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A Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics

Part II: User's Manual

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CONTENTS

A COMPREHENSIVE ANALYTICAL MODEL OF ROTORCRAFT AERODYNAMICS AND DYNAMICS

Part II: User's Manual

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SUMMARY

The use of 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 describes the use of the computer program that implements the analysis.

1. PROGRAM SUMMARY

The computer program calculates the loads and motion of helicopter rotors and airframe. First the trim solution is obtained; then the flutter, flight dynamics, and/or transient behavior can be calculated. Either a new job can be initiated, or further calculations can be performed for an old job.

For a new job, the input consists of block data or an input file (the program can create the input file from the block data), and airfoil files. Then namelists are read for additional data, particularly case-specific inputs. One or more cases can be run for a new job.

For an old job, the input consists of a restart file (written during the execution of a previous job), and namelists. Only one case can be run for an old job. The job can be resumed either at the point where the trim solution was completed, or it can be resumed in one of the subsequent tasks. For a trim restart, any or all of the other tasks can be initiated. For flutter, flight dynamics, or transient restarts, only that task can be done.

For both new and old jobs, a scratch file is usually needed; and the job may write data on the restart file. In the flutter and flight dynamics tasks, eigenvalue data may be written on a file.

For both new and old jobs, a case namelist is always read to define the job, and a trim namelist is read to define the flight condition and analysis tasks. Component and task namelists may be read as required.

The loads and motion solution is obtained by an iterative process. The inner-most loop consists of the rotor and airframe motion calculation, for prescribed control positions, induced velocity distribution, and mean shaft motion. Convergence of the motion solution is determined by comparing the calculated harmonics every few revolutions. The next loop consists of the uniform or nonuniform rotor-induced velocity calculation, followed by the motion solution. Convergence is determined by comparing the rotor thrust or circulation used to calculate the induced velocity with that resulting after the motion has been re-calculated. Before beginning the circulation and motion iterations, the blade bending and torsion modes are calculated. If the rotor nonuniform induced velocity is used, there is an additional outer loop, consisting of calculation of the rotor wake influence coefficients followed by the circulation and motion iterations. To calculate the influence coefficients, the prescribed or free wake geometry must be evaluated. Having completed the motion solution, the performance, loads, vibration, and noise can be evaluated as required.

The trim analysis proceeds in stages. In the first stage the trim solution is obtained for uniform inflow; in the second and third stages the trim solution is obtained for nonuniform inflow, with prescribed or free wake geometry respectively. The analysis can stop at any of these stages. Within each stage, the aircraft controls and orientation are incremented until the equilibrium of forces required for the specified trim state is achieved.

In the flutter analysis, the matrices are constructed that describe the linear differential equations of motion, and the equations are analyzed. Optionally the equations are reduced to just the aircraft rigid body degrees of freedom (by a quasistatic reduction), and the equations are analyzed as for the flight dynamics task.

In the flight dynamics analysis, the stability derivatives are calculated and the matrices are constructed that describe the linear differential equations of motion. These equations are analyzed (optionally including a numerical integration as for the transient analysis).

In the transient analysis, the rigid body equations of motion are numerically integrated, for a prescribed transient gust or control input.

2. SUBPROGRAM FUNCTIONS

The following pages list the subprograms that cons. ute the analysis, and state the primary function of each subprogram. Only the subprograms for rotor #1 are listed; the subprograms for rotor #2 have identical functions.

Subprogram Name	
MAIN	Primary job and analysis control
TIMER	Program timer
INPTN	Input for new job
INPTO	Input for old job
INPTA1	Read airfoil table file
INPTR1	Read rotor namelist
INPTW1	Read wake namelist
INPTB	Read body namelist
INPTL1	Read loads namelist
INPTF	Read flutter namelist for new job
INPTS	Read flight dynamics namelist for new job
INPTT	Read transient namelist for new job
INPTG	Read flutter namelist for old job
INPTU	Read flight dynamics namelist for old job
INPTV	Read transient namelist for old job
FILEI	Read or write input file
FILEJ	Read or write trim data file
FILER	Read or write restart file
FILEF	Read or write flutter restart file
FILES	Read or write flight dynamics restart file
FILET	Read or write transient restart file
FILEE	Write eigenvalue file
INIT	Initialization
INITA	Initialize environment parameters
INITC	Initialize case parameters
INITR1	Initialize rotor parameters
INITB	Initialize airframe parameters
INITE	Initialize drive train parameters
CHEKR1	Check for fatal errors

Subprogram Name	
PRNTJ	Print job input data
PRNTC	Print case input data
PRNT	Print trim input data
PRNTR1	Print rotor input data
PRNTW1	Print wake input data
PRNTB	Print body input data
PRNTF	Print flutter input data
PRNTS	Print flight dynamics input data
PRNTT	Print transient input data
PRNTG	Print transient gust and control input data
TRIM	Trim
TRIMI	Calculate trim solution by iteration
TRIMP	Print trim solution
FLUT	Flutter
FLUTM	Calculate flutter matrices
FLUTB	Calculate flutter aircraft matrices
FLUTR1	Calculate flutter rotor matrices
FLUTI1	Calculate flutter inertia coefficients
FLUTA1	Calculate flutter aerodynamic coefficients
FLUTL	Analyze flutter constant coefficient linear equations
STAB	Flight dynamics
STABM	Calculate flight dynamics stability derivatives and matrices
STABD	Print stability derivatives
STABE	Calculate flight dynamics equations
STABL	Analyze flight dynamics linear equations
STABP	Print flight dynamics transient solution
TRAN	Transient
TRANI	Calculate transient acceleration for numerical integration
TRANP	Print transient solution
TRANC	Calculate transient gust and control
CONTRL	Calculate transient control time history
GUSTU	Calculate uniform gust time history
GUSTC	Calculate convected gust wave shape
PERF	Performance
PERFR1	Calculate and print rotor performance

Subprogram Name	
LOAD	Loads, vibration, and noise
LOADR1	Calculate and print rotor loads
LOADH1	Calculate and print hub and control loads
LOADS1	Calculate and print blade section loads
LOADI1	Calculate inertia coefficients for section loads
LOADF	Calculate fatigue damage
LOADM	Calculate mean and half peak-to-peak
GEOMP1	Printer-plot of wake geometry
POLRPP	Printer-plot of polar plot
HISTPP	Printer-plot of azimuthal time history
NOISR1	Calculate and print far field rotational noise
BESSEL	Calculate J Bessel function
RAMF	Calculate rotor/airframe periodic motion and forces
MODE1	Blade modes
MODEC1	Initialize blade mode parameters
MODEB1	Calculate blade bending modes
MODEG	Calculate Galerkin functions for bending modes
MODEA1	Calculate articulated blade flap and lag modes
MODET1	Calculate blade torsion modes
MODEK1	Calculate kinematic pitch-bending coupling
MODED1	Calculate blade root geometry
INRTC1	Calculate blade inertia coefficients
MODEP1	Print blade modes
BODYC	Initialize airframe parameters at trim
ENGNC	Initialize drive train parameters at trim
MOTNC1	Initialize rotor parameters at trim
BODYM1	Calculate airframe transfer function matrix
ENGNM1	Calculate drive train transfer function matrix
WAKEU1	Calculate uniform wake-induced velocity
WAKEN1	Calculate nonuniform wake-induced velocity
INRTM1	Calculate rotor transfer function matrix
INRTI	Calculate inverse of transfer function matrix
MOTNH1	Calculate harmonics of hub motion
MOTNR1	Calculate harmonics of rotor motion
MOTNB1	Calculate blade and hub motion
AEROF1	Calculate blade aerodynamic forces
AEROS1	Calculate blade section aerodynamic coefficients
AEROT1	Interpolate airfoil tables
BODYV1	Calculate harmonics of airframe motion
ENGNV1	Calculate harmonics of drive train motion
MOTNF1	Calculate rotor generalized forces
MOTNS	Calculate static elastic motion
BODYF	Calculate airframe generalized forces
BODYA	Calculate body aerodynamic forces

Subprogram Name	
WAKEC1	Calculate influence coefficients for nonuniform inflow
WAKEB1	Calculate blade position
VTXL	Calculate vortex line segment induced velocity
VTXS	Calculate vortex sheet segment induced velocity
GEOME1	Evaluate wake geometry
GEOMR1	Calculate wake geometry distortion
GEOMF1	Calculate free wake geometry distortion
MINV	Calculate inverse of matrix
MINVC	Calculate inverse of complex matrix
EIGENJ	Calculate eigenvalues and eigenvectors of matrix
DERED	Eliminate equations and variables from system of differential equations
QSTRAN	Quasistatic reduction of system of linear differential equations
CSYSAN	Analyze system of constant coefficient linear differential equations
DETRAN	Transform equations to state variable form
SINE	Calculate frequency response from matrices
STATIC	Calculate static response from matrices
ZERO	Calculate zeros
ZETRAN	Transform matrix for zero calculation
BODE	Calculate and printer-plot transfer function (Bode plot)
BODEPP	Printer-plot transfer function magnitude and phase
TRACKS	Calculate and printer-plot time history of time-invariant system response
TRCKPP	Printer-plot time history
GUSTS	Calculate and print rms gust response
PSYSAN	Analyze system of periodic coefficient linear differential equations
DEPRAN	Transform equations to state variable form

3. NAMELIST, FILE, AND COMMON BLOCK LABELS

The list below gives the namelist labels used by the program, and the type of input data read in each. The corresponding common block labels are given in the right-hand column.

Namelist Label		Common Block Label
NLCASE	Job data	
NLTRIM	Trim data	TMDATA
NLRTR	Rotor data	R1DATA
NLWAKE	Wake data	G1DATA,W1DATA
NLBODY	Airframe and drive train data	BDDATA,BADATA,ENDATA
NLLOAD	Loads data	LADATA,L1DATA
NLFLUT	Flutter data	FLDATA
NLSTAB	Flight dynamics data	STDATA,GCDATA
NLTRAN	Transient data	TNDATA,GCDATA

The list below gives the files used by the program. The left-hand column gives the input parameter that defines the file unit number.

Unit Number	
NFDAT	Input data
NFAF1	Rotor #1 airfoil data
NFAF2	Rotor #2 airfoil data
NFRS	Restart data
NFEIG	Eigenvalue data
NFSCR	Scratch data

The list below gives the labels of the common blocks used by the program, and states the type of data contained in each. Only the common blocks for rotor #1 are listed; the common blocks for rotor #2 have identical functions.

Common Block Label	
TMDATA	Input trim data
R1DATA	Input rotor data
W1DATA	Input wake data
G1DATA	Input free wake geometry data
BDDATA	Input airframe data
BADATA	Input airframe aerodynamics data
ENDATA	Input drive train data
L1DATA	Input rotor loads data
LADATA	Input airframe loads data
GCDATA	Input gust and control data
TNDATA	Input transient data
STDATA	Input flight dynamics data
FLDATA	Input flutter data
A1TABL	Rotor airfoil tables
UNITNO	Input/output unit numbers
CASECM	Job description
TRIMCM	Calculated trim data
RTR1CM	Calculated rotor data
RH1CM	Transfer function matrices
BODYCM	Calculated airframe data
ENGNCM	Calculated drive train data
GUSTCM	Gust and transient control
CONTCM	Aircraft controls and motion
CONVCM	Circulation and motion convergence
MD1CM	Blade modes
INC1CM	Rotor inertial coefficients
WKV1CM	Induced velocity
MNH1CM	Hub motion
AES1CM	Blade section aerodynamics
MNR1CM	Rotor motion and airframe vibration
MNSCM	Static elastic motion
AEF1CM	Rotor forces
QR1CM	Rotor generalized forces
QBDCM	Airframe generalized forces
WG1CM	Wake geometry
WKC1CM	Wake influence coefficients
AEMNCM	Calculated motion data
LDMNCM	Calculated loads data
FLMCM	Flutter matrices
FLM1CM	Flutter rotor matrices
FLMACM	Flutter airframe matrices
FLINCM	Flutter inertial coefficients
FLAECM	Flutter aerodynamic coefficients
STDCM	Flight dynamics stability derivatives
STMCM	Flight dynamics matrices
TRANCM	Calculated transient data

4. PROGRAM SKELETON

The following pages present a schematic of the program, showing the basic flow of control and the major loops, options, and decisions. The appearance of a subprogram name (always in capital letters) means that the subprogram is called at that point in the analysis. The contents of a subprogram are shown by means of a three-sided box appearing below the subprogram name. The schematic defines the input and output structure of the program. Timer calls and trace-debug prints are also shown.

MAIN

```
read namelist NLCASE
if new job and BLKDAT > 0
        DATE (for FILEID)
        TIME (for FILEID)
        FILEI (input file write)
PRNTJ
for JCASE = 1 to NCASES
        TIMER (initialize)
        TIMER
        DATE (for IDENT)
        TIME (for IDENT)
        if new job
                INPTN
                INIT
                 INITA
                 INITC
                 INITR1
                 INITR2
                 INITB
                 INITE
                 CHEKR1
                 CHEKR2
        if old job
                INPTO
        PRNTC
        if new job or trim restart
                TRIM
                FILEJ (trim data scratch file write)
        if ANTYPE(1) ≠ 0 or flutter restart
                FLUT
                FILEJ (trim data scratch file read)
        if ANTYPE(2) ≠ 0 or flight dynamics restart
                STAB
                FILEJ (trim data scratch file read)
        if ANTYPE(3) ≠ 0 or transient restart
                TRAN
        TIMER
        TIMER (print)
```

```
INPTN                                                  BLKDAT,RDFILE
FILEI (input file read)
read namelist NLTRIM
if OPREAD(1) ≠ 0
        INPTR1
        read namelist NLRTR
if OPREAD(2) ≠ 0
        INPTW1
        read namelist NLWAKE
if OPREAD(3) ≠ 0
        INPTR2
        read namelist NLRTR
if OPREAD(4) ≠ 0
        INPTW2
        read namelist NLWAKE
if OPREAD(5) ≠ 0
        INPTB
        read namelist NLBODY
if OPREAD(6) ≠ 0
        INPTL1
        read namelist NLLOAD
if OPREAD(7) ≠ 0
        INPTL2
        read namelist NLLOAD
if OPREAD(8) ≠ 0
        INPTF
        read namelist NLFLUT
if OPREAD(9) ≠ 0
        INPTS
        read namelist NLSTAB
if OPREAD(10) ≠ 0
        INPTT
        read namelist NLTRAN
if first case
        INPTA1
        read airfoil #1 file
        INPTA2
        read airfoil #2 file
```

```
INPTO
FILER (restart file read)
    FILEI
    FILEJ
    FILEF                                            flutter restart
    FILES                                   flight dynamics restart
    FILET                                         transient restart
read namelist NLTRIM
if OPREAD(6) ≠ 0
        INPTL1
        read namelist NLLOAD
if OPREAD(7) ≠ 0
        INPTL2
        read namelist NLLOAD
if OPREAD(8) ≠ 0
        INPTF
        read namelist NLFLUT                           trim restart
        INPTG
        read namelist NLFLUT                        flutter restart
if OPREAD(9) ≠ 0
        INPTS
        read namelist NLSTAB                           trim restart
        INPTU
        read namelist NLSTAB    flutter or flight dynamics restart
if OPREAD(10) ≠ 0
        INPTT
        read namelist NLTRAN                           trim restart
        INPTV
        read namelist NLTRAN                      transient restart
```

```
TRIM
TIMER
if trim restart, go to restart entry point

uniform inflow
if ITERU ≠ 0
        TRIMI
        if NPRNTT = 1
                PERF                                        NPRNTP > 0
                LOAD                                        NPRNTL > 0

nonuniform inflow, prescribed wake geometry
for IT = 1 to ITERR
        WAKEC1                                              LEVEL(1) ≥ 1
        WAKEC2                                              LEVEL(2) ≥ 1
        TRIMI
        if IT = multiple NPRNTT
                PERF
                LOAD                                        NPRNTP > 0
                                                            NPRNTL > 0
nonuniform inflow, free wake geometry
for IT = 1 to ITERF
        WAKEC1                                              LEVEL(1) ≥ 1
        WAKEC2                                              LEVEL(2) ≥ 1
        TRIMI
        if IT = multiple NPRNTT
                PERF                                        NPRNTP > 0
                LOAD                                        NPRNTL > 0

FILER (restart file write)                                  RSWRT ≠ 0
  FILEI
  FILEJ

trim restart entry point
PRNT
  PRNTC
  if NPRNTI ≠ 0
        PRNTR1
        PRNTW1
        PRNTR2
        PRNTW2
        PRNTB
MODEP1
MODEP2
TRIMP
PERF
LOAD
TIMER
```

