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ASTROP2 Users Manual: A Program for Aeroelastic Stability Analysis of Propfans

T.S.R. Reddy
University of Toledo
Toledo, Ohio

and

John M. Lucero
Lewis Research Center
Cleveland, Ohio

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Version 2.0

T.S.R. Reddy*
University of Toledo
Toledo, Ohio 43606

John M. Lucero+
NASA Lewis Research Center
Cleveland, Ohio 44135

SUMMARY

This manual describes the input data required for using the second version of the ASTROP2 (Aeroelastic STability and Response Of Propulsion systems - 2 dimensional analysis) computer code. In ASTROP2, version 2.0, the program is divided into two modules: 2DSTRIP, which calculates the structural dynamic information; and 2DASTROP, which calculates the unsteady aerodynamic force coefficients from which the aeroelastic stability can be determined. In the original version of ASTROP2, these two aspects were performed in a single program. The improvements to version 2.0 include an option to account for counter rotation, improved numerical integration, accommodation for non-uniform inflow distribution, and an iterative scheme to flutter frequency convergence.

ASTROP2 can be used for flutter analysis of multibladed structures such as those found in compressors, turbines, counter rotating propellers or propfans. The analysis combines a two-dimensional, unsteady cascade aerodynamics model and a three dimensional, normal mode structural model using strip theory. The flutter analysis is formulated in the frequency domain resulting in an eigenvalue determinant. The flutter frequency and damping can be inferred from the eigenvalues.

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*NASA Resident Research Associate at Lewis Research Center
+Research Engineer

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1. INTRODUCTION

During the last decade several aeroelastic analyses for propfans and turbomachines have been developed at NASA Lewis Research Center. This work has resulted in several individual codes with variations in the aerodynamic and structural models used, Ref. 1. One of the codes is named ASTROP2. ASTROP2 uses strip theory to integrate the aerodynamic forces calculated using a two dimensional aerodynamic model with a three dimensional structural model. The theoretical development of ASTROP2 and a user's manual for the original ASTROP2 code was given in Ref. 2. The original version combined calculation of structural dynamic characteristics of selected blade sections called strips, and the calculation of the aeroelastic stability in one large program.

In the present updated version, the original program is divided into two programs. The first program, 2DSTRIP calculates the structural dynamic characteristics at the required strips for the aeroelastic analysis. The second program, 2DASTROP, uses the structural data obtained from 2DSTRIP and calculates the aeroelastic stability. In this way each program can be used and modified independently. The user has to run 2DSTRIP first, and then 2DASTROP. However, for the same structural model, only 2DASTROP need to be run for different flow conditions.

Additional improvements were made in ASTROP2 version 2.0. These include (1) an option to account for counter rotation, (2) improved numerical integration, (3) accommodation for nonuniform inflow distribution in the velocity calculations, and (4) an iterative scheme for flutter convergence.

This manual will help the user in the preparation of the input data files required for using 2DSTRIP and 2DASTROP. In the following, a brief description of the analysis is given in section 2. In section 3, the input and output description, followed by input and output for an example case for 2DSTRIP is given. Section 4, gives the input and output description, followed by an actual input and output for an example case using 2DASTROP. A job run stream for a Cray YMP computer, and the program calling tree are also given for each program.

The codes were developed in the Structural Dynamics Branch at the NASA Lewis Research Center. They are made available strictly as a research tool. Neither NASA, nor any individuals who have contributed to the development of the code, assume any liability resulting from the use of the codes beyond research needs. Both the 2DSTRIP and 2DASTROP codes are written in

FORTRAN. They are operational on the Cray YMP computer at the NASA Lewis Research Center under the UNICOS operating system.

Dr. G.V. Narayanan originally developed this program under the direction of Dr. K.R.V. Kaza. The first author of this report was responsible for the present version. Additional improvements and modifications were made by Dr. A.J. Mahajan and by the second author of this report.

2. ANALYSIS

The aeroelastic analysis uses the unsteady aerodynamic forces calculated at selected blade sections (strips) of a three dimensional structure. The aerodynamic forces are calculated using a two dimensional unsteady aerodynamic model. The aerodynamic model calculates the unsteady forces at the selected strips for an airfoil undergoing rigid body pitching and plunging motions. The 2DSTRIP program calculates the pitching and plunging values for the strips, and the 2DASTROP program uses this information to calculate the aeroelastic stability. The formulation and aeroelastic analysis are described in detail in Ref. 2.

The three dimensional normal mode structural characteristics are obtained from a finite element analysis, and used as input to the 2DSTRIP program. Two types of output files (to be used as input to 2DSTRIP) are used from the finite element analysis. One, a non-linear steady state blade deflection analysis output. The other, a free vibration analysis output in the form of mode shapes and frequencies. 2DSTRIP can be run without the nonlinear steady state blade deflection if its effect on the flutter stability is assumed negligible. However, the effect of structural non-linearity due to blade deflection must be included in the calculation of the natural frequencies and mode shapes. The program 2DSTRIP calculates the equivalent rigid pitching and plunging values, stagger angle, gap to chord ratio and strip widths at the desired strips. This information is stored as a file and used as input to 2DASTROP.

Currently, the 2DSTRIP program is set up to use the NASTRAN (NASA STRuctural ANalysis program) finite element analysis program. Two forms of NASTRAN are available at NASA Lewis; one is COSMIC/NASTRAN and the other is MSC/NASTRAN. The non-linear steady-state blade deflection configuration of a rotating blade is obtained from a geometric nonlinear analysis. This analysis is done in COSMIC/NASTRAN by using the available solution sequence number 4. The normal mode vibration analysis of the blade is done by using the solution sequence number 9. The respective solution sequence numbers in MSC/NASTRAN are 64 and 63. See Ref. 3 for more details on how to run NASTRAN for rotating flexible blades. If other finite element programs are used in obtaining the structural characteristics, the formats in the relevant subroutines have to be changed.

The output file from 2DSTRIP for strip data information is read by 2DASTROP and used to calculate the unsteady aerodynamic force coefficients. The unsteady aerodynamic forces are obtained with a two dimensional unsteady aerodynamic model. The aerodynamic model provides unsteady aerodynamic forces for airfoils undergoing rigid pitching (twist) and plunging (bending) motions. For subsonic flow the Rao and Jones theory (Ref. 4) is used. For supersonic flow with subsonic leading edge, the Adamczyk and Goldstein theory (Ref. 5) is used. The strip structural information along with an assumed frequency are used to calculate the unsteady aerodynamic forces. These unsteady aerodynamic coefficients are then used in an eigen analysis. The eigen values determine the flutter frequency and damping. The flutter calculations are iterated (the required number of iterations is given as input) until the assumed frequency is close or equal to the calculated flutter frequency. The ASTROP2 program has been used to predict flutter of the SR3CX2 propfan observed in experiments, Ref. 6-7, and to assist in the design of other propfans systems, Ref. 8.

The coordinate system used for both programs is shown in Fig.1. The X axis is the axis of rotation. It is assumed to be along the direction of axial flow and positive in the direction of flow. The blade pitch axis is the Y axis. It is taken normal to the X axis with positive values in the direction of increasing radius. The Z axis is then defined to form a right-hand coordinate system. The plane of rotation is the plane formed by the Y and Z axes. A typical strip, with mid point, at a distance "d" is shown in Fig. 1. The axial velocity is V and the rotational speed is "Ω", and Ve is the effective (relative) velocity. The tangent (tangent to blade leading edge), chord and normal vectors ("t,c,n" respectively) at the mid point of the strip are defined as shown. "s" denotes the arc length measured along the leading edge. Figure 2 shows the section A-A of the strip showing the rigid pitching (α) and plunging (h) motions for the strip, assuming the reference axis for the aeroelastic analysis is at the leading edge.

3. PROGRAM 2DSTRIP

In this section the input and output for the 2DSTRIP program is given. The source code is designated as *2dstrip.f*, and the input data for the code is provided in the input file *2dstrip.in*. As mentioned before, in addition to this input file, 2DSTRIP requires input files from finite element structural analysis giving the structural dynamic characteristics of the blade. The naming and linking of these input files is also given in the following sections.

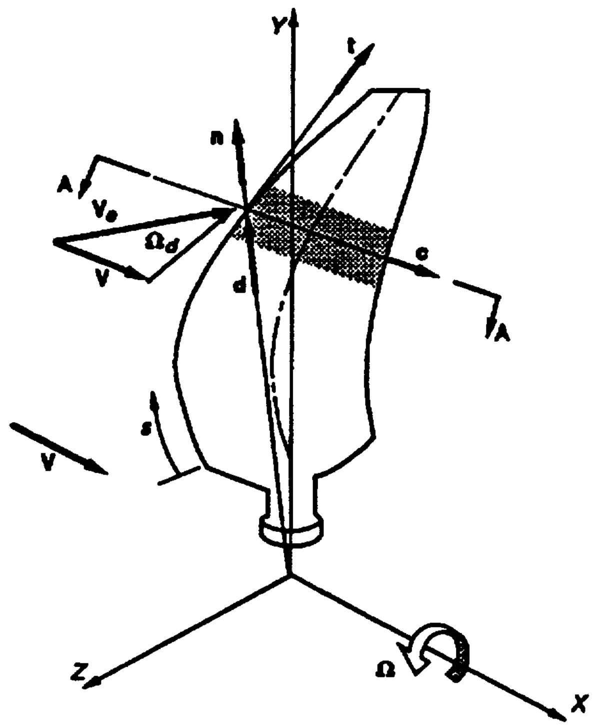
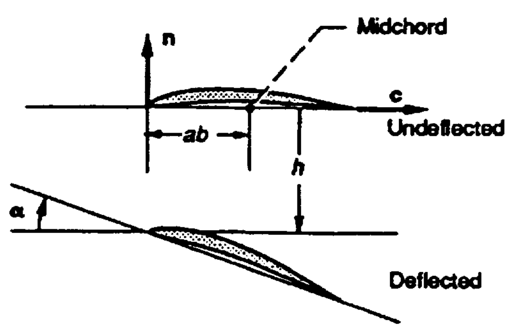


Figure 1. : 2DSTRIP and 2DASTROP coordinate system for a rotating propfan blade



section A-A

Figure 2. : Section A-A showing rigid pitching (α) and plunging (h) motions for the strip (reference axis =leading edge)

3.1 Dimension Statement for the Program

The program is currently dimensioned for a maximum of 20 strips, and 500 finite elements with six degrees of freedom. It is dimensioned for reading natural mode shape information and frequencies for six modes. If the user needs to change these limits, the dimension statements have to be changed globally in the source code, and compiled for execution.

3.2 Description of Input Variables

The input is given through a data file named **2dstrip.in** . This file contains the standard (unit 5) input that the 2DSTRIP code requires. Unless stated otherwise, real values are read in 8F10.4 format and integer values are read in 8I10 format.

Some lines of the input data are preceded by a line containing the names of the variables. These lines are an aid in preparing the input file and are read by the program but not used as data in the calculations.

