FPCAS3D User’s Guide: A Three Dimensional Full Potential Aeroelastic Program
Version 1.0

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Abstract

The FPCAS3D computer code has been developed for aeroelastic stability analysis of bladed disks such as those in fans, compressors, turbines, propellers, or propfans. The aerodynamic analysis used in this code is based on the unsteady three-dimensional full potential equation which is solved for a blade row. The structural analysis is based on a finite-element model for each blade. Detailed explanations of the aerodynamic analysis, the numerical algorithms, and the aeroelastic analysis are not given in this report. This guide can be used to assist in the preparation of the input data required by the FPCAS3D code. A complete description of the input data is provided in this report. In addition, six examples, including inputs and outputs, are provided.

Acknowledgments

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1. INTRODUCTION

This is a user's guide for the FPCAS3D computer code which was developed for aeroelastic stability analysis of bladed disks such as those found in compressors, turbines, propellers, or propfans. This guide will help the user in the preparation of the input data files required by the FPCAS3D code. Detailed explanations of the aerodynamic analysis, the numerical algorithms, and the aeroelastic analysis will not be given in this guide. Instead, the reader is directed to specific references that deal with each of these items. The FPCAS3D code was developed at the Structural Dynamics Branch at NASA Lewis Research Center. It is made available strictly as a research tool. Neither NASA Lewis Research Center, nor any individuals who have contributed to the development of the code, assume any liability resulting from the use of this code beyond research needs.

The aerodynamic analysis used in this code is based on the unsteady three-dimensional full potential equation. This equation is solved for a complete blade row or for a specified number of blade passages in a blade row. The structural analysis is based on a finite element model for each blade. Either a frequency domain or a time domain flutter analysis is possible.

2. ANALYSIS

Detailed descriptions of the aerodynamic and aeroelastic analyses can be found in Refs. 1 and 2. These references contain a full description of the full potential formulation including the governing equations and boundary conditions. The transformation of the equations to the computational plane and the subsequent discretization and solution of these equations is also described in detail. A finite volume approach is used to solve the full potential equation and a Newton-iteration method is used to solve the non-linear problem as a series of linear problems. Refs. 3 and 4, describe the extension of the analysis to arbitrary interblade phase angles. In Ref. 5, the combined pulse response and influence coefficient method is detailed.

3. DESCRIPTION OF CODE

The FPCAS3D code is written in FORTRAN. It was developed and is operational on the Cray YMP computer at NASA Lewis Research Center under the UNICOS operating system. It is also operational on the NAS Cray C-90 computer at NASA Ames Research Center under the UNICOS operating system. There are six different versions of the FPCAS3D code, as described in the following table.
Although the six versions have a lot of common code, each version has some unique features. A trade-off between the in-core storage requirement and the computational time requirement is possible for cases involving large number of blades (blade passages). For example, if large amount of in-core storage is available, then versions 2 and 5 would be preferred over versions 1 and 4 since these require lower amount of computational time.

**Features of the six versions of FPCAS3D**

<table>
<thead>
<tr>
<th>Version</th>
<th>Flutter Method</th>
<th>Feature(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>freq. domain</td>
<td>In-core storage requirement is reduced by swapping data to disk files.</td>
</tr>
<tr>
<td>2</td>
<td>freq. domain</td>
<td>All data storage is in-core, leading to large in-core storage requirements.</td>
</tr>
<tr>
<td>3</td>
<td>freq. domain</td>
<td>All data storage is in-core; one blade passage is used for in-phase blade motion calculations.</td>
</tr>
<tr>
<td>4</td>
<td>time domain</td>
<td>In-core storage requirement is reduced by swapping data to disk files.</td>
</tr>
<tr>
<td>5</td>
<td>time domain</td>
<td>All data storage is in-core, leading to large in-core storage requirements.</td>
</tr>
<tr>
<td>6</td>
<td>time domain</td>
<td>All data storage is in-core; one blade passage is used for in-phase blade motion calculations.</td>
</tr>
</tbody>
</table>

**4. DESCRIPTION OF INPUT DATA**

In addition to the selected version of the source code fpcas3d.f, three parameter definition files para1.f, para2.f, and para3.f are required. These are used to specify the problem-dependent array dimensions. Input data, modal structural data, and blade shape data required by the code are provided in the files fpcas3d.input, fpcas3d.mode.input, and fpcas3d.blade.input, respectively.
4.1 Parameter Definition Files: para1.f, para2.f, and para3.f

These files contain parameter definitions that are dependent on the size of the problem. These parameters are used to specify dimensions of arrays used within the code. The use of the parameter definition files eliminates the need to edit the source code for the purpose of changing array dimensions. The contents of the parameter definition files are transferred to the source code (at the time of compilation) by INCLUDE statements in the code. Each line in these files cannot be more than 72 characters in length. Each parameter definition file contains a single PARAMETER statement.

In file para1.f, three parameters IMX, JM, and KM are listed in the form shown below. These three parameters specify the maximum number of grid points in the streamwise, circumferential, and spanwise directions in each blade passage. The actual number of grid points used in a problem must be less than or equal to these maximum limits.

\[
\text{PARAMETER ( IMX=56, JM=11, KM=24 )}
\]

In file para2.f, three parameters NXPM, NRPM, and NNODEM are listed in the form shown below. NXPM and NRPM specify the maximum number of grid points on the blade surface in the chordwise and spanwise directions. NNODEM is the maximum number of all finite element grid points.

\[
\text{PARAMETER ( NXPM=21, NRPM=21, NNODEM=500 )}
\]

In file para3.f, the maximum number of blade passages (or blades) NFS is specified as shown below. The file para3.f is required only with versions 2, 4, and 5.

\[
\text{PARAMETER ( NFS=2 )}
\]

4.2 Input Data File: fpcas3d.input

This file contains the standard (unit 5) input that the FPCAS3D code requires. All input is read in free format using 'READ (5,*)' FORTRAN statements. Typically, each READ statement is used to read the values of many input variables. In such cases, the input values are separated by one or more blank spaces. If all the input values do not fit on a single line, they can be placed on several additional lines. No continuation character is required, but individual values cannot be split across lines. In the input file, the values of each set of input variables is preceded by a line containing the names of the variables. The code does not read these names of variables and these are included in the input
The input variables are described below in the order in which they are required in the input data file. Note that some input variables are required only in specific versions of FPCAS3D; the versions for which a particular variable is required are listed after the description.

variable: TITLE  
type: character variable of length 80  
description: job title  
versions: all

variable: IEXTR  
type: integer variable  
description: flowfield extrapolation scheme flag:  
*IEXTR=1 initial guess extrapolated linearly from previous two time levels  
*IEXTR=0 flowfield at previous time level used as initial guess  
versions: all

variable: INUM  
type: integer variable  
description: number of Newton sub-iterations to be performed at each time level  
versions: all

variable: INI  
type: integer variable  
description: initial flowfield flag:  
INI=0 assume initial flowfield to be uniform; generally used with NSTDY=0 to obtain a steady flowfield  
INI=1 read initial flowfield from restart files from unit 8; a restart file is written to unit 8 at the end of a steady run (NSTDY=0)  
versions: all

variable: MINF  
type: real variable  
description: Mach number of flow at inlet
versions: all

variable: ADV
type: real variable
description: advance ratio
versions: all

variable: BET3Q
type: real variable
description: blade setting angle at three-quarter span location (degrees)
versions: all

variable: SOMGA
type: real variable
description: in versions 1, 2, and 3,
for NSTDY=0, it is not used
for NSTDY=1, it is the vibration frequency of the blade
  non-dimensionalized by reference speed of sound and tip diameter of the blade
for NSTDY=2, it is the duration of the pulse motion of the blade
  non-dimensionalized by reference speed of sound and tip diameter of the blade

in versions 4, 5, and 6,
for NSTDY=0, it is not used
for NSTDY=2, it is used to specify initial velocity of the blades
  in conjunction with VELS(NBLADE) and FACTOR; refer to the source code of subroutine ELAS for details
versions: all; different meaning in versions 1-3 and 4-6

variable: NTMX
type: integer variable
description: total number of time steps
versions: all

variable: DTAU
type: real variable
description: time step non-dimensionalized by reference speed of sound and tip diameter of the blade
versions: all

variable: NBS
type: integer variable
description: number of blades (or blade passages)
versions: all, except versions 3 and 6, which are restricted to one blade (blade passage) or NBS=1

