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

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A COMPREHENSIVE ANALYTICAL MODEL OF
ROTORCRAFT AERODYNAMICS AND DYNAMICS

Part II: User's Manual

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SUMMARY

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

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

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

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

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

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

The loads and motion solution is obtained by an iterative process. The inner-most loop consists of the rotor and airframe motion calculation, for prescribed control positions, induced velocity distribution, and mean shaft motion. Convergence of the motion solution is determined by comparing the calculated harmonics every few revolutions. The next loop consists of
the uniform or nonuniform rotor-induced velocity calculation, followed by the motion solution. Convergence is determined by comparing the rotor thrust or circulation used to calculate the induced velocity with that resulting after the motion has been re-calculated. Before beginning the circulation and motion iterations, the blade bending and torsion modes are calculated. If the rotor nonuniform induced velocity is used, there is an additional cutar 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
INPTL1 Read loads namelist
INPTF Read flutter namelist for new job
INPTS Read flight dynamics namelist for new job
INPTT Read transient namelist for new job
INPTG Read flutter namelist for old job
INPTU Read flight dynamics namelist for old job
INPTV Read transient namelist for old job
FILEI Read or write input file
FILEJ Read or write trim data file
FILER Read or write restart file
FILEF Read or write flutter restart file
FILES Read or write flight dynamics restart file
FILET Read or write transient restart file
FILEE Write eigenvalue file
INIT Initialization
INITA Initialize environment parameters
INITC Initialize case parameters
INITR1 Initialize rotor parameters
INITB Initialize airframe parameters
INITE Initialize drive train parameters
CHEKR1 Check for fatal errors
<table>
<thead>
<tr>
<th>Subprogram</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRNTJ</td>
<td>Print job input data</td>
</tr>
<tr>
<td>PRNTC</td>
<td>Print case input data</td>
</tr>
<tr>
<td>PRT</td>
<td>Print trim input data</td>
</tr>
<tr>
<td>PRNTR1</td>
<td>Print rotor input data</td>
</tr>
<tr>
<td>PRNVT1</td>
<td>Print wake input data</td>
</tr>
<tr>
<td>PRNTB</td>
<td>Print body input data</td>
</tr>
<tr>
<td>PRNTF</td>
<td>Print flutter input data</td>
</tr>
<tr>
<td>PRNTS</td>
<td>Print flight dynamics input data</td>
</tr>
<tr>
<td>PRNTT</td>
<td>Print transient input data</td>
</tr>
<tr>
<td>PRNTG</td>
<td>Print transient gust and control input data</td>
</tr>
<tr>
<td>TRIM</td>
<td>Trim</td>
</tr>
<tr>
<td>TRIMI</td>
<td>Calculate trim solution by iteration</td>
</tr>
<tr>
<td>TRIMP</td>
<td>Print trim solution</td>
</tr>
<tr>
<td>FLUT</td>
<td>Flutter</td>
</tr>
<tr>
<td>FLUTM</td>
<td>Calculate flutter matrices</td>
</tr>
<tr>
<td>FLUTB</td>
<td>Calculate flutter aircraft matrices</td>
</tr>
<tr>
<td>FLUTR1</td>
<td>Calculate flutter rotor matrices</td>
</tr>
<tr>
<td>FLUTI1</td>
<td>Calculate flutter inertia coefficients</td>
</tr>
<tr>
<td>FLUTA1</td>
<td>Calculate flutter aerodynamic coefficients</td>
</tr>
<tr>
<td>FLUTL</td>
<td>Analyze flutter constant coefficient linear equations</td>
</tr>
<tr>
<td>STAB</td>
<td>Flight dynamics</td>
</tr>
<tr>
<td>STABM</td>
<td>Calculate flight dynamics stability derivatives and matrices</td>
</tr>
<tr>
<td>STABD</td>
<td>Print stability derivatives</td>
</tr>
<tr>
<td>STABE</td>
<td>Calculate flight dynamics equations</td>
</tr>
<tr>
<td>STABL</td>
<td>Analyze flight dynamics linear equations</td>
</tr>
<tr>
<td>STABP</td>
<td>Print flight dynamics transient solution</td>
</tr>
<tr>
<td>TRAN</td>
<td>Transient</td>
</tr>
<tr>
<td>TRANI</td>
<td>Calculate transient acceleration for numerical integration</td>
</tr>
<tr>
<td>TRANP</td>
<td>Print transient solution</td>
</tr>
<tr>
<td>TRANC</td>
<td>Calculate transient gust and control</td>
</tr>
<tr>
<td>CONTRL</td>
<td>Calculate transient control time history</td>
</tr>
<tr>
<td>GUSTU</td>
<td>Calculate uniform gust time history</td>
</tr>
<tr>
<td>GUSTC</td>
<td>Calculate convected gust wave shape</td>
</tr>
<tr>
<td>PFRF</td>
<td>Performance</td>
</tr>
<tr>
<td>PFRFR1</td>
<td>Calculate and print rotor performance</td>
</tr>
<tr>
<td>Subprogram</td>
<td>Name</td>
</tr>
<tr>
<td>------------</td>
<td>------</td>
</tr>
<tr>
<td>LOAD</td>
<td>Loads, vibration, and noise</td>
</tr>
<tr>
<td>LOADR1</td>
<td>Calculate and print rotor loads</td>
</tr>
<tr>
<td>LOADH1</td>
<td>Calculate and print hub and control loads</td>
</tr>
<tr>
<td>LOADS1</td>
<td>Calculate and print blade section loads</td>
</tr>
<tr>
<td>LOADI1</td>
<td>Calculate inertia coefficients for section loads</td>
</tr>
<tr>
<td>LOADF</td>
<td>Calculate fatigue damage</td>
</tr>
<tr>
<td>LOADM</td>
<td>Calculate mean and half peak-to-peak</td>
</tr>
<tr>
<td>GEOMP1</td>
<td>Printer-plot of wake geometry</td>
</tr>
<tr>
<td>POLRPP</td>
<td>Printer-plot of polar plot</td>
</tr>
<tr>
<td>HISTTPP</td>
<td>Printer-plot of azimuthal time history</td>
</tr>
<tr>
<td>NOISRP1</td>
<td>Calculate and print far field rotational noise</td>
</tr>
<tr>
<td>BESSEL</td>
<td>Calculate J Bessel function</td>
</tr>
<tr>
<td>RAMF</td>
<td>Calculate rotor/airframe periodic motion and forces</td>
</tr>
<tr>
<td>MODE1</td>
<td>Blade modes</td>
</tr>
<tr>
<td>MODEC1</td>
<td>Initialize blade mode parameters</td>
</tr>
<tr>
<td>MODEB1</td>
<td>Calculate blade bending modes</td>
</tr>
<tr>
<td>MODEG</td>
<td>Calculate Galerkin functions for bending modes</td>
</tr>
<tr>
<td>MODEA1</td>
<td>Calculate articulated blade flap and lag modes</td>
</tr>
<tr>
<td>MODET1</td>
<td>Calculate blade torsion modes</td>
</tr>
<tr>
<td>MODEK1</td>
<td>Calculate kinematic pitch-bending coupling</td>
</tr>
<tr>
<td>MODE1</td>
<td>Calculate blade root geometry</td>
</tr>
<tr>
<td>MODEP1</td>
<td>Calculate blade inertia coefficients</td>
</tr>
<tr>
<td>MODEP1</td>
<td>Print blade modes</td>
</tr>
<tr>
<td>BODYC</td>
<td>Initialize airframe parameters at trim</td>
</tr>
<tr>
<td>ENGM0</td>
<td>Initialize drive train parameters at trim</td>
</tr>
<tr>
<td>MOTNC1</td>
<td>Initialize rotor parameters at trim</td>
</tr>
<tr>
<td>BODYM1</td>
<td>Calculate airframe transfer function matrix</td>
</tr>
<tr>
<td>ENGM1</td>
<td>Calculate drive train transfer function matrix</td>
</tr>
<tr>
<td>WAKEU1</td>
<td>Calculate uniform wake-induced velocity</td>
</tr>
<tr>
<td>WAKEN1</td>
<td>Calculate nonuniform wake-induced velocity</td>
</tr>
<tr>
<td>INRTF1</td>
<td>Calculate rotor transfer function matrix</td>
</tr>
<tr>
<td>INRTF1</td>
<td>Calculate inverse of transfer function matrix</td>
</tr>
<tr>
<td>MOTNH1</td>
<td>Calculate harmonics of hub motion</td>
</tr>
<tr>
<td>MOTNR1</td>
<td>Calculate harmonics of rotor motion</td>
</tr>
<tr>
<td>MOTNB1</td>
<td>Calculate blade and hub motion</td>
</tr>
<tr>
<td>AEROF1</td>
<td>Calculate blade aerodynamic forces</td>
</tr>
<tr>
<td>AEROS1</td>
<td>Calculate blade section aerodynamic coefficients</td>
</tr>
<tr>
<td>AEROT1</td>
<td>Interpolate airfoil tables</td>
</tr>
<tr>
<td>BODYV1</td>
<td>Calculate harmonics of airframe motion</td>
</tr>
<tr>
<td>ENGSV1</td>
<td>Calculate harmonics of drive train motion</td>
</tr>
<tr>
<td>MOTNF1</td>
<td>Calculate rotor generalized forces</td>
</tr>
<tr>
<td>MOTNS</td>
<td>Calculate static elastic motion</td>
</tr>
<tr>
<td>BODYF</td>
<td>Calculate airframe generalized forces</td>
</tr>
<tr>
<td>BODYA</td>
<td>Calculate body aerodynamic forces</td>
</tr>
<tr>
<td>Subprogram Name</td>
<td>Description</td>
</tr>
<tr>
<td>-----------------</td>
<td>-------------</td>
</tr>
<tr>
<td>WAKECl</td>
<td>Calculate influence coefficients for nonuniform inflow</td>
</tr>
<tr>
<td>WAKES1</td>
<td>Calculate blade position</td>
</tr>
<tr>
<td>VTXL</td>
<td>Calculate vortex line segment induced velocity</td>
</tr>
<tr>
<td>VTXS</td>
<td>Calculate vortex sheet segment induced velocity</td>
</tr>
<tr>
<td>GEOME1</td>
<td>Evaluate wake geometry</td>
</tr>
<tr>
<td>GEOMFI</td>
<td>Calculate free wake geometry distortion</td>
</tr>
<tr>
<td>MINV</td>
<td>Calculate inverse of matrix</td>
</tr>
<tr>
<td>MINVCI</td>
<td>Calculate inverse of complex matrix</td>
</tr>
<tr>
<td>EIGENJ</td>
<td>Calculate eigenvalues and eigenvectors of matrix</td>
</tr>
<tr>
<td>DERED</td>
<td>Eliminate equations and variables from system of differential equations</td>
</tr>
<tr>
<td>QSTRAN</td>
<td>Quasistatic reduction of system of linear differential equations</td>
</tr>
<tr>
<td>CSYSAN</td>
<td>Analyze system of constant coefficient linear differential equations</td>
</tr>
<tr>
<td>DEETAN</td>
<td>Transform equations to state variable form</td>
</tr>
<tr>
<td>SINE</td>
<td>Calculate frequency response from matrices</td>
</tr>
<tr>
<td>STATIC</td>
<td>Calculate static response from matrices</td>
</tr>
<tr>
<td>ZERO</td>
<td>Calculate zeros</td>
</tr>
<tr>
<td>ZETRAI</td>
<td>Transform matrix for zero calculation</td>
</tr>
<tr>
<td>BOSE</td>
<td>Calculate and print-plot transfer function (Bode plot)</td>
</tr>
<tr>
<td>BODEPP</td>
<td>Printer-plot transfer function magnitude and phase</td>
</tr>
<tr>
<td>TRACKS</td>
<td>Calculate and print-plot time history of time-invariant system response</td>
</tr>
<tr>
<td>TRCKPP</td>
<td>Printer-plot time history</td>
</tr>
<tr>
<td>GUSTS</td>
<td>Calculate and print rms gust response</td>
</tr>
<tr>
<td>PSYSAN</td>
<td>Analyze system of periodic coefficient linear differential equations</td>
</tr>
<tr>
<td>DEPRAN</td>
<td>Transform equations to state variable form</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Namelist Label</th>
<th>Common Block Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>NLCASE</td>
<td>Job data</td>
</tr>
<tr>
<td>NLTRIM</td>
<td>Trim data</td>
</tr>
<tr>
<td>NLTRR</td>
<td>Rotor data</td>
</tr>
<tr>
<td>NLAWEK</td>
<td>Wake data</td>
</tr>
<tr>
<td>NLBODY</td>
<td>Airframe and drive train data</td>
</tr>
<tr>
<td>NLLOAD</td>
<td>Loads data</td>
</tr>
<tr>
<td>NLFILT</td>
<td>Flutter data</td>
</tr>
<tr>
<td>NLSTAB</td>
<td>Flight dynamics data</td>
</tr>
<tr>
<td>NLTRAN</td>
<td>Transient data</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Unit Number</th>
<th>Input data</th>
</tr>
</thead>
<tbody>
<tr>
<td>NFDAT</td>
<td>Rotor #1 airfoil data</td>
</tr>
<tr>
<td>NFAF1</td>
<td>Rotor #2 airfoil data</td>
</tr>
<tr>
<td>NFRS</td>
<td>Restart data</td>
</tr>
<tr>
<td>NFEIG</td>
<td>Eigenvalue data</td>
</tr>
<tr>
<td>NFSR</td>
<td>Scratch data</td>
</tr>
</tbody>
</table>