The first line in the input file is the title card read in 20A4 format, used for identification of the structure to be analyzed. The rest of the input variables are described below in the order in which they appear in the input data file (see section 3.7 for an example input file).

variable:	`NAEROP`
type:	integer variable
description:	number of strips (aero points) at which structural information has to be generated for stability analysis (maximum 20).
example:	`10`

variable:	`NMODE`
type:	integer variable
description:	number of modes for which structural information is available (maximum 6).
example:	`6`

variable:	`ITEST`
type:	integer variable
description:	`ITEST = 0` read and check finite element structural information and then proceed to calculate the required data for the aeroelastic analysis `ITEST=1` read and check finite element structural information
example:	`0`

variable:	`I6364`
type:	integer variable

description	Indicator for using MSC/NASTRAN combined solution sequence 6364 output file `I6364 = 0` `I6364 = 1` If the structural input file is from MSC/NASTRAN combined solution 6364 sequence.
example:	`0`

variable:	`NASTRAN OUPUT TYPE`
type:	character variable of length A4 followed by a blank and then an integer number in I2 format.

description:	denotes the type of finite element structural input files for free vibration (mode shapes and frequencies) and steady state solution input files followed by the file unit number.
	At present COSMIC/NASTRAN and MSC/NASTRAN are supported. Input NULL indicates that there is no input file for steady state solution.
	`COSM04 NULL08`
	`MSC04 NULL08`

example:	`COSM04 NULL08`

NOTE: If the input is from any other source (other than COSMIC or MSC), the formats in subroutines RDNAS, RDISP, RDMODS have to be modified.

variable:	`IPG`
type:	integer variable
description:	control for printing structural grid data `IPG = 0` do not print `IPG = 1` print
example:	`1`

variable:	`IPD`
type:	integer variable
description:	control for printing structural steady data `IPD = 0` do not print `IPD = 1` print
example:	`0`

variable:	`IPM`
type:	integer variable
description:	control for printing structural modal data `IPM = 0` do not print `IPM = 1` print
example:	`1`

variable:	`ISET`
type:	integer variable
description:	defines blade coordinate axis system of the structural input `ISET = 0` Z along span, X along velocity and chord (eg. COSMIC or MSC NASTRAN axis system) `ISET = 1` Y along span, X along velocity and chord (as shown in Fig. 1 i.e. ASTROP2 coordinate system)

ISET = 2 X along span, Y along velocity and chord
Note: with this input, the structural data input is transformed to ASTROP2 coordinate system, Fig. 1.

example: 0

NOTE: If the finite element structural input axis system is other than that described above, relevant statements in RDNAS, RDDISP and RDMODS must be modified.

variable: ICONFIG
type: integer variable
description: indicator for counter rotation
ICONFIG = 0 no counter rotation
ICONFIG = 1 counter rotation
example: 0

variable: BETA75
type: real variable
description: setting angle at 75% span in degrees. If this angle is different by 0.005 degrees (0.001 radians) from the finite element structural input the program stops. If required, this tolerance can be increased in subroutine SETB75
example: 61.2

variable: N1
type: integer variable
description: leading edge node number near and below 75% span station
example: 157

variable: N2
type: integer variable
description: trailing edge node number near and below 75% span station
example: 165

variable: N3
type: integer variable
description: leading edge node number near and above 75% span station
example: 166

variable: N4
type: integer variable
description: trailing edge node number near and above 75% span station
example: 174

variable: ZETA75
type: real variable
description: spanwise coordinate at 75% span
example: 9.1875

Note: values of N1, N2, N3, N4 and ZETA75 are used to calculate the setting angle from the NASTRAN output, and then checked with the input value BETA75.

variable: LECOY
type: real variable
description: spanwise coordinate (lowest Y-coordinate) value above which leading edge line is effective
example: 4.00

variable: TECOY
type: real variable
description: spanwise coordinate (lowest Y-coordinate) value above which trailing edge line is effective
example: 4.00

variable: IDREAD
type: integer variable
description: option to read the node numbers of the leading and trailing edges.
IDREAD=0 determine the leading and trailing edge node numbers
IDREAD=1 input the leading and trailing edge node numbers
example: 1

variable: NLE
type: integer variable
description: number of leading edge nodes (required if IDREAD = 1)
example: 18

variable: NTE
type: integer variable
description: number of trailing edge nodes (required if IDREAD =1)
example: 18

NOTE: values of NLE and NTE are read in 2I5 format

variable: LENODES
type: integer variable
description: leading edge node numbers of the finite element structural model with spanwsie coordinate (Y-coordinate) value greater than LECOY in 16I5 format (required if IDREAD =1)
example:
00067000760008500094001030011200121001300013900148001570016600175001840019300202
0021100220

variable: TENODES
type: integer variable
description: trailing edge node numbers of the finite element structural model with spanwise coordinate (Y-coordinate) value greater than TECOY in 16I5 format (required if IDREAD =1)
example:
00075000840009300102001110012000129001380014700156001650017400183001920020100210
0021900228

variable: METHOD
type: integer variable
description: METHOD =0, no steady displacements (fabricated blade geometry)
METHOD =1, steady displacements added (deformed blade geometry)
example: 0

variable: AEROPOINTS COORDINATES
type: character variable
description: this card is followed by the spanwise coordinate (strip mid point) value of the strips, equal to NAEROP values.
example:
```
4.2500
4.5000
4.7500
5.6361
*
*
12.200
```

variable: CAL
type: real variable
description: indicator for calculation of rigid pitching amplitude values (α)
CAL = -1.0, read from the structural input file
CAL =0.0, calculate from displacements (h)
CAL =1.0, calculated from average rotations
example: 1.0

3.3 Additional Input Files

The program requires that the structural dynamic characteristics data files from a finite element analysis be linked to unit 4 and unit 8. The natural frequencies and mode shapes input file must be linked to unit 4, and steady displacement input file should be linked to unit 8. At present both COSMIC and MSC NASTRAN are supported. If the structural data files are from any other source, the formats in routines RDNAS, RDDISP, and RDMODS have to be modified accordingly.

3.4 Additional Notes

The 2DSTRIP program is setup to work with the finite element structural model having node numbers from root to tip, and increasing in the +ve X direction. It also works well if the chord lines (lines parallel to X-axis) are at a constant spanwise location. The leading edge line is taken as the reference axis for calculating pitching and plunging values.

The program is implemented on the Cray YMP at NASA Lewis Research Center. However, the program can be implemented on a workstation or personal computer. It required about 1.1 MW memory, and took about 12 seconds to compile and about 16 seconds to execute for the example given in section 3.7.

3.5 Job run stream on Cray YMP

A sample Cray job stream to run 2DSTRIP at the NASA Lewis Research Center is given in this section. For this case, the modal information output file (sol9cos.out) from finite element structural analysis is linked to unit 4. The source code, 2dstrip.f, is compiled using cft77 with standard options. The input to 2DSTRIP is contained in the file named 2dstrip.in. The standard unit 6 output is written to a file named 2dstrip.out. The information required for 2DASTROP is written to unit 7 as file fort.7. This file is renamed as fort7.2dstrip. The rest of the file contains UNICOS and Cray related commands.

```
#! /bin/csh
# QSUB -r sr3cx2
# QSUB -lM 1.2Mw
# QSUB
/bin/rm 2dstrip.out
ln sol9cos.out fort.4
cft77 -V -a static 2dstrip.f
segldr -o 2dstrip 2dstrip.o
time 2dstrip<2dstrip.in>2dstrip.out
mv fort.7 fort7.2dstrip
```

3.6 Description of Output files

Unit 6 (2dstrip.out) output : All the output is written on to unit 6, with selected output rewritten on to unit 7 to be used by 2DASTROP program. The user has to check for the correctness of the following items in the output:

(1) the input file from the finite element structural output (grid and modal values);

(2) the tangent, normal and streamline vectors for all points on the leading edge;

(3) the coordinates of each of the aeropoints;

(4) the tangent, streamline and normal vectors at the aeropoints;

(5) the modal values (rigid pitching and plunging values) for each strip and for each mode; and

(6) the sweep and stagger angles, semichord (SEMICHD) values at each strip, and strip widths (STRIPW).

Unit 7 output: This file contains the relevant information of the strips required by the 2DASTROP program.

3.7 Example Case: Calculation of Structural Dynamic Characteristics at Selected Strips for SR3CX2 Propfan

In this section the actual input and output are given for the SR3CX2 propfan which fluttered during wind tunnel testing, Refs. 6-7. The input file is named 2dstrip.in. The COSMIC/ NASTRAN input file for six modes and frequencies (NMODE=6) is linked to unit 4 (COSM04). There is no steady state blade deflection input file (NULL). The NASTRAN grid and mode shapes are to be printed (IPG =1, IPM=1), and the example is not for counter rotation (ICONFIG=0). The setting angle at 75% span (BETA75) is 61.2 degrees. It is required to calculate strip data at ten strip stations (NAEROP=10). The strip locations along the span are given as AEROPOINTS COORDINATES. The equivalent rigid pitching (α) has to be calculated as an average of the rotation values of the nodes on the strip (CAL=1).

Input file (2dstrip.in)

```
READING NASTRAN OUTPUT AND PROCESSING for SR3CX2 propfan
    NAEROP      NMODE      ITEST      I6364 (READ IN MAIN)
        10          6          0          0
NASTRAN OUTPUT TYPE (RDNAS)
COSM04 NULL08
       IPG        IPD        IPM       ISET   ICONFIG
        01         00         01         00        00
BETA75(SETTING ANGLE AT 75% SPAN)
     61.20
        N1         N2         N3         N4
       157        165        166        174
   ZBETA75
    9.1875
     LECOY
     4.000
     TECOY
     4.000
    IDREAD
         1
  NLE  NTE
   18   18
LENODES
00067000760008500094001030011200121001300013900148001570016600175001840019300202
0021100220
TENODES
00075000840009300102001110012000129001380014700156001650017400183001920020100210
0021900228
    METHOD
         0
```

```
AEROPOINTS COORDINATES(LOCGRI)
4.2500
4.5000
4.7500
5.6361
6.9739
8.8736
9.7114
10.8758
11.7553
12.2000
CAL(RDNAS1)
1.0       CAL:(=-1 NODAL VALUES,=0 ALFA/DISP, =1 ALFA/ALFA)
```

Unit 6 output file (2dstrip.out)