variable: NSTDY
type: integer variable
description: flag to indicate type of motion:
  NSTDY=0 for no elastic motion (rigid blades)
  NSTDY=1 for harmonic vibration (versions 1, 2, and 3)
  NSTDY=2 for pulse motion (versions 1, 2, and 3)
  NSTDY=2 for aeroelastic vibration motion (versions 4, 5, and 6)
versions: all

variable: FACTOR
type: real variable
description: scaling factor used to scale down the mode shape functions to prevent very large displacement of blades
versions: all

variable: ( IMOV(NBLADE), NBLADE = 1, NBS )
type: array of integer variables
description: blade motion flags:
  IMOV(NBLADE)=0 for blade to be held rigid
  IMOV(NBLADE)=1 for blade to be vibrated
versions: versions 1 and 2 only

variable: MOVEMODE
type: integer variable
description: index of mode to be used for blade vibration
versions: versions 1-3 only

variable: RHUB0
type: real variable
description: radius of hub as a fraction of tip diameter of blade
versions: all

variable: NMODE
type: integer variable
description: number of modes in aeroelastic calculation
versions: versions 4-6 only
variable: \( P_0 \)
  type: real variable
  description: reference pressure (psi)
  versions: versions 4-6 only

variable: \( A_0 \)
  type: real variable
  description: reference speed of sound (inch/sec)
  versions: versions 4-6 only

variable: \( \{ \text{OM}(\text{IM}), \text{IM} = 1, \text{NMODE} \} \)
  type: array of real variables
  description: natural frequency of vibration (Hz) for each mode
  versions: versions 4-6 only

variable: \( \{ \text{GM}(\text{IM}), \text{IM} = 1, \text{NMODE} \} \)
  type: array of real variables
  description: generalized mass for each mode
  versions: versions 4-6 only

variable: \( \{ \text{VELS}(\text{NBLADE}), \text{NBLADE} = 1, \text{NBS} \} \)
  type: array of real variables
  description: used to specify initial velocity of each blade in conjunction with SOMGA and FACTOR; refer to the source code of subroutine ELAS for details
  versions: versions 4-6 only

variable: \( \text{IAIRFL} \)
  type: integer variable
  description: flag for blade shape:
  \( \text{IAIRFL} = 0 \) to use the same chordwise thickness distribution at all spanwise locations on the blade; this thickness distribution is specified by \( \text{CHD16}(1) \) and the maximum thickness distribution in the spanwise direction is specified by \( \text{TMAX}(J) \)
  \( \text{IAIRFL} = 1 \) to use a thickness distribution array \( \text{TMPTTBL}(I,J) \)
  versions: all

variable: \( \{ \text{TMAX}(J), J = 1, 15 \} \)
  type: array of real variable
  description: spanwise maximum thickness distribution for \( \text{IAIRFL} = 0 \), non-dimensionalized by local chord length
4.3 Blade Shape Data File: fpcas3d.blade.input

This file contains the input required by the grid (mesh) generator. All versions of the FPCAS3D code require this blade shape data file and all the input values in it. Note that this file contains values for some input variables which have only one meaningful value. For example, the number of blade rows (NBLROW) must be one since the FPCAS3D code does not model more than one blade row. For such variables, values other than those specified in the description will lead to meaningless results. These variables are retained only to provide compatibility of input with other codes that utilize the same grid generator. All input values are read in free format from unit 4. The input variables are described below in the order in which they are required in the input file. The blade tip radius is used to non-dimensionalize all variables with length dimensions.

variable: IGEOM
type: integer variable
description: must be set to IGEOM=2

variable: NBLROW
type: integer variable
description: must be set to NBLROW=1

variable: ITHETA
type: integer variable
description: **must** be set to `ITHETA=1`

variable: `NINPTS`  
type: integer variable  
description: number of points in the inlet section; the inlet section consists of a region of the grid near the inlet boundary where the axial grid spacing is uniform; `NINPTS=0` is recommended

variable: `NEXPTS`  
type: integer variable  
description: number of points in the exit section; the exit section consists of a region of the grid near the exit boundary where the axial grid spacing is uniform; `NEXPTS=0` is recommended

variable: `NBLPTZ`  
type: integer variable  
description: number of points on the blade surface in the chordwise direction

variable: `NBLPTR`  
type: integer variable  
description: number of points on the blade surface in the spanwise direction

variable: `NBLPTT`  
type: integer variable  
description: number of points on the blade surface in the circumferential direction

variable: `ZINLET`  
type: real variable  
description: axial location of inlet boundary

variable: `ZEXIT`  
type: real variable  
description: axial location of exit boundary

variable: `RATIN`  
type: real variable  
description: ratio of axial spacing between adjacent grid lines from blade leading edge to the inlet boundary
<table>
<thead>
<tr>
<th>Variable</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RATEX</td>
<td>real</td>
<td>ratio of axial spacing between adjacent grid lines from blade trailing edge to the exit boundary</td>
</tr>
<tr>
<td>RATBB</td>
<td>real</td>
<td>must be set to RATBB=1.0</td>
</tr>
<tr>
<td>RATBLZ</td>
<td>real</td>
<td>ratio of axial spacing between adjacent grid lines on blade surface</td>
</tr>
<tr>
<td>RATBLR</td>
<td>real</td>
<td>ratio of radial spacing between adjacent grid lines on blade surface</td>
</tr>
<tr>
<td>RATBLT</td>
<td>real</td>
<td>ratio of circumferential spacing between adjacent grid lines on blade surface</td>
</tr>
<tr>
<td>PJkTTIP</td>
<td>real</td>
<td>ratio of radial spacing between adjacent grid lines from blade tip to outer boundary</td>
</tr>
<tr>
<td>NHUB</td>
<td>integer</td>
<td>number of points used to specify the shape of the hub</td>
</tr>
<tr>
<td>NTIP</td>
<td>integer</td>
<td>number of points used to specify the shape of the outer boundary</td>
</tr>
<tr>
<td>ZHUB(I)</td>
<td>real</td>
<td>array of real variables</td>
</tr>
<tr>
<td>ZHUB(I), I = 1, NHUB</td>
<td>array of real variables</td>
<td>axial locations of points used to specify the shape of the hub</td>
</tr>
</tbody>
</table>
variable: \( \text{RHub}(I), I = 1, \text{NHUB} \)
type: array of real variables
description: radial locations of points used to specify the shape of the hub

variable: \( \text{ZTip}(I), I = 1, \text{NHUB} \)
type: array of real variables
description: axial locations of points used to specify the shape of the outer boundary

variable: \( \text{RTip}(I), I = 1, \text{NHUB} \)
type: array of real variables
description: radial locations of points used to specify the shape of the outer boundary

variable: \( \text{NBLD} \)
type: integer variable
description: number of blades in the blade row

variable: \( \text{NBLPL} \)
type: integer variable
description: must be \( \text{NBLPL}=15 \)

variable: \( \text{NPPP} \)
type: integer variable
description: must be \( \text{NPPP}=15 \)

### 4.4 Blade Modal Structural Data File: fpcas3d.mode.input

This file contains the modal structural input data. All versions of the FPCAS3D code require this input file. This file includes the finite element grid point coordinates and the mode shape functions. Note that all this data is required even for steady calculations, although the mode shape functions are not actually used in the calculations. All input values are read in free format from unit 3. The input variables are described below in the order in which they are required in the input file.

variable: \( \text{NNODE} \)
type: integer variable
description: number of grid points (nodes) in the finite element model

variable: BET3Q0
type: real variable
description: blade setting angle at three-quarter span location (degrees) for the finite element model; if this differs from the value of BET3Q0 specified in fpcas3d.input, the finite element grid and mode shape functions will be rotated by the difference.

variable: (GRID0(JN,K), K = 1, 3 )
type: array of real variables
description: x, y, and z coordinates of each finite element grid point; a do loop is used to read these coordinates so that a new line is read for each new grid point:

DO 10 JN = 1, NNODE
    READ (3,*) ( GRID0(JN,K), K = 1, 3 )
10 CONTINUE

variable: NMODE
type: integer variable
description: number of mode shapes to be read

variable: JMODE
type: integer variable
description: index of mode shape to be read next

variable: (T1K(K), K = 1, 6 )
type: array of real variables
description: displacements and rotations of each finite element grid point; a triple do loop is used to read these coordinates so that a new line is read for each new grid point:

DO 30 IM = 1, NMODE
    READ (3,*) JMODE
    DO 20 IN = 1, NNODE
        READ (3,*) ( T1(K), K = 1, 6 )
        DO 10 K = 1, 3
            UN(IN,K) = T1(K)
10 CONTINUE
20 CONTINUE
30 CONTINUE

Note that rotations $T1K(4)$, $T1K(5)$, $T1K(6)$ are not used in the calculations.
5. EXAMPLES

In this section, some examples are presented. For each example, a brief description is given. The contents of the input file, parameter definition files, and output file are listed. A list of additional files created by the code is given. These examples are provided so that the user can verify the correct installation and operation of the code.