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
BD1DATA  Input airframe data
BADATA   Input airframe aerodynamics data
BN1DATA  Input drive train data
L1DATA   Input rotor loads data
L1DATA   Input airframe loads data
GC1DATA  Input gust and control data
TN1DATA  Input transient data
ST1DATA  Input flight dynamics data
FL1DATA  Input flutter data
A1TABL   Rotor airfoil tables
UNITNO   Input/output unit numbers
CASECM   Job description

TR1CM    Calculated trim data
RT1CM    Calculated rotor data
RH1CM    Transfer function matrices
BD1CM    Calculated airframe data
BN1CM    Calculated drive train data
GUSTCM   Gust and transient control
CONTCM   Aircraft controls and motion
CONVCM   Circulation and motion convergence
ND1CM    Blade modes
INC1CM   Rotor inertial coefficients
WKV1CM   Induced velocity
MHR1CM   Hub motion
ABS1CM   Blade section aerodynamics
MN1CM    Rotor motion and airframe vibration
MSEC1CM  Static elastic motion
AEF1CM   Rotor forces
QR1CM    Rotor generalized forces
QBD1CM   Airframe generalized forces
WG1CM    Wake geometry
WK1CM    Wake influence coefficients

AB1NM1CM  Calculated motion data
LD1NM1CM  Calculated loads data
FL1CM    Flutter matrices
FR1CM    Flutter rotor matrices
FAM1CM   Flutter airframe matrices
FINCM    Flutter inertial coefficients
FIAB1CM  Flutter aerodynamic coefficients
STDM1CM  Flight dynamics stability derivatives
STM1CM   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.
read namelist NLCase
if new job and BLKDAT > 0
  DATE (for FILEID)
  TIME (for FILEID)
  FILEI (input file write)
FRNTJ
for JCASE = 1 to NCASES
  TIMER (initialize)
  TIMER
  DATE (for IDENT)
  TIME (for IDENT)
  if new job
    INPTN
    INIT
      INITA
      INITC
      INITR1
      INTR2
      INITB
      INITE
      CHEKR1
      CHEKR2
  if old job
    INPTO
    FRNTO
    if new job or trim re-start
      TRIM
      FILEJ (trim data scratch file write)
    if ANTPE(1) ≠ 0 or flutter re-start
      FLUT
      FILEJ (trim data scratch file read)
    if ANTPE(2) ≠ 0 or flight dynamics re-start
      STAB
      FILEJ (trim data scratch file read)
    if ANTPE(3) ≠ 0 or transient re-start
      TRAN
      TIMER (print)
FILE1 (input file read)
read namelist NLTRIM
if Opread(1) # 0
INPTR1
   read namelist NLTRIM
if Opread(2) # 0
INPTW1
   read namelist NLWAKE
if Opread(3) # 0
INPTR2
   read namelist NLTRIM
if Opread(4) # 0
INPTW2
   read namelist NLWAKE
if Opread(5) # 0
INPTB
   read namelist NLBODY
if Opread(6) # 0
INPTL1
   read namelist NLOAD
if Opread(7) # 0
INPTL2
   read namelist NLOAD
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

FILEI (restart file read)
FILEJ
FILEF
FILES
FILET

read namelist NLTRIM
if OPREAD(6) ≠ 0
   INPTL1
      read namelist NLLOAD
if OPREAD(7) ≠ 0
   INPTL2
      read namelist NLLOAD
if OPREAD(8) ≠ 0
   INPTF
      read namelist NLFLUT
   INPTG
      read namelist NLFLUT
if OPREAD(9) ≠ 0
   INPTS
      read namelist NLSTAB
   INPTU
      read namelist NLSTAB
if OPREAD(10) ≠ 0
   INPTT
      read namelist NLTRAN
   INPTV
      read namelist NLTRAN

flutter restart
flight dynamics restart
 transient restart

trim restart
flutter restart
flutter or flight dynamics restart
trim restart
trim restart
transient restart
TRIM

TIMER
if trim restart, go to restart entry point
uniform inflow
if ITERU ≠ 0
TRIM
    if NPRNNT = 1
        PERF
        LOAD
        NPRNTP > 0
        NPRNTL > 0
nonuniform inflow, prescribed wake geometry
for IT = 1 to ITERR
    WAKEC1
    WAKEC2
    TRIM
        if IT = multiple NPRNNT
            PERF
            LOAD
            NPRNTP > 0
            NPRNTL > 0
nonuniform inflow, free wake geometry
for IT = 1 to ITERF
    WAKEC1
    WAKEC2
    TRIM
        if IT = multiple NPRNNT
            PERF
            LOAD
            NPRNTP > 0
            NPRNTL > 0
FILE (restart file write)
FILEI
FILEJ
TRIM restart entry point
PRNT
    PRNTC
    if NPRNTI ≠ 0
        PRNTR1
        PRNTR2
        PRNTW1
        PRNTW2
        PRNTB
MODEP1
MODEP2
TRIMP
PERF
LOAD
TIMER
TRIMI

RAMP
if MTRIM <= 0 or no trim iteration, return
if DEBUG(4) >= 1, print trim iteration
for COUNTT = 1 to MTRIM
    if COUNTT-1 = multiple MTRIMD, construct D-1
        for I = 1 to MT
            increment controls
            RAMF
    MINV
        increment controls
        RAMF
    if DEBUG(4) >= 1, print trim iteration
    test trim convergence

PERF

TIMER
PERF1
PERF2
TIMER
LOAD

TIMER

LOADR1

\texttt{\textasciitilde TNB1}

: " MALOAD # 0

\texttt{GEOM01}
\texttt{HISTPP}
\texttt{GEOMP1}
\texttt{POLRFP}
\texttt{HISTPP}

\texttt{if MLOAD # 0}

\texttt{LOADM1}

\texttt{LOADM}
\texttt{LOADF}
\texttt{HISTPP}

\texttt{NPLLOT(1-4)}
\texttt{NPLLOT(5-67)}
\texttt{NPLLOT(5-67)}

\texttt{NPLLOT(68-71)}

\texttt{NPLLOT(72-75)}

\texttt{for IR = 1 to MLOAD}

\texttt{LOADS1}

\texttt{LOADF1}
\texttt{LO' A}
\texttt{LOADF}
\texttt{HISTPP}

\texttt{for IN = 1 to MNOISE}

\texttt{WJIS1}

\texttt{BESSEL}
FLUT

TIMER

for OFFLOW ≤ 0 (constant coefficients)
  if flutter restart, go to restart entry point
  FLUTM
  FILEF (restart file write)  PSWRT ≠ 0
  flutter restart entry point
  PRNTF
  MODEP1
  MODEP2
  FLUTL

  TIMER
  CSYSAN
  FILEE (eigenvalue file write)  ANTYPE(1) ≠ 0
  BOIE
  ANTYPE(2) ≠ 0
  TRACKS
  ANTYPE(3) ≠ 0
  GUSTS
  ANTYPE(4) ≠ 0
  TIMER

  if OPIFAM ≠ 0
    STABD
    STABE

for OFFLOW > 0 (periodic coefficients)
for NT = 0 to MPSIPC
  FLUTM
  if NT = MPSIPC
    PRNTF
    MODEP1
    MODEP2
  PSYSAN
  if NT = MPSIPC
    FILEE (eigenvalue file write)
FLUTM

MODE1
MODE2
FLUTR1
FLUTR2
FLUTB

[BODYF]

FLUTR1

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

TIMER
PRINTS
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
      RAMP
      PERF
      LOAD

FILES (restart file write)
flight dynamics restart entry point
STABD
STABE
TIMER

STABE

for IEQ = 1 to 12
   EQTYPE(IEQ) ≠ 0
   DERED
   STABL

   TIMER
   CSYSAN
   FILEE (eigenvalue file write)
   BODE
   TRACKS
   GUSTS
   numerical integration
   MINV
   STABP
   FRWTG
      for IT = 1 to TMAX/TSTEP
      TRANC
         CONT
         GUSTU
         GUSTC
      if IT = multiple NPRNTT
         STABP
   TRCKPP
   TIMER

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TRAN

TIMER
PRMTT
PRNTG

if transient restart, go to restart entry point

MINV

TRANP
for IT = 1 to TMAX/TSTEP

TRANC

<table>
<thead>
<tr>
<th>CONTRL</th>
<th>OPTRAN = 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>GUSTU</td>
<td>OPTRAN = 2</td>
</tr>
<tr>
<td>GUSTC</td>
<td>OPTRAN = 3</td>
</tr>
</tbody>
</table>

TRANI

for IT = 1 to IERT

<table>
<thead>
<tr>
<th>WAKEC1</th>
<th>LEVEL(1) ≥ 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>WAKEC2</td>
<td>LEVEL(2) ≥ 1</td>
</tr>
<tr>
<td>RAMF</td>
<td></td>
</tr>
</tbody>
</table>

if IT = multiple NFRNTT

TRANP

<table>
<thead>
<tr>
<th>MERF</th>
<th>NPRNTP &gt; 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOAD</td>
<td>NPRNTL &gt; 0</td>
</tr>
</tbody>
</table>

if IT = multiple NBRSTRT

FILET (restart file write)  

transient restart entry point

TRCKFP

TIMER
for COUNTC = 1 to ITERC (circulation iteration)
    WAKEU1
    WAKEN1
    WAKEU2
    WAKEN2
    for COUNTM = 1 to ITERM (motion iteration)
        INRTM1
            INRTI
            INRTI
            INRTI
        ENGNC
        ENGNM1
            INRTI
            ENGNM2
            INRTI
        for JPSI = 0 to MREV * MPSI by MPSIR (Ψ loop)
            MOTNH1
            MOTNR1
            MOTNH2
            MOTNR2
            BODIV1
            ENGNV1
            MOTNF1
            BODIV2
            ENGNV2
            MOTNF2
            MOTNS
        test motion convergence
            EPMOTN
        test circulation convergence
            EPCIRC

BODYF
    BODYA
    TIMER
MODE1

TIMER
MODEC1
if $\Delta > \varepsilon_{\text{MODE}}$

\[ \text{MODEB1} \]

\[ \text{MODEG} \]
\[ \text{MINV} \]
\[ \text{EIGENJ} \]

\[ \text{MODEA1} \]
\[ \text{MODEK1} \]
\[ \text{MODED1} \]

HINGE = 2

MOTNBl

TIMER

for JP = JPSI + 1 to JPSI + MPSIR ($\Psi$ step)

MOTNBl

AEROF1

for IR = 1 to MRA

AEROS1

AEROT1

TIMER
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 FT50FO01,,SCRATCH,DISP=NEW,RET=T
DDEF FT41FO01,,AIRFOIL,DISP=OLD
LOAD HELA; LOAD HELR1; LOAD HELR2
CALL MAINPROG
&NLCASE JOB=0,NCASES=2,RSWRT=0,BLKDAT=-1,
NFAF1=41,NFAF2=41,NFSCR=50,NFES=1,NFEIG=1,
&END
&NLTRIM VKTS=x,OLLL=x,LATCYC=x,LANGCYC=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 HELO; LOAD HELR1; LOAD HELR2
CALL MAINPROG
&NLCASE JOB=0,NCASES=1,RSWRT=0,BLKDAT=1,
NFAF1=41,NFAF2=42,NFSR=50,NFRS=1,NFEIG=45,
&END
&NLTRM .M VTTS=x.,
COLL=x.,LATCYC=x.,LMCyc=x.,PEPAL=x.,APITCH=x.,AROLL=x.,
ANYPE=3*1,OPREAD=10*1,
&END
&NLTR data,&END
&NLMAKE data,&END
&NLMAKE 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 HELO; LOAD HELR1; LOAD HELR2
CALL MAINPROG
&NLTRIM data,&END
&END

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

DDEF FT50FO01,,SCRATCH,DISP=NEW,RET=T
DDEF FT41FO01,,AIRFOIL,DISP=OLD
DDEF FT4EF001,,INPUT,DISP=OLD
CALL MAINFROG
&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 FT50FO01,,SCRATCH,DISP=NEW,RET=T
DDEF FT41FO01,,AIRFOIL,DISP=OLD
DDEF FT4EF001,,RESTART1,DISP=NEW
DDEF FT4EF002,,RESTART2,DISP=NEW
LOAD HELA; LOAD HELR1; LOAD HELR2
CALL MAINFROG
&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 FT50FO01,,SCRATCH,DISP=NEW,RET=T
DDEF FT4EF001,,RESTART,DISP=OLD
CALL MAINFROG
&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 OREAD(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.

