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# User's Guide for ECAP2D: An Euler Unsteady Aerodynamic and Aeroelastic Analysis Program for Two Dimensional Oscillating Cascades

Version 1.0

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# User's Guide for ECAP2D : An Euler Unsteady Aerodynamic and Aeroelastic Analysis Program for Two Dimensional Oscillating Cascades

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**SUMMARY**

This guide describes the input data required for using ECAP2D( Euler Cascade Aeroelastic Program - Two Dimensional). ECAP2D can be used for steady or unsteady aerodynamic and aeroelastic analysis of two dimensional cascades. Euler equations are used to obtain aerodynamic forces. The structural dynamic equations are written for a rigid typical section undergoing pitching (torsion) and plunging (bending) motion. The solution methods include harmonic oscillation method, influence coefficient method, pulse response method, and time integration method. For harmonic oscillation method, example inputs and outputs are provided for pitching motion and plunging motion. For the rest of the methods, input and output for pitching motion only are given.

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## 1. INTRODUCTION

For the last several years NASA Lewis Research Center has been developing aeroelastic analyses for turbomachines and propfans. This work has resulted in individual codes with differences in the aerodynamic and structural models, Ref. 1. One of the codes was based on Euler equations. This code is named ECAP2D( Euler Cascade Aeroelastic Program - Two Dimensional ), and can be used for steady, unsteady aerodynamic and aeroelastic analysis of two dimensional linear cascades. This guide will help the user in the preparation of the input data file required by the ECAP2D code. Detailed explanations of the aerodynamic analysis, the numerical algorithms, and the aeroelastic analysis are not given in this guide. Instead, the reader is directed to specific references that deal with each of these items. In the following sections, first a brief description of the analysis is given. This is followed by two sections describing the input and output to the program. A job running stream for Cray is given next. Actual input and output files for four examples are given next. The guide ends with a listing of the program calling tree for ECAP2D and references.

The ECAP2D 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.

## 2. ANALYSIS

The aerodynamic analysis used in this code is based on the unsteady two-dimensional Euler equations. These equations are solved for a cascade of blades. A finite volume approach is used to solve the Euler equations. A hybrid approach of flux vector splitting scheme (FVS) on left-hand-side, and flux difference splitting scheme (FDS) on right-hand-side terms is used. The coordinate system used is shown in Fig. 1. The transformation of the equations to the computational plane and the subsequent discretization and solution of these equations is described in Refs. 2 and 3. Detailed description of the aerodynamic analysis, and gird motion can be found in these references. The references also contain full description of the formulation including the governing equations and boundary conditions.

The aeroelastic analysis is described in Refs. 4 and 5. The structural model for each blade is a rigid typical section model with two degrees of freedom, pitching and plunging, as shown in Fig. 2. The aeroelastic equations can be solved either in frequency domain or time domain for inferring aeroelastic stability. For frequency domain aeroelastic analysis, the blades are oscillated harmonically. The time history of the forces (lift and moment) from this harmonic oscillation is Fourier analyzed to obtain unsteady aerodynamic harmonic coefficients. These unsteady aerodynamic coefficients are then used in an eigen analysis. The eignevalues determine the flutter condition. To reduce computational time in calculating the unsteady aerodynamic coefficients, two time saving methods, namely, influence coefficient method and pulse response method are also implemented in the code. For the time domain aeroelastic analysis, the aeroelastic equations are integrated in time using Newmark's method. A response with growing amplitude indicates flutter.

## 3. DESCRIPTION OF INPUT DATA

The ECAP2D 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. The source code is designated as *ecap2d.f*, and the input data for the code is provided in the input file *ecap2d.in*.

### 3.1 Dimension Statement for the Program

The dimensions required for the code are defined through two parameter statements. The first parameter statement defines the number of blocks (passages or blades) to be used in the analysis. The second statement defines the grid size, number of grid points in the axial and circumferential direction. For a required number of blocks and for a given grid size, the parameter statement should be changed **globally** in the source code, then compiled. The number of blocks and grid size automatically define required dimensions for computation. The parameter statements are as follows (defined for two blocks and 91x41 grid):

```
parameter(nbs=2)
parameter(ni=91, nj=41)
```

where

nbs = number of passages/blocks/blades for computation
ni = number of grid points in the axial (chordwise) direction
nj = number of grid points in the circumferential direction

It should be noted here that the computational grid, if read as input from outside the code, is required for only block. The code while executing arranges

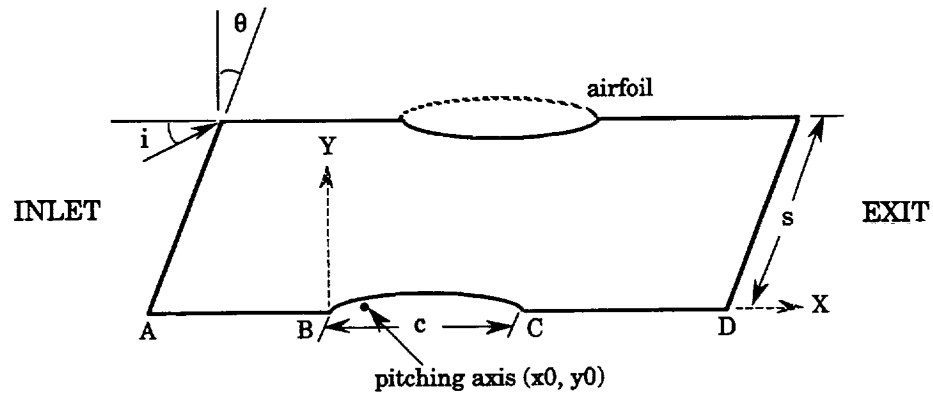


Figure 1: Cascade geometry showing stagger angle ($\theta$), chord length ($c$), incidence angle ($i$) and gap ($s$).

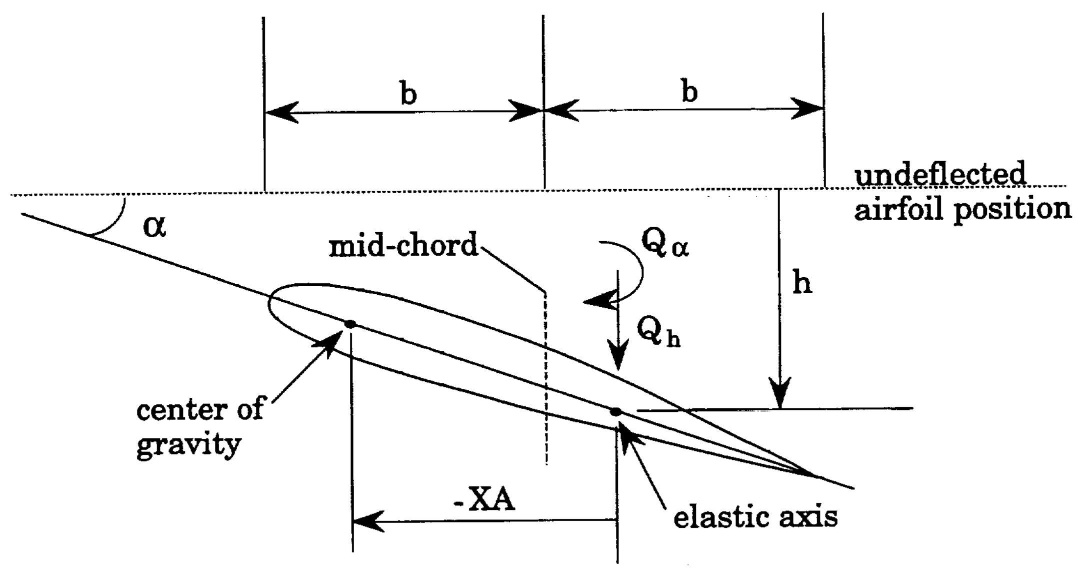


Figure 2: Typical section blade model showing plunging (h), pitching (α), degrees of freedom, lift (Qh), moment (Qα), distance between center of gravity and elastic axis (XA)

the grid for the 'nbs' required number of blocks. If the grid is generated outside of this code, the values of 'ni' and 'nj' should be set for that grid size before compiling the code.

### 3.2 Description of Input Variables

The input is given through a data file named **ecap2d.in** . This file contains the standard (unit 5) input that the ECAP2D code requires. In the input file, the values of each set of input variables is preceded by a line containing the names of the variables. This line is read in 8A10 format. Following this line, the values of the variables are read. Real values are read in 8F10.4 format and integer values are read in 8I10 format.

For clarity, the flow variables, algorithm variables, and structural variables are sometimes separated by an extra line denoted as "spacer". This line is read in A80 format.

description: spacer
```
*.........*.........*.........*.........*.........*.
```

The input variables are described below in the order in which they appear in the input data file (see section 7.1.1 for actual input file).

variable: `MOTION`
type: integer variable
description: defines type of solution method
`MOTION = 0` steady
`MOTION = 1` harmonic oscillation method
`MOTION = 2` influence coefficient method
`MOTION = 3` pulse response method
`MOTION =-1` time domain method

variable: `INEW`
type: integer variable
description: control for future use
`INEW = 0` presently

variable: `FSMACH`
type: real variable
description: Mach number of flow at inlet

variable: `PHASE`
type: real variable
description: interblade phase angle in degrees. Used only for harmonic oscillation method. No meaning for influence, pulse response or time domain methods.

variable: REDFRE
type: real variable
description: reduced frequency of oscillation, non-dimensionalized with airfoil semi-chord and inlet (free-stream) velocity. Used to select pulse duration in pulse response method. No meaning for time domain method.

variable: ALPHA
type: real variable
description: incidence angle (i) in degrees. See Fig. 1.

variable: H0/C
type: real variable
description: plunging amplitude of oscillation, non-dimensionalized with airfoil chord, c. Required for calculations with plunging motion (see Fig.2). Used for harmonic oscillation method (MOTION=1), influence coefficient method (MOTION=2), and pulse response method (MOTION=3).

variable: ALFA0D
type: real variable
description: pitching amplitude of oscillation in degrees. Required for calculations with pitching motion (see Fig.2). Used in harmonic oscillation method (MOTION=1), influence coefficient method (MOTION=2), and pulse response method (MOTION=3).

variable: CFL
type: real variable
description: maximum value of the CFL number. The time step used in the solution is determined by the maximum value of the CFL. For a given grid cell size, a small value of CFL will give small time step, and a large value will give large time step. CFL number is proportional to time step and grid cell size.

variable: PRAT
type: real variable
description: exit pressure ratio, ratio of pressure at the exit plane to the total pressure. Used in subsonic flow and supersonic flow with subsonic axial component velocity. Not required for supersonic through-flow cases.

variable: PSI
type: real variable
description: algorithm control, depends on ORDER and LIMIT (see below)

variable: ORDER
type: real variable
description: order of the solution method

ORDER = 2 use second order spatial accuracy
ORDER = 3 use third order spatial accuracy

variable: LIMIT
type: real variable
description: flux limiter
LIMIT = 0 use no flux limiters
LIMIT = 1 use minmod flux limiter (see MINMOD routine)
LIMIT = 2 use superbee flux limiter (see SUPBEE routine)
LIMIT = 3 use van Leer flux limiter (see VL routine)

variable: X0
type: real variable
description: x-location of pitching (elastic) axis, in units of chord, referenced from leading edge, see Fig.1.

variable: Y0
type: real variable
description: y-location of pitching (elastic) axis, in units of chord, referenced from leading edge, see Fig.1.

variable: SBYC
type: real variable
description: cascade gap (s) -to-chord (c) ratio, see Fig.1.

variable: STAGGER
type: real variable
description: cascade stagger angle ( $\theta$ ) in degrees, see Fig.1.

variable: NCYC
type: integer variable
description: number of cycles of oscillation of the airfoils (MOTION=1,2). Not used for pulse response method (MOTION =3) or for time domain method ( MOTION=-1)

variable: NTSS
type: integer variable
description: number of time steps for which the airfoils remain steady. Used for initializing the flow before blade oscillation begins.

variable: NTTOT
type: integer variable
description: total number of time steps in the calculation ( MOTION =0,3,-1); for MOTION=1,2, this value is not used.

variable: NTPRNT
type: integer variable
description: the number of time steps after which information is written to standard output (unit 6) in routine FORCE.

variable: ILE
type: integer variable
description: airfoil leading edge grid i - index number

variable: ITE
type: integer variable
description: airfoil trailing edge grid i - index number

variable: IGB
type: integer variable
description: indicator to determine how the grid is generated.
IGB=0 generates with in the program
IGB=-1 read externally generated grid (read (2) x(ni,nj),y(ni,nj))
IGB=1 read grid generated by grid generator of Ref. 6

variable: IAFOIL
type: integer variable
description: airfoil type
IAFOIL=0 (flat plate)
IAFOIL=1 NACA 0012
IAFOIL=2 Biconvex
IAFOIL=3 NACA 66006
IAFOIL=4 (left open)
IAFOIL=5 read upper surface and lower surface coordinates of any given airfoil. y values available at x values given by 1.0/number of points on the airfoil (see GRIDGEN subroutine).

variable: XLEFT
type: real variable
description: inlet (left) boundary location of the computational grid in units of chord; distance AB in Fig. 1.

variable: XRIGHT
type: real variable
description: exit (right) boundary location of the computational grid in units of chord; distance CD in Fig.1.

variable: KIN
type: integer variable
description: restart unit number
KIN=0 for first run
KIN=8 if solution starts from previous run, the code reads a binary (restart) file from unit 8.

variable: KOUT
type: integer variable
description: unit to save output for restart
KOUT=0 do not save for restart run
KOUT=9 save for restart run; the code writes a binary file to unit 9.

variable: MOOVEE
type: integer variable
description: unit to write files for movie making
MOOVEE=0 do not save solution for movie
MOOVEE=1 save solution for movie

variable: IMODE
type: integer variable
description: mode of airfoil oscillation
IMODE=0 for plunging
IMODE=1 for pitching
IMODE=2 for combined plunging-pitching motion in time domain flutter calculations

variable: IFLTR
type: integer variable
description: flag for flutter calculation
IFLTR = 0 steady analysis ( MOTION=0 )
IFLTR =1 single degree freedom, harmonic oscillation method, (MOTION=1)
IFLTR =1 two degrees of freedom, harmonic oscillation method, (MOTION=1)
IFLTR=-1 single degree freedom, time domain method, (MOTION=-1)
IFLTR=-2 two degrees of freedom, time domain method, (MOTION=-1)

variable: IFREE
type: integer variable
description: to enable for free vibration analysis only of the structural model
IFREE=0 do aeroelastic analysis
IFREE=1 do free vibration analysis

variable: VSTAR
type: real variable
description: reduced velocity non-dimensionalized with airfoil semi-chord and natural frequency in torsion (pitching) for MOTION=-1

variable: GHS
type: real variable
description: natural frequency in bending (plunging) in cycles per second.

variable: GAS
type: real variable
description: natural frequency in torsion (pitching) in cycles per second.

variable: ZHS
type: real variable
description: ratio of damping in bending (plunging) to critical damping (non-dimensional)

variable: ZAS
type: real variable
description: ratio of damping in torsion (pitching) to critical damping (non-dimensional)

variable: XMU
type: real variable
description: mass ratio, XMU = m/( $\pi$ $\rho$ b**2), where m is the airfoil mass, $\rho$ is the air density and b is the semi-chord.

variable: XRA
type: real variable
description: radius of gyration of typical section about pitching (elastic) axis in semi-chord units

variable: XA
type: real variable
description: distance of center of gravity (c.g.) from the elastic axis in semi-chord units; positive for c.g. aft of elastic axis.

variable: HD0
type: real variable
description: initial condition on plunging velocity (plunging displacement per unit time; plunging displacement is non-dimensionalized by chord and time by chord and speed of sound) MOTION=-1)

variable: ALFAD0
type: real variable
description: initial condition on pitching velocity (degree per unit time; time is non-dimensionalized by chord and speed of sound) (MOTION=-1)

variable: H0
type: real variable
description: initial condition on plunging displacement (non-dimensionalized with chord) (MOTION=-1)

variable: ALFA0
type: real variable
description: initial condition on pitching displacement (degrees), (MOTION=-1)

NOTE : The lines containing the names and values of variables GHS, GAS, ZHS, ZAS, XMU, XRA, XA and HD0, ALFAD0, H0 & ALFA0 are repeated for each block / passage/ blade.

### 3.3 Additional Input Files

If the option IGB= - 1 or 1 is used, the grid is read as input. For IGB= - 1 option, the grid file should be available in binary format and the file should be linked to unit 2 (for Cray compilers, the file is named fort.2). As mentioned earlier, it is read as read(2)xin,yin. The xin and yin arrays are of (ni,nj) length. For the IGB =1 option, the file should be named 'grid'. The sdblib.a package, which is available at NASA Lewis Research Center, is used to read this file.

It is sufficient that grid is available for only one block. The grid should be available in the coordinate system shown in Fig.1.

For the first run, the program creates a unit 9 file (fort.9 file on Cray). This file contains all the data necessary for restart option. This file becomes input file for subsequent runs, and has to be linked to unit 8 (i.e. for Cray, fort.9 is renamed fort.8 ) before running the code for the same case.

## 4. DESCRIPTION OF OUTPUT FILES

The code creates the following output files:

(1) Unit 6 output: This output contains an echo of the input for verification. It is also used for verifying that the stagger angle, and gap-to-chord ratio calculated from input grid file is same as the input value. The calculated time step used in the computation is also printed. In addition, for the harmonic oscillation method and for the influence coefficient method, it prints the unsteady aerodynamic coefficients of lift and moment for each cycle of oscillation. Additionally, when required, it prints the eigen values from the flutter analysis. For the pulse response method, the number of time steps for the pulse duration (nperiod) is also printed. For steady solution (not given in this manual), it prints the values of the rms values, for checking convergence of the solution.

(2) FORT.7: a formatted file of the grid. See MAIN program for the format description. Useful to check the grid before calculations begin. Can be read by PLOT3D program available at NASA centers.

(3) FORT.90 (OUT.DCP): file containing the real and imaginary components of unsteady pressures for harmonic oscillation method. It has six columns which are index, chord distance, real component, imaginary component, magnitude and phase.

(4) FORT.91 (OUT.HIST) : file containing the information on force coefficients versus time. It has five columns which are time step number, time, lift, moment and drag coefficients.

(5) FORT.96 (OUT.CP): file containing the pressure distribution on the airfoil surface. It has eight columns which are upper surface coordinate, Mach number, isentropic Mach number, pressure coefficient, lower surface coordinate, Mach number, isentropic Mach number, and pressure coefficient.

(6) GRID.BIN, FLOW.BIN: binary grid (airfoil coordinates) and flow files (values of density, two velocity components and energy at each grid point) respectively created at the end of the calculations for plotting. These are printed using routines in sdblib.a package. See routine GROUT subroutine in ECAP2D program for format description. Can be read by PLOT3D plotting program.

(7) FORT.9: binary file for restart run. For first run `KIN=0, KOUT=9`; on Cray creates fort.9 file; for restart run fort.9 is renamed fort.8 with `KIN=8, KOUT=9`.

(8) FORT.50+i, i =1,nbs. From influence coefficient method, it has three columns, which are index, total lift and total moment.

FORT.50+i, i =1,nbs. From pulse response method it has five columns, which are index, unsteady lift, unsteady moment, total lift and total moment.

FORT.50+i, i =1,nbs. From time domain analysis it has seven columns, which are index, plunging displacement, pitching displacement, unsteady lift, unsteady moment, total lift and total moment.

(Note: total lift and total moment include the contributions from steady and unsteady motion; unsteady lift and unsteady moment include only contribution due to unsteady motion only.).

(9) FORT.60+i,i=1,nbs. Shows the history of the grid motion. Used in pulse response method. It has five columns, which are index, plunging displacement, change in plunging displacement, pitching displacement, and change in pitching displacement.

## 5. ADDITIONAL NOTES

The code requires the IMSL (International Mathematical and Scientific Library) routine FFTRF for obtaining the harmonic components of the time history. Also, at present the code is compiled with sdblib.a which is a package to transfer binary files independent of machines. PLOT3D is required for graphical visualization of grid and flow data. The existing grid generation routine within the code may be good for flat plates cases only. For other cases, grid can be generated outside and read through unit 2.

For pulse response method, a separate program **pric.f** is used to obtain the unsteady aerodynamic coefficients for required phase angles and frequencies of interest (see example in section 7.3).

For the example given in section 7.1, with a 91x41 grid for two blocks, and for Mach number = 2.61, reduced frequency =1.0, with a CFL number of 4.0, the calculated time step was 0.00443. About 273 time steps per cycle were required, and for three cycles, the cpu time is 317 seconds on Cray YMP. The cpu time included the time required for SSD (about 70 seconds). The code required 3.73 MW memory. The memory can be considerably reduced by doing the Fourier transform outside the program.

## 6. JOB RUN STREAM ON CRAY YMP

A sample Cray job stream to run ECAP2D at NASA Lewis Research Center is given in this section. Two solid state devices (ssd) are touched to store and retrieve intermediate data, since two blocks (nbs=2) are used for computations. The source code, ecap2d.f, is compiled using cft77 with standard options. The compiled code is loaded and linked with IMSL (version 10) library, and sdblib.a, a package for transferring binary files. The input is contained in the file named ecap2d.in. For this case there are no additional input data files to be linked. The standard unit 6 output is written to a file named ecap2d.out. The rest of the file contains UNICOS and Cray related commands.

```
#! /bin/csh
# QSUB -r plate
# QSUB -lM 4.0 Mw
# QSUB
ja
#
touch ssd.11 ; env FILENV=sss assign -s u -a ssd.11 fort.11
touch ssd.12 ; env FILENV=sss assign -s u -a ssd.11 fort.12
#
cft77 ecap2d.f
segldr -o e2d ecap2d.o sdblib.a /tpsw/imsl/imslib.a
env FILENV = sss time e2d <ecap2d.in> ecap2d.out
rm ssd.1* sss
js -st
```

## 7. EXAMPLE CASES:

The input and output for four methods, namely harmonic oscillation method, influence coefficient method, pulse response method, and time domain method are given in the following sections. For the harmonic oscillation method, an example with pitching motion only and an example with plunging motion only are given. For the other three methods, examples with pitching motion only are given. Also, a list of additional files of interest created by the code is given. These cases are provided so that the user can verify the correct installation and operation of the code.

A flat plate cascade at zero angle of attack (ALPHA=0.0) is considered for all the examples. The cascade stagger angle (STAGGER) is 28 degrees, and the gap-to-chord ratio (SBYC) is 0.311. The Mach number at the inlet (FSMACH) is 2.61. The pitching axis is located at about 30% of chord from the leading edge (XO = 0.3, YO=0.0). The structural properties used are the mass ratio (XMU) is 456, the radius of gyration (XRA) is 0.588, natural frequencies in bending and torsion in cycles per second respectively are 0.567 and 1.0 i.e. GAS=0.567 and GHS=1.0, and the offset (XA) between elastic axis and center of gravity is zero, with no structural damping (ZHS, ZAS = 0.0). The elastic axis and the pitching axis are assumed identical in the code, and for all the examples presented here.

The grid is generated with in the code (IGB=0) for the flat plate geometry (IAFOIL=0). The grid has 91 points in the chordwise direction (ni=91) and 41 points in the circumferential direction (nj=41). There are 50 points on the airfoil, and 20 points between inlet and leading edge (ILE=20, ITE=70).

### 7.1 Unsteady Aerodynamics of a Flat-Plate Cascade using Harmonic Oscillation Method

In this section, two examples are given. One example is given for pitching motion only and the other for plunging motion only. For both the examples, two blocks (passages) are used in the calculations i.e. nbs=2 in the parameter definition. The source code is compiled with the following parameter statements.

```
parameter(nbs=2)
parameter(ni=91, nj=41)
```

#### 7.1.1 Pitching Motion

In this example, the unsteady aerodynamic coefficients are calculated for pitching about 30% of chord from leading edge (XO = 0.3, YO=0.0) at a reduced frequency (REDFREQ) of 1.0. The unsteady aerodynamic coefficients are calculated by harmonically oscillating (MOTION=1) the blades in 180 degrees phase angle (PHASE=180.). A pitching amplitude (ALFA0D) of 0.15 degrees is used. A CFL number of 4.0 is used to give a time step (dtmin) of 0.00442. This value of the time step, for the given value of reduced frequency, yields 272 steps per cycle (nperiod=272). Calculations are performed for 3 cycles (NCYC=3) of oscillation. At the end of calculations for each cycle of oscillation, the forces (lift followed by moment) are Fourier analyzed and harmonics are printed. In addition, eigen values for flutter analysis are also printed.

