with x_i column replaced by v_j column of B)
MZ	number of states, MX2

Output:

Z(MZ*MZ)	matrix A_1 (eigenvalues of which are the zeros); the factor K_1 is in Z(MZ*MZ+1)
MZ	number of zeros GT 0 finite number of zeros exists EQ 0 no zeros, K_1 = Z(1) LT 0 x_i not controllable by v_j

BODE

Name: BODE(MX,MX1,MV,A2,A1,A0,B0,DOF1,NAMEX,NAMEV,NPLOT,NAMEXP,NAEMVP,
NX,NV,NF0,NF1,ND,MSCALE,NFOUT)

Function: calculate and printer-plot transfer function (Bode plot)

General reference: section 7.2.3

A2(MX*MX) A1(MX*MX) A0(MX*MX)	coefficient matrices
B0(MX*MV)	control matrix
MX	number of degrees of freedom
MX1	number of first order degrees of freedom
MV	number of controls (maximum MX2 = 2*MX - MX1 = 60; maximum MV = 60)
DOF1(MX)	integer vector designating first order degrees of freedom; DOF1(I) = 0 for x_i first order
NAMEX(MX)	vector of variable names
NAMEV(MV)	vector of control names
NPLOT	frequency response calculation method: if 1, from matrices; if 2, from poles and zeros
NAMEXP(NX)	vector of variable names to be plotted (inconsistent names ignored)
NAMEVP(NV)	vector of control names to be plotted (inconsistent names ignored)
NX	number of degrees of freedom to be plotted; maximum 30
NV	number of controls to be plotted; maximum 30
NF0	exponent (base 10) of beginning frequency
NF1	exponent (base 10) of end frequency
ND	frequency steps per decade (maximum NF = (NF1 - NF0)*ND + 1 = 151)
MSCALE	magnitude plot scale: if 1, plot relative maximum value; if 2, plot relative 10**K; if 3 plot relative 10.
NFOUT	unit number for printed output

BODEPP

Name: BODEPP(HM,HP,NFO,NF1,ND,OPTION,NFOUT)

Function: printer-plot transfer function magnitude and phase

HM(N)	transfer function magnitude
HP(N)	transfer function phase (degrees, -180 to 180) (N = (NF1 - NFO)*ND + 1)
NFO	exponent (base 10) of beginning frequency
NF1	exponent (base 10) of end frequency
ND	frequency steps per decade
OPTION	magnitude plot scale: if 1, plot relative maximum value; if 2, plot relative 10**K; if 3, plot relative 10.
NFOUT	unit number for printed output

TRACKS

Name: TRACKS(A2,A1,A0,B0,MX,MX1,MV,DOF1,OMEGA,NAMEX,NAMEV,NPLOT,
PERIOD,DELT,TMAX,NAMEXP,NAMEVP,NX,NV,NPOUT)

Function: calculate and printer-plot time history of time-invariant system response

General reference: section 7.2.5

Calculate eigenvalue matrix and modal matrix:

MRED = M without unused states (rows)

MB = $M^{-1}B$ without unused controls (columns)

A2(MX*MX) A1(MX*MX) A0(MX*MX)	coefficient matrices
B0(MV*MX)	control matrix
MX	number of degrees of freedom
MX1	number of first order degrees of freedom
MV	number of controls (maximum MX2 = 2*MX - MX1 = 60; maximum MV = 60)
DOF1(MX)	integer vector designating first order degrees of freedom; DOF1(I) = 0 for x_i first order
NAMEX(MX)	vector of variable names
NAMEV(MV)	vector of control names
OMEGA	frequency scale (rad/sec)
NPLOT	control input type 1 step 2 impulse 3 cosine impulse 4 sine doublet 5 square impulse 6 square doublet
PERIOD	period T (sec) for impulse or doublet (NPLOT = 3 to 6)
DELT	time step (sec)
TMAX	maximum time (sec) (maximum NX*NV*TMAX/DELT = 7200)

NAMEXP(NX)	vector of variable names to be plotted (inconsistent names ignored)
NAMEVP(NV)	vector of control names to be plotted (inconsistent names ignored)
NX	number of degrees of freedom to be plotted; maximum 30
NV	number of controls to be plotted; maximum 30
NFOUT	unit number for printed output

TRCKPP

Name: TRCKPP(TRACE,NX,NV,MT,DELT,NAMEXP,NAMEVP,NFOUT)