TRIMI

```
RAMF
if MTRIM ≤ 0 or no trim iteration, return
if DEBUG(4) ≥ 1, print trim iteration
for COUNTT = 1 to MTRIM
        if COUNTT-1 = multiple MTRIMD, construct D^-1
                for I = 1 to MT
                        increment controls                  OPTRIM
                        RAMF
                MINV
        increment controls                                  CPTRIM
        RAMF
        if DEBUG(4) ≥ 1, print trim iteration
        test trim convergence                               EPTRIM,CPTRIM
```

PERF

```
TIMER
PERFR1
PERFR2
TIMER
```

```
LOAD
┌──────────────────────────
│ TIMER
│ LOADR1
│ LOADR2
│ TIMER
└──────────────────────────

LOADR1
┌──────────────────────────
│ ROTNB1
│ if MALOAD ≠ 0
│         GEOMB1
│         HISTPP                                    NPLOT(1-4)
│         GEOMP1                                        MWKCMP
│         POLRPP                                   NPLOT(5-67)
│         HISTPP                                   NPLOT(5-67)
│ if MHLOAD ≠ 0
│         LOADH1
│         ┌────────
│         │LOADM
│         │LOADF
│         │HISTPP                                 NPLOT(68-71)
│         └────────
│ for IR = 1 to MRLOAD
│         LOADS1
│         ┌────────
│         │LOADT1
│         │LOADM
│         │LOADF
│         │HISTPP                                 NPLOT(72-75)
│         └────────
│ for IN = 1 to MNOISE
│         NOISR1
│         ┌────────
│         │BESSEL
│         └────────
└──────────────────────────
```

FLUT

```
TIMER
for OPFLOW ≤ 0 (constant coefficients)
        if flutter restart, go to restart entry point
        FLUTM
        FILEF (restart file write)                               RSWRT ≠ 0
        flutter restart entry point
        PRNTF
        MODEP1
        MODEP2
        FLUTL
         TIMER
         CSYSAN                                                  ANTYPE(1) ≠ 0
         FILEE (eigenvalue file write)
         BODE                                                    ANTYPE(2) ≠ 0
         TRACKS                                                  ANTYPE(3) ≠ 0
         GUSTS                                                   ANTYPE(4) ≠ 0
         TIMER
        if OPFDAN ≠ 0
                 STABD
                 STABE
for OPFLOW > 0 (periodic coefficients)
        for NT = 0 to MPSIPC
                 FLUTM
                 if NT = MPSIPC
                          PRNTF
                          MODEP1
                          MODEP2
                 PSYSAN
                 if NT = MPSIPC
                          FILEE (eigenvalue file write)
```

FLUTM

```
MODE1
MODE2
FLUTR1
FLUTR2
FLUTB
    BODYF
```

FLUTR1

```
NB = NBLADE if OPFLOW > 0, 1 if OPFLOW = 0, MPSICC if OPFLOW < 0
for JPSI = 1 to NB
        FLUTI1
        FLUTA1
        for IR = 1 to MRA
                AEROS1
```

```
STAB
 TIMER
 PRNTS
 if flight dynamics restart, go to restart entry point
 STABM
  for ID = 1 to 21
        increment controls or motion
        for IT = 1 to ITERS
                WAKEC1                                    LEVEL(1) ≥ 1
                WAKEC2                                    LEVEL(2) ≥ 1
                RAMF
                PERF                                       NPRNTP > 0
                LOAD                                       NPRNTL > 0
 FILES (restart file write)                                 RSWRT ≠ 0
 flight dynamics restart entry point
 STABD
 STABE
 TIMER


STABE
 for IEQ = 1 to 12                                   EQTYPE(IEQ) ≠ 0
         DERED
         STABL
          TIMER
          CSYSAN                                       ANTYPE(1) ≠ 0
          FILEE (eigenvalue file write)
          BODE                                         ANTYPE(2) ≠ 0
          TRACKS                                       ANTYPE(3) ≠ 0
          GUSTS                                        ANTYPE(4) ≠ 0
          numerical integration                        ANTYPE(5) ≠ 0
                MINV
                STABP
                 PRNTG
                for IT = 1 to TMAX/TSTEP
                        TRANC
                         CONTRL                          OPTRAN = 1
                         GUSTU                           OPTRAN = 2
                         GUSTC                           OPTRAN = 3
                        if IT = multiple NPRNTT
                                STABP
                TRCKPP
          TIMER
```

TRAN

```
TIMER
PRNTT
  PRNTG
if transient restart, go to restart entry point
MINV
TRANP
for IT = 1 to TMAX/TSTEP
        TRANC
          CONTRL                                    OPTRAN = 1
          GUSTU                                     OPTRAN = 2
          GUSTC                                     OPTRAN = 3
        TRANI
          for IT = 1 to ITERT
                 WAKEC1                            LEVEL(1) ≥ 1
                 WAKEC2                            LEVEL(2) ≥ 1
                 RAMF
        if IT = multiple NPRNTT
                 TRANP
                 PERF                               NPRNTP > 0
                 LOAD                               NPRNTL > 0
        if IT = multiple NRSTRT
                 FILET (restart file write)          RSWRT ≠ 0
        transient restart entry point
TRCKPP
TIMER
```

```
RAMF
TIMER
BODYC
MOTNC1
MODE1
BODYM1
 [INRTI]
MOTNC2
MODE2
BODYM2
 [INRTI]
for COUNTC = 1 to ITERC (circulation iteration)
        WAKEU1
        WAKEN1
        WAKEU2
        WAKEN2
        for COUNTM = 1 to ITERM (motion iteration)
                INRTM1
                 [INRTI]
                INRTM2
                 [INRTI]
                ENGNC
                ENGNM1
                 [INRTI]
                ENGNM2
                 [INRTI]
                for JPSI = 0 to MREV*MPSI by MPSIR (Ψ loop)
                         MOTNH1
                         MOTNR1
                         MOTNH2
                         MOTNR2
                         BODYV1
                         ENGNV1
                         MOTNF1
                         BODYV2
                         ENGNV2
                         MOTNF2
                         MOTNS
                test motion convergence                          EPMOTN
        test circulation convergence                             EPCIRC
BODYF
 [BODYA]
TIMER
```

```
MODE1
 ______________________________________________
| TIMER
| MODEC1
| if Δθ > EPMODE
|            MODEB1                                            HINGE ≠ 2
|             ________
|            | MODEG
|            | MINV
|            | EIGENJ
|            |________
|            MODEA1                                            HINGE = 2
|            MODEK1
|            MODED1
| MODET1
|  ________
| | MINV
| | EIGENJ
| |________
| INRTC1
| TIMER
|______________________________________________
```

```
MOTNR1
 ______________________________________________
| TIMER
| for JP = JPSI + 1 to JPSI + MPSIR (Ψ step)
|            MOTNB1
|            AEROF1
|             ______________________
|            | for IR = 1 to MRA
|            |          AEROS1
|            |           ________
|            |          | AEROT1
|            |__________|________
| TIMER
|______________________________________________
```

```
WAKEC1
 GEOMR1
  TIMER
  GEOMF1                                                    LEVEL = 2
  TIMER
 TIMER
 WAKEB1                                                      DBV ≯ 0.
 GEOME1                                                      DBV ≯ 0.
 for I = 1 to MPSI (Ψ loop)
         WAKEB1
         WAKEB2                                          INFLOW(3) = 3
         for M = 1 to NBLADE (blade loop)
                 GEOME1
                 VTXL
                 for K = 1 to KFW or KDW (φ loop)
                          GEOME1
                          VTXL
                          VTXS
 TIMER
```

CSYSAN

- DETRAN
- EIGENJ
- SINE
- STATIC
- ZERO
  - ZETRAN
  - EIGENJ

BODE

- DETRAN
- EIGENJ
- ZERO
  - ZETRAN
  - EIGENJ
- BODEPP

TRACKS

- DETRAN
- EIGENJ
- MINVC
- TRCKPP

GUSTS

- DETRAN
- EIGENJ
- MINVC

PSYSAN

- DEPRAN
- EIGENJ

5. JOB STRUCTURE

In this section the structure of a job to run the program is defined. The basic structure consists of the following steps:

1) File definition as required for job
2) Block data load for airframe and each rotor
3) Main program call
4) Namelist &NLCASE
5) Namelist &NLTRIM (for each case)
6) Component and task namelists as required

File definition parameters:

a) RET = T	Erase file at logoff
b) DISP = NEW	New file to be created
c) DISP = OLD	Existing file

Sample jobs are presented below.

New job, 2 cases; trim analysis; block data input, basic namelist input, same airfoil table for both rotors

```
DDEF FT50F001,,SCRATCH,DISP=NEW,RET=T
DDEF FT41F001,,AIRFOIL,DISP=OLD
LOAD HELA; LOAD HELR1; LOAD HELR2
CALL MAINPROG
 &NLCASE JOB=0,NCASES=2,RSWRT=0,BLKDAT=-1,
 NFAF1=41,NFAF2=41,NFSCR=50,NFRS=-1,NFEIG=-1,
 &END
 &NLTRIM VKTS=x.,COLL=x.,LATCYC=x.,LNGCYC=x.,PEDAL=x.,APITCH=x.,AROLL=x.,
 ANTYPE=3*0,OPREAD=10*0,
 &END
 &NLTRIM data for second case,&END
%END
```

New job, 1 case; trim, flutter, flight dynamics, and transient analysis; block data input, all namelist inputs, different airfoil table for each rotor; write eigenvalue file

```
DDEF FT50F001,,SCRATCH,DISP=NEW,RET=T
DDEF FT41F001,,AIRFOIL1,DISP=OLD
DDEF FT42F001,,AIRFOIL2,DISP=OLD
DDEF FT45F001,,EIGEN,DISP=NEW
LOAD HELA; LOAD HELR1; LOAD HELR2
CALL MAINPROG
 &NLCASE JOB=0,NCASES=1,RSWRT=0,BLKDAT=-1,
 NFAF1=41,NFAF2=42,NFSCR=50,NFRS=-1,NFEIG=45,
 &END
 &NLTRIM VKTS=x.,
 COLL=x.,LATCYC=x.,LNGCYC=x.,PEDAL=x.,APITCH=x.,AROLL=x.,
 ANTYPE=3*1,OPREAD=10*1,
 &END
 &NLRTR  data,&END
 &NLWAKE data,&END
 &NLRTR  data,&END
 &NLWAKE data,&END
 &NLBODY data,&END
 &NLLOAD data,&END
 &NLLOAD data,&END
 &NLFLUT data,&END
 &NLSTAB data,&END
 &NLTRAN data,&END
%END
```

New job, 1 case; trim analysis; block data input and write input file

```
DDEF FT50F001,,SCRATCH,DISP=NEW,RET=T
DDEF FT41F001,,AIRFOIL,DISP=OLD
DDEF FT40F001,,INPUT,DISP=NEW
LOAD HELA; LOAD HELR1; LOAD HELR2
CALL MAINPROG
 &NLCASE JOB=0,NCASES=1,RSWRT=0,BLKDAT=1,
 NFAF1=41,NFAF2=41,NFSCR=50,NFRS=-1,NFEIG=-1,NFDAT=40,
 &END
 &NLTRIM data,&END
%END
```

New job, 1 case; trim analysis; read input file

```
DDEF FT50F001,,SCRATCH,DISP=NEW,RET=T
DDEF FT41F001,,AIRFOIL,DISP=OLD
DDEF FT40F001,,INPUT,DISP=OLD
CALL MAINPROG
 &NLCASE JOB=0,NCASES=1,RSWRT=0,BLKDAT=0,RDFILE=1,
 NFAF1=41,NFAF2=41,NFSCR=50,NFRS=-1,NFEIG=-1,NFDAT=40,
 &END
 &NLTRIM data,&END
%END
```

New job, 2 cases; trim and flutter analysis; write restart file

```
DDEF FT50F001,,SCRATCH,DISP=NEW,RET=T
DDEF FT41F001,,AIRFOIL,DISP=OLD
DDEF FT44F001,,RESTART1,DISP=NEW
DDEF FT44F002,,RESTART2,DISP=NEW
LOAD HELA; LOAD HELR1; LOAD HELR2
CALL MAINPROG
 &NLCASE JOB=0,NCASES=2,RSWRT=1,BLKDAT=-1,
 NFAF1=41,NFAF2=41,NFSCR=50,NFEIG=-1,NFRS=44,
 &END
 &NLTRIM data for first case,
 ANTYPE=1,0,0,0PREAD(8)=1,
 &END
 &NLFLUT data,&END
 &NLTRIM data for second case,&END
 &NLFLUT data,&END
%END
```

Old job; trim restart with flutter analysis

```
DDEF FT50F001,,SCRATCH,DISP=NEW,RET=T
DDEF FT44F001,,RESTART,DISP=OLD
CALL MAINPROG
 &NLCASE JOB=1,RSWRT=1,START=1,
 NFSCR=50,NFEIG=-1,NFRS=44,
 &END
 &NLTRIM ANTYPE=1,0,0,0PREAD(8)=1,
 &END
 &NLFLUT data,&END
%END
```

Old job; flutter restart

```
DDEF FT50F001,,SCRATCH,DISP=NEW,RET=T
DDEF FT44F001,,RESTART,DISP=OLD
CALL MAINPROG
 &NLCASE JOB=1,RSWRT=0,START=2,
 NFSCR=50,NFEIG=-1,NFRS=44,
 &END
 &NLTRIM OPREAD(8)=1,
 &END
 &NLFLUT data,&END
%END
```

6. INPUT DESCRIPTION

In this section the input variables for the program are defined. The variables are catagorized according to the namelist that reads them. The program namelist labels are listed in the table below.