<table>
<thead>
<tr>
<th>Namelist</th>
<th>Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>NLCASE</td>
<td>Job data</td>
</tr>
<tr>
<td>NLTRIM</td>
<td>Trim data</td>
</tr>
<tr>
<td>NLRTR</td>
<td>Rotor data</td>
</tr>
<tr>
<td>NLWAKE</td>
<td>Wake data</td>
</tr>
<tr>
<td>NLBDY</td>
<td>Airframe and drive train data</td>
</tr>
<tr>
<td>NLLOAD</td>
<td>Loads data</td>
</tr>
<tr>
<td>NLFLUT</td>
<td>Flutter data</td>
</tr>
<tr>
<td>NLSTAB</td>
<td>Flight dynamics data</td>
</tr>
<tr>
<td>NLTRAN</td>
<td>Transient data</td>
</tr>
</tbody>
</table>

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

NFAFI1 rotor #1 airfoil file (new job only); default = 41

NFAF2 rotor #2 airfoil file (new job only; only if have two rotors);
         default = 42

NRFS restart file (no file write if LE 0); default = 44

NREIG eigenvalue file (no file write if LE 0); default = 45

NFSRC 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

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Namelist NLTRIM

OPREAD(10) integer vector defining namelist read structure: EQ 0 to suppress read:

   components (new job only)
   (1) NLRTTR, rotor #1
   (2) NLWAKE, rotor #1
   (3) NLRTTR, rotor #2
   - (4) NLWAKE, rotor #2
   (5) NLBCDY

   tasks
   (6) NLLoad, rotor #1
   (7) NLLoad, rotor #2
   (8) NLFLUT
   (9) NLSTAB
   (10) NLTRAN

NFRNTI 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 (RAMP)
(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, MOfNF, MOTNS)
(17) rotor motion, 2-3 (MOTNR)
(18) rotor aerodynamics, 2-3 (AEROF)
(19) blade section aerodynamics, 3 (AERCS)
(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)
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VKTS</td>
<td>aircraft speed ( V ) (knots)</td>
</tr>
<tr>
<td>VEL</td>
<td>velocity ratio ( \frac{V}{\Omega R} )</td>
</tr>
<tr>
<td>VTIP</td>
<td>rotor #1 tip speed ( \Omega R ) (ft/sec or m/sec)</td>
</tr>
<tr>
<td>RPM</td>
<td>rotor #1 rotational speed (rpm)</td>
</tr>
<tr>
<td>OPDENS</td>
<td>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</td>
</tr>
<tr>
<td>ALTMSL</td>
<td>altitude above mean sea level (ft or m), for OPDENS = 1 or 2</td>
</tr>
<tr>
<td>TEMP</td>
<td>air temperature (( ^\circ F ) or ( ^\circ C )), for OPDENS = 2 or 3</td>
</tr>
<tr>
<td>DENSE</td>
<td>air density (slug/ft(^3) or kg/m(^3)), for OPDENS = 3</td>
</tr>
<tr>
<td>OPCGRND</td>
<td>integer parameter controlling ground effect analysis: EQ 0 for out of ground effect, NE 0 for in ground effect</td>
</tr>
<tr>
<td>HAGL</td>
<td>altitude helicopter center of gravity above ground for ground effect analysis (ft or m)</td>
</tr>
<tr>
<td>OPENCN</td>
<td>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</td>
</tr>
<tr>
<td>AFLAP</td>
<td>wing flap angle ( \delta_F ) (deg)</td>
</tr>
<tr>
<td>RTURN</td>
<td>for free flight, trim turn rate ( \dot\psi_F ) (deg/sec), positive to right</td>
</tr>
</tbody>
</table>
initial values of controls (trimmed as appropriate)

**COLL**
- collective stick displacement \( \delta_0 \) or \( \Delta \theta_{gov} \) (deg), positive up

**LATCYC**
- lateral cyclic stick displacement \( \delta_c \) (deg), positive left

**LNGCYC**
- longitudinal cyclic stick displacement \( \delta_s \) (deg), positive aft

**PEDAL**
- pedal displacement \( \delta_p \) (deg), positive to right

**APITCH**
- for free flight, aircraft pitch angle \( \theta_{FP} \) (deg), positive nose up; for wind tunnel, rotor shaft angle of attack \( \theta_T \) (deg), positive nose up

**AROLL**
- for free flight, aircraft roll angle \( \phi_{FP} \) (deg), positive to right

(\( \theta_{FP} \) and \( \phi_{FP} \) define orientation of body axes relative to earth axes)

**ACLIMB**
- for free flight, aircraft climb angle \( \Theta_{FP} \) (deg), positive up

**AYAW**
- for free flight, aircraft yaw angle \( \Psi_{FP} \) (deg), positive to right; for wind tunnel, test module yaw angle \( \Psi_T \) (deg), positive to right

(\( \Theta_{FP} \) and \( \Psi_{FP} \) 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

**EFMOTN**
- tolerance for motion convergence (deg)

**ITERC**
- maximum number of circulation iterations

**EPCIRC**
- tolerance for circulation convergence (\( \Delta C_{Pc} \))
integer vector defining degrees of freedom used in vibratory motion solution, 0 if not used; order:

rotor #1 \(q_1 \ldots q_{10} \quad p_0 \ldots p_4 \quad g\)

rotor #2 \(q_1 \ldots q_{10} \quad p_0 \ldots p_4 \quad g\)

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

airframe \(\phi_F \quad \Theta_F \quad \psi_F \quad x_F \quad y_F \quad z_F \quad q_{s7} \ldots q_{s16}\)

(rigid body) (flexible body, max 10)

drive train \(\psi_e \quad \psi_i \quad \psi_e \quad \Delta \Theta_t \quad \Delta \Theta_{govr_1} \quad \Delta \Theta_{govr_2}\)

(rotor/engine speed) (governor)

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

rotor #1 \(q_1 \quad q_2 \quad q_3 \quad q_4\)

rotor #2 \(q_1 \quad q_2 \quad q_3 \quad q_4\)

(bending, max 4)

number of harmonics in rotor motion analysis; maximum 20; EQ 0 for mean only

\(1\) rotor #1

\(2\) rotor #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 CPH/IVB)

\(1\) rotor #1

\(2\) rotor #2

integer parameter specifying rotor wake analysis level:

0 for uniform inflow, 1 for nonuniform inflow with prescribed wake geometry, 2 for nonuniform inflow with free wake geometry (must be consistent with INFLOW)

\(1\) rotor #1

\(2\) rotor #2
number of wake and trim iterations

ITERU at uniform inflow level; EQ 0 to skip

ITERR at nonuniform inflow/prescribed wake geometry level; EQ 0 to skip

ITERF at nonuniform inflow/free wake geometry level

NPRTTT integer parameter n: trim/performance/load print every n-th iteration; LE 0 to suppress

NPRTTP integer parameter controlling performance print; LE 0 to suppress

NPRTTL 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

ORGOVT integer parameter specifying governor trim
0 trim collective stick $\delta_0$
1 trim rotor #1 governor
2 trim rotor #2 governor
3 trim both rotor governors

targets for wind tunnel trim cases

CXRIM $C_x/\rho $
XTRIM $X/q$ (ft$^2$ or m$^2$)
CTRIM $C_T/\rho$ or $C_L/\rho$
CPTRIM $C_P/\rho$
CYTRIM $C_Y/\rho$
BCTRIM $\phi_e$ (deg)
BSTRIM $\phi_s$ (deg)
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
   \[ \delta_o \delta_c \delta_s \delta_p \Theta_{FT} \phi_{FP} \]

4. trim forces, moments, and power with
   \[ \delta_o \delta_c \delta_s \delta_p \Theta_{FT} \psi_{FP} \phi_{FP} \]

5. trim symmetric forces and moments with
   \[ \delta_o \delta_s \Theta_{FT} \]

6. trim symmetric forces, moments, and power with
   \[ \delta_o \delta_s \Theta_{FT} \phi_{FP} \]

**wind tunnel cases**

OPTRIM = 10  no trim

11. trim \( C_T \) with \( \delta_o \)

12. trim \( C_N \) with \( \Theta_T \)

13. trim \( C_D \) with \( \delta_o \)

14. trim \( \beta_c \) with \( \delta_o \)

15. trim \( C_T \) with \( \beta_c \) with \( \delta_o \)

16. trim \( C_L \) \( C_X \) with \( \delta_o \)

17. trim \( C_L \) \( C_Y \) with \( \delta_o \)

18. trim \( C_L \) \( \beta_c \) with \( \delta_o \)

19. trim \( C_L \) \( X/q \) \( C_Y \) with \( \delta_o \)

20. trim \( C_L \) \( X/q \) \( \Theta_T \) with \( \delta_o \)

21. trim \( C_L \) \( X/q \) \( \beta_s \) with \( \delta_o \)

22. trim \( \beta_c \) with \( \delta_s \)

23. trim \( C_T \) \( \beta_c \) with \( \delta_o \)

24. trim \( C_L \) \( C_X \) with \( \delta_o \)

25. trim \( C_L \) \( C_Y \) with \( \delta_o \)

26. trim \( C_L \) \( \beta_c \) with \( \delta_o \)

27. trim \( C_L \) \( X/q \) \( \Theta_T \) with \( \delta_o \)

28. trim \( C_L \) \( X/q \) \( \Theta_T \) with \( \delta_o \)

29. trim \( C_L \) \( X/q \) \( \beta_c \) with \( \delta_o \)

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<table>
<thead>
<tr>
<th>WEIGHT</th>
<th>see namelist NLBCDY</th>
</tr>
</thead>
<tbody>
<tr>
<td>IXX</td>
<td></td>
</tr>
<tr>
<td>IYY</td>
<td></td>
</tr>
<tr>
<td>IZZ</td>
<td></td>
</tr>
<tr>
<td>IXY</td>
<td></td>
</tr>
<tr>
<td>IXZ</td>
<td></td>
</tr>
<tr>
<td>IYZ</td>
<td></td>
</tr>
<tr>
<td>ATILT</td>
<td></td>
</tr>
<tr>
<td>FSCG</td>
<td></td>
</tr>
<tr>
<td>BLCG</td>
<td></td>
</tr>
<tr>
<td>WLCG</td>
<td></td>
</tr>
</tbody>
</table>
Namelist NLRTR

TITLE(20) title for rotor and wake data (80 characters)
TYPE rotor identification (4 characters); suggest MAIN, FRNT, or RGT for rotor #1; and MMR, MMR, or LEFT for rotor #2
VTIPN normal tip speed $\Omega R_o$ (ft/sec or m/sec)
RADIUS blade radius $R$ (ft or m)
SIGMA solidity ratio $\sigma = N_c m / \pi R$ (based on mean chord)
GAMMA blade Lock number $\chi = \rho \omega C R^4 / I_b$ (based on standard density, $\rho = 5.7$, and mean chord)
(N and $\sigma$ 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)
TDAMPC cyclic
TDAMFR rotating

NUGC longitudinal gimbal natural frequency $\nu_G$ or teeter natural frequency $\nu_T$ (per rev at normal tip speed $\Omega R_o$)
NUGS lateral gimbal natural frequency $\nu_S$ (per rev at normal tip speed $\Omega R_o$)

GDAMPC longitudinal gimbal damping $C_{GG}$ or teeter damping $C_T$ (ft-lb/rad/sec or m-N/rad/sec)
GDAMPS lateral gimbals damping $C_G$ (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.