The output information is printed, and given here in the order mentioned in section 3.6, and is self explanatory. In this report, most of the output is deleted, and only key output is retained to help the user to check the output before going through the large printed output. For easy debugging and understanding, the output from each subroutine is identified by "entered (subroutine) xxxx" and "leaving (subroutine) xxxxx". It is to be noted that the rigid body pitching (α) and plunging values (h) are denoted by A-VALUE and H-VALUE with appropriate names for their derivatives.

```
          READING NASTRAN OUTPUT AND PROCESSING for SR3CX2 propfan

     *** ENTERED RDNAS ***

 ECHO PRINT OF FINITE ELEMENT ANALYSIS OUTPUT
     IN ASTROP2 COORDINATE SYSTEM

  IPG=    1  IPD=    0  IPM=    1  ISETUP=    0
     NUMBER OF GRID POINTS =   228
  GRID     1     -0.699   1.700  -0.038
  GRID     2     -0.399   1.700  -0.022
  GRID     3     -0.200   1.700  -0.011
  GRID     4      0.000   1.700   0.000
  GRID     5      0.200   1.700   0.011
  GRID     6      0.399   1.700   0.022
  GRID     7      0.699   1.700   0.038
***
*******lines deleted for brevity ***
***
  GRID   220      1.905  12.250  -1.739
  GRID   221      2.079  12.250  -1.885
  GRID   222      2.253  12.250  -2.023
  GRID   223      2.426  12.250  -2.159
  GRID   224      2.600  12.250  -2.291
  GRID   225      2.772  12.250  -2.422
  GRID   226      2.945  12.250  -2.550
  GRID   227      3.118  12.250  -2.674
  GRID   228      3.291  12.250  -2.791
```

```
      GIVEN SETTING ANGLE =    61.20000 DIFF.=     0.00000
       Z1,Z2,X1,X2 IN SETB75 BETA1=      0.76110     -1.31350     -1.39020
2.47060    -0.49308
       Z1,Z2,X1,X2 IN SETB75 BETA1=      0.76110     -1.31350     -1.39020
2.47060     1.07772
      SAME AS ABOVE IN SETB75 BETA2=      0.54020     -1.53350     -0.99070
2.64270    -0.51862
      SAME AS ABOVE IN SETB75 BETA2=      0.54020     -1.53350     -0.99070
2.64270     1.05217
      CALCULATED SETTING ANGLE =    61.19985
      GIVEN SETTING ANGLE =    61.20000 DIFF.=    -0.00015
      GRID COORDINATES IN ROUTINE SETB75
      RETURNING FROM ROUTINE SETB75
     ***ENTERED RDDISP(NGP,NFC)***  228    1
     ***ENTERED RDMODS***
     FREQ IN HZ=   0.221082E+03  GEN. MASS =  0.100000E+01
     FREQ IN HZ=   0.402129E+03  GEN. MASS =  0.100000E+01
     FREQ IN HZ=   0.698200E+03  GEN. MASS =  0.100000E+01
     FREQ IN HZ=   0.816943E+03  GEN. MASS =  0.100000E+01
     FREQ IN HZ=   0.106519E+04  GEN. MASS =  0.100000E+01
     FREQ IN HZ=   0.115721E+04  GEN. MASS =  0.100000E+01


     NUMBER OF EIGENVALUES EXTRACTED =      6
     NOTE THAT MAX. NO. OF EIGENVALUES RETAINED IS 6

     FREQUENCY(OMEGA**2)  =    0.192960E+07
     FREQUENCY(OMEGA**2)  =    0.638395E+07
     FREQUENCY(OMEGA**2)  =    0.192451E+08
     FREQUENCY(OMEGA**2)  =    0.263477E+08
     FREQUENCY(OMEGA**2)  =    0.447934E+08
     FREQUENCY(OMEGA**2)  =    0.528671E+08
     ** MODAL DISPLACEMENTS AT EACH NODE ***     6

     *** LEAVING RDMODS ***
     ** MODAL DISPLACEMENTS AT EACH NODE ***     6

  MODE NUMBER  1  FREQENCY 0.1929603E+07
   NODE     1      0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
0.000000E+00 0.000000E+00
*
*NOTE: grids 1 thru 7 are fixed at the base thus displacement = 0
*
  NODE   8  -0.304607E-02-0.806913E-03 0.147851E-02 0.120198E-01 0.181593E-
01 0.000000E+00
  NODE   9  -0.333980E-02-0.933904E-03-0.138738E-02-0.109695E-01 0.916673E-
02 0.000000E+00
  NODE  10  -0.312842E-02-0.986026E-03-0.315005E-02-0.305093E-01 0.912233E-
02 0.000000E+00
  NODE  11  -0.206363E-02-0.127986E-02-0.420668E-02-0.410897E-01 0.337328E-
02 0.000000E+00
  NODE  12  -0.650327E-03-0.238605E-03-0.413737E-02-0.414708E-01-0.374381E-
02 0.000000E+00
  NODE  13  -0.100480E-03 0.137419E-02-0.319257E-02-0.311352E-01-0.489164E-
02 0.000000E+00
  NODE  14  -0.508570E-03 0.153128E-02-0.568214E-03-0.110998E-01-0.200406E-
01 0.000000E+00
  NODE  15  -0.834550E-02-0.226911E-02-0.755601E-03-0.270103E-02 0.347927E-
```

```
01 0.000000E+00
  NODE  16  -0.816145E-02-0.205379E-02-0.667316E-02-0.354511E-01 0.368838E-
01 0.000000E+00
  NODE  17  -0.715473E-02-0.211537E-02-0.132772E-01-0.675880E-01 0.261375E-
01 0.000000E+00
  NODE  18  -0.510992E-02-0.274521E-02-0.164227E-01-0.805298E-01 0.116495E-
01 0.000000E+00
  NODE  19  -0.261430E-02-0.125851E-02-0.169016E-01-0.848442E-01-0.545229E-
02 0.000000E+00
  NODE  20  -0.392116E-03 0.277116E-02-0.144540E-01-0.778615E-01-0.216500E-
01 0.000000E+00
***
*******lines deleted for brevity ***
***
    NODE  219    -0.116350E+03-0.407301E+02-0.201573E+03  0.000000E+00
0.811890E+02 0.124330E+01
    NODE  220    -0.538991E+02-0.193324E+02-0.116813E+03  0.000000E+00
0.397867E+02 0.226917E+01
    NODE  221    -0.603932E+02-0.213408E+02-0.124651E+03  0.217392E+02
0.546571E+02 0.268687E+02
    NODE  222    -0.674061E+02-0.236378E+02-0.133485E+03  0.000000E+00
0.553667E+02-0.150818E+01
    NODE  223    -0.752087E+02-0.261159E+02-0.143511E+03  0.264773E+02
0.693699E+02 0.322665E+02
    NODE  224    -0.833544E+02-0.288660E+02-0.154295E+03  0.000000E+00
0.662551E+02-0.212215E+01
    NODE  225    -0.920327E+02-0.317458E+02-0.165770E+03-0.117279E+01
0.703865E+02-0.420867E+01
    NODE  226    -0.100975E+03-0.348671E+02-0.177933E+03  0.135083E+01
0.751524E+02 0.000000E+00
    NODE  227    -0.110112E+03-0.380907E+02-0.190600E+03-0.110234E+02
0.735406E+02-0.175985E+02
    NODE  228    -0.119026E+03-0.414257E+02-0.203769E+03  0.000000E+00
0.815080E+02-0.802315E+00
*
*****similar output for modes 2 thru 6 has been deleted***
*
  FINISHED ECHOING FEA OUTPUT
     *** LEAVING RDNAS***
 *** ENTERED ROUTINE ASTROP ***
     ENTERED RDNAS1
     NUMBER OF MODES USED=   6
     ** ENTERED LETEDG (NGP,IDREAD) **  228    1
     ENTERED ROUTINE RDLTNS     18   18
   67   -2.4215    4.0000    0.6462   76   -2.5971    4.5000    0.8019   85
-2.7349    5.0000    0.9417
   94   -2.8152    5.5000    1.0565  103   -2.8205    6.0000    1.1372  112
-2.7366    6.5000    1.1770
  121   -2.5662    7.0000    1.1750  130   -2.3366    7.5000    1.1335  139
-2.0649    8.0000    1.0540
  148   -1.7488    8.5000    0.9309  157   -1.3902    9.0000    0.7611  166
-0.9907    9.5000    0.5402
  175   -0.5511   10.0000    0.2666  184   -0.0704   10.5000   -0.0689  193
0.4520   11.0000   -0.4692
  202    1.0024   11.5000   -0.9262  211    1.5822   12.0000   -1.4427  220
1.9048   12.2500   -1.7386
   75    1.9588    4.0000   -0.3136   84    1.8736    4.5000   -0.3132   93
1.8326    5.0000   -0.3335
```

```
  102    1.8060     5.5000    -0.3760  111    1.8005     6.0000    -0.4404  120
1.8282    6.5000    -0.5280
  129    1.9023     7.0000    -0.6402  138    2.0190     7.5000    -0.7770  147
2.1567    8.0000    -0.9348
  156    2.3066     8.5000    -1.1140  165    2.4706     9.0000    -1.3135  174
2.6427    9.5000    -1.5335
  183    2.8139    10.0000    -1.7726  192    2.9716    10.5000    -2.0215  201
3.1039   11.0000    -2.2645
  210    3.2148    11.5000    -2.4990  219    3.2915    12.0000    -2.7131  228
3.2906   12.2500    -2.7913
****
```