5.1 Example 1: F21 propfan — Steady flow

Description:
In this example, the steady flow around the F21 propfan is calculated using version 3 of the FPCAS3D code (Ref. 3). The propfan has 13 blades. For this steady calculation, only one blade passage is included in the calculations. The free-stream Mach number is 0.5, the advance ratio is 2.3 and the blade setting angle is 53 deg. The grid has 15 points on the blade surface in both the chordwise and spanwise directions; there are 11 points in the circumferential direction. A non-dimensional time step of 0.015 is used with 4 Newton sub-iterations at each time step. The code is run for a total of 600 time steps, which is sufficient to reach steady state.

para1.f:

```
PARAMETER ( IMX=56, JMX=11, KMX=24 )
```

para2.f:

```
PARAMETER ( NXPM=21, NRPM=21, NNODM=500 )
```

fpcas3d.input:

```
TITLE
F21 BLADE; STEADY RUN.
IEXTR INUM INI
 0  4  0
MINF 0.5
ADV BET3Q SOMGA
 2.3 54.01 2.0
NTMX DTAU
 600 0.015
NSTDY FACTOR
 0  0.0
RHUB0 0.45
IAIRFL 1
   ( ( TMPTBL(I,J), I = 1, 15 ), J = 1, 15 )
   0.00000  0.00896  0.01322  0.01584  0.01761
   0.01842  0.01866  0.01824  0.01721  0.01593
   0.01395  0.01169  0.00919  0.00685  0.00000
```
fpcas3d.blade.input:
**********************************************************************
* F21 blade configuration 1: naca 0016 blade section  (grdn12)
**********************************************************************
+igeom----nblrow---+itheta---+-------------------------------------+
 2 1 1
+ninpts--nexpts--nblptz--nblptr--nblptt-------------------------------------+
 0 0 15 15 11
+zinlet++zexit++-----------------------------------------------
-0.6 0.600
+ratin++ratex++ratbb++ratblz++ratblr++ratblt++rattip--
 1.15 1.15 1.0 1.0 1.0 1.0 1.0 1.10
************************************************************************
+nhub---ntip--------------------------------------------------+
 18 2
+-----------------------------------------------+
-0.60 -3000 -2500 -2250 -2125 -2000 -1750 -150
-1.250 -.10 -.075 -.05 -.025 .000 0.0250 0.0500
.200 0.6
0.450 0.450 0.450 0.450 0.450 0.450 0.450 0.450
0.450 0.450
+-----------------------------------------------+
-0.600 0.600
1.5 1.5
************************************************************************
+nbld----nblpl---nppp--------------------------------------------------+
 13 15 15
+-----------------------------------------------+

fpcas3d.mode.input:
NASTRAN MODEL
351
55.0 SETTING ANGLE
-0.122655E+01 -0.647716E+00 0.543327E+01
-0.958605E+00 -0.484295E+00 0.535619E+01
-0.695795E+00 -0.360734E+00 0.527894E+01

345 lines deleted for brevity
345 lines deleted for brevity

-0.382106E+02 -0.273933E+02 0.557676E+02
-0.165240E+03 0.220175E+03 -0.634772E+01
-0.385890E+02 -0.271691E+02 0.565569E+02

2
-0.506236E+00 0.205176E+01 0.925785E+00
-0.843569E+01 0.000000E+00 0.196907E+01
-0.491026E+00 0.186282E+01 0.585961E+00

345 lines deleted for brevity

0.285083E+02 0.365781E+02 -0.291558E+03
0.370969E+03 -0.331670E+03 -0.207886E+02
0.317514E+02 0.341807E+02 -0.296961E+03

3
0.185382E+00 -0.383809E+01 -0.329603E+01
0.131264E+02 0.000000E+00 -0.185722E+01
0.650755E-02 -0.332906E+01 -0.216637E+01

345 lines deleted for brevity

-0.158338E+03 -0.156232E+03 -0.852136E+03
0.530542E+03 -0.535735E+03 -0.147507E+02
-0.145571E+03 -0.164916E+03 -0.879521E+03

fpcas3d.output:

f21 blade; steady run.

iextr = 0
inum = 4
ini = 0
minf = 0.5000
adv = 2.3000
bet3q = 54.0100
ntmx = 600
dtau = 0.0150
ns = 1
nsdy = 0
somga = 2.0000
factor = 0.00000e+00
rhub0 = 0.45000e+00

((tpttbl(i,j), i = 1, 15), j = 1, 15):
0.00000e+00 0.89600e-02 0.1322e-01 0.1584e-01 0.1593e-01
0.1842e-01 0.1866e-01 0.1824e-01 0.1721e-01 0.1761e-01
0.1395e-01 0.1169e-01 0.9190e-02 0.6850e-02 0.00000e+00

39 lines deleted for brevity

0.00000e+00 0.89600e-02 0.1322e-01 0.1584e-01 0.1593e-01
0.1842e-01 0.1866e-01 0.1824e-01 0.1721e-01 0.1761e-01
0.1395e-01 0.1169e-01 0.9190e-02 0.6850e-02 0.00000e+00
from nast1, in degrees, dbet = 0.99000e+00
FROM NASTI, RTIP = 0.12016E+02
NT = 0 UNDEFORMED BLADE
IMAX = 48
JMAX = 11
KMAX = 24
ILE = 19
ITE = 33
JTIP = 15

FROM GRID:
XXLE, YYLE, ZZLE = -0.73255E-01 0.37500E+00 -0.17386E+00
XXTE, YYTE, ZZTE = 0.3851E-01 0.37500E+00 0.51349E-01
BETA =

0.52997E+02

NT = 1 NITER = 1 NBLOCK = 1
TSRES = 0.4798E-03 SDPHI = 0.2533E-03 SDPHDT = 0.2452E-13
NT = 1 NITER = 2 NBLOCK = 1
TSRES = 0.1406E-03 SDPHI = 0.3794E-04 SDPHDT = 0.2526E-01
NT = 1 NITER = 3 NBLOCK = 1
TSRES = 0.5819E-04 SDPHI = 0.9967E-05 SDPHDT = 0.2429E-01
NT = 1 NITER = 4 NBLOCK = 1
TSRES = 0.4355E-04 SDPHI = 0.3896E-05 SDPHDT = 0.2471E-01
NT = 1 NITER = 5 NBLOCK = 1
TSRES = 0.3764E-04 SDPHI = 0.2171E-05 SDPHDT = 0.2466E-01
NT = 2 NITER = 1 NBLOCK = 1
TSRES = 0.6588E-03 SDPHI = 0.4032E-03 SDPHDT = 0.8229E-02
NT = 2 NITER = 2 NBLOCK = 1
TSRES = 0.2292E-03 SDPHI = 0.5650E-04 SDPHDT = 0.3243E-01
NT = 2 NITER = 3 NBLOCK = 1
TSRES = 0.1190E-03 SDPHI = 0.1481E-04 SDPHDT = 0.3141E-01
NT = 2 NITER = 4 NBLOCK = 1
TSRES = 0.1123E-03 SDPHI = 0.4934E-05 SDPHDT = 0.3191E-01
NT = 2 NITER = 5 NBLOCK = 1
TSRES = 0.1081E-03 SDPHI = 0.2516E-05 SDPHDT = 0.3187E-01

