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A Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics. Part II: User's Manual.

Wayne Johnson

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A Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics

Part II: User's Manual

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



National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035

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



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A COMPREHENSIVE ANALYTICAL MODEL OF
ROTORCRAFT AERODYNAMICS AND DYNAMICS

Part II: User's Manual

Wayne Johnson

Ames Research Center
and
Aeromechanics Laboratory
AVRADCOM Research and Technology Laboratories

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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 constitute 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
INF.L1	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
INTT	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
ZETLAN	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
NLOAD	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	
NF DAT	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
QBD1CM	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
    INPIW1
    read namelist NLWAKE
if OPREAD(3) ≠ 0
    INPTR2
    read namelist NLRTR
if OPREAD(4) ≠ 0
    INPIW2
    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
FILES
FILET

flutter restart
flight dynamics restart
transient restart

read namelist NLTRIM

if OPREAD(6) $\neq$ 0

INPTL1

read namelist NLLOAD

if OPREAD(7) $\neq$ 0

INPTL2

read namelist NLLOAD

if OPREAD(8) $\neq$ 0

INPTF

read namelist NLFLUT

trim restart

INPTG

read namelist NLFLUT

flutter restart

if OPREAD(9) $\neq$ 0

INPTS

read namelist NLSTAB

trim restart

INPTU

read namelist NLSTAB

flutter or flight dynamics restart

if OPREAD(10) $\neq$ 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  $\neq$  0
    TRIMI
    if NPRNTT = 1
        PERF
        LOAD
        NPRNTP > 0
        NPRNTL > 0

nonuniform inflow, prescribed wake geometry
for IT = 1 to ITERR
    WAKEC1
    WAKEC2
    TRIMI
    if IT = multiple NPRNTT
        PERF
        LOAD
        NPRNTP > 0
        NPRNTL > 0

nonuniform inflow, free wake geometry
for IT = 1 to ITERF
    WAKEC1
    WAKEC2
    TRIMI
    if IT = multiple NPRNTT
        PERF
        LOAD
        NPRNTP > 0
        NPRNTL > 0

FILER (restart file write)
        RSWRT  $\neq$  0

FILEI
FILEJ

trim restart entry point
PRNT
    PRNTC
    if NPRNTI  $\neq$  0
        PRNTR1
        PRNTW1
        PRNTR2
        PRNTW2
        PRNTB

MODEP1
MODEP2
TRIMP
PERF
LOAD
TIMER

```

TRIMI

RAMF

if MTRIM $\leq$ 0 or no trim iteration, return

if DEBUG(4) $\geq$ 1, print trim iteration

for COUNTT = 1 to MTRIM

if COUNTT-1 = multiple MTRIMD, construct D-1

for I = 1 to MT

increment controls

RAMF

OPTRIM

MINV

increment controls

OPTRIM

RAMF

if DEBUG(4) $\geq$ 1, print trim iteration

test trim convergence

EPTRIM,OPTRIM

PERF

TIMER

PERFR1

PERFR2

TIMER

LOAD

TIMER
LOADR1
LOADR2
TIMER

LOADR1

MOTNB1

if MALOAD $\neq$ 0

GEOME1

HISTPP

GEOMP1

POLRPP

HISTPP

if MHLOAD $\neq$ 0

LOADH1

LOADM

LOADF

HISTPP

for IR = 1 to MRLOAD

LOADS1

LOADI1

LOADM

LOADF

HISTPP

for IN = 1 to MNOISE

NOISR1

BESSEL

NPLOT(1-4)

MWKGMP

NPLOT(5-67)

NPLOT(5-67)

NPLOT(68-71)

NPLOT(72-75)

FLUT

```
TIMER
for OPFLOW ≤ 0 (constant coefficients)
    if flutter restart, go to restart entry point
    FLUTM
    FILEF (restart file write)
    flutter restart entry point
    PRNTF
    MODEP1
    MODEP2
    FLUTL
    

TIMER
        CSYSAN
        FILEE (eigenvalue file write)
        BODE
        TRACKS
        GUSTS
        TIMER


    if OFFDAN ≠ 0
        STABD
        STABE
    if OPFLOW > 0 (periodic coefficients)
        for NT = 0 to MPSIPC
            FLUTM
            if NT = MPSIPC
                PRNTF
                MODEP1
                MODEP2
            PSYSAN
            if NT = MPSIPC
                FILEE (eigenvalue file write)
```

RSWRT ≠ 0

ANTYPE(1) ≠ 0

ANTYPE(2) ≠ 0

ANTYPE(3) ≠ 0

ANTYPE(4) ≠ 0

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
      WAKEC2
      RAMF
      PERF
      LOAD
FILES (restart file write)
flight dynamics restart entry point
STABD
STABE
TIMER