*******lines deleted for brevity ***

```
***
     LEADING EDGE(REF. AXIS) GRID COORDINATES: KYL =      18
          1   67        -2.4215          4.0000          0.6462
          2   76        -2.5971          4.5000          0.8019
          3   85        -2.7349          5.0000          0.9417
          4   94        -2.8152          5.5000          1.0565
          5  103        -2.8205          6.0000          1.1372
          6  112        -2.7366          6.5000          1.1770
          7  121        -2.5662          7.0000          1.1750
          8  130        -2.3366          7.5000          1.1335
          9  139        -2.0649          8.0000          1.0540
         10  148        -1.7488          8.5000          0.9309
         11  157        -1.3902          9.0000          0.7611
         12  166        -0.9907          9.5000          0.5402
         13  175        -0.5511         10.0000          0.2666
         14  184        -0.0704         10.5000         -0.0689
         15  193         0.4520         11.0000         -0.4692
         16  202         1.0024         11.5000         -0.9262
         17  211         1.5822         12.0000         -1.4427
         18  220         1.9048         12.2500         -1.7386
     TRAILING EDGE GRID COORDINATES : KYT =     18
          1   75         1.9588          4.0000         -0.3136
          2   84         1.8736          4.5000         -0.3132
          3   93         1.8326          5.0000         -0.3335
          4  102         1.8060          5.5000         -0.3760
          5  111         1.8005          6.0000         -0.4404
          6  120         1.8282          6.5000         -0.5280
          7  129         1.9023          7.0000         -0.6402
          8  138         2.0190          7.5000         -0.7770
          9  147         2.1567          8.0000         -0.9348
         10  156         2.3066          8.5000         -1.1140
         11  165         2.4706          9.0000         -1.3135
         12  174         2.6427          9.5000         -1.5335
         13  183         2.8139         10.0000         -1.7726
         14  192         2.9716         10.5000         -2.0215
         15  201         3.1039         11.0000         -2.2645
         16  210         3.2148         11.5000         -2.4990
         17  219         3.2915         12.0000         -2.7131
         18  228         3.2906         12.2500         -2.7913
     *** LEAVING ROUTINE LETEDG ***

     *** LEAVING ROUTINE LETEDG ***

     NUMBER OF MODES USED=    6
      1-TH MODAL FREQUENCY(OMEGA:RAD/SEC) =    1929603.00
      2-TH MODAL FREQUENCY(OMEGA:RAD/SEC) =    6383953.00
```

```
 3-TH MODAL FREQUENCY(OMEGA:RAD/SEC) =  19245060.00
 4-TH MODAL FREQUENCY(OMEGA:RAD/SEC) =  26347720.00
 5-TH MODAL FREQUENCY(OMEGA:RAD/SEC) =  44793420.00
 6-TH MODAL FREQUENCY(OMEGA:RAD/SEC) =  52867090.00


 STEADY DISP. NOT ADDED: METHOD=  0
***********************************
NUMBER OF MODES USED=   6
*** ENTERED TSNFAL***
TANGENT VECTOR AT GRIDPOINT 67 ARE
   -0.3467         0.8915         0.2917
TANGENT VECTOR AT GRIDPOINT 76 ARE
   -0.2941         0.9157         0.2738
TANGENT VECTOR AT GRIDPOINT 85 ARE
   -0.2233         0.9426         0.2485
TANGENT VECTOR AT GRIDPOINT 94 ARE
   -0.0991         0.9751         0.1986
TANGENT VECTOR AT GRIDPOINT103 ARE
    0.0717         0.9898         0.1233
TANGENT VECTOR AT GRIDPOINT112 ARE
    0.2622         0.9644         0.0357
TANGENT VECTOR AT GRIDPOINT121 ARE
    0.3873         0.9210        -0.0419
TANGENT VECTOR AT GRIDPOINT130 ARE
    0.4499         0.8868        -0.1057
TANGENT VECTOR AT GRIDPOINT139 ARE
    0.4994         0.8498        -0.1685
TANGENT VECTOR AT GRIDPOINT148 ARE
    0.5449         0.8055        -0.2330
TANGENT VECTOR AT GRIDPOINT157 ARE
    0.5778         0.7610        -0.2950
TANGENT VECTOR AT GRIDPOINT166 ARE
    0.6018         0.7173        -0.3512
TANGENT VECTOR AT GRIDPOINT175 ARE
    0.6187         0.6728        -0.4056
TANGENT VECTOR AT GRIDPOINT184 ARE
    0.6309         0.6240        -0.4610
TANGENT VECTOR AT GRIDPOINT193 ARE
    0.6328         0.5871        -0.5048
TANGENT VECTOR AT GRIDPOINT202 ARE
    0.6270         0.5605        -0.5411
TANGENT VECTOR AT GRIDPOINT211 ARE
    0.6283         0.5233        -0.5756
TANGENT VECTOR AT GRIDPOINT220 ARE
    0.6447         0.4755        -0.5986
TESTP =      2.7952     PLEQC =      4.5939
TESTP =      3.2706     PLEQC =      4.5939
TESTP =      3.7246     PLEQC =      4.5939
TESTP =      4.1672     PLEQC =      4.5939
TESTP =      4.5960     PLEQC =      4.5939
VAL1 =      5.5000     VAL2 =      6.0000
YVAL =      5.7500     DY   =      0.2500
VAL1 =      5.7500     VAL2 =      6.0000
YVAL =      5.8750     DY   =      0.3750
VAL1 =      5.8750     VAL2 =      6.0000
YVAL =      5.9375     DY   =      0.4375
VAL1 =      5.9375     VAL2 =      6.0000
```

```
YVAL =      5.9688      DY    =      0.4688
STREAMLINE VECTOR AT  67 -TH GRIDPOINT =     0.8828    0.4117   -0.2262
STRUCTURAL PRE-TWIST OF BLADE AT  67 -TH GRIDPOINT   =   76.9241
NORMAL VECTOR AT  67 -TH GRIDPOINT =   -0.3218    0.1791   -0.9297
TESTP =      3.0011      PLEQC =      5.1040
TESTP =      3.4841      PLEQC =      5.1040
TESTP =      3.9485      PLEQC =      5.1040
TESTP =      4.4025      PLEQC =      5.1040
TESTP =      4.8444      PLEQC =      5.1040
TESTP =      5.2701      PLEQC =      5.1040
VAL1 =      6.0000      VAL2 =      6.5000
YVAL =      6.2500      DY    =      0.2500
STREAMLINE VECTOR AT  76 -TH GRIDPOINT =     0.8971    0.3563   -0.2612
STRUCTURAL PRE-TWIST OF BLADE AT  76 -TH GRIDPOINT   =   74.8562
NORMAL VECTOR AT  76 -TH GRIDPOINT =   -0.3368    0.1688   -0.9263
****
*******lines deleted for brevity ***
***
TESTP =      3.3524      PLEQC =      8.0934
TESTP =      3.5350      PLEQC =      8.0934
TESTP =      3.7585      PLEQC =      8.0934
TESTP =      4.0045      PLEQC =      8.0934
TESTP =      4.2773      PLEQC =      8.0934
TESTP =      4.5853      PLEQC =      8.0934
TESTP =      4.9380      PLEQC =      8.0934
TESTP =      5.3329      PLEQC =      8.0934
TESTP =      5.7538      PLEQC =      8.0934
TESTP =      6.1955      PLEQC =      8.0934
TESTP =      6.6584      PLEQC =      8.0934
TESTP =      7.1388      PLEQC =      8.0934
TESTP =      7.6300      PLEQC =      8.0934
TESTP =      8.1184      PLEQC =      8.0934
VAL1 =     10.0000      VAL2 =     10.5000
YVAL =     10.2500      DY    =      0.2500
VAL1 =     10.2500      VAL2 =     10.5000
YVAL =     10.3750      DY    =      0.3750
VAL1 =     10.3750      VAL2 =     10.5000
YVAL =     10.4375      DY    =      0.4375
STREAMLINE VECTOR AT 220 -TH GRIDPOINT =     0.4970   -0.8595   -0.1195
STRUCTURAL PRE-TWIST OF BLADE AT 220 -TH GRIDPOINT   =   83.1355
NORMAL VECTOR AT 220 -TH GRIDPOINT =   -0.5713   -0.2205   -0.7904
*** LEAVING TSNFAL***
NUMBER OF MODES USED=   6
ENTERED LOCGRI
* NO. OF AEROELASTIC PTS FOR "LOCGRI"*= 10
(DEFAULT: INPUT 7 AEROPOINTS)

 Y - COORDINATE  OF 1-TH AEROELASTIC POINT:      4.25000
 Y - COORDINATE  OF 2-TH AEROELASTIC POINT:      4.50000
 Y - COORDINATE  OF 3-TH AEROELASTIC POINT:      4.75000
 Y - COORDINATE  OF 4-TH AEROELASTIC POINT:      5.63610
 Y - COORDINATE  OF 5-TH AEROELASTIC POINT:      6.97390
 Y - COORDINATE  OF 6-TH AEROELASTIC POINT:      8.87360
 Y - COORDINATE  OF 7-TH AEROELASTIC POINT:      9.71140
 Y - COORDINATE  OF 8-TH AEROELASTIC POINT:     10.87580
 Y - COORDINATE  OF 9-TH AEROELASTIC POINT:     11.75530
 Y - COORDINATE  OF10-TH AEROELASTIC POINT:     12.20000
*** ENTERED LOCXZ***
```

```
****
```
*******lines deleted for brevity ***
```
***
     POINT  1 X-CO =  -2.513537 Y-CO =   4.250000 Z-CO    =  0.725816
     POINT  2 X-CO =  -2.597100 Y-CO =   4.500000 Z-CO    =  0.801900
     POINT  3 X-CO =  -2.671259 Y-CO =   4.750000 Z-CO    =  0.874009
     POINT  4 X-CO =  -2.825452 Y-CO =   5.636100 Z-CO    =  1.082509
     POINT  5 X-CO =  -2.577051 Y-CO =   6.973900 Z-CO    =  1.176128
     POINT  6 X-CO =  -1.484797 Y-CO =   8.873600 Z-CO    =  0.808617
     POINT  7 X-CO =  -0.809747 Y-CO =   9.711400 Z-CO    =  0.431453
     POINT  8 X-CO =   0.319148 Y-CO =  10.875800 Z-CO    = -0.364181
     POINT  9 X-CO =   1.293340 Y-CO =  11.755300 Z-CO    = -1.181533
     POINT 10 X-CO =   1.837465 Y-CO =  12.200000 Z-CO    = -1.676337
****
```
*******lines deleted for brevity ***
```
***
     POINT  1 X-CO =   1.909270 Y-CO =   4.250000 Z-CO    = -0.310858
     POINT  2 X-CO =   1.873600 Y-CO =   4.500000 Z-CO    = -0.313200
     POINT  3 X-CO =   1.850524 Y-CO =   4.750000 Z-CO    = -0.320663
     POINT  4 X-CO =   1.801821 Y-CO =   5.636100 Z-CO    = -0.391327
     POINT  5 X-CO =   1.896989 Y-CO =   6.973900 Z-CO    = -0.633688
     POINT  6 X-CO =   2.427798 Y-CO =   8.873600 Z-CO    = -1.261101
     POINT  7 X-CO =   2.715210 Y-CO =   9.711400 Z-CO    = -1.632949
     POINT  8 X-CO =   3.073039 Y-CO =  10.875800 Z-CO    = -2.204533
     POINT  9 X-CO =   3.260289 Y-CO =  11.755300 Z-CO    = -2.612417
     POINT 10 X-CO =   3.294167 Y-CO =  12.200000 Z-CO    = -2.778188
     *** LEAVING LOCXZ***
     ENTER CUBE DIMEN. ALONG STACKING AXIS,IN INCHES, TO    LOCATE
     STRUCTURAL GRID NOS. AND HENCE, ITS X-,Y-,Z-         COORDINATES.
     (DEFAULT CUBE DIMENSION = 2.0)

     ENTER CONTROL VALUE TO PRINT GRID CONNECTION ARRAY
          TYPE 1 TO USE THIS PRINT OPTION

     *** LEAVING LOCGRI***
     NUMBER OF MODES USED=   6
     ALFA VALUES FROM AVERAGE ALFA
    ******************************
     NUMBER OF MODES USED=   6


      FOR MODE NUMBER  1
     ******************
     *** ENTERED AVEMV2***
     ***AVERAGE ROTATION FROM ROTATIONS AT GRID POINTS***
****
```
*******lines deleted for brevity ***
```
***
     MODE NO =  1   ALPHA VALUES FROM TIP TOWARDS HUB
        -3.0417   -9.0542   -6.2417   -7.1214   -6.9717   -6.3822   -5.9653
-5.2683
        -5.5081   -5.8454   -6.9008   -7.5113   -9.8267  -12.4296  -16.3741
-22.1784
       -29.1149  -31.2989
     *** LEAVING AVEMV2***
     *** ENTERED HAINTS***
     THE LEADING EDGE NODES ARE
```

```
  67   76   85   94  103  112  121  130
 139  148  157  166  175  184  193  202
 211  220
*** ENTERED RLENC ***
 SLEN(  1 ) =    0.000000
 SLEN(  2 ) =    0.552423
 SLEN(  3 ) =    1.089718
 SLEN(  4 ) =    1.609389
 SLEN(  5 ) =    2.116627
 SLEN(  6 ) =    2.626125
 SLEN(  7 ) =    3.154886
 SLEN(  8 ) =    3.706856
 SLEN(  9 ) =    4.281621
 SLEN( 10 ) =    4.886038
 SLEN( 11 ) =    5.524519
 SLEN( 12 ) =    6.201727
 SLEN( 13 ) =    6.921677
 SLEN( 14 ) =    7.692331
 SLEN( 15 ) =    8.518967
 SLEN( 16 ) =    9.391846
 SLEN( 17 ) =   10.315491
 SLEN( 18 ) =   10.819666
*** LEAVING RLENC***
****
*******lines deleted for brevity ***
***
 AT GRID NO  67,  H-DISP= -0.85677149E+00  A-ROT= -0.30417404E+01
 AT GRID NO  76,  H-DISP= -0.23271259E+01  A-ROT= -0.90542090E+01
 AT GRID NO  85,  H-DISP= -0.41668405E+01  A-ROT= -0.62417229E+01
 AT GRID NO  94,  H-DISP= -0.62370540E+01  A-ROT= -0.71214226E+01
 AT GRID NO 103,  H-DISP= -0.85312713E+01  A-ROT= -0.69716610E+01
 AT GRID NO 112,  H-DISP= -0.11246058E+02  A-ROT= -0.63821847E+01
 AT GRID NO 121,  H-DISP= -0.14687740E+02  A-ROT= -0.59652618E+01
 AT GRID NO 130,  H-DISP= -0.18990035E+02  A-ROT= -0.52683215E+01
 AT GRID NO 139,  H-DISP= -0.23948742E+02  A-ROT= -0.55080652E+01
 AT GRID NO 148,  H-DISP= -0.29253928E+02  A-ROT= -0.58453933E+01
 AT GRID NO 157,  H-DISP= -0.35091410E+02  A-ROT= -0.69007687E+01
 AT GRID NO 166,  H-DISP= -0.41663892E+02  A-ROT= -0.75112929E+01
 AT GRID NO 175,  H-DISP= -0.49065662E+02  A-ROT= -0.98267179E+01
 AT GRID NO 184,  H-DISP= -0.57838489E+02  A-ROT= -0.12429613E+02
 AT GRID NO 193,  H-DISP= -0.70096814E+02  A-ROT= -0.16374141E+02
 AT GRID NO 202,  H-DISP= -0.88089094E+02  A-ROT= -0.22178403E+02
 AT GRID NO 211,  H-DISP= -0.11246933E+03  A-ROT= -0.29114876E+02
 AT GRID NO 220,  H-DISP= -0.12738349E+03  A-ROT= -0.31298910E+02

 IKAP =       1
  AT POINT  =    4.250000, FUNCTION VALUE =    0.278031
 IKAP =       1
  AT POINT  =    0.278031, FUNCTION VALUE =   -1.540085
 IKAP =       1
  AT POINT  =    0.278031, FUNCTION VALUE =   -7.404140
 AT  1-TH AEROPOINT ,MODAL DISP  =  -1.54008
 AT  1-TH AEROPOINT, MODAL ROTATION  =  -7.40414
 AT  1-TH AEROPOINT ,MODAL DISP PRIME =  -2.65048
 AT  1-TH AEROPOINT, MODAL ROTATION PRIME = -11.60601
 AT  1-TH AEROPOINT ,MODAL DISP DBLE PRIME =  -1.48127
 AT  1-TH AEROPT., MODAL ROT.  DBLE PRIME =  38.50773
****
```