20 lines deleted for brevity

NT = 5 NITER = 1 NBLOCK = 1
TSRES = 0.5580E-03 SDPHI = 0.3959E-03 SDPHDT = 0.1331E-01
NT = 5 NITER = 2 NBLOCK = 1
TSRES = 0.3474E-03 SDPHI = 0.3869E-04 SDPHDT = 0.2824E-01
NT = 5 NITER = 3 NBLOCK = 1
TSRES = 0.2998E-03 SDPHI = 0.9625E-05 SDPHDT = 0.2878E-01
NT = 5 NITER = 4 NBLOCK = 1
TSRES = 0.3165E-03 SDPHI = 0.2998E-05 SDPHDT = 0.2878E-01
NT = 5 NITER = 5 NBLOCK = 1
TSRES = 0.3171E-03 SDPHI = 0.1357E-05 SDPHDT = 0.2876E-01
NT = 596 NITER = 1 NBLOCK = 1
TSRES = 0.3911E-03 SDPHI = 0.4608E-04 SDPHDT = 0.1585E-02
NT = 596 NITER = 2 NBLOCK = 1
TSRES = 0.3882E-03 SDPHI = 0.2710E-05 SDPHDT = 0.3065E-02
NT = 596 NITER = 3 NBLOCK = 1
TSRES = 0.3881E-03 SDPHI = 0.2011E-05 SDPHDT = 0.3128E-02
NT = 596 NITER = 4 NBLOCK = 1
TSRES= 0.3881E-03  SDPHI= 0.1898E-05  SDPHDT= 0.3156E-02
NT=  596  NITER=  5  NBLOCK=  1
TSRES= 0.3881E-03  SDPHI= 0.1906E-05  SDPHDT= 0.3167E-02
NT=  597  NITER=  1  NBLOCK=  1
TSRES= 0.3911E-03  SDPHI= 0.4608E-04  SDPHDT= 0.1585E-02
NT=  597  NITER=  2  NBLOCK=  1
TSRES= 0.3882E-03  SDPHI= 0.2710E-05  SDPHDT= 0.3065E-02
NT=  597  NITER=  3  NBLOCK=  1
TSRES= 0.3881E-03  SDPHI= 0.2011E-05  SDPHDT= 0.3128E-02
NT=  597  NITER=  4  NBLOCK=  1
TSRES= 0.3881E-03  SDPHI= 0.1898E-05  SDPHDT= 0.3156E-02
NT=  597  NITER=  5  NBLOCK=  1
TSRES= 0.3881E-03  SDPHI= 0.1906E-05  SDPHDT= 0.3167E-02

20 lines deleted for brevity

NT=  600  NITER=  1  NBLOCK=  1
TSRES= 0.3911E-03  SDPHI= 0.4608E-04  SDPHDT= 0.1585E-02
NT=  600  NITER=  2  NBLOCK=  1
TSRES= 0.3882E-03  SDPHI= 0.2710E-05  SDPHDT= 0.3065E-02
NT=  600  NITER=  3  NBLOCK=  1
TSRES= 0.3881E-03  SDPHI= 0.2011E-05  SDPHDT= 0.3128E-02
NT=  600  NITER=  4  NBLOCK=  1
TSRES= 0.3881E-03  SDPHI= 0.1898E-05  SDPHDT= 0.3156E-02
NT=  600  NITER=  5  NBLOCK=  1
TSRES= 0.3881E-03  SDPHI= 0.1906E-05  SDPHDT= 0.3167E-02

( DCP(I), I = ILE, ITE ) AT K= 1
0.50523 0.94608 0.49758 0.24279 0.18446 0.27816 0.42450 0.50458
0.51120 0.49922 0.45464 0.39515 0.33983 0.19294 0.03824

( DCP(I), I = ILE, ITE ) AT K= 2
0.43516 0.90902 0.60486 0.32275 0.21749 0.23740 0.32999 0.41966
0.45192 0.44854 0.42934 0.40964 0.38214 0.22690 0.04801

( DCP(I), I = ILE, ITE ) AT K= 3
0.49104 1.00176 0.65260 0.36266 0.21294 0.18232 0.23174 0.30336
0.35915 0.38760 0.37711 0.38245 0.43182 0.30880 0.07740

27 lines deleted for brevity

( DCP(I), I = ILE, ITE ) AT K= 13
0.33858 0.72652 0.61339 0.50796 0.41355 0.33068 0.26322 0.21754
0.19731 0.20548 0.24470 0.30255 0.33105 0.26673 0.09651

( DCP(I), I = ILE, ITE ) AT K= 14
0.35668 0.76914 0.63041 0.47572 0.35963 0.27900 0.22954 0.19830
0.18412 0.19070 0.22373 0.28769 0.32011 0.22165 0.04536

( DCP(I), I = ILE, ITE ) AT K= 15
0.00000 0.00636 0.00954 0.01602 0.01243 0.01265 0.01304 0.01332
0.01334 0.01308 0.01323 0.01421 0.01540 0.01585 0.01140

POWER COEFFICIENT : 0.12514E+01
THRUST COEFFICIENT : 0.41645E+00
EFFICIENCY : 0.76541E+00

CP-STAR= -0.21334E+01
5.2 Example 2: F21 propfan — Frequency Domain Flutter

Description:
In this example, frequency domain flutter calculations are performed for the F21 propfan blade (Ref. 3). For this flutter calculation, only in-phase (zero interblade phase angle) motion is considered. Only one blade passage is included in the calculations. Version 3 of the FPCAS3D code is used. The steady flow conditions and the grid used are the same as in example 1. As for the steady case, a non-dimensional time step of 0.015 is used with 4 Newton sub-iterations at each time step. The blade is moved in a pulse motion in the first mode. The non-dimensional duration of the pulse is 1.5 and calculations are continued until a non-dimensional time of 4.5 (total of 300 time steps).

For this example, additional post-processing of the results from FPCAS3D is required. The pulse response method is used to calculate the generalized aerodynamic forces required for flutter calculations. The post-processing code rootsfp.f incorporates this calculation together with a flutter calculation. A shell script links the output files from FPCAS3D with the appropriate unit numbers that are used to read these files in rootsfp.f. The input and output of rootsfp.f are also included in this section.

FPCAS3D must be run as many times as the number of modes in the flutter calculation. In this example, three modes are used and FPCAS3D is run thrice, for MOVEMODE=1, 2, and 3 respectively. The input and output files for the second and third runs are not listed here.

An additional post-processing code influnce.f implements only the pulse response method with no flutter calculation. This code can be used to generate the variation of generalized aerodynamic (force) coefficients for different vibration frequencies. Sample input and output for influnce.f are included in this section.

para1.f:

```
PARAMETER ( IMX=56, JMx=11, KMX=24 )
```

para2.f:

```
PARAMETER ( NXPM=21, NRPM=21, NNODM=500 )
```
fpcas3d.input:

TITLE
F21 BLADE; UNSTEADY RUN.
IEXTR INUMINI
0 4 1
MINF
0.5
ADV BET3Q SOMGA
2.3 54.01 1.5
NTMX DTAU
300 0.015
NSTDY FACTOR
2 2.0E-05
MOVEMODE
1
RHUB0
0.45
IAIRFL
1
( ( TMPTTBL(I,J), I = 1, 15 ), J = 1, 15 )
0.00000 0.00896 0.01322 0.01584 0.01761
0.01842 0.01866 0.01824 0.01721 0.01593
0.01395 0.01169 0.00919 0.00685 0.00000
* 39 lines deleted for brevity
* 0.00000 0.00896 0.01322 0.01584 0.01761
0.01842 0.01866 0.01824 0.01721 0.01593
0.01395 0.01169 0.00919 0.00685 0.00000

fpcas3d.blade.input:
same as in example 1

fpcas3d.mode.input:
same as in example 1

fpcas3d.output:

F21 BLADE; UNSTEADY RUN.