```

LEVEL(1) $\geq$ 1
LEVEL(2) $\geq$ 1

NPRNTP > 0
NPRNTL > 0

RSWRT $\neq$ 0

STABE

```

for IEQ = 1 to 12
  DERED
  STABL
    TIMER
    CSYSAN
    FILEE (eigenvalue file write)
    BODE
    TRACKS
    GUSTS
    numerical integration
      MINV
      STABP
      PRNTC
      for IT = 1 to TMAX/TSTEP
        TRANC
        CONTRJ
        GUSTU
        GUSTC
        if IT = multiple NPRNTT
          STABP
      TRCKPP
    TIMER

```

EQTYPE(IEQ) $\neq$ 0

ANTYPE(1) $\neq$ 0

ANTYPE(2) $\neq$ 0

ANTYPE(3) $\neq$ 0

ANTYPE(4) $\neq$ 0

ANTYPE(5) $\neq$ 0

OPTRAN = 1

OPTRAN = 2

OPTRAN = 3

TRAN

TIMER

PRNTT

PRNTG

if transient restart, go to restart entry point

MINV

TRANP

for IT = 1 to TMAX/TSTEP

TRANC

CONTRL

GUSTU

GUSTC

OPTRAN = 1

OPTRAN = 2

OPTRAN = 3

TRANI

for IT = 1 to ITERT

WAKEC1

WAKEC2

RAMF

LEVEL(1) ≥ 1

LEVEL(2) ≥ 1

if IT = multiple NPRNTT

TRANP

PERF

LOAD

NPRNTP > 0

NPRNTL > 0

if IT = multiple NRSTRT

FIWET (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 ITCR (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
test circulation convergence

EPMOTN
EPCIRC

BODYF

BODYA

TIMER

MODE1

```
TIMER
MODEC1
if  $\Delta\theta > \text{EPMODE}$ 
  MODEB1
    MODEG
    MINV
    EIGENJ
  MODEA1
  MODEK1
  MODED1
```

HINGE $\neq$ 2

HINGE = 2

MODET1

```
MINV
EIGENJ
```

```
INRTC1
TIMER
```

MOTNR1

```
TIMER
for JP = JPSI + 1 to JPSI + MPSIR ( $\Psi$  step)
  MOTNB1
  AEROF1
    for IR = 1 to MRA
      AEROS1
        AEROT1
  TIMER
```

WAKEC1

GEOMR1

TIMER
GEOMF1
TIMER

LEVEL = 2

TIMER

WAKEB1

DBV $\geq$ 0.

GEOME1

DBV $\geq$ 0.

for I = 1 to MPSI (Ψ loop)

WAKEB1

WAKEB2

for M = 1 to NBLADE (blade loop)

GEOME1

VTXL

for K = 1 to KFW or KDW (ϕ loop)

GEOME1

VTXL

VTXS

INFLOW(3) = 3

TIMER

CSYSAN

DETRAN
EIGENJ
SINE
STATIC
ZERO

ZETLAN
EIGENJ

BODE

DETRAN
EIGENJ
ZERO

ZETLAN
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 MAINFROG
&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,OPREAD(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,OPREAD(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 categorized 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
NLOAD	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) NLLCAD, rotor #1
(7) NLLCAD, 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)

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
 TIP 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 ($^{\circ}\text{F}$ or $^{\circ}\text{C}$), for OPDENS = 2 or 3
 DENSE air density (slug/ft³ or kg/m³), 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)
 OPENGH 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 ($\Delta C_T / \epsilon$)

DOF(54)

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

rotor #1	$q_1 \dots q_{10}$	$p_0 \dots p_4$	β_G
rotor #2	$q_1 \dots q_{10}$	$p_0 \dots p_4$	β_G
	(bending, max 10)	(torsion, max 5)	(gimbal/teeter)
airframe	$\phi_F \ \theta_F \ \psi_F \ x_F \ y_F \ z_F$	$q_{s7} \dots q_{s16}$	
	(rigid body)	(flexible body, max 10)	
drive train	$\omega_s \ \omega_I \ \omega_e$	$\Delta\theta_t \ \Delta\theta_{govr1} \ \Delta\theta_{govr2}$	
	(rotor/engine speed)	(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

NLTRIM

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 (ft² or m²)

CTTRIM C_T/σ or C_L/σ

CPTRIM C_P/σ

CYTRIM C_Y/σ

BCTRIM β_0 (deg)

BSTRIM β_s (deg)