*******lines deleted for brevity ***

```
***
     AT 10-TH AEROPOINT ,MODAL DISP  =-124.17147
     AT 10-TH AEROPOINT, MODAL ROTATION  = -30.99385
     AT 10-TH AEROPOINT ,MODAL DISP PRIME = -30.38635
     AT 10-TH AEROPOINT, MODAL ROTATION PRIME =  -3.13811
     AT 10-TH AEROPOINT ,MODAL DISP DBLE PRIME =  -5.59814
     AT 10-TH AEROPT., MODAL ROT.  DBLE PRIME =  11.23637
     *** LEAVING HAINTS***

      FOR MODE NUMBER  1
     ******************
  PT.    H-VALUE          A-VALUE        HP-VALUE        AP-VALUE       HPP-VALUE
APP-VALUE       HD-VALUE        HDD-VALUE
     ----------------------------------------------------------------------------
  1  -0.15401E+01  -0.74041E+01  -0.26505E+01  -0.11606E+02  -0.14813E+01
0.38508E+02   0.00000E+00   0.00000E+00

  2  -0.23271E+01  -0.90542E+01  -0.31019E+01   0.41897E+00  -0.13621E+01
0.14500E+01   0.00000E+00   0.00000E+00

  3  -0.32109E+01  -0.75414E+01  -0.34261E+01   0.79799E+01  -0.12149E+01
-0.46401E+01   0.00000E+00   0.00000E+00

  4  -0.68320E+01  -0.71166E+01  -0.44000E+01   0.32047E-01  -0.10374E+01
0.21310E+01   0.00000E+00   0.00000E+00

  5  -0.14485E+02  -0.59894E+01  -0.71812E+01   0.84405E+00  -0.27125E+01
-0.23912E+00   0.00000E+00   0.00000E+00

  6  -0.33556E+02  -0.66212E+01  -0.92709E+01  -0.19033E+01  -0.79620E+00
-0.12593E+01   0.00000E+00   0.00000E+00

  7  -0.44685E+02  -0.84228E+01  -0.10287E+02  -0.32436E+01  -0.73941E+00
-0.69398E+00   0.00000E+00   0.00000E+00

  8  -0.66616E+02  -0.15185E+02  -0.16125E+02  -0.53830E+01  -0.71867E+01
-0.34197E+01   0.00000E+00   0.00000E+00

  9  -0.99850E+02  -0.25676E+02  -0.26406E+02  -0.78140E+01  -0.39630E+01
0.14973E+00   0.00000E+00   0.00000E+00

 10  -0.12417E+03  -0.30994E+02  -0.30386E+02  -0.31381E+01  -0.55981E+01
0.11236E+02   0.00000E+00   0.00000E+00
***
```

*****similar output for modes 2 to 6 is deleted****

```
***
     *** ENTERED TSNCAL ***
      IKAP =  1
     TANGENT X-,Y-,Z-COMPONENTS AT AEROPOINT 1 ARE
        -0.3163          0.9060          0.2813
     STRU. SWEEP ANGLE OF BLADE AT  1-TH AEROPOINT=  -25.0446
     TANGENT X-,Y-,Z-COMPONENTS AT AEROPOINT 2 ARE
        -0.2941          0.9157          0.2738
     STRU. SWEEP ANGLE OF BLADE AT  2-TH AEROPOINT=  -23.6928
****
```

*******lines deleted for brevity ***

```
***
```

```
    TANGENT X-,Y-,Z-COMPONENTS AT AEROPOINT 9 ARE
       0.6278          0.5409          -0.5598
    STRU. SWEEP ANGLE OF BLADE AT  9-TH AEROPOINT=   57.2568
    TANGENT X-,Y-,Z-COMPONENTS AT AEROPOINT10 ARE
       0.6444          0.4820          -0.5936
    STRU. SWEEP ANGLE OF BLADE AT 10-TH AEROPOINT=   61.1818

    STRUCTURAL PRE-TWIST OF BLADE AT  1 -TH AEROPOINT  =    75.8581
    STRUCTURAL PRE-TWIST OF BLADE AT  2 -TH AEROPOINT  =    74.8562
****
*******lines deleted for brevity ***
***
    STRUCTURAL PRE-TWIST OF BLADE AT  9 -TH AEROPOINT  =    80.8365
    STRUCTURAL PRE-TWIST OF BLADE AT 10 -TH AEROPOINT  =    82.4217
    *** LEAVING TSNCAL ***
    *** LEAVING RDNAS1 ***
      NUMBER OF MODES =  6
     1-TH MODAL FREQUENCY(OMEGA:RAD/SEC) =       1389.10
     2-TH MODAL FREQUENCY(OMEGA:RAD/SEC) =       2526.65
     3-TH MODAL FREQUENCY(OMEGA:RAD/SEC) =       4386.92
     4-TH MODAL FREQUENCY(OMEGA:RAD/SEC) =       5133.00
     5-TH MODAL FREQUENCY(OMEGA:RAD/SEC) =       6692.79
     6-TH MODAL FREQUENCY(OMEGA:RAD/SEC) =       7270.98
    NUMBER OF AEROPOINTS(NAEROP)=   10
      X-,Y-,Z- COORD OF AEROPOINT NO.  1 =-2.513537   4.250000    0.725816
      X-,Y-,Z- COORD OF AEROPOINT NO.  2 = -2.597100  4.500000    0.801900
****
*******lines deleted for brevity ***
***
      X-,Y-,Z- COORD OF AEROPOINT NO.  9 = 1.293340  11.755300   -1.181533
      X-,Y-,Z- COORD OF AEROPOINT NO. 10 =  1.837465 12.200000   -1.676337
      X-,Y-,Z- COORD OF STLINE POINT   1 =  1.803263  6.125000   -0.460014
      X-,Y-,Z- COORD OF STLINE POINT   2 =  1.808957  6.250000   -0.481173
****
*******lines deleted for brevity ***
***
      X-,Y-,Z- COORD OF STLINE POINT   9 =  2.685601  9.625000   -1.592055
      X-,Y-,Z- COORD OF STLINE POINT  10 =  2.934168 10.375000   -1.959611
****
*******lines deleted for brevity ***
***
     REF. SEMI-CHORD (AT THE ROOT) =      2.24211
        0.24268E+01  0.24557E+01  0.24843E+01  0.24517E+01  0.25051E+01
0.22884E+01 0.20388E+01 0.16567E+01 0.12889E+01 0.10740E+01

    NUMBER OF NODES ON THE LEADING EDGE(KYL)=    18
    NUMBER OF NODES ON THE TRAILING EDGE(KYT)=    18
 *** LEAVING ROUTINE ASTROP ***

    COMPONENTS OF SVEC--------------------(chordline( streamline) vector)
  0.88942      0.38632     -0.24432
  0.89710      0.35631     -0.26124
  0.90340      0.32706     -0.27731
  0.94398      0.09971     -0.31458
  0.87863     -0.36903     -0.30302
  0.71770     -0.64151     -0.27088
  0.65667     -0.71092     -0.25174
```

```
  0.57670    -0.79248    -0.19847
  0.54009    -0.82640    -0.15925
  0.51058    -0.84965    -0.13188
    COMPONENTS OF TANV---------------------(tangent vector)
 -0.31635     0.90598     0.28129
 -0.29410     0.91571     0.27382
 -0.25498     0.93145     0.25958
 -0.04845     0.98323     0.17580
  0.38009     0.92417    -0.03800
  0.56967     0.77225    -0.28124
  0.60934     0.69795    -0.37625
  0.63241     0.59567    -0.49521
  0.62779     0.54088    -0.55976
  0.64439     0.48203    -0.59364
    COMPONENTS OF NVEC-----------------------(normal vector)
 -0.33002     0.17290    -0.92800
 -0.33679     0.16881    -0.92628
 -0.34320     0.16379    -0.92487
 -0.32684     0.15071    -0.93298
 -0.29406     0.08179    -0.95227
 -0.38961    -0.04753    -0.91970
 -0.44319    -0.09368    -0.89152
 -0.51067    -0.16007    -0.84470
 -0.54872    -0.20234    -0.81093
 -0.56796    -0.21812    -0.79362

 PT.     SEMICHD       SETTA        STAGGER       SWEEP ANG
 -----------------------------------------------------------
 1       2.42676      75.85810      14.14190     -25.04462
 2       2.45571      74.85620      15.14380     -23.69282
 3       2.48429      73.90004      16.09996     -21.33763
 4       2.45170      71.66442      18.33558     -10.50709
 5       2.50506      72.36114      17.63886      22.45675
 6       2.28843      74.28347      15.71653      39.44325
 7       2.03883      75.41933      14.58067      45.73715
 8       1.65669      78.55250      11.44750      53.43972
 9       1.28890      80.83649       9.16351      57.25675
10       1.07397      82.42165       7.57835      61.18180

    *** ENTERED RLENCA***
****
*******lines deleted for brevity ***
***
      STRIPW(  1 ) =   0.274364-----------------------(strip width)
      STRIPW(  2 ) =   0.272468
      STRIPW(  3 ) =   0.598613
      STRIPW(  4 ) =   0.989694
      STRIPW(  5 ) =   1.610702
      STRIPW(  6 ) =   1.376096
      STRIPW(  7 ) =   1.591950
      STRIPW(  8 ) =   1.569312
      STRIPW(  9 ) =   1.214444
      STRIPW( 10 ) =   0.859577
    *** LEAVING RLENCA***
```

3.8 Program Calling Tree

The following is the static calling tree for the 2DSTRIP code:

```
MAIN---- ASTROP---RDNAS1---ADISP1---ADDDIS

                                   |------AVEMV0------SEQNOD
                                   |------AVEMV1--NORMAL-- IQHSCU--UERTST--UGETIO
                                                                          |--USPKD
                                              |------SEQNOD
                                   |------AVEMV2-------SEQNOD


                                   |------HAINTS--FDDRP--FUNCD --IQHSCU--UERTST--UGETIO
                                                                                |--USPKD
                                              |--- FUNCD---IQHSCU ---UERTST---UGETIO
                                                                              USPKD
                                              |---RLENC---IQHSCU---UERTST---UGETIO
                                                                              USPKD
                                              |--- SEQNOD
                                              |---SPLINT--IQHSCU--UERTST--UGETIO
                                                                        |-USPKD


                                   |------LETEDG------DETLTN------SORTX
                                              |-RDLTNS------SEQNOD
                                                   |--SPLINT--IQHSCU--UERTST--UGETIO
                                                                             |-USPKD
                                              |SEQNOD
                                              | SORTX


                                   |------LOCGRI---LOCXZ--- IQHSCU---UERTST--- UGETIO
                                                                          |---USPKD
                                   |------TSNCAL--IQHSCU--UERTST----UGETIO
                                                                  |---USPKD
                                   |------TSNFAL--IQHSCU--UERTST--UGETIO
                                                                 |-USPKD


          |-------RDNAS-------RDDISP
                     |------RDMODS
                     |------SETB75------ROTATE


          |-------RLENCA------IQHSCU----UERTST------UGETIO
                                             |----USPKD
```

4. PROGRAM 2DASTROP

In this section the input and output for an example problem for using the 2DASTROP program is given. The source code is designated as *2dastrop.f*, and the input data for the code is provided in the input file *2dastrop.in*. In addition to this input file, 2DASTROP requires the structural characteristic information at the selected strips. This information was obtained by first executing 2DSTRIP program.

4.1 Dimension Statement for the Program

The program is dimensioned for a maximum of 20 strips, six modes and frequencies, and for 20 blades (phase angles). If the user needs to change these limits, the dimension statements have to be changed globally in the source code, and compiled for execution.

4.2 Description of Input Variables

The input is given through a data file named **2dastrop.in**. This file contains the standard (unit 5) input that the 2DASTROP code requires. Unless otherwise stated, real values are read in 8F10.4 format and integer values are read in 8I10 format.

Some lines of the input data are preceded by a line containing the names of the variables. These lines are an aid in preparing the input file and are read by the program but not used as data in the calculations.