IEXTR = 0
INUM = 4
INI = 1
MINF = 0.5000
ADV = 2.3000
BET3Q = 54.0100
NTMX = 300
DTAU = 0.0150
NBS = 1
NSTDY = 2
SOMGA = 1.5000
FACTOR = 0.20000E-04
RHUB0 = 0.45000E+00
( ( TMPTTBL(I,J), I = 1, 15 ), J = 1, 15 ):
0.000E+00 0.8960E-02 0.1322E-01 0.1584E-01 0.1761E-01
FROM NASTI, IN DEGREES, DBET = 0.99000E+00
FROM NASTI, RTIP = 0.12016E+02

NT = 0 UNDEFORMED BLADE
IMAX = 48
JMAX = 11
KMAX = 24
ILE = 19
ITE = 33
JTIP = 15

FROM GRID:
XXLE, YYLE, ZZLE = -0.73255E-01 0.37500E+00 -0.17386E+00
XXTE, YYTE, ZZTE = 0.38571E-01 0.37500E+00 0.51349E-01
BETA = 0.52997E+02

NBLOCK = 1
NT = 1 DEFORMED BLADE
NT = 1 NITER = 1 NBLOCK = 1
TSRES = 0.3911E-03 SDPHI = 0.4604E-04 SDPHDT = 0.1585E-02
NT = 1 NITER = 2 NBLOCK = 1
TSRES = 0.3882E-03 SDPHI = 0.2709E-05 SDPHDT = 0.3061E-02
NT = 1 NITER = 3 NBLOCK = 1
TSRES = 0.3881E-03 SDPHI = 0.2011E-05 SDPHDT = 0.3124E-02
NT = 1 NITER = 4 NBLOCK = 1
TSRES = 0.3881E-03 SDPHI = 0.1898E-05 SDPHDT = 0.3152E-02
NT = 1 NITER = 5 NBLOCK = 1
TSRES = 0.3881E-03 SDPHI = 0.1906E-05 SDPHDT = 0.3163E-02
NT = 2 NITER = 1 NBLOCK = 1
TSRES = 0.3911E-03 SDPHI = 0.4598E-04 SDPHDT = 0.1583E-02
NT = 2 NITER = 2 NBLOCK = 1
TSRES = 0.3881E-03 SDPHI = 0.2708E-05 SDPHDT = 0.3057E-02
NT = 2 NITER = 3 NBLOCK = 1
TSRES = 0.3881E-03 SDPHI = 0.2011E-05 SDPHDT = 0.3119E-02
NT = 2 NITER = 4 NBLOCK = 1
TSRES = 0.3881E-03 SDPHI = 0.1898E-05 SDPHDT = 0.3148E-02
NT = 2 NITER = 5 NBLOCK = 1
TSRES = 0.3881E-03 SDPHI = 0.1906E-05 SDPHDT = 0.3159E-02

70 lines deleted for brevity

NT = 300 NITER = 1 NBLOCK = 1
TSRES = 0.3911E-03 SDPHI = 0.4608E-04 SDPHDT = 0.1585E-02
NT = 300 NITER = 2 NBLOCK = 1
TSRES = 0.3882E-03 SDPHI = 0.2710E-05 SDPHDT = 0.3065E-02
NT = 300 NITER = 3 NBLOCK = 1
additional output files:

- fort.53-57: time history of residuals
- fort.60: time history of blade motion (displacement)
- fort.61: time history of generalized forces on blade

rootsfp input:

```
rootsfp input:
F21 DATA
  A0    P0
  13341.0  14.7
  ADV    MINF    RTIP    BET3Q
  2.30    0.5    12.02    54.01
  NMODE    NBS    NOM
  3    1    2
  GM(1)    OM(1)
  1.0    287.05
  GM(2)    OM(2)
  1.0    480.27
  GM(3)    OM(3)
  1.0    798.40

STRDAMP
  0.0
FREQ(IOM), IOM=1,NOM
  400.0  550.0
```

In the above, RTIP is calculated by FPCAS3D from the finite element grid. NOM is the number of frequencies to be used in the root-finding algorithm; these frequencies are input as (FREQ(IOM), IOM = i, NOM) in Hz. STRDAMP is the amount of structural damping.

rootsfp output:

```
*****************************************
*  Aeroelastic stability analysis    *
*  using normal mode structural model *
*  in FREQUENCY DOMAIN               *
*  with Full Potential aerodynamic model *
*****************************************
+++
+ atmospheric conditions
+ pressure=14.69999999999999
+ speed of sound (in/sec)=13341.
+ density=1.156294878589626E-7
+++
+ operating conditions:
+ rotor speed(rpm)=7238.479346017411
+ rotor speed(rad/sec)=758.0117845536552
```
Mach no. = 0.5
advance ratio (J) = 2.299999999999997
* tip radius (inches) = 12.01999999999998
setting angle (deg.) = 54.00999999999999

---

analysis for 1 angles:
analysis using 3 modes:

structural model

<table>
<thead>
<tr>
<th>mode</th>
<th>freq(hz)</th>
<th>gen. mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>287.05</td>
<td>0.1000E+01</td>
</tr>
<tr>
<td>1</td>
<td>2.38</td>
<td>0.4980E+04</td>
</tr>
<tr>
<td>2</td>
<td>480.27</td>
<td>0.1000E+01</td>
</tr>
<tr>
<td>2</td>
<td>3.98</td>
<td>0.4980E+04</td>
</tr>
<tr>
<td>3</td>
<td>798.40</td>
<td>0.1000E+01</td>
</tr>
<tr>
<td>3</td>
<td>6.62</td>
<td>0.4980E+04</td>
</tr>
</tbody>
</table>

analysis using 2 frequencies.

iom, om(iom), freq(hz):
1 0.45288E+01 0.40000E+03
2 0.62271E+01 0.55000E+03

movemode index = 1

READING MOTION FILE
101 LINES IN MOTION FILE
DELT = 1.500000000000001E-2

READING FORCE FILE(S)
301 LINES IN FORCE FILE(S)

frequency = 4.528829166767025

phase index, mode index = 2*1 qij =
-0.22916E+04 -0.43129E+04
phase index, mode index = 1, 2 qij =
-0.83328E+03 -0.13443E+03
phase index, mode index = 1, 3 qij =
-0.17969E+04 -0.16630E+04
frequency = 6.227140104304652

phase index, mode index = 2*1 qij =
-0.14897E+04 -0.56636E+04
phase index, mode index = 1, 2 qij =
-0.93960E+03 -0.19414E+03
phase index, mode index = 1, 3 qij =
-0.18292E+04 -0.23948E+04

several lines deleted for brevity

$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
eigensolution for ip = 1
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

several lines deleted for brevity

several lines deleted for brevity
all eigenvalues (hz):
1  -0.19683E+02  0.75246E+03
2  -0.23742E+02  0.46901E+03
3  -0.17579E+02  0.30348E+03

root 2 is closest to center of interpolation

influence input and output:

enter movemode number
1
ENTER NUMBER OF BLADES IN CALCULATION.
1
ENTER INDEX OF BLADE THAT WAS MOVED.
1
ENTER NUMBER OF MODES IN CALCULATION.
3

READING MOTION FILE
101 LINES IN MOTION FILE
DELT = 1.500000000000001E-2

READING FORCE FILE(S)
301 LINES IN FORCE FILE(S)

WORKING . . .

DONE !!

The above execution of influence code results in a file movemode_1.fort81, which contains some of the generalized aerodynamic coefficients. To obtain all the generalized aerodynamic coefficients, the influence code must be executed two more times with movemode number input as 2 and 3. These two runs will result in two additional files movemode_2.fort81 and movemode_3.fort81 being created, which contain the remaining generalized aerodynamic coefficients.

5.3 Example 3: F21 propfan — Time Domain Flutter

Description:
In this example, time domain flutter calculations are performed for the F21 propfan blade (Ref. 4). For this flutter calculation, only in-phase motion is considered. Only one blade passage is included in the calculations. Version 6 of the FPCAS3D code is used. The steady flow conditions and the grid used are the same as in example 1, except that the advance ratio is 2.7. A steady solution is obtained, first as in example 1. Then, a time domain flutter calculation is performed. As before, a non-dimensional time step of 0.015 is used with 4 Newton sub-iterations at each time step. The blade is given a small initial velocity in each mode. The calculations are continued until a non-dimensional time of 15.0 (total of 1000 time steps).
para1.f:
PARAMETER ( IMX=56, JMX=11, KMX=24 )

para2.f:
PARAMETER ( NXPM=21, NRPM=21, NNODM=500 )

fpcas3d.input:
TITLE
F21 BLADE; TIME DOMAIN FLUTTER RUN.
IEXTR INUM INI
0  4  1
MINF
0.5
ADV BET3Q SOMGA
2.7  54.01  1.5
NTMX DTAU
1000  0.015
NSTDY FACTOR
2  2.0E-05
RHUB0
0.45
P0 A0
14.7  13341.0
NMODE
3
( OM(IM), IM = 1, NMODE )
287.05  480.27  798.40
( GM(IM), IM = 1, NMODE )
1.0  1.0  1.0
IAIRFL
1
( ( TMPTTBL(I,J), I = 1, 15 ), J = 1, 15 )
0.00000  0.00896  0.01322  0.01584  0.01761
0.01842  0.01866  0.01824  0.01721  0.01593
0.01395  0.01169  0.00919  0.00685  0.00000