LDAMFR lag velocity $\xi_{LD}$ where maximum moment of lag damper occurs (rad/sec); hydraulic damping below $\xi_{LD}$ and friction damping above

GSB(NBM) bending mode structural damping $g_b$
GST(NTM) torsion mode structural damping $g_t$

ROTATE integer parameter specifying rotor rotation direction: 1 for counter-clockwise, -1 for clockwise (viewed from above)
OMVIB(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

RTIP tip loss parameter $B$

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

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

TWISTL linear twist rate $\theta_{tw}$ (deg); used to calculate TWISTA and TWISTI if LINW 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 ($15^o < |\alpha| < 165^o$)

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, $r_{root}/R$

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

\( THETAZL(MRA) \)  
incremental pitch of zero lift line, \( \Theta_{ZL} \) (deg); can be  
include in TWISTA; \( \Theta_{ZL} \) 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 \( .75R \), \( \Theta_{tw} \) (deg)

\( XAC(MRA) \)  
offset of aerodynamic center (for unsteady aerodynamics)  
aff 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 \( kg/m \))

\( EI(XX(MRI) \)  
chordwise bending stiffness (lb-ft\(^2\) or N-m\(^2\))

\( EI(ZZ(MRI) \)  
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, \( k_p^2/R^2 \)

\( ITM(ETA(MRI) \)  
section moment of inertia about elastic axis, \( I_\Theta \)  
 slug-ft or kg-m)

\( GJ(MRI) \)  
torsional stiffness, \( GJ \) (lb-ft\(^2\) or N-m\(^2\))

\( TWISTA(MRI) \)  
blade twist relative \( .75R \), \( \Theta_{tw} \) (deg)
Stall model

**CPSTLL**

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.)

**CPYAW**

integer parameter defining yawed flow corrections

0  both yawed flow and radial drag included
1  no yawed flow (cos \( \alpha \) = 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:
\( \tau_L, \tau_D, \tau_M \) (calculated if \( LT 0. \))

**ADELAY**

maximum angle of attack increment due to stall delay,
\( \alpha_{\text{max delay}} \) (deg)

**AMAXNS**

angle of attack in linear range for no stall model, \( \alpha_{\text{max}} \) (deg)

**FSIDS(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: \( \alpha_{ds} \) (deg)

**ALFRE(3)**

stall recovery angle of attack for lift, drag, and moment: \( \alpha_{\text{re}} \) (deg)

**CLDSP**

maximum peak dynamic stall vortex induced lift coefficient:
\( \Delta c_{Lds} \)

**CDDSP**

maximum peak dynamic stall vortex induced drag coefficient:
\( \Delta c_{Dds} \)

**CMDSP**

maximum peak dynamic stall vortex induced moment coefficient:
\( \Delta c_{Mds} \)
<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_{h}$</td>
<td>factor for hover induced velocity (typically 1.1)</td>
</tr>
<tr>
<td>$K_{f}$</td>
<td>factor for forward flight induced velocity (typically 1.2)</td>
</tr>
<tr>
<td>$f_{r}$</td>
<td>factor for linear inflow variation in forward flight (typically 1.5)</td>
</tr>
<tr>
<td>$f_{l}$</td>
<td>factor for linear inflow variation in forward flight (typically 1.1)</td>
</tr>
<tr>
<td>$f_{h}$</td>
<td>factor on linear inflow variation due to hub moment (typically 1.1)</td>
</tr>
<tr>
<td>FACTWU</td>
<td>factor introducing lag in $C_{p}$, $C_{M_{x}}$, and $C_{M_{y}}$ used to calculate induced velocity (typically 0.5)</td>
</tr>
<tr>
<td>$K_{\text{INTH}}$</td>
<td>factor for hover interference velocity at other rotor ($K_{21}$ or $K_{12}$)</td>
</tr>
<tr>
<td>$K_{\text{INTF}}$</td>
<td>factor for forward flight interference velocity at other rotor ($K_{21}$ or $K_{12}$) (linear variation between $K_{\text{INTH}}$ at $\mu = 0.05$ and $K_{\text{INTF}}$ at $\mu = 0.10$ is used)</td>
</tr>
<tr>
<td>$K_{\text{INTWB}}$</td>
<td>factor for rotor-induced interference velocity at wing-body, $K_{W}$</td>
</tr>
<tr>
<td>$K_{\text{INTHT}}$</td>
<td>factor for rotor-induced interference velocity at horizontal tail, $K_{H}$</td>
</tr>
<tr>
<td>$K_{\text{INTVT}}$</td>
<td>factor for rotor-induced interference velocity at vertical tail, $K_{V}$</td>
</tr>
<tr>
<td>$K_{W}, K_{H}, K_{V}$</td>
<td>equal fraction of fully-developed wake times maximum fraction surface in wake</td>
</tr>
<tr>
<td>HINGE</td>
<td>integer parameter specifying blade mode type</td>
</tr>
<tr>
<td>0</td>
<td>hinged</td>
</tr>
<tr>
<td>1</td>
<td>cantilever</td>
</tr>
<tr>
<td>2</td>
<td>articulated (flap and lag modes only)</td>
</tr>
<tr>
<td>NCOLB</td>
<td>number of collocation functions for bending mode calculations (total flap and lag, alternating); maximum 20</td>
</tr>
<tr>
<td>NCCLT</td>
<td>number of collocation functions for torsion mode calculations; maximum 10</td>
</tr>
<tr>
<td>NONROT</td>
<td>integer parameter: NE 0 to calculate nonrotating bending frequencies</td>
</tr>
<tr>
<td>EPMODE</td>
<td>criterion on change of collective pitch to update blade modes, $\Delta \Theta_{75}$ (deg)</td>
</tr>
<tr>
<td><strong>MASST</strong></td>
<td>tip mass (slug or kg); the tip mass can also be included directly in the section mass distribution</td>
</tr>
<tr>
<td><strong>XIT</strong></td>
<td>offset of tip mass center of gravity aft of elastic axis, ( x_{T/R} )</td>
</tr>
<tr>
<td><strong>MBLADE</strong></td>
<td>blade mass (slug or kg); if ( i.S. = 0 ), integral of section mass used (with mass included at ( r = 0 ), to account for the hub mass)</td>
</tr>
<tr>
<td><strong>KFLAP</strong></td>
<td>flap hinge offset ( e_{f}/R ) (extent of rigid hub for cantilever blade)</td>
</tr>
<tr>
<td><strong>KLAG</strong></td>
<td>lag hinge offset ( e_{l}/R ) (extent of rigid hub for cantilever blade)</td>
</tr>
<tr>
<td><strong>KFLAP</strong></td>
<td>flap hinge spring (ft-lb/rad or m-N/rad)</td>
</tr>
<tr>
<td><strong>KLAG</strong></td>
<td>lag hinge spring (ft-lb/rad or m-N/rad)</td>
</tr>
<tr>
<td><strong>RCPLS</strong></td>
<td>hinge spring parameter, ( \Theta_{s} )</td>
</tr>
<tr>
<td><strong>TSRPNG</strong></td>
<td>hinge spring parameter, ( \Theta_{so} )</td>
</tr>
<tr>
<td><strong>RCPL</strong></td>
<td>structural coupling parameter ( \Theta ) (effective pitch angle ( \Theta ) used to calculate blade bending modes; normally ( \Theta = 1 ).)</td>
</tr>
<tr>
<td><strong>NIPB</strong></td>
<td>integer parameter specifying twist inboard of ( r_{FA} ): ( E _1 ) for no pitch bearing</td>
</tr>
<tr>
<td><strong>WTIN</strong></td>
<td>integer parameter defining control system stiffness input: 1 for ( K_{\Theta} ), 2 for ( \omega_{\Theta} )</td>
</tr>
<tr>
<td><strong>FTO</strong></td>
<td>control system frequency ( \omega_{\Theta} ) (per rev, at normal tip speed ( V_{TIPN} ))</td>
</tr>
<tr>
<td><strong>FTC</strong></td>
<td>collective</td>
</tr>
<tr>
<td><strong>FTR</strong></td>
<td>cyclic</td>
</tr>
<tr>
<td><strong>FTR</strong></td>
<td>reactionless</td>
</tr>
<tr>
<td><strong>KTO</strong></td>
<td>control system stiffness ( K_{\Theta} ) (ft-lb/rad or m-N/rad)</td>
</tr>
<tr>
<td><strong>KTC</strong></td>
<td>collective</td>
</tr>
<tr>
<td><strong>KTR</strong></td>
<td>cyclic</td>
</tr>
<tr>
<td><strong>KTR</strong></td>
<td>reactionless</td>
</tr>
<tr>
<td><strong>KPIN</strong></td>
<td>integer parameter defining pitch/bending coupling input: 1 for input, 2 for calculated (negative to suppress cosine factors in ( K_{PB} ) and ( K_{PC} ))</td>
</tr>
<tr>
<td><strong>PHIPH</strong></td>
<td>pitch horn cant angle, ( \Phi_{PH} ) (deg)</td>
</tr>
<tr>
<td><strong>PHIPL</strong></td>
<td>pitch link cant angle, ( \Phi_{PL} ) (deg)</td>
</tr>
<tr>
<td><strong>RFB</strong></td>
<td>pitch bearing radial location, ( r_{PB}/R )</td>
</tr>
<tr>
<td><strong>RPH</strong></td>
<td>pitch horn radial location, ( r_{PH}/R )</td>
</tr>
<tr>
<td><strong>XPH</strong></td>
<td>pitch horn length, ( x_{PH}/R )</td>
</tr>
</tbody>
</table>
ATAN(KBM) pitch/bending coupling \( \tan^{-1}K_{P1} \) (deg), for pitch horn level (\( KPIN = 1 \) or \( -1 \))

DEL(JG) pitch/gimbal coupling \( \tan^{-1}K_{P2} \) (deg), for pitch horn level

RFA feathering axis radial location, \( r_{FA}/R \)

ZFA gimbal undersling, \( z_{FA}/R \)

XFA torque offset, \( x_{FA}/R \)

\( \gamma \) precone angle \( \delta_{FA1} \) (deg), positive up

DROOP droop angle \( \delta_{FA2} \) (deg) at \( \gamma_{75} = 0 \), positive down from precone

SWEEP sweep angle \( \delta_{FA3} \) (deg) at \( \gamma_{75} = 0 \), positive aft

FROOP feathering axis droop angle \( \delta_{FA4} \) (deg), positive down from precone

FSWEEP feathering axis sweep angle \( \delta_{FA5} \) (deg), positive aft
**Namelist NLWAKE**

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

**OPVXVY**
integer parameter: EQ 0 to suppress x and y components of induced velocity calculated at the rotors

**KNW**
extent of near wake, $K_{NW}$

**KRW**
extent of rolling up wake, $K_{RW}$

**KFW**
extent of far wake and tip vortices, $K_{FW}$

**KDW**
extent of far wake and tip vortices for points off rotor disk, $K_{DW}$

\[ (\text{age } \phi = K \Delta \Psi; \text{ all } K \geq 1) \]

**RRU**
initial radial station of wake rollup, $r_{RU}/R$

**FRU**
initial tip vortex fraction of $\Gamma_{\max}$ for rollup, $f_{RU}$

**FRU**
extent of rollup in wake age, $\phi_{RU}$ (deg)

**FNW**
tip vortex fraction of $\Gamma_{H}$ 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

**OPRMS**
integer parameter: NE 0 to include rotation matrices ($R_{TS}$, etc.) in influence coefficients
NLWAKE

\[ WKMODL(13) \]

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: \( n_{G1} \) 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: \( n_{L1} \) for
\( i = 1 \) to MRL

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

1) EQ 0 to suppress inplane motion
2) EQ 0 to suppress all harmonics except mean
3) EQ 0 for linear from \( r = r_{root}/R \) to \( r = 1 \).
VELB  core burst propagation rate, \( V_b = \frac{\Delta \phi}{\Delta \psi} \)

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

LBV  core burst test parameter \( d_{b_v} \), LT 0. to suppress bursting

QDEBUG  velocity criterion for debug print: print if \( |V \cdot \vec{F}| / \Gamma | > \) 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 \( \lambda \)
3  from input \( K_1 \), \( K_2 \), \( K_3 \), \( K_4 \)

   Landgrebe prescribed wake geometry

4  from \( C_T \)
5  from \( \Gamma_{\text{max}} \)
6  from \( \lambda \)
7  from \( \lambda \) without interference

   Kocurek and Tangler prescribed wake geometry

8  from \( C_T \)
9  from \( \Gamma_{\text{max}} \)
10  from \( \lambda \)
11  from \( \lambda \) without interference