Namelist Label	
NLCASE	Job data
NLTRIM	Trim data
NLRTR	Rotor data
NLWAKE	Wake data
NLBODY	Airframe and drive train data
NLLOAD	Loads data
NLFLUT	Flutter data
NLSTAB	Flight dynamics data
NLTRAN	Transient data

The corresponding common block labels, for the block data form of input, may be obtained from Section 3. In the description of the input parameters for the rotor, the variables NBM and NTM are used:

a) NBM is the index of the highest-frequency blade bending mode used in the analysis;

b) NTM is the index of the highest-frequency blade torsion mode used in the analysis.

Namelist NLCASE

JOB	integer parameter defining job: EQ 0 for new job (default); NE 0 for old job or restart (one case only)
RSWRT	integer parameter controlling restart file write: 0 to suppress write (default)
	New job only
NCASES	number of cases (default = 1)
BLKDAT	integer parameter defining input source: EQ 0 read input file (default) GT 0 use loaded block data and write input file LT 0 use loaded block data
RDFILE	integer parameter controlling input file read: EQ 0 read file for first case only NE 0 read file for every case (default)
	Old job only
START	integer parameter defining task: 1 for trim restart (default) 2 for flutter restart 3 for flight dynamics restart 4 for transient restart trim restart can be followed by any or all of the other tasks (as defined by ANTYPE); for flutter, flight dynamics, or transient restart, only that task can be done
	Input/output unit numbers
NFDAT	input data file (new job only); default = 40
NFAF1	rotor #1 airfoil file (new job only); default = 41
NFAF2	rotor #2 airfoil file (new job only; only if have two rotors); default = 42
NFRS	restart file (no file write if LE 0); default = 44
NFEIG	eigenvalue file (no file write if LE 0); default = 45
NFSCR	scratch file; default = 50
NUIN	namelist input; default = 5
NUOUT	printer (and debug level 1); default = 6
NUDB	debug output (levels 2 and 3); default = 6
NUPP	printer-plots; default = 6
NULIN	linear system analysis; default = 6

Namelist NLTRIM

OPREAD(10)	integer vector defining namelist read structure; EQ 0 to suppress read: components (new job only) (1) NLRTR, rotor #1 (2) NLWAKE, rotor #1 (3) NLRTR, rotor #2 (4) NLWAKE, rotor #2 (5) NLBODY tasks (6) NLLOAD, rotor #1 (7) NLLOAD, rotor #2 (8) NLFLUT (9) NLSTAB (10) NLTRAN
NPRNTI	integer parameter controlling input data print: EQ 0 for short form print only
ANTYPE(3)	integer vector defining tasks for new job or trim restart; EQ 0 to suppress: (1) flutter (2) flight dynamics (3) transient
TITLE(20)	title for job and case (80 characters)
CODE	alphanumeric code for job and case identification; 4 characters
OPUNIT	integer parameter designating unit system: 1 for English units (ft-slug-sec); 2 for metric units (m-kg-sec)
NROTOR	number of rotors

DEBUG(25) integer vector controlling debug print:

0	no debug print
1	trace print
2	low level print
3	high level print

(1) time (sec) at which debug print enabled
(2) input, 2-3 (INPTx)
(3) initialization, 2 (INITC, INITR, INITB, INITE)
(4) trim iteration, 1-2 (TRIMI)
(5) loads, 2 (LOADI)
(6) flutter matrices, 2-3 (FLUTM)
(7) flutter coefficients, 2-3 (FLUTI, FLUTA)
(8) flight dynamics, 2-3 (STABM, STABE)
(9) transient, 2 (TRANI)
(10) rotor/airframe motion and forces, 2-3 (RAMF)
(11) blade modes, 2 (MODE, MODEx)
(12) inertia coefficients, 2 (INRTC)
(13) airframe constants and matrices, 2 (BODYC, ENGNC, MOTNC, BODYM, ENGNM)
(14) induced velocity, 2 (WAKEU, WAKEN)
(15) rotor matrices, 2-3 (INRTM)
(16) hub/airframe motion and generalized forces, 2 (MOTNH, BODYV, ENGNV, MOTNF, MOTNS)
(17) rotor motion, 2-3 (MOTNR)
(18) rotor aerodynamics, 2-3 (AEROF)
(19) blade section aerodynamics, 3 (AEROS)
(20) body forces and aerodynamics, 2 (BODYF)
(21) wake influence coefficients, 2 (WAKEC)
(22) vortex line and sheet, 3 (VTXL, VTXS)
(23) prescribed wake geometry, 2-3 (GEOMR)
(24) free wake geometry, 1-3 (GEOMF)
(25) timer, 1 (TIMER)

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VKTS	aircraft speed V (knots)
VEL	velocity ratio $V/\Omega R$
	input either VEL or VKTS by namelist; if neither parameter is defined, V = 0 is used
VTIP	rotor #1 tip speed ΩR (ft/sec or m/sec)
RPM	rotor #1 rotational speed (rpm)
	input either VTIP or RPM by namelist; if neither parameter is defined, the normal tip speed VTIPN is used; rotor #2 speed is calculated from the gear ratio TRATIO
OPDENS	integer parameter defining specification of aerodynamic environment: if 1, given altitude and standard day; if 2, given altitude and temperature; if 3, given density and temperature
ALTMSL	altitude above mean sea level (ft or m), for OPDENS = 1 or 2
TEMP	air temperature (^{o}F or ^{o}C), for OPDENS = 2 or 3
DENSE	air density (slug/ft^3 or kg/m^3), for OPDENS = 3
OPGRND	integer parameter controlling ground effect analysis: EQ 0 for out of ground effect, NE 0 for in ground effect
HAGL	altitude helicopter center of gravity above ground for ground effect analysis (ft or m)
OPENGN	integer parameter specifying engine state: 1 for autorotation (engine inertia, engine damping, and throttle control torque zero; no engine speed degree of freedom); 2 for engine out (engine damping and throttle control torque zero); 0 for normal operation
AFLAP	wing flap angle δ_F (deg)
RTURN	for free flight, trim turn rate $\dot{\psi}_F$ (deg/sec), positive to right

initial values of controls (trimmed as appropriate)

COLL	collective stick displacement δ_o or $\Delta\theta_{govr}$ (deg), positive up
LATCYC	lateral cyclic stick displacement δ_c (deg), positive left
LNGCYC	longitudinal cyclic stick displacement δ_s (deg), positive aft
PEDAL	pedal displacement δ_p (deg), positive to right
APITCH	for free flight, aircraft pitch angle θ_{FT} (deg), positive nose up; for wind tunnel, rotor shaft angle of attack θ_T, (deg), positive nose up
AROLL	for free flight, aircraft roll angle ϕ_{FT} (deg), positive to right
	(θ_{FT} and ϕ_{FT} define orientation of body axes relative to earth axes)
ACLIMB	for free flight, aircraft climb angle θ_{FP} (deg), positive up
AYAW	for free flight, aircraft yaw angle ψ_{FP} (deg), positive to right; for wind tunnel, test module yaw angle ψ_T (deg), positive to right
	(θ_{FP} and ψ_{FP} define orientation of velocity axes relative to earth axes; $V_{climb} = V \sin \theta_{FP}$ and $V_{side} = V \sin\psi_{FP} \cos\theta_{FP}$)

MPSI	number of azimuth steps per revolution in motion and loads analysis, maximum 36; for nonuniform inflow must be multiple of number of blades; for free wake geometry, maximum 24
MPSIR	in harmonic motion solution, number of azimuth steps between update of airframe vibration and rotor matrices
MREV	in harmonic motion solution, number of revolutions between tests for motion convergence
ITERM	maximum number of motion iterations
EPMOTN	tolerance for motion convergence (deg)
ITERC	maximum number of circulation iterations
EPCIRC	tolerance for circulation convergence ($\Delta C_T/\sigma$)

DOF(54) integer vector defining degrees of freedom used in vibratory motion solution, 0 if not used; order:

rotor #1 $q_1 \cdots q_{10}$ $p_0 \cdots p_4$ β_G

rotor #2 $q_1 \cdots q_{10}$ $p_0 \cdots p_4$ β_G

(bending, max 10) (torsion, max 5) (gimbal/teeter)

airframe ϕ_F θ_F ψ_F x_F y_F z_F (rigid body) $q_{s7} \cdots q_{s16}$ (flexible body, max 10)

drive train ψ_s ψ_I ψ_e (rotor/engine speed) $\Delta\theta_t$ $\Delta\theta_{govr_1}$ $\Delta\theta_{govr_2}$ (governor)

DOFT(8) integer vector defining blade bending degrees of freedom used for mean deflection (subset of DOF), 0 if not used; order:

rotor #1 q_1 q_2 q_3 q_4

rotor #2 q_1 q_2 q_3 q_4

(bending, max 4)

MHARM(2) number of harmonics in rotor motion analysis; maximum 20; EQ 0 for mean only
(1) rotor #1
(2) rotor #2

MHARMF(2) number of harmonics in airframe vibration analysis (harmonics of N/rev); maximum 10; EQ 0 for static elastic only; suggest LE MHARM/NBLADE, and the same value for both rotors if coupled hub vibration used (see OPHVIB)
(1) rotor #1
(2) rotor #2

LEVEL(2) integer parameter specifying rotor wake analysis level: 0 for uniform inflow, 1 for nonuniform inflow with prescribed wake geometry, 2 for nonuniform inflow with free wake geometry (must be consistent with INFLOW)
(1) rotor #1
(2) rotor #2

	number of wake and trim iterations
ITERU	at uniform inflow level; EQ 0 to skip
ITERR	at nonuniform inflow/prescribed wake geometry level; EQ 0 to skip
ITERF	at nonuniform inflow/free wake geometry level
NPRNTT	integer parameter n: trim/performance/load print every n-th iteration; LE 0 to suppress
NPRNTP	integer parameter controlling performance print; LE 0 to suppress
NPRNTL	integer parameter controlling loads print; LE 0 to suppress
MTRIM	maximum number of iterations on controls to achieve trim
MTRIMD	number of trim iterations between update of trim derivative matrix
DELTA	control step in trim derivative calculation (stick displacement, deg)
FACTOR	factor reducing control increment in order to improve trim convergence (typically 0.5)
EPTRIM	tolerance on trim convergence
OPGOVT	integer parameter specifying governor trim 0 trim collective stick δ_0 1 trim rotor #1 governor 2 trim rotor #2 governor 3 trim both rotor governors
	targets for wind tunnel trim cases
CXTRIM	C_X/σ
XTRIM	X/q (ft^2 or m^2)
CTTRIM	C_T/σ or C_L/σ
CPTRIM	C_P/σ
CYTRIM	C_Y/σ
BCTRIM	β_c (deg)
BSTRIM	β_s (deg)

OPTRIM integer parameter specifying trim option

free flight cases

OPTRIM = 0 no trim

1 trim forces and moments with
δ_o δ_c δ_s δ_p θ_{FT} ϕ_{FT}

2 trim forces and moments with
δ_o δ_c δ_s δ_p θ_{FT} Ψ_{FP}

3 trim forces, moments, and power with
δ_o δ_c δ_s δ_p θ_{FT} ϕ_{FT} θ_{FP}

4 trim forces, moments, and power with
δ_o δ_c δ_s δ_p θ_{FT} Ψ_{FP} θ_{FP}

5 trim symmetric forces and moments with
δ_o δ_s θ_{FT}

6 trim symmetric forces, moments, and power with
δ_o δ_s θ_{FT} θ_{FP}

wind tunnel cases

OPTRIM = 10 no trim

11	trim C_T/σ	with	δ_o
12	trim C_T/σ	with	θ_T
13	trim C_P/σ	with	δ_o
14	trim β_c β_s	with	δ_c δ_s
15	trim C_T/σ β_c β_s	with	δ_o δ_c δ_s
16	trim C_L/σ C_X/σ C_Y/σ	with	δ_o δ_c δ_s
17	trim C_L/σ C_X/σ C_Y/σ	with	δ_o δ_c θ_T
18	trim C_L/σ C_X/σ β_c β_s	with	δ_o δ_c δ_s θ_T
19	trim C_L/σ X/q C_Y/σ	with	δ_o δ_c δ_s
20	trim C_L/σ X/q C_Y/σ	with	δ_o δ_c θ_T
21	trim C_L/σ X/q β_c β_s	with	δ_o δ_c δ_s θ_T
22	trim β_c	with	δ_s
23	trim C_T/σ β_c	with	δ_o δ_s
24	trim C_L/σ C_X/σ	with	δ_o δ_s
25	trim C_L/σ C_X/σ	with	δ_o θ_T
26	trim C_L/σ C_X/σ β_c	with	δ_o δ_s θ_T
27	trim C_L/σ X/q	with	δ_o δ_s
28	trim C_L/σ X/q	with	δ_o θ_T
29	trim C_L/σ X/q β_c	with	δ_o δ_s θ_T

WEIGHT	see namelist NLBODY
IXX	
IYY	
IZZ	
IXY	
IXZ	
IYZ	
ATILT	
FSCG	
BLCG	
WLCG	

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Namelist NLRTR

TITLE(20)	title for rotor and wake data (80 characters)
TYPE	rotor identification (4 characters); suggest MAIN, FRNT, or RGHT for rotor #1; and TAIL, REAR, or LEFT for rotor #2
VTIPN	normal tip speed ΩR_o (ft/sec or m/sec)
RADIUS	blade radius R (ft or m)
SIGMA	solidity ratio $\sigma = Nc_m/\pi R$ (based on mean chord)
GAMMA	blade Lock number $\gamma_o = \rho_o a c_m R^4/I_b$ (based on standard density, a = 5.7, and mean chord)
	(γ and σ are only used to calculate the normalization parameters c_m and I_b)
NBLADE	number of blades
	control system damping (ft-lb/rad/sec or m-N/rad/sec)
TDAMPO	collective
TDAMPC	cyclic
TDAMPR	rotating
NUGC	longitudinal gimbal natural frequency ν_{GC} or teeter natural frequency ν_T (per rev at normal tip speed VTIPN)
NUGS	lateral gimbal natural frequency ν_{GS} (per rev at normal tip speed VTIPN)
GDAMPC	longitudinal gimbal damping C_{GC} or teeter damping C_T (ft-lb/rad/sec or m-N/rad/sec)
GDAMPS	lateral gimbal damping C_{GS} (ft-lb/rad/sec or m-N/rad/sec)
LDAMPC	linear lag damper coefficient C_ζ (ft-lb/rad/sec or m-N/rad/sec); estimated damping if a nonlinear damper is used (LDAMPM GT 0.); the lag mode has structural damping also (GSB)
LDAMPM	maximum moment of nonlinear lag damper, M_{LD} (ft-lb or m-N); linear lag damper used if LDAMPM EQ 0.
LDAMPR	lag velocity $\dot{\zeta}_{LD}$ where maximum moment of lag damper occurs (rad/sec); hydraulic damping below $\dot{\zeta}_{LD}$ and friction damping above
GSB(NBM)	bending mode structural damping g_s
GST(NTM)	torsion mode structural damping g_s
ROTATE	integer parameter specifying rotor rotation direction: 1 for counter-clockwise, -1 for clockwise (viewed from above)