- 39 lines deleted for brevity -

0.00000  0.00896  0.01322  0.01584  0.01761
0.01842  0.01866  0.01824  0.01721  0.01593
0.01395  0.01169  0.00919  0.00685  0.00000

fpcas3d.blade.input:
same as in example 1

fpcas3d.mode.input:
same as in example 1

fpcas3d.output:
F21 BLADE; TIME DOMAIN FLUTTER RUN
IEXTR = 0
INUM = 4
INI = 1
MINF = 0.5000
ADV = 2.7000
BET3Q = 54.0100
NTMX = 1000
DTAU = 0.0150
NBS = 1
NSTDY = 2
SOMGA = 1.5000
FACTOR = 0.20000E-04
RHUB0 = 0.45000E+00
P0, A0 :
0.1470E+02 0.1334E+05
NMODE = 3
CM(IM), IM = 1, NMODE :
0.2870E+03 0.4803E+03 0.7984E+03
CM(IM), IM = 1, NMODE :
0.1000E+01 0.1000E+01 0.1000E+01
( ( TMPTTBL(I,J), I = 1, 15 ), J = 1, 15 ): 
0.0000E+00 0.8960E-02 0.1322E-01 0.1584E-01 0.1761E-01
0.1842E-01 0.1866E-01 0.1824E-01 0.1721E-01 0.1593E-01
0.1395E-01 0.1169E-01 0.9190E-02 0.6850E-02 0.0000E+00
FROM NAST1, IN DEGREES, DBET=

FROM NAST1, RTIP= 0.12016E+02
NT= 0 UNDEFORMED BLADE
IMAX = 48
JMAX = 11
KMAX = 24
ILE = 19
ITE = 33
JTIP = 15
FROM GRID:
XXLE, YYLE, ZZLE =
-0.73255E-01 0.37500E+00 -0.17386E+00
XXTE, YYTE, ZZTE =
0.38571E-01 0.37500E+00 0.51349E-01
BETA = 0.52997E+02
NT= 1 NITER= 1 NBLOCK= 1
TSRES= 0.1175E-03 SDPHI= 0.5442E-05 SDPHDT= 0.1834E-03
NT= 1 NITER= 2 NBLOCK= 1
TSRES= 0.1172E-03 SDPHI= 0.8901E-06 SDPHDT= 0.3613E-03
NT= 1 NITER= 3 NBLOCK= 1
TSRES= 0.1173E-03 SDPHI= 0.8627E-06 SDPHDT= 0.3698E-03
NT= 1 NITER= 4 NBLOCK= 1
TSRES= 0.1173E-03 SDPHI= 0.8567E-06 SDPHDT= 0.3739E-03
NT= 1 NITER= 5 NBLOCK= 1
TSRES= 0.1173E-03 SDPHI= 0.8584E-06 SDPHDT= 0.3753E-03
5.4 Example 4: SR3C-X2 propfan — Steady flow

Description:
In this example, the steady flow around the SR3C-X2 propfan is calculated using version 3 of the FPCAS3D code (Ref. 3). This example is very similar to example 1 and it is included here only because the steady solution generated in this example is used in the next two examples. The propfan has 8 blades. For this steady calculation, only one blade passage is included in the calculations. The freestream Mach number is 0.7, the advance ratio is 3.55 and the blade setting
angle is 61.2 deg. The grid has 15 points on the blade surface in both the chordwise and spanwise directions; there are 11 points in the circumferential direction. A non-dimensional time step of 0.02 is used with 4 Newton sub-iterations at each time step. The code is run for a total of 600 time steps, which is sufficient to reach steady state.

fpcas3d.input:

**TITLE**
SR3CX2 BLADE; STEADY RUN.

**IEXTR INUM INI**
0 4 0

**MINF**
0.7

**ADV BET3Q SOMGA**
3.55 61.2 2.0

**NTMX DTAU**
600 0.02

**NSTDY FACTOR**
0 0.0

**RHUB0**
0.325

**IAIRFL**
0

( **TMAX(J), J = 1, 15** )
0.085 0.073 0.055 0.049 0.040
0.037 0.033 0.030 0.027 0.024
0.021 0.0205 0.02 0.02 0.02

( **CHDI6(J), J = i, 15** )
0.085 0.073 0.055 0.049 0.040
0.037 0.033 0.030 0.027 0.024
0.021 0.0205 0.02 0.02 0.02

fpcas3d.blade.input:

*******************************************************************************
** sr3 blade configuration 1: naca 0016 blade section (grdn12) : mesh input *******
*******************************************************************************
+igeom---+nblrow++ltheta----+------------------------------------+-
 2 1 1
+ninpts++nexpts++nblptz++nblptr++nblptt--++----------------------------------+-
 0 0 15 15 11
+zinlet++zexit------------------------++-------------------------------+-
 0.6 0.600
+ratin++ratex++ratbb++ratblz++ratblr++ratblt++rattip++-----------------------+-
 1.15 1.15 1.0 1.0 1.0 1.0 1.10
*******************************************************************************
+nhub++ntip------------------------++-------------------------------+-
 18 2
+------------------------------------++-------------------------------+-
-0.60 -0.3000 -.2500 -.2250 -.2125 -.2000 -.1750 -.150

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fpcas3d.mode.input:

NASTRAN MODEL
228
61.2 SETTING ANGLE
-0.699, 3.78E-2, 1.7
-0.3994, 2.16E-2, 1.7
-0.1997, 1.07E-2, 1.7

222 lines deleted for brevity

• 2.9451, 2.5496, 12.25
  3.1181, 2.6745, 12.25
  3.2906, 2.7913, 12.25
  3
  1221.082, 2.408413E-5
  0., 0., 0., 0., 0., 0.
  0., 0., 0., 0., 0., 0.
  0., 0., 0., 0., 0., 0.

222 lines deleted for brevity

• -0.4955444, 0.8732229, -0.171114, 6.617669E-3, 0., 0.3687983
-0.5403824, 0.9353858, -0.1869332, -5.394974E-2, 8.613998E-2, 0.3609418
-0.5841199, 1., -0.2032966, 0., 3.973398E-3, 0.399895

2 402.1287, 2.444044E-5
  0., 0., 0., 0., 0., 0.
  0., 0., 0., 0., 0., 0.
  0., 0., 0., 0., 0., 0.

222 lines deleted for brevity

• -0.7769125, 0.5828328, -5.463228E-3, 0.5090338, 0., 1.237072
-0.9233983, 0.7859724, -3.896407E-2, -0.2050837, 0.435869, 1.194069
-1.06826, 1., -7.816583E-2, 0., 0.7318393, 1.153952

3 698.2002, 1.445758E-5
  0., 0., 0., 0., 0., 0.
  0., 0., 0., 0., 0., 0.
  0., 0., 0., 0., 0., 0.

222 lines deleted for brevity

• -0.2114946, 0.3936796, -0.1211723, 0.9387482, 0., 1.765229
-0.4192395, 0.6821609, -0.1912199, 0.3283257, 0.8994851, 1.713123

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fpcas3d.output:

SR3CX2 BLADE; STEADY RUN

IEXTR = 0
INUM = 4
INI = 0
MINF = 0.7000
ADV = 3.5500
BET3Q = 61.2000
NTMX = 600
DTAU = 0.0200
NBS = 1
NSTDY = 0
SOMGA = 2.0000
FACTOR = 0.00000E+00
RHUB0 = 0.32500E+00

TMAX(J), J = 1, 15:
0.8500E-01 0.7300E-01 0.5500E-01 0.4900E-01 0.4000E-01 0.3600E-01 0.3200E-01 0.2900E-01 0.2700E-01 0.2400E-01 0.2100E-01 0.2050E-01 0.2000E-01 0.2000E-01

CHDI6(J), J = 1, 15:
0.0000E+00 0.2400E+00 0.3400E+00 0.3900E+00 0.4350E+00 0.4700E+00 0.5000E+00 0.5000E+00 0.4900E+00 0.4650E+00 0.4300E+00 0.3950E+00 0.2950E+00 0.2250E+00

FROM NAST1, IN DEGREES, DBET=
0.00000E+00

FROM NAST1, RTIP=
0.12458E+02

NT = 0 UNDEFORMED BLADE

IMAX = 47
JMAX = 11
KMAX = 22
ILE = 20
YTE = 34
JTIP = 15

FROM GRID:
XXLE, YYLE, ZZLE =
-0.45218E-01 0.37500E+00 -0.66245E-01
XXTE, YYTE, ZZTE =
0.10285E+00 0.37500E+00 0.15224E+00
BETA =
0.61091E+02