Factors \( f_1 \) and \( f_2 \) for prescribed wake geometry

FWGT(2)  tip vortex

FWGSI(2)  inside sheet edge

FWGSO(2)  outside sheet edge

KWGT(4)  tip vortex

KWGSI(4)  inside sheet edge

KWGSO(4)  outside sheet edge
Free wake geometry

KFWG
extent of free wake geometry distortion calculation, $k_{FWG}$
(age $\phi = K_{FWG}$); 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 $r/R$
(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 $\lambda_{IM}$; general update every $\lambda_{IM}$ increment
in boundary age; suggest $180^\circ/\Delta\psi$

NDMWG(MPSI)
integer parameter $n_{IM}(\psi_i)$: boundary update every $n_{IM}$
increment in age, function of $\psi_i = j\Delta\psi$, $j = 1$ to MPSI;
suggest $90^\circ/\Delta\psi$, for and aft, and $45^\circ/\Delta\psi$ on sides

DQWG(2)
incremental velocity criteria; suggest 0.04 $\lambda_1$ to 0.06 $\lambda_1$
(1) near wake elements defined by $|\Delta \phi| > DQWG(1)$
(2) integrate bound vortex line in time over
if $|\Delta \phi| > DQWG(2)$
NLWAKE

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

(1) IPR: print distortion before general update every $\text{IPR} \times \Delta \Psi$; $\text{EQ} 0$ to suppress

(2) INPS: print distortion after each iteration every $\text{INPS} \times \Delta \Psi$; $\text{EQ} 0$ to suppress; last iteration printed in full

QWGDB  parameter controlling debug level 3 print: induced velocity contribution of wake element printed if $|\Delta \Psi| > \text{QWGDB}$; 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)
IXX Ixx aircraft moments of inertia including rotors (slug-ft² or kg-m²)
IYY Iyy
IZZ Izz
IXY Ixy
IXZ Ixz
IYZ Iyz
TRATIO ratio of rotor #2 rotational speed to rotor #1 rotational speed, Ω₂/Ω₁ (transmission gear ratio r₁/r₂)
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 Θₐ (deg), positive rearward
  (1) rotor #1
  (2) rotor #2
ACANT(2) shaft cant angle φₐ (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 αₚ (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 Δψ₂ (deg); rotor #2 azimuth angle ψ₂ when rotor #1 azimuth angle ψ₁ = 0; must be 0 if Ω₂/Ω₁ ≠ 1.
CANTHT horizontal tail cant angle φₜ (deg), positive to left
CANTVT vertical tail cant angle φᵥ (deg), positive to right
location (fuselage station, butt line, and waterline) of aircraft components relative to a body fixed reference system having an arbitrary orientation and origin; fuselage station (FS) positive aft, butt line (BL) positive to right, and waterline (WL) positive up (ft or m)

FSCG

aircraft center of gravity location

BLCG

VLCG

FSR1

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

BLR1

WLR1

FSR2

rotor #2 hub location

BLR2

WLR2

FSWB

wing-body center of action

BLWB

WLWB

FSHT

horizontal tail center of action

BLHT

WLHT

FSVT

vertical tail center of action

BLVT

WLVT

FSOFF

wint off rotor disk (for induced velocity calculation)

BUFF

WUFF

¥noff rotor disk (for induced velocity calculation)

CNTRL2(11) control inputs (deg) for all sticks centered ($\frac{v_p}{p} = 0$):

$$\hat{\phi}^T = \left( \phi_0 \phi_{c1} \phi_{ls} \phi_0 \phi_{c1} \phi_{ls} \phi_f \phi_e \phi_a \phi_r \phi_t \right)^T$$

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

| $K_{OCFE}$ | $K_0$, collective stick to collective pitch |
| $K_{CCE}$ | $K_\psi$, lateral cyclic stick to cyclic or differential collective pitch |
| $K_{SCFE}$ | $K_s$, longitudinal cyclic stick to cyclic pitch |
| $K_{PCE}$ | $K_r$, pedal to tail rotor collective or differential cyclic pitch |
| $F_{CFE}$ | $\Delta \psi$, lateral cyclic stick to cyclic pitch (one rotor, or single main rotor and tail rotor configurations) |
| $P_{CFE}$ | $\Delta \psi_s$, longitudinal cyclic stick to cyclic pitch |
| $P_{PCF}$ | $\Delta \psi$, pedal to differential cyclic pitch (tilting proprotor configuration only) |

tandem main rotor configuration

| $K_{PCFE}$ | $K_{0F}$, collective stick to front collective pitch |
| $K_{RCE}$ | $K_{0R}$, collective stick to rear collective pitch |
| $K_{FCF}$ | $K_{FC}$, lateral cyclic stick to front cyclic pitch |
| $K_{RCF}$ | $K_{RC}$, lateral cyclic stick to rear cyclic pitch |
| $K_{SCF}$ | $K_{FS}$, longitudinal cyclic stick to front collective pitch |
| $K_{RCE}$ | $K_{RS}$, longitudinal cyclic stick to rear collective pitch |
| $K_{PCE}$ | $K_{FP}$, pedal to front cyclic pitch |
| $K_{PCE}$ | $K_{FR}$, pedal to rear cyclic pitch |
| $F_{FCF}$ | $\Delta \psi_{FC}$, lateral cyclic stick to front cyclic pitch |
| $F_{RCF}$ | $\Delta \psi_{RC}$, lateral cyclic stick to rear cyclic pitch |
| $F_{PCE}$ | $\Delta \psi_{FP}$, pedal to front cyclic pitch |
| $F_{PCE}$ | $\Delta \psi_{RP}$, pedal to rear cyclic pitch |

aircraft controls (all configurations)

<p>| $K_{CFE}$ | $K_f$, collective stick to flapern |
| $K_{TCE}$ | $K_t$, collective stick to throttle |
| $K_{ACE}$ | $K_a$, lateral cyclic stick to ailerons |
| $K_{CE}$ | $K_e$, longitudinal cyclic stick to elevator |
| $K_{RCE}$ | $K_r$, pedal to rudder |</p>
<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEM</td>
<td>Number of airframe modes for which data supplied; maximum 10</td>
</tr>
<tr>
<td>QMASS(NEM)</td>
<td>Generalized mass $M_k$ including rotors (slug or kg)</td>
</tr>
<tr>
<td>QFREQ(NEM)</td>
<td>Generalized frequency $\Omega_k$ (Hz)</td>
</tr>
<tr>
<td>QDAMP(NEM)</td>
<td>Structural damping $\xi_s$</td>
</tr>
<tr>
<td>QDAMPA(NEM)</td>
<td>Aerodynamic damping $F_{q_k \xi_k} = \frac{\delta(q_k/\frac{1}{2}v^2)\delta(\xi_k)}{q_0^2}$ (ft$^2$ or m$^2$)</td>
</tr>
<tr>
<td>QCNTRL4(NEM)</td>
<td>Control derivatives $F_{q_k \xi_k} = \frac{\delta(q_k/\frac{1}{2}v^2)\delta(\xi_k)}{q_0^2}$ (ft$^2$/rad or m$^2$/rad)</td>
</tr>
<tr>
<td>DOFSYM(NEM)</td>
<td>Integer vector designating type of mode: GT 0 for symmetric, LT 0 for antisymmetric; only required for flutter analysis with CFSYM NE 0</td>
</tr>
<tr>
<td>ZETAR1(3,NEM)</td>
<td>Linear mode shape $i_k$ at rotor #1 hub (ft/ft or m/m)</td>
</tr>
<tr>
<td>ZETAR2(3,NEM)</td>
<td>Linear mode shape $i_k$ at rotor #2 hub (ft/ft or m/m)</td>
</tr>
<tr>
<td>GAMAR1(3,NEM)</td>
<td>Angular mode shape $\psi_k$ at rotor #1 hub (rad/ft or rad/m)</td>
</tr>
<tr>
<td>GAMAR2(3,NEM)</td>
<td>Angular mode shape $\psi_k$ at rotor #2 hub (rad/ft or rad/m)</td>
</tr>
<tr>
<td>KPMCl(NEM)</td>
<td>Pitch/mast-bending coupling (rad/ft or rad/m)</td>
</tr>
<tr>
<td>KPMCl(NEM)</td>
<td>$K_{MC_k} = -\frac{\partial \Theta_{1c}}{\partial q_{sk}}$ for rotor #1</td>
</tr>
<tr>
<td>KPMSt(NEM)</td>
<td>$K_{MS_k} = -\frac{\partial \Theta_{1s}}{\partial q_{sk}}$ for rotor #1</td>
</tr>
<tr>
<td>KPMc2(NEM)</td>
<td>$K_{MC_k} = -\frac{\partial \Theta_{1c}}{\partial q_{sk}}$ for rotor #2</td>
</tr>
<tr>
<td>KPMs2(NEM)</td>
<td>$K_{MS_k} = -\frac{\partial \Theta_{1s}}{\partial q_{sk}}$ for rotor #2</td>
</tr>
</tbody>
</table>
Aircraft aerodynamic characteristics

**Wing-body**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Expression</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>LFTAW</td>
<td>$L_\alpha/q$</td>
<td>(ft²/rad or m²/rad)</td>
</tr>
<tr>
<td>LFTFW</td>
<td>$L_{6\phi}/q$</td>
<td>(ft²/rad or m²/rad)</td>
</tr>
<tr>
<td>LFTDW</td>
<td>$L_{\delta_f}/q$</td>
<td>(ft²/rad or m²/rad)</td>
</tr>
<tr>
<td>AMAXW</td>
<td>$\alpha_{\text{max}}$</td>
<td>(deg)</td>
</tr>
<tr>
<td>IWB</td>
<td>$\theta_{WB}$</td>
<td>(deg)</td>
</tr>
<tr>
<td>DRGW</td>
<td>$f_{\text{WB}} = D_0/q$</td>
<td>(ft² or m²)</td>
</tr>
<tr>
<td>DRGW</td>
<td>$f_{\text{vert}}^{-1} = (A(D_0/q)/A(L/q)^2)^{-1}$</td>
<td>(ft² or m²)</td>
</tr>
<tr>
<td>DRGW</td>
<td>$D_{0\delta_f}/q$</td>
<td>(ft²/rad or m²/rad)</td>
</tr>
<tr>
<td>DRGW</td>
<td>$D_{0\delta_f}/q$</td>
<td>(ft²/rad or m²/rad)</td>
</tr>
<tr>
<td>MCMOW</td>
<td>$M_0/q$</td>
<td>(ft³ or m³)</td>
</tr>
<tr>
<td>MOMAW</td>
<td>$M_{\alpha}/q$</td>
<td>(ft³/rad or m³/rad)</td>
</tr>
<tr>
<td>MCMFW</td>
<td>$M_{6\phi}/q$</td>
<td>(ft³/rad or m³/rad)</td>
</tr>
<tr>
<td>MOMDW</td>
<td>$M_{\delta_f}/q$</td>
<td>(ft³/rad or m³/rad)</td>
</tr>
<tr>
<td>SIDEB</td>
<td>$Y_{\phi}/q$</td>
<td>(ft²/rad or m²/rad)</td>
</tr>
<tr>
<td>SIDEP</td>
<td>$V_{Y_{p}}/q$</td>
<td>(ft³/rad or m³/rad)</td>
</tr>
<tr>
<td>SIDER</td>
<td>$V_{Y_{r}}/q$</td>
<td>(ft³/rad or m³/rad)</td>
</tr>
<tr>
<td>ROLLB</td>
<td>$N_{x_{\phi}}/q$</td>
<td>(ft³/rad or m³/rad)</td>
</tr>
<tr>
<td>ROLLP</td>
<td>$N_{x_{\phi}}/q$</td>
<td>(ft³/rad or m³/rad)</td>
</tr>
<tr>
<td>ROLLR</td>
<td>$V_{N_{p}}/q$</td>
<td>(ft⁴/rad or m⁴/rad)</td>
</tr>
<tr>
<td>ROLLA</td>
<td>$N_{x_{\delta_f}}/q$</td>
<td>(ft³/rad or m³/rad)</td>
</tr>
<tr>
<td>YAWB</td>
<td>$N_{z_{\phi}}/q$</td>
<td>(ft³/rad or m³/rad)</td>
</tr>
<tr>
<td>YAWP</td>
<td>$V_{N_{p}}/q$</td>
<td>(ft⁴/rad or m⁴/rad)</td>
</tr>
<tr>
<td>YAWR</td>
<td>$V_{N_{\delta_f}}/q$</td>
<td>(ft⁴/rad or m⁴/rad)</td>
</tr>
<tr>
<td>YAWA</td>
<td>$N_{z_{\delta_f}}/q$</td>
<td>(ft³/rad or m³/rad)</td>
</tr>
</tbody>
</table>