The first line in the input file is the title card read in 20A4 format, used for identification of the structure to be analyzed. The rest of the input variables are described below in the order in which they appear in the input data file (see section 4.7 for an example input file).

variable: `P0`
type: real variable
description: static pressure in psi
example: `13.1023`

variable: `SPS`
type: real variable
description: speed of sound in feet per second
example: `1130.0`

variable: `NMODEU`
type: real variable (converted to integer value with in the program)

description: actual number of modes to be used in the flutter calculation (NMODEU<NMODE in the 2DSTRIP run)
example: `4.0`

variable: `NSEGS`
type: real variable (converted to integer value with in the program)
description: number of the first strip to be used in integration
example: `1.0`

variable: `CONFIG`
type: real variable (converted to integer value with in the program)
description: indicator for counter rotation
`CONFIG = 0.0` front rotor in a counter rotation setup
`CONFIG = 1.0` aft rotor in a counter rotation setup
example: `0.0`

variable: `RTIP`
type: real variable
description: blade tip radius in inches
example: `12.25`

variable: `UINFL`
type: real variable (converted to integer value with in the program)
description: indicator for inflow description
`UINFL = 0.0` uniform inflow
`UINFL > 0.0` number of points in the inflow velocity data set
example: `0.0`

Note: If `UINFL >0.0`, the velocity distribution (axial, and tangential) is read as input from unit 11 (see section 4.7)

variable: `NONROT`
type: integer variable
description: `NONROT = 0` non-rotating blades
`NONROT = 1` rotating blades
example: `1`

variable: `NATHE`
type: integer variable
description: indicator for subsonic cascade aerodynamic theory used
`NATHE = 22` Rao and Jones aerodynamic theory
example: `22`

variable: `NQUASI`
type: integer variable
description: indicator for quasi-steady aerodynamics
`NQUASI = 0` no quasi steady aerodynamics
`NQUASI = 1` quasi steady aerodynamics used
example: `0`

variable: IREAD
type: integer variable
description: unit number for reading 2DSTRIP output
example: 7

variable: ISOAFL
type: integer variable
description: option for isolated airfoil or cascade aerodynamic theory
ISOAFL = 0 cascade aerodynamics
ISOAFL = 1, isolated airfoil aerodynamics
example: 0

variable: IAUTO
type: integer variable
description: indicator for automatic flutter analysis
IAUTO = 0 no auto flutter analysis
IAUTO = 1, auto flutter analysis
example: 0

variable: INTEG
type: integer variable
description: indicator for numerical integration method used
INTEG = 0 Newton-Cotes formula for spanwise integration
INTEG = 1 trapezoidal rule used
example: 1

variable: FSF
type: real variable
description: frequency scale factors on calculated frequencies up to NMODEU modes in 8F10.0 format.
example: 1.0 1.0 1.0 1.0 1.0 1.0

variable: GDAMP
type: real variable
description: generalized structural damping ratio values for each mode up to NMODEU modes in 8F10.0 format.
example: 0.0 0.0 0.0 0.0 0.0 0.0

variable: RPM
type: real variable
description: rotor rotational speed in revolutions per minute
example: 6080.0

variable: FRF
type: real variable
description: estimated flutter frequency in HZ to start aeroelastic calculations. An initial value may be equal to one of the natural frequencies of the blade
example: 261.0

variable: MACH
type: real variable
description: free stream Mach number
example: 0.60

variable: BR
type: real variable
description: reference chord
example: 1.0

variable: NBLD
type: real variable (converted to integer in the program)
description: number of phase angles to be evaluated
NBLD = 1 calculate for the phase angle given in SIGMA
NBLD >1, calculate for all phase angles 1 through BLDN
example: 1.0

variable: BLDN
type: real variable
description: number of blades on the rotor
example: 8.0

variable: SIGMA
type: real variable
description: interblade phase angle in degrees, if NBLD=1. Ignored if NBLD >1
example: 225.0

variable: SWEEP
type: real variable
description: user input sweep angle in degrees
example: 0.0

variable: GAP/CHD
type: real variable
description: user input gap to chord ratio value
example: 0.0

variable: STAG
type: real variable
description: user input stagger angle in degrees
example: 0.0

NOTE: User input values of SWEEP, GAP/CHD, and STAG are used only if NONROT = 0

variable: NITER
type: integer variable
description: number of iterations for flutter convergence
example: 3 (usually enough if the assumed frequency is near the natural frequency of the mode of interest).

4.3 Additional Input Files

The program uses the strip data obtained from 2DSTRIP on unit 7. In addition, if UINFL is not zero, a velocity distribution file, for example VEL.IN (see below), should be linked to unit 11.

4.4 Additional Notes

The aeroelastic analysis assumes the leading edge as the reference axis, the axis to which values of pitching and plunging values are referred. The iterative procedure for obtaining the flutter condition is explained in appendix B of Ref. 2.

The program is implemented on Cray YMP at NASA Lewis Research Center. However, the program can be implemented on a workstation or personal computer. It required about 1.2 MW memory, and took about 27 seconds to compile and about 32 seconds to execute for the example given in section 4.7.

4.5 Job Run Stream on Cray YMP

A sample Cray job stream to run 2DASTROP at the NASA Lewis Research Center is given in this section. The strip data file, fort7.2dstrip, from 2DSTRIP is linked to unit 7. The source code, 2dastrop.f, is compiled using cft77 with standard options. The input is contained in the file named 2dastrop.in. The standard unit 6 output is written to a file named 2dastrop.out. The rest of the file contains UNICOS and Cray related commands.

```
#! /bin/csh
# QSUB -r M55
# QSUB -lM 1.2Mw
# QSUB
/bin/rm 2dastrop.out
ln fort7.2dstrip fort.7***************************(file created by 2DSTRIP)
ln vel.in fort.11 ********************************************(if needed)
cft77 -V -a static 2dastrop.f
segldr -o 2dastrop 2dastrop.o
time 2dastrop<2dastrop.in>2dastrop.out
```

4.6 Description of Output file

Unit 6 (2dastrop.out) output: Only one output file, 2dastrop.out, is generated. This output contains

(1) the atmospheric conditions;

(2) a printout of the fort.7 file (obtained from 2DSTRIP program). This is printed to check for proper reading by 2DASTROP. This printout includes

(a)the rigid pitching (α-value) and plunging (h-value) values) at aeropoints (strips) for all the modes.
(b) the leading edge coordinates, the tangent, streamline and normal vectors at each strip, setting angles, sweep angles, semichord values and strip width.
(c) the generalized mass, frequencies and damping values;

(3) for the given Mach number, and for the reference frequency, 2DASTROP prints, in a tabular form

the helical Mach number, effective Mach number, reduced frequency, semichord and gap/chord ratio, stagger and sweep angle at each strip (aeropoint);

(4) the eigen values indicating frequency and damping.

4.7 Example case: Calculation of Unsteady Aerodynamic Forces at the Strips and Aeroelastic Stability of SR3CX2 propfan

In this section, the actual input and output are given for the SR3CX2 propfan. This propfan fluttered in experiments, Refs. 6-7. The air static pressure (PO) is 13.1023 psi, and the speed of sound(SPS) is 1130 feet per second. Four modes (NMODEU=4) are used in the aeroelastic stability calculation. The example is not for counter rotation (CONFIG=0.0). The modal data for the strips (pitching and plunging values) are available on unit 7 (IREAD=7). There are no scaling factors on the frequency, and the structural damping is zero. The propfan is rotating at 6080 RPM (RPM=6080). The free stream Mach number (MACH) is 0.60, and the assumed flutter frequency (FRF) is 261 HZ. The calculation of the aeroelastic stability is required at only one (NBLD=1) inter blade phase angle (SIGMA) of 225. degrees. The propfan has eight blades (BLDN=8). The flutter calculations are done for three iterations (NITERF=3). The iterations are indicated as ifast=1,2,3 in the output.

Input file (2dastrop.in)

```
  FLUTTER ANALYSIS OF SR3CX2 PROPFAN
   P0(psi)  SPS(fps)    NMODEU      NSEGS     CONFIG       RTIP      UINFL
   13.1023    1130.0       4.0       1.00        0.0      12.25        0.0
    NONROT     NATHE    NQUASI      IREAD     ISOAFL      IAUTO      INTEG
        01        22        00         07         00          0          1
FSF(Frequency Scaling Factors, I=1,NMODEU)
       1.0   1.00000      1.00        1.0        1.0        1.0
GDAMP(Generalized DAMPing) ratios (I=1,NMODEU)
       0.0       0.0       0.0        0.0        0.0        0.0
       RPM  FRF (HZ)      MACH         BR       NBLD       BLDN
     6080.    261.00      0.60        1.0        1.0        8.0
     SIGMA
     225.0
     SWEEP   GAP/CHD   STAGGER
       0.0       0.0       0.0
   NITERF
        3
```

Input file (vel.in)

The following input file should be provided if UINFL is not zero. In this example, the velocity distribution is given at 15 radial stations (UINFL=15).

```
  J        r/R          v-axial        v-tang
  1     0.41081017    -0.16728285    -0.05450882
  2     0.44025650    -0.16872721    -0.05451032
  3     0.47642539    -0.17227991    -0.05357961
  4     0.51606186    -0.18472728    -0.05425016
  5     0.56907335    -0.20119552    -0.05350141
  6     0.62218097    -0.21676765    -0.05081225
  7     0.67530677    -0.23388092    -0.04875675
  8     0.73462527    -0.25145703    -0.04527572
  9     0.79412632    -0.26515110    -0.03736664
 10     0.85373921    -0.27467869    -0.03441140
 11     0.90105147    -0.27602396    -0.04618262
 12     0.94203777    -0.26435932    -0.07675376
 13     0.97108997    -0.23443168    -0.10637459
 14     0.98845123    -0.18557730    -0.11354895
 15     1.00000000    -0.09629623    -0.02621240
```

Unit 6 output file (2dastrop.out)