### Input file (ecap2d.in)

```
   MOTION      INEW
        1         0
   FSMACH     PHASE   REDFREQ     ALPHA
     2.61   180.000    1.0000      0.00
     H0/C    ALFA0D
   0.0000    0.1500
.........*.........*.........*.........*.........*
      CFL      PRAT       PSI     ORDER     LIMIT
      4.0    0.7320    0.3333       3.0       1.0
       X0        Y0      SBYC   STAGGER
   0.3000       0.0     0.311     28.00
.........*.........*.........*.........*
     NCYC      NTSS     NTTOT    NTPRNT
        3       100      1000        50
      ILE       ITE       IGB    IAFOIL
       20        70         0         0
.........*.........*
    XLEFT    XRIGHT
     -0.3       1.5
.........*.........*.........*
      KIN      KOUT    MOOVEE
        0         9         0
    IMODE    IFLTR     IFREE
        1         1         0
.........*.........*.........*.........*.........*.........*.........*
    VSTAR
     8.00
      GHS       GAS       ZHS       ZAS       XMU       XRA        XA
    0.567       1.0       0.0       0.0     456.0     0.588     0.000
      HD0    ALFAD0        H0     ALFA0
    0.000      0.05       0.0       0.0
      GHS       GAS       ZHS       ZAS       XMU       XRA        XA
    0.567       1.0       0.0       0.0     456.0     0.588     0.000
      HD0    ALFAD0        H0     ALFA0
    0.000   0.01545       0.0       0.0
```

### ecap2d.out

```
*******************************************************
                              HARMONIC MOTION
*******************************************************
```

```
   factors for vibration =       1.0000        1.0000
  FSMACH      PHASE   REDFREQ     ALPHA
  2.6100  180.0000    1.0000    0.0000
    H0/C     ALFA0D
  0.0000     0.1500
     CFL       PRAT       PSI     ORDER     LIMIT
  4.0000     0.7320    0.3333    3.0000    1.0000
      X0         Y0      SBYC   STAGGER
  0.3000     0.0000    0.3110   28.0000
    NCYC       NTSS     NTTOT    NTPRNT
       3        100      1000        50
     ILE        ITE       IGB    IAFOIL
      20         70         0         0
   XLEFT     XRIGHT
 -0.3000     1.5000
   KMODE       KFFT     LIMIT
       1          1         1
     KIN       KOUT    MOOVEE
       0          9         0

****** Oscillating Cascade Analysis ******
input run stream:

number of blocks =    2 where each block has dimensions of:
              ni =   91
              nj =   41
              nk =    2

freestream mach number  =  2.6100
inlet incidence angle   =  0.0000 (degrees)
exit pressure ratio     =  0.7320 (p/ptot)
inter-blade phase angle =180.0000 (degrees)
reduced frequency       =  1.0000 (based on semichord)
reduced frequency       =  5.2200 (in terms of omega)
amplitude of plunge     =  0.0000 (percent chord)
amplitude of pitch      =  0.1500 (degrees)
airfoil moment center   =  0.3000 (x0, percent chord)
airfoil moment center   =  0.0000 (y0, percent chord)
cascade stagger angle   = 28.0000 (degrees)
cascade spacing         =  0.3110 (percent chord)

ile     =   20 (airfoil leading edge index)
ite     =   70 (airfoil trailing edge index)
nb      =    3 (total number of cycles)
kin     =    0 (restart input number -if 0 not used)
kout    =    9 (restart output number -if 0 not used)
kfft    =    1 (no fft analysis if kfft=0)
moovee  =    0 (save certain steps for animation)
kmode   =    1 (stationary or oscillating cascade)

a fft analysis will be done at the end of each cycle

     flux limiter input information:

          limit =    1
          psi   = 0.333
          order =   3.0
```

```
 note with limit=1, MINMOD limiter has been invoked

     grid generated now , igb =      0
     IMODE      IFLTR      IFREE
        1          1          0
     PITCHING MOTION
     FLUTTER IN FREQ. DOMAIN: SINGLE DEGREE OF FREEDOM

     **** PRINT INTERVAL, NTPRNT **** =   50

     motion indicator for blade    1:   1.0000
     GAMA H =      0.56700      GAMA ALPHA =      1.00000
     ZETA H =      0.00000      ZETA ALPHA =      0.00000
     MASS RATIO(XMU)                     =   936.00000
     RADIUS OF GYRATION(XRA)             =     0.61500
     DT. BETWEEN E.A. AND C.G.(XALFA)    =     0.00000
     initial plunging velocity           =     0.00000
     initial pitching velocity           =     0.05000
     initial plunging displacement       =     0.00000
     initial pitching displacemnet       =     0.00000

     motion indicator for blade    2:   1.0000
     GAMA H =      0.56700      GAMA ALPHA =      1.00000
     ZETA H =      0.00000      ZETA ALPHA =      0.00000
     MASS RATIO(XMU)                     =   936.00000
     RADIUS OF GYRATION(XRA)             =     0.61500
     DT. BETWEEN E.A. AND C.G.(XALFA)    =     0.00000
     initial plunging velocity           =     0.00000
     initial pitching velocity           =     0.01545
     initial plunging displacement       =     0.00000
     initial pitching displacemnet       =     0.00000

     IN ROUTINE GRIDGEN:STAG,SC,CHORD,X1,X4,NIF,NIB,IRUN
    28.00000     0.31100     1.00000    -0.30000     1.50000    20    70     0
  stagger angle (deg.) from input file =
                          28.0000000000
  stagger angle (deg.) from grid file =
                          28.0000000000
  stagger angle (deg.) used in the cal. =
                          28.0000000000
  gap-to-chord ratio from input file =
                           0.3110000000
  gap-to-chord ratio from grid file =
                           0.3110000000
  gap-to-chord ratio used in the calculation =
                           0.3110000000
     finished reading grid coordinates in routine rdgrid
     *** x coordinates at 0,ile,ilt,last
         -0.30000     0.00000     1.00000     1.50000

Starting the initial grid calculation
  For block  1:
     dtmin (as computed in eigenv) at cfl =  4.0 is      0.00442
  For block  2:
     dtmin (as computed in eigenv) at cfl =  4.0 is      0.00442
Successful completion of initial grid generation

 The flow solution will use dtmin= 0.00443 and nperiod=   272
```

to give a maximum cfl close to 4.000

Surface Mach Number, Isentropic Mach Number and CP; block = 1 and ncyc = 272

| x/c | machu | imachu | cpu | x/c | machl | imachl | cpl |
|---|---|---|---|---|---|---|---|
| -0.2939 | 2.6100 | 2.6100 | 0.0000 | -0.2939 | 2.6100 | 2.6100 | 0.0000 |
| -0.2816 | 2.6100 | 2.6100 | 0.0000 | -0.2816 | 2.6100 | 2.6100 | 0.0000 |
| -0.2689 | 2.6100 | 2.6100 | 0.0000 | -0.2689 | 2.6100 | 2.6100 | 0.0000 |
| -0.2558 | 2.6100 | 2.6100 | 0.0000 | -0.2558 | 2.6100 | 2.6100 | 0.0000 |
| -0.2424 | 2.6100 | 2.6100 | 0.0000 | -0.2424 | 2.6100 | 2.6100 | 0.0000 |
| -0.2286 | 2.6100 | 2.6100 | 0.0000 | -0.2286 | 2.6100 | 2.6100 | 0.0000 |
| -0.2144 | 2.6100 | 2.6100 | 0.0000 | -0.2144 | 2.6100 | 2.6100 | 0.0000 |
| -0.1998 | 2.6100 | 2.6100 | 0.0000 | -0.1998 | 2.6100 | 2.6100 | 0.0000 |
| -0.1848 | 2.6100 | 2.6100 | 0.0000 | -0.1848 | 2.6100 | 2.6100 | 0.0000 |
| -0.1694 | 2.6100 | 2.6100 | 0.0000 | -0.1694 | 2.6100 | 2.6100 | 0.0000 |
| -0.1536 | 2.6100 | 2.6100 | 0.0000 | -0.1536 | 2.6100 | 2.6100 | 0.0000 |
| -0.1373 | 2.6100 | 2.6100 | 0.0000 | -0.1373 | 2.6100 | 2.6100 | 0.0000 |
| -0.1206 | 2.6100 | 2.6100 | 0.0000 | -0.1206 | 2.6100 | 2.6100 | 0.0000 |
| -0.1034 | 2.6100 | 2.6100 | 0.0000 | -0.1034 | 2.6100 | 2.6100 | 0.0000 |
| -0.0858 | 2.6100 | 2.6100 | 0.0000 | -0.0858 | 2.6100 | 2.6100 | 0.0000 |
| -0.0676 | 2.6100 | 2.6100 | 0.0000 | -0.0676 | 2.6100 | 2.6100 | 0.0000 |
| -0.0489 | 2.6100 | 2.6100 | 0.0000 | -0.0489 | 2.6100 | 2.6100 | 0.0000 |
| -0.0297 | 2.6100 | 2.6100 | 0.0000 | -0.0297 | 2.6100 | 2.6100 | 0.0000 |
| -0.0100 | 2.6100 | 2.6100 | 0.0000 | -0.0100 | 2.6100 | 2.6100 | 0.0000 |
| 0.0100 | 2.6133 | 2.6160 | 0.0020 | 0.0100 | 2.6133 | 2.6156 | 0.0018 |
| 0.0300 | 2.6124 | 2.6166 | 0.0021 | 0.0300 | 2.6124 | 2.6166 | 0.0021 |
| 0.0500 | 2.6121 | 2.6166 | 0.0021 | 0.0500 | 2.6120 | 2.6166 | 0.0021 |
| 0.0700 | 2.6118 | 2.6166 | 0.0021 | 0.0700 | 2.6116 | 2.6166 | 0.0021 |
| 0.0900 | 2.6115 | 2.6165 | 0.0021 | 0.0900 | 2.6111 | 2.6165 | 0.0021 |
| 0.1100 | 2.6112 | 2.6165 | 0.0021 | 0.1100 | 2.6107 | 2.6165 | 0.0021 |
| 0.1300 | 2.6109 | 2.6165 | 0.0021 | 0.1300 | 2.6102 | 2.6164 | 0.0021 |
| 0.1500 | 2.6107 | 2.6164 | 0.0021 | 0.1500 | 2.6097 | 2.6164 | 0.0021 |
| 0.1700 | 2.6104 | 2.6164 | 0.0021 | 0.1700 | 2.6093 | 2.6164 | 0.0021 |
| 0.1900 | 2.6102 | 2.6164 | 0.0021 | 0.1900 | 2.6090 | 2.6164 | 0.0021 |
| 0.2100 | 2.6100 | 2.6163 | 0.0020 | 0.2100 | 2.6088 | 2.6163 | 0.0020 |
| 0.2300 | 2.6098 | 2.6163 | 0.0020 | 0.2300 | 2.6088 | 2.6163 | 0.0020 |
| 0.2500 | 2.6097 | 2.6163 | 0.0020 | 0.2500 | 2.6088 | 2.6163 | 0.0020 |
| 0.2700 | 2.6096 | 2.6162 | 0.0020 | 0.2700 | 2.6088 | 2.6163 | 0.0020 |
| 0.2900 | 2.6096 | 2.6162 | 0.0020 | 0.2900 | 2.6088 | 2.6162 | 0.0020 |
| 0.3100 | 2.6096 | 2.6162 | 0.0020 | 0.3100 | 2.6088 | 2.6162 | 0.0020 |
| 0.3300 | 2.6096 | 2.6162 | 0.0020 | 0.3300 | 2.6089 | 2.6162 | 0.0020 |
| 0.3500 | 2.6097 | 2.6161 | 0.0020 | 0.3500 | 2.6090 | 2.6162 | 0.0020 |
| 0.3700 | 2.6097 | 2.6161 | 0.0020 | 0.3700 | 2.6092 | 2.6161 | 0.0020 |
| 0.3900 | 2.6098 | 2.6161 | 0.0020 | 0.3900 | 2.6095 | 2.6161 | 0.0020 |
| 0.4100 | 2.6099 | 2.6161 | 0.0020 | 0.4100 | 2.6097 | 2.6162 | 0.0020 |
| 0.4300 | 2.6100 | 2.6160 | 0.0019 | 0.4300 | 2.6101 | 2.6162 | 0.0020 |
| 0.4500 | 2.6101 | 2.6160 | 0.0019 | 0.4500 | 2.6102 | 2.6161 | 0.0020 |
| 0.4700 | 2.6102 | 2.6160 | 0.0019 | 0.4700 | 2.6103 | 2.6155 | 0.0018 |
| 0.4900 | 2.6102 | 2.6160 | 0.0019 | 0.4900 | 2.6098 | 2.6144 | 0.0014 |
| 0.5100 | 2.6103 | 2.6160 | 0.0019 | 0.5100 | 2.6090 | 2.6130 | 0.0010 |
| 0.5300 | 2.6103 | 2.6160 | 0.0019 | 0.5300 | 2.6082 | 2.6117 | 0.0005 |
| 0.5500 | 2.6104 | 2.6159 | 0.0019 | 0.5500 | 2.6074 | 2.6106 | 0.0002 |
| 0.5700 | 2.6104 | 2.6159 | 0.0019 | 0.5700 | 2.6067 | 2.6099 | 0.0000 |
| 0.5900 | 2.6105 | 2.6159 | 0.0019 | 0.5900 | 2.6061 | 2.6095 | -0.0002 |
| 0.6100 | 2.6105 | 2.6159 | 0.0019 | 0.6100 | 2.6061 | 2.6097 | -0.0001 |
| 0.6300 | 2.6105 | 2.6159 | 0.0019 | 0.6300 | 2.6062 | 2.6101 | 0.0000 |
| 0.6500 | 2.6106 | 2.6160 | 0.0019 | 0.6500 | 2.6064 | 2.6107 | 0.0002 |
| 0.6700 | 2.6107 | 2.6161 | 0.0020 | 0.6700 | 2.6069 | 2.6114 | 0.0005 |
| 0.6900 | 2.6108 | 2.6162 | 0.0020 | 0.6900 | 2.6074 | 2.6121 | 0.0007 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0.7100 | 2.6108 | 2.6161 | 0.0020 | 0.7100 | 2.6079 | 2.6128 | 0.0009 |
| 0.7300 | 2.6107 | 2.6158 | 0.0019 | 0.7300 | 2.6086 | 2.6133 | 0.0011 |
| 0.7500 | 2.6105 | 2.6153 | 0.0017 | 0.7500 | 2.6092 | 2.6139 | 0.0013 |
| 0.7700 | 2.6100 | 2.6145 | 0.0014 | 0.7700 | 2.6099 | 2.6144 | 0.0014 |
| 0.7900 | 2.6095 | 2.6135 | 0.0011 | 0.7900 | 2.6106 | 2.6149 | 0.0016 |
| 0.8100 | 2.6089 | 2.6126 | 0.0008 | 0.8100 | 2.6112 | 2.6154 | 0.0017 |
| 0.8300 | 2.6083 | 2.6119 | 0.0006 | 0.8300 | 2.6117 | 2.6159 | 0.0019 |
| 0.8500 | 2.6078 | 2.6113 | 0.0004 | 0.8500 | 2.6121 | 2.6165 | 0.0021 |
| 0.8700 | 2.6073 | 2.6109 | 0.0003 | 0.8700 | 2.6124 | 2.6170 | 0.0023 |
| 0.8900 | 2.6070 | 2.6106 | 0.0002 | 0.8900 | 2.6126 | 2.6176 | 0.0024 |
| 0.9100 | 2.6068 | 2.6105 | 0.0002 | 0.9100 | 2.6127 | 2.6181 | 0.0026 |
| 0.9300 | 2.6067 | 2.6106 | 0.0002 | 0.9300 | 2.6127 | 2.6187 | 0.0028 |
| 0.9500 | 2.6068 | 2.6109 | 0.0003 | 0.9500 | 2.6126 | 2.6193 | 0.0030 |
| 0.9700 | 2.6070 | 2.6113 | 0.0004 | 0.9700 | 2.6126 | 2.6198 | 0.0032 |
| 0.9900 | 2.6074 | 2.6122 | 0.0007 | 0.9900 | 2.6123 | 2.6206 | 0.0034 |
| 1.0100 | 2.6046 | 2.6053 | -0.0015 | 1.0100 | 2.6092 | 2.6143 | 0.0014 |
| 1.0302 | 2.6054 | 2.6056 | -0.0014 | 1.0302 | 2.6094 | 2.6140 | 0.0013 |
| 1.0507 | 2.6058 | 2.6056 | -0.0014 | 1.0507 | 2.6094 | 2.6139 | 0.0013 |
| 1.0716 | 2.6062 | 2.6057 | -0.0014 | 1.0716 | 2.6092 | 2.6138 | 0.0012 |
| 1.0928 | 2.6065 | 2.6058 | -0.0014 | 1.0928 | 2.6092 | 2.6137 | 0.0012 |
| 1.1144 | 2.6069 | 2.6059 | -0.0013 | 1.1144 | 2.6092 | 2.6136 | 0.0012 |
| 1.1363 | 2.6073 | 2.6059 | -0.0013 | 1.1363 | 2.6093 | 2.6135 | 0.0011 |
| 1.1586 | 2.6076 | 2.6059 | -0.0013 | 1.1586 | 2.6094 | 2.6136 | 0.0012 |
| 1.1813 | 2.6080 | 2.6058 | -0.0014 | 1.1813 | 2.6095 | 2.6137 | 0.0012 |
| 1.2044 | 2.6084 | 2.6058 | -0.0014 | 1.2044 | 2.6097 | 2.6139 | 0.0013 |
| 1.2279 | 2.6087 | 2.6058 | -0.0014 | 1.2279 | 2.6098 | 2.6140 | 0.0013 |
| 1.2518 | 2.6091 | 2.6058 | -0.0014 | 1.2518 | 2.6099 | 2.6140 | 0.0013 |
| 1.2761 | 2.6093 | 2.6059 | -0.0013 | 1.2761 | 2.6100 | 2.6140 | 0.0013 |
| 1.3008 | 2.6095 | 2.6060 | -0.0013 | 1.3008 | 2.6100 | 2.6139 | 0.0013 |
| 1.3259 | 2.6096 | 2.6060 | -0.0013 | 1.3259 | 2.6100 | 2.6139 | 0.0012 |
| 1.3515 | 2.6097 | 2.6061 | -0.0013 | 1.3515 | 2.6101 | 2.6138 | 0.0012 |
| 1.3775 | 2.6098 | 2.6061 | -0.0013 | 1.3775 | 2.6101 | 2.6137 | 0.0012 |
| 1.4039 | 2.6100 | 2.6062 | -0.0012 | 1.4039 | 2.6101 | 2.6135 | 0.0011 |
| 1.4308 | 2.6100 | 2.6062 | -0.0012 | 1.4308 | 2.6101 | 2.6135 | 0.0011 |
| 1.4582 | 2.6101 | 2.6061 | -0.0013 | 1.4582 | 2.6101 | 2.6136 | 0.0012 |
| 1.4860 | 2.6098 | 2.6055 | -0.0015 | 1.4860 | 2.6105 | 2.6143 | 0.0014 |

******** inlet conditions ********

| j | u | v | mach | angle | p/pt |
|---|---|---|---|---|---|
| 2 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 3 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 4 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 5 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 6 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 7 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 8 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 9 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 10 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 11 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 12 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 13 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 14 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 15 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 16 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 17 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 18 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 19 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |

| | | | | | |
|---|---|---|---|---|---|
| 20 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 21 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 22 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 23 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 24 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 25 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 26 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 27 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 28 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 29 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 30 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 31 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 32 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 33 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 34 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 35 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 36 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 37 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 38 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 39 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 40 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 41 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |

The average inlet Mach number is: 2.6100

******** exit conditions ********

| j | u | v | mach | angle | p/pt |
|---|---|---|---|---|---|
| 2 | 2.608 | 0.004 | 2.600 | 0.093 | 0.0497 |
| 3 | 2.607 | 0.004 | 2.599 | 0.095 | 0.0497 |
| 4 | 2.606 | 0.004 | 2.598 | 0.093 | 0.0496 |
| 5 | 2.606 | 0.004 | 2.599 | 0.094 | 0.0496 |
| 6 | 2.606 | 0.004 | 2.600 | 0.094 | 0.0496 |
| 7 | 2.606 | 0.004 | 2.601 | 0.095 | 0.0496 |
| 8 | 2.606 | 0.004 | 2.602 | 0.097 | 0.0495 |
| 9 | 2.607 | 0.005 | 2.603 | 0.099 | 0.0495 |
| 10 | 2.607 | 0.005 | 2.604 | 0.103 | 0.0494 |
| 11 | 2.607 | 0.005 | 2.606 | 0.107 | 0.0494 |
| 12 | 2.607 | 0.005 | 2.607 | 0.114 | 0.0493 |
| 13 | 2.608 | 0.006 | 2.609 | 0.121 | 0.0493 |
| 14 | 2.608 | 0.006 | 2.611 | 0.132 | 0.0492 |
| 15 | 2.608 | 0.007 | 2.612 | 0.144 | 0.0492 |
| 16 | 2.608 | 0.007 | 2.614 | 0.159 | 0.0491 |
| 17 | 2.608 | 0.008 | 2.616 | 0.174 | 0.0491 |
| 18 | 2.608 | 0.008 | 2.618 | 0.184 | 0.0490 |
| 19 | 2.609 | 0.008 | 2.619 | 0.183 | 0.0490 |
| 20 | 2.609 | 0.008 | 2.620 | 0.170 | 0.0489 |
| 21 | 2.609 | 0.006 | 2.620 | 0.141 | 0.0489 |
| 22 | 2.608 | 0.004 | 2.619 | 0.091 | 0.0489 |
| 23 | 2.608 | 0.002 | 2.618 | 0.037 | 0.0490 |
| 24 | 2.608 | 0.000 | 2.618 | -0.004 | 0.0490 |
| 25 | 2.608 | -0.001 | 2.619 | -0.033 | 0.0490 |
| 26 | 2.609 | -0.002 | 2.620 | -0.055 | 0.0489 |
| 27 | 2.609 | -0.003 | 2.621 | -0.069 | 0.0489 |
| 28 | 2.609 | -0.003 | 2.622 | -0.077 | 0.0489 |
| 29 | 2.609 | -0.004 | 2.622 | -0.082 | 0.0489 |
| 30 | 2.609 | -0.004 | 2.622 | -0.086 | 0.0488 |
| 31 | 2.609 | -0.004 | 2.622 | -0.088 | 0.0489 |

```
  32  2.609 -0.004  2.622 -0.090  0.0489
  33  2.609 -0.004  2.622 -0.091  0.0489
  34  2.609 -0.004  2.622 -0.092  0.0489
  35  2.609 -0.004  2.621 -0.092  0.0489
  36  2.608 -0.004  2.620 -0.091  0.0489
  37  2.608 -0.004  2.619 -0.090  0.0489
  38  2.609 -0.004  2.620 -0.091  0.0489
  39  2.610 -0.004  2.620 -0.090  0.0490
  40  2.610 -0.004  2.620 -0.091  0.0490
  41  2.610 -0.004  2.619 -0.088  0.0490

 The average exit Mach number is:    2.6141

Surface Mach Number, Isentropic Mach Number and CP; block =  2 and ncyc =   272
                    ****
                    ****
                    ****
```

***** The output for block 2, similar to block 1, is deleted for brevity ****
****** until it prints average exit Mach number ****.

```
                    ****
                    ****
                    ****
 The average exit Mach number is:    2.6141

 FOURIER COEFFICIENTS FOR CYCLE      1
    ZERO TH HARMONIC =      0.1183
     higher HARMONICS = 1,2,3,4
        0.5690     0.0480     0.5710     4.8224
        0.0465    -0.0662     0.0809   -54.9393                    (lift)
        0.0194     0.0183     0.0267    43.2915
       -0.0451     0.0207     0.0496   155.3183
    FOURIER COEFFICIENTS FOR CYCLE      1
    ZERO TH HARMONIC =      0.0490
     higher HARMONICS = 1,2,3,4
        0.0811    -0.0218     0.0840   -15.0388
        0.0336    -0.0283     0.0439   -40.0532
        0.0229     0.0122     0.0259    28.1635                    (moment)
       -0.0094     0.0169     0.0193   119.0661
 Unsteady Pressure Distribution, First Harmonic of dcp:
    FOURIER COEFFICIENTS FOR CYCLE      1
   i       x/c        Real       Imag        Mag        Phase
 272
   21     0.0100     0.6418     0.4064     0.7597     32.3398
   22     0.0300     0.7507     0.4429     0.8716     30.5375
   23     0.0500     0.7528     0.4144     0.8594     28.8318
   24     0.0700     0.7476     0.3833     0.8401     27.1437
   25     0.0900     0.7428     0.3531     0.8225     25.4255
   26     0.1100     0.7384     0.3232     0.8060     23.6407
   27     0.1300     0.7341     0.2927     0.7903     21.7399
   28     0.1500     0.7300     0.2613     0.7754     19.6914
   29     0.1700     0.7263     0.2297     0.7617     17.5480
   30     0.1900     0.7226     0.1984     0.7493     15.3552
   31     0.2100     0.7189     0.1672     0.7381     13.0960
   32     0.2300     0.7154     0.1355     0.7281     10.7280
   33     0.2500     0.7121     0.1033     0.7196      8.2511
   34     0.2700     0.7091     0.0708     0.7126      5.7026
   35     0.2900     0.7062     0.0382     0.7072      3.1000
   36     0.3100     0.7035     0.0055     0.7035      0.4516
```

```
  37    0.3300   0.7007  -0.0269   0.7012   -2.1986
  38    0.3500   0.6979  -0.0595   0.7004   -4.8766
  39    0.3700   0.6963  -0.0943   0.7026   -7.7089
  40    0.3900   0.6968  -0.1314   0.7090  -10.6763
  41    0.4100   0.6983  -0.1666   0.7179  -13.4194
  42    0.4300   0.6979  -0.1931   0.7241  -15.4627
  43    0.4500   0.6878  -0.2034   0.7173  -16.4776
  44    0.4700   0.6505  -0.1786   0.6746  -15.3527
  45    0.4900   0.5824  -0.1195   0.5945  -11.5991
  46    0.5100   0.5002  -0.0450   0.5022   -5.1461
  47    0.5300   0.4202   0.0253   0.4210    3.4501
  48    0.5500   0.3580   0.0747   0.3657   11.7919
  49    0.5700   0.3203   0.0980   0.3349   17.0126
  50    0.5900   0.3043   0.0966   0.3193   17.6096
  51    0.6100   0.3146   0.0739   0.3232   13.2178
  52    0.6300   0.3388   0.0398   0.3411    6.7018
  53    0.6500   0.3731  -0.0004   0.3731   -0.0603
  54    0.6700   0.4119  -0.0399   0.4139   -5.5375
  55    0.6900   0.4480  -0.0729   0.4539   -9.2422
  56    0.7100   0.4745  -0.0939   0.4837  -11.1930
  57    0.7300   0.4857  -0.0982   0.4956  -11.4323
  58    0.7500   0.4801  -0.0869   0.4879  -10.2561
  59    0.7700   0.4619  -0.0637   0.4663   -7.8491
  60    0.7900   0.4365  -0.0340   0.4378   -4.4561
  61    0.8100   0.4113  -0.0039   0.4113   -0.5408
  62    0.8300   0.3935   0.0207   0.3941    3.0075
  63    0.8500   0.3877   0.0353   0.3893    5.2054
  64    0.8700   0.3935   0.0385   0.3954    5.5856
  65    0.8900   0.4114   0.0301   0.4125    4.1821
  66    0.9100   0.4402   0.0113   0.4403    1.4731
  67    0.9300   0.4773  -0.0143   0.4775   -1.7167
  68    0.9500   0.5233  -0.0449   0.5252   -4.9033
  69    0.9700   0.5695  -0.0801   0.5751   -8.0048
  70    0.9900   0.6510  -0.1188   0.6618  -10.3434
****
****
****
```