OPHVIB(3) integer parameter controlling hub vibration contributions; gravity and static velocity terms always retained; 0 to suppress:

- (1) vibration due to this rotor
- (2) vibration due to other rotor (must supress if $\Omega_2/\Omega_1 \neq 1$)
- (3) static elastic motion

BTIP tip loss parameter B

OPTIP integer parameter specifying tip loss type: 1 for tip loss factor, 2 for Prandtl function

LINTW integer parameter specifying twist type: EQ 0 for nonlinear twist, NE 0 for linear twist

TWISTL linear twist rate θ_{tw} (deg); used to calculate TWISTA and TWISTI if LINTW NE 0

OPUSLD integer parameter controlling use of unsteady lift, moment, and circulation terms: if 0, suppress; if 1, include; if 2, zero for stall ($15^{\circ} < |\alpha| < 165^{\circ}$)

OPCOMP integer parameter controlling aerodynamic model, EQ 0 for incompressible loads

Inflow model

INFLOW(6) integer vector defining induced velocity calculation (must be consistent with LEVEL)

- (1) at this rotor: 0 for uniform, 1 for nonuniform
- (2) at other rotor: 0 for zero, 1 for empirical, 2 for average at hub, 3 for nonuniform (only if $\Omega_2/\Omega_1 = 1$)
- (3) at wing-body: 0 for zero, 1 for empirical, 2 for nonuniform
- (4) at horizontal tail: 0 for zero, 1 for empirical, 2 for nonuniform
- (5) at vertical tail: 0 for zero, 1 for empirical, 2 for nonuniform
- (6) at point off rotor disk: 0 for zero, 1 for nonuniform

RROOT root vortex position for wake model, r_{root}/R

RGMAX $r_{G_{max}}/R$ (induced velocity calculated using maximum bound circulation magnitude outboard of $r_{G_{max}}$)

	Blade section aerodynamic characteristics
MRA	number of aerodynamic segments; maximum 30
RAE(MRA + 1)	radial stations r/R at edges of aerodynamic segments; sequential, from root to tip
	Following quantities are specified at midpoint of aerodynamic segment
CHORD(MRA)	blade chord, c/R
XA(MRA)	offset of aerodynamic center aft of elastic axis, x_A/R; x_A is the point about which the moment data in the airfoil tables is given
THETZL(MRA)	incremental pitch of zero lift line, θ_{ZL} (deg); can be included in TWISTA; θ_{ZL} is the pitch of the axis corresponding to zero angle of attack in the airfoil tables, relative to the twist angle (TWISTA)
TWISTA(MRA)	blade twist relative .75R, θ_{tw} (deg)
XAC(MRA)	offset of aerodynamic center (for unsteady aerodynamics) aft of elastic axis, x_{AC}/R
MCORRL(MRA)	Mach number correction factor $f_M = M_{eff}/M$ for lift
MCORRD(MRA)	Mach number correction factor $f_M = M_{eff}/M$ for drag
MCORRM(MRA)	Mach number correction factor $f_M = M_{eff}/M$ for moment
	Blade section inertial and structural characteristics
MRI	number of radial stations where characteristics defined; maximum 51
RI(MRI)	radial stations r/R; sequential, from root to tip, RI(1) = 0. and RI(MRI) = 1.
MASS(MRI)	section mass, m (slug/ft or kg/m)
EIXX(MRI)	chordwise bending stiffness (lb-ft^2 or N-m^2)
EIZZ(MRI)	flapwise bending stiffness (lb-ft^2 or N-m^2)
XI(MRI)	offset of center of gravity aft of elastic axis, x_I/R
XC(MRI)	offset of tension center aft of elastic axis, x_C/R (at the tip, XC should be set nearly equal XI)
KP2(MRI)	polar radius of gyration about elastic axis, k_P^2/R^2
ITHETA(MRI)	section moment of inertia about elastic axis, I_θ (slug-ft or kg-m)
GJ(MRI)	torsional stiffness, GJ (lb-ft^2 or N-m^2)
TWISTI(MRI)	blade twist relative .75R, θ_{tw} (deg)

Stall model

OPSTLL	integer parameter defining stall model 0 no stall 1 static stall 2 McCroskey stall delay 3 McCroskey stall delay with dynamic stall vortex loads 4 Boeing stall delay 5 Boeing stall delay with dynamic stall vortex loads (the stall delay can be suppressed by setting TAU = 0.)
OPYAW	integer parameter defining yawed flow corrections 0 both yawed flow and radial drag included 1 no yawed flow ($\cos\Lambda = 1.$) 2 no radial drag ($F_r = 0.$) 3 neither yawed flow nor radial drag included
TAU(3)	stall delay time constants for lift, drag, and moment: τ_L, τ_D, τ_M (calculated if LT 0.)
ADELAY	maximum angle of attack increment due to stall delay, $\alpha_{max\ delay}$ (deg)
AMAXNS	angle of attack in linear range for no stall model, α_{max} (deg)
PSIDS(3)	dynamic stall vortex load rise and fall time (azimuth increment) for lift, drag, and moment: $\Delta\Psi_{ds}$ (deg)
ALFDS(3)	dynamic stall angle of attack for lift, drag, and moment: α_{ds} (deg)
ALFRE(3)	stall recovery angle of attack for lift, drag, and moment: α_{re} (deg)
CLDSP	maximum peak dynamic stall vortex induced lift coefficient: $\Delta c_{\ell_{ds}}$
CDDSP	maximum peak dynamic stall vortex induced drag coefficient: $\Delta c_{d_{ds}}$
CMDSP	maximum peak dynamic stall vortex induced moment coefficient: $\Delta c_{m_{ds}}$

KHLMDA	factor κ_h for hover induced velocity (typically 1.1)
KFLMDA	factor κ_f for forward flight induced velocity (typically 1.2)
FXLMDA	factor f_x for linear inflow variation in forward flight (typically 1.5)
FYLMDA	factor f_y for linear inflow variation in forward flight (typically 1.)
FMLMDA	factor f_m on linear inflow variation due to hub moment (typically 1.)
FACTWU	factor introducing lag in C_T, C_{M_x}, and C_{M_y} used to calculate induced velocity (typically .5)
KINTH	factor for hover interference velocity at other rotor (κ_{21} or κ_{12})
KINTF	factor for forward flight interference velocity at other rotor (κ_{21} or κ_{12})
	(linear variation between KINTH at $\mu = 0.05$ and KINTF at $\mu = 0.10$ is used)
KINTWB	factor for rotor-induced interference velocity at wing-body, K_W
KINTHT	factor for rotor-induced interference velocity at horizontal tail, K_H
KINTVT	factor for rotor-induced interference velocity at vertical tail, K_V
	(K_W, K_H, K_V equal fraction of fully-developed wake times maximum fraction surface in wake)
HINGE	integer parameter specifying blade mode type 0 hinged 1 cantilever 2 articulated (flap and lag modes only)
NCOLB	number of collocation functions for bending mode calculations (total flap and lag, alternating); maximum 20
NCCLT	number of collocation functions for torsion mode calculations; maximum 10
NONROT	integer parameter: NE 0 to calculate nonrotating bending frequencies
EPMODE	criterion on change of collective pitch to update blade modes, $\Delta\theta_{75}$ (deg)

MASST — tip mass (slug or kg); the tip mass can also be included directly in the section mass distribution

XIT — offset of tip mass center of gravity aft of elastic axis, x_I/R

MBLADE — blade mass (slug or kg); if LE 0., integral of section mass used (with mass included at r = 0. to account for the hub mass)

EFLAP — flap hinge offset e_f/R (extent of rigid hub for cantilver blade)

ELAG — lag hinge offset e_l/R (extent of rigid hub for cantilver blade)

KFLAP — flap hinge spring (ft-lb/rad or m-N/rad)

KLAG — lag hinge spring (ft-lb/rad or m-N/rad)

RCPLS — hinge spring parameter, R_s

TSPRNG — hinge spring parameter, θ_{so}
(hinge spring pitch angle is $\theta_s = \theta_{so} + R_s \theta_{75}$)

RCPL — structural coupling parameter R (effective pitch angle $R\theta$ used to calculate blade bending modes; normally R = 1.)

NOPB — integer parameter specifying twist inboard of r_{FA}: EQ 1 for no pitch bearing

WTIN — integer parameter defining control system stiffness input: 1 for K_θ, 2 for ω_θ

control system frequency ω_θ (per rev, at normal tip speed VTIPN)

FTO — collective

FTC — cyclic

FTR — reactionless

control system stiffness K_θ (ft-lb/rad or m-N/rad)

KTO — collective

KTC — cyclic

KTR — reactionless

KPIN — integer parameter defining pitch/bending coupling input: 1 for input, 2 for calculated (negative to suppress cosine factors in K_{P_1} and K_{P_G})

root geometry to calculate pitch/bending coupling (KPIN = 2 or -2)

PHIPH — pitch horn cant angle, ϕ_{PH} (deg)

PHIPL — pitch link cant angle, ϕ_{PL} (deg)

RPB — pitch bearing radial location, r_{PB}/R

RPH — pitch horn radial location, r_{PH}/R

XPH — pitch horn length, x_{PH}/R

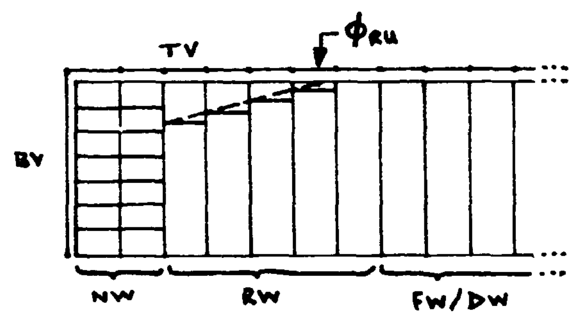
ATANKP(NBM)	pitch/bending coupling $\tan^{-1}K_{P_i}$ (deg), for pitch horn level (KPIN = 1 or -1)
DEL3G	pitch/gimbal coupling $\tan^{-1}K_{P_G}$ (deg), for pitch horn level
RFA	feathering axis radial location, r_{FA}/R
ZFA	gimbal undersling, z_{FA}/R
XFA	torque offset, x_{FA}/R
CONE	precone angle δ_{FA_1} (deg), positive up
DROOP	droop angle δ_{FA_2} (deg) at $\theta_{75} = 0$, positive down from precone
SWEEP	sweep angle δ_{FA_3} (deg) at $\theta_{75} = 0$, positive aft
FDROOP	feathering axis droop angle δ_{FA_4} (deg), positive down from precone
FSWEEP	feathering axis sweep angle δ_{FA_5} (deg), positive aft

Namelist NLWAKE

FACTWN	factor introducing lag in bound circulation used to calculate induced velocity
OPVXVY	integer parameter: EQ 0 to suppress x and y components of induced velocity calculated at the rotors
KNW	extent of near wake, K_{NW}
KRW	extent of rolling up wake, K_{RW}
KFW	extent of far wake and tip vortices, K_{FW}
KDW	extent of far wake and tip vortices for points off rotor disk, K_{DW} (age $\phi = K\Delta\Psi$; all K GE 1)
RRU	initial radial station of wake rollup, r_{RU}/R
FRU	initial tip vortex fraction of Γ_{max} for rollup, f_{RU}
PRU	extent of rollup in wake age, ϕ_{RU} (deg)
FNW	tip vortex fraction of Γ_M for near wake, f_{NW}
DVS	sheet edge test parameter d_{vs}; LT 0. to suppress test
DLS	lifting surface correction parameter d_{ls}; LT 0. to suppress correction
CORE(5)	vortex core radii r_c/R (1) tip vortices (2) burst tip vortices (3) tip vortices in far wake off rotor (4) trailed lines (LT 0. for default = s/2) (5) shed lines (LT 0. for default = t/2)
OPCORE(2)	integer parameter specifying vortex core type: 0 for distributed vorticity, 1 for concentrated vorticity (1) tip vortices (2) inboard wake
OPNWS(2)	integer parameter controlling action when inflow and circulation points coincide in near wake ($\phi = 0$) and sheets are being used: 0 to use two sheets, 1 to use lines, 2 to use single sheet (1) shed wake (2) trailed wake
LHW	number of spirals of far wake for axisymmetric case, L_{HW}
OPHW	integer parameter: EQ 0 for axisymmetric wake geometry
OPRTS	integer parameter: NE 0 to include rotation matrices (R_{TS}, etc.) in influence coefficients

WKMODL(13) integer parameter defining wake model: 0 to omit element, 1 for line segment with stepped circulation distribution, 2 for line segment with linear circulation distribution, 3 for vortex sheet element

(1) tip vortices (stepped line or linear line)
(2) near wake shed vorticity
(3) near wake trailed vorticity
(4) rolling up wake shed vorticity
(5) rolling up wake trailed vorticity
(6) far wake shed vorticity
(7) far wake trailed vorticity
(8) far wake (off rotor) shed vorticity
(9) far wake (off rotor) trailed vorticity
(10) bound vortices (no sheet model)
(11) axisymmetrical wake axial vorticity (no line model)
(12) axisymmetrical wake shed vorticity (no line model)
(13) axisymmetrical wake ring vorticity (no line model)



MRG number of circulation points for near wake; LE MRA

NG(MRG) circulation points, identified by aerodynamic segment number: n_{G_i} for i = 1 to MRG (corresponding r_i must be between r_{root}/R and 1.)

MRL number of inflow points; LE MRA

NL(MRL) points at which the induced velocity is calculated, identified by aerodynamic segment number: n_{L_i} for i = 1 to MRL

OPWKBP(3) integer parameter controlling blade position model for wake analysis

(1) EQ 0 to suppress inplane motion
(2) EQ 0 to suppress all harmonics except mean
(3) EQ 0 for linear from $r = r_{root}/R$ to $r = 1$.