The output information is printed, and given here in the order mentioned in section 4.6, and is self explanatory. In this report, most of the output is deleted, and only key output is retained to help the user to check his output before going through the large printed output. For easy debugging and understanding, the subroutine, from which the output is generated, is identified by statements '** ENTERED (SUBROUTINE) **' and '**LEAVING (SUBROUTINE) **'.

```
                    FLUTTER ANALYSIS OF SR3CX2 PROPFAN

      STATIC PRESSURE(PSI) =         13.102
      SPEED OF SOUND (FT/SEC) =       1130.000
      AIR DENSITY (LBF-SEC**2/IN**4) =  0.99759944E-07

       *** DATA FROM 2DSTRIP PROGRAM ***

      NO. OF MODES=  6
      NO.OF AEROPOINTS=   10

       FOR MODE NUMBER  1
      ********************
   PT.    H-VALUE         A-VALUE         HP-VALUE        AP-VALUE        HPP-VALUE
APP-VALUE
   --------------------------------------------------------------------------------
   1  -0.15401E+01   -0.74041E+01   -0.26505E+01   -0.11606E+02   -0.14813E+01
0.38508E+02

   2  -0.23271E+01   -0.90542E+01   -0.31019E+01    0.41897E+00   -0.13621E+01
0.14500E+01

   3  -0.32109E+01   -0.75414E+01   -0.34261E+01    0.79799E+01   -0.12149E+01
-0.46401E+01

   4  -0.68320E+01   -0.71166E+01   -0.44000E+01    0.32047E-01   -0.10374E+01
0.21310E+01

   5  -0.14485E+02   -0.59894E+01   -0.71812E+01    0.84405E+00   -0.27125E+01
-0.23912E+00

   6  -0.33556E+02   -0.66212E+01   -0.92709E+01   -0.19033E+01   -0.79620E+00
-0.12593E+01

   7  -0.44685E+02   -0.84228E+01   -0.10287E+02   -0.32436E+01   -0.73941E+00
-0.69398E+00

   8  -0.66616E+02   -0.15185E+02   -0.16125E+02   -0.53830E+01   -0.71867E+01
-0.34197E+01

   9  -0.99850E+02   -0.25676E+02   -0.26406E+02   -0.78140E+01   -0.39630E+01
0.14973E+00

  10  -0.12417E+03   -0.30994E+02   -0.30386E+02   -0.31381E+01   -0.55981E+01
0.11236E+02

***
****similar output for modes 2 thru 6 are deleted****
***
     ** FREQUENCIES (OMEGA: RAD/SEC) **
  ************************************************
     0.138910E+04  0.252665E+04  0.438692E+04
0.513300E+04  0.669279E+04  0.727098E+04
     ** GENERALIZED MASS **
  ************************************************
     0.100000E+01  0.100000E+01  0.100000E+01
0.100000E+01  0.100000E+01  0.100000E+01
```

```
     ** LEADING EDGE COORDINATES **
   ************************************************
     -.251354E+01  0.425000E+01  0.725820E+00
-.259710E+01  0.450000E+01  0.801900E+00
-.267126E+01  0.475000E+01  0.874010E+00
-.282545E+01  0.563610E+01  0.108251E+01
-.257705E+01  0.697390E+01  0.117613E+01
-.148480E+01  0.887360E+01  0.808620E+00
-.809750E+00  0.971140E+01  0.431450E+00
0.319150E+00  0.108758E+02  -.364180E+00
0.129334E+01  0.117553E+02  -.118153E+01
0.183747E+01  0.122000E+02  -.167634E+01
     ** TANGENT VECTOR AT AEROPOINTS **
   ************************************************
     -.316350E+00  0.905980E+00  0.281290E+00
-.294100E+00  0.915710E+00  0.273820E+00
-.254980E+00  0.931450E+00  0.259580E+00
-.484500E-01  0.983230E+00  0.175800E+00
0.380090E+00  0.924170E+00  -.380000E-01
0.569670E+00  0.772250E+00  -.281240E+00
0.609340E+00  0.697950E+00  -.376250E+00
0.632410E+00  0.595670E+00  -.495210E+00
0.627790E+00  0.540880E+00  -.559760E+00
0.644390E+00  0.482030E+00  -.593640E+00
     ** CHORD LINE VECTOR AT AEROPOINTS **
   ************************************************
     0.889420E+00  0.386320E+00  -.244320E+00
0.897100E+00  0.356310E+00  -.261240E+00
0.903400E+00  0.327060E+00  -.277310E+00
0.943980E+00  0.997100E-01  -.314580E+00
0.878630E+00  -.369030E+00  -.303020E+00
0.717700E+00  -.641510E+00  -.270880E+00
0.656670E+00  -.710920E+00  -.251740E+00
0.576700E+00  -.792480E+00  -.198470E+00
0.540090E+00  -.826400E+00  -.159250E+00
0.510580E+00  -.849650E+00  -.131880E+00
     ** NORMAL VECTOR AT AEROPOINTS **
   ************************************************
     -.330020E+00  0.172900E+00  -.928000E+00
-.336790E+00  0.168810E+00  -.926280E+00
-.343200E+00  0.163790E+00  -.924870E+00
-.326840E+00  0.150710E+00  -.932980E+00
-.294060E+00  0.817900E-01  -.952270E+00
-.389610E+00  -.475300E-01  -.919700E+00
-.443190E+00  -.936800E-01  -.891520E+00
-.510670E+00  -.160070E+00  -.844700E+00
-.548720E+00  -.202340E+00  -.810930E+00
-.567960E+00  -.218120E+00  -.793620E+00
     ** SETTING ANGLE AT 75% SPAN **
   ************************************************
     0.611998E+02
     * REF. SEMI-CHORD AT ROOT FROM ASTROP2 *
   ************************************************
     0.224211E+01
     ** TRAILING EDGE COORDINATES **
   ************************************************
     0.190927E+01  0.425000E+01  -.310860E+00
0.187360E+01  0.450000E+01  -.313200E+00
```

```
0.185052E+01  0.475000E+01  -.320660E+00
0.180182E+01  0.563610E+01  -.391330E+00
0.189699E+01  0.697390E+01  -.633690E+00
0.242780E+01  0.887360E+01  -.126110E+01
0.271521E+01  0.971140E+01  -.163295E+01
0.307304E+01  0.108758E+02  -.220453E+01
0.326029E+01  0.117553E+02  -.261242E+01
0.329417E+01  0.122000E+02  -.277819E+01
      ** STLP COORDINATES **
  ****************************************************
      0.180326E+01  0.612500E+01  -.460010E+00
0.180896E+01  0.625000E+01  -.481170E+00
0.181735E+01  0.637500E+01  -.503850E+00
0.180326E+01  0.612500E+01  -.460010E+00
0.182500E+01  0.512500E+01  -.342020E+00
0.179999E+01  0.593750E+01  -.431150E+00
0.186792E+01  0.681250E+01  -.595070E+00
0.222998E+01  0.825000E+01  -.102179E+01
0.268560E+01  0.962500E+01  -.159206E+01
0.293417E+01  0.103750E+02  -.195961E+01
      ** SETTING ANGLES AT AEROPOINTS **
  ****************************************************
      0.758581E+02  0.748562E+02  0.739000E+02
0.716644E+02  0.723611E+02  0.742835E+02
0.754193E+02  0.785525E+02  0.808365E+02
0.824217E+02
      ** SWEEP ANGLES AT AEROPOINTS **
  ****************************************************
      -.250446E+02  -.236928E+02  -.213376E+02
-.105071E+02  0.224568E+02  0.394433E+02
0.457371E+02  0.534397E+02  0.572568E+02
0.611818E+02
      ** STAGGER ANGLES AT AEROPOINTS **
  ****************************************************
      0.141419E+02  0.151438E+02  0.161000E+02
0.183356E+02  0.176389E+02  0.157165E+02
0.145807E+02  0.114475E+02  0.916351E+01
0.757835E+01
      ** SEMICHORD VALUES AT AEROPOINTS **
  ****************************************************
      0.242676E+01  0.245571E+01  0.248429E+01
0.245170E+01  0.250506E+01  0.228843E+01
0.203883E+01  0.165669E+01  0.128890E+01
0.107397E+01

      ** LENGTH BETWEEN GRID POINTS ALONG LEADING EDGE **
  *************************************************************
         0.00000    0.55242    1.08972    1.60939    2.11663    2.62613    3.15489
3.70686    4.28162    4.88604
         5.52452    6.20173    6.92168    7.69233    8.51897    9.39185   10.31549
10.81967
      ** STRIP WIDTH **
  **************************************
         0.27436    0.27247    0.59861    0.98969    1.61070    1.37610    1.59195
1.56931    1.21444    0.85958

 *** END OF ECHOING DATA FROM 2DSTRIP ***
```

```
 FREQUENCY FACTORS      1.000      1.000      1.000      1.000

 MODE. GEN. MASS    FREQ(RAD/S)      DAMP.
 --------------------------------------------------
  1   0.10000E+01   0.13891E+04   0.00000E+00
  2   0.10000E+01   0.25266E+04   0.00000E+00
  3   0.10000E+01   0.43869E+04   0.00000E+00
  4   0.10000E+01   0.51330E+04   0.00000E+00

    RPM =       6080.000
 ----------------------------------------------------------------------------
  PT.        STN          SWEEP ANG.      SEMICHD         GAP/CHD        STAGGER
 SETANG
 ----------------------------------------------------------------------------
  1       5.18750      -25.04462       2.42676         0.83944        14.14190
 75.85810
  2       5.37500      -23.69282       2.45571         0.85953        15.14380
 74.85620
  3       5.56250      -21.33763       2.48429         0.87928        16.09996
 73.90004
  4       5.88055      -10.50709       2.45170         0.94191        18.33558
 71.66442
  5       6.04945       22.45675       2.50506         0.94833        17.63886
 72.36114
  6       7.40555       39.44325       2.28843         1.27081        15.71653
 74.28347
  7       8.26195       45.73715       2.03883         1.59133        14.58067
 75.41933
  8       9.56290       53.43972       1.65669         2.26677        11.44750
 78.55250
  9      10.69015       57.25675       1.28890         3.25705         9.16351
 80.83649
 10      11.28750       61.18180       1.07397         4.12729         7.57835
 82.42165
 ----------------------------------------------------------------------------
    ** number of modes used in the analysis **      4
    ** ENTERED SMAP(NB,NMODES) **     1    4
    *** LEAVING SMAP ***
 ----------------------------------------------------------------------------
                       **  FLUTTER ANALYSIS **
 ----------------------------------------------------------------------------
 No. of ITER. for flutter convergence 3
 ifast = 1-----------------------------------------------(first iteration)
    *** ENTERED PRPAN ***

    FREE STREAM MACH NO   =       0.60000

    ** ENTERED RELVEL(SPEED OF SOUND)= ** 0.13560E+05
    ***LEAVING RELVEL***

    REFERENCE FREQUENCY(RAD/SEC & HZ) =    1639.91137   261.00000

  IPRNT= 0
 ----------------------------------------------------------------------------
  PT.        STN            HMACH        SWEEP ANG.       EFF. M       SEMICHD
 RED. FREQ        GAP/CHD        STAGGER          SETANG
 ----------------------------------------------------------------------------
  1       5.18750        0.63323      -25.04462        0.57369        2.42676
```

```
0.51157        0.83944      14.14190      76.80836

  2        5.37500      0.63723     -23.69282      0.58352      2.45571
0.50896        0.85953      15.14380      75.99482

  3        5.56250      0.64143     -21.33763      0.59746      2.48429
0.50287        0.87928      16.09996      75.20042

  4        5.88055      0.65774     -10.50709      0.64671      2.45170
0.45848        0.94191      18.33558      72.33271

  5        6.04945      0.68577      22.45675      0.63376      2.50506
0.47803        0.94833      17.63886      67.97589

  6        7.40555      0.73146      39.44325      0.56488      2.28843
0.48994        1.27081      15.71653      62.12168

  7        8.26195      0.75388      45.73715      0.52617      2.03883
0.46861        1.59133      14.58067      59.64454

  8        9.56290      0.78808      53.43972      0.46943      1.65669
0.42680        2.26677      11.44750      56.24627

  9       10.69015      0.81715      57.25675      0.44198      1.28890
0.35268        3.25705       9.16351      53.96537

 10       11.28750      0.83327      61.18180      0.40166      1.07397
0.32336        4.12729       7.57835      52.89609
  ------------------------------------------------------------------------
    ** ENTERED AMAP **
    W0      =  1639.911365
    XMACHA      =      0.600000
    NUMBER OF SEGMENTS, N =  9
    THE CORRESPONDING WEIGHTING MATRIX FOR INTEGRATION IS:
        0.50000000
        1.00000000
        1.00000000
        1.00000000
        1.00000000
        1.00000000
        1.00000000
        1.00000000
        1.00000000
        0.50000000
    TRAPEZOIDAL FORMULA FOR INTEGRATION
    ----------------------------------------------------
    ENTERING DEINVE
    LEAVING DEINVE
 LEAVING AMAP
      REF FREQ =   0.164E+04 RAD/SEC,   =   0.261E+03 HZ
    EIGZC: INFER AND IER =      0     0
     INTER BLADE PHASE ANGLE =      225.000
     1 -TH DAMPING(HZ) =    -0.14137E+03
     1 -TH FREQ (HZ) =     0.78911E+03

     2 -TH DAMPING(HZ) =    -0.29494E+03
     2 -TH FREQ (HZ) =     0.19294E+03
```

```
     3 -TH DAMPING(HZ) =    0.55686E+01
     3 -TH FREQ (HZ) =    0.27232E+03

     4 -TH DAMPING(HZ) =   -0.10921E+03
     4 -TH FREQ (HZ) =    0.36121E+03

    SMALLEST DAMPING VALUE =  0.55686E+01 HZ
    CORRESPONDING FREQUENCY =  0.27232E+03 HZ
    CORRESPONDING INTERBLADE PHASE ANGLE =  225.0 DEG
ifast = 2---------------------------------------------(second iteration)
    *** ENTERED PRPAN ***

    FREE STREAM MACH NO  =      0.60000

    ** ENTERED RELVEL(SPEED OF SOUND)= ** 0.13560E+05
    ***LEAVING RELVEL***

    REFERENCE FREQUENCY(RAD/SEC & HZ) =   1711.05389   272.32268

  IPRNT= 0

  -------------------------------------------------------------------------
  PT.        STN          HMACH        SWEEP ANG.       EFF. M       SEMICHD
RED. FREQ        GAP/CHD       STAGGER        SETANG
  -------------------------------------------------------------------------
  1       5.18750       0.63323      -25.04462        0.57369       2.42676
0.53376        0.83944       14.14190       76.80836

  2       5.37500       0.63723      -23.69282        0.58352       2.45571
0.53104        0.85953       15.14380       75.99482

  3       5.56250       0.64143      -21.33763        0.59746       2.48429
0.52469        0.87928       16.09996       75.20042

  4       5.88055       0.65774      -10.50709        0.64671       2.45170
0.47837        0.94191       18.33558       72.33271

  5       6.04945       0.68577       22.45675        0.63376       2.50506
0.49876        0.94833       17.63886       67.97589

  6       7.40555       0.73146       39.44325        0.56488       2.28843
0.51120        1.27081       15.71653       62.12168

  7       8.26195       0.75388       45.73715        0.52617       2.03883
0.48894        1.59133       14.58067       59.64454

  8       9.56290       0.78808       53.43972        0.46943       1.65669
0.44532        2.26677       11.44750       56.24627

  9      10.69015       0.81715       57.25675        0.44198       1.28890
0.36798        3.25705        9.16351       53.96537

 10      11.28750       0.83327       61.18180        0.40166       1.07397
0.33739        4.12729        7.57835       52.89609
  -------------------------------------------------------------------------

    ** ENTERED AMAP **
    W0      =  1711.053886
```

```
    XMACHA      =      0.600000
***
****lines deleted for brevity****
***
 LEAVING AMAP
       REF FREQ =   0.171E+04 RAD/SEC,  =   0.272E+03 HZ
     EIGZC: INFER AND IER =      0    0
      INTER BLADE PHASE ANGLE =      225.000
      1 -TH DAMPING(HZ) =   -0.13849E+03
      1 -TH FREQ (HZ) =    0.79085E+03

      2 -TH DAMPING(HZ) =   -0.30141E+03
      2 -TH FREQ (HZ) =    0.21534E+03

      3 -TH DAMPING(HZ) =    0.15226E+01
      3 -TH FREQ (HZ) =    0.26961E+03

      4 -TH DAMPING(HZ) =   -0.10627E+03
      4 -TH FREQ (HZ) =    0.36589E+03

     SMALLEST DAMPING VALUE =  0.15226E+01 HZ
     CORRESPONDING FREQUENCY =  0.26961E+03 HZ
     CORRESPONDING INTERBLADE PHASE ANGLE =  225.0 DEG
 ifast = 3-----------------------------------------(third iteration)
     *** ENTERED PRPAN ***

     FREE STREAM MACH NO  =      0.60000

     ** ENTERED RELVEL(SPEED OF SOUND)= ** 0.13560E+05
     ***LEAVING RELVEL***


     REFERENCE FREQUENCY(RAD/SEC & HZ) =   1693.98904   269.60673

   IPRNT= 0
   ------------------------------------------------------------------------
   PT.        STN          HMACH        SWEEP ANG.       EFF. M       SEMICHD
 RED. FREQ        GAP/CHD       STAGGER          SETANG
   ------------------------------------------------------------------------
   1       5.18750      0.63323     -25.04462       0.57369       2.42676
 0.52844       0.83944      14.14190       76.80836

   2       5.37500      0.63723     -23.69282       0.58352       2.45571
 0.52574       0.85953      15.14380       75.99482

   3       5.56250      0.64143     -21.33763       0.59746       2.48429
 0.51945       0.87928      16.09996       75.20042

   4       5.88055      0.65774     -10.50709       0.64671       2.45170
 0.47360       0.94191      18.33558       72.33271

   5       6.04945      0.68577      22.45675       0.63376       2.50506
 0.49379       0.94833      17.63886       67.97589

   6       7.40555      0.73146      39.44325       0.56488       2.28843
 0.50610       1.27081      15.71653       62.12168

   7       8.26195      0.75388      45.73715       0.52617       2.03883
```

```
0.48407        1.59133      14.58067      59.64454

  8       9.56290       0.78808      53.43972       0.46943       1.65669
0.44088        2.26677      11.44750      56.24627

  9      10.69015       0.81715      57.25675       0.44198       1.28890
0.36431        3.25705       9.16351      53.96537

 10      11.28750       0.83327      61.18180       0.40166       1.07397
0.33403        4.12729       7.57835      52.89609
  -------------------------------------------------------------------------
     ** ENTERED AMAP **
     W0      =  1693.989044
     XMACHA      =       0.600000
***
****lines deleted for brevity****
***

 LEAVING AMAP
       REF FREQ =    0.169E+04 RAD/SEC,   =    0.270E+03 HZ
     EIGZC: INFER AND IER =      0    0
      INTER BLADE PHASE ANGLE =       225.000
      1 -TH DAMPING(HZ) =    -0.13918E+03
      1 -TH FREQ (HZ) =     0.79043E+03

      2 -TH DAMPING(HZ) =    -0.30001E+03
      2 -TH FREQ (HZ) =     0.20992E+03

      3 -TH DAMPING(HZ) =     0.24343E+01
      3 -TH FREQ (HZ) =     0.27027E+03

      4 -TH DAMPING(HZ) =    -0.10693E+03
      4 -TH FREQ (HZ) =     0.36481E+03

     SMALLEST DAMPING VALUE =  0.24343E+01 HZ
     CORRESPONDING FREQUENCY =  0.27027E+03 HZ
     CORRESPONDING INTERBLADE PHASE ANGLE =  225.0 DEG
```