OPTRIM integer parameter specifying trim option
free flight cases

- OPTRIM = 0 no trim
- 1 trim forces and moments with $\delta_o \delta_c \delta_s \delta_p \theta_{FT} \phi_{FT}$
 - 2 trim forces and moments with $\delta_o \delta_c \delta_s \delta_p \theta_{FT} \psi_{FP}$
 - 3 trim forces, moments, and power with $\delta_o \delta_c \delta_s \delta_p \theta_{FT} \phi_{FT} \theta_{FP}$
 - 4 trim forces, moments, and power with $\delta_o \delta_c \delta_s \delta_p \theta_{FT} \psi_{FP} \theta_{FP}$
 - 5 trim symmetric forces and moments with $\delta_o \delta_s \theta_{FT}$
 - 6 trim symmetric forces, moments, and power with $\delta_o \delta_s \theta_{FT} \theta_{FP}$

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 $\beta_c \beta_s$ with $\delta_c \delta_s$
 - 15 trim $C_T/\sigma \beta_c \beta_s$ with $\delta_o \delta_c \delta_s$
 - 16 trim $C_L/\sigma C_X/\sigma C_Y/\sigma$ with $\delta_o \delta_c \delta_s$
 - 17 trim $C_L/\sigma C_X/\sigma C_Y/\sigma$ with $\delta_o \delta_c \theta_T$
 - 18 trim $C_L/\sigma C_X/\sigma \beta_c \beta_s$ with $\delta_o \delta_c \delta_s \theta_T$
 - 19 trim $C_L/\sigma X/q C_Y/\sigma$ with $\delta_o \delta_c \delta_s$
 - 20 trim $C_L/\sigma X/q C_Y/\sigma$ with $\delta_o \delta_c \theta_T$
 - 21 trim $C_L/\sigma X/q \beta_c \beta_s$ with $\delta_o \delta_c \delta_s \theta_T$
 - 22 trim β_c with δ_s
 - 23 trim $C_T/\sigma \beta_c$ with $\delta_o \delta_s$
 - 24 trim $C_L/\sigma C_X/\sigma$ with $\delta_o \delta_s$
 - 25 trim $C_L/\sigma C_X/\sigma$ with $\delta_o \theta_T$
 - 26 trim $C_L/\sigma C_X/\sigma \beta_c$ with $\delta_o \delta_s \theta_T$
 - 27 trim $C_L/\sigma X/q$ with $\delta_o \delta_s$
 - 28 trim $C_L/\sigma X/q$ with $\delta_o \theta_T$
 - 29 trim $C_L/\sigma X/q \beta_c$ with $\delta_o \delta_s \theta_T$

NLTPIM

WEIGHT see namelist NLBCDY

IXX

IYY

IZZ

IXY

IXZ

IVZ

ATILT

FSCG

BLCG

WLCG



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_0 (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 $\gamma_0 = \rho_0 a c_m R^4/I_b$ (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
 TDAMPO control system damping (ft-lb/rad/sec or m-N/rad/sec) collective
 TDAMPC cyclic
 TDAMPR rotating
 NUGC longitudinal gimbal natural frequency ω_{GC} or teeter natural frequency ω_T (per rev at normal tip speed VTIPN)
 NUGS lateral gimbal natural frequency ω_{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_s (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 $\dot{s}_{LD}$ where maximum moment of lag damper occurs (rad/sec); hydraulic damping below $\dot{s}_{LD}$ 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 suppress 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

RRCOT 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)

EIXY(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,
 $\alpha_{\max \text{ delay}}$ (deg)

AMAXNS angle of attack in linear range for no stall model, $\alpha_{\max}$ (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:
 Δc_{lds}

CDLSP maximum peak dynamic stall vortex induced drag coefficient:
 Δc_{dds}

CMDSP maximum peak dynamic stall vortex induced moment coefficient:
 $\Delta c_{m_{ds}}$

KHLMDA factor k_h for hover induced velocity (typically 1.1)
 KFLMDA factor k_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_{Mx} , and C_{My} used to calculate induced velocity (typically .5)
 KINTH factor for hover interference velocity at other rotor (K_{21} or K_{12})
 KINTF factor for forward flight interference velocity at other rotor (K_{21} or K_{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
 NCOLT 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, $\mathcal{R}_s$

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

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

NOFB 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

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

FTC cyclic

FTR reactionless

KTO control system stiffness K_θ (ft-lb/rad or m-N/rad)
 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_i} and K_{p_g})

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

NLRT

ATANKP(NBM)	pitch/bending coupling $\tan^{-1} K_{P1}$ (deg), for pitch horn level (KPIN = 1 or -1)
DEL3G	pitch/gimbal coupling $\tan^{-1} K_{PG}$ (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_{FA1} (deg), positive up
DROOP	droop angle δ_{FA2} (deg) at $\Theta_{75} = 0$, positive down from precone
SWEEP	sweep angle δ_{FA3} (deg) at $\Theta_{75} = 0$, positive aft
FDROOP	feathering axis droop angle δ_{FA4} (deg), positive down from precone
FSWEEP	feathering axis sweep angle δ_{FA5} (deg), positive aft