VELB — core burst propagation rate, $V_b = \partial\phi/\partial\psi$

DPHIB — core burst age increment, $\Delta\phi_b$ (deg)

DBV — core burst test parameter d_{bv}; LT 0. to suppress bursting

QDEBUG — velocity criterion for debug print: print if $|\vec{V}\cdot\vec{k}/\Gamma| >$ QDEBUG

Prescribed wake geometry

KRWG — extent of prescribed wake geometry, K_{RWG} (age $\phi = K\Delta\psi$); maximum 144

OPRWG — integer parameter defining prescribed wake geometry model

1 from $K_1=f_1\lambda$, $K_2=f_2\lambda$, input K_3, input K_4

2 option #1, without interference velocity in λ

3 from input K_1, K_2, K_3, K_4

Landgrebe prescribed wake geometry

4 from C_T

5 from Γ_{max}

6 from λ

7 from λ without interference

Kocurek and Tangler prescribed wake geometry

8 from C_T

9 from Γ_{max}

10 from λ

11 from λ without interference

Factors f_1 and f_2 for prescribed wake geometry

FWGT(2) — tip vortex

FWGSI(2) — inside sheet edge

FWGSO(2) — outside sheet edge

Constants K_1, K_2, K_3, K_4 for prescribed wake geometry

KWGT(4) — tip vortex

KWGSI(4) — inside sheet edge

KWGSO(4) — outside sheet edge

	Free wake geometry
KFWG	extent of free wake geometry distortion calculation, K_{FWG} (age $\phi = K\Delta\psi$); suggest $(.4/\mu)$MPSI; maximum 96, multiple MPSI
OPFWG	integer parameter defining free wake geometry model 1 Scully free wake geometry 2 option #1, without interference velocity
ITERWG	number of wake geometry iterations; suggest 2 or 3
FACTWG	factor introducing lag in distortion calculation to improve convergence; suggest 0.5
RTWG(2)	radial station r/R of trailed vorticity (1) inside sheet edge (2) outside sheet edge, or trailed line (suggest .4)
WGMODL(2)	integer parameter defining wake model: 0 to omit, 1 for line segment, 2 for sheet element (1) inboard trailed wake elements (2) shed wake elements
CCREWG(4)	vortex core radii r_c/R (1) tip vortices (2) burst tip vortices (LE 0. for default = unburst value) (3) inboard trailed lines (LE 0. for default = $\frac{1}{2}$(RTWG(2) - RTWG(1))) (4) shed lines (LE 0. for default = $0.4\Delta\psi$)
MRVBWG	number of wake revolutions used below point where induced velocity is being calculated; suggest 2
LDMWG	integer parameter ℓ_{DM}: general update every $\ell_{DM}\Delta\psi$ increment in boundary age; suggest $180^\circ/\Delta\psi$
NDMWG(MPSI)	integer parameter $n_{DM}(\psi_j)$: boundary update every n_{DM} increment in age, function of $\psi_j = j\Delta\psi$, j = 1 to MPSI; suggest $90^\circ/\Delta\psi$ fore and aft, and $45^\circ/\Delta\psi$ on sides
DQWG(2)	incremental velocity criteria; suggest $0.04\lambda_i$ to $0.08\lambda_i$ (1) near wake elements defined by $\lvert\Delta\vec{q}\rvert >$ DQWG(1) (2) integrate bound vortex line in time over if $\lvert\Delta\vec{q}\rvert >$ DQWG(2)

IPWGDB(2) integer parameters controlling debug level 3 print of wake geometry distortion

(1) IPR: print distortion before general update every IPR * $\Delta\Psi$; EQ 0 to suppress
(2) INPS: print distortion after each iteration every INPS * $\Delta\Psi$; EQ 0 to suppress; last iteration printed in full

QWGDB parameter controlling debug level 3 print: induced velocity contribution of wake element printed if $|\Delta\vec{q}| >$ QWGDB; suggest $0.5\lambda_1$ to $1.0\lambda_1$

Namelist NLBODY

TITLE(20)	title for airframe and drive train data (80 characters)
WEIGHT	aircraft gross weight including rotors (lb or kg)
	aircraft moments of inertia including rotors (slug-ft^2 or kg-m^2)
IXX	I_{xx}
IYY	I_{yy}
IZZ	I_{zz}
IXY	I_{xy}
IXZ	I_{xz}
IYZ	I_{yz}
TRATIO	ratio of rotor #2 rotational speed t rotor #1 rotational speed, Ω_2/Ω_1 (transmission gear ratio r_{I_1}/r_{I_2})
CONFIG	integer parameter specifying helicopter configuration 0 for one rotor 1 for single main rotor and tail rotor (rotor #2 is the tail rotor) 2 for tandem main rotors (rotor #2 is the rear rotor) 3 for tilting proprotor aircraft (rotor #2 is the left rotor)
ASHAFT(2)	shaft angle of attack θ_R (deg), positive rearward (1) rotor #1 (2) rotor #2
ACANT(2)	shaft cant angle ϕ_R (deg); positive to right for main rotor; positive upward for tail rotor; positive inward in helicopter mode for tilt rotor (1) rotor #1 (2) rotor #2
ATILT	nacelle tilt angle α_p (deg), for tilting proprotor configuration only; 0. for airplane mode, 90. for helicopter mode
HMAST	rotor mast length from pivot to hub (ft or m), for tilting proprotor configuration only
DPSI21	$\Delta\Psi_{21}$ (deg); rotor #2 azimuth angle Ψ_2 when rotor #1 azimuth angle $\Psi_1 = 0$; must be 0. if $\Omega_2/\Omega_1 \neq 1$.
CANTHT	horizontal tail cant angle ϕ_{HT} (deg), positive to left
CANTVT	vertical tail cant angle ϕ_{VT} (deg), positive to right

location (fuselage station, butt line, and waterline) of aircraft components relative to a body fixed reference system having an arbitrary orientation and origin; fuselage station (FS) positive aft, butt line (BL) positive to right, and waterline (WL) positive up (ft or m)

FSCG — aircraft center of gravity location

BLCG

WLCG

FSR1 — rotor #1 hub location (right nacelle pivot location for tilting proprotor configuration)

BLR1

WLR1

FSR2 — rotor #2 hub location

BLR2

WLR2

FSWB — wing-body center of action

BLWB

WLWB

FSHT — horizontal tail center of action

BLHT

WLHT

FSVT — vertical tail center of action

BLVT

WLVT

FSOFF — point off rotor disk (for induced velocity calculation)

BLOFF

WLOFF

CNTRLZ(11) — control inputs (deg) for all sticks centered ($\vec{v}_p = 0$):

$$\vec{v}_0 = (\underbrace{\theta_0 \;\; \theta_{1c} \;\; \theta_{1s}}_{\text{rotor \#1}} \;\; \underbrace{\theta_0 \;\; \theta_{1c} \;\; \theta_{1s}}_{\text{rotor \#2}} \;\; \underbrace{\delta_f \;\; \delta_e \;\; \delta_a \;\; \delta_r \;\; \theta_t}_{\text{aircraft}})^T$$

description of control system (for T_{CFE}); K parameters are gains (deg per stick deflection), $\Delta\psi$ parameters are swashplate azimuth lead angles (deg)

one rotor, single main rotor and tail rotor, tilting proprotor configurations

KOCFE	K_0, collective stick to collective pitch
KCCFE	K_c, lateral cyclic stick to cyclic or differential collective pitch
KSCFE	K_s, longitudinal cyclic stick to cyclic pitch
KPCFE	K_p, pedal to tail rotor collective or differential cyclic pitch
PCCFE	$\Delta\psi_c$, lateral cyclic stick to cyclic pitch (one rotor, or single main rotor and tail rotor configurations)
PSCFE	$\Delta\psi_s$, longitudinal cyclic stick to cyclic pitch
PPCFE	$\Delta\psi_p$, pedal to differential cyclic pitch (tilting proprotor configuration only)

tandem main rotor configuration

KFOCFE	K_{FO}, collective stick to front collective pitch
KROCFE	K_{RO}, collective stick to rear collective pitch
KFCCFE	K_{FC}, lateral cyclic stick to front cyclic pitch
KRCCFE	K_{RC}, lateral cyclic stick to rear cyclic pitch
KFSCFE	K_{FS}, longitudinal cyclic stick to front collective pitch
KRSCFE	K_{RS}, longitudinal cyclic stick to rear collective pitch
KFPCFE	K_{FP}, pedal to front cyclic pitch
KRPCFE	K_{RP}, pedal to rear cyclic pitch
PFCCFE	$\Delta\psi_{FC}$, lateral cyclic stick to front cyclic pitch
PRCCFE	$\Delta\psi_{RC}$, lateral cyclic stick to rear cyclic pitch
PFPCFE	$\Delta\psi_{FP}$, pedal to front cyclic pitch
PRPCFE	$\Delta\psi_{RP}$, pedal to rear cyclic pitch

aircraft controls (all configurations)

KFCFE	K_f, collective stick to flaperon
KTCFE	K_t, collective stick to throttle
KACFE	K_a, lateral cyclic stick to ailerons
KECFE	K_e, longitudinal cyclic stick to elevator
KRCFE	K_r, pedal to rudder

NEM	number of airframe modes for which data supplied; maximum 10
QMASS(NEM)	generalized mass M_k including rotors (slug or kg)
QFREQ(NEM)	generalized frequency ω_k (Hz)
QDAMP(NEM)	structural damping g_s
QDAMPA(NEM)	erodynamic damping $F_{q_k \dot{q}_k} = \partial(Q_k/\frac{1}{2}\rho V^2)/\partial(\dot{q}_{s_k}/V)$ (ft^2 or m^2)
QCNTRL(4,NEM)	control derivatives $F_{q_k \delta} = \partial(Q_k/\frac{1}{2}\rho V^2)/\partial\delta$ for δ_f, δ_e, δ_a, δ_r (ft^2/rad or m^2/rad)
DOFSYM(NEM)	integer vector designating type of mode: GT 0 for symmetric, LT 0 for antisymmetric; only required for flutter analysis with OPSYMM NE 0
ZETAR1(3,NEM)	linear mode shape $\vec{\zeta}_k$ at rotor #1 hub (ft/ft or m/m)
ZETAR2(3,NEM)	linear mode shape $\vec{\zeta}_k$ at rotor #2 hub (ft/ft or m/m)
GAMAR1(3,NEM)	angular mode shape $\vec{\gamma}_k$ at rotor #1 hub (rad/ft or rad/m)
GAMAR2(3,NEM)	angular mode shape $\vec{\gamma}_k$ at rotor #2 hub (rad/ft or rad/m)
	pitch/mast-bending coupling (rad/ft or rad/m)
KPMC1(NEM)	$K_{MC_k} = -\partial\theta_{1c}/\partial q_{s_k}$ for rotor #1
KPMS1(NEM)	$K_{MS_k} = -\partial\theta_{1s}/\partial q_{s_k}$ for rotor #1
KPMC2(NEM)	$K_{MC_k} = -\partial\theta_{1c}/\partial q_{s_k}$ for rotor #2
KPMS2(NEM)	$K_{MS_k} = -\partial\theta_{1s}/\partial q_{s_k}$ for rotor #2

Aircraft aerodynamic characteristics

Wing-body

LFTAW	L_{α}/q	(ft^2/rad or m^2/rad)
LFTFW	L_{δ_f}/q	(ft^2/rad or m^2/rad)
LFTDW	L_{δ_F}/q	(ft^2/rad or m^2/rad)
AMAXW	α_{max}	(deg)
IWB	i_{WB}	(deg)
DRGOW	$f_{WB} = D_0/q$	(ft^2 or m^2)
DRGVW	f_{vert}	(ft^2 or m^2)
DRGIW	$\pi e \ell_W^2 = (\partial(D_i/q)/ \partial(L/q)^2)^{-1}$	(ft^2 or m^2)
DRGFW	$D_{0_{\delta_f}}/q$	(ft^2/rad or m^2/rad)
DRGDW	$D_{0_{\delta_F}}/q$	(ft^2/rad or m^2/rad)
MOMOW	M_0/q	(ft^3 or m^3)
MOMAW	M_{α}/q	(ft^3/rad or m^3/rad)
MOMFW	M_{δ_f}/q	(ft^3/rad or m^3/rad)
MOMDW	M_{δ_F}/q	(ft^3/rad or m^3/rad)
SIDEB	Y_{β}/q	(ft^2/rad or m^2/rad)
SIDEP	VY_p/q	(ft^3/rad or m^3/rad)
SIDER	VY_r/q	(ft^3/rad or m^3/rad)
ROLLB	$N_{x_{\beta}}/q$	(ft^3/rad or m^3/rad)
ROLLP	VN_{x_p}/q	(ft^4/rad or m^4/rad)
ROLLR	VN_{x_r}/q	(ft^4/rad or m^4/rad)
ROLLA	$N_{x_{\delta_a}}/q$	(ft^3/rad or m^3/rad)
YAWB	$N_{z_{\beta}}/q$	(ft^3/rad or m^3/rad)
YAWP	VN_{z_p}/q	(ft^4/rad or m^4/rad)
YAWR	VN_{z_r}/q	(ft^4/rad or m^4/rad)
YAWA	$N_{z_{\delta_a}}/q$	(ft^3/rad or m^3/rad)

Horizontal tail

LFTAH	L_{α}/q	(ft^2/rad or m^2/rad)
LFTEH	L_{δ_e}/q	(ft^2/rad or m^2/rad)
AMAXH	α_{max}	(deg)
IHT	i_{HT}	(deg)

	Vertical tail	
LFTAV	L_α/q	(ft^2/rad or m^2/rad)
LFTRV	L_{δ_T}/q	(ft^2/rad or m^2/rad)
AMAXV	α_{max}	(deg)
IVT	i_{VT}	(deg)
	Airframe interference	
FETAIL	$f_\epsilon = (\partial\epsilon/\partial(L/q))^{-1}$	(ft^2 or m^2)
LHTAIL	horizontal tail length ℓ_{HT} for ϵ (ft or m)	
HVTAIL	vertical tail height h_{VT} for σ, positive up (ft or m)	
OPTINT	integer parameter controlling airframe/tail aerodynamic interference: EQ 0 to suppress ($\epsilon = 0$ and $\sigma = 0$)	

Engine and drive train parameters

ENGPOS	integer parameter specifying drive train configuration: 0 one rotor 1 asymmetric, engine by rotor #1 2 asymmetric, engine by rotor #2 3 symmetric
IENG	engine rotational inertia $r_E^2 I_E$, for both engines if symmetric configuration (slug-ft^2 or kg-m^2)
	drive train spring constants (ft-lb/rad or m-N/rad)
KMAST1	rotor #1 shaft, K_{M_1} or K_M
KMAST2	rotor #2 shaft, K_{M_2}
KICS	interconnect shaft, $r_{I_2}^2 K_I$ or $r_I^2 K_I$
KENG	engine shaft, $r_E^2 K_E$
GSE	engine shaft structural damping g_s (ψ_e degree of freedom)
GSI	interconnect shaft structural damping g_s (ψ_I degree of freedom)
KEDAMP	engine damping factor K; typically 1.0 for turboshaft engines, or 10. for induction electric motors
THRTLC	$\partial P_E/\partial\theta_t$ (dimensional), for both engines if symmetric configuration; if the throttle variable θ_t is only used for the governor, just the products $K_P\,\partial P_E/\partial\theta_t = -\partial P/\partial\dot\psi_s$ $K_I\,\partial P_E/\partial\theta_t = -\partial P/\partial\psi_s$ must be correct ($P = \Omega_R Q_R = \Omega_E Q_E$)
	governor proportional feedback gains (sec)
KPGOVE	to throttle, $K_P = -\partial\theta_t/\partial\dot\psi_s$
KPGOV1	to rotor #1 collective, $K_P = \partial\theta/\partial\dot\psi_s$
KPGOV2	to rotor #2 collective, $K_P = \partial\theta/\partial\dot\psi_s$
	governor integral feedback gains
KIGOVE	to throttle, $K_I = -\partial\theta_t/\partial\psi_s$
KIGOV1	to rotor #1 collective, $K_I = \partial\theta/\partial\psi_s$
KIGOV2	to rotor #2 collective, $K_I = \partial\theta/\partial\psi_s$

	governor time lag $\tau_1 = 2\zeta/\omega_n$ (sec)
T1GOVE	throttle
T1GOV1	rotor #1
T1GOV2	rotor #2
	governor time lag $\tau_2 = 1/\omega_n^2$ (sec^2)
T2GOVE	throttle
T2GOV1	rotor #1
T2GOV2	rotor #2