Function: printer-plot time history

TRACE(NX,NV,MT)	array of time history traces to be plotted
NX	number of degrees of freedom to be plotted
NV	number of controls to be plotted (maximum NX*NV = 26)
MT	number of time steps to be plotted
DELT	time step (sec)
NAMEXP(NX)	vector of variable names
NAMEVP(NV)	vector of control names
NFOUT	unit number for printed output

GUSTS

Name: GUSTS(A2,A1,A0,B0,MX,MX1,MV,MG,DOF1,NAMEX,RADIUS,OMEGA,GRAV,
EULER,VEL,LGUST,MGUST,NAMEXR,NAMEXL,ML,NAMEXA,MACC,
FREQA,RACC,NEM,ZETA,NAMEXB,NFCUT)

Function: calculate and print rms gust response

General reference: section 7.2.6

A2(MX*MX) A1(MX*MX) A0(MX*MX)	coefficient matrices
B0(MX*MV)	control matrix (gust in last MG columns)
MX	number of degrees of freedom
MX1	number of first order degrees of freedom
MV	number of controls and gusts
MG	number of gust components (maximum MX2 = 2*MX - MX1 + MACC + MG = 60) (maximum MG = 3)
DOF1(MX)	integer vector designating first order degrees of freedom; DOF1(I) = 0 for x_i first order
NAMEX(MX)	vector of variable names
RADIUS	length scale R (ft or m)
OMEGA	frequency scale Ω (rad/sec)
GRAV	acceleration due to gravity (ft/sec^2 or m/sec^2)
EULER(2)	trim Euler angles θ_{FT} and ϕ_{FT} (rad); required for body axis acceleration only
VEL(3)	velocity components in body axis frame (divided by ΩR); only magnitude required (for τ_G) unless body axis acceleration calculated
LGUST(MG)	real vector of gust correlation lengths: if GT 0, dimensional correlation length L (τ_G = L/2V); if EQ 0, L = 400. used; if LT 0, magnitude is correlation time τ_G (dimensionless), so break frequency is $\omega = \Omega/\tau_G$
MGUST(MG)	real vector of gust component relative magnitudes
NAMEXR(3)	names of β_{1c}, ζ_{1c}, θ_{1c} in state vector (NAMEX); analysis assumes that β_{1s}, ζ_{1s}, θ_{1s} follow immediately (inconsistent names ignored)

NAMEXL(ML)	names of linear degrees of freedom in state vector (NAMEX) for dimensional output (ft or m, obtained from R); degrees of freedom not identified are angular (degrees) (inconsistent names ignored)
ML	number of linear degrees of freedom
NAMEXA(MACC)	names of degrees of freedom (NAMEX) for which acceleration calculated; last three names must equal ACCB to calculate body axis acceleration (all three or none) (inconsistent names ignored)
FREQA(MACC)	accelerometer break frequency (Hz), in same order as NAMEXA; 2/rev used if FREQA ≤ 0.
MACC	number of accelerometers; none if MACC ≤ 0
RACC(3)	x, y, z location of point at which body axis acceleration calculated (dimensionless)
ZETA(3,NEM)	airframe elast mode shapes, k = 1 to NEM; required for body axis acceleration only
NEM	number of airframe elastic modes; none if NEM ≤ 0; maximum 10
NAMEXB(6+NEM)	names of ϕ_F, θ_F, ψ_F, x_F, y_F, z_F, $q_{F_1} \cdots q_{F_{NEM}}$ in state vector (NAMEX); assumes all elastic airframe states are consequtive; required for body axis acceleration only (inconsistent names ignored)
NFOUT	unit number for printed output

PSYSAN

Name: PSYSAN(MX,MX1,A2,A1,A0,PHI,DT,NT,MT,PERIOD,DOF1,NINT,NFOUT)

Function: analyze system of periodic coefficient linear differential equations

General reference: section 7.3

A2(MX*MX) A1(MX*MX) A0(MX*MX)	coefficient matrices
MX	number of degrees of freedom
MX1	number of first order degrees of freedom (maximum MX2 = 2*MX - MX1 = 60)
DOF1(MX)	integer vector designating first order degrees of freedom (zero columns in A0); DOF1(I) = 0 for x_i first order
DT	time increment; may vary with NT, but for Runge-Kutta integration successive pairs must be equal
NT	time step counter (NT = 0, 1, 2, ... MT)
MT	total number of time steps in numerical integration; for Runge-Kutta integeration, must be even
PERIOD	period T of the system
PHI	temporary storage of state transition matrix Φ and last A; dimension 2*MX2*MX2 for modified trapezoidal integration; dimension 3*MX2*MX2 for Runge-Kutta integration (MX2 = 2*MX - MX1)
NINT	numerical integration method: if 1, modified trapezoidal method, error order DT**3; if 2, Runge-Kutta method, error order (2*DT)**5
NFOUT	unit number for printed output