***** **Output of surface Mach number, etc., for cycle 2, for** ****
****** **blocks 1 and 2 are deleted for brevity** ****

```
****
****
****
    FOURIER COEFFICIENTS FOR CYCLE      2
    ZERO TH HARMONIC =      0.0037
     higher HARMONICS = 1,2,3,4
        0.6422     0.2060     0.6744    17.7856
        0.0005    -0.0011     0.0012   -67.4163
        0.0007    -0.0017     0.0018   -67.7587                    (lift)
        0.0004     0.0001     0.0004     7.4828
    FOURIER COEFFICIENTS FOR CYCLE      2
    ZERO TH HARMONIC =      0.0011
     higher HARMONICS = 1,2,3,4
        0.1006     0.0518     0.1132    27.2308
       -0.0008    -0.0008     0.0012  -134.0940
       -0.0001    -0.0011     0.0011   -92.9047                  (moment)
        0.0000    -0.0001     0.0001   -71.9884
 Unsteady Pressure Distribution, First Harmonic of dcp:
    FOURIER COEFFICIENTS FOR CYCLE      2
```

```
  i      x/c        Real       Imag        Mag       Phase
272
  21    0.0100    0.7265     0.4289     0.8437    30.5560
  22    0.0300    0.8200     0.4533     0.9370    28.9319
  23    0.0500    0.8185     0.4241     0.9218    27.3903
  24    0.0700    0.8128     0.3931     0.9029    25.8119
  25    0.0900    0.8083     0.3637     0.8864    24.2256
  26    0.1100    0.8040     0.3347     0.8709    22.6039
  27    0.1300    0.7996     0.3050     0.8558    20.8773
  28    0.1500    0.7956     0.2741     0.8415    19.0092
  29    0.1700    0.7917     0.2431     0.8282    17.0679
  30    0.1900    0.7878     0.2127     0.8160    15.1064
  31    0.2100    0.7839     0.1825     0.8048    13.1040
  32    0.2300    0.7799     0.1518     0.7945    11.0121
  33    0.2500    0.7761     0.1204     0.7854     8.8215
  34    0.2700    0.7724     0.0889     0.7775     6.5634
  35    0.2900    0.7687     0.0572     0.7709     4.2564
  36    0.3100    0.7651     0.0255     0.7655     1.9073
  37    0.3300    0.7613    -0.0057     0.7613    -0.4307
  38    0.3500    0.7571    -0.0369     0.7580    -2.7936
  39    0.3700    0.7537    -0.0708     0.7570    -5.3630
  40    0.3900    0.7524    -0.1081     0.7601    -8.1731
  41    0.4100    0.7529    -0.1435     0.7664   -10.7885
  42    0.4300    0.7530    -0.1678     0.7715   -12.5660
  43    0.4500    0.7443    -0.1725     0.7640   -13.0460
  44    0.4700    0.7078    -0.1305     0.7198   -10.4453
  45    0.4900    0.6379    -0.0434     0.6394    -3.8928
  46    0.5100    0.5514     0.0656     0.5553     6.7861
  47    0.5300    0.4655     0.1711     0.4959    20.1818
  48    0.5500    0.3974     0.2506     0.4698    32.2314
  49    0.5700    0.3562     0.2960     0.4632    39.7259
  50    0.5900    0.3370     0.3120     0.4593    42.7922
  51    0.6100    0.3517     0.2968     0.4602    40.1573
  52    0.6300    0.3805     0.2666     0.4646    35.0212
  53    0.6500    0.4219     0.2270     0.4791    28.2807
  54    0.6700    0.4696     0.1878     0.5058    21.8022
  55    0.6900    0.5143     0.1560     0.5375    16.8760
  56    0.7100    0.5493     0.1398     0.5668    14.2734
  57    0.7300    0.5676     0.1461     0.5861    14.4340
  58    0.7500    0.5666     0.1750     0.5930    17.1673
  59    0.7700    0.5508     0.2212     0.5935    21.8800
  60    0.7900    0.5263     0.2772     0.5949    27.7745
  61    0.8100    0.5019     0.3345     0.6032    33.6822
  62    0.8300    0.4864     0.3846     0.6200    38.3353
  63    0.8500    0.4842     0.4209     0.6415    41.0015
  64    0.8700    0.4956     0.4404     0.6630    41.6239
  65    0.8900    0.5194     0.4444     0.6835    40.5515
  66    0.9100    0.5568     0.4331     0.7054    37.8745
  67    0.9300    0.6053     0.4127     0.7326    34.2838
  68    0.9500    0.6649     0.3860     0.7688    30.1337
  69    0.9700    0.7251     0.3531     0.8065    25.9658
  70    0.9900    0.8314     0.3218     0.8915    21.1592
****
****
****
```

***** Output of surface Mach number, etc., for cycle 2, for ****
****blocks 1 and 2 are deleted for brevity****

```
****
```

```
****
****
    FOURIER COEFFICIENTS FOR CYCLE      3
    ZERO TH HARMONIC =      0.0037
     higher HARMONICS = 1,2,3,4
        0.6423     0.2061     0.6745    17.7895
        0.0005    -0.0010     0.0012   -64.5998
        0.0007    -0.0016     0.0018   -66.4773                    (lift)
        0.0004     0.0001     0.0004    13.6517
    FOURIER COEFFICIENTS FOR CYCLE      3
    ZERO TH HARMONIC =      0.0010
     higher HARMONICS = 1,2,3,4
        0.1007     0.0519     0.1133    27.2385
       -0.0008    -0.0008     0.0011  -135.3271
        0.0000    -0.0010     0.0010   -92.6008                    (moment)
        0.0000    -0.0001     0.0001   -66.9799
 Unsteady Pressure Distribution, First Harmonic of dcp:
    FOURIER COEFFICIENTS FOR CYCLE      3
```

| i | x/c | Real | Imag | Mag | Phase |
|---|---|---|---|---|---|
| 272 | | | | | |
| 21 | 0.0100 | 0.7265 | 0.4289 | 0.8437 | 30.5560 |
| 22 | 0.0300 | 0.8200 | 0.4533 | 0.9370 | 28.9319 |
| 23 | 0.0500 | 0.8185 | 0.4241 | 0.9218 | 27.3903 |
| 24 | 0.0700 | 0.8128 | 0.3931 | 0.9029 | 25.8119 |
| 25 | 0.0900 | 0.8083 | 0.3637 | 0.8864 | 24.2256 |
| 26 | 0.1100 | 0.8040 | 0.3347 | 0.8709 | 22.6039 |
| 27 | 0.1300 | 0.7996 | 0.3050 | 0.8558 | 20.8773 |
| 28 | 0.1500 | 0.7956 | 0.2741 | 0.8415 | 19.0091 |
| 29 | 0.1700 | 0.7917 | 0.2431 | 0.8282 | 17.0679 |
| 30 | 0.1900 | 0.7878 | 0.2127 | 0.8160 | 15.1064 |
| 31 | 0.2100 | 0.7839 | 0.1825 | 0.8048 | 13.1041 |
| 32 | 0.2300 | 0.7799 | 0.1518 | 0.7945 | 11.0122 |
| 33 | 0.2500 | 0.7761 | 0.1204 | 0.7854 | 8.8215 |
| 34 | 0.2700 | 0.7724 | 0.0889 | 0.7775 | 6.5634 |
| 35 | 0.2900 | 0.7687 | 0.0572 | 0.7709 | 4.2563 |
| 36 | 0.3100 | 0.7651 | 0.0255 | 0.7655 | 1.9073 |
| 37 | 0.3300 | 0.7613 | -0.0057 | 0.7613 | -0.4307 |
| 38 | 0.3500 | 0.7572 | -0.0369 | 0.7581 | -2.7934 |
| 39 | 0.3700 | 0.7537 | -0.0708 | 0.7570 | -5.3626 |
| 40 | 0.3900 | 0.7524 | -0.1081 | 0.7601 | -8.1726 |
| 41 | 0.4100 | 0.7529 | -0.1434 | 0.7664 | -10.7861 |
| 42 | 0.4300 | 0.7530 | -0.1678 | 0.7715 | -12.5658 |
| 43 | 0.4500 | 0.7443 | -0.1725 | 0.7640 | -13.0449 |
| 44 | 0.4700 | 0.7079 | -0.1305 | 0.7198 | -10.4430 |
| 45 | 0.4900 | 0.6379 | -0.0434 | 0.6394 | -3.8899 |
| 46 | 0.5100 | 0.5514 | 0.0656 | 0.5553 | 6.7889 |
| 47 | 0.5300 | 0.4655 | 0.1711 | 0.4960 | 20.1844 |
| 48 | 0.5500 | 0.3975 | 0.2506 | 0.4699 | 32.2340 |
| 49 | 0.5700 | 0.3563 | 0.2961 | 0.4632 | 39.7309 |
| 50 | 0.5900 | 0.3371 | 0.3120 | 0.4593 | 42.7914 |
| 51 | 0.6100 | 0.3517 | 0.2968 | 0.4602 | 40.1653 |
| 52 | 0.6300 | 0.3804 | 0.2667 | 0.4646 | 35.0288 |
| 53 | 0.6500 | 0.4218 | 0.2270 | 0.4790 | 28.2873 |
| 54 | 0.6700 | 0.4695 | 0.1878 | 0.5057 | 21.8040 |
| 55 | 0.6900 | 0.5142 | 0.1560 | 0.5373 | 16.8780 |
| 56 | 0.7100 | 0.5492 | 0.1397 | 0.5667 | 14.2710 |
| 57 | 0.7300 | 0.5675 | 0.1460 | 0.5860 | 14.4287 |
| 58 | 0.7500 | 0.5665 | 0.1749 | 0.5929 | 17.1562 |

```
  59    0.7700     0.5507     0.2210     0.5934    21.8670
  60    0.7900     0.5263     0.2770     0.5948    27.7614
  61    0.8100     0.5020     0.3344     0.6032    33.6694
  62    0.8300     0.4866     0.3845     0.6202    38.3187
  63    0.8500     0.4845     0.4209     0.6418    40.9811
  64    0.8700     0.4961     0.4405     0.6635    41.6021
  65    0.8900     0.5201     0.4445     0.6842    40.5183
  66    0.9100     0.5577     0.4335     0.7064    37.8573
  67    0.9300     0.6063     0.4133     0.7338    34.2839
  68    0.9500     0.6660     0.3869     0.7702    30.1554
  69    0.9700     0.7261     0.3542     0.8079    26.0065
  70    0.9900     0.8322     0.3232     0.8927    21.2231
 >>>>>>>>  AERODYNAMIC COEFFICIENTS  <<<<<<<<

MACH NUMBER=  2.6100
REDUCED FREQUENCY (BASED ON CHORD)=  2.0000
INTER-BLADE PHASE ANGLE=  180.0000
STAGGER ANGLE=   28.0000

    CLRE=      1.28459     CLIM=     -0.41218
    CMRE=      0.20145     CMIM=     -0.10370
 CFL  =   (  -0.2044 ,   0.0656 )      LHL  =   (  -0.4089 ,    0.1312 )
 CMA  =   (  -0.0321 ,   0.0165 )      LLL  =   (  -0.1282 ,    0.0660 )

    GAMA H =      0.56700     GAMA ALPHA =      1.00000
    ZETA H =      0.00000     ZETA ALPHA =      0.00000
    MASS RATIO(XMU)                 =   936.00000
    RADIUS OF GYRATION(XRA)         =     0.61500
    DT. BETWEEN E.A. AND C.G.(XALFA)=     0.00000

NU=      0.56700     MU=      0.00000     HB=      1.00000     AP=      0.00000
NU=      1.00018     MU=      0.00009     HB=      0.00068     AP=      1.00000

    block  1 written on unit  9 ncyc =     816

    block  2 written on unit  9 ncyc =     816

 MAXMEM= 3949056.
 MAXMEM= 3.76611328125 MEGAWORDS
```

**Additional Output of Interest:**

OUT.HIST: file containing the time history of force coefficients versus time of the center blade.

### 7.1.2 Plunging Motion

In this example, the unsteady aerodynamic coefficients are calculated with the cascade oscillating in plunging motion only. The reduced frequency (REDFREQ) is 1.0. The unsteady aerodynamic coefficients are calculated by harmonically oscillating (MOTION=1) the blades in 180 degrees phase angle (PHASE=180.). A plunging amplitude (H0/c) of 0.002 is used. Note that the plunging amplitude is non-dimensionalized with chord. A CFL number of 4.0 is used to give a time step (dtmin) of 0.00440. This value of the time step, for the given value of reduced frequency, yields 272 steps per cycle (nperiod=272). Calculations are performed for 3 cycles (NCYC=3) of oscillation. At the end of calculations for each cycle of oscillation, the forces (lift followed by moment) are Fourier analyzed and harmonics are printed. In addition, eigen values for flutter analysis are also printed.

In this section, the input and output for plunging motion only is given. The input file description contains only the data that is different from the input for pitching motion given earlier.

**Input file (ecap2d.in):**

```
    H0/C    ALFA0D
  0.0020    0.0000
   IMODE     IFLTR     IFREE
       0         1         0
```

All other inputs are the same as given in the previous example.

**ecap2d.out**

```
*****************************************************
                          HARMONIC MOTION
*****************************************************

    factors for vibration =       1.0000      1.0000
  FSMACH      PHASE   REDFREQ      ALPHA
  2.6100  180.0000    1.0000     0.0000
    H0/C    ALFA0D
  0.0020    0.0000
     CFL      PRAT       PSI      ORDER      LIMIT
  4.0000    0.7320    0.3333     3.0000     1.0000
      X0        Y0      SBYC    STAGGER
  0.3000    0.0000    0.3110    28.0000
    ncyc      NTSS     NTTOT     NTPRNT
       3       100      1000         50
     ILE       ITE       IGB     IAFOIL
      20        70         0          0
   XLEFT    XRIGHT
 -0.3000    1.5000
   KMODE      KFFT     LIMIT
       1         1         1
     KIN      KOUT    MOOVEE
       0         9         0

 ****** Oscillating Cascade Analysis ******
 input run stream:

 number of blocks =    2 where each block has dimensions of:
               ni =   91
               nj =   41
               nk =    2

 freestream mach number  =  2.6100
```

```
inlet incidence angle    =  0.0000 (degrees)
exit pressure ratio      =  0.7320 (p/ptot)
inter-blade phase angle =180.0000 (degrees)
reduced frequency        =  1.0000 (based on semichord)
reduced frequency        =  5.2200 (in terms of omega)
amplitude of plunge      =  0.0020 (percent chord)
amplitude of pitch       =  0.0000 (degrees)
airfoil moment center    =  0.3000 (x0, percent chord)
airfoil moment center    =  0.0000 (y0, percent chord)
cascade stagger angle    = 28.0000 (degrees)
cascade spacing          =  0.3110 (percent chord)

ile      =   20 (airfoil leading edge index)
ite      =   70 (airfoil trailing edge index)
nb       =    3 (total number of cycles)
kin      =    0 (restart input number -if 0 not used)
kout     =    9 (restart output number -if 0 not used)
kfft     =    1 (no fft analysis if kfft=0)
moovee   =    0 (save certain steps for animation)
kmode    =    1 (stationary or oscillating cascade)

a fft analysis will be done at the end of each cycle

      flux limiter input information:

            limit =    1
            psi   = 0.333
            order =   3.0

note with limit=1, MINMOD limiter has been invoked

    grid generated now , igb =      0
    IMODE      IFLTR      IFREE
        0          1          0
    PLUNGING MOTION
    FLUTTER IN FREQ. DOMAIN: SINGLE DEGREE OF FREEDOM

    **** PRINT INTERVAL, NTPRNT **** =    50

    motion indicator for blade     1:    1.0000
    GAMA H =       0.56700      GAMA ALPHA =      1.00000
    ZETA H =       0.00000      ZETA ALPHA =      0.00000
    MASS RATIO(XMU)                       =   936.00000
    RADIUS OF GYRATION(XRA)               =     0.61500
    DT. BETWEEN E.A. AND C.G.(XALFA)      =     0.00000
    initial plunging velocity             =     0.00000
    initial pitching velocity             =     0.05000
    initial plunging displacement         =     0.00000
    initial pitching displacemnet         =     0.00000

    motion indicator for blade     2:    1.0000
    GAMA H =       0.56700      GAMA ALPHA =      1.00000
    ZETA H =       0.00000      ZETA ALPHA =      0.00000
    MASS RATIO(XMU)                       =   936.00000
    RADIUS OF GYRATION(XRA)               =     0.61500
    DT. BETWEEN E.A. AND C.G.(XALFA)      =     0.00000
    initial plunging velocity             =     0.00000
    initial pitching velocity             =     0.01545
```

```
   initial plunging displacement     =     0.00000
   initial pitching displacemnet     =     0.00000

   IN ROUTINE GRIDGEN:STAG,SC,CHORD,X1,X4,NIF,NIB,IRUN
  28.00000     0.31100     1.00000    -0.30000     1.50000   20   70     0
 stagger angle (deg.) from input file =
                          28.0000000000
 stagger angle (deg.) from grid file =
                          28.0000000000
 stagger angle (deg.) used in the cal. =
                          28.0000000000
 gap-to-chord ratio from input file =
                          0.3110000000
 gap-to-chord ratio from grid file =
                          0.3110000000
 gap-to-chord ratio used in the calculation =
                          0.3110000000
   finished reading grid coordinates in routine rdgrid
   *** x coordinates at 0,ile,ilt,last
      -0.30000     0.00000     1.00000     1.50000

Starting the initial grid calculation
  For block  1:
    dtmin (as computed in eigenv) at cfl =  4.0 is      0.00440
  For block  2:
    dtmin (as computed in eigenv) at cfl =  4.0 is      0.00440
Successful completion of initial grid generation

 The flow solution will use dtmin= 0.00443 and nperiod=   272
 to give a maximum cfl close to   4.000
```

Surface Mach Number, Isentropic Mach Number and CP; block = 1 and ncyc = 272

| x/c | machu | imachu | cpu | x/c | machl | imachl | cpl |
|---|---|---|---|---|---|---|---|
| -0.2939 | 2.6100 | 2.6100 | 0.0000 | -0.2939 | 2.6100 | 2.6100 | 0.0000 |
| -0.2816 | 2.6100 | 2.6100 | 0.0000 | -0.2816 | 2.6100 | 2.6100 | 0.0000 |
| -0.2689 | 2.6100 | 2.6100 | 0.0000 | -0.2689 | 2.6100 | 2.6100 | 0.0000 |
| -0.2558 | 2.6100 | 2.6100 | 0.0000 | -0.2558 | 2.6100 | 2.6100 | 0.0000 |
| -0.2424 | 2.6100 | 2.6100 | 0.0000 | -0.2424 | 2.6100 | 2.6100 | 0.0000 |
| -0.2286 | 2.6100 | 2.6100 | 0.0000 | -0.2286 | 2.6100 | 2.6100 | 0.0000 |
| -0.2144 | 2.6100 | 2.6100 | 0.0000 | -0.2144 | 2.6100 | 2.6100 | 0.0000 |
| -0.1998 | 2.6100 | 2.6100 | 0.0000 | -0.1998 | 2.6100 | 2.6100 | 0.0000 |
| -0.1848 | 2.6100 | 2.6100 | 0.0000 | -0.1848 | 2.6100 | 2.6100 | 0.0000 |
| -0.1694 | 2.6100 | 2.6100 | 0.0000 | -0.1694 | 2.6100 | 2.6100 | 0.0000 |
| -0.1536 | 2.6100 | 2.6100 | 0.0000 | -0.1536 | 2.6100 | 2.6100 | 0.0000 |
| -0.1373 | 2.6100 | 2.6100 | 0.0000 | -0.1373 | 2.6100 | 2.6100 | 0.0000 |
| -0.1206 | 2.6100 | 2.6100 | 0.0000 | -0.1206 | 2.6100 | 2.6100 | 0.0000 |
| -0.1034 | 2.6100 | 2.6100 | 0.0000 | -0.1034 | 2.6100 | 2.6100 | 0.0000 |
| -0.0858 | 2.6100 | 2.6100 | 0.0000 | -0.0858 | 2.6100 | 2.6100 | 0.0000 |
| -0.0676 | 2.6100 | 2.6100 | 0.0000 | -0.0676 | 2.6100 | 2.6100 | 0.0000 |
| -0.0489 | 2.6100 | 2.6100 | 0.0000 | -0.0489 | 2.6100 | 2.6100 | 0.0000 |
| -0.0297 | 2.6100 | 2.6100 | 0.0000 | -0.0297 | 2.6100 | 2.6100 | 0.0000 |
| -0.0100 | 2.6100 | 2.6100 | 0.0000 | -0.0100 | 2.6100 | 2.6100 | 0.0000 |
| 0.0100 | 2.6102 | 2.6102 | 0.0001 | 0.0100 | 2.6098 | 2.6102 | 0.0001 |
| 0.0300 | 2.6105 | 2.6103 | 0.0001 | 0.0300 | 2.6109 | 2.6102 | 0.0001 |
| 0.0500 | 2.6112 | 2.6103 | 0.0001 | 0.0500 | 2.6121 | 2.6103 | 0.0001 |
| 0.0700 | 2.6119 | 2.6104 | 0.0001 | 0.0700 | 2.6128 | 2.6103 | 0.0001 |
| 0.0900 | 2.6124 | 2.6105 | 0.0001 | 0.0900 | 2.6131 | 2.6104 | 0.0001 |
| 0.1100 | 2.6127 | 2.6105 | 0.0002 | 0.1100 | 2.6132 | 2.6104 | 0.0001 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0.1300 | 2.6129 | 2.6106 | 0.0002 | 0.1300 | 2.6133 | 2.6105 | 0.0002 |
| 0.1500 | 2.6132 | 2.6106 | 0.0002 | 0.1500 | 2.6135 | 2.6105 | 0.0002 |
| 0.1700 | 2.6133 | 2.6107 | 0.0002 | 0.1700 | 2.6135 | 2.6106 | 0.0002 |
| 0.1900 | 2.6133 | 2.6107 | 0.0002 | 0.1900 | 2.6135 | 2.6106 | 0.0002 |
| 0.2100 | 2.6133 | 2.6108 | 0.0002 | 0.2100 | 2.6134 | 2.6106 | 0.0002 |
| 0.2300 | 2.6133 | 2.6108 | 0.0003 | 0.2300 | 2.6132 | 2.6107 | 0.0002 |
| 0.2500 | 2.6132 | 2.6109 | 0.0003 | 0.2500 | 2.6129 | 2.6107 | 0.0002 |
| 0.2700 | 2.6130 | 2.6109 | 0.0003 | 0.2700 | 2.6125 | 2.6108 | 0.0002 |
| 0.2900 | 2.6128 | 2.6109 | 0.0003 | 0.2900 | 2.6120 | 2.6108 | 0.0003 |
| 0.3100 | 2.6126 | 2.6110 | 0.0003 | 0.3100 | 2.6114 | 2.6108 | 0.0003 |
| 0.3300 | 2.6123 | 2.6110 | 0.0003 | 0.3300 | 2.6109 | 2.6109 | 0.0003 |
| 0.3500 | 2.6121 | 2.6110 | 0.0003 | 0.3500 | 2.6104 | 2.6109 | 0.0003 |
| 0.3700 | 2.6119 | 2.6111 | 0.0003 | 0.3700 | 2.6100 | 2.6108 | 0.0003 |
| 0.3900 | 2.6117 | 2.6111 | 0.0004 | 0.3900 | 2.6096 | 2.6108 | 0.0002 |
| 0.4100 | 2.6115 | 2.6111 | 0.0004 | 0.4100 | 2.6093 | 2.6107 | 0.0002 |
| 0.4300 | 2.6113 | 2.6111 | 0.0004 | 0.4300 | 2.6093 | 2.6109 | 0.0003 |
| 0.4500 | 2.6112 | 2.6111 | 0.0004 | 0.4500 | 2.6095 | 2.6121 | 0.0007 |
| 0.4700 | 2.6110 | 2.6111 | 0.0004 | 0.4700 | 2.6104 | 2.6146 | 0.0015 |
| 0.4900 | 2.6109 | 2.6111 | 0.0004 | 0.4900 | 2.6119 | 2.6180 | 0.0026 |
| 0.5100 | 2.6108 | 2.6111 | 0.0003 | 0.5100 | 2.6134 | 2.6218 | 0.0038 |
| 0.5300 | 2.6107 | 2.6111 | 0.0003 | 0.5300 | 2.6145 | 2.6252 | 0.0049 |
| 0.5500 | 2.6106 | 2.6110 | 0.0003 | 0.5500 | 2.6152 | 2.6279 | 0.0057 |
| 0.5700 | 2.6105 | 2.6110 | 0.0003 | 0.5700 | 2.6153 | 2.6296 | 0.0063 |
| 0.5900 | 2.6104 | 2.6110 | 0.0003 | 0.5900 | 2.6145 | 2.6305 | 0.0065 |
| 0.6100 | 2.6103 | 2.6109 | 0.0003 | 0.6100 | 2.6136 | 2.6305 | 0.0065 |
| 0.6300 | 2.6102 | 2.6108 | 0.0003 | 0.6300 | 2.6123 | 2.6303 | 0.0065 |
| 0.6500 | 2.6100 | 2.6107 | 0.0002 | 0.6500 | 2.6109 | 2.6301 | 0.0064 |
| 0.6700 | 2.6099 | 2.6106 | 0.0002 | 0.6700 | 2.6095 | 2.6298 | 0.0063 |
| 0.6900 | 2.6099 | 2.6107 | 0.0002 | 0.6900 | 2.6082 | 2.6296 | 0.0062 |
| 0.7100 | 2.6101 | 2.6114 | 0.0004 | 0.7100 | 2.6071 | 2.6293 | 0.0062 |
| 0.7300 | 2.6108 | 2.6128 | 0.0009 | 0.7300 | 2.6061 | 2.6291 | 0.0061 |
| 0.7500 | 2.6116 | 2.6149 | 0.0016 | 0.7500 | 2.6053 | 2.6289 | 0.0060 |
| 0.7700 | 2.6126 | 2.6173 | 0.0024 | 0.7700 | 2.6048 | 2.6286 | 0.0059 |
| 0.7900 | 2.6136 | 2.6199 | 0.0032 | 0.7900 | 2.6044 | 2.6283 | 0.0059 |
| 0.8100 | 2.6145 | 2.6224 | 0.0040 | 0.8100 | 2.6042 | 2.6281 | 0.0058 |
| 0.8300 | 2.6152 | 2.6247 | 0.0047 | 0.8300 | 2.6041 | 2.6278 | 0.0057 |
| 0.8500 | 2.6156 | 2.6265 | 0.0053 | 0.8500 | 2.6042 | 2.6275 | 0.0056 |
| 0.8700 | 2.6157 | 2.6278 | 0.0057 | 0.8700 | 2.6043 | 2.6273 | 0.0055 |
| 0.8900 | 2.6156 | 2.6287 | 0.0060 | 0.8900 | 2.6045 | 2.6270 | 0.0054 |
| 0.9100 | 2.6150 | 2.6291 | 0.0061 | 0.9100 | 2.6048 | 2.6267 | 0.0054 |
| 0.9300 | 2.6144 | 2.6291 | 0.0061 | 0.9300 | 2.6051 | 2.6265 | 0.0053 |
| 0.9500 | 2.6136 | 2.6290 | 0.0061 | 0.9500 | 2.6053 | 2.6262 | 0.0052 |
| 0.9700 | 2.6127 | 2.6288 | 0.0060 | 0.9700 | 2.6056 | 2.6259 | 0.0051 |
| 0.9900 | 2.6119 | 2.6285 | 0.0059 | 0.9900 | 2.6059 | 2.6257 | 0.0050 |
| 1.0100 | 2.6008 | 2.6105 | 0.0002 | 1.0100 | 2.5945 | 2.6090 | -0.0003 |
| 1.0302 | 2.6074 | 2.6114 | 0.0005 | 1.0302 | 2.6040 | 2.6085 | -0.0005 |
| 1.0507 | 2.6112 | 2.6112 | 0.0004 | 1.0507 | 2.6092 | 2.6087 | -0.0004 |
| 1.0715 | 2.6156 | 2.6111 | 0.0004 | 1.0715 | 2.6141 | 2.6087 | -0.0004 |
| 1.0928 | 2.6198 | 2.6111 | 0.0004 | 1.0928 | 2.6184 | 2.6088 | -0.0004 |
| 1.1144 | 2.6237 | 2.6112 | 0.0004 | 1.1144 | 2.6215 | 2.6089 | -0.0004 |
| 1.1363 | 2.6267 | 2.6112 | 0.0004 | 1.1363 | 2.6233 | 2.6089 | -0.0003 |
| 1.1586 | 2.6283 | 2.6113 | 0.0004 | 1.1586 | 2.6242 | 2.6090 | -0.0003 |
| 1.1813 | 2.6289 | 2.6113 | 0.0004 | 1.1813 | 2.6243 | 2.6091 | -0.0003 |
| 1.2044 | 2.6287 | 2.6113 | 0.0004 | 1.2044 | 2.6241 | 2.6092 | -0.0003 |
| 1.2279 | 2.6281 | 2.6111 | 0.0004 | 1.2279 | 2.6237 | 2.6093 | -0.0002 |
| 1.2518 | 2.6275 | 2.6110 | 0.0003 | 1.2518 | 2.6232 | 2.6092 | -0.0003 |
| 1.2761 | 2.6267 | 2.6108 | 0.0002 | 1.2761 | 2.6224 | 2.6091 | -0.0003 |
| 1.3008 | 2.6257 | 2.6106 | 0.0002 | 1.3008 | 2.6216 | 2.6090 | -0.0003 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1.3259 | 2.6247 | 2.6104 | 0.0001 | 1.3259 | 2.6211 | 2.6091 | -0.0003 |
| 1.3515 | 2.6236 | 2.6102 | 0.0001 | 1.3515 | 2.6207 | 2.6094 | -0.0002 |
| 1.3775 | 2.6226 | 2.6102 | 0.0001 | 1.3775 | 2.6204 | 2.6098 | -0.0001 |
| 1.4039 | 2.6219 | 2.6104 | 0.0001 | 1.4039 | 2.6199 | 2.6100 | 0.0000 |
| 1.4308 | 2.6210 | 2.6110 | 0.0003 | 1.4308 | 2.6194 | 2.6099 | 0.0000 |
| 1.4582 | 2.6205 | 2.6117 | 0.0005 | 1.4582 | 2.6186 | 2.6096 | -0.0001 |
| 1.4860 | 2.6189 | 2.6134 | 0.0011 | 1.4860 | 2.6178 | 2.6083 | -0.0005 |