Namelist NLLOAD

	Airframe vibration
MVIB	number of stations for airframe vibration calculation and print; maximum 10; LE 0 to suppress
	airframe location for vibration calculation (ft or m)
FSVIB(MVIB)	fuselage station
BLVIB(MVIB)	butt line
WLVIB(MVIB)	waterline
ZETAV(3,NEM,MVIB)	linear mode shape $\vec{\zeta}_k$ at airframe vibration stations (ft/ft or m/m)
MALOAD	integer parameter controlling print of motion and aerodynamics: EQ 0 to suppress; LT 0 for only plots
MHLOAD	integer parameter controlling print of hub and control loads: EQ 0 to suppress
MRLOAD	number of radial stations for blade section load calculation and print; maximum 20; LE 0 to suppress
RLOAD(MRLOAD)	blade radial stations r/R for section loads
MHARML	number of harmonics in loads analysis; maximum 30; LT 0 for no harmonic analysis; suggest about MPSI/3
NPOLAR	integer parameter n for polar plots: symbol printed every n-th step
NWKGMP(4)	integer parameter controlling wake geometry printer plot; EQ 0 to suppress (1) top view (2) side view (3) back view (4) axial convection
MWKGMP	number of azimuth stations at which wake geometry plotted; maximum 8; LE 0 for no plots
JWKGMP(MWKGMP)	azimuth stations at which wake geometry plotted ($\psi = j\Delta\psi$)

NPLOT(75) integer parameter controlling printer-plots of motion and aerodynamics: 0 for no plot, 1 for time history plot, 2 for polar plot, 3 for both (only time history available for 1-4 and 68-75)

(1) bending motion
(2) torsion motion
(3) maximum circulation
(4) λ off rotor

(5) α
(6) M
(7) Λ
(8) c_ℓ
(9) c_d
(10) c_m
(11) $c_{d_{radial}}$
(12) Γ
(13) u_P
(14) u_T
(15) u_R
(16) U
(17) θ
(18) ϕ
(19) lag
(20) flap
(21) α_{eff}, lift
(22) drag
(23) moment
(24) M_{eff}, lift
(25) drag
(26) moment
(27) λ_x
(28) λ_y
(29) λ_z
(30) interference λ_x
(31) λ_y
(32) λ_z
(33) u_G
(34) v_G
(35) w_G
(36) L/c
(37) D/c
(38) M/c
(39) D_r/c
(40) F_x/c
(41) F_r/c
(42) $F_z/c = C_T/\sigma$
(43) $\underset{\sim}{M}_a/c$
(44) $\tilde{F}_r/c$

(45) not used
(46) not used
(47) not used
(48) C_P/σ
(49) C_{P_i}/σ
(50) $C_{P_{int}}/\sigma$
(51) C_{P_o}/σ
(52) L *
(53) D *
(54) M *
(55) D_r *
(56) F_x *
(57) F_r *
(58) $F_z = T$ *
(59) M_a *
(60) F_c *
(61) not used
(62) not used
(63) not used
(64) P *
(65) P_i *
(66) P_{int} *
(67) P_o *
(68) rotating frame root loads
(69) nonrotating frame hub loads
(70) rotating frame root loads *
(71) nonrotating frame hub loads *
(72) section loads, shaft axes
(73) section loads, principal axes
(74) section loads, shaft axes *
(75) section loads, principal axes *

*dimensional quantities

for polar plots, last digit of integer part of (value/increment) is printed, if it is a multiple of NPOLAR; the plot increment is defined as follows

.01 plots 27-35
.1 plots 6, 8-16, 24-26, 36-51
1. plots 5, 7, 17-23, 52-61
10. plots 62-67

KFATIG parameter K in fatigue damage calculation; suggest 3 or 4

SENDUR(18) endurance limit S_E (dimensional force or moment)

CMAT(18) material constant C

EXMAT(18) material exponent M

rotating frame root loads
(1) inplane shear f_x
(2) axial shear f_r
(3) vertical shear f_z
(4) flap moment m_x
(5) lag moment m_z
(6) control moment m_c
nonrotating frame hub loads
(7) drag force H
(8) side force Y
(9) thrust T
(10) roll moment M_x
(11) pitch moment M_y
(12) torque Q
section loads (principal axes)
(13) chord shear f_x
(14) axial shear f_r
(15) normal shear f_z
(16) flatwise moment m_x
(17) edgewise moment m_z
(18) torsion moment m_t

the S-N curve is approximated by $N = C/(S/S_E - 1)^M$

use S_E LT 0. or C LT 0. to suppress damage fraction calculation; use M EQ 0. to suppress equivalent peak-to-peak load calculation as well

Far field rotational noise

MNOISE	number of microphones; maximum 10; LE 0 for no noise analysis
RANGE(MNOISE)	microphone range relative hub (ft or m)
ELVATN(MNOISE)	microphone elevation relative hub (deg), positive above rotor disk
AZMUTH(MNOISE)	microphone azimuth relative hub (deg), defined as for rotor azimuth
MHARMN(3)	number of harmonics (1) in noise calculation; maximum 500 (2) in aerodynamic load harmonic analysis (suggest MPSI/3) (3) in print of noise (LE 0 for no print)
MTIMEN(3)	number of time steps (LE 0 to suppress) (1) in period of noise calculation; maximum 500 (2) increment in noise print (3) increment in noise plot
AXS(MRA)	blade cross section area A_{XS}/c^2 at aerodynamic segments, for thickness noise calculation(typically 0.685 times thickness ratio)
OPNOIS(4)	integer parameter controlling noise calculation: 0 to suppress, 1 for impulsive chordwise loading, 2 for distributed chordwise loading (1) lift noise (2) drag noise (3) radial force noise (4) thickness noise

Namelist NLFLUT

OPFLOW	integer parameter specifying analysis type: LT 0 for constant coefficient approximation; EQ 0 for axial flow; GT 0 for periodic coefficients
OPSYMM	integer parameter: NE 0 for symmetric and antisymmetric analyses (tilting proprotor configuration only)
OPFDAN	integer parameter: EQ 0 to suppress flight dynamics analysis
NBLDFL	integer parameter: EQ 1 for independent rotor blade analysis
MPSIPC	number of azimuth steps in period for nonaxial flow, periodic coefficient analysis (OPFLOW GT 0); $\Delta\psi = 360/(N_{bld}M)$ for odd number of blades, $\Delta\psi = 720/(N_{bld}M)$ for even number of blades
NINTPC	integer parameter specifying numerical integration option for periodic coefficient analysis (OPFLOW GT 0): 1 for modified trapezoidal method, 2 for Runge-Kutta method
MPSICC	number of azimuth stations (per revolution) in evaluation of average coefficients for constant coefficient approximation (OPFLOW LT 0); $\Delta\psi = 360^{\circ}/M$
DALPHA	angle of attack increment $\Delta\alpha$ (deg) for calculation of c_ℓ, c_d, and c_m derivatives in aerodynamic coefficients
DMACH	Mach number increment $\Delta M/M$ for calculation of c_ℓ, c_d, and c_m derivatives in aerodynamic coefficients
OPUSLD	integer parameter controlling use of unsteady lift and moment in flutter analysis: 0 to suppress; 1 to include; 2 for zero in stall ($15^{\circ} < \lvert\alpha\rvert < 165^{\circ}$)
DELTA	control and motion increment for aircraft stability derivative calculation (dimensionless)
OPRINT	integer parameter: EQ 0 to suppress rotor/body aerodynamic interference in flutter analysis
OPGRND	integer parameter controlling ground effect analysis: EQ 0 for out of ground effect, NE 0 for in ground effect
KASGE	factor for antisymmetric ground effect: 0. to suppress, 1.0 for unstable roll moment due to ground effect (tilting proprotor configuration only)
OPSAS	integer parameter controlling use of SAS: EQ 0 to suppress
KCSAS	lateral SAS gain $K_c = -\partial\delta_c/\partial\phi_F$ (deg/deg)
KSSAS	longitudinal SAS gain $K_s = \partial\delta_s/\partial\theta_F$ (deg/deg)
TCSAS	lateral SAS lead time τ_c (sec)
TSSAS	longitudinal SAS lead time τ_s (sec)

OPTORS(2) integer parameter: EQ 0 for rigid pitch model (infinite control system stiffness, no p_0 degree of freedom)
(1) rotor #1
(2) rotor #2

DOF(80) integer vector defining degrees of freedom for flutter analysis; 0 if not used, 1 if used, 2 if quasistatic variable; order:

	bending (15)	pitch/torsion (9)	gimbal teeter	rotor speed	inflow
rotor #1	$\beta_0^{(i)}\ \beta_{1c}^{(i)}\ \beta_{1s}^{(i)} \cdots \beta_{N/2}^{(i)}$	$\theta_0^{(i)}\ \theta_{1c}^{(i)}\ \theta_{1s}^{(i)} \cdots \theta_{N/2}^{(i)}$	$\beta_{GC}\ \beta_{GS}$	ψ_s	$\lambda_u\ \lambda_x\ \lambda_y$
rotor #2	$\beta_0^{(i)}\ \beta_{1c}^{(i)}\ \beta_{1s}^{(i)} \cdots \beta_{N/2}^{(i)}$	$\theta_0^{(i)}\ \theta_{1c}^{(i)}\ \theta_{1s}^{(i)} \cdots \theta_{N/2}^{(i)}$	$\beta_{GC}\ \beta_{GS}$	ψ_I	$\lambda_u\ \lambda_x\ \lambda_y$

	rigid body	flexible body (10)	engine speed	governor
airframe	$\phi_F\ \theta_F\ \psi_F\ x_F\ y_F\ z_F$	$q_{s7} \cdots q_{s16}$	ψ_e	$\Delta\theta_t\ \Delta\theta_{govr_1}\ \Delta\theta_{govr_2}$

CON(26) integer vector defining control variables, 0 if not used; order:

rotor #1 $\theta_0\ \ \theta_{1c}\ \ \theta_{1s} \cdots \theta_{N/2}$

rotor #2 $\theta_0\ \ \theta_{1c}\ \ \theta_{1s} \cdots \theta_{N/2}$
pitch (8)

airframe $\delta_y\ \delta_e\ \delta_a\ \delta_r\ \theta_t$

pilot $\delta_0\ \delta_c\ \delta_s\ \delta_p\ \delta_T$

GUS(3) integer vector defining gust components, 0 if not used; order: u_G, v_G, w_G

for a two-bladed rotor, β_{GC} is replaced by β_T

tnere are N_{bld} rotor pitch control variables; except for a two-bladed rotor, which has the 4 variables θ_0, θ_{1c}, θ_{1s}, θ_1

ANTYPE(4) — integer parameter specifying tasks in linear system analysis, EQ 0 to suppress
(1) eigenanalysis
(2) transfer function printer-plot
(3) time history printer-plot
(4) rms gust response

Eigenanalysis

NSYSAN — calculation control: 0 for eigenvalues, 1 for eigenvalues and eigenvectors; 10 or 11 for zeros as well

NSTEP — static response calculated if NE 0

NFREQ — number of frequencies for which frequency response calculated; LE 0 to suppress; maximum 100

FREQ(NFREQ) — vector of frequencies (per rev)

Transfer function printer-plot

NBPLOT — calculation method: if 1, from matrices; if 2, from poles and zeros

NXPLT — number of degrees of freedom to be plotted; maximum 80

NVPLT — number of controls to be plotted; maximum 29

NAMEXP(NXPLT) — vector of variable names to be plotted (inconsistent names ignored)

NAMEVP(NVPLT) — vector of control names to be plotted (inconsistent names ignored)

NDPLT — frequency steps per decade

NF0PLT — exponent (base 10) of beginning frequency

NF1PLT — exponent (base 10) of end frequency
(maximum NF = (NF1PLT - NF0PLT) * NDPLT + 1 = 151)

MSPLT — magnitude plot scale: if 1, plot relative maximum value; if 2, plot relative 10.**K; if 3, plot relative 10.

	Time history printer-plot
NTPLOT	control input type: 1 for step, 2 for impulse, 3 for cosine impulse, 4 for sine doublet, 5 for square impulse, 6 for square doublet
PERPLT	period T for impulse or doublet (sec)
DTPLT	time step (sec)
TMXPLT	maximum time (sec); maximum NXPLT*NVPLT*TMXPLT/DTPLT = 7200
NXPLT	number of degrees of freedom to be plotted; maximum 80
NVPLT	number of controls to be plotted; maximum 29
NAMEXP(NXPLT)	vector of variable names to be plotted (inconsistent names ignored)
NAMEVP(NVPLT)	vector of control names to be plotted (inconsistent names ignored)
	Rms gust response
LGUST(MG)	real vector of gust correlation lengths: GT 0., dimensional length L ($\tau_G = L/2V$); EQ 0., set L = 400.; LT 0., magnitude is dimensionless correlation time τ_G (frequency $\omega = \Omega/\tau_G$)
MGUST(MG)	real vector of gust component relative magnitudes
	MG = number of gust components; maximum 3
NAMEXA(MACC)	vector of names of degrees of freedom for which acceleration calculated; last 3 equal ACCB for body axis acceleration (all 3 or none) (inconsistent names ignored)
FREQA(MACC)	vector of acceleration break frequencies (Hz); 2/rev used if LT 0.; in same order as NAMEXA
MACC	number of accelerometers; LE 0 for none; maximum 83
	location of point at which body axis acceleration calculated (ft or m)
FSACC	fuselage station
BLACC	butt line
WLACC	waterline
ZETACC(3,NEM)	linear mode shape $\vec{\zeta}_k$ at point where body axis acceleration calculated
NAMEXR(3)	names of β_{1c}, ζ_{1c}, and θ_{1c} in state vector; assumed that β_{1s}, ζ_{1s}, and θ_{1s} follow immediately (inconsistent names ignored)

Variable names for linear system analysis

Degrees of freedom

1B1	$\beta_0^{(i)}\ \beta_{1c}^{(i)}\ \beta_{1s}^{(i)} \dots \beta_{N/2}^{(i)}$	bending	rotor #1
⋮			
1B15			
1T1	$\theta_0^{(i)}\ \theta_{1c}^{(i)}\ \theta_{1s}^{(i)} \dots \theta_{N/2}^{(i)}$	pitch/torsion	
⋮			
1T9			
1BGC	β_{GC}	gimbal/teeter	
1BGS	β_{GS}		
PSIS	Ψ_S	rotor speed	
1LU	λ_u	inflow	
1LX	λ_x		
1LY	λ_y		
2B1	$\beta_0^{(i)}\ \beta_{1c}^{(i)}\ \beta_{1s}^{(i)} \dots \beta_{N/2}^{(i)}$	bending	rotor #2
⋮			
2B15			
2T1	$\theta_0^{(i)}\ \theta_{1c}^{(i)}\ \theta^{(i)} \dots \theta_{N/2}^{(i)}$	pitch/torsion	
⋮			
2T9			
2BGC	β_{GC}	gimbal/teeter	
2BGS	β_{GS}		
PSII	Ψ_I	rotor speed	
2LU	λ_u	inflow	
2LX	λ_x		
2LY	λ_y		
PHIF	ϕ_F	rigid body	airframe
THTF	θ_F		
PSIF	ψ_F		
XF	x_F		
YF	y_F		
ZF	z_F		