Output:

LAMDA(MX2)	roots λ (principal value)
LAMDAC(MX2)	eigenvalues λ_c of $\Phi(T)$
MX2	number of poles

available in the following common block:

```
COMMON /EIGVP/LAMDA(60),LAMDAC(60),MX2
COMPLEX LAMDA,LAMDAC
```

Typical usage:

```
      DT = PERIOD/MT
      DO 1 NT = 0,MT
      T = DT * NT
      calculate coefficient matrices at time T
    1 CALL PSYSAN
```

DEPRAN

Name: DEPRAN(A,MX,MX1,A2,A1,A0,DOF1,NFOUT)

Function: transform equations to state variable form

General reference: section 7.1

Input:

A2(MX*MX) A1(MX*MX) A0(MX*MX)	coefficient matrices
MX	number of degrees of freedom; maximum 60
MX1	number of first order degrees of freedom
DOF1(MX)	integer designator of first order degrees of freedom; DOF1(I) = 0 for x_i first order
NFOUT	unit number for printed output

Output:

A(MX2*MX2)	coefficient matrix (MX2 = 2*MX - MX1)

MAINTB

Name: MAINTB

Function: airfoil table preparation

General reference: section 2.4.4

Subprograms required: AEROT, AEROPP, C81INT, C81RD, REDCL, TABFIX

AEROT

Name: AEROT(ALPHA,MACH,RADIAL,OPTION,CL,CD,CM)

Function: interpolate airfoil tables

General reference: section 2.4.4

ALPHA	angle of attack α (deg)
MACH	Mach number M
RADIAL	radial station r/R
OPTION	integer parameter: if 1 calculate c_ℓ; if 2 calculate c_d, if 3 calculate c_m, if 4 calculate all three coefficients
CL	$c_{\ell_{2D}}$
CD	$c_{d_{2D}}$
CM	$c_{m_{2D}}$

AEROPP

Name: AEROPP(CL,CD,CM,MA,AMAX)

Function: printer-plot airfoil aerodynamic characteristics

Calculate ordinate limits:

a) c = maximum value of magnitude

b) N = [log c] (N = N - 1 if c < 1.)

c) K = [c/10**N] + 1

d) use for scale X = K * 10**N

CL(MA)	array of c_ℓ to be plotted
CD(MA)	array of c_d to be plotted
CM(MA)	array of c_m to be plotted
MA	number of angle of attack values; odd number
AMAX	maximum angle of attack; data in arrays for $\alpha = -\alpha_{max}$ to α_{max}, in MA steps

3. COMPUTER SYSTEM SUBPROGRAMS

The following computer system subprograms (or the equivalent) are required to determine the calendar date and time of day, which form the identification for jobs and files.

a) CALL TIME(ITIME)

Function: returns time of day (8 alphanumeric characters) in array ITIME(2)

b) CALL DATE(IDATE)

Function: returns calendar date (8 alphanumeric characters) in array IDATE(2)

The following computer system subprograms (or the equivalent) are required in the timing subprogram.

a) CALL SETTIM(0,0)

Function: initializes timer

b) ITIME = INTVAL(0,0)

Function: returns CPU time, in milliseconds since initialization

4 CORE REQUIREMENTS

The program requires 4.04 megabytes of core storage. Of this total, 1.84 megabytes is for the subprograms and 2.20 megabytes is for the common blocks. The common blocks for the nonuniform inflow influence coefficients (both rotors) require 0.96 megabytes.

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16 Abstract

The computer program for a comprehensive analytical model of rotorcraft aerodynamics and dynamics is described. This analysis is designed to calculate rotor performance, loads, and noise; the helicopter vibration and gust response; the flight dynamics and handling qualities; and the system aeroelastic stability. The analysis is a combination of structural, inertial, and aerodynamic models, that is applicable to a wide range of problems and a wide class of vehicles. The analysis is intended for use in the design, testing, and evaluation of rotors and rotorcraft, and to be a basis for further development of rotary wing theories. This report documents the computer program that implements the analysis.

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