******** inlet conditions ********

| j | u | v | mach | angle | p/pt |
|---|---|---|---|---|---|
| 2 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 3 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 4 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 5 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 6 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 7 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 8 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 9 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 10 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 11 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 12 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 13 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 14 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 15 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 16 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 17 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 18 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 19 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 20 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 21 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 22 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 23 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 24 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 25 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 26 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 27 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 28 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 29 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 30 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 31 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 32 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 33 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 34 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 35 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 36 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 37 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 38 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 39 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 40 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |
| 41 | 2.610 | 0.000 | 2.610 | 0.000 | 0.0493 |

The average inlet Mach number is: 2.6100

******** exit conditions ********

| j | u | v | mach | angle | p/pt |
|---|---|---|---|---|---|
| 2 | 2.617 | 0.011 | 2.625 | 0.233 | 0.0491 |

```
  3  2.616  0.011  2.623  0.240  0.0491
  4  2.611  0.011  2.619  0.245  0.0491
  5  2.605  0.011  2.613  0.252  0.0491
  6  2.602  0.012  2.610  0.257  0.0491
  7  2.603  0.012  2.611  0.263  0.0490
  8  2.603  0.012  2.612  0.270  0.0490
  9  2.604  0.013  2.612  0.277  0.0490
 10  2.604  0.013  2.612  0.285  0.0490
 11  2.603  0.013  2.612  0.292  0.0490
 12  2.603  0.014  2.613  0.299  0.0490
 13  2.603  0.014  2.613  0.306  0.0490
 14  2.603  0.014  2.613  0.311  0.0490
 15  2.603  0.014  2.612  0.314  0.0490
 16  2.602  0.014  2.611  0.316  0.0490
 17  2.602  0.014  2.609  0.309  0.0491
 18  2.601  0.013  2.604  0.283  0.0492
 19  2.599  0.010  2.596  0.223  0.0495
 20  2.597  0.006  2.585  0.137  0.0498
 21  2.595  0.002  2.574  0.044  0.0502
 22  2.595  0.000  2.570 -0.009  0.0503
 23  2.595 -0.001  2.570 -0.024  0.0503
 24  2.595 -0.002  2.571 -0.036  0.0503
 25  2.595 -0.002  2.572 -0.049  0.0502
 26  2.595 -0.003  2.574 -0.057  0.0502
 27  2.595 -0.003  2.576 -0.066  0.0501
 28  2.596 -0.003  2.579 -0.072  0.0500
 29  2.596 -0.004  2.582 -0.082  0.0499
 30  2.597 -0.004  2.584 -0.094  0.0498
 31  2.597 -0.005  2.586 -0.108  0.0498
 32  2.597 -0.005  2.588 -0.121  0.0497
 33  2.598 -0.006  2.590 -0.135  0.0496
 34  2.598 -0.007  2.592 -0.147  0.0496
 35  2.598 -0.007  2.592 -0.157  0.0496
 36  2.596 -0.008  2.591 -0.166  0.0495
 37  2.596 -0.008  2.591 -0.175  0.0495
 38  2.601 -0.008  2.597 -0.183  0.0495
 39  2.609 -0.009  2.605 -0.190  0.0495
 40  2.614 -0.009  2.611 -0.196  0.0495
 41  2.616 -0.009  2.613 -0.201  0.0495

 The average exit Mach number is:    2.5978

Surface Mach Number, Isentropic Mach Number and CP; block =  2 and ncyc =   272
                   ****
                   ****
                   ****
```

***** **The output for block 2 is deleted for brevity until it******
****** **prints average exit Mach number** ****.

```
                   ****
                   ****
                   ****
 The average exit Mach number is:    2.5978

    FOURIER COEFFICIENTS FOR CYCLE      1
    ZERO TH HARMONIC =      0.1956
     higher HARMONICS = 1,2,3,4
       0.8270    -1.6555     1.8505   -63.4566
      -0.0805    -0.2223     0.2365 -109.9140
```

```
     0.0159   -0.1587    0.1595  -84.2789                            (lift)
     0.0292   -0.0800    0.0851  -69.9746
 FOURIER COEFFICIENTS FOR CYCLE      1
 ZERO TH HARMONIC =     0.0953
  higher HARMONICS = 1,2,3,4
     0.3674   -0.3500    0.5074  -43.6150
    -0.0358   -0.1038    0.1098 -109.0092
     0.0045   -0.0767    0.0769  -86.6464                            (moment)
     0.0125   -0.0407    0.0426  -72.9637
Unsteady Pressure Distribution, First Harmonic of dcp:
 FOURIER COEFFICIENTS FOR CYCLE      1
```

| i | x/c | Real | Imag | Mag | Phase |
|---|---|---|---|---|---|
| 272 | | | | | |
| 21 | 0.0100 | 0.0596 | -1.4507 | 1.4519 | -87.6476 |
| 22 | 0.0300 | 0.0463 | -1.6445 | 1.6452 | -88.3882 |
| 23 | 0.0500 | 0.0548 | -1.6521 | 1.6530 | -88.0991 |
| 24 | 0.0700 | 0.0648 | -1.6474 | 1.6487 | -87.7488 |
| 25 | 0.0900 | 0.0688 | -1.6388 | 1.6402 | -87.5960 |
| 26 | 0.1100 | 0.0740 | -1.6320 | 1.6337 | -87.4026 |
| 27 | 0.1300 | 0.0828 | -1.6286 | 1.6307 | -87.0882 |
| 28 | 0.1500 | 0.0913 | -1.6251 | 1.6277 | -86.7833 |
| 29 | 0.1700 | 0.0974 | -1.6194 | 1.6223 | -86.5581 |
| 30 | 0.1900 | 0.1023 | -1.6122 | 1.6155 | -86.3698 |
| 31 | 0.2100 | 0.1072 | -1.6051 | 1.6087 | -86.1778 |
| 32 | 0.2300 | 0.1124 | -1.5984 | 1.6024 | -85.9779 |
| 33 | 0.2500 | 0.1173 | -1.5919 | 1.5962 | -85.7866 |
| 34 | 0.2700 | 0.1212 | -1.5850 | 1.5896 | -85.6282 |
| 35 | 0.2900 | 0.1244 | -1.5775 | 1.5824 | -85.4914 |
| 36 | 0.3100 | 0.1278 | -1.5691 | 1.5743 | -85.3446 |
| 37 | 0.3300 | 0.1306 | -1.5596 | 1.5650 | -85.2144 |
| 38 | 0.3500 | 0.1299 | -1.5489 | 1.5543 | -85.2065 |
| 39 | 0.3700 | 0.1237 | -1.5393 | 1.5442 | -85.4049 |
| 40 | 0.3900 | 0.1176 | -1.5338 | 1.5383 | -85.6143 |
| 41 | 0.4100 | 0.1211 | -1.5335 | 1.5383 | -85.4830 |
| 42 | 0.4300 | 0.1587 | -1.5402 | 1.5483 | -84.1170 |
| 43 | 0.4500 | 0.2758 | -1.5579 | 1.5822 | -79.9597 |
| 44 | 0.4700 | 0.4669 | -1.5823 | 1.6497 | -73.5582 |
| 45 | 0.4900 | 0.6944 | -1.6090 | 1.7524 | -66.6564 |
| 46 | 0.5100 | 0.9130 | -1.6345 | 1.8722 | -60.8123 |
| 47 | 0.5300 | 1.0895 | -1.6558 | 1.9821 | -56.6566 |
| 48 | 0.5500 | 1.2074 | -1.6709 | 2.0615 | -54.1474 |
| 49 | 0.5700 | 1.2693 | -1.6835 | 2.1084 | -52.9852 |
| 50 | 0.5900 | 1.2875 | -1.6883 | 2.1232 | -52.6696 |
| 51 | 0.6100 | 1.2812 | -1.6891 | 2.1200 | -52.8194 |
| 52 | 0.6300 | 1.2613 | -1.6860 | 2.1056 | -53.2014 |
| 53 | 0.6500 | 1.2351 | -1.6813 | 2.0862 | -53.6989 |
| 54 | 0.6700 | 1.2082 | -1.6776 | 2.0674 | -54.2381 |
| 55 | 0.6900 | 1.1860 | -1.6785 | 2.0553 | -54.7555 |
| 56 | 0.7100 | 1.1768 | -1.6859 | 2.0560 | -55.0841 |
| 57 | 0.7300 | 1.1904 | -1.7016 | 2.0767 | -55.0239 |
| 58 | 0.7500 | 1.2396 | -1.7220 | 2.1218 | -54.2517 |
| 59 | 0.7700 | 1.3217 | -1.7401 | 2.1851 | -52.7816 |
| 60 | 0.7900 | 1.4295 | -1.7537 | 2.2625 | -50.8153 |
| 61 | 0.8100 | 1.5527 | -1.7621 | 2.3486 | -48.6150 |
| 62 | 0.8300 | 1.6818 | -1.7656 | 2.4384 | -46.3933 |
| 63 | 0.8500 | 1.8043 | -1.7659 | 2.5247 | -44.3831 |
| 64 | 0.8700 | 1.9091 | -1.7658 | 2.6005 | -42.7658 |
| 65 | 0.8900 | 1.9912 | -1.7681 | 2.6629 | -41.6041 |

```
  66     0.9100     2.0491    -1.7716     2.7088   -40.8464
  67     0.9300     2.0848    -1.7760     2.7388   -40.4272
  68     0.9500     2.1011    -1.7816     2.7548   -40.2966
  69     0.9700     2.1022    -1.7859     2.7583   -40.3495
  70     0.9900     2.1037    -1.7999     2.7686   -40.5499
****
****
****
```

***** Output of surface Mach number, etc., for cycle 2, for ****
****blocks 1 and 2 are deleted for brevity****

```
****
****
****
     FOURIER COEFFICIENTS FOR CYCLE      2
     ZERO TH HARMONIC =      0.0031
      higher HARMONICS = 1,2,3,4
         1.0881    -1.4432     1.8074   -52.9859
        -0.0042     0.0038     0.0056   137.6791
         0.0037    -0.0059     0.0070   -58.0297                        (lift)
         0.0007    -0.0031     0.0032   -76.7133
     FOURIER COEFFICIENTS FOR CYCLE      2
     ZERO TH HARMONIC =     -0.0009
      higher HARMONICS = 1,2,3,4
         0.4951    -0.2435     0.5517   -26.1887
         0.0015     0.0048     0.0051    72.3255
         0.0019    -0.0017     0.0026   -41.0615                        (moment)
         0.0003    -0.0007     0.0008   -67.8596
 Unsteady Pressure Distribution, First Harmonic of dcp:
     FOURIER COEFFICIENTS FOR CYCLE      2
   i     x/c        Real       Imag        Mag       Phase
 272
  21     0.0100     0.0194    -1.4721     1.4722   -89.2440
  22     0.0300     0.0194    -1.6519     1.6521   -89.3279
  23     0.0500     0.0311    -1.6610     1.6613   -88.9260
  24     0.0700     0.0431    -1.6558     1.6563   -88.5077
  25     0.0900     0.0490    -1.6461     1.6468   -88.2964
  26     0.1100     0.0558    -1.6384     1.6394   -88.0496
  27     0.1300     0.0665    -1.6346     1.6359   -87.6715
  28     0.1500     0.0768    -1.6303     1.6321   -87.3022
  29     0.1700     0.0848    -1.6237     1.6259   -87.0094
  30     0.1900     0.0916    -1.6155     1.6181   -86.7559
  31     0.2100     0.0982    -1.6075     1.6105   -86.5029
  32     0.2300     0.1053    -1.6000     1.6035   -86.2359
  33     0.2500     0.1123    -1.5926     1.5965   -85.9663
  34     0.2700     0.1184    -1.5847     1.5891   -85.7255
  35     0.2900     0.1239    -1.5760     1.5809   -85.5052
  36     0.3100     0.1298    -1.5663     1.5717   -85.2621
  37     0.3300     0.1357    -1.5550     1.5610   -85.0129
  38     0.3500     0.1380    -1.5423     1.5484   -84.8851
  39     0.3700     0.1331    -1.5312     1.5370   -85.0324
  40     0.3900     0.1264    -1.5265     1.5317   -85.2677
  41     0.4100     0.1298    -1.5273     1.5328   -85.1436
  42     0.4300     0.1718    -1.5325     1.5421   -83.6051
  43     0.4500     0.3131    -1.5400     1.5715   -78.5066
  44     0.4700     0.5568    -1.5366     1.6344   -70.0800
  45     0.4900     0.8571    -1.5211     1.7460   -60.5990
  46     0.5100     1.1584    -1.4947     1.8910   -52.2235
  47     0.5300     1.4107    -1.4630     2.0323   -46.0433
```

| | | | | | |
|---|---|---|---|---|---|
| 48 | 0.5500 | 1.5880 | -1.4314 | 2.1379 | -42.0307 |
| 49 | 0.5700 | 1.6896 | -1.4074 | 2.1989 | -39.7935 |
| 50 | 0.5900 | 1.7268 | -1.3886 | 2.2159 | -38.8054 |
| 51 | 0.6100 | 1.7262 | -1.3755 | 2.2072 | -38.5507 |
| 52 | 0.6300 | 1.7046 | -1.3660 | 2.1845 | -38.7071 |
| 53 | 0.6500 | 1.6721 | -1.3593 | 2.1549 | -39.1074 |
| 54 | 0.6700 | 1.6359 | -1.3557 | 2.1246 | -39.6495 |
| 55 | 0.6900 | 1.6036 | -1.3571 | 2.1008 | -40.2419 |
| 56 | 0.7100 | 1.5876 | -1.3622 | 2.0919 | -40.6303 |
| 57 | 0.7300 | 1.6028 | -1.3707 | 2.1090 | -40.5369 |
| 58 | 0.7500 | 1.6723 | -1.3723 | 2.1632 | -39.3721 |
| 59 | 0.7700 | 1.7898 | -1.3607 | 2.2483 | -37.2436 |
| 60 | 0.7900 | 1.9444 | -1.3356 | 2.3590 | -34.4847 |
| 61 | 0.8100 | 2.1207 | -1.2994 | 2.4871 | -31.4980 |
| 62 | 0.8300 | 2.3017 | -1.2578 | 2.6230 | -28.6561 |
| 63 | 0.8500 | 2.4673 | -1.2177 | 2.7514 | -26.2672 |
| 64 | 0.8700 | 2.6026 | -1.1839 | 2.8592 | -24.4612 |
| 65 | 0.8900 | 2.7020 | -1.1593 | 2.9402 | -23.2219 |
| 66 | 0.9100 | 2.7641 | -1.1428 | 2.9911 | -22.4621 |
| 67 | 0.9300 | 2.7942 | -1.1327 | 3.0150 | -22.0661 |
| 68 | 0.9500 | 2.7975 | -1.1284 | 3.0165 | -21.9671 |
| 69 | 0.9700 | 2.7821 | -1.1270 | 3.0018 | -22.0524 |
| 70 | 0.9900 | 2.7713 | -1.1406 | 2.9968 | -22.3713 |

****
****
****

***** **Output of surface Mach number, etc., for cycle 2, for** ****
****blocks 1 and 2 are deleted for brevity****

****
****
****

```
     FOURIER COEFFICIENTS FOR CYCLE      3
     ZERO TH HARMONIC =      0.0027
      higher HARMONICS = 1,2,3,4
        1.0882   -1.4429    1.8072  -52.9782
       -0.0041    0.0040    0.0057  135.9465
        0.0037   -0.0058    0.0069  -57.3030                    (lift)
        0.0007   -0.0030    0.0031  -76.1098
     FOURIER COEFFICIENTS FOR CYCLE      3
     ZERO TH HARMONIC =     -0.0011
      higher HARMONICS = 1,2,3,4
        0.4951   -0.2434    0.5517  -26.1759
        0.0016    0.0049    0.0052   72.3526
        0.0019   -0.0016    0.0025  -39.7178                  (moment)
        0.0003   -0.0007    0.0007  -66.1223
 Unsteady Pressure Distribution, First Harmonic of dcp:
     FOURIER COEFFICIENTS FOR CYCLE      3
```

| i | x/c | Real | Imag | Mag | Phase |
|---|---|---|---|---|---|
| 272 | | | | | |
| 21 | 0.0100 | 0.0194 | -1.4721 | 1.4722 | -89.2440 |
| 22 | 0.0300 | 0.0194 | -1.6519 | 1.6521 | -89.3279 |
| 23 | 0.0500 | 0.0311 | -1.6610 | 1.6613 | -88.9260 |
| 24 | 0.0700 | 0.0431 | -1.6558 | 1.6563 | -88.5077 |
| 25 | 0.0900 | 0.0490 | -1.6461 | 1.6468 | -88.2964 |
| 26 | 0.1100 | 0.0558 | -1.6384 | 1.6394 | -88.0496 |
| 27 | 0.1300 | 0.0665 | -1.6346 | 1.6359 | -87.6716 |
| 28 | 0.1500 | 0.0768 | -1.6303 | 1.6321 | -87.3022 |
| 29 | 0.1700 | 0.0848 | -1.6237 | 1.6259 | -87.0094 |

| | | | | | |
|---|---|---|---|---|---|
| 30 | 0.1900 | 0.0916 | -1.6155 | 1.6181 | -86.7559 |
| 31 | 0.2100 | 0.0982 | -1.6075 | 1.6105 | -86.5028 |
| 32 | 0.2300 | 0.1053 | -1.6000 | 1.6035 | -86.2359 |
| 33 | 0.2500 | 0.1123 | -1.5926 | 1.5965 | -85.9662 |
| 34 | 0.2700 | 0.1184 | -1.5847 | 1.5891 | -85.7255 |
| 35 | 0.2900 | 0.1239 | -1.5760 | 1.5809 | -85.5052 |
| 36 | 0.3100 | 0.1298 | -1.5663 | 1.5717 | -85.2622 |
| 37 | 0.3300 | 0.1357 | -1.5550 | 1.5610 | -85.0134 |
| 38 | 0.3500 | 0.1380 | -1.5423 | 1.5484 | -84.8856 |
| 39 | 0.3700 | 0.1331 | -1.5312 | 1.5370 | -85.0333 |
| 40 | 0.3900 | 0.1263 | -1.5265 | 1.5317 | -85.2687 |
| 41 | 0.4100 | 0.1297 | -1.5273 | 1.5328 | -85.1448 |
| 42 | 0.4300 | 0.1717 | -1.5326 | 1.5422 | -83.6060 |
| 43 | 0.4500 | 0.3131 | -1.5400 | 1.5715 | -78.5078 |
| 44 | 0.4700 | 0.5569 | -1.5366 | 1.6344 | -70.0787 |
| 45 | 0.4900 | 0.8572 | -1.5211 | 1.7460 | -60.5966 |
| 46 | 0.5100 | 1.1584 | -1.4947 | 1.8911 | -52.2231 |
| 47 | 0.5300 | 1.4111 | -1.4629 | 2.0326 | -46.0330 |
| 48 | 0.5500 | 1.5886 | -1.4312 | 2.1382 | -42.0172 |
| 49 | 0.5700 | 1.6902 | -1.4069 | 2.1991 | -39.7742 |
| 50 | 0.5900 | 1.7276 | -1.3880 | 2.2161 | -38.7797 |
| 51 | 0.6100 | 1.7269 | -1.3749 | 2.2073 | -38.5254 |
| 52 | 0.6300 | 1.7052 | -1.3653 | 2.1844 | -38.6823 |
| 53 | 0.6500 | 1.6726 | -1.3584 | 2.1547 | -39.0805 |
| 54 | 0.6700 | 1.6362 | -1.3547 | 2.1243 | -39.6236 |
| 55 | 0.6900 | 1.6038 | -1.3561 | 2.1003 | -40.2159 |
| 56 | 0.7100 | 1.5876 | -1.3611 | 2.0912 | -40.6068 |
| 57 | 0.7300 | 1.6026 | -1.3696 | 2.1081 | -40.5184 |
| 58 | 0.7500 | 1.6720 | -1.3713 | 2.1624 | -39.3562 |
| 59 | 0.7700 | 1.7894 | -1.3598 | 2.2475 | -37.2326 |
| 60 | 0.7900 | 1.9438 | -1.3349 | 2.3580 | -34.4786 |
| 61 | 0.8100 | 2.1199 | -1.2989 | 2.4862 | -31.4954 |
| 62 | 0.8300 | 2.3009 | -1.2575 | 2.6221 | -28.6569 |
| 63 | 0.8500 | 2.4667 | -1.2175 | 2.7508 | -26.2692 |
| 64 | 0.8700 | 2.6022 | -1.1839 | 2.8589 | -24.4628 |
| 65 | 0.8900 | 2.7018 | -1.1594 | 2.9400 | -23.2254 |
| 66 | 0.9100 | 2.7643 | -1.1428 | 2.9912 | -22.4619 |
| 67 | 0.9300 | 2.7947 | -1.1326 | 3.0155 | -22.0610 |
| 68 | 0.9500 | 2.7985 | -1.1281 | 3.0174 | -21.9544 |
| 69 | 0.9700 | 2.7834 | -1.1266 | 3.0028 | -22.0350 |
| 70 | 0.9900 | 2.7729 | -1.1397 | 2.9980 | -22.3438 |

>>>>>>>> AERODYNAMIC COEFFICIENTS <<<<<<<<

MACH NUMBER= 2.6100
REDUCED FREQUENCY (BASED ON CHORD)= 2.0000
INTER-BLADE PHASE ANGLE= 180.0000
STAGGER ANGLE= 28.0000

CLRE= 2.17635 CLIM= 2.88583
CMRE= 0.99022 CMIM= 0.48673
CFQ = ( -0.2296 , 0.1732 ) LHH = ( -0.3464 , -0.4593 )
CMQ = ( -0.0387 , 0.0788 ) LLH = ( -0.3152 , -0.1549 )

GAMA H = 0.56700 GAMA ALPHA = 1.00000
ZETA H = 0.00000 ZETA ALPHA = 0.00000
MASS RATIO(XMU) = 936.00000
RADIUS OF GYRATION(XRA) = 0.61500
DT. BETWEEN E.A. AND C.G.(XALFA)= 0.00000

```
NU=     0.56710     MU=    -0.00014     HB=     0.00000     AP=     1.00000
NU=     1.00000     MU=     0.00000     HB=     0.00000     AP=     1.00000
     block  1 written on unit  9 ncyc =    816

     block  2 written on unit  9 ncyc =    816
```

**Additional Outputs of Interest:**

OUT.HIST: file containing the time history of force coefficients versus time of the center blade.

## 7.2 Unsteady Aerodynamics of a Flat-Plate Cascade in Pitching Motion Using the Influence Coefficient Method

In this example, the influence coefficient (IC) method is used to obtain unsteady aerodynamic coefficients for the same flow and geometric conditions as in section 7.1.1. However, four blocks are used for computation i.e. nbs=4 in the parameter statement. Only one change, `MOTION=2`, is required in the input file compared to that for harmonic analysis example given in section 7.1.1. The IC method gives the aerodynamic coefficients for **all** possible interblade phase angles ( 0, 90, 180, 270 degrees in this case) in one run, for **a** given frequency of oscillation (`REDFREQ =1.0`, in this example). Therefore, the input value for the parameter `PHASE` is not used in the calculations. It should be noted that the possible interblade angles are equal to the number of blocks used in the computations.