**Horizontal tail**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Expression</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>LFTAH</td>
<td>$L_\alpha/q$</td>
<td>(ft²/rad or m²/rad)</td>
</tr>
<tr>
<td>LFTEH</td>
<td>$L_{6\phi}/q$</td>
<td>(ft²/rad or m²/rad)</td>
</tr>
<tr>
<td>AMAXH</td>
<td>$\alpha_{\text{max}}$</td>
<td>(deg)</td>
</tr>
<tr>
<td>IHT</td>
<td>$\theta_{HT}$</td>
<td>(deg)</td>
</tr>
</tbody>
</table>

-55-
Vertical tail

$L_{\omega/q} \quad (ft^2/\text{rad} \text{ or } m^2/\text{rad})$

$L_{\omega x/q} \quad (ft^2/\text{rad} \text{ or } m^2/\text{rad})$

$\alpha_{\max} \quad \text{(deg)}$

$1_{VT} \quad \text{(deg)}$

Airframe interference

$\alpha = (\Delta \epsilon/ \Delta(L/q))^{-1} \quad (ft^2 \text{ or } m^2)$

$L_{HT} \quad \text{horizontal tail length} \quad \text{for } \epsilon \text{ (ft or m)}$

$h_{VT} \quad \text{vertical tail height} \quad \text{for } \sigma, \text{ positive up (ft or m)}$

OPTINT \quad \text{integer parameter controlling airframe/tail aerodynamic interference: EQ 0 to suppress } (\epsilon = 0 \text{ 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

IEENG engine rotational inertia $r_2^2$, for both engines if symmetric configuration (slug-ft$^2$ or kg-m$^2$)

drive train spring constants (ft-lb/rad or m-N/rad)

KMAST1 rotor #1 shaft, $K_{M1}$ or $K_M$
KMAST2 rotor #2 shaft, $K_{M2}$
KICS interconnect shaft, $r_{I2}^2K_I$ or $r_I^2K_I$
KENG engine shaft, $r_E^2K_E$

GSE engine shaft structural damping $g_s$ ($\Psi_e$ degree of freedom)

GSI interconnect shaft structural damping $g_s$ ($\Psi_i$ degree of freedom)

KEDAMP engine damping factor $K_e$; typically 1.0 for turboshaft engines, or 10.0 for induction electric motors

THRTLC $\Delta P/\Delta \Theta_t$ (dimensional), for both engines if symmetric configuration; if the throttle variable $\Theta_t$ is only used for the governor, just the products

$K_P \Delta P/\Delta \Theta_t = -\Delta P/\Delta \Psi_s$

$K_I \Delta P/\Delta \Theta_t = -\Delta P/\Delta \Psi_s$

must be correct ($P = \Omega_R \Omega_S = \Omega_{E2}$)

governor proportional feedback gains (sec)

KPGOVE to throttle, $K_P = -\Delta \Theta_t/\Delta \Psi_s$
KPGOV1 to rotor #1 collective, $K_P = \Delta \Theta/\Delta \Psi_S$
KPGOV2 to rotor #2 collective, $K_P = \Delta \Theta/\Delta \Psi_S$

governor integral feedback gains

KIGOVE to throttle, $K_I = -\Delta \Theta_t/\Delta \Psi_s$
KIGOV1 to rotor #1 collective, $K_I = \Delta \Theta/\Delta \Psi_S$
KIGOV2 to rotor #2 collective, $K_I = \Delta \Theta/\Delta \Psi_S$
governor time lag $\tau_1 = 2\, \bar{\gamma}/\omega_n$ (sec)

T1GOV  throttle
T1GOV1  rotor #1
T1GOV2  rotor #2

governor time lag $\tau_2 = 1/\omega_n^2$ (sec$^2$)

T2GOV  throttle
T2GOV1  rotor #1
T2GOV2  rotor #2
**Namelist NLOAD**

**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)

**BLVIB(MVIB)**
but line

**WLVIB(MVIB)**
waterline

**ZETAV(3,NEM,MVIB)**
linear mode shape \( \tilde{f}_n \) 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

**MWKGM(4)**
integer parameter controlling wake geometry printer plot; EQ 0 to suppress

1. top view
2. side view
3. back view
4. axial convection

**MWKGM**
number of azimuth stations at which wake geometry plotted; maximum 8; LE 0 for no plots

**JWKGM(MWKGM)**
azimuth stations at which wake geometry plotted \( (\psi = j\Delta \psi) \)
NLLOAD

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) off rotor

(5) $\alpha$
(6) $M$
(7) $A$
(8) $c_R$
(9) $c_d$
(10) $c_m$
(11) $c_d$radial
(12) $r$
(13) $u_p$
(14) $u_T$
(15) $u_R$
(16) $U$
(17) $\phi$
(18) lag
(19) flap
(20) $\alpha_{\text{eff}}$ lift
(21) $\alpha_{\text{eff}}$ drag
(22) $M_{\text{eff}}$ lift
(23) $M_{\text{eff}}$ moment
(24) $M_{\text{eff}}$ drag
(25) $M_{\text{eff}}$ moment
(26) $\lambda_x$
(27) $\lambda_y$
(28) $\lambda_z$
(29) interference $\lambda_x$
(30) $\lambda_y$
(31) $\lambda_z$
(32) $v_C$
(33) $v_C$
(34) $w_C$
(35) $L/c$
(36) $D/c$
(37) $M/c$
(38) $D_p/c$
(39) $F_x/c$
(40) $F_T/c$
(41) $F_z/c = C_T/V$
(42) $M_a/c$
(43) $F_r/c$

-60-
(45) not used
(46) not used
(47) not used
(48) \( C_{p}/\theta \)
(49) \( C_{p1}/\theta \)
(50) \( C_{pint}/\theta \)
(51) \( C_{p0}/\theta \)
(52) L
(53) D
(54) M
(55) \( D_{a} \)
(56) \( F_{z} \)
(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) \( P_{l} \)
(66) \( P_{int} \)
(67) \( F_{0} \)

(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 62-87
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 $f_T$
(3)  vertical shear $f_z$
(4)  flap moment $m_x$
(5)  lag moment $m_z$
(6)  control moment $m$

nonrotating frame hub loads
(7)  drag force $H$
(8)  side force $Y$
(9)  thrust $T$
(10)  roll moment $M_x$
(11)  pitch moment $M_y$
(12)  torque $Q$

section loads (principal axes)
(13)  chord shear $f_x$
(14)  axial shear $f_T$
(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 $S_E \leq 0$, or $C \leq 0$, to suppress damage fraction calculation; use $M \leq 0$, to suppress equivalent peak-to-peak load calculation as well
Far field rotational noise

MNOISE  number of microphones; maximum 10; LE 0 for no noise analysis

RANGE(MNOISE)  microphone range relative hub (ft or m)

ELVATN(MNOISE)  microphone elevation relative hub (deg), positive above rotor disk

AZMUTH(MNOISE)  microphone azimuth relative hub (deg), defined as for rotor azimuth

MHARMN(3)  number of harmonics
 (1) in noise calculation; maximum 500
 (2) in aerodynamic load harmonic analysis (suggest MPSI/3)
 (3) in print of noise (LE 0 for no print)

MTIMEN(3)  number of time steps (LE 0 to suppress)
 (1) in period of noise calculation; maximum 500
 (2) increment in noise print
 (3) increment in noise plot

AXS(MRA)  blade cross section area $A_{\epsilon\phi}$ 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

**OPSYM**
integer parameter: NE 0 for symmetric and antisymmetric analyses (tilting proprotor configuration only)

**OPFDAN**
integer parameter: EQ 0 to suppress flight dynamics analysis

**NBLIP**
integer parameter: EQ 1 for independent rotor blade analysis

**MPSIFC**
number of azimuth steps in period for nonaxial flow, periodic coefficient analysis (CPFLOW GT 0); \( \Delta \psi = \frac{360}{N_{\text{odd number of blades}}} \) for odd number of blades, \( \Delta \psi = \frac{720}{N_{\text{even number of blades}}} \)

**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): \( \Delta \psi = \frac{360 \, \text{deg}}{M} \)

**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

**OPUSLD**
integer parameter controlling use of unsteady lift and moment in flutter analysis: 0 to suppress; 1 to include; 2 for zero in stall (15° < \( \omega \) < 165°)

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

**OPPRINT**
integer parameter: EQ 0 to suppress rotor/body aerodynamic interference in flutter analysis

**OPGRND**
integer parameter controlling ground effect analysis: EQ 0 for out of ground effect, NE 0 for in ground effect

**KASGE**
factor for antisymmetric ground effect: 0. to suppress, 1.0 for unstable roll moment due to ground effect (tilting proprotor configuration only)

**OPSAS**
integer parameter controlling use of SAS: EQ 0 to suppress

**KCSAS**
lateral SAS gain \( K_c = \frac{\Delta \delta_c}{\Delta \phi_p} \) (deg/deg)

**KSSAS**
longitudinal SAS gain \( K_s = \frac{\Delta \delta_s}{\Delta \Theta_p} \) (deg/deg)

**TCSAS**
lateral SAS lead time \( T_{\text{c}} \) (sec)

**TSSAS**
longitudinal SAS lead time \( T_{\text{s}} \) (sec)
OPTORS(2) integer parameter: \( \text{EQ 0 for rigid pitch model (infinite control system stiffness, no } p_0 \text{ degree of freedom)} \)

(1) rotor #1
(2) rotor #2

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

rotor #1 \( \beta_0(1), \theta_0(1), \ldots, \theta_{n//2}(1), \beta_0(3), \theta_0(3), \ldots, \theta_{n//2}(3), \beta_0(5), \theta_0(5), \ldots, \theta_{n//2}(5) \)

rotor #2 \( \beta_0(10), \theta_0(10), \ldots, \theta_{n//2}(10), \beta_0(13), \theta_0(13), \ldots, \theta_{n//2}(13), \beta_0(15), \theta_0(15), \ldots, \theta_{n//2}(15) \)

bending pitch/torsion gimbal rotor inflow

airframe \( \delta_{\theta}, \delta_{\phi}, \delta_{\theta}, \delta_{\phi}, \delta_{\phi}, \delta_{\phi}, \delta_{\phi}, \delta_{\phi}, \delta_{\phi} \)

rigid body flexible engine governor

body (10) speed

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

rotor #1 \( \theta_0, \theta_1, \theta_2, \ldots, \theta_{n//2} \)

rotor #2 \( \theta_0, \theta_1, \theta_2, \ldots, \theta_{n//2} \)

pitch (8)

airframe \( \delta_{\phi}, \delta_{\phi}, \delta_{\phi}, \delta_{\phi} \)

pilot \( \delta_0, \delta_0, \delta_0, \delta_0 \)

GUS(3) integer vector defining gust components, 0 if not used; order: \( u_c, v_c, w_c \)

for a two-bladed rotor, \( \beta_{GC} \) is replaced by \( \beta_T \)

there are \( N_{\text{rotor}} \) rotor pitch control variables; except for a two-bladed rotor, which has the 4 variables \( \theta_0, \theta_1, \theta_1, \theta_1 \)
**LUT**

**ANTYPE(4)** integer parameter specifying tasks in linear system

- **(1)** eigenanalysis
- **(2)** transfer function printer-plot
- **(3)** time history printer-plot
- **(4)** rms gust response

**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)

**NBPLT**

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

**NXPLT**

number of degrees of freedom to be plotted; maximum 80

**NVPLT**

number of controls to be plotted; maximum 29

**NAMEXP(NXPLT)**

vector of variable names to be plotted (inconsistent names ignored)

**NAMEVP(NVPLT)**

vector of control names to be plotted (inconsistent names ignored)

**NDPLT**

frequency steps per decade

**NFOPLT**

exponent (base 10) of beginning frequency

**NF1PLT**

exponent (base 10) of end frequency

\[ \text{(maximum NF} = (\text{NF1PLT} - \text{NFOPLT}) \times \text{NDPLT} + 1 = 151) \]

**MSPLT**

magnitude plot scale: if 1, plot relative maximum value; if 2, plot relative 10^{-6}; if 3, plot relative 10.
**NLFLPT**

Time history printer-plot

**NTFLPT**
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

**PTFLPT**
period \( T \) for impulse or doublet (sec)

**DTFLPT**
time step (sec)

**TMAXPLT**
maximum time (sec); maximum \( N_{XPLT}*N_{VPLT}*T_{MXPLT}/D_{TPLT} = 7200 \)

**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: \( CT \) 0., dimensional length \( L \) (\( \tau_G = L/2V \)); \( EQ \) 0., set \( L = 400. \); \( LT \) 0., magnitude is dimensionless correlation time \( \tau_G \) (frequency \( \omega = \Omega/\tau_G \))