Namelist NLWAKE

FACTWN factor introducing lag in bound circulation used to calculate induced velocity

OFVXVY 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

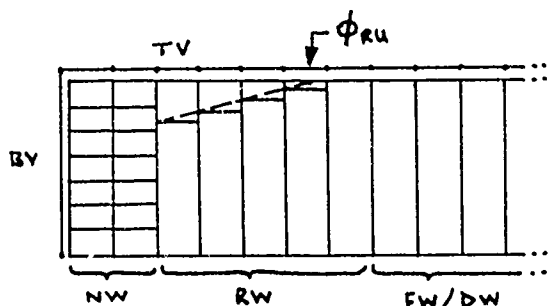
LHW number of spirals of far wake for axisymmetric case, L_{HW}

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

OPWKB(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 $r = r_{\text{root}}/R$ 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
 tip vortex

FWGT(2)

FWGSI(2) inside sheet edge

FWGSO(2) outside sheet edge

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

KWGT(4)

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 λ_{DM} : general update every $\lambda_{DM}\Delta\Psi$ 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 $0.04\lambda_1$ to $0.08\lambda_1$
(1) near wake elements defined by
 $|\Delta\vec{q}| > DQWG(1)$
(2) integrate bound vortex line in time over
if $|\Delta\vec{q}| > DQWG(2)$

NLWAKE

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-ft² or kg-m²)

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 to rotor #1 rotational speed, Ω_2/Ω_1 (transmission gear ratio r_{I1}/r_{I2})

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

NLBODY

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	
FSWP	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 ($\vec{v}_P = 0$):

$$\vec{v}_0 = (\theta_0 \quad \theta_{1c} \quad \theta_{1s} \quad \theta_0 \quad \theta_{1c} \quad \theta_{1s} \quad \delta_f \quad \delta_e \quad \delta_a \quad \delta_r \quad e_t)^T$$

rotor #1 rotor #2 aircraft

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_{F0} , collective stick to front collective pitch
KROCFE	K_{R0} , collective stick to rear collective pitch
KFCFE	K_{FC} , lateral cyclic stick to front cyclic pitch
KRCFE	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
FFCCFE	$\Delta\psi_{FC}$, lateral cyclic stick to front cyclic pitch
PRCCFE	$\Delta\psi_{RC}$, lateral cyclic stick to rear cyclic pitch
FFPCFE	$\Delta\psi_{FP}$, 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

NLBODY

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) aerodynamic damping $F_{q_k \dot{q}_k} = \partial(Q_k/2 \dot{q}_k^2)/\partial(\dot{q}_{sk}/V)$
(ft² or m²)

QCNTL(4,NEM) control derivatives $F_{q_k \delta} = \partial(Q_k/2 \dot{q}_k^2)/\partial \delta$ for $\delta_f, \delta_e, \delta_a, \delta_r$ (ft²/rad or m²/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 $\vec{z}_k$ at rotor #1 hub (ft/ft or m/m)

ZETAR2(3,NEM) linear mode shape $\vec{z}_k$ 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)

KPMC1(NEM) pitch/mast-bending coupling (rad/ft or rad/m)
 $K_{MC_k} = - \partial \theta_{1c} / \partial q_{sk}$ for rotor #1

KPMS1(NEM) $K_{MS_k} = - \partial \theta_{1s} / \partial q_{sk}$ for rotor #1

KPMC2(NEM) $K_{MC_k} = - \partial \theta_{1c} / \partial q_{sk}$ for rotor #2

KPMS2(NEM) $K_{MS_k} = - \partial \theta_{1s} / \partial q_{sk}$ 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	$\alpha_{\max}$	(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	$\pi e \rho_w^2 = (\Delta(D_i/q)/\Delta(L/q)^2)^{-1}$	(ft ² or m ²)
DRGFw	$D_{0\delta_i}/q$	(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	$Y_{\dot{p}}/q$	(ft ³ /rad or m ³ /rad)
SIDFR	$Y_{\dot{r}}/q$	(ft ³ /rad or m ³ /rad)
ROLLB	$N_{x\beta}/q$	(ft ³ /rad or m ³ /rad)
ROLLP	$VN_{x\dot{p}}/q$	(ft ⁴ /rad or m ⁴ /rad)
ROLLR	$VN_{x\dot{r}}/q$	(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	$VN_{z\dot{p}}/q$	(ft ⁴ /rad or m ⁴ /rad)
YAWR	$VN_{z\dot{r}}/q$	(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	$\alpha_{\max}$	(deg)
IHT	i_{HT}	(deg)