Calculations are performed for three cycles of blade oscillation. Only one blade is oscillated, and all other blades remain stationary (done automatically in the program). The aerodynamic coefficients are obtained for 0, 90, 180, 270 degrees phase angles, since four blocks are used in the calculations. The source code is compiled with the following parameter statements.

```
parameter(nbs=4)
parameter(ni=91, nj=41)
```

**Input file (ecap2d.in)**

```
   MOTION      INEW
        2         0
   FSMACH     PHASE   REDFREQ     ALPHA
     2.61   180.000    1.0000      0.00
     H0/C    ALFA0D
   0.0000    0.1500
.........*.........*.........*.........*.........*
      CFL      PRAT       PSI     ORDER     LIMIT
      4.0    0.7320    0.3333       3.0       1.0
       X0        Y0      SBYC   STAGGER
   0.3000       0.0     0.311     28.00
```

```
.........*.........*.........*.........*
     NCYC      NTSS     NTTOT    NTPRNT
        3       100      1000        50
      ILE       ITE       IGB    IAFOIL
       20        70         0         0
.........*.........*
    XLEFT    XRIGHT
     -0.3       1.5
.........*.........*.........*
      KIN      KOUT    MOOVEE
        0         9         0
    IMODE     IFLTR     IFREE
        1         1         0
.........*.........*.........*.........*.........*.........*.........*
    VSTAR
     8.00
      GHS       GAS       ZHS       ZAS       XMU       XRA        XA
    0.567       1.0       0.0       0.0     456.0     0.588     0.000
      HD0    ALFAD0        H0     ALFA0
    0.000      0.05       0.0       0.0
      GHS       GAS       ZHS       ZAS       XMU       XRA        XA
    0.567       1.0       0.0       0.0     456.0     0.588     0.000
      HD0    ALFAD0        H0     ALFA0
    0.000   0.01545       0.0       0.0
      GHS       GAS       ZHS       ZAS       XMU       XRA        XA
    0.567       1.0       0.0       0.0     456.0     0.588     0.000
      HD0    ALFAD0        H0     ALFA0
    0.000      0.05       0.0       0.0
      GHS       GAS       ZHS       ZAS       XMU       XRA        XA
    0.567       1.0       0.0       0.0     456.0     0.588     0.000
      HD0    ALFAD0        H0     ALFA0
    0.000   0.01545       0.0       0.0
```

## Output file (ecap2d.out)

```
*******************************************************
                          INFLUENCE FUNCTION
 *******************************************************
 factors for vibration =       1.0000      0.0000      0.0000      0.0000

    FSMACH     PHASE   REDFREQ     ALPHA
    2.6100    0.0000    1.0000    0.0000
      H0/C    ALFA0D
    0.0000    0.1500
       CFL      PRAT       PSI     ORDER     LIMIT
    4.0000    0.7320    0.3333    3.0000    1.0000
        X0        Y0      SBYC   STAGGER
    0.3000    0.0000    0.3110   28.0000
      NCYC      NTSS     NTTOT    NTPRNT
         3       100      1000        50
       ILE       ITE       IGB    IAFOIL
        20        70         0         0
     XLEFT    XRIGHT
   -0.3000    1.5000
     KMODE      KFFT     LIMIT
         1         1         1
       KIN      KOUT    MOOVEE
         0         9         0
```

```
****** Oscillating Cascade Analysis ******
input run stream:

number of blocks =    4 where each block has dimensions of:
              ni =   91
              nj =   41
              nk =    2

freestream mach number   =  2.6100
inlet incidence angle    =  0.0000 (degrees)
exit pressure ratio      =  0.7320 (p/ptot)
inter-blade phase angle =   0.0000 (degrees)
reduced frequency        =  1.0000 (based on semichord)
reduced frequency        =  5.2200 (in terms of omega)
amplitude of plunge      =  0.0000 (percent chord)
amplitude of pitch       =  0.1500 (degrees)
airfoil moment center    =  0.3000 (x0, percent chord)
airfoil moment center    =  0.0000 (y0, percent chord)
cascade stagger angle    = 28.0000 (degrees)
cascade spacing          =  0.3110 (percent chord)

ile      =   20 (airfoil leading edge index)
ite      =   70 (airfoil trailing edge index)
nb       =    3 (total number of cycles)
kin      =    0 (restart input number -if 0 not used)
kout     =    9 (restart output number -if 0 not used)
kfft     =    1 (no fft analysis if kfft=0)
moovee   =    0 (save certain steps for animation)
kmode    =    1 (stationary or oscillating cascade)

a fft analysis will be done at the end of each cycle

     flux limiter input information:

           limit =    1
           psi   = 0.333
           order =   3.0

note with limit=1, MINMOD limiter has been invoked

   grid generated now , igb =      0
   IMODE      IFLTR      IFREE
       1          1          0
   PITCHING MOTION
   FLUTTER IN FREQ. DOMAIN: SINGLE DEGREE OF FREEDOM

   **** PRINT INTERVAL, NTPRNT **** =   50

   motion indicator for blade     1:   1.0000
   GAMA H =       0.56700      GAMA ALPHA =      1.00000
   ZETA H =       0.00000      ZETA ALPHA =      0.00000
   MASS RATIO(XMU)                     =   936.00000
   RADIUS OF GYRATION(XRA)             =     0.61500
   DT. BETWEEN E.A. AND C.G.(XALFA)    =     0.00000
   initial plunging velocity           =     0.00000
   initial pitching velocity           =     0.05000
```

```
initial plunging displacement     =     0.00000
initial pitching displacemnet     =     0.00000

motion indicator for blade     2:   0.0000
GAMA H =      0.56700     GAMA ALPHA =      1.00000
ZETA H =      0.00000     ZETA ALPHA =      0.00000
MASS RATIO(XMU)                     =   936.00000
RADIUS OF GYRATION(XRA)             =     0.61500
DT. BETWEEN E.A. AND C.G.(XALFA)    =     0.00000
initial plunging velocity           =     0.00000
initial pitching velocity           =     0.01545
initial plunging displacement       =     0.00000
initial pitching displacemnet       =     0.00000

motion indicator for blade     3:   0.0000
GAMA H =      0.56700     GAMA ALPHA =      1.00000
ZETA H =      0.00000     ZETA ALPHA =      0.00000
MASS RATIO(XMU)                     =   936.00000
RADIUS OF GYRATION(XRA)             =     0.61500
DT. BETWEEN E.A. AND C.G.(XALFA)    =     0.00000
initial plunging velocity           =     0.00000
initial pitching velocity           =     0.05000
initial plunging displacement       =     0.00000
initial pitching displacemnet       =     0.00000

motion indicator for blade     4:   0.0000
GAMA H =      0.56700     GAMA ALPHA =      1.00000
ZETA H =      0.00000     ZETA ALPHA =      0.00000
MASS RATIO(XMU)                     =   936.00000
RADIUS OF GYRATION(XRA)             =     0.61500
DT. BETWEEN E.A. AND C.G.(XALFA)    =     0.00000
initial plunging velocity           =     0.00000
initial pitching velocity           =     0.01545
initial plunging displacement       =     0.00000
initial pitching displacemnet       =     0.00000

  IN ROUTINE GRIDGEN:STAG,SC,CHORD,X1,X4,NIF,NIB,IRUN
28.00000    0.31100    1.00000    -0.30000    1.50000    20    70    0
stagger angle (deg.) from input file =
                                 28.0000000000
stagger angle (deg.) from grid file =
                                 28.0000000000
stagger angle (deg.) used in the cal. =
                                 28.0000000000
gap-to-chord ratio from input file =
                                  0.3110000000
gap-to-chord ratio from grid file =
                                  0.3110000000
gap-to-chord ratio used in the calculation =
                                  0.3110000000
   finished reading grid coordinates in routine rdgrid
   *** x coordinates at 0,ile,ilt,last
       -0.30000     0.00000     1.00000     1.50000

Starting the initial grid calculation
  For block  1:
     dtmin (as computed in eigenv) at cfl =  4.0 is      0.00449
  For block  2:
```

```
    dtmin (as computed in eigenv) at cfl =  4.0 is      0.00449
 For block  3:
    dtmin (as computed in eigenv) at cfl =  4.0 is      0.00449
 For block  4:
    dtmin (as computed in eigenv) at cfl =  4.0 is      0.00449
Successful completion of initial grid generation

 The flow solution will use dtmin= 0.00449 and nperiod=   268
 to give a maximum cfl close to   4.000

    DONE IN ROUTINE CPINT
    DONE IN ROUTINE CPINT
    DONE IN ROUTINE CPINT
    DONE IN ROUTINE CPINT
    DONE IN ROUTINE FORCE
***
***
***lot of similar lines are deleted
***
***
    FOURIER COEFFICIENTS FOR BLOCK    1  FOR CYCLE     1
    FOURIER COEFFICIENTS FOR BLOCK    2  FOR CYCLE     1
    FOURIER COEFFICIENTS FOR BLOCK    3  FOR CYCLE     1
    FOURIER COEFFICIENTS FOR BLOCK    4  FOR CYCLE     1
    FOURIER COEFFICIENTS FOR BLOCK    1  FOR CYCLE     1
    FOURIER COEFFICIENTS FOR BLOCK    2  FOR CYCLE     1
    FOURIER COEFFICIENTS FOR BLOCK    3  FOR CYCLE     1
    FOURIER COEFFICIENTS FOR BLOCK    4  FOR CYCLE     1
  >>>>>>>>  INFLUENCE COEFFICIENTS  <<<<<<<<

 MACH NUMBER=  2.6100
 REDUCED FREQUENCY based semi-chord=  1.0000
 STAGGER ANGLE=   28.0000

  LIFT AND MOMENT COEFFICIENTS FOR BLADE K= 1

        AM(CL) TH(CL)  RE(CL)  IM(CL)    AM(CM) TH(CM)  RE(CM)  IM(CM)
 1ST:    0.809  -19.4   0.763  -0.269     0.232  -50.7   0.147  -0.179

  LIFT AND MOMENT COEFFICIENTS FOR BLADE K= 2

        AM(CL) TH(CL)  RE(CL)  IM(CL)    AM(CM) TH(CM)  RE(CM)  IM(CM)
 1ST:    0.265  -95.9  -0.027  -0.264     0.124 -100.8  -0.023  -0.122

  LIFT AND MOMENT COEFFICIENTS FOR BLADE K= 3

        AM(CL) TH(CL)  RE(CL)  IM(CL)    AM(CM) TH(CM)  RE(CM)  IM(CM)
 1ST:    0.000    0.0   0.000   0.000     0.000    0.0   0.000   0.000

  LIFT AND MOMENT COEFFICIENTS FOR BLADE K= 4

        AM(CL) TH(CL)  RE(CL)  IM(CL)    AM(CM) TH(CM)  RE(CM)  IM(CM)
 1ST:    0.104  -78.9   0.020  -0.102     0.062  -79.2   0.012  -0.060

 axial mach number (axialm) = 2.304493217362
    phase angle                  CL                                  CM
 0.00000000E+00  0.75504316E+00 -0.63398274E+00  0.13527142E+00 -0.36119167E+00
 0.90000000E+02  0.92451683E+00 -0.31608941E+00  0.20798301E+00 -0.21385888E+00
```

```
0.18000000E+03  0.77013673E+00  0.96268164E-01  0.15831830E+00  0.28258893E-02
0.27000000E+03  0.60066306E+00 -0.22162516E+00  0.85606707E-01 -0.14450690E+00
0.36000000E+03  0.75504316E+00 -0.63398274E+00  0.13527142E+00 -0.36119167E+00

    DONE IN ROUTINE CPINT
    DONE IN ROUTINE CPINT
    DONE IN ROUTINE CPINT
    DONE IN ROUTINE CPINT
    DONE IN ROUTINE FORCE***
***
***lot of similar lines are deleted
***
    FOURIER COEFFICIENTS FOR BLOCK    1  FOR CYCLE     2
    FOURIER COEFFICIENTS FOR BLOCK    2  FOR CYCLE     2
    FOURIER COEFFICIENTS FOR BLOCK    3  FOR CYCLE     2
    FOURIER COEFFICIENTS FOR BLOCK    4  FOR CYCLE     2
    FOURIER COEFFICIENTS FOR BLOCK    1  FOR CYCLE     2
    FOURIER COEFFICIENTS FOR BLOCK    2  FOR CYCLE     2
    FOURIER COEFFICIENTS FOR BLOCK    3  FOR CYCLE     2
    FOURIER COEFFICIENTS FOR BLOCK    4  FOR CYCLE     2

 >>>>>>>>  INFLUENCE COEFFICIENTS  <<<<<<<<

MACH NUMBER=  2.6100
REDUCED FREQUENCY based semi-chord=  1.0000
STAGGER ANGLE=   28.0000

 LIFT AND MOMENT COEFFICIENTS FOR BLADE K= 1

        AM(CL) TH(CL)  RE(CL)  IM(CL)    AM(CM) TH(CM)  RE(CM)  IM(CM)
1ST:    0.810  -21.6   0.754  -0.298     0.243  -53.7   0.144  -0.196

 LIFT AND MOMENT COEFFICIENTS FOR BLADE K= 2

        AM(CL) TH(CL)  RE(CL)  IM(CL)    AM(CM) TH(CM)  RE(CM)  IM(CM)
1ST:    0.359  -82.6   0.046  -0.356     0.160  -88.0   0.006  -0.160

 LIFT AND MOMENT COEFFICIENTS FOR BLADE K= 3

        AM(CL) TH(CL)  RE(CL)  IM(CL)    AM(CM) TH(CM)  RE(CM)  IM(CM)
1ST:    0.000    0.0   0.000   0.000     0.000    0.0   0.000   0.000

 LIFT AND MOMENT COEFFICIENTS FOR BLADE K= 4

        AM(CL) TH(CL)  RE(CL)  IM(CL)    AM(CM) TH(CM)  RE(CM)  IM(CM)
1ST:    0.160  -66.9   0.063  -0.147     0.095  -66.9   0.037  -0.087

axial mach number (axialm) = 2.304493217362
   phase angle                    CL                                CM
0.00000000E+00  0.86297743E+00 -0.80091921E+00  0.18675115E+00 -0.44324511E+00
0.90000000E+02  0.96207103E+00 -0.31452304E+00  0.21630952E+00 -0.22745119E+00
0.18000000E+03  0.64431867E+00  0.20481904E+00  0.10086512E+00  0.51496201E-01
0.27000000E+03  0.54522507E+00 -0.28157712E+00  0.71306755E-01 -0.16429772E+00
0.36000000E+03  0.86297743E+00 -0.80091921E+00  0.18675115E+00 -0.44324511E+00

    DONE IN ROUTINE CPINT
    DONE IN ROUTINE CPINT
    DONE IN ROUTINE CPINT
```

```
    DONE IN ROUTINE CPINT
    DONE IN ROUTINE FORCE***
***
```

***lot of similar lines are deleted

```
***
    FOURIER COEFFICIENTS FOR BLOCK    1  FOR CYCLE     3
    FOURIER COEFFICIENTS FOR BLOCK    2  FOR CYCLE     3
    FOURIER COEFFICIENTS FOR BLOCK    3  FOR CYCLE     3
    FOURIER COEFFICIENTS FOR BLOCK    4  FOR CYCLE     3
    FOURIER COEFFICIENTS FOR BLOCK    1  FOR CYCLE     3
    FOURIER COEFFICIENTS FOR BLOCK    2  FOR CYCLE     3
    FOURIER COEFFICIENTS FOR BLOCK    3  FOR CYCLE     3
    FOURIER COEFFICIENTS FOR BLOCK    4  FOR CYCLE     3

 >>>>>>>>  INFLUENCE COEFFICIENTS  <<<<<<<<

MACH NUMBER=  2.6100
REDUCED FREQUENCY based semi-chord=  1.0000
STAGGER ANGLE=   28.0000

 LIFT AND MOMENT COEFFICIENTS FOR BLADE K= 1

       AM(CL) TH(CL)  RE(CL)  IM(CL)   AM(CM) TH(CM)  RE(CM)  IM(CM)
1ST:   0.810  -21.6   0.754  -0.298    0.243  -53.7   0.144  -0.196

 LIFT AND MOMENT COEFFICIENTS FOR BLADE K= 2

       AM(CL) TH(CL)  RE(CL)  IM(CL)   AM(CM) TH(CM)  RE(CM)  IM(CM)
1ST:   0.359  -82.6   0.046  -0.356    0.160  -88.0   0.006  -0.160

 LIFT AND MOMENT COEFFICIENTS FOR BLADE K= 3

       AM(CL) TH(CL)  RE(CL)  IM(CL)   AM(CM) TH(CM)  RE(CM)  IM(CM)
1ST:   0.000    0.0   0.000   0.000    0.000    0.0   0.000   0.000

 LIFT AND MOMENT COEFFICIENTS FOR BLADE K= 4

       AM(CL) TH(CL)  RE(CL)  IM(CL)   AM(CM) TH(CM)  RE(CM)  IM(CM)
1ST:   0.160  -66.9   0.063  -0.147    0.095  -66.9   0.037  -0.087

axial mach number (axialm) = 2.304493217362
   phase angle                 CL                                     CM
0.00000000E+00  0.86295102E+00 -0.80094933E+00  0.18675936E+00 -0.44327175E+00
0.90000000E+02  0.96205350E+00 -0.31448687E+00  0.21632267E+00 -0.22743557E+00
0.18000000E+03  0.64423438E+00  0.20486405E+00  0.10083569E+00  0.51516725E-01
0.27000000E+03  0.54513190E+00 -0.28159841E+00  0.71272382E-01 -0.16431946E+00
0.36000000E+03  0.86295102E+00 -0.80094933E+00  0.18675936E+00 -0.44327175E+00

    block  1 written on unit  9 ncyc =    804
    block  2 written on unit  9 ncyc =    804
    block  3 written on unit  9 ncyc =    804
    block  4 written on unit  9 ncyc =    804
```

**Additional Output of Interest:**

FORT.50+i, i =1,nbs is produced giving the time history of force coefficients for each blade.

## 7.3 Unsteady Aerodynamics of a Flat-Plate Cascade in Pitching Motion using the Pulse Response Method

In this example, the pulse response (PR) method is used to obtain unsteady aerodynamic coefficients for the same flow and geometric conditions as in section 7.1.1. Only one change, MOTION=3, is required in the input file. The pulse response method gives the aerodynamic coefficients for **all** interblade phase angles in one run, for **all** frequencies of interest. Four blocks are used for computation i.e. nbs=4 in the parameter statement. The pulse width, the number of time steps of the pulse duration, is determined by the values input for REDFRE and CFL. For the example given below, the inputs REDFREQ=4.0 and CFL=2.0, yield a pulse duration of 134 steps (nperiod=134 in the output).

Calculations are performed for a total of NTTOT=1000 steps. The first 100 steps have no blade motion (NTSS=100), and then 134 steps for pulse duration, and the remaining with no blade oscillation. The inputs for PHASE, and NCYC are not used in the computation. Only one blade is oscillated, and all other blades remain stationary (automatically done in the program). The unsteady aerodynamic coefficients for all phase angles and all frequencies of interest are obtained by combining the pulse response method and influence coefficient method in a separate program, pric.f. The output files, fort.61, fort.5i, i=1,nbs, are used as input to pric.f. The source code is compiled with the following parameter statements.

```
parameter(nbs=4)
parameter(ni=91, nj=41)
```

### Input file (ecap2d.in)

```
  MOTION      INEW
       3         0
  FSMACH     PHASE   REDFREQ     ALPHA
    2.61     0.000    4.0000      0.00
    HO/C    ALFAOD
  0.0000    0.1500
.........*.........*.........*.........*.........*.........*.........*
     CFL      PRAT       PSI     ORDER     LIMIT
     2.0    0.7320    0.3333       3.0       1.0
      X0        Y0      SBYC   STAGGER
  0.3000       0.0     0.311     28.00
.........*.........*.........*.........*.........*.........*
    NCYC      NTSS     NTTOT    NTPRNT
       3       100      1000        50
     ILE       ITE       IGB    IAFOIL
      20        70         0         0
.........*.........*.........*.........*.........*.........*
   XLEFT    XRIGHT
    -0.3       1.5
```

```
.........*.........*.........*.........*.........*.........*
      KIN      KOUT    MOOVEE
        0         9         0
    IMODE     IFLTR     IFREE
        1         1         0
.........*.........*.........*.........*.........*.........*.........*
    VSTAR
     8.00
      GHS       GAS       ZHS       ZAS       XMU       XRA        XA
    0.567       1.0       0.0       0.0     936.0     0.615     0.000
      HD0    ALFAD0        H0     ALFA0
    0.000      0.05       0.0       0.0
      GHS       GAS       ZHS       ZAS       XMU       XRA        XA
    0.567       1.0       0.0       0.0     936.0     0.615     0.000
      HD0    ALFAD0        H0     ALFA0
    0.000   0.01545       0.0       0.0
      GHS       GAS       ZHS       ZAS       XMU       XRA        XA
    0.567       1.0       0.0       0.0     936.0     0.615     0.000
      HD0    ALFAD0        H0     ALFA0
    0.000      0.05       0.0       0.0
      GHS       GAS       ZHS       ZAS       XMU       XRA        XA
    0.567       1.0       0.0       0.0     936.0     0.615     0.000
      HD0    ALFAD0        H0     ALFA0
    0.000   0.01545       0.0       0.0
```

## Output file (ecap2d.out)

```
 *****************************************************
                           PULSE RESPONSE
 *****************************************************
  factors for vibration =       0.0000       0.0000       0.0000       0.0000

    FSMACH       PHASE     REDFREQ       ALPHA
    2.6100      0.0000      4.0000      0.0000
      H0/C      ALFA0D
    0.0000      0.1500
       CFL        PRAT         PSI       ORDER       LIMIT
    2.0000      0.7320      0.3333      3.0000      1.0000
        X0          Y0        SBYC     STAGGER
    0.3000      0.0000      0.3110     28.0000
      NCYC        NTSS      NTTOT      NTPRNT
         3         100        1000          50
       ILE         ITE         IGB      IAFOIL
        20          70           0           0
     XLEFT      XRIGHT
   -0.3000      1.5000
     KMODE        KFFT       LIMIT
         1           0           1
       KIN        KOUT      MOOVEE
         0           9           0

  ****** Oscillating Cascade Analysis ******
  input run stream:

  number of blocks =    4 where each block has dimensions of:
                ni =   91
                nj =   41
```

```
               nk =    2

 freestream mach number  =  2.6100
 inlet incidence angle   =  0.0000 (degrees)
 exit pressure ratio     =  0.7320 (p/ptot)
 inter-blade phase angle =  0.0000 (degrees)
 reduced frequency       =  4.0000 (based on semichord)
 reduced frequency       = 20.8800 (in terms of omega)
 amplitude of plunge     =  0.0000 (percent chord)
 amplitude of pitch      =  0.1500 (degrees)
 airfoil moment center   =  0.3000 (x0, percent chord)
 airfoil moment center   =  0.0000 (y0, percent chord)
 cascade stagger angle   = 28.0000 (degrees)
 cascade spacing         =  0.3110 (percent chord)

 ile      =   20 (airfoil leading edge index)
 ite      =   70 (airfoil trailing edge index)
 nb       =    3 (total number of cycles)
 kin      =    0 (restart input number -if 0 not used)
 kout     =    9 (restart output number -if 0 not used)
 kfft     =    0 (no fft analysis if kfft=0)
 moovee   =    0 (save certain steps for animation)
 kmode    =    1 (stationary or oscillating cascade)

 NOTE: no fft anaylsis will be performed

      flux limiter input information:
            limit =    1
            psi   = 0.333
            order =   3.0

note with limit=1, MINMOD limiter has been invoked

    grid generated now , igb =     0
    IMODE     IFLTR     IFREE
        1         1         0
    PITCHING MOTION
    FLUTTER IN FREQ. DOMAIN: SINGLE DEGREE OF FREEDOM


    **** PRINT INTERVAL, NTPRNT **** =   50

    motion indicator for blade    1:   0.0000
    GAMA H =      0.56700     GAMA ALPHA =      1.00000
    ZETA H =      0.00000     ZETA ALPHA =      0.00000
    MASS RATIO(XMU)                     =   936.00000
    RADIUS OF GYRATION(XRA)             =     0.61500
    DT. BETWEEN E.A. AND C.G.(XALFA)    =     0.00000
    initial plunging velocity           =     0.00000
    initial pitching velocity           =     0.05000
    initial plunging displacement       =     0.00000
    initial pitching displacemnet       =     0.00000

    motion indicator for blade    2:   0.0000
    GAMA H =      0.56700     GAMA ALPHA =      1.00000
    ZETA H =      0.00000     ZETA ALPHA =      0.00000
    MASS RATIO(XMU)                     =   936.00000
    RADIUS OF GYRATION(XRA)             =     0.61500
```

```
    DT. BETWEEN E.A. AND C.G.(XALFA)  =     0.00000
    initial plunging velocity         =     0.00000
    initial pitching velocity         =     0.01545
    initial plunging displacement     =     0.00000
    initial pitching displacemnet     =     0.00000

    motion indicator for blade    3:   0.0000
    GAMA H =      0.56700     GAMA ALPHA =     1.00000
    ZETA H =      0.00000     ZETA ALPHA =     0.00000
    MASS RATIO(XMU)                   =   936.00000
    RADIUS OF GYRATION(XRA)           =     0.61500
    DT. BETWEEN E.A. AND C.G.(XALFA)  =     0.00000
    initial plunging velocity         =     0.00000
    initial pitching velocity         =     0.05000
    initial plunging displacement     =     0.00000
    initial pitching displacemnet     =     0.00000

    motion indicator for blade    4:   0.0000
    GAMA H =      0.56700     GAMA ALPHA =     1.00000
    ZETA H =      0.00000     ZETA ALPHA =     0.00000
    MASS RATIO(XMU)                   =   936.00000
    RADIUS OF GYRATION(XRA)           =     0.61500
    DT. BETWEEN E.A. AND C.G.(XALFA)  =     0.00000
    initial plunging velocity         =     0.00000
    initial pitching velocity         =     0.01545
    initial plunging displacement     =     0.00000
    initial pitching displacemnet     =     0.00000

    IN ROUTINE GRIDGEN:STAG,SC,CHORD,X1,X4,NIF,NIB,IRUN
   28.00000     0.31100     1.00000    -0.30000     1.50000   20   70    0
  stagger angle (deg.) from input file =
                          28.0000000000
  stagger angle (deg.) from grid file =
                          28.0000000000
  stagger angle (deg.) used in the cal. =
                          28.0000000000
  gap-to-chord ratio from input file =
                           0.3110000000
  gap-to-chord ratio from grid file =
                           0.3110000000
  gap-to-chord ratio used in the calculation =
                           0.3110000000
    finished reading grid coordinates in routine rdgrid
    *** x coordinates at 0,ile,ilt,last
        -0.30000     0.00000     1.00000     1.50000

Starting the initial grid calculation
  For block  1:
    dtmin (as computed in eigenv) at cfl =  2.0 is      0.00225
  For block  2:
    dtmin (as computed in eigenv) at cfl =  2.0 is      0.00225
  For block  3:
    dtmin (as computed in eigenv) at cfl =  2.0 is      0.00225
  For block  4:
    dtmin (as computed in eigenv) at cfl =  2.0 is      0.00225
Successful completion of initial grid generation

 The flow solution will use dtmin= 0.00225 and nperiod=   134
```

```
to give a maximum cfl close to   2.000

    DONE IN ROUTINE CPINT
    DONE IN ROUTINE CPINT
    DONE IN ROUTINE CPINT
    DONE IN ROUTINE CPINT
    DONE IN ROUTINE FORCE

.........******............
.........******............
.........******............
.........******............
```

.........**** lot of simialr lines are deleted****.....