**MGUST(MG)**
real vector of gust component relative magnitudes

\[ MG = \text{number of gust components; maximum 3} \]

**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); \( 2/\text{rev used} \) if \( LT \) 0.; in same order as **NAMEA**

**MACC**
number of accelerometers; \( LE \) 0 for none; maximum 83

**FSACC**
fuselage station

**BLACC**
butt line

**WLACC**
waterline

**ZETACC(3,NEM)**
linear mode shape \( \tilde{Z}_k \) at point where body axis acceleration calculated

**NAMEXR(3)**
names of \( \beta_k, \xi_k, \) and \( \Theta \) in state vector; assumed that \( \beta_k, \xi_k, \) and \( \Theta \) follow immediately (inconsistent names ignored)
Variable names for linear system analysis

Degrees of freedom

1B1 \( \beta^{(1)}_{1} \beta^{(1)}_{2} \beta^{(1)}_{3} \ldots \beta^{(N)}_{N} \), bending - rotor #1

1B15

1T1 \( \theta^{(1)}_{1} \theta^{(1)}_{2} \theta^{(1)}_{3} \ldots \theta^{(N)}_{N} \), pitch/torsion

1T9

1BGc \( \beta_{GC} \), gimbal/teeter

1BGS \( \beta_{GS} \), rotor speed

PSIS \( \psi_{S} \), inflow

1LU \( \lambda_{u} \)

1LX \( \lambda_{x} \)

1LY \( \lambda_{y} \)

2B1 \( \beta^{(1)}_{1} \beta^{(1)}_{2} \beta^{(1)}_{3} \ldots \beta^{(N)}_{N} \), bending - rotor #2

2B15

2T1 \( \theta^{(1)}_{1} \theta^{(1)}_{2} \theta^{(1)}_{3} \ldots \theta^{(N)}_{N} \), pitch/torsion

2T9

2BGc \( \beta_{GC} \), gimbal/teeter

2BGS \( \beta_{GS} \), rotor speed

PSII \( \psi_{X} \), inflow

2LU \( \lambda_{u} \)

2LX \( \lambda_{x} \)

2LY \( \lambda_{y} \)

PHIF \( \phi_{F} \), rigid body

THIF \( \theta_{F} \)

PSIF \( \psi_{F} \)

XF \( x_{F} \)

YF \( y_{F} \)

ZF \( z_{F} \)

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Flexible body

Control variables

- \( \phi_k \) (\( k \geq 7 \))
- \( \psi_e \)
- \( \Delta \Theta_e \)
- \( \Delta \Theta_{gov} \)
- \( \Delta \Theta_{gov2} \)
- \( \Theta_0, \Theta_1, \Theta_5, \ldots, \Theta_{N/2} \) (rotors #1 and #2)
- \( \delta_x \)
- \( \delta_c \)
- \( \delta_a \)
- \( \delta_r \)
- \( \Theta_e \)
- \( \delta_0 \)
- \( \delta_c \)
- \( \delta_s \)
- \( \delta_p \)
- \( \delta_t \)
Gust components

UG \quad u_G
VG \quad v_G
WG \quad w_G

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

<table>
<thead>
<tr>
<th>CONFIG</th>
<th>BCC</th>
<th>BCC with configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>blank (left justified)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>M or T</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>F or R</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>R or L (CPSYM = 0)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>S or A (CPSYM ≠ 0)</td>
<td></td>
</tr>
</tbody>
</table>

For a two bladed rotor, BCC 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**

NPRNTF  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

OFLMDA  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)

DELSA  control and motion increment for stability derivative calculation (dimensionless)

DOF(7)  integer vector defining degrees of freedom, 0 if not used; order: $\phi_f, \theta_f, \psi_f, x_p, y_p, z_p, \psi_s$

CON(16)  integer vector defining control variables, 0 if not used; order:
  rotor #1 $\theta_o \theta_{1c} \theta_{1s}$
  rotor #2 $\theta_o \theta_{1c} \theta_{1s}$
  airframe $\delta_k \delta_o \delta_o \delta_r \theta_c$
  pilot $\delta_o \delta_o \delta_o \delta_p \delta_r$

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

CPPRT(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, $K_c = - \Delta \chi_c / \Delta \phi_f$ (deg/deg)

KSSAS  longitudinal SAS gain, $K_s = \chi_s / \theta_f$ (deg/deg)

TCSAS  lateral SAS lead time $\tau_c$ (sec)

TSSAS  longitudinal SAS lead time $\tau_s$ (sec)
EQTYPE(12) integer parameter specifying equations to be analyzed, EQ 0 to suppress
with \( \Psi \), with SAS
(1) complete
(2) symmetric
(3) antisymmetric
with \( \Psi \), without SAS
(4) complete
(5) symmetric
(6) antisymmetric
without \( \Psi \), with SAS
(7) complete
(8) symmetric
(9) antisymmetric
without \( \Psi \), 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

NSTEF 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

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

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

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

NXPLT number of degrees of freedom to be plotted; maximum 7

NVPLT number of controls to be plotted; maximum 19

NDPLT frequency steps per decade

NFOPLT exponent (base 10) of beginning frequency

NF1PLT exponent (base 10) of end frequency

(maximum NF = (NF1PLT - NFOPLT) * NDPLT + 1 = 151)

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

Time history printer-plot

NTPLT 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

NXFLT number of degrees of freedom to be plotted; maximum 7

NVFLT number of controls to be plotted; maximum 19

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

NAMEVP(NVFLT) 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 \(\tau_G^*\) (frequency \(\omega = \Omega/\tau_G^*\))

MGUST(MG) real vector of gust component relative magnitudes

\[ MG = \text{number of gust components}, \text{ maximum 3} \]
**NLSTAB**

- **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.

- **FSACC**: fuselage station.

- **BLACC**: butt line.

- **WLACC**: waterline.

- **TSTEP**: numerical integration of transient 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:

  \[ \Theta_x, \Theta_y, \theta_x, \theta_y, z_x, z_y, \dot{\theta}_x, \dot{\theta}_y, \ddot{x}, \ddot{y}, \dddot{x}, \dddot{y} \]

- **OPTRAN**: see namelist NLTRAN.

- **CTIME**, **CMAG(5)**, **CTIME**, **GMAG(3)**, **GDIST(2)**, **VELG**, **PSIG**, **OPGUST(3)**
Variable names for linear system analysis

<table>
<thead>
<tr>
<th>Degrees of freedom</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PHIF</td>
<td>$\phi_F$</td>
<td>rigid body</td>
</tr>
<tr>
<td>THTH</td>
<td>$\theta_F$</td>
<td></td>
</tr>
<tr>
<td>PSIF</td>
<td>$\psi_F$</td>
<td></td>
</tr>
<tr>
<td>XF</td>
<td>$x_F$</td>
<td></td>
</tr>
<tr>
<td>YF</td>
<td>$y_F$</td>
<td></td>
</tr>
<tr>
<td>ZF</td>
<td>$z_F$</td>
<td></td>
</tr>
<tr>
<td>PSIS</td>
<td>$\psi_S$</td>
<td>rotor speed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Control variables</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1C0</td>
<td>$\omega_0$</td>
<td>rotor #1</td>
</tr>
<tr>
<td>1C1C</td>
<td>$\omega_{1c}$</td>
<td></td>
</tr>
<tr>
<td>1C1S</td>
<td>$\omega_{1s}$</td>
<td></td>
</tr>
<tr>
<td>2C0</td>
<td>$\omega_0$</td>
<td>rotor #2</td>
</tr>
<tr>
<td>2C1C</td>
<td>$\omega_{1c}$</td>
<td></td>
</tr>
<tr>
<td>2C1S</td>
<td>$\omega_{1s}$</td>
<td></td>
</tr>
<tr>
<td>DELF</td>
<td>$\delta_F$</td>
<td>aircraft</td>
</tr>
<tr>
<td>DELE</td>
<td>$\delta_e$</td>
<td></td>
</tr>
<tr>
<td>DELA</td>
<td>$\delta_a$</td>
<td></td>
</tr>
<tr>
<td>DELR</td>
<td>$\delta_r$</td>
<td>pilot</td>
</tr>
<tr>
<td>CT</td>
<td>$\Theta_t$</td>
<td></td>
</tr>
<tr>
<td>DELO</td>
<td>$\delta_0$</td>
<td>pilot</td>
</tr>
<tr>
<td>DELC</td>
<td>$\delta_c$</td>
<td></td>
</tr>
<tr>
<td>DELS</td>
<td>$\delta_s$</td>
<td></td>
</tr>
<tr>
<td>DELP</td>
<td>$\delta_p$</td>
<td></td>
</tr>
<tr>
<td>DELT</td>
<td>$\delta_t$</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gust components</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>UG</td>
<td>$u_G$</td>
<td></td>
</tr>
<tr>
<td>VG</td>
<td>$v_G$</td>
<td></td>
</tr>
<tr>
<td>WG</td>
<td>$w_G$</td>
<td></td>
</tr>
</tbody>
</table>
For the rotor control names, the leading character (1 or 2) is replaced as follows, depending on the helicopter configuration:

<table>
<thead>
<tr>
<th>CONFIG</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>blank (left justified)</td>
<td>M or T</td>
<td>F or R</td>
<td>R or L</td>
</tr>
</tbody>
</table>

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

NPRNTL integer parameter controlling loads print; LE 0 to suppress

NRSTRT integer parameter n: restart file written only every n-th integration step; LE 0 to suppress

TSTEP time step in numerical integration (sec)

TMAX maximum time in numerical integration (sec)

ITERT number of wake influence coefficients/motion and forces iterations

CFLMDA 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)

DOP(7) integer vector defining degrees of freedom in numerical integration; EQ 0 to suppress acceleration; order: $\phi_F$, $\theta_F$, $\psi_F$, $x_F$, $y_F$, $z_F$, $\omega_S$

CFSAS integer parameter controlling use of SAS; EQ 0 to suppress

KCSAS lateral SAS gain, $K_C = -\Delta S_C/\Delta \phi_F$ (deg/deg)

KSSAS longitudinal SAS gain, $K_S = \Delta S_S/\Delta \theta_F$ (deg/deg)

TCSAS lateral SAS lead time $\tau_C$ (sec)

TSSAS longitudinal SAS lead time $\tau_S$ (sec)

OPPLOT integer parameter controlling printer plot of body motion; EQ 0 to suppress

DOPFLT(21) integer vector designating variables to be plotted; EQ 0 for not plotted; order:

$\phi_F$, $\theta_F$, $\psi_F$, $x_F$, $y_F$, $z_F$, $\phi_F$, $\theta_F$, $\psi_F$, $x_F$, $y_F$, $z_F$, $\phi_F$, $\theta_F$, $\psi_F$, $x_F$, $y_F$, $z_F$
Transient gust and control

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

**CTIME**
period T for control (sec)

**CMAG(5)**
control magnitude $\mathbf{v}_{P_0} = (\delta_0, \delta_c, \delta_b, \delta_p, \delta_v)^T$ (deg)

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

**CTIME**
period T for uniform gust (sec)

**CMAG(3)**
gust magnitude $\mathbf{v}_o = (u_G, v_G, w_G)^T$ (ft/sec or m/sec)

defines cosine uniform gust transient with period T and magnitude $\mathbf{v}_o$

**GDIST(2)**
lengths for convected gust (ft or m)

1. wavelength L
2. starting position $L_o$

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

**PSIG**
azimuth angle of convected gust wave front $\psi_g$ (deg)

**OPGUST(3)**
integer parameters defining convected gust model

1. EQ 0 to not use $V_g$
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 $\mathbf{v}_o$; for $L_o = R$ the wave starts at edge of rotor disk, for $L_o = 0$, 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, $C(x)$. The subroutines presently calculate a cosine-impulse gust:

\[
\begin{align*}
\text{CONTRL} & \quad C(t) = \frac{1}{2}(1 - \cos 2\pi t/T) \\
\text{GUSTU} & \quad G(t) = \frac{1}{2}(1 - \cos 2\pi t/T) \\
\text{GUSTC} & \quad G(x) = \frac{1}{2}(1 - \cos 2\pi (x - L_0)/L)
\end{align*}
\]

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
ANTYFi(4)
NSYSAN
NAMEXR(3)

Namelist NLSTAB
CPFRTT(4)
KCSAS
KSSAS
TCSAS
TSSAS
EQTYPE(12)
ANTYPE(5)
NSYSAN
NAMEXR(3)