QF1	q_{s_k} $(k \geq 7)$	flexible body	airframe
⋮			
QF10			
PSIE	ψ_e	engine speed	
TGOV	$\Delta\theta_T$	governor	
1GOV	$\Delta\theta_{govr_1}$		
2GOV	$\Delta\theta_{govr_2}$		

Control variables

1C0	$\theta_0\ \theta_{1c}\ \theta_{1s} \ldots \theta_{N/2}$	rotor #1
1C1C		
1C1S		
1C4		
⋮		
1C8		
2C0	$\theta_0\ \theta_{1c}\ \theta_{1s} \ldots \theta_{N/2}$	rotor #2
2C1C		
2C1S		
2C4		
⋮		
2C8		
DELF	δ_f	airframe
DELE	δ_e	
DELA	δ_a	
DELR	δ_r	
CT	θ_t	
DELO	δ_o	pilot
DELC	δ_c	
DELS	δ_s	
DELP	δ_p	
DELT	δ_t	

Gust components

UG u_G

VG v_G

WG w_G

For the rotor names, the leading character (1 or 2) is replaced as follows, depending on the helicopter configuration

CONFIG =	0	blank (left justified)
	1	M or T
	2	F or R
	3	R or L (OPSYMM = 0)
	3	S or A (OPSYMM $\neq$ 0)

For a two bladed rotor, BGC is replaced by BT

For first order degrees of freedom, the only state is the velocity, hence it is the velocity that will be plotted

Namelist NLSTAB

NPRNTP — integer parameter controlling performance print during stability derivative calculation: LE 0 to suppress

NPRNTL — integer parameter controlling loads print during stability derivative calculation: LE 0 to suppress

ITERS — number of wake influence coefficient/motion and forces iterations

OPLMDA — integer parameter controlling induced velocity calculation: if 0, update influence coefficients and inflow; if 1, suppress influence coefficient update; if 2, suppress inflow update (and influence coefficient update)

DELTA — control and motion increment for stability derivative calculation (dimensionless)

DOF(7) — integer vector defining degrees of freedom, 0 if not used; order: ϕ_F, θ_F, ψ_F, x_F, y_F, z_F, ψ_s

CON(16) — integer vector defining control variables, 0 if not used; order:

rotor #1	θ_o θ_{1c} θ_{1s}
rotor #2	θ_o θ_{1c} θ_{1s}
airframe	δ_f δ_e δ_a δ_r θ_t
pilot	δ_o δ_c δ_s δ_p δ_t

GUS(3) — integer vector defining gust components, 0 if not used; order: u_G, v_G, w_G

OPPRNT(4) — integer parameters controlling stability derivative print, EQ 0 to suppress:
(1) rotor coefficient form, dimensionless
(2) rotor coefficient form, dimensional
(3) stability derivative form, dimensionless
(4) stability derivative form, dimensional

KCSAS — lateral SAS gain, $K_c = -\partial\delta_c/\partial\phi_F$ (deg/deg)

KSSAS — longitudinal SAS gain, $K_s = \partial\delta_s/\partial\theta_F$ (deg/deg)

TCSAS — lateral SAS lead time τ_c (sec)

TSSAS — longitudinal SAS lead time τ_s (sec)

EQTYPE(12) — integer parameter specifying equations to be analyzed, EQ 0 to suppress

with $\dot{\psi}_s$, with SAS
- (1) complete
- (2) symmetric
- (3) antisymmetric

with $\dot{\psi}_s$, without SAS
- (4) complete
- (5) symmetric
- (6) antisymmetric

without $\dot{\psi}_s$, with SAS
- (7) complete
- (8) symmetric
- (9) antisymmetric

without $\dot{\psi}_s$, without SAS
- (10) complete
- (11) symmetric
- (12) antisymmetric

ANTYPE(5) — integer parameter specifying tasks in linear system analysis, EQ 0 to suppress
- (1) eigenanalysis
- (2) transfer function printer-plot
- (3) time history printer-plot
- (4) rms gust response
- (5) numerical integration of transient

Eigenanalysis

NSYSAN — calculation control: 0 for eigenvalues, 1 for eigenvalues and eigenvectors; 10 or 11 for zeros as well

NSTEP — static response calculated if NE 0

NFREQ — number of frequencies for which frequency response calculated; LE 0 to suppress; maximum 100

FREQ(NFREQ) — vector of frequencies (per rev)

Transfer function printer-plot

NBPLOT	calculation method: if 1, from matrices; if 2, from poles and zeros
NAMEXP(NXPLT)	vector of variable names to be plotted (inconsistent names ignored)
NAMEVP(NVPLT)	vector of control names to be plotted (inconsistent names ignored)
NXPLT	number of degrees of freedom to be plotted; maximum 7
NVPLT	number of controls to be plotted; maximum 19
NDPLT	frequency steps per decade
NFOPLT	exponent (base 10) of beginning frequency
NF1PLT	exponent (base 10) of end frequency
	(maximum NF = (NF1PLT NFOPLT) * NDPLT + 1 = 151)
MSPLT	magnitude plot scale: if 1, plot relative maximum value; if 2, plot relative 10**K; if 3, plot relative 10.

Time history printer-plot

NTPLOT	control input type: 1 for step, 2 for impulse, 3 for cosine impulse, 4 for sine doublet, 5 for square impulse, 6 for square doublet
PERPLT	period T for impulse or doublet (sec)
DTPLT	time step (sec)
TMXPLT	maximum time (sec); maximum NXPLT*NVPLT*TMXPLT/DTPLT = 7200
NXPLT	number of degrees of freedom to be plotted; maximum 7
NVPLT	number of controls to be plotted; maximum 19
NAMEXP(NXPLT)	vector of variable names to be plotted (inconsistent names ignored)
NAMEVP(NVPLT)	vector of control names to be plotted (inconsistent names ignored)

Rms gust response

LGUST(MG)	real vector of gust correlation lengths: GT 0., dimensional length L (τ_G = L/2V); EQ 0., set L = 400.; LT 0., magnitude is dimensionless correlation time τ_G (frequency $\omega = \Omega/\tau_G$)
MGUST(MG)	real vector of gust component relative magnitudes
	MG = number of gust components, maximum 3

NAMEXA(MACC)	vector of names of degrees of freedom for which acceleration calculated; last 3 equal ACCB for body axis acceleration (all 3 or none) (inconsistent names ignored)
FREQA(MACC)	vector of acceleration break frequencies (Hz); 2/rev used if LT 0.; same order as NAMEXA
MACC	number of accelerometers; LE 0 for none; maximum 10
	location of point at which body axis acceleration calculated (ft or m)
FSACC	fuselage station
BLACC	butt line
WLACC	waterline
	Numerical integration of transient
TSTEP	time step in numerical integration (sec)
TMAX	maximum time in numerical integration (sec)
NPRNTT	integer parameter n: transient print every n-th integration step; LE 0 to suppress
OPPLOT	integer parameter controlling printer plot of body motion: EQ 0 to suppress
DOFPLT(21)	integer vector designating variables to be plotted, EQ 0 if not plotted; order: $\phi_F\ \theta_F\ \psi_F\ x_F\ y_F\ z_F\ \psi_s\ \dot\phi_F\ \dot\theta_F\ \dot\psi_F\ \dot x_F\ \dot y_F\ \dot z_F\ \dot\psi_s\ \ddot\phi_F\ \ddot\theta_F\ \ddot\psi_F\ \ddot x_F\ \ddot y_F\ \ddot z_F\ \ddot\psi_s$
OPTRAN	see namelist NLTRAN
CTIME	
CMAG(5)	
GTIME	
GMAG(3)	
GDIST(2)	
VELG	
PSIG	
OPGUST(3)	

Variable names for linear system analysis

Degrees of freedom

PHIF	ϕ_F	rigid body
THTF	θ_F	
PSIF	ψ_F	
XF	x_F	
YF	y_F	
ZF	z_F	
PSIS	ψ_S	rotor speed

Control variables

1C0	θ_0	rotor #1
1C1C	θ_{1c}	
1C1S	θ_{1s}	
2C0	θ_0	rotor #2
2C1C	θ_{1c}	
2C1S	θ_{1s}	
DELF	δ_f	aircraft
DELE	δ_e	
DELA	δ_a	
DELR	δ_r	
CT	θ_t	
DELO	δ_o	pilot
DELC	δ_c	
DELS	δ_s	
DELP	δ_p	
DELT	δ_t	

Gust components

UG	u_G
VG	v_G
WG	w_G

For the rotor control names, the leading character (1 or 2)
is replaced as follows, depending on the helicopter configuration

CONFIG = 0	blank (left justified)
1	M or T
2	F or R
3	R or L

For first order degrees of freedom the only state is the
velocity; hence it is the velocity that will be plotted

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Namelist NLTRAN

NPRNTT	integer parameter n: transient/performance/loads print every n-th integration step; LE 0 to suppress
NPRNTP	integer parameter controlling performance print: LE 0 to suppress
NPRNTL	integer parameter controlling loads print: LE 0 to suppress
NRSTRT	integer parameter n: restart file written only every n-th integration step; LE 0 to suppress
TSTEP	time step in numerical integration (sec)
TMAX	maximum time in numerical integration (sec)
ITERT	number of wake influence coefficients/motion and forces iterations
OPLMDA	integer parameter controlling induced velocity calculation: if 0, update influence coefficients and inflow; if 1, suppress influence coefficient update; if 2, suppress inflow update (and influence coefficient update)
DOF(7)	integer vector defining degrees of freedom in numerical integration; EQ 0 to suppress acceleration; order: ϕ_F, θ_F, ψ_F, x_F, y_F, z_F, ψ_s
OPSAS	integer parameter controlling use of SAS: EQ 0 to suppress
KCSAS	lateral SAS gain, $K_c = -\partial\delta_c/\partial\phi_F$ (deg/deg)
KSSAS	longitudinal SAS gain, $K_s = \partial\delta_s/\partial\theta_F$ (deg/deg)
TCSAS	lateral SAS lead time τ_c (sec)
TSSAS	longitudinal SAS lead time τ_s (sec)
OPPLOT	integer parameter controlling printer plot of body motion: EQ 0 to suppress
DOFPLT(21)	integer vector designating variables to be plotted; EQ 0 for not plotted; order: $\phi_F\ \theta_F\ \psi_F\ x_F\ y_F\ z_F\ \psi_s\ \dot\phi_F\ \dot\theta_F\ \dot\psi_F\ \dot x_F\ \dot y_F\ \dot z_F\ \dot\psi_s\ \ddot\phi_F\ \ddot\theta_F\ \ddot\psi_F\ \ddot x_F\ \ddot y_F\ \ddot z_F\ \ddot\psi_s$

Transient gust and control

OPTRAN integer parameter specifying transient option; 1 for control; 2 for uniform gust; 3 for convected gust

CTIME period T for control (sec)

CMAG(5) control magnitude $\vec{v}_{P_0} = (\delta_0 \ \delta_c \ \delta_s \ \delta_p \ \delta_t)^T$ (deg)

defines cosine control transient with period T and magnitude $\vec{v}_{P_0}$

GTIME period T for uniform gust (sec)

GMAG(3) gust magnitude $\vec{g}_0 = (u_G \ v_G \ w_G)^T$ (ft/sec or m/sec)

defines cosine uniform gust transient with period T and magnitude $\vec{g}_0$

GDIST(2) lengths for convected gust (ft or m)
(1) wavelength L
(2) starting position L_0

VELG gust convection velocity V_g (ft/sec or m/sec)

PSIG azimuth angle of convected gust wave front ψ_g (deg)

OPGUST(3) integer parameters defining convected gust model
(1) EQ 0 to not use V_a
(2) rotor #1: 0 for gust at hub, 1 for over disk
(3) rotor #2: 0 for gust at hub, 1 for over disk

defines cosine convected gust transient with wavelength L and magnitude $\vec{g}_0$; for $L_0 = R$ the wave starts at edge of rotor disk, for $L_0 = 0.$ the wave starts at hub -- assuming the aircraft center of gravity is directly below the hub; convected at rate V_g relative to moving aircraft if V_a is not used, at rate V_g relative to fixed frame if V_a is used

Transient gust and control subroutines

The subroutine CONTRL calculates the transient control time history, $C(t)$. The subroutine GUSTU calculates the uniform gust time history, $G(t)$. The subroutine GUSTC calculates the convected gust wave shape, $G(x_g)$. The subroutines presently calculate a cosine-impulse gust:

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

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

GUSTC $G(x_g) = \frac{1}{2}(1 - \cos 2\pi(x_g - L_o)/L)$

Other transients may be used by replacing these subroutines as required.

Namelist Inputs for Old Job (Restart)

Namelist NLTRIM

ANTYPE(3)

OPREAD(10)

DEBUG(25)

NPRNTI

Namelist NLFLUT

ANTYPE(4)

NSYSAN

⋮

NAMEXR(3)

Namelist NLSTAB

OPPRNT(4)

KCSAS

KSSAS

TCSAS

TSSAS

EQTYPE(12)

ANTYPE(5)

NSYSAN

⋮

OPGUST(3)

Namelist NLTRAN

NPRNTT

NPRNTP

NPRNTL

NRSTRT

TMAX

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7. NOTES ON PRINTED OUTPUT

This section presents notes on the printed output of the program, particularly regarding the units of the variables appearing in the output.

Print of Performance (Program PERF)

Operating condition:

a) motion: 1st number imensionless, 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) $\dot{\psi}_s$ = 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 ($\leq$ 1. if converged)

Motion convergence:

a) tolerance, BETA (etc) in deg
b) BETA/E (etc) = ratio error to tolerance ($\leq$ 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:

a) dimensional (HP); number in parentheses is percent total power
b) 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 = $M = 1 - P_{non\text{-}ideal}/P_{total}$

<u>Print of Rotor Loads (Program LOADR1)</u>

Print aerodynamics (function r and ψ)

a) dimensionless quantities generally, angles in degrees

b) induced velocity in nonrotating shaft axes ($\lambda_x, -\lambda_y, -\lambda_z$)

c) interference induced velocity is that due to other rotor

d) gust components i. [illegible]ocity axes

Force/c_{mean} (dimensionless):

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

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

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

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

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

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

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

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

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

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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)

Print During Stability Derivative Calculation (Program STABM)

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 $\gamma 2C/\sigma a$ form (rotor #1 parameters, body axes); torque in $-\gamma C_Q/\sigma a$ form (rotor #1 parameters)

Print of Stability Derivatives (Program STABD)

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	moments	torque
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
	(FF)	(FM)	(FQ)

b) subscripts

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

Print During Flight Dynamics Numerical Integration (Program STABP)

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

Print Transient Solution (Program TRANP)

a) controls in deg

b) gust velocity 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

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)

8. UNITS

The program will work with English or metric (SI) units for input and output. Some of the input parameters and most of the internal program parameters are dimensionless (based on the rotor radius, the rotor rotational speed, and the air density). The units for input and output parameters are based on the consistent mass-length-time system (foot-slug-second or meter-kilogram-second), with the following exceptions:

a) The aircraft gross weight is input in pounds or kilograms.

b) The aircraft velocity is input in knots for both systems of units (alternatively the dimensionless speed can be input).

c) Power is output in horsepower for both systems of units.