**Additional Outputs of Interest:**

(1) FORT.60+i,i=1,nbs. This output shows the history of the grid motion. Used in Fourier transform. Only FORT.61 is used with pric.f. (since only one blade is given the motion). It has five columns, which are index, plunging displacement, change in plunging displacement, pitching displacement, and change in pitching displacement. Second column data for plunging motion, and fourth column data for pitching motion are the required information for Fourier transform.

Output of fort.61

```
2.61,  0.4886921905584,  0.311
2.2456629593339E-3,  0.3,  100
```

Next 99 lines are deleted, since there is no blade motion

| | | | | |
|---|---|---|---|---|
| 100 | 0.0000000E+00 | 0.0000000E+00 | 0.0000000E+00 | 0.0000000E+00 |
| 101 | 0.0000000E+00 | 0.0000000E+00 | -0.1573433E-05 | -0.1573433E-05 |
| 102 | 0.0000000E+00 | 0.0000000E+00 | -0.6245875E-05 | -0.4672442E-05 |
| 103 | 0.0000000E+00 | 0.0000000E+00 | -0.1394474E-04 | -0.7698863E-05 |
| 104 | 0.0000000E+00 | 0.0000000E+00 | -0.2459635E-04 | -0.1065161E-04 |
| 105 | 0.0000000E+00 | 0.0000000E+00 | -0.3812593E-04 | -0.1352958E-04 |
| 106 | 0.0000000E+00 | 0.0000000E+00 | -0.5445759E-04 | -0.1633167E-04 |
| 107 | 0.0000000E+00 | 0.0000000E+00 | -0.7351434E-04 | -0.1905675E-04 |
| 108 | 0.0000000E+00 | 0.0000000E+00 | -0.9521804E-04 | -0.2170369E-04 |
| 109 | 0.0000000E+00 | 0.0000000E+00 | -0.1194894E-03 | -0.2427135E-04 |
| 110 | 0.0000000E+00 | 0.0000000E+00 | -0.1462479E-03 | -0.2675856E-04 |
| 111 | 0.0000000E+00 | 0.0000000E+00 | -0.1754121E-03 | -0.2916415E-04 |
| 112 | 0.0000000E+00 | 0.0000000E+00 | -0.2068991E-03 | -0.3148696E-04 |
| 113 | 0.0000000E+00 | 0.0000000E+00 | -0.2406248E-03 | -0.3372579E-04 |
| 114 | 0.0000000E+00 | 0.0000000E+00 | -0.2765043E-03 | -0.3587945E-04 |
| 115 | 0.0000000E+00 | 0.0000000E+00 | -0.3144510E-03 | -0.3794673E-04 |
| 116 | 0.0000000E+00 | 0.0000000E+00 | -0.3543775E-03 | -0.3992642E-04 |
| 117 | 0.0000000E+00 | 0.0000000E+00 | -0.3961948E-03 | -0.4181731E-04 |
| 118 | 0.0000000E+00 | 0.0000000E+00 | -0.4398129E-03 | -0.4361817E-04 |
| 119 | 0.0000000E+00 | 0.0000000E+00 | -0.4851407E-03 | -0.4532777E-04 |
| 120 | 0.0000000E+00 | 0.0000000E+00 | -0.5320856E-03 | -0.4694488E-04 |
| 121 | 0.0000000E+00 | 0.0000000E+00 | -0.5805538E-03 | -0.4846827E-04 |
| 122 | 0.0000000E+00 | 0.0000000E+00 | -0.6304505E-03 | -0.4989670E-04 |

| | | | | |
|---|---|---|---|---|
| 123 | 0.0000000E+00 | 0.0000000E+00 | -0.6816795E-03 | -0.5122895E-04 |
| 124 | 0.0000000E+00 | 0.0000000E+00 | -0.7341433E-03 | -0.5246379E-04 |
| 125 | 0.0000000E+00 | 0.0000000E+00 | -0.7877433E-03 | -0.5359998E-04 |
| 126 | 0.0000000E+00 | 0.0000000E+00 | -0.8423796E-03 | -0.5463631E-04 |
| 127 | 0.0000000E+00 | 0.0000000E+00 | -0.8979511E-03 | -0.5557157E-04 |
| 128 | 0.0000000E+00 | 0.0000000E+00 | -0.9543557E-03 | -0.5640456E-04 |
| 129 | 0.0000000E+00 | 0.0000000E+00 | -0.1011490E-02 | -0.5713409E-04 |
| 130 | 0.0000000E+00 | 0.0000000E+00 | -0.1069249E-02 | -0.5775899E-04 |
| 131 | 0.0000000E+00 | 0.0000000E+00 | -0.1127527E-02 | -0.5827810E-04 |
| 132 | 0.0000000E+00 | 0.0000000E+00 | -0.1186217E-02 | -0.5869031E-04 |
| 133 | 0.0000000E+00 | 0.0000000E+00 | -0.1245212E-02 | -0.5899450E-04 |
| 134 | 0.0000000E+00 | 0.0000000E+00 | -0.1304401E-02 | -0.5918959E-04 |
| 135 | 0.0000000E+00 | 0.0000000E+00 | -0.1363676E-02 | -0.5927454E-04 |
| 136 | 0.0000000E+00 | 0.0000000E+00 | -0.1422924E-02 | -0.5924835E-04 |
| 137 | 0.0000000E+00 | 0.0000000E+00 | -0.1482034E-02 | -0.5911005E-04 |
| 138 | 0.0000000E+00 | 0.0000000E+00 | -0.1540893E-02 | -0.5885872E-04 |
| 139 | 0.0000000E+00 | 0.0000000E+00 | -0.1599386E-02 | -0.5849348E-04 |
| 140 | 0.0000000E+00 | 0.0000000E+00 | -0.1657400E-02 | -0.5801354E-04 |
| 141 | 0.0000000E+00 | 0.0000000E+00 | -0.1714818E-02 | -0.5741814E-04 |
| 142 | 0.0000000E+00 | 0.0000000E+00 | -0.1771525E-02 | -0.5670660E-04 |
| 143 | 0.0000000E+00 | 0.0000000E+00 | -0.1827403E-02 | -0.5587833E-04 |
| 144 | 0.0000000E+00 | 0.0000000E+00 | -0.1882336E-02 | -0.5493280E-04 |
| 145 | 0.0000000E+00 | 0.0000000E+00 | -0.1936205E-02 | -0.5386960E-04 |
| 146 | 0.0000000E+00 | 0.0000000E+00 | -0.1988894E-02 | -0.5268838E-04 |
| 147 | 0.0000000E+00 | 0.0000000E+00 | -0.2040283E-02 | -0.5138895E-04 |
| 148 | 0.0000000E+00 | 0.0000000E+00 | -0.2090254E-02 | -0.4997121E-04 |
| 149 | 0.0000000E+00 | 0.0000000E+00 | -0.2138689E-02 | -0.4843518E-04 |
| 150 | 0.0000000E+00 | 0.0000000E+00 | -0.2185470E-02 | -0.4678106E-04 |
| 151 | 0.0000000E+00 | 0.0000000E+00 | -0.2230479E-02 | -0.4500915E-04 |
| 152 | 0.0000000E+00 | 0.0000000E+00 | -0.2273599E-02 | -0.4311997E-04 |
| 153 | 0.0000000E+00 | 0.0000000E+00 | -0.2314714E-02 | -0.4111418E-04 |
| 154 | 0.0000000E+00 | 0.0000000E+00 | -0.2353706E-02 | -0.3899266E-04 |
| 155 | 0.0000000E+00 | 0.0000000E+00 | -0.2390463E-02 | -0.3675648E-04 |
| 156 | 0.0000000E+00 | 0.0000000E+00 | -0.2424870E-02 | -0.3440695E-04 |
| 157 | 0.0000000E+00 | 0.0000000E+00 | -0.2456815E-02 | -0.3194561E-04 |
| 158 | 0.0000000E+00 | 0.0000000E+00 | -0.2486189E-02 | -0.2937428E-04 |
| 159 | 0.0000000E+00 | 0.0000000E+00 | -0.2512885E-02 | -0.2669504E-04 |
| 160 | 0.0000000E+00 | 0.0000000E+00 | -0.2536795E-02 | -0.2391029E-04 |
| 161 | 0.0000000E+00 | 0.0000000E+00 | -0.2557818E-02 | -0.2102274E-04 |
| 162 | 0.0000000E+00 | 0.0000000E+00 | -0.2575853E-02 | -0.1803546E-04 |
| 163 | 0.0000000E+00 | 0.0000000E+00 | -0.2590805E-02 | -0.1495188E-04 |
| 164 | 0.0000000E+00 | 0.0000000E+00 | -0.2602581E-02 | -0.1177583E-04 |
| 165 | 0.0000000E+00 | 0.0000000E+00 | -0.2611092E-02 | -0.8511579E-05 |
| 166 | 0.0000000E+00 | 0.0000000E+00 | -0.2616256E-02 | -0.5163820E-05 |
| 167 | 0.0000000E+00 | 0.0000000E+00 | -0.2617994E-02 | -0.1737745E-05 |
| 168 | 0.0000000E+00 | 0.0000000E+00 | -0.2616233E-02 | 0.1760948E-05 |
| 169 | 0.0000000E+00 | 0.0000000E+00 | -0.2610907E-02 | 0.5326016E-05 |
| 170 | 0.0000000E+00 | 0.0000000E+00 | -0.2601956E-02 | 0.8950643E-05 |
| 171 | 0.0000000E+00 | 0.0000000E+00 | -0.2589329E-02 | 0.1262741E-04 |
| 172 | 0.0000000E+00 | 0.0000000E+00 | -0.2572981E-02 | 0.1634824E-04 |
| 173 | 0.0000000E+00 | 0.0000000E+00 | -0.2552876E-02 | 0.2010439E-04 |
| 174 | 0.0000000E+00 | 0.0000000E+00 | -0.2528990E-02 | 0.2388642E-04 |
| 175 | 0.0000000E+00 | 0.0000000E+00 | -0.2501306E-02 | 0.2768412E-04 |
| 176 | 0.0000000E+00 | 0.0000000E+00 | -0.2469819E-02 | 0.3148652E-04 |
| 177 | 0.0000000E+00 | 0.0000000E+00 | -0.2434537E-02 | 0.3528183E-04 |
| 178 | 0.0000000E+00 | 0.0000000E+00 | -0.2395480E-02 | 0.3905742E-04 |
| 179 | 0.0000000E+00 | 0.0000000E+00 | -0.2352680E-02 | 0.4279980E-04 |
| 180 | 0.0000000E+00 | 0.0000000E+00 | -0.2306186E-02 | 0.4649459E-04 |

| | | | | |
|---|---|---|---|---|
| 181 | 0.0000000E+00 | 0.0000000E+00 | -0.2256059E-02 | 0.5012648E-04 |
| 182 | 0.0000000E+00 | 0.0000000E+00 | -0.2202380E-02 | 0.5367925E-04 |
| 183 | 0.0000000E+00 | 0.0000000E+00 | -0.2145244E-02 | 0.5713575E-04 |
| 184 | 0.0000000E+00 | 0.0000000E+00 | -0.2084766E-02 | 0.6047791E-04 |
| 185 | 0.0000000E+00 | 0.0000000E+00 | -0.2021079E-02 | 0.6368674E-04 |
| 186 | 0.0000000E+00 | 0.0000000E+00 | -0.1954337E-02 | 0.6674238E-04 |
| 187 | 0.0000000E+00 | 0.0000000E+00 | -0.1884713E-02 | 0.6962413E-04 |
| 188 | 0.0000000E+00 | 0.0000000E+00 | -0.1812402E-02 | 0.7231052E-04 |
| 189 | 0.0000000E+00 | 0.0000000E+00 | -0.1737623E-02 | 0.7477943E-04 |
| 190 | 0.0000000E+00 | 0.0000000E+00 | -0.1660615E-02 | 0.7700815E-04 |
| 191 | 0.0000000E+00 | 0.0000000E+00 | -0.1581641E-02 | 0.7897360E-04 |
| 192 | 0.0000000E+00 | 0.0000000E+00 | -0.1500989E-02 | 0.8065244E-04 |
| 193 | 0.0000000E+00 | 0.0000000E+00 | -0.1418967E-02 | 0.8202139E-04 |
| 194 | 0.0000000E+00 | 0.0000000E+00 | -0.1335910E-02 | 0.8305743E-04 |
| 195 | 0.0000000E+00 | 0.0000000E+00 | -0.1252172E-02 | 0.8373819E-04 |
| 196 | 0.0000000E+00 | 0.0000000E+00 | -0.1168129E-02 | 0.8404232E-04 |
| 197 | 0.0000000E+00 | 0.0000000E+00 | -0.1084179E-02 | 0.8394998E-04 |
| 198 | 0.0000000E+00 | 0.0000000E+00 | -0.1000736E-02 | 0.8344335E-04 |
| 199 | 0.0000000E+00 | 0.0000000E+00 | -0.9182288E-03 | 0.8250726E-04 |
| 200 | 0.0000000E+00 | 0.0000000E+00 | -0.8370989E-03 | 0.8112990E-04 |
| 201 | 0.0000000E+00 | 0.0000000E+00 | -0.7577953E-03 | 0.7930360E-04 |
| 202 | 0.0000000E+00 | 0.0000000E+00 | -0.6807696E-03 | 0.7702569E-04 |
| 203 | 0.0000000E+00 | 0.0000000E+00 | -0.6064703E-03 | 0.7429938E-04 |
| 204 | 0.0000000E+00 | 0.0000000E+00 | -0.5353354E-03 | 0.7113485E-04 |
| 205 | 0.0000000E+00 | 0.0000000E+00 | -0.4677853E-03 | 0.6755013E-04 |
| 206 | 0.0000000E+00 | 0.0000000E+00 | -0.4042131E-03 | 0.6357217E-04 |
| 207 | 0.0000000E+00 | 0.0000000E+00 | -0.3449754E-03 | 0.5923774E-04 |
| 208 | 0.0000000E+00 | 0.0000000E+00 | -0.2903812E-03 | 0.5459415E-04 |
| 209 | 0.0000000E+00 | 0.0000000E+00 | -0.2406814E-03 | 0.4969982E-04 |
| 210 | 0.0000000E+00 | 0.0000000E+00 | -0.1960571E-03 | 0.4462435E-04 |
| 211 | 0.0000000E+00 | 0.0000000E+00 | -0.1566089E-03 | 0.3944813E-04 |
| 212 | 0.0000000E+00 | 0.0000000E+00 | -0.1223477E-03 | 0.3426123E-04 |
| 213 | 0.0000000E+00 | 0.0000000E+00 | -0.9318638E-04 | 0.2916132E-04 |
| 214 | 0.0000000E+00 | 0.0000000E+00 | -0.6893577E-04 | 0.2425061E-04 |
| 215 | 0.0000000E+00 | 0.0000000E+00 | -0.4930429E-04 | 0.1963149E-04 |
| 216 | 0.0000000E+00 | 0.0000000E+00 | -0.3390337E-04 | 0.1540092E-04 |
| 217 | 0.0000000E+00 | 0.0000000E+00 | -0.2225960E-04 | 0.1164377E-04 |
| 218 | 0.0000000E+00 | 0.0000000E+00 | -0.1383425E-04 | 0.8425345E-05 |
| 219 | 0.0000000E+00 | 0.0000000E+00 | -0.8050160E-05 | 0.5784093E-05 |
| 220 | 0.0000000E+00 | 0.0000000E+00 | -0.4324659E-05 | 0.3725501E-05 |
| 221 | 0.0000000E+00 | 0.0000000E+00 | -0.2105740E-05 | 0.2218919E-05 |
| 222 | 0.0000000E+00 | 0.0000000E+00 | -0.9067883E-06 | 0.1198952E-05 |
| 223 | 0.0000000E+00 | 0.0000000E+00 | -0.3339810E-06 | 0.5728073E-06 |
| 224 | 0.0000000E+00 | 0.0000000E+00 | -0.1003934E-06 | 0.2335876E-06 |
| 225 | 0.0000000E+00 | 0.0000000E+00 | -0.2301790E-07 | 0.7737553E-07 |
| 226 | 0.0000000E+00 | 0.0000000E+00 | -0.3636776E-08 | 0.1938113E-07 |
| 227 | 0.0000000E+00 | 0.0000000E+00 | -0.3375812E-09 | 0.3299194E-08 |
| 228 | 0.0000000E+00 | 0.0000000E+00 | -0.1411187E-10 | 0.3234693E-09 |
| 229 | 0.0000000E+00 | 0.0000000E+00 | -0.1646248E-12 | 0.1394724E-10 |
| 230 | 0.0000000E+00 | 0.0000000E+00 | -0.2057925E-15 | 0.1644190E-12 |
| 231 | 0.0000000E+00 | 0.0000000E+00 | -0.2954362E-20 | 0.2057895E-15 |
| 232 | 0.0000000E+00 | 0.0000000E+00 | -0.5995502E-30 | 0.2954362E-20 |
| 233 | 0.0000000E+00 | 0.0000000E+00 | 0.0000000E+00 | 0.0000000E+00 |

Next, 234 to 1000 lines are deleted, since the blade is again stationery.

(2) FORT.50+i, i =1,nbs. It has five columns, which are index, unsteady lift, unsteady moment, total lift and total moment. All the files are used with pric.f.

output of fort.51(other files are not shown)

| | | | | |
|---|---|---|---|---|
| 1 | 0.9778685E-15 | 0.0000000E+00 | 0.9778685E-15 | 0.0000000E+00 |
| 2 | 0.1043060E-14 | 0.4318267E-16 | 0.1043060E-14 | 0.4318267E-16 |
| 3 | 0.1173442E-14 | 0.1295480E-15 | 0.1173442E-14 | 0.1295480E-15 |
| 4 | 0.1320123E-14 | 0.2303076E-15 | 0.1320123E-14 | 0.2303076E-15 |
| 5 | 0.1369016E-14 | 0.3460872E-15 | 0.1369016E-14 | 0.3460872E-15 |
| 6 | 0.1466803E-14 | 0.4036641E-15 | 0.1466803E-14 | 0.4036641E-15 |
| 7 | 0.1417909E-14 | 0.3967799E-15 | 0.1417909E-14 | 0.3967799E-15 |
| 8 | 0.1434207E-14 | 0.4739664E-15 | 0.1434207E-14 | 0.4739664E-15 |
| 9 | 0.1434207E-14 | 0.4739664E-15 | 0.1434207E-14 | 0.4739664E-15 |
| 10 | 0.1434207E-14 | 0.4739664E-15 | 0.1434207E-14 | 0.4739664E-15 |
| 11 | 0.1434207E-14 | 0.4739664E-15 | 0.1434207E-14 | 0.4739664E-15 |
| 12 | 0.1434207E-14 | 0.4739664E-15 | 0.1434207E-14 | 0.4739664E-15 |
| 13 | 0.1369016E-14 | 0.4307837E-15 | 0.1369016E-14 | 0.4307837E-15 |
| 14 | 0.1369016E-14 | 0.4307837E-15 | 0.1369016E-14 | 0.4307837E-15 |
| 15 | 0.1222336E-14 | 0.3300241E-15 | 0.1222336E-14 | 0.3300241E-15 |
| 16 | 0.1287527E-14 | 0.3419150E-15 | 0.1287527E-14 | 0.3419150E-15 |
| 17 | 0.1287527E-14 | 0.3106232E-15 | 0.1287527E-14 | 0.3106232E-15 |
| 18 | 0.1401612E-14 | 0.3369083E-15 | 0.1401612E-14 | 0.3369083E-15 |
| 19 | 0.1173442E-14 | 0.2555496E-15 | 0.1173442E-14 | 0.2555496E-15 |
| 20 | 0.1303825E-14 | 0.2830864E-15 | 0.1303825E-14 | 0.2830864E-15 |
| 21 | 0.1238633E-14 | 0.2399037E-15 | 0.1238633E-14 | 0.2399037E-15 |
| 22 | 0.1173442E-14 | 0.2555496E-15 | 0.1173442E-14 | 0.2555496E-15 |
| 23 | 0.1238633E-14 | 0.2711955E-15 | 0.1238633E-14 | 0.2711955E-15 |
| 24 | 0.1173442E-14 | 0.2280129E-15 | 0.1173442E-14 | 0.2280129E-15 |
| 25 | 0.1173442E-14 | 0.2280129E-15 | 0.1173442E-14 | 0.2280129E-15 |
| 26 | 0.1222336E-14 | 0.2173737E-15 | 0.1222336E-14 | 0.2173737E-15 |
| 27 | 0.7496992E-15 | 0.5403050E-16 | 0.7496992E-15 | 0.5403050E-16 |
| 28 | 0.8474861E-15 | 0.1184916E-15 | 0.8474861E-15 | 0.1184916E-15 |
| 29 | 0.4889343E-15 | -0.2190425E-16 | 0.4889343E-15 | -0.2190425E-16 |
| 30 | 0.4889343E-15 | -0.2190425E-16 | 0.4889343E-15 | -0.2190425E-16 |
| 31 | 0.4237430E-15 | -0.6508693E-16 | 0.4237430E-15 | -0.6508693E-16 |
| 32 | 0.3585518E-15 | -0.1082696E-15 | 0.3585518E-15 | -0.1082696E-15 |
| 33 | 0.3585518E-15 | -0.1082696E-15 | 0.3585518E-15 | -0.1082696E-15 |
| 34 | 0.3585518E-15 | -0.1082696E-15 | 0.3585518E-15 | -0.1082696E-15 |
| 35 | 0.3585518E-15 | -0.1082696E-15 | 0.3585518E-15 | -0.1082696E-15 |
| 36 | 0.3585518E-15 | -0.1082696E-15 | 0.3585518E-15 | -0.1082696E-15 |
| 37 | 0.3585518E-15 | -0.1082696E-15 | 0.3585518E-15 | -0.1082696E-15 |
| 38 | 0.3096584E-15 | -0.1514523E-15 | 0.3096584E-15 | -0.1514523E-15 |
| 39 | 0.3096584E-15 | -0.1514523E-15 | 0.3096584E-15 | -0.1514523E-15 |
| 40 | 0.3096584E-15 | -0.1514523E-15 | 0.3096584E-15 | -0.1514523E-15 |
| 41 | 0.4237430E-15 | -0.6508693E-16 | 0.4237430E-15 | -0.6508693E-16 |
| 42 | 0.4889343E-15 | -0.5194438E-16 | 0.4889343E-15 | -0.5194438E-16 |
| 43 | 0.4889343E-15 | -0.5194438E-16 | 0.4889343E-15 | -0.5194438E-16 |
| 44 | 0.4237430E-15 | -0.9512705E-16 | 0.4237430E-15 | -0.9512705E-16 |
| 45 | 0.4237430E-15 | -0.9512705E-16 | 0.4237430E-15 | -0.9512705E-16 |
| 46 | 0.4237430E-15 | -0.9512705E-16 | 0.4237430E-15 | -0.9512705E-16 |
| 47 | 0.4237430E-15 | -0.9512705E-16 | 0.4237430E-15 | -0.9512705E-16 |
| 48 | 0.4237430E-15 | -0.9512705E-16 | 0.4237430E-15 | -0.9512705E-16 |
| 49 | 0.4237430E-15 | -0.9512705E-16 | 0.4237430E-15 | -0.9512705E-16 |
| 50 | 0.3748496E-15 | -0.1383097E-15 | 0.3748496E-15 | -0.1383097E-15 |
| * | | | | |
| 60 | 0.3911474E-15 | -0.1295480E-15 | 0.3911474E-15 | -0.1295480E-15 |
| * | | | | |
| 70 | 0.3911474E-15 | -0.1295480E-15 | 0.3911474E-15 | -0.1295480E-15 |
| * | | | | |
| 80 | 0.3259562E-15 | -0.1364322E-15 | 0.3259562E-15 | -0.1364322E-15 |