NT =
1 NITER =
1 NBLOCK = 1
TSRES =
0.8375E-03 SDPHI =
0.4406E-03 SDPHDT =
0.1937E-13
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TSRES =
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0.7529E-04 SDPHDT =
0.3300E-01
NT =
1 NITER =
3 NBLOCK = 1
TSRES =
0.7166E-04 SDPHI =
0.1994E-04 SDPHDT =
0.3090E-01
NT =
1 NITER =
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TSRES =
0.4087E-04 SDPHI =
0.6741E-05 SDPHDT =
0.3167E-01
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TSRES =
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0.3895E-05 SDPHDT =
0.3151E-01
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POWER COEFFICIENT : 0.14134E+01
THRUST COEFFICIENT : 0.33966E+00
EFFICIENCY : 0.85312E+00

CP-STAR = -0.77907E+00

additional output files:
fort. 8    restart data
fort. 51   time history of power and thrust coefficients
fort. 53-57 time history of residuals
fort. 71-74 blade surface grid and pressure distribution plot files
fort. 81-83 grid and flow files in plot3d format

5.5 Example 5: SR3C-X2 propfan — Frequency Domain Flutter

Description:
In this example, frequency domain flutter calculations are performed for the SR3C-X2 propfan blade (Ref. 3). For this flutter calculation, phase angles of 0 and 180 deg. are considered (in-phase and out-of-phase motions). Two blade passages are included in the calculations. Version 2 of the FPCAS3D code is used. The steady flow conditions and the grid used are the same as in example 4. As for the steady case, a non-dimensional time step of 0.02 is used with 4 Newton sub-iterations at each time step. The blade is moved in a pulse motion in the first mode. The non-dimensional duration of the pulse is 2.0 and calculations are continued until a non-dimensional time of 6.0 (total of 300 time steps).

For this example, additional post-processing of the results from FPCAS3D is required. The combined pulse response and influence coefficient method is used to calculate the generalized aerodynamic forces required for flutter calculations. The post-processing code rootsfp.f incorporates this calculation together with a flutter calculation. A shell script links the output files from FPCAS3D with the appropriate unit numbers that are used to read these files in rootsfp.f. The input and output of rootsfp.f are also included in this section.

FPCAS3D must be run as many times as the number of modes in the flutter calculation. In this example, three modes are used and FPCAS3D is run thrice, for movemode=1, 2, and 3 respectively. The input and output files for the second and third runs are not listed here.
An additional post-processing code influce.f implements only the combined pulse response and influence coefficient method with no flutter calculation. This code can be used to generate the variation of generalized aerodynamic (force) coefficients for different vibration frequencies and phase angles. Sample input and output for influce.f are included in this section.

\textbf{para1.f:}
\begin{verbatim}
PARAMETER ( IMX=56, JMX=11, KMX=24 )
\end{verbatim}

\textbf{para2.f:}
\begin{verbatim}
PARAMETER ( NXPM=21, NRPM=21, NNODM=500 )
\end{verbatim}

\textbf{para3.f:}
\begin{verbatim}
PARAMETER ( NPS=2 )
\end{verbatim}

\textbf{fpcas3d.input:}
\begin{verbatim}
TITLE
SR3CX2 BLADE; UNSTEADY RUN.
IEXTR INUM INI
0 4 1
MINF
0.7
ADV BET3Q SOMGA
3.55 61.2 2.0
NTMX DTAU NBS
300 0.02 2
NSTDY FACTOR
2 0.01
( IMOV(NBLADE), NBLADE = I, NBS )
1 0
MOVEMODE
1
RHUB0
0.325
IAIRFL
0
( TMAX(J), J = 1, 15 )
0.085 0.073 0.055 0.049 0.040
0.037 0.033 0.030 0.027 0.024
0.021 0.0205 0.02 0.02 0.02
( CHD16(J), J = 1, 15 )
0. 0.240 0.340 0.390 0.435
0.470 0.492 0.500 0.490 0.465
0.430 0.395 0.295 0.155 0.01
\end{verbatim}

\textbf{fpcas3d.blade.input:}
same as in example 4

\textbf{fpcas3d.mode.input:}
same as in example 4
fpcas3d.output:

SR3CX2 BLADE; UNSTEADY RUN

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FROM GRID:
XXLE, YYLE, ZZLE =
-0.45218E-01 0.37500E+00 -0.66245E-01
XXTE, YYTE, ZZTE =
0.10285E+00 0.37500E+00 0.15224E+00
BETA = 0.61091E+02

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NBLOCK= 2
NT= 1 DEFORMED BLADE
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160 lines deleted for brevity

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CP-STAR= -0.77907E+00

additional output files:
fort.53-57 time history of residuals
fort.60 time history of blade motion (displacement)
fort.61-62 time history of generalized forces on blades

rootsfp input:
SR3CX2 DATA
A0  P0
13560.0 13.102
ADV  MINF  RTIP  BET3Q
3.55  0.7  12.458  61.2
NMODE  NBS  NOM
3  2  2
GM(1)  OM(1)
In the above, RTIP is calculated by FPCAS3D from the finite element grid. NOM is the number of frequencies to be used in the root-finding algorithm; these frequencies are input as (FREQ(OM), OMG = 1, NOM) in Hz. STRDAMP is the amount of structural damping.

**rootsfp output:**

```
* Aeroelastic stability analysis *
* using normal mode structural model *
* in FREQUENCY DOMAIN *
* with Full Potential aerodynamic model *
***********************************************************************
+++ atmosphere conditions ++++++++ 
+ pressure=13.10199999999998 
+ speed of sound (in/sec)=13560. 
+ density=9.975765960964404E-8 
+++ operating conditions: 
* rotor speed(rpm)=6438.760997514968 
* rotor speed(rad/sec)=674.2654749337817 
* Mach no. = 0.6999999999999993 
* advance ratio (J)= 3.549999999999997 
* tip radius (inches)=12.45800000000003 
* setting angle (deg.) =61.20000000000005 
```

analysis for 2 angles:
analysis using 3 modes:

```
```

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<tr>
<td>1</td>
<td>2.06</td>
<td>0.1249E+00</td>
</tr>
<tr>
<td>2</td>
<td>402.13</td>
<td>0.2444E-04</td>
</tr>
<tr>
<td>2</td>
<td>3.75</td>
<td>0.1267E+00</td>
</tr>
<tr>
<td>3</td>
<td>698.20</td>
<td>0.1446E-04</td>
</tr>
<tr>
<td>3</td>
<td>6.51</td>
<td>0.7496E-01</td>
</tr>
</tbody>
</table>

```

```
```

```
```

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movemode index = 1

READING MOTION FILE
100 LINES IN MOTION FILE
DELT = 2.00000000000001E-2

READING FORCE FILE(S)
301 LINES IN FORCE FILE(S)
frequency = 2.309024264213676
phase index, mode index = 2*1 qij =
-0.26432E+00 -0.89449E-01
phase index, mode index = 1, 2 qij =
0.12763E+00 -0.33062E-01
phase index, mode index = 1, 3 qij =
0.14507E+00 0.16861E-01
phase index, mode index = 2, 1 qij =
-0.32325E+00 -0.15853E-01
phase index, mode index = 2*2 qij =
0.18278E+00 -0.99929E-01
phase index, mode index = 2, 3 qij =
0.14265E+00 0.23949E-01

several lines deleted for brevity

$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
eigensolution for ip = 1
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
several lines deleted for brevity

all eigenvalues (hz):
1 -0.54889E+02 0.61297E+03
2 -0.10400E+03 0.39558E+03
3 0.53876E+01 0.29302E+03

root 3 is closest to center of interpolation

$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
eigensolution for ip = 2
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
several lines deleted for brevity

all eigenvalues (hz):
1 -0.47086E+02 0.60742E+03
2 -0.12104E+03 0.40502E+03
3 0.24085E+02 0.28809E+03

root 3 is closest to center of interpolation
The above execution of influnce code results in files movemode_1.fort81 and movemode_1.fort82, which contain some of the generalized aerodynamic coefficients. To obtain all the generalized aerodynamic coefficients, the influnce code must be executed two more times with movemode number input as 2 and 3. These two runs will result in four additional files movemode_2.fort81, movemode_2.fort82, movemode_3.fort81 and movemode_3.fort82 being created, which contain the remaining generalized aerodynamic coefficients.

5.6 Example 6: SR3C-X2 propfan — Time Domain Flutter

Description:
In this example, time domain flutter calculations are performed for the SR3C-X2 propfan blade (Ref. 4). For this flutter calculation, both in-phase and out-of-phase motions are considered. Two blade passages are included in the calculations. Version 4 of the FPCAS3D code is used. The steady flow conditions and the grid used are the same as in example 4, except that the number of Newton sub-iterations used in the steady run is 5. As before, a non-dimensional time step of 0.02 is used with 2 Newton sub-iterations at each time step. The two blades are given a small initial velocity in each mode. The velocity given to the blades is equal in magnitude and opposite in direction (sign). The calculations are continued until a non-dimensional time of 10.0 (total of 500 time steps).

paral.f:

```
PARAMETER ( IMX=56, JMX=11, KMX=24 )
```
**para2.f:**

PARAMETER ( NXPM=21, NRPM=21, NNODM=500 )

**para3.f:**

PARAMETER ( NPS=2 )

**fpcas3d.input:**

TITLE
SR3CX2 BLADE; TIME DOMAIN FLUTTER RUN.
IEXTR INUM INI
0 2 1
MINF
0.7
ADV BET3Q SOMGA
3.55 61.2 1.0
NTMX DTAU NBS
500 0.02 2
NSTDY FACTOR
2 0.01
RHub0
0.325
P0 A0
13.102 13560.0
NMODE
3
( OM(IM), IM = 1, NMODE )
221.082 402.1287 698.2002
( GM(IM), IM = 1, NMODE )
2.408413E-05 2.444044E-05 1.445758E-05
( VELS(NBLADE), NBLADE = 1, NBS )
1.0 -1.0
IAIRFL
0
( TMAX(J), J = 1, 15 )
0.085 0.073 0.055 0.049 0.040
0.037 0.033 0.030 0.027 0.024
0.021 0.0205 0.02 0.02 0.02
( CHD16(J), J = 1, 15 )
0.240 0.340 0.390 0.435
0.470 0.492 0.500 0.490 0.465
0.430 0.395 0.295 0.155 0.01

**fpcas3d.blade.input:**

same as in example 4

**fpcas3d.mode.input:**

same as in example 4

**fpcas3d.output:**

SR3CX2 BLADE; TIME DOMAIN FLUTTER RUN

IEXTR = 0
INUM = 2
INI = 1
MINF = 0.7000
ADV = 3.5500
BET3Q = 61.2000
NTMX = 500
DTAU = 0.0200
NBS = 2
NSTDY = 2
SOMGA = 1.0000
FACTOR = 0.100000E-01
RHub0 = 0.325000E+00
P0, A0 :
0.1310E+02 0.1356E+05
NMODE = 3
GM(IM), IM = 1, NMODE :
0.2211E+03 0.4021E+03 0.6982E+03
GM(IM), IM = 1, NMODE :
0.2408E-04 0.2444E-04 0.1446E-04
VELS(NBLADE), NBLADE = 1, NBS :
0.1000E+01 -0.1000E+01
TMAX(J), J = 1, 15 :
0.8500E-01 0.7300E-01 0.5500E-01 0.4900E-01 0.4000E-01
0.3700E-01 0.3300E-01 0.3000E-01 0.2700E-01 0.2400E-01
0.2100E-01 0.2050E-01 0.2000E-01 0.2000E-01 0.2000E-01
CHD16(J), J = 1, 15 :
0.0000E+00 0.2400E+00 0.3400E+00 0.3900E+00 0.4350E+00
0.4700E+00 0.4920E+00 0.5000E+00 0.4900E+00 0.4650E+00
0.4300E+00 0.3950E+00 0.2950E+00 0.1550E+00 0.1000E+01
FROM NAST1, IN DEGREES, DBET = 0.000000E+00
FROM NAST1, RTIP = 0.12458E+02
NT = 0 UNDEFORMED BLADE
IMAX = 47
JMAX = 11
KMAX = 22
ILE = 20
ITE = 34
JTIP = 15
FROM GRID:
XXLE, YYLE, ZZLE =
-0.45218E+01 0.37500E+00 -0.66245E-01
XXTE, YYTE, ZZTE =
0.10285E+00 0.37500E+00 0.15224E+00
BETA =
0.61091E+02
NT = 1 NITER = 1 NBLOCK = 1
TSRES = 0.3898E-03 SDPHI = 0.7613E-05 SDPHDT = 0.1870E-03
NT = 1 NITER = 1 NBLOCK = 2
TSRES = 0.3900E-03 SDPHI = 0.7462E-05 SDPHDT = 0.1870E-03
NT = 1 NITER = 2 NBLOCK = 1
TSRES = 0.3898E-03 SDPHI = 0.2370E-05 SDPHDT = 0.4461E-03
NT = 1 NITER = 2 NBLOCK = 2
TSRES = 0.3899E-03 SDPHI = 0.2373E-05 SDPHDT = 0.4359E-03
NT = 1 NITER = 3 NBLOCK = 1
TSRES = 0.3898E-03 SDPHI = 0.1759E-05 SDPHDT = 0.3856E-03

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NT = 1 NITER = 3 NBLOCK = 2
TSRES = 0.3899E-03 SDPHI = 0.1753E-05 SDPHDT = 0.3783E-03

216 lines deleted for brevity

NT = 500 NITER = 1 NBLOCK = 1
TSRES = 0.3929E-03 SDPHI = 0.2650E-05 SDPHDT = 0.4161E-03

NT = 500 NITER = 2 NBLOCK = 1
TSRES = 0.3869E-03 SDPHI = 0.2850E-05 SDPHDT = 0.6217E-03

NT = 500 NITER = 2 NBLOCK = 2
TSRES = 0.3935E-03 SDPHI = 0.1699E-05 SDPHDT = 0.3676E-03

NT = 500 NITER = 2 NBLOCK = 2
TSRES = 0.3863E-03 SDPHI = 0.1906E-05 SDPHDT = 0.6116E-03

NT = 500 NITER = 3 NBLOCK = 1
TSRES = 0.3933E-03 SDPHI = 0.2265E-05 SDPHDT = 0.4328E-03

NT = 500 NITER = 3 NBLOCK = 2
TSRES = 0.3865E-03 SDPHI = 0.2520E-05 SDPHDT = 0.6669E-03

CP-STAR = -0.77907E+00

additional output files:

fort.53-57 time history of residuals
fort.61-62 time history of blade motion (modal displacements)
fort.71-72 time history of generalized forces on blades
6. PROGRAM CALLING TREE

The following is the static calling tree for the FPCAS3D code. Superscripts indicate version numbers of FPCAS3D in which the routines appear exclusively.

```
FPCAS3D_ELAS 4.5
    |____ETASWP____TRIDIG
    |____FIW____WAKE____SWP1____TRIDIG
    | |____SWP2____TRIDIG
    | |____ZRG 2.5
    | |____ZRQ 2.5
    | |____ZWQ 2.5
    |____FOUT____ELAS 6
    |____GRID____BLADE____NAST1____LOOK
    | |    |____ROT
    | |    |____NAST2____LOOK
    |    |____HMESS____GENBL____INRSCT____SPLINT
    |    |____SPLINT
    |    |____GENEX____INRSCT____SPLINT
    |    |____SPLINT
    |    |____GENIN____INRSCT____SPLINT
    |    |____SPLINT
    |____NUMPTS
    |____ZRG 2.5
    |____ZWG 2.5
____GROUT
____OUTPUT
____START____GRID____BLADE____NAST1____LOOK
    |    |____ROT
    |    |____NAST2____LOOK
    |____HMESS____GENBL____INRSCT____SPLINT
    |____SPLINT
    |____GENEX____INRSCT____SPLINT
    |____SPLINT
    |____GENIN____INRSCT____SPLINT
    |____SPLINT
    |____NUMPTS
    |____ZRG 2.5
    |____ZWG 2.5
____INIT
____XISWP____TRIDIG
____ZETSWP____TRIDIG
    |____ZRG 2.5
    |____ZRQ 2.5
    |____ZWQ 2.5
```
7. REFERENCES


The FPCAS3D computer code has been developed for aeroelastic stability analysis of bladed disks such as those in fans, compressors, turbines, propellers, or propfans. The aerodynamic analysis used in this code is based on the unsteady three-dimensional full potential equation which is solved for a blade row. The structural analysis is based on a finite-element model for each blade. Detailed explanations of the aerodynamic analysis, the numerical algorithms, and the aeroelastic analysis are not given in this report. This guide can be used to assist in the preparation of the input data required by the FPCAS3D code. A complete description of the input data is provided in this report. In addition, six examples, including inputs and outputs, are provided.