Namelist NLTRAN
NFRNTT
NFRNTF
NFRNTL
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, \( q = \text{lb}/\text{ft}^2 \) or \( \text{N}/\text{m}^2 \)
      3) weight, \( C_w/\varpi = \text{lb} \) or \( \text{N} \)
      4) body motion = deg/sec, ft/sec or m/sec
      5) \( \ddot{\theta} = \text{ft}/\text{sec}^2 \) or \( \text{m}/\text{sec}^2 \)
      6) \( \dot{\varphi} = \text{rpm} \)

   b) body orientation and controls in deg

Circulation convergence:
   a) tolerance, CG/S in \( C_w/\varpi \) form
   b) G/E = ratio error to tolerance (\( \leq 1 \), if converged)

Motion convergence:
   a) tolerance, BETA (etc) in deg
   b) BETA/E (etc) = ratio error to tolerance (\( \leq 1 \), if converged)

Airframe performance: section 4.2.6
   a) aerodynamic loads: dimensional
   b) components
      1) angles in deg
      2) loads, q dimensional
      3) induced velocity, total velocity dimensionless

Gust velocity: dimensionless

System power:
   a) dimensional (HP); number in parentheses is percent total power
   b) climb power = \( V_c W \)
System efficiency parameters:

a) gross weight, \( W = 1 \text{b or N} \)
b) drag-rotor = \( D_r = (P_1 + P_0)/V \); \( D/q\)-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 LCADRI)

Print aerodynamics (function \( r \) and \( \Psi \))

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 1. city axes

Force/c mean (dimensionless):

\[
\begin{align*}
L/C & = \frac{1}{2} U^2 (c/c_{mean}) c_R = L/c_{mean} \\
D/C & = \frac{1}{2} U^2 (c/c_{mean}) c_d = D/c_{mean} \\
M/C & = \frac{1}{2} U^2 (c^2/c_{mean}) c_m = M/c_{mean} \\
D/C & = \frac{1}{2} U^2 (c/c_{mean}) c_{radial} = D_{radial}/c_{mean} \\
FZ/C & = C T/S = F_z/c_{mean} = d(c_T/\psi)/dr \\
F_X/C & = F_x/c_{mean} \\
MA/C & = M_a/c_{mean} \\
FR/C & = F_r/c_{mean} \\
FR/C & = F_r/c_{mean}
\end{align*}
\]
Forces (dimensional)

\[ L = \text{section lift (lb/ft or N/m)} \]
\[ D = \text{section drag (lb/ft or N/m)} \]
\[ M = \text{section pitch moment (ft-lb/ft or m-N/m)} \]
\[ DR = \text{section radial drag (lb/ft or N/m)} \]
\[ rZ = F_z = dT/dr \]
\[ FX = F_X \]
\[ MA = M_a \]
\[ FR = F_r \]
\[ FRT = F_{rt} \]

Blade section power: section 5.2.1

\[ CF/S = d(C_P)/dr \]
\[ P = \text{section power (HP/ft or HF/m)} \]

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) \( \dot{\omega} = \text{rpm} \)
4) \( \ddot{z}_r = \text{ft/sec}^2 \text{ or m/sec}^2 \)
5) controls = deg

\( c) \) generalized forces: moments and forces in \( \dot{\alpha}/\omega^2 \) form
(rotor #1 parameters, body axes); torque in \( -\dot{\alpha}\dot{\alpha}/\omega^2 \) form (rotor #1 parameters)

Print of Stability Derivatives (Program STABD)

Options:

a) rotor coefficient form, \( M^* = \dot{\alpha}/\omega^2 \)

b) stability derivative form, \( X \) (acceleration)

c) dimensionless or dimensional
Dimensions:

a) force or moment

<table>
<thead>
<tr>
<th>forces</th>
<th>moments</th>
<th>torque</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{1}{2}N_t\Omega^2/R$</td>
<td>$\frac{1}{2}N_b\Omega^2$</td>
<td>$N_t\Omega^2$</td>
</tr>
<tr>
<td>$\Omega_R$</td>
<td>$\Omega$</td>
<td>$\Omega$</td>
</tr>
<tr>
<td>(FF)</td>
<td>(FM)</td>
<td>(FQ)</td>
</tr>
</tbody>
</table>

b) subscripts

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

Print During Flight Dynamics Numerical Integration (Program STABP)

a) controls in deg

b) gust velocity: 1st number dimensionless, 2nd number dimensional

c) aircraft motion: 1st number dimensionless, 2nd number dimensional

1) displacement = deg, ft or m
2) velocity = deg/sec, ft/sec or m/sec
3) acceleration = deg/sec$^2$, g
4) inertial axes = deg/sec, g

Print Transient Solution (Program TRANP)

a) controls in deg

b) gust velocity dimensional

c) aircraft motion: 1st number dimensionless, 2nd number dimensional

1) displacement = deg, ft or m
2) velocity = deg/sec, ft/sec or m/sec
3) acceleration = deg/sec$^2$, g
4) inertial axes = deg/sec, g
d) generalized forces: moments and forces in $\mathbf{2C/v-a}$ form (rotor #1 parameters, body axes); torque in $-\mathbf{C/v-a}$ 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-1 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)
AERCT Interpolate airfoil tables
AERCPP Printer-plot airfoil aerodynamic characteristics

Namelist Label
NLITABL 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 NLITABL
5) For each radial station (CPREAD ≠ 0), either
   a) Namelist NLCHAR (CPREAD = 1)
   b) Airfoil table card deck (CPREAD = 2)

Sample jobs are presented below.

Create airfoil table using analytical expressions.

```plaintext
DDEF FT40FOO1,,AIRFOIL
CALL MAINPROG
title card
&NLITABL table data,NFAF=40,CPREAD=1,&END
&NLCHAR airfoil characteristics data,&END
&END
```

-87-
Create airfoil table using C81 format airfoil card deck

DDEF F14OF001,,AIRFOIL
CALL MAINPROG

**title card**

&NLTABL table data,NFAF=40,CPREAD=2,&END

* airfoil card deck

%END

Print and plot airfoil table data

DDEF F14OF001,,AIRFOIL
CALL MAINPROG

**blank card**

&NLTABL output data,NFAF=40,CPREAD=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 CPREAD EQ 0

**Namelist NLTABL**

angle of attack boundaries

- number of boundaries, N_a; maximum 20
- indices at boundaries, n_x
- at boundaries (deg, -180° to 180°)

Mach number boundaries

- number of boundaries, N_x; maximum 20
- indices at boundaries, n_x
- at boundaries (0. to 1.)

radial segments

- number of segments, N_r; maximum 10
- boundaries of segments (R(1)=0., R(NRB+1)=1.)
- maximum NAB*NMB*NRB = 5000
OPPRINT(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

NAPRNT Mach number values for print and plot

APRNT(NAPRNT) number of angle of attack values for print; maximum 60

WAF 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_0} at M = 0 (per rad) (default 5.7)

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

CLM A\cmax at M = 0 (default 1.2)

FSTALL factor f_s for c_{\text{max}} (default 0.5)

MSTALL Mach number M_s for c_{\text{max}} (default 0.4)

GSTALL factor g_s for stall c_d (default 1.2)

HSTALL factor h_s for stall c_d (default 0.4)

CLF c_{\text{max}} for stall c_d (default 1.12)

CMAC c_{\text{mac}} (default 0.)

CMS c_{\text{ms}} (default -0.07)

DEL0 \delta_0 (default 0.0084)

DEL1 \delta_1 (default -0.0102)

DEL2 \delta_2 (default 0.394)

DCDIM \delta_{c_d}/\delta M (default 0.65)

MCRIT critical Mach number at \alpha = 0 (default 0.80)

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

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

CDF c_{d_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 table
      NAL, number of angle of attack entries in c table
      NMD, number of Mach number entries in c table
      NAD, number of angle of attack entries in c table
      NMM, number of Mach number entries in c table
      NAM, number of angle of attack entries in c table

II. Lift Coefficient Table
   b) Card 2, format (7X,9F7.0); 2 or more cards if NML 10
      Mach numbers $M_1$ to $M_{NML}$
   c) Card 3a, format (F7.0,9F7.0)
      angle of attack, $\alpha_1$
      lift coefficients $c_\alpha$ at $M = M_1$ to $M_{NML}$ or $M_9$
   Card 3b, format (7X,9F7.0); 1 or more cards if NML 10
      lift coefficients $c_\alpha$ at $M = M_10$ to $M_{NML}$
   d) repeat card 3 for $\alpha = \alpha_1$ to $\alpha_{NAL}$

III. Drag Coefficient Table
   e-g) format as or lift coefficient table

IV. Moment Coefficient Table
   h-j) format as for lift coefficient table

V. Parameter Limits
   a) $M_1 = 0$; data extrapolated for $M > M_{NM}$; Mach numbers in sequential order
   b) $\alpha_1 = -180^\circ$, $\alpha_{NA} = 180^\circ$; angles of attack in sequential order
   c) $NM \geq 2$, $NA \geq 2$ for lift, drag, and moment
   d) $(NM+1)(NA+1) \leq 501$ for lift, 1101 for drag, 576 for moment
For GREAD = 1, the program calculates representative airfoil characteristics using the following expressions (refer to the accompanying figures).

A) Below stall

\[
c_{a} = \begin{cases} 
\frac{a}{\sqrt{1-M^2}} & M < M_{\text{div}} \\
\frac{a(1-M)/((1-M_{\text{div}})\sqrt{1-M^2_{\text{div}}})}{\left(1-M/\sqrt{(1-M_{\text{div}})\sqrt{1-M^2_{\text{div}}}}\right)} + \frac{(M-M_{\text{div}}-1)/(1-M_{\text{div}})} & H_{\text{div}} < M < M_{\text{crit}}^{+1} \\
\frac{a(1-M)/((1-M_{\text{div}})\sqrt{1-M^2_{\text{div}}})}{\left(1-M/\sqrt{(1-M_{\text{div}})\sqrt{1-M^2_{\text{div}}}}\right)} + \frac{(M-M_{\text{div}}-1)/(1-M_{\text{div}})} & M < M_{\text{div}}^{+1}
\end{cases}
\]

\[c_{\alpha} = c_{\alpha_{\alpha}}\]
\[c_{m} = c_{m_{\alpha}}\]
\[c_{d} = \delta_{0} + \delta_{1} \alpha + \delta_{2} \alpha^2 + \Delta c_{d}\]
\[\Delta c_{d} = \max (0, \delta_{2} \alpha^2 + \Delta c_{d})\]
\[M_{c} = \max (0, M_{\text{crit}} (1-\alpha_{\text{crit}}))\]

B) Stall angle

\[c_{\alpha_{s}} = c_{\alpha_{\text{max}}} \min \left(1, \frac{(1-M) + f_{s}(M-M_{s})}{1-M_{s}} \right)\]
\[\alpha_{s} = c_{\alpha_{s}} / c_{\alpha_{\alpha}}\]

C) Stalled lift \((|\alpha| > \alpha_{s})\)

\[c_{\alpha} = \text{sign}(\alpha) \max \left[\frac{(g_{s} \alpha_{s} - |\alpha|)c_{g_{s}} + (|\alpha| - \alpha_{s})h_{s}c_{g_{s}}}{g_{s} \alpha_{s} - \alpha_{s}}, \right.\]
\[\text{max} \left(h_{s}c_{\alpha_{s}}, c_{\alpha_{f}} \sin 2|\alpha|\right)\]
\[c_{\alpha} = c_{\alpha_{f}} \sin 2\alpha \quad \text{if} \quad |\alpha| > 45^0\]
D) Stalled moment ($|\alpha| > \alpha_s$)

$$c_m = \begin{cases} 
\text{sign}(\alpha) \frac{(60 - |\alpha|)c_{ms} + (|\alpha| - \alpha_s)^2 c_{mf}}{60 - \alpha_s} & |\alpha| < 60^\circ \\
\text{sign}(\alpha) \frac{(90 - |\alpha|)75c_{mf} + (|\alpha| - 60)c_{mf}}{30} & |\alpha| > 60^\circ 
\end{cases}$$

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

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

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

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

use effective angle of attack and account for moment axis shift

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

$$c_m = c_m + \left(\frac{1}{2} \cos \alpha_e\right)c_{\lambda} + \left(\frac{1}{2} \sin \alpha_e\right)c_d$$
a. Lift and drag information

Fig. 1.- Airfoil Characteristics
Fig. 1.- Concluded

b. Moment and lift curve slope

$c_m (\alpha = 90) = -\frac{1}{3} c_d (\alpha = 90)$