| | | | | |
|---|---|---|---|---|
| * | | | | |
| 90 | 0.3259562E-15 | -0.1364322E-15 | 0.3259562E-15 | -0.1364322E-15 |
| * | | | | |
| 100 | 0.0000000E+00 | 0.0000000E+00 | 0.3259562E-15 | -0.1364322E-15 |
| 101 | 0.3771141E-04 | 0.2276940E-04 | 0.3771141E-04 | 0.2276940E-04 |
| 102 | 0.1503586E-03 | 0.9037663E-04 | 0.1503586E-03 | 0.9037663E-04 |
| 103 | 0.3285750E-03 | 0.1962337E-03 | 0.3285750E-03 | 0.1962337E-03 |
| 104 | 0.5337570E-03 | 0.3164296E-03 | 0.5337570E-03 | 0.3164296E-03 |
| 105 | 0.7399267E-03 | 0.4351769E-03 | 0.7399267E-03 | 0.4351769E-03 |
| 106 | 0.9343957E-03 | 0.5449098E-03 | 0.9343957E-03 | 0.5449098E-03 |
| 107 | 0.1114129E-02 | 0.6438923E-03 | 0.1114129E-02 | 0.6438923E-03 |
| 108 | 0.1281994E-02 | 0.7339382E-03 | 0.1281994E-02 | 0.7339382E-03 |
| 109 | 0.1443237E-02 | 0.8183068E-03 | 0.1443237E-02 | 0.8183068E-03 |
| 110 | 0.1603102E-02 | 0.9002654E-03 | 0.1603102E-02 | 0.9002654E-03 |
| 111 | 0.1765123E-02 | 0.9820098E-03 | 0.1765123E-02 | 0.9820098E-03 |
| 112 | 0.1930596E-02 | 0.1064357E-02 | 0.1930596E-02 | 0.1064357E-02 |
| 113 | 0.2098852E-02 | 0.1146956E-02 | 0.2098852E-02 | 0.1146956E-02 |
| 114 | 0.2268200E-02 | 0.1228862E-02 | 0.2268200E-02 | 0.1228862E-02 |
| 115 | 0.2436929E-02 | 0.1309039E-02 | 0.2436929E-02 | 0.1309039E-02 |
| 116 | 0.2603662E-02 | 0.1386691E-02 | 0.2603662E-02 | 0.1386691E-02 |
| 117 | 0.2767662E-02 | 0.1461388E-02 | 0.2767662E-02 | 0.1461388E-02 |
| 118 | 0.2928593E-02 | 0.1532990E-02 | 0.2928593E-02 | 0.1532990E-02 |
| 119 | 0.3086360E-02 | 0.1601533E-02 | 0.3086360E-02 | 0.1601533E-02 |
| 120 | 0.3241147E-02 | 0.1667239E-02 | 0.3241147E-02 | 0.1667239E-02 |
| 121 | 0.3393343E-02 | 0.1730375E-02 | 0.3393343E-02 | 0.1730375E-02 |
| 122 | 0.3543179E-02 | 0.1791130E-02 | 0.3543179E-02 | 0.1791130E-02 |
| 123 | 0.3690753E-02 | 0.1849513E-02 | 0.3690753E-02 | 0.1849513E-02 |
| 124 | 0.3835756E-02 | 0.1905456E-02 | 0.3835756E-02 | 0.1905456E-02 |
| 125 | 0.3977772E-02 | 0.1958830E-02 | 0.3977772E-02 | 0.1958830E-02 |
| 126 | 0.4116399E-02 | 0.2009468E-02 | 0.4116399E-02 | 0.2009468E-02 |
| 127 | 0.4251252E-02 | 0.2057186E-02 | 0.4251252E-02 | 0.2057186E-02 |
| 128 | 0.4381973E-02 | 0.2101814E-02 | 0.4381973E-02 | 0.2101814E-02 |
| 129 | 0.4508282E-02 | 0.2143220E-02 | 0.4508282E-02 | 0.2143220E-02 |
| 130 | 0.4629946E-02 | 0.2181306E-02 | 0.4629946E-02 | 0.2181306E-02 |
| 131 | 0.4746756E-02 | 0.2216036E-02 | 0.4746756E-02 | 0.2216036E-02 |
| 132 | 0.4858601E-02 | 0.2247411E-02 | 0.4858601E-02 | 0.2247411E-02 |
| 133 | 0.4965401E-02 | 0.2275425E-02 | 0.4965401E-02 | 0.2275425E-02 |
| 134 | 0.5067051E-02 | 0.2300055E-02 | 0.5067051E-02 | 0.2300055E-02 |
| 135 | 0.5163333E-02 | 0.2321226E-02 | 0.5163333E-02 | 0.2321226E-02 |
| 136 | 0.5254059E-02 | 0.2338876E-02 | 0.5254059E-02 | 0.2338876E-02 |
| 137 | 0.5339025E-02 | 0.2352974E-02 | 0.5339025E-02 | 0.2352974E-02 |
| 138 | 0.5417844E-02 | 0.2363433E-02 | 0.5417844E-02 | 0.2363433E-02 |
| 139 | 0.5490301E-02 | 0.2370125E-02 | 0.5490301E-02 | 0.2370125E-02 |
| 140 | 0.5556123E-02 | 0.2372951E-02 | 0.5556123E-02 | 0.2372951E-02 |
| 141 | 0.5614686E-02 | 0.2371664E-02 | 0.5614686E-02 | 0.2371664E-02 |
| 142 | 0.5665518E-02 | 0.2366158E-02 | 0.5665518E-02 | 0.2366158E-02 |
| 143 | 0.5709417E-02 | 0.2356897E-02 | 0.5709417E-02 | 0.2356897E-02 |
| 144 | 0.5746423E-02 | 0.2344139E-02 | 0.5746423E-02 | 0.2344139E-02 |
| 145 | 0.5776426E-02 | 0.2327833E-02 | 0.5776426E-02 | 0.2327833E-02 |
| 146 | 0.5799041E-02 | 0.2307742E-02 | 0.5799041E-02 | 0.2307742E-02 |
| 147 | 0.5813697E-02 | 0.2283531E-02 | 0.5813697E-02 | 0.2283531E-02 |
| 148 | 0.5820000E-02 | 0.2254966E-02 | 0.5820000E-02 | 0.2254966E-02 |
| 149 | 0.5817496E-02 | 0.2221833E-02 | 0.5817496E-02 | 0.2221833E-02 |
| 150 | 0.5805875E-02 | 0.2183980E-02 | 0.5805875E-02 | 0.2183980E-02 |
| 151 | 0.5785105E-02 | 0.2141443E-02 | 0.5785105E-02 | 0.2141443E-02 |
| 152 | 0.5755293E-02 | 0.2094343E-02 | 0.5755293E-02 | 0.2094343E-02 |
| 153 | 0.5716467E-02 | 0.2042803E-02 | 0.5716467E-02 | 0.2042803E-02 |
| 154 | 0.5668529E-02 | 0.1986955E-02 | 0.5668529E-02 | 0.1986955E-02 |

| | | | | |
|---|---|---|---|---|
| 155 | 0.5611288E-02 | 0.1926883E-02 | 0.5611288E-02 | 0.1926883E-02 |
| 156 | 0.5544627E-02 | 0.1862605E-02 | 0.5544627E-02 | 0.1862605E-02 |
| 157 | 0.5468481E-02 | 0.1794116E-02 | 0.5468481E-02 | 0.1794116E-02 |
| 158 | 0.5382714E-02 | 0.1721391E-02 | 0.5382714E-02 | 0.1721391E-02 |
| 159 | 0.5287313E-02 | 0.1644426E-02 | 0.5287313E-02 | 0.1644426E-02 |
| 160 | 0.5182177E-02 | 0.1563227E-02 | 0.5182177E-02 | 0.1563227E-02 |
| 161 | 0.5067303E-02 | 0.1477829E-02 | 0.5067303E-02 | 0.1477829E-02 |
| 162 | 0.4942638E-02 | 0.1388289E-02 | 0.4942638E-02 | 0.1388289E-02 |
| 163 | 0.4808255E-02 | 0.1294689E-02 | 0.4808255E-02 | 0.1294689E-02 |
| 164 | 0.4664202E-02 | 0.1197125E-02 | 0.4664202E-02 | 0.1197125E-02 |
| 165 | 0.4510610E-02 | 0.1095711E-02 | 0.4510610E-02 | 0.1095711E-02 |
| 166 | 0.4347565E-02 | 0.9905748E-03 | 0.4347565E-02 | 0.9905748E-03 |
| 167 | 0.4175225E-02 | 0.8818603E-03 | 0.4175225E-02 | 0.8818603E-03 |
| 168 | 0.3993789E-02 | 0.7697325E-03 | 0.3993789E-02 | 0.7697325E-03 |
| 169 | 0.3803388E-02 | 0.6543689E-03 | 0.3803388E-02 | 0.6543689E-03 |
| 170 | 0.3604351E-02 | 0.5359741E-03 | 0.3604351E-02 | 0.5359741E-03 |
| 171 | 0.3396878E-02 | 0.4147600E-03 | 0.3396878E-02 | 0.4147600E-03 |
| 172 | 0.3181367E-02 | 0.2909478E-03 | 0.3181367E-02 | 0.2909478E-03 |
| 173 | 0.2958144E-02 | 0.1647937E-03 | 0.2958144E-02 | 0.1647937E-03 |
| 174 | 0.2727656E-02 | 0.3652852E-04 | 0.2727656E-02 | 0.3652852E-04 |
| 175 | 0.2490341E-02 | -0.9352128E-04 | 0.2490341E-02 | -0.9352128E-04 |
| 176 | 0.2246810E-02 | -0.2249624E-03 | 0.2246810E-02 | -0.2249624E-03 |
| 177 | 0.1997720E-02 | -0.3573435E-03 | 0.1997720E-02 | -0.3573435E-03 |
| 178 | 0.1743779E-02 | -0.4902654E-03 | 0.1743779E-02 | -0.4902654E-03 |
| 179 | 0.1485665E-02 | -0.6233123E-03 | 0.1485665E-02 | -0.6233123E-03 |
| 180 | 0.1224188E-02 | -0.7560431E-03 | 0.1224188E-02 | -0.7560431E-03 |
| 181 | 0.9602126E-03 | -0.8879681E-03 | 0.9602126E-03 | -0.8879681E-03 |
| 182 | 0.6946470E-03 | -0.1018547E-02 | 0.6946470E-03 | -0.1018547E-02 |
| 183 | 0.4285619E-03 | -0.1147209E-02 | 0.4285619E-03 | -0.1147209E-02 |
| 184 | 0.1629865E-03 | -0.1273328E-02 | 0.1629865E-03 | -0.1273328E-02 |
| 185 | -0.1008424E-03 | -0.1396259E-02 | -0.1008424E-03 | -0.1396259E-02 |
| 186 | -0.3616445E-03 | -0.1515328E-02 | -0.3616445E-03 | -0.1515328E-02 |
| 187 | -0.6181717E-03 | -0.1629799E-02 | -0.6181717E-03 | -0.1629799E-02 |
| 188 | -0.8688964E-03 | -0.1738955E-02 | -0.8688964E-03 | -0.1738955E-02 |
| 189 | -0.1112385E-02 | -0.1842012E-02 | -0.1112385E-02 | -0.1842012E-02 |
| 190 | -0.1347245E-02 | -0.1938134E-02 | -0.1347245E-02 | -0.1938134E-02 |
| 191 | -0.1571864E-02 | -0.2026499E-02 | -0.1571864E-02 | -0.2026499E-02 |
| 192 | -0.1784482E-02 | -0.2106298E-02 | -0.1784482E-02 | -0.2106298E-02 |
| 193 | -0.1983158E-02 | -0.2176746E-02 | -0.1983158E-02 | -0.2176746E-02 |
| 194 | -0.2166223E-02 | -0.2236981E-02 | -0.2166223E-02 | -0.2236981E-02 |
| 195 | -0.2332054E-02 | -0.2286140E-02 | -0.2332054E-02 | -0.2286140E-02 |
| 196 | -0.2479037E-02 | -0.2323388E-02 | -0.2479037E-02 | -0.2323388E-02 |
| 197 | -0.2605598E-02 | -0.2347958E-02 | -0.2605598E-02 | -0.2347958E-02 |
| 198 | -0.2710061E-02 | -0.2359073E-02 | -0.2710061E-02 | -0.2359073E-02 |
| 199 | -0.2788524E-02 | -0.2354559E-02 | -0.2788524E-02 | -0.2354559E-02 |
| 200 | -0.2841872E-02 | -0.2335717E-02 | -0.2841872E-02 | -0.2335717E-02 |
| 201 | -0.2872146E-02 | -0.2303646E-02 | -0.2872146E-02 | -0.2303646E-02 |
| 202 | -0.2877499E-02 | -0.2256941E-02 | -0.2877499E-02 | -0.2256941E-02 |
| 203 | -0.2855415E-02 | -0.2194422E-02 | -0.2855415E-02 | -0.2194422E-02 |
| 204 | -0.2804290E-02 | -0.2115649E-02 | -0.2804290E-02 | -0.2115649E-02 |
| 205 | -0.2724604E-02 | -0.2021108E-02 | -0.2724604E-02 | -0.2021108E-02 |
| 206 | -0.2616935E-02 | -0.1911812E-02 | -0.2616935E-02 | -0.1911812E-02 |
| 207 | -0.2482735E-02 | -0.1789120E-02 | -0.2482735E-02 | -0.1789120E-02 |
| 208 | -0.2324015E-02 | -0.1654757E-02 | -0.2324015E-02 | -0.1654757E-02 |
| 209 | -0.2143669E-02 | -0.1510655E-02 | -0.2143669E-02 | -0.1510655E-02 |
| 210 | -0.1944783E-02 | -0.1359128E-02 | -0.1944783E-02 | -0.1359128E-02 |
| 211 | -0.1731913E-02 | -0.1202588E-02 | -0.1731913E-02 | -0.1202588E-02 |
| 212 | -0.1510003E-02 | -0.1043784E-02 | -0.1510003E-02 | -0.1043784E-02 |

| | | | | |
|---|---|---|---|---|
| 213 | -0.1284195E-02 | -0.8857812E-03 | -0.1284195E-02 | -0.8857812E-03 |
| 214 | -0.1060345E-02 | -0.7318588E-03 | -0.1060345E-02 | -0.7318588E-03 |
| 215 | -0.8441696E-03 | -0.5854716E-03 | -0.8441696E-03 | -0.5854716E-03 |
| 216 | -0.6415065E-03 | -0.4500223E-03 | -0.6415065E-03 | -0.4500223E-03 |
| 217 | -0.4578691E-03 | -0.3286709E-03 | -0.4578691E-03 | -0.3286709E-03 |
| 218 | -0.2979304E-03 | -0.2239883E-03 | -0.2979304E-03 | -0.2239883E-03 |
| 219 | -0.1651746E-03 | -0.1377189E-03 | -0.1651746E-03 | -0.1377189E-03 |
| 220 | -0.6125689E-04 | -0.7051678E-04 | -0.6125689E-04 | -0.7051678E-04 |
| 221 | 0.1404028E-04 | -0.2191193E-04 | 0.1404028E-04 | -0.2191193E-04 |
| 222 | 0.6320324E-04 | 0.9904388E-05 | 0.6320324E-04 | 0.9904388E-05 |
| 223 | 0.9092383E-04 | 0.2780424E-04 | 0.9092383E-04 | 0.2780424E-04 |
| 224 | 0.1023345E-03 | 0.3562699E-04 | 0.1023345E-03 | 0.3562699E-04 |
| 225 | 0.1034563E-03 | 0.3716926E-04 | 0.1034563E-03 | 0.3716926E-04 |
| 226 | 0.1002580E-03 | 0.3603180E-04 | 0.1002580E-03 | 0.3603180E-04 |
| 227 | 0.9702919E-04 | 0.3476790E-04 | 0.9702919E-04 | 0.3476790E-04 |
| 228 | 0.9548322E-04 | 0.3445825E-04 | 0.9548322E-04 | 0.3445825E-04 |
| 229 | 0.9513300E-04 | 0.3484660E-04 | 0.9513300E-04 | 0.3484660E-04 |
| 230 | 0.9562464E-04 | 0.3571611E-04 | 0.9562464E-04 | 0.3571611E-04 |
| 231 | 0.9635080E-04 | 0.3667162E-04 | 0.9635080E-04 | 0.3667162E-04 |
| 232 | 0.9659404E-04 | 0.3736047E-04 | 0.9659404E-04 | 0.3736047E-04 |
| 233 | 0.9625776E-04 | 0.3771133E-04 | 0.9625776E-04 | 0.3771133E-04 |
| 234 | 0.9547615E-04 | 0.3778134E-04 | 0.9547615E-04 | 0.3778134E-04 |
| 235 | 0.9437024E-04 | 0.3762734E-04 | 0.9437024E-04 | 0.3762734E-04 |
| 236 | 0.9325606E-04 | 0.3742910E-04 | 0.9325606E-04 | 0.3742910E-04 |
| 237 | 0.9230909E-04 | 0.3725786E-04 | 0.9230909E-04 | 0.3725786E-04 |
| 238 | 0.9149735E-04 | 0.3711985E-04 | 0.9149735E-04 | 0.3711985E-04 |
| 239 | 0.9075183E-04 | 0.3699239E-04 | 0.9075183E-04 | 0.3699239E-04 |
| 240 | 0.8994958E-04 | 0.3681817E-04 | 0.8994958E-04 | 0.3681817E-04 |
| 241 | 0.8899322E-04 | 0.3654613E-04 | 0.8899322E-04 | 0.3654613E-04 |
| 242 | 0.8784467E-04 | 0.3615607E-04 | 0.8784467E-04 | 0.3615607E-04 |
| 243 | 0.8649920E-04 | 0.3565642E-04 | 0.8649920E-04 | 0.3565642E-04 |
| 244 | 0.8495299E-04 | 0.3505439E-04 | 0.8495299E-04 | 0.3505439E-04 |
| 245 | 0.8321068E-04 | 0.3435060E-04 | 0.8321068E-04 | 0.3435060E-04 |
| 246 | 0.8126844E-04 | 0.3355001E-04 | 0.8126844E-04 | 0.3355001E-04 |
| 247 | 0.7916347E-04 | 0.3265514E-04 | 0.7916347E-04 | 0.3265514E-04 |
| 248 | 0.7689741E-04 | 0.3167047E-04 | 0.7689741E-04 | 0.3167047E-04 |
| 249 | 0.7452205E-04 | 0.3058627E-04 | 0.7452205E-04 | 0.3058627E-04 |
| 250 | 0.7204778E-04 | 0.2939728E-04 | 0.7204778E-04 | 0.2939728E-04 |
| 251 | 0.6947458E-04 | 0.2809697E-04 | 0.6947458E-04 | 0.2809697E-04 |
| 252 | 0.6682533E-04 | 0.2668333E-04 | 0.6682533E-04 | 0.2668333E-04 |
| 253 | 0.6414437E-04 | 0.2516072E-04 | 0.6414437E-04 | 0.2516072E-04 |
| 254 | 0.6142196E-04 | 0.2353289E-04 | 0.6142196E-04 | 0.2353289E-04 |
| 255 | 0.5861420E-04 | 0.2181008E-04 | 0.5861420E-04 | 0.2181008E-04 |
| 256 | 0.5572463E-04 | 0.2000157E-04 | 0.5572463E-04 | 0.2000157E-04 |
| 257 | 0.5277922E-04 | 0.1811312E-04 | 0.5277922E-04 | 0.1811312E-04 |
| 258 | 0.4978536E-04 | 0.1615070E-04 | 0.4978536E-04 | 0.1615070E-04 |
| 259 | 0.4674407E-04 | 0.1411916E-04 | 0.4674407E-04 | 0.1411916E-04 |
| 260 | 0.4363753E-04 | 0.1202435E-04 | 0.4363753E-04 | 0.1202435E-04 |
| 261 | 0.4047964E-04 | 0.9868805E-05 | 0.4047964E-04 | 0.9868805E-05 |
| 262 | 0.3727275E-04 | 0.7654107E-05 | 0.3727275E-04 | 0.7654107E-05 |
| 263 | 0.3399332E-04 | 0.5383469E-05 | 0.3399332E-04 | 0.5383469E-05 |
| 264 | 0.3065481E-04 | 0.3062606E-05 | 0.3065481E-04 | 0.3062606E-05 |
| 265 | 0.2726486E-04 | 0.6923602E-06 | 0.2726486E-04 | 0.6923602E-06 |
| 266 | 0.2382249E-04 | -0.1722069E-05 | 0.2382249E-04 | -0.1722069E-05 |
| 267 | 0.2032500E-04 | -0.4175601E-05 | 0.2032500E-04 | -0.4175601E-05 |
| 268 | 0.1676316E-04 | -0.6666222E-05 | 0.1676316E-04 | -0.6666222E-05 |
| 269 | 0.1315085E-04 | -0.9191633E-05 | 0.1315085E-04 | -0.9191633E-05 |
| 270 | 0.9522833E-05 | -0.1174796E-04 | 0.9522833E-05 | -0.1174796E-04 |

| | | | | |
|---|---|---|---|---|
| 271 | 0.5899469E-05 | -0.1432922E-04 | 0.5899469E-05 | -0.1432922E-04 |
| 272 | 0.2296612E-05 | -0.1693253E-04 | 0.2296612E-05 | -0.1693253E-04 |
| 273 | -0.1275774E-05 | -0.1955332E-04 | -0.1275774E-05 | -0.1955332E-04 |
| 274 | -0.4804483E-05 | -0.2218531E-04 | -0.4804483E-05 | -0.2218531E-04 |
| 275 | -0.8292996E-05 | -0.2482199E-04 | -0.8292996E-05 | -0.2482199E-04 |
| 276 | -0.1173637E-04 | -0.2746090E-04 | -0.1173637E-04 | -0.2746090E-04 |
| 277 | -0.1513325E-04 | -0.3009884E-04 | -0.1513325E-04 | -0.3009884E-04 |
| 278 | -0.1845563E-04 | -0.3272803E-04 | -0.1845563E-04 | -0.3272803E-04 |
| 279 | -0.2169726E-04 | -0.3534587E-04 | -0.2169726E-04 | -0.3534587E-04 |
| 280 | -0.2486932E-04 | -0.3794807E-04 | -0.2486932E-04 | -0.3794807E-04 |
| 281 | -0.2798419E-04 | -0.4053004E-04 | -0.2798419E-04 | -0.4053004E-04 |
| 282 | -0.3103977E-04 | -0.4308790E-04 | -0.3103977E-04 | -0.4308790E-04 |
| 283 | -0.3400335E-04 | -0.4561460E-04 | -0.3400335E-04 | -0.4561460E-04 |
| 284 | -0.3688126E-04 | -0.4810729E-04 | -0.3688126E-04 | -0.4810729E-04 |
| 285 | -0.3967277E-04 | -0.5055867E-04 | -0.3967277E-04 | -0.5055867E-04 |
| 286 | -0.4237959E-04 | -0.5296555E-04 | -0.4237959E-04 | -0.5296555E-04 |
| 287 | -0.4500577E-04 | -0.5532212E-04 | -0.4500577E-04 | -0.5532212E-04 |
| 288 | -0.4754489E-04 | -0.5762367E-04 | -0.4754489E-04 | -0.5762367E-04 |
| 289 | -0.4998169E-04 | -0.5986200E-04 | -0.4998169E-04 | -0.5986200E-04 |
| 290 | -0.5230730E-04 | -0.6203338E-04 | -0.5230730E-04 | -0.6203338E-04 |
| 291 | -0.5450363E-04 | -0.6412867E-04 | -0.5450363E-04 | -0.6412867E-04 |
| 292 | -0.5657487E-04 | -0.6614124E-04 | -0.5657487E-04 | -0.6614124E-04 |
| 293 | -0.5852652E-04 | -0.6807341E-04 | -0.5852652E-04 | -0.6807341E-04 |
| 294 | -0.6032531E-04 | -0.6991629E-04 | -0.6032531E-04 | -0.6991629E-04 |
| 295 | -0.6195270E-04 | -0.7166009E-04 | -0.6195270E-04 | -0.7166009E-04 |
| 296 | -0.6340601E-04 | -0.7330037E-04 | -0.6340601E-04 | -0.7330037E-04 |
| 297 | -0.6468085E-04 | -0.7482865E-04 | -0.6468085E-04 | -0.7482865E-04 |
| 298 | -0.6577064E-04 | -0.7623539E-04 | -0.6577064E-04 | -0.7623539E-04 |
| 299 | -0.6664632E-04 | -0.7751171E-04 | -0.6664632E-04 | -0.7751171E-04 |
| 300 | -0.6727480E-04 | -0.7864941E-04 | -0.6727480E-04 | -0.7864941E-04 |
| 301 | -0.6766957E-04 | -0.7964758E-04 | -0.6766957E-04 | -0.7964758E-04 |
| 302 | -0.6783379E-04 | -0.8050576E-04 | -0.6783379E-04 | -0.8050576E-04 |
| 303 | -0.6780642E-04 | -0.8123201E-04 | -0.6780642E-04 | -0.8123201E-04 |
| 304 | -0.6760288E-04 | -0.8182375E-04 | -0.6760288E-04 | -0.8182375E-04 |
| 305 | -0.6720074E-04 | -0.8226837E-04 | -0.6720074E-04 | -0.8226837E-04 |
| 306 | -0.6657202E-04 | -0.8255735E-04 | -0.6657202E-04 | -0.8255735E-04 |
| 307 | -0.6571304E-04 | -0.8269035E-04 | -0.6571304E-04 | -0.8269035E-04 |
| 308 | -0.6463350E-04 | -0.8266945E-04 | -0.6463350E-04 | -0.8266945E-04 |
| 309 | -0.6335912E-04 | -0.8249599E-04 | -0.6335912E-04 | -0.8249599E-04 |
| 310 | -0.6189358E-04 | -0.8217156E-04 | -0.6189358E-04 | -0.8217156E-04 |
| * | | | | |
| 320 | -0.3715628E-04 | -0.7069053E-04 | -0.3715628E-04 | -0.7069053E-04 |
| * | | | | |
| 330 | 0.2065710E-05 | -0.4660243E-04 | 0.2065710E-05 | -0.4660243E-04 |
| * | | | | |
| 340 | 0.4144131E-04 | -0.1933187E-04 | 0.4144131E-04 | -0.1933187E-04 |
| * | | | | |
| 350 | 0.6763789E-04 | 0.1124280E-05 | 0.6763789E-04 | 0.1124280E-05 |
| * | | | | |
| 360 | 0.8220852E-04 | 0.1450309E-04 | 0.8220852E-04 | 0.1450309E-04 |
| * | | | | |
| 370 | 0.9217780E-04 | 0.2518093E-04 | 0.9217780E-04 | 0.2518093E-04 |
| * | | | | |
| 380 | 0.1018361E-03 | 0.3608389E-04 | 0.1018361E-03 | 0.3608389E-04 |
| * | | | | |
| 390 | 0.1093322E-03 | 0.4575731E-04 | 0.1093322E-03 | 0.4575731E-04 |
| * | | | | |
| 400 | 0.1150935E-03 | 0.5438289E-04 | 0.1150935E-03 | 0.5438289E-04 |

```
   *
 410    0.1178991E-03    0.6103118E-04    0.1178991E-03    0.6103118E-04
   *
 420    0.1161201E-03    0.6439776E-04    0.1161201E-03    0.6439776E-04
   *
 430    0.1085710E-03    0.6346884E-04    0.1085710E-03    0.6346884E-04
   *
 440    0.9477540E-04    0.5768859E-04    0.9477540E-04    0.5768859E-04
   *
 450    0.7550459E-04    0.4740230E-04    0.7550459E-04    0.4740230E-04
   *
 460    0.5398184E-04    0.3473980E-04    0.5398184E-04    0.3473980E-04
   *
 470    0.3360874E-04    0.2208608E-04    0.3360874E-04    0.2208608E-04
   *
 480    0.1698561E-04    0.1136262E-04    0.1698561E-04    0.1136262E-04
   *
 490    0.5868019E-05    0.3981327E-05    0.5868019E-05    0.3981327E-05
   *
 590   -0.2037327E-06   -0.1478782E-06   -0.2037327E-06   -0.1478782E-06
   *
 690    0.1290614E-06    0.6931886E-07    0.1290614E-06    0.6931886E-07
   *
 790    0.4206659E-08    0.2871404E-08    0.4206659E-08    0.2871404E-08
   *
 890   -0.4037456E-12    0.9487046E-13   -0.4034197E-12    0.9473402E-13
   *
 990   -0.4018225E-12    0.9620203E-13   -0.4014965E-12    0.9606559E-13
   *
 991   -0.4014639E-12    0.9625773E-13   -0.4011380E-12    0.9612129E-13
   *
 992   -0.4015454E-12    0.9626878E-13   -0.4012195E-12    0.9613235E-13
   *
 993   -0.4017573E-12    0.9620808E-13   -0.4014313E-12    0.9607164E-13
   *
 994   -0.4018225E-12    0.9616427E-13   -0.4014965E-12    0.9602784E-13
   *
 995   -0.4016921E-12    0.9620432E-13   -0.4013661E-12    0.9606789E-13
   *
 996   -0.4013498E-12    0.9638790E-13   -0.4010239E-12    0.9625147E-13
   *
 997   -0.4014802E-12    0.9636579E-13   -0.4011543E-12    0.9622936E-13
   *
 998   -0.4014802E-12    0.9638832E-13   -0.4011543E-12    0.9625189E-13
   *
 999   -0.4016595E-12    0.9628151E-13   -0.4013335E-12    0.9614508E-13
   *
1000   -0.4022788E-12    0.9600134E-13   -0.4019529E-12    0.9586491E-13
```

(Note: * indiactes that lines are deleted)

**Additional run for pulse response method:**

Routine pric.f is now run with the output file motion, fort.61, and output files for force, fort.51, fort.52, and fort.54. Note that output file fort.53 is not required for supersonic axial flow case.