The "dimensional" output for angles is in degrees; the "dimensionless" form for angles is in radians.

9. AIRFOIL TABLE PREPARATION

This section describes a program that constructs airfoil table files in the form required by the rotor analysis. The program will also print or printer-plot the airfoil data in the file being created or in an existing file. The airfoil tables are constructed using either analytical expressions or an airfoil table deck (in C81 format). The subprogram functions and namelist input labels are summarized below.

Subprogram Name	
MAINTB	Airfoil table preparation (main program)
AEROT	Interpolate airfoil tables
AEROPP	Printer-plot airfoil aerodynamic characteristics

Namelist Label	
NLTABL	Table and print/plot data
NLCHAR	Airfoil characteristics data

The structure of a job to run the airfoil table preparation program is defined below. The basic structure consists of the following steps:

1) Airfoil file definition
2) Main program call
3) Title card
4) Namelist NLTABL
5) For each radial station (OPREAD $\neq$ 0), either
    a) Namelist NLCHAR (OPREAD = 1)
    b) Airfoil table card deck (OPREAD = 2)

Sample jobs are presented below.

Create airfoil table using analytical expressions.

```
DDEF FT40F001,,AIRFOIL
CALL MAINPROG
title card
 &NLTABL table data,NFAF=40,OPREAD=1,&END
 &NLCHAR airfoil characteristics data,&END
%END
```

Create airfoil table using C81 format airfoil card deck

```
DDEF FT40F001,,AIRFOIL
CALL MAINPROG
title card
 &NLTABL table data,NFAF=40,OPREAD=2,&END
:
airfoil card deck
:
%END
```

Print and plot airfoil table data

```
DDEF FT40F001,,AIRFOIL
CALL MAINPROG
blank card
 &NLTABL output data,NFAF=40,OPREAD=0,&END
%END
```

The following pages described the input variables and data for the airfoil table preparation program.

First Card

TITLE(20) title (80 characters); blank card for OPREAD EQ 0

Namelist NLTABL

	angle of attack boundaries
NAB	number of boundaries, N_a; maximum 20
NA(NAB)	indicies at boundaries, n_k
A(NAB)	α at boundaries (deg, -180° to 180°)
	Mach number boundaries
NMB	number of boundaries, N_m; maximum 20
NM(NMB)	indicies at boundaries, n_k
M(NMB)	M at boundaries (0. to 1.)
	radial segments
NRB	number of segments, N_r; maximum 10
R(NRB+1)	boundaries of segments (R(1)=0., R(NRB+1)=1.)

maximum NAB*NMB*NRB = 5000

OPPRNT(3)	integer parameter controlling output; EQ 0 to suppress; default value is 1 (1) interpolate and print (2) interpolate and plot (3) list tables
NMPRNT	number of Mach number values for print and plot; maximum 10
MPRNT(NMPRNT)	Mach number values for print and plot
NAPRNT	number of angle of attack values for print; maximum 60
APRNT(NAPRNT)	angle of attack values (deg)
NFAF	unit number for airfoil table file (default 40)
OPREAD	integer parameter: EQ 0 to read airfoil table and print data only; EQ 1 to create airfoil table using analytical expressions, write airfoil file, and print data (default); EQ 2 to create airfoil table using C81 format airfoil card deck, write airfoil file, and print data

<u>Namelist NLCHAR</u> (for each radial station; if OPREAD = 1)

CLA	$a = c_{\ell_\alpha}$ at $M = 0$ (per rad) (default 5.7)
MDIV	lift divergence Mach number M_{div} (default .75)
CLMAX	$c_{\ell_{max}}$ at $M = 0$ (default 1.2)
FSTALL	factor f_s for $c_{\ell_{max}}$ (default 0.5)
MSTALL	Mach number M_s for $c_{\ell_{max}}$ (default 0.4)
GSTALL	factor g_s for stall c_ℓ (default 1.2)
HSTALL	factor h_s for stall c_ℓ (default 0.4)
CLF	c_{ℓ_f} for stall c_ℓ (default 1.12)
CMAC	$c_{m_{ac}}$ (default 0.)
CMS	c_{m_s} (default -0.07)
DEL0	δ_0 (default 0.0084)
DEL1	δ_1 (default -0.0102)
DEL2	δ_2 (default 0.384)
DCDDM	$\partial c_d/\partial M$ (default 0.65)
MCRIT	critical Mach number at $\alpha = 0$ (default 0.83)
ACRIT	critical Mach number zero at $\alpha = \alpha_{crit}$ (default 33.)
ALFD	drag stall angle (deg) (default 10.)
CDF	c_{d_f} for stall c_d (default 2.05)

<u>Airfoil Card Deck</u> (for each radial station; if OPREAD = 2)

I. Header

a) Card 1, format (30A1,6I2)

title, 30 alphanumeric characters
NML, number of Mach number entries in c_ℓ table
NAL, number of angle of attack entries in c_ℓ table
NMD, number of Mach number entries in c_d table
NAD, number of angle of attack entries in c_d table
NMM, number of Mach number entries in c_m table
NAM, number of angle of attack entries in c_m table

II. Lift Coefficient Table

b) Card 2, format (7X,9F7.0); 2 or more cards if NML $\geq$ 10

Mach numbers M_1 to M_{NML}

c) Card 3a, format (F7.0,9F7.0)

angle of attack, α_1

lift coefficients c_ℓ at $M = M_1$ to M_{NML} or M_9

Card 3b, format (7X,9F7.0); 1 or more cards if NML $\geq$ 10

lift coefficients c_ℓ at $M = M_{10}$ to M_{NML}

d) repeat card 3 for $\alpha = \alpha_1$ to α_{NAL}

III. Drag Coefficient Table

e-g) format as or lift coefficient table

IV. Moment Coefficient Table

h-j) format as for lift coefficient table

V. Parameter Limits

a) $M_1 = 0$; data extrapolated for $M > M_{NM}$; Mach numbers in sequential order

b) $\alpha_1 = -180^\circ$, $\alpha_{NA} = 180^\circ$; angles of attack in sequential order

c) NM $\geq$ 2, NA $\geq$ 2 for lift, drag, and moment

d) (NM+1)(NA+1) $\leq$ 501 for lift, 1101 for drag, 576 for moment

For OPREAD = 1, the program calculates representative airfoil characteristics using the following expressions (refer to the accompanying figures).

A) Below stall

$$c_{\ell_\alpha} = \begin{cases} a/\sqrt{1-M^2} & M < M_{div} \\ a(1-M)/((1-M_{div})\sqrt{1-M_{div}^2}\ ) & M_{div} < M < M_{div}+.1 \\ a\Big[(1-M)/((1-M_{div})\sqrt{1-M_{div}^2} & M < M_{div}+.1 \\ \quad + (M-M_{div}-.1)/(1-M_{div}-.1)\Big] & \end{cases}$$

$$c_\ell = c_{\ell_\alpha}\alpha$$

$$c_m = c_{m_{ac}}$$

$$c_d = \delta_0 + \delta_1\alpha + \delta_2\alpha^2 + \Delta c_d$$

$$\Delta c_d = \max\left(0,\ \partial c_d/\partial M\ (M-M_c)\ \right)$$

$$M_c = \max\left(0,\ M_{crit}\ (1- |\alpha|/\alpha_{crit})\right)$$

B) Stall angle

$$c_{\ell_s} = c_{\ell_{max}} \min\left(1,\ \frac{(1-M) + f_s(M-M_s)}{1-M_s}\right)$$

$$\alpha_s = c_{\ell_s}/c_{\ell_\alpha}$$

C) Stalled lift ($|\alpha| > \alpha_s$)

$$c_\ell = \text{sign}(\alpha)\ \max\left[\frac{(g_s\alpha_s - |\alpha|)c_{\ell_s} + (|\alpha| - \alpha_s)h_s c_{\ell_s}}{g_s\alpha_s - \alpha_s},\ \max\left(h_s c_{\ell_s},\ c_{\ell_f}\sin 2|\alpha|\right)\right]$$

$$c_\ell = c_{\ell_f}\sin 2\alpha \qquad \text{if } |\alpha| > 45^\circ$$

D) Stalled moment ($|\alpha| > \alpha_s$)

$$c_m = \begin{cases} \operatorname{sign}(\alpha) \dfrac{(60-|\alpha|)c_{m_s} + (|\alpha| - \alpha_s).75c_{m_f}}{60-\alpha_s} & |\alpha| < 60^\circ \\ \operatorname{sign}(\alpha) \dfrac{(90-|\alpha|).75c_{m_f} + (|\alpha| -60)c_{m_f}}{30} & |\alpha| > 60^\circ \end{cases}$$

$$c_{m_f} = -\tfrac{1}{4}c_d(\alpha = 90) = -\tfrac{1}{4}(c_d(\alpha = \alpha_d) + c_{d_f})$$

E) Stalled drag ($|\alpha| > \alpha_d$)

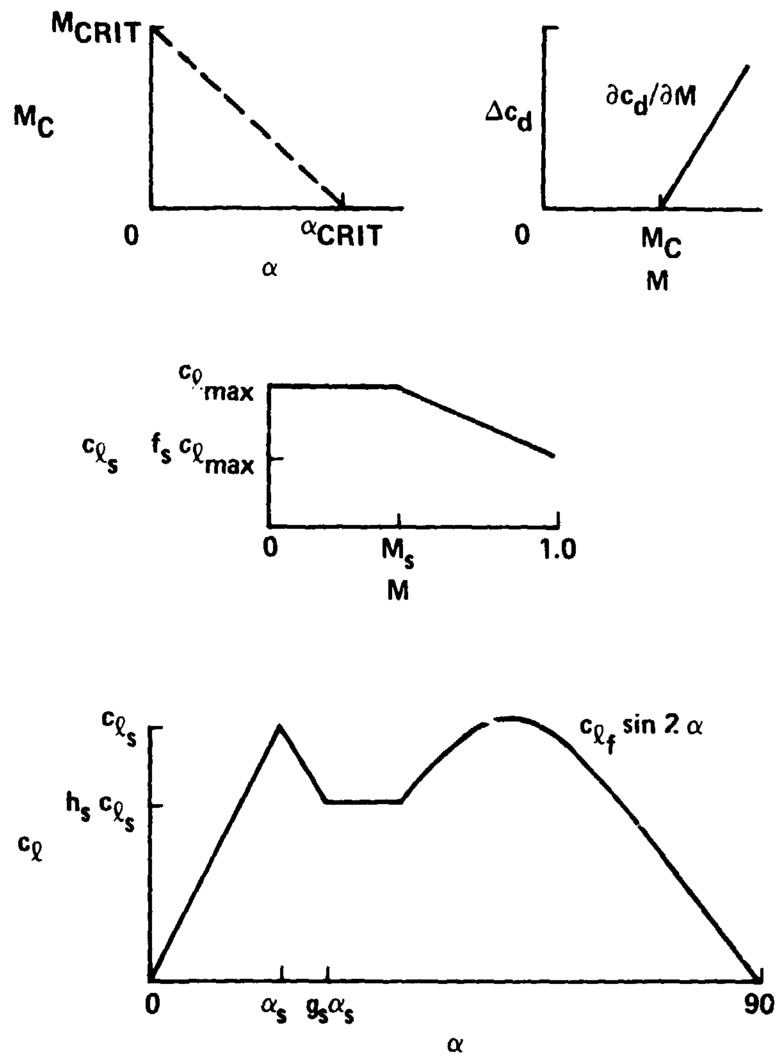
$$c_d = c_d(\alpha = \alpha_d) + c_{d_f} \sin\left(\frac{|\alpha| - \alpha_d}{90 - \alpha_d} 90\right)$$

F) Reverse flow ($|\alpha| > 90$)

use effective angle of attack and account for moment axis shift

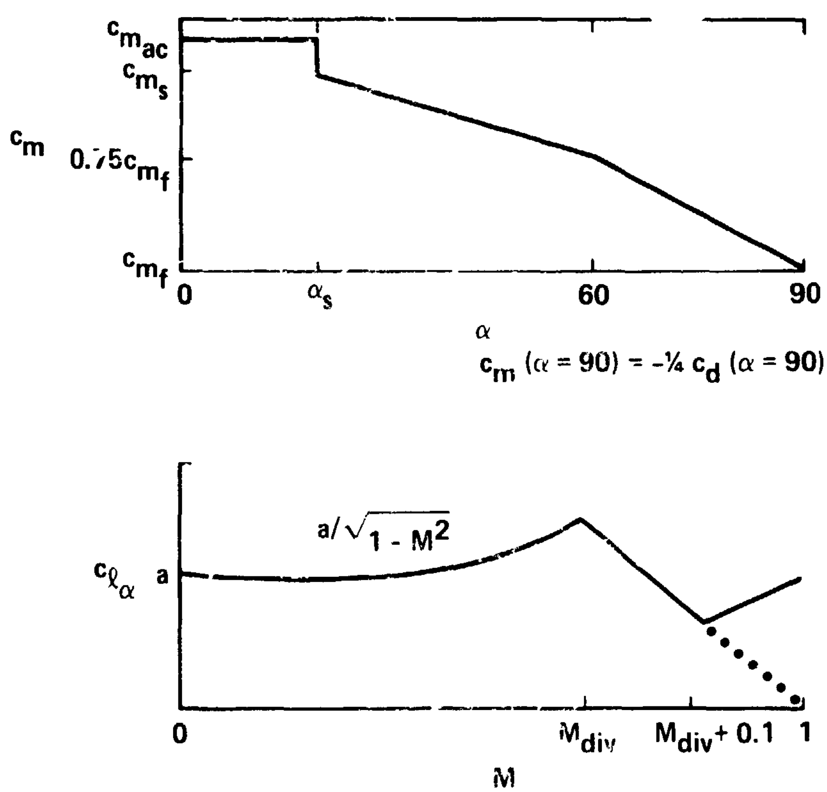
$$\alpha_e = \alpha - \pi \operatorname{sign}\alpha$$

$$c_m = c_m + (\tfrac{1}{2} \cos\alpha_e)c_\ell + (\tfrac{1}{2} \sin\alpha_e)c_d$$



a. Lift and drag information

Fig. 1.- Airfoil Characteristics



b. Moment and lift curve slope

Fig. 1.- Concluded