Vertical tail

LFTAV	L_{α}/q	(ft ² /rad or m ² /rad)
LFTRV	L_{δ_r}/q	(ft ² /rad or m ² /rad)
AMAXV	$\alpha_{\max}$	(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)
KMAST1	drive train spring constants (ft-lb/rad or n-N/rad) rotor #1 shaft, K_{M1} or K_M
KMAST2	rotor #2 shaft, K_{M2}
KICS	interconnect shaft, $r_{I2}^2 K_I$ 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)
GS1	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
THRTL	$\partial P_E / \partial \theta_t$ (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 ($P = \Omega_R Q_R = \Omega_E Q_E$)
KPGOVE	governor proportional feedback gains (sec) 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, $K_P = \partial \theta / \partial \dot{\Psi}_s$
KIGOVE	governor integral feedback gains 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, $K_I = \partial \theta / \partial \Psi_s$

NLBODY

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

FSVIB(MVIB) airframe location for vibration calculation (ft or m)
 fuselage station

BLVIB(MVIB) butt line

WLVIB(MVIB) waterline

ZETAV(3,NEM,MVIB) linear mode shape $\vec{z}_k$ 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_x
- (9) c_d
- (10) c_m
- (11) $c_{d\text{radial}}$
- (12) τ
- (13) up
- (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) M_a/c
- (44) 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_r	*
(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
 (14) axial shear f_x
 (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
 (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

CPFLOW integer parameter specifying analysis type: LT 0 for constant coefficient approximation; EQ 0 for axial flow; GT 0 for periodic coefficients

CPSYMM integer parameter: NE 0 for symmetric and antisymmetric analyses (tilting propotor configuration only)

CFFDAN 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 (CPFLOW 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 (CPFLOW 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 (CPFLOW LT 0); $\Delta\psi = 360^\circ/M$

DALPHA angle of attack increment $\Delta\alpha$ (deg) for calculation of c_x , c_d , and c_m derivatives in aerodynamic coefficients

DMACH Mach number increment $\Delta M/M$ for calculation of c_x , c_d , and c_m derivatives in aerodynamic coefficients

CPUSLD integer parameter controlling use of unsteady lift and moment in flutter analysis: 0 to suppress; 1 to include; 2 for zero in stall ($15^\circ < \alpha < 165^\circ$)

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 propotor 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(30) integer vector defining degrees of freedom for flutter analysis; 0 if not used, 1 if used, 2 if quasistatic variable; order:

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

airframe $\phi_F \theta_F \Psi_F X_F Y_F Z_F \gamma_{s7} \dots \gamma_{s16} \Psi_C \Delta\theta_C \Delta\theta_{gwr1} \Delta\theta_{gwr2}$
rigid body flexible engine governor
body (10) speed

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

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

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

airframe $\delta_y \delta_c \delta_a \delta_r \theta_c$

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

GUC(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

there are N_{bld} rotor pitch control variables; except for a two-bladed rotor, which has the 4 variables $\theta_0, \theta_{1c}, \theta_{1s}, \theta_1$

ANTYPE(4)

NLFOUT

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

NAMEXI(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

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 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

ZLACC(3,NEM) linear mode shape $\vec{\zeta}_k$ at point where body axis acceleration calculated

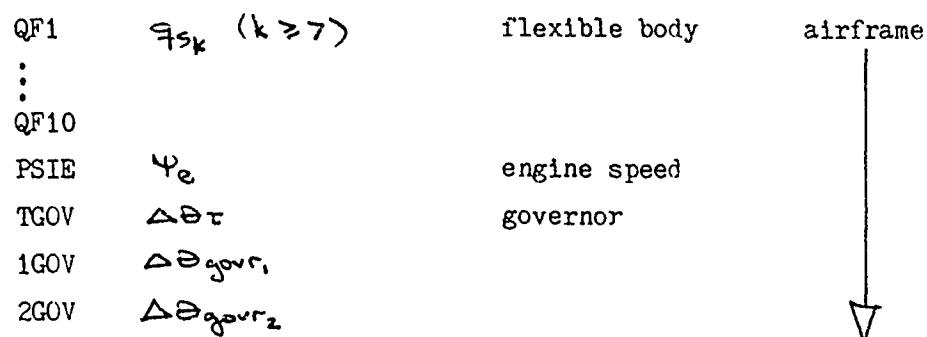
NAMEXR(3) names of β_{1c} , ξ_{1c} , and θ_{1c} in state vector; assumed that β_{1s} , ξ_{1s} , and θ_{1s} follow immediately (inconsistent names ignored)