The calculated damping value obtained above for M (Mach number) = 0.6, and for the phase angle of 225 degrees is positive indicating instability. The 2DASTROP program is again run for M=0.55, and the following eigen values are obtained after 3rd iteration.

```
 ifast = 3-----------------------------------------------(third iteration)
     *** ENTERED PRPAN ***

     FREE STREAM MACH NO  =       0.55000

     ** ENTERED RELVEL(SPEED OF SOUND)= ** 0.13560E+05
     ***LEAVING RELVEL***

     REFERENCE FREQUENCY(RAD/SEC & HZ) =   1679.50802   267.30200

  IPRNT= 0
  -------------------------------------------------------------------------
  PT.        STN          HMACH        SWEEP ANG.      EFF. M      SEMICHD
RED. FREQ        GAP/CHD       STAGGER         SETANG
```

```
-----------------------------------------------------------------------------
  1       5.18750        0.58607      -25.04462        0.53097        2.42676
0.56608        0.83944        14.14190       76.80836

  2       5.37500        0.59039      -23.69282        0.54063        2.45571
0.56260        0.85953        15.14380       75.99482

  3       5.56250        0.59492      -21.33763        0.55414        2.48429
0.55527        0.87928        16.09996       75.20042

  4       5.88055        0.61247      -10.50709        0.60220        2.45170
0.50426        0.94191        18.33558       72.33271

  5       6.04945        0.64248       22.45675        0.59376        2.50506
0.52256        0.94833        17.63886       67.97589

  6       7.40555        0.69104       39.44325        0.53366        2.28843
0.53112        1.27081        15.71653       62.12168

  7       8.26195        0.71473       45.73715        0.49885        2.03883
0.50622        1.59133        14.58067       59.64454

  8       9.56290        0.75071       53.43972        0.44718        1.65669
0.45887        2.26677        11.44750       56.24627

  9      10.69015        0.78118       57.25675        0.42252        1.28890
0.37783        3.25705         9.16351       53.96537

 10      11.28750        0.79802       61.18180        0.38467        1.07397
0.34580        4.12729         7.57835       52.89609
-----------------------------------------------------------------------------
    ** ENTERED AMAP **
    WO      =  1679.508017
    XMACHA      =      0.550000
 LEAVING AMAP
      REF FREQ =   0.168E+04 RAD/SEC,   =   0.267E+03 HZ
    EIGZC: INFER AND IER =       0    0
     INTER BLADE PHASE ANGLE =          225.000
     1 -TH DAMPING(HZ) =    -0.13124E+03
     1 -TH FREQ (HZ) =     0.78521E+03

     2 -TH DAMPING(HZ) =    -0.30854E+03
     2 -TH FREQ (HZ) =     0.23974E+03

     3 -TH DAMPING(HZ) =    -0.25824E+01
     3 -TH FREQ (HZ) =     0.26804E+03

     4 -TH DAMPING(HZ) =    -0.97135E+02
     4 -TH FREQ (HZ) =     0.36791E+03

    SMALLEST DAMPING VALUE = -0.25824E+01 HZ
    CORRESPONDING FREQUENCY =  0.26804E+03 HZ
    CORRESPONDING INTERBLADE PHASE ANGLE =  225.0 DEG
```

The calculated damping shows a negative value for M=0.55, indicating the blade is stable. The flutter Mach number can be interpolated to zero damping, to give about 0.575, which is very close to the experimental value of 0.58.

4.8 Program Calling Tree

The following is the static calling tree for the 2DASTROP code:

```
MAIN --------DATAP

     |------PRPAN-----------AMAP------ATITLE
                            |------CTVP
                            |------DEINVE
                            |------NCOTEW
                            |------PRMATX------REALMP
                            |------RAO------------GAUSSR
                                           |------ LM
                            |------SSCASC---------AKAPM
                                           |-------AKAPPA
                                           |-------AKP2
                                           |-------ALAMDA
                                           |-------ASYCON
                                           |-------DLKAPM
                                           |-------DRKAPM
                |-------- EIGEN2------EIGZC------ELZHC
                                           |---ELZVC------UERTST-----UGETIO
                                                                 |- --USPKD
                                           |---UERTST------UGETIO
                                                        |-----USPKD
                |------ RELVEL ------INFLOW
                            |------INTERP
                            |------VCROSP
     |------QNEWTU------PRPAN------AMAP------ATITLE
                            |------CTVP
                            |------DEINVE
                            |------NCOTEW
                            |------PRMATX------REALMP
                            |------RAO  ------------GAUSSR
                                           |------ LM
                            |------SSCASC---------AKAPM
                                           |-------AKAPPA
                                           |-------AKP2
                                           |-------ALAMDA
                                           |-------ASYCON
                                           |-------DLKAPM
                                           |-------DRKAPM
                            |-------- EIGEN2------EIGZC---ELZHC
                                                     |-----ELZVC--UERTST-UGETIO
                                                                         |--USPKD
                                                     |------UERTST-----------UGETIO
                                                                  |-----------USPKD
                            |------ RELVEL ------INFLOW
                                           |------INTERP
                                           |------VCROSP
     |------READMV
     |------RPLACE
     |------SMAP
```

5. ACKNOWLEDGEMENTS

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13. ABSTRACT ***(Maximum 200 words)***

This manual describes the input data required for using the second version of the ASTROP2 (Aeroelastic STability and Response Of Propulsion systems - 2 dimensional analysis) computer code. In ASTROP2, version 2.0, the program is divided into two modules: 2DSTRIP, which calculates the structural dynamic information; and 2DASTROP, which calculates the unsteady aerodynamic force coefficients from which the aeroelastic stability can be determined. In the original version of ASTROP2, these two aspects were performed in a single program. The improvements to version 2.0 include an option to account for counter rotation, improved numerical integration, accommodation for non-uniform inflow distribution, and an iterative scheme to flutter frequency convergence. ASTROP2 can be used for flutter analysis of multibladed structures such as those found in compressors, turbines, counter rotating propellers or propfans. The analysis combines a two-dimensional, unsteady cascade aerodynamics model and a three dimensional, normal mode structural model using strip theory. The flutter analysis is formulated in the frequency domain resulting in an eigenvalue determinant. The flutter frequency and damping can be inferred from the eigenvalues.

14. SUBJECT TERMS

Aeroelastic stability; Flutter; Normal modes; Cascades; NASTRAN; Finite element analysis; Strip theory; Eigenvalues; Pitching and plunging; Subsonic axial flow; Propfans

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