Variable names for linear system analysis

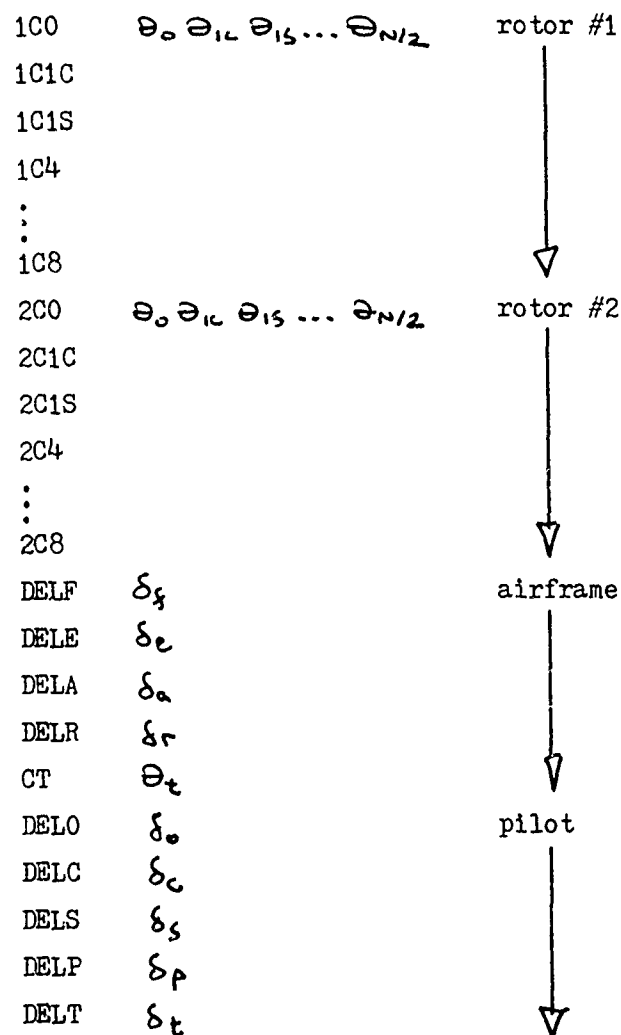
Degrees of freedom

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	$\theta_0^{(i)} \theta_{1c}^{(i)} \theta_{1s}^{(i)} \dots \theta_{N/2}^{(i)}$	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		

NLFLUT



Control variables



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_0	θ_{1c}	θ_{1s}
rotor #2	θ_0	θ_{1c}	θ_{1s}
airframe	δ_f	δ_c	δ_a δ_r θ_t
pilot	δ_0	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

CPPRNT(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)
 MSFLT magnitude plot scale: if 1, plot relative maximum value; if 2, plot relative 10**K; if 3, plot relative 10.

Time history printer-plot

NTFLO 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 ($\tau_G = L/2V$); 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.; 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:

$$\phi_F \theta_F \psi_F x_F y_F z_F \dot{\phi}_F \dot{\theta}_F \dot{\psi}_F \dot{x}_F \dot{y}_F \dot{z}_F \ddot{\phi}_F \ddot{\theta}_F \ddot{\psi}_F \ddot{x}_F \ddot{y}_F \ddot{z}_F \ddot{\psi}_F$$

OPTRAN see namelist NLTRAN

CTIME

CMAG(5)

GTIME

GMAG(3)

GDIST()

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_c	
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

NLSTAB

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

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
 NPRNLT 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
 CPLMDA 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: $\phi_F, \theta_F, \psi_F, x_F, y_F, z_F, \psi_S$
 CPSAS 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)
 TCEAS lateral SAS lead time τ_C (sec)
 TSSAS longitudinal SAS lead time τ_S (sec)
 OPLOT 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:
 $\phi_F, \theta_F, \psi_F, x_F, y_F, z_F, \psi_S, \dot{\phi}_F, \dot{\theta}_F, \dot{\psi}_F, \dot{x}_F, \dot{y}_F, \dot{z}_F, \ddot{\phi}_F, \ddot{\theta}_F, \ddot{\psi}_F, \ddot{x}_F, \ddot{y}_F, \ddot{z}_F, \ddot{\psi}_S$

Transient gust and control

CPTRAN 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 $\vec{v}_{P_0}$
 CTIME 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:

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

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

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

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

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 dimensionless, 2nd number dimensional
 - 1) velocity = ft/sec or m/sec
 - 2) dynamic pressure, $q = \text{lb/ft}^2$ or N/m^2
 - 3) weight, $C_W/\sqrt{\sigma} = \text{lb}$ or N
 - 4) body motion = deg/sec, ft/sec or m/sec
 - 5) $\ddot{z} = \text{ft/sec}^2$ or m/sec^2
 - 6) $\dot{\psi}_s = \text{rpm}$
- b) body orientation and controls in deg

Circulation convergence:

- a) tolerance, CG/S in $C_T/\sqrt{\sigma}$ form
- b) $G/E = \text{ratio error to tolerance}$ (≤ 1 . if converged)

Motion convergence:

- a) tolerance, BETA (etc) in deg
- b) BETA/E (etc) = ratio error to tolerance (≤ 1 . if converged)

Airframe performance: section 4.2.6

- a) aerodynamic loads: dimensional
- b) components
 - 1) angles in deg
 - 2) loads, q dimensional
 - 3) induced velocity, total velocity dimensionless

Gust velocity: dimensionless

System power:

- 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 $= M = 1 - P_{non-ideal}/P_{total}$

Print of Rotor Loads (Program LCADR1)

Print aerodynamics (function r and η)

- 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 in velocity axes

Force/ c_{mean} (dimensionless):

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

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

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

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

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

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

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

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

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

Forces (dimensional)

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

Blade section power: section 5.2.1

$$CP/S = d(C_P/\sigma)/dr$$
$$P = \text{section power (HP/ft or HP/m)}$$

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) $\dot{\Psi}_s = \text{rpm}$
 - 4) $\ddot{z}_F = \text{ft/sec}^2 \text{ or m/sec}^2$
 - 5) controls = deg
- c) generalized forces: moments and forces in $\delta C_{\sigma}/\sigma$ form (rotor #1 parameters, body axes); torque in $-\delta C_Q/\sigma$ form (rotor #1 parameters)

Print of Stability Derivatives (Program STABD)

Options:

- a) rotor coefficient form, $M^* X = \delta C_{\sigma}/\sigma$
- 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	$\Omega^2 R$	Ω^2	Ω^2
	(FF)	(FM)	(FQ)

b) subscripts

acceleration ($\ddot{z}$)	=	$\Omega^2 R$	(FA)
angular velocity	=	Ω	
linear velocity	=	ΩR	(FV)
controls	=	5%.3	
gust velocity	=	ΩR	(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/sec², g
 - 4) inertial axes = deg/sec, g

Print Transient Solution (Program TRANS)

- 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/sec², g
 - 4) inertial axes = deg/sec, g

- d) generalized forces: moments and forces in $\delta C/\delta a$ form (rotor #1 parameters, body axes); torque in $-\delta C_Q/\delta a$ 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 FT4OF001,,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)	indices 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)	indices 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

Namelist NLCHAR (for each radial station; if OPREAD = 1)

CLA $a = c_{\alpha}$ at $M = 0$ (per rad) (default 5.7)

MDIV lift divergence Mach number M_{div} (default .75)

CLMAX $c_{l_{max}}$ at $M = 0$ (default 1.2)

FSTALL factor f_s for $c_{l_{max}}$ (default 0.5)

MSTALL Mach number M_s for $c_{l_{max}}$ (default 0.4)

GSTALL factor g_s for stall c_l (default 1.2)

HSTALL factor h_s for stall c_d (default 0.4)

CLF c_{l_f} for stall c_l (default 1.12)

CMAC c_{mac} (default 0.)

CMS c_{ms} (default -0.07)

DELO δ_0 (default 0.0084)

DEL1 δ_1 (default -0.0102)

DEL2 δ_2 (default 0.384)

DCDDM $\delta c_d / \delta M$ (default 0.65)

MCRT critical Mach number at $\alpha = 0$ (default 0.83)

ACRT critical Mach number zero at $\alpha = \alpha_{crit}$ (default 33.)

ALFD drag stall angle (deg) (default 10.)

CDF cd_f for stall c_d (default 2.05)

Airfoil Card Deck (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_x table

NAL, number of angle of attack entries in c_x 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_x 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_x 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 for 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 GPREAD = 1, the program calculates representative airfoil characteristics using the following expressions (refer to the accompanying figures).

A) Below stall

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

$$c_l = c_{l\alpha} \alpha$$

$$c_m = c_{m_{\infty c}}$$

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

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

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

B) Stall angle

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

$$\alpha_s = c_{l_s} / c_{l\alpha}$$

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

$$c_l = \text{sign}(\alpha) \max \left[\frac{(\alpha_s - |\alpha|) c_{l_s} + (|\alpha| - \alpha_s) h_s c_{l_s}}{\alpha_s - \alpha_s}, \max(h_s c_{l_s}, c_{l_f} \sin 2|\alpha|) \right]$$

$$c_l = c_{l_f} \sin 2\alpha \quad \text{if } |\alpha| > 45^\circ$$

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

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

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

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

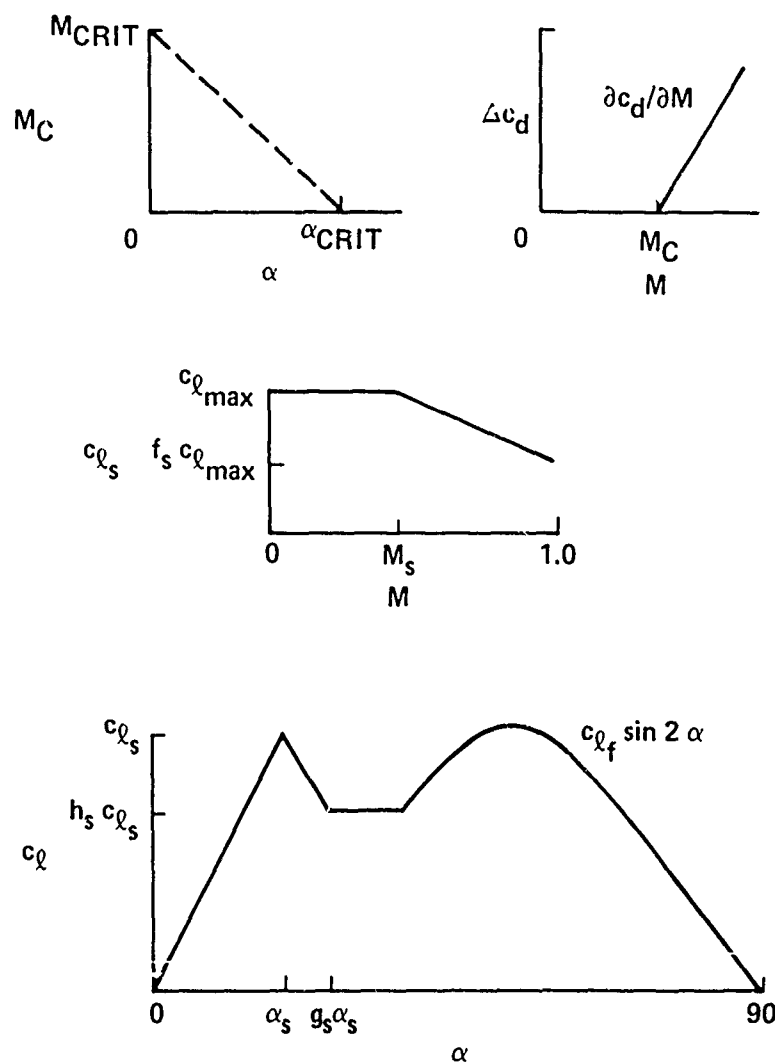
$$c_d = c_d(\alpha = \alpha_d) + c_{df} \sin\left(\frac{|\alpha| - \alpha_d}{90 - \alpha_d} 90\right)$$

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

use effective angle of attack and account for moment axis shift

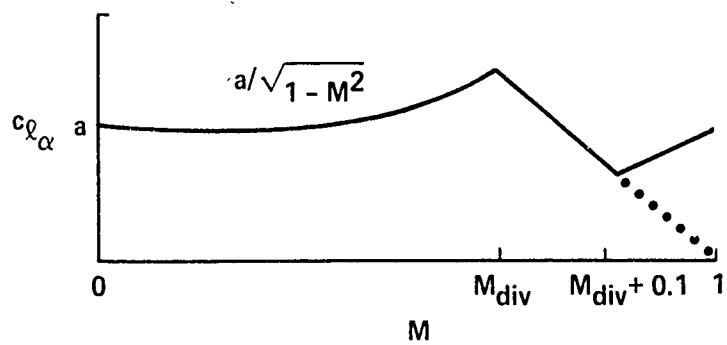
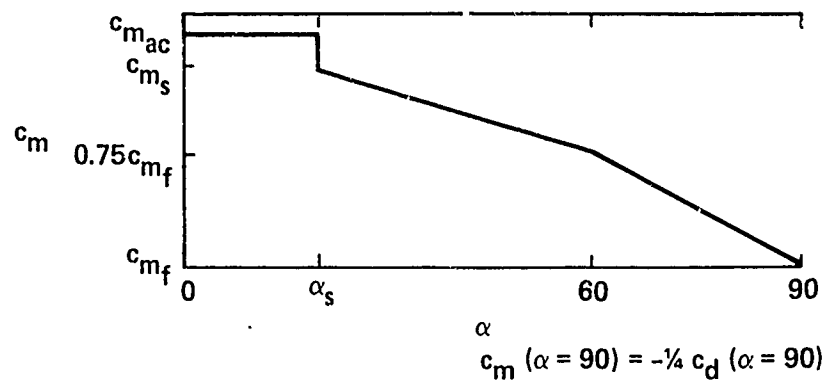
$$\alpha_e = \alpha - \pi \text{sign} \alpha$$

$$c_m = c_m + \left(\frac{1}{2} \cos \alpha_e\right)c_x + \left(\frac{1}{2} \sin \alpha_e\right)c_d$$



a. Lift and drag information

Fig. 1.- Airfoil Characteristics



b. Moment and lift curve slope

Fig. 1.- Concluded

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16 Abstract					
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.					
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