## Pric.in

```
cat >pric.i <<"=eof="
FSMACH     STAGGER    SBYC
2.61       28.0       0.311
NPSG(nbs)  REDFRE     X0
3.00       1.00       0.300
=eof=
#pitching about 30% chord (flat plate example)
#
cp $HOME/examp/plate/pitch/fort.61 fort.9
cp $HOME/examp/plate/pitch/fort.51 fort.31
cp $HOME/examp/plate/pitch/fort.52 fort.32
cp $HOME/examp/plate/pitch/fort.54 fort.33
#
time pric <pric.i> pric.out
```

## Pric.out

```
     CFD aerodynamic model
  >>>>>>>>  READING CFD DATA  <<<<<<<<

 MACH NUMBER=  2.6100
 STAGGER ANGLE=   28.0000
 GAP TO CHORD RATIO=     0.3110
 REDUCED FREQUENCY BASED ON CHORD=  2.0000

  data from pulse response method used
 nblade  3
 dtpc, xpitch, ntss = 2.25E-3,  0.3,  100
  finished reading steady motion part
  finished reading unsteady motion part
 nstep = 901
 delt 2.25E-3
 delt* xminf 5.8725E-3
 kc= 2.

 PITCHING MOTION
    1  0.75704763E+00 -0.28596771E+00  0.14624368E+00 -0.19427208E+00
    2  0.52395191E-01 -0.34971703E+00  0.89568783E-02 -0.15728373E+00
    3  0.61335449E-01 -0.15116553E+00  0.36020651E-01 -0.89561150E-01

  >>>>>>>>  INFLUENCE COEFFICIENTS  <<<<<<<<

 MACH NUMBER=  2.6100
 REDUCED FREQUENCY based on chord=  2.0000
 INTER-BLADE PHASE ANGLE=    0.0000
 STAGGER ANGLE=   28.0000

  LIFT AND MOMENT COEFFICIENTS FOR BLADE K= 1
 0.75704763E+00 -0.28596771E+00  0.14624368E+00 -0.19427208E+00

  LIFT AND MOMENT COEFFICIENTS FOR BLADE K= 2
 0.52395191E-01 -0.34971703E+00  0.89568783E-02 -0.15728373E+00

  LIFT AND MOMENT COEFFICIENTS FOR BLADE K= 3
 0.61335449E-01 -0.15116553E+00  0.36020651E-01 -0.89561150E-01
```

```
axial mach number (axialm) = 2.304493217362

phase angle(deg.)        Lift coefficient (CL)         Moment coefficient(CM)
 0.00000000E+00  0.87077827E+00 -0.78685026E+00  0.19122120E+00 -0.44111696E+00
 0.90000000E+02  0.95559914E+00 -0.29490796E+00  0.21396625E+00 -0.22133585E+00
 0.18000000E+03  0.64331699E+00  0.21491485E+00  0.10126615E+00  0.52572795E-01
 0.27000000E+03  0.55849612E+00 -0.27702745E+00  0.78521098E-01 -0.16720831E+00
```

The preceding output shows the unsteady aerodynamic coefficients for four phase angles. As can be seen, they are close to those predicted by harmonic oscillation method (section 7.1.1) and influence coefficient method (section 7.2).

## 7.4 Time Domain Flutter Analysis of a Flat-Plate Cascade in Pitching Motion

In this example, a time domain analysis (MOTION=-1; IFLTR=-1) is done for the same flow and geometric conditions as in section 7.1.1. The input values for PHASE, REDFRE, H0/C and ALFA0D are not used in the computation. The structural properties used are the mass ratio (XMU) is 456, the radius of gyration (XRA) is 0.588, natural frequencies in bending and torsion in cycles per second respectively are 0.567 and 1.0 i.e. GAS=0.567 and GHS=1.0, with no structural damping (ZHS, ZAS = 0.0). The offset (XA) between elastic axis and center of gravity is zero. The elastic axis is assumed to be same as the pitching axis i.e. X0 = 0.3, Y0=0.0.

Calculations are performed for NTTOT =1200 time steps. The calculations start running the code in steady mode for NTSS =100 steps. A reduced velocity parameter (VSTAR) of 1.1 is used. Two blocks are used for computation (parameter, nbs=2 in the source file). The initial conditions are selected such that the blades oscillate with 180 degrees phase angle between them ( ALFAD0 = 0.05 for blade 1 and ALFAD0 = -0.05 for blade 2). The source code is compiled with the following parameter statements.

```
parameter(nbs=2)
parameter(ni=91, nj=41, nk=2)
```

**Input file (ecap2d.in)**

```
    MOTION      INEW
       -1          0
    FSMACH     PHASE    REDFREQ     ALPHA
      2.61   180.000     1.0000      0.00
      H0/C    ALFA0D
    0.0000    0.1500
.........*.........*.........*.........*.........*
       CFL      PRAT        PSI     ORDER     LIMIT
       4.0    0.7320     0.3333       3.0       1.0
        X0        Y0       SBYC   STAGGER
    0.3000       0.0      0.311     28.00
.........*.........*.........*.........*
```

```
     NCYC      NTSS     NTTOT    NTPRNT
        1       100      1200        50
      ILE       ITE       IGB    IAFOIL
       20        70         0         0
.........*.........*
    XLEFT    XRIGHT
     -0.3       1.5
.........*.........*.........*
      KIN      KOUT    MOOVEE
        0         9         0
    IMODE     IFLTR     IFREE
        1        -1         0
.........*.........*.........*.........*.........*.........*.........*
    VSTAR
      1.1
      GHS       GAS       ZHS       ZAS       XMU       XRA        XA
    0.567       1.0       0.0       0.0     456.0     0.588     0.000
      HD0    ALFAD0        H0    ALFA0
    0.000      0.05       0.0       0.0
      GHS       GAS       ZHS       ZAS       XMU       XRA        XA
    0.567       1.0       0.0       0.0     456.0     0.588     0.000
      HD0    ALFAD0        H0    ALFA0
    0.000   -0.0500       0.0       0.0
```

## ecap2d.out

## Unit 6 output

```
 *****************************************************
                TIME DOMAIN AEROELASTIC ANALYSIS
 *****************************************************

    factors for vibration =       1.0000      1.0000
   FSMACH     PHASE   REDFREQ     ALPHA
   2.6100  180.0000    1.0000    0.0000
     H0/C    ALFA0D
   0.0000    0.1500
      CFL      PRAT       PSI     ORDER     LIMIT
   4.0000    0.7320    0.3333    3.0000    1.0000
       X0        Y0      SBYC   STAGGER
   0.3000    0.0000    0.3110   28.0000
     NCYC      NTSS     NTTOT    NTPRNT
        1       100      1200        50
      ILE       ITE       IGB    IAFOIL
       20        70         0         0
    XLEFT    XRIGHT
  -0.3000    1.5000
    KMODE      KFFT     LIMIT
        1         1         1
      KIN      KOUT    MOOVEE
        0         9         0

 ****** Oscillating Cascade Analysis ******
 input run stream:

 number of blocks =    2 where each block has dimensions of:
                ni =   91
                nj =   41
```

```
               nk =     2

 freestream mach number   =  2.6100
 inlet incidence angle    =  0.0000 (degrees)
 exit pressure ratio      =  0.7320 (p/ptot)
 inter-blade phase angle =180.0000 (degrees)
 reduced frequency        =  1.0000 (based on semichord)
 reduced frequency        =  5.2200 (in terms of omega)
 amplitude of plunge      =  0.0000 (percent chord)
 amplitude of pitch       =  0.1500 (degrees)
 airfoil moment center    =  0.3000 (x0, percent chord)
 airfoil moment center    =  0.0000 (y0, percent chord)
 cascade stagger angle    = 28.0000 (degrees)
 cascade spacing          =  0.3110 (percent chord)

 ile     =    20 (airfoil leading edge index)
 ite     =    70 (airfoil trailing edge index)
 nb      =     1 (total number of cycles)
 kin     =     0 (restart input number -if 0 not used)
 kout    =     9 (restart output number -if 0 not used)
 kfft    =     1 (no fft analysis if kfft=0)
 moovee  =     0 (save certain steps for animation)
 kmode   =     1 (stationary or oscillating cascade)

a fft analysis will be done at the end of each cycle

      flux limiter input information:

            limit =    1
            psi   = 0.333
            order =   3.0

note with limit=1, MINMOD limiter has been invoked

    grid generated now , igb =     0
    IMODE     IFLTR     IFREE
       1        -1         0
    PITCHING MOTION
    **** PRINT INTERVAL, NTPRNT **** =   50

    motion indicator for blade    1:   1.0000
    GAMA H =      0.56700     GAMA ALPHA =      1.00000
    ZETA H =      0.00000     ZETA ALPHA =      0.00000
    MASS RATIO(XMU)                     =   456.00000
    RADIUS OF GYRATION(XRA)             =     0.58800
    DT. BETWEEN E.A. AND C.G.(XALFA)    =     0.00000
    initial plunging velocity           =     0.00000
    initial pitching velocity           =     0.05000
    initial plunging displacement       =     0.00000
    initial pitching displacemnet       =     0.00000

    motion indicator for blade    2:   1.0000
    GAMA H =      0.56700     GAMA ALPHA =      1.00000
    ZETA H =      0.00000     ZETA ALPHA =      0.00000
    MASS RATIO(XMU)                     =   456.00000
    RADIUS OF GYRATION(XRA)             =     0.58800
    DT. BETWEEN E.A. AND C.G.(XALFA)    =     0.00000
    initial plunging velocity           =     0.00000
```

```
    initial pitching velocity          =    -0.05000
    initial plunging displacement      =     0.00000
    initial pitching displacemnet      =     0.00000

    VELOCITY PARAMETER FOR TIME DOMAIN ANALYSIS      1.10000

     TIME DOMAIN: pitching motion only

    no. of time steps for steady solution, ntss  =  100
    no. of total time steps,               nttot = 1200
    IN ROUTINE GRIDGEN:STAG,SC,CHORD,X1,X4,NIF,NIB,IRUN
 28.00000     0.31100     1.00000     -0.30000     1.50000   20   70    0
 stagger angle (deg.) from input file =
                            28.0000000000
 stagger angle (deg.) from grid file =
                            28.0000000000
 stagger angle (deg.) used in the cal. =
                            28.0000000000
 gap-to-chord ratio from input file =
                             0.3110000000
 gap-to-chord ratio from grid file =
                             0.3110000000
 gap-to-chord ratio used in the calculation =
                             0.3110000000
    finished reading grid coordinates in routine rdgrid
    *** x coordinates at 0,ile,ilt,last
        -0.30000     0.00000     1.00000     1.50000

Starting the initial grid calculation
  For block  1:
    dtmin (as computed in eigenv) at cfl =  4.0 is      0.00449
  For block  2:
    dtmin (as computed in eigenv) at cfl =  4.0 is      0.00449
Successful completion of initial grid generation

 The flow solution will use dtmin= 0.00449 and nperiod=   268
 to give a maximum cfl close to   4.000

     finished job in routine strdat

    DONE IN ROUTINE CPINT
    DONE IN ROUTINE CPINT
    DONE IN ROUTINE FORCE
***
***lot of similar lines are deleted
***
    INITIAL CONDITIONS ON BLADE      1
   0.00000E+00    0.00000E+00    0.00000E+00    0.41412E-02    0.00000E+00
0.00000E+00
    INITIAL CONDITIONS ON BLADE      2
   0.00000E+00    0.00000E+00    0.00000E+00   -0.41412E-02    0.00000E+00
0.00000E+00
    done in routine struct
    done in routine steptd
***
***lot of similar lines are deleted
***
```

```
The average inlet Mach number is:    2.6100

The average exit Mach number is:    2.6113

The average inlet Mach number is:    2.6100
The average exit Mach number is:    2.6087

    block  1 written on unit  9 ncyc =    1200

    block  2 written on unit  9 ncyc =    1200
```

**Additional Outputs of Interest:**

(1) FORT.50+i, i =1,nbs is produced giving the time history of pitching and plunging motion for each blade. It has seven columns, which are index, plunging displacement, pitching displacement, unsteady lift, unsteady moment, total lift and total moment.

FORT.51 output:

For blade 1, the variation of pitching amplitude is given in the third column. Only selected output is shown for brevity.

```
  100      0.0000000E+00      0.0000000E+00      0.0000000E+00      0.0000000E+00
-0.2281693E-15    -0.1182830E-15
  101      0.0000000E+00      0.1859732E-04     -0.2965603E-03     -0.1799298E-03
-0.2965603E-03    -0.1799298E-03
  102      0.0000000E+00      0.3718610E-04     -0.5424090E-03     -0.3225689E-03
-0.5424090E-03    -0.3225689E-03
  103      0.0000000E+00      0.5575761E-04     -0.6578179E-03     -0.3788261E-03
-0.6578179E-03    -0.3788261E-03
  104      0.0000000E+00      0.7430312E-04     -0.6739973E-03     -0.3732731E-03
-0.6739973E-03    -0.3732731E-03
  105      0.0000000E+00      0.9281408E-04     -0.6582964E-03     -0.3475899E-03
-0.6582964E-03    -0.3475899E-03
  106      0.0000000E+00      0.1112821E-03     -0.6467441E-03     -0.3251838E-03
-0.6467441E-03    -0.3251838E-03
  107      0.0000000E+00      0.1296987E-03     -0.6561414E-03     -0.3176626E-03
-0.6561414E-03    -0.3176626E-03
  108      0.0000000E+00      0.1480558E-03     -0.6855260E-03     -0.3246082E-03
-0.6855260E-03    -0.3246082E-03
  109      0.0000000E+00      0.1663448E-03     -0.7226161E-03     -0.3372616E-03
-0.7226161E-03    -0.3372616E-03
  110      0.0000000E+00      0.1845576E-03     -0.7601996E-03     -0.3500473E-03
-0.7601996E-03    -0.3500473E-03
  111      0.0000000E+00      0.2026858E-03     -0.7922324E-03     -0.3588453E-03
-0.7922324E-03    -0.3588453E-03
  112      0.0000000E+00      0.2207212E-03     -0.8182444E-03     -0.3631529E-03
-0.8182444E-03    -0.3631529E-03
  113      0.0000000E+00      0.2386555E-03     -0.8405922E-03     -0.3648215E-03
-0.8405922E-03    -0.3648215E-03
  114      0.0000000E+00      0.2564806E-03     -0.8615898E-03     -0.3656190E-03
-0.8615898E-03    -0.3656190E-03
  115      0.0000000E+00      0.2741885E-03     -0.8833663E-03     -0.3672142E-03
-0.8833663E-03    -0.3672142E-03
```

| | | | | | | |
|---|---|---|---|---|---|---|
| 116 | 0.0000000E+00 | 0.2917709E-03 | -0.9067850E-03 | -0.3702533E-03 | -0.9067850E-03 | -0.3702533E-03 |
| 117 | 0.0000000E+00 | 0.3092200E-03 | -0.9310317E-03 | -0.3742004E-03 | -0.9310317E-03 | -0.3742004E-03 |
| 118 | 0.0000000E+00 | 0.3265279E-03 | -0.9552214E-03 | -0.3782995E-03 | -0.9552214E-03 | -0.3782995E-03 |
| 119 | 0.0000000E+00 | 0.3436866E-03 | -0.9787799E-03 | -0.3820102E-03 | -0.9787799E-03 | -0.3820102E-03 |
| 120 | 0.0000000E+00 | 0.3606884E-03 | -0.1001387E-02 | -0.3850670E-03 | -0.1001387E-02 | -0.3850670E-03 |
| 121 | 0.0000000E+00 | 0.3775255E-03 | -0.1023164E-02 | -0.3875665E-03 | -0.1023164E-02 | -0.3875665E-03 |
| 122 | 0.0000000E+00 | 0.3941902E-03 | -0.1044237E-02 | -0.3896574E-03 | -0.1044237E-02 | -0.3896574E-03 |
| 123 | 0.0000000E+00 | 0.4106751E-03 | -0.1064766E-02 | -0.3915113E-03 | -0.1064766E-02 | -0.3915113E-03 |
| 124 | 0.0000000E+00 | 0.4269725E-03 | -0.1084967E-02 | -0.3933123E-03 | -0.1084967E-02 | -0.3933123E-03 |
| 125 | 0.0000000E+00 | 0.4430752E-03 | -0.1104888E-02 | -0.3951207E-03 | -0.1104888E-02 | -0.3951207E-03 |
| 130 | 0.0000000E+00 | 0.5204136E-03 | -0.1198253E-02 | -0.4023061E-03 | -0.1198253E-02 | -0.4023061E-03 |
| 140 | 0.0000000E+00 | 0.6565012E-03 | -0.1343222E-02 | -0.4024100E-03 | -0.1343222E-02 | -0.4024100E-03 |
| 150 | 0.0000000E+00 | 0.7627928E-03 | -0.1428234E-02 | -0.3853879E-03 | -0.1428234E-02 | -0.3853879E-03 |
| 160 | 0.0000000E+00 | 0.8344819E-03 | -0.1439556E-02 | -0.3495649E-03 | -0.1439556E-02 | -0.3495649E-03 |
| 170 | 0.0000000E+00 | 0.8683318E-03 | -0.1409487E-02 | -0.3130289E-03 | -0.1409487E-02 | -0.3130289E-03 |
| 180 | 0.0000000E+00 | 0.8628184E-03 | -0.1438518E-02 | -0.3191726E-03 | -0.1438518E-02 | -0.3191726E-03 |
| 190 | 0.0000000E+00 | 0.8181913E-03 | -0.1461756E-02 | -0.3370959E-03 | -0.1461756E-02 | -0.3370959E-03 |
| 200 | 0.0000000E+00 | 0.7364665E-03 | -0.1391012E-02 | -0.3222587E-03 | -0.1391012E-02 | -0.3222587E-03 |
| 300 | 0.0000000E+00 | -0.7869381E-03 | 0.9397287E-03 | 0.1557704E-03 | 0.9397287E-03 | 0.1557704E-03 |
| 400 | 0.0000000E+00 | 0.1014616E-03 | 0.3147815E-03 | 0.1133382E-03 | 0.3147815E-03 | 0.1133382E-03 |
| 500 | 0.0000000E+00 | 0.6801175E-03 | -0.1270678E-02 | -0.2736252E-03 | -0.1270678E-02 | -0.2736252E-03 |
| 600 | 0.0000000E+00 | -0.8269655E-03 | 0.1046204E-02 | 0.1815105E-03 | 0.1046204E-02 | 0.1815105E-03 |
| 700 | 0.0000000E+00 | 0.2006279E-03 | 0.1629266E-03 | 0.8358148E-04 | 0.1629266E-03 | 0.8358148E-04 |
| 800 | 0.0000000E+00 | 0.6144569E-03 | -0.1216028E-02 | -0.2682436E-03 | -0.1216028E-02 | -0.2682436E-03 |
| 900 | 0.0000000E+00 | -0.8562794E-03 | 0.1139637E-02 | 0.2051266E-03 | 0.1139637E-02 | 0.2051266E-03 |
| 1000 | 0.0000000E+00 | 0.2976684E-03 | 0.7741104E-05 | 0.5208973E-04 | 0.7741104E-05 | 0.5208973E-04 |
| 1100 | 0.0000000E+00 | 0.5403325E-03 | -0.1145731E-02 | -0.2596151E-03 | -0.1145731E-02 | -0.2596151E-03 |
| 1190 | 0.0000000E+00 | -0.8358127E-03 | 0.1065526E-02 | 0.1859671E-03 | 0.1065526E-02 | 0.1859671E-03 |
| 1191 | 0.0000000E+00 | -0.8414217E-03 | 0.1083089E-02 | 0.1903868E-03 | 0.1083089E-02 | 0.1903868E-03 |

```
 1192      0.0000000E+00    -0.8466482E-03     0.1100210E-02     0.1947439E-03
0.1100210E-02     0.1947439E-03
 1193      0.0000000E+00    -0.8514896E-03     0.1116811E-02     0.1989903E-03
0.1116811E-02     0.1989903E-03
 1194      0.0000000E+00    -0.8559439E-03     0.1132901E-02     0.2031438E-03
0.1132901E-02     0.2031438E-03
 1195      0.0000000E+00    -0.8600090E-03     0.1148500E-02     0.2072150E-03
0.1148500E-02     0.2072150E-03
 1196      0.0000000E+00    -0.8636830E-03     0.1163543E-02     0.2111769E-03
0.1163543E-02     0.2111769E-03
 1197      0.0000000E+00    -0.8669642E-03     0.1178025E-02     0.2150297E-03
0.1178025E-02     0.2150297E-03
 1198      0.0000000E+00    -0.8698512E-03     0.1191975E-02     0.2187920E-03
0.1191975E-02     0.2187920E-03
 1199      0.0000000E+00    -0.8723426E-03     0.1205383E-02     0.2224615E-03
0.1205383E-02     0.2224615E-03
 1200      0.0000000E+00    -0.8744373E-03     0.1218215E-02     0.2260250E-03
0.1218215E-02     0.2260250E-03
```

FORT.52 output:

For blade 1, the variation of pitching amplitude is given in the third column. Only selected output is shown for brevity.

```
  100      0.0000000E+00     0.0000000E+00     0.0000000E+00     0.0000000E+00
0.5867211E-15     0.3460872E-15
  101      0.0000000E+00    -0.1859732E-04     0.3225184E-03     0.1895799E-03
0.3225184E-03     0.1895799E-03
  102      0.0000000E+00    -0.3718609E-04     0.5994305E-03     0.3439580E-03
0.5994305E-03     0.3439580E-03
  103      0.0000000E+00    -0.5575757E-04     0.7280525E-03     0.4050255E-03
0.7280525E-03     0.4050255E-03
  104      0.0000000E+00    -0.7430302E-04     0.7214072E-03     0.3896087E-03
0.7214072E-03     0.3896087E-03
  105      0.0000000E+00    -0.9281385E-04     0.6848133E-03     0.3560667E-03
0.6848133E-03     0.3560667E-03
  106      0.0000000E+00    -0.1112817E-03     0.6557120E-03     0.3273474E-03
0.6557120E-03     0.3273474E-03
  107      0.0000000E+00    -0.1296982E-03     0.6541789E-03     0.3160407E-03
0.6541789E-03     0.3160407E-03
  108      0.0000000E+00    -0.1480550E-03     0.6774862E-03     0.3203260E-03
0.6774862E-03     0.3203260E-03
  109      0.0000000E+00    -0.1663439E-03     0.7165786E-03     0.3341201E-03
0.7165786E-03     0.3341201E-03
  110      0.0000000E+00    -0.1845565E-03     0.7615537E-03     0.3504916E-03
0.7615537E-03     0.3504916E-03
  111      0.0000000E+00    -0.2026845E-03     0.8006214E-03     0.3626354E-03
0.8006214E-03     0.3626354E-03
  112      0.0000000E+00    -0.2207198E-03     0.8290530E-03     0.3679087E-03
0.8290530E-03     0.3679087E-03
  113      0.0000000E+00    -0.2386539E-03     0.8479766E-03     0.3672924E-03
0.8479766E-03     0.3672924E-03
  114      0.0000000E+00    -0.2564788E-03     0.8647200E-03     0.3656159E-03
0.8647200E-03     0.3656159E-03
  115      0.0000000E+00    -0.2741865E-03     0.8832384E-03     0.3655086E-03
0.8832384E-03     0.3655086E-03
  116      0.0000000E+00    -0.2917688E-03     0.9051237E-03     0.3678963E-03
```

```
0.9051237E-03    0.3678963E-03
  117     0.0000000E+00    -0.3092177E-03    0.9303368E-03    0.3725955E-03
0.9303368E-03    0.3725955E-03
  118     0.0000000E+00    -0.3265254E-03    0.9569082E-03    0.3782047E-03
0.9569082E-03    0.3782047E-03
  119     0.0000000E+00    -0.3436839E-03    0.9825845E-03    0.3831792E-03
0.9825845E-03    0.3831792E-03
  120     0.0000000E+00    -0.3606855E-03    0.1006144E-02    0.3867345E-03
0.1006144E-02    0.3867345E-03
  121     0.0000000E+00    -0.3775224E-03    0.1027226E-02    0.3887258E-03
0.1027226E-02    0.3887258E-03
  122     0.0000000E+00    -0.3941870E-03    0.1046847E-02    0.3898992E-03
0.1046847E-02    0.3898992E-03
  123     0.0000000E+00    -0.4106717E-03    0.1066095E-02    0.3910062E-03
0.1066095E-02    0.3910062E-03
  124     0.0000000E+00    -0.4269690E-03    0.1085651E-02    0.3924988E-03
0.1085651E-02    0.3924988E-03
  125     0.0000000E+00    -0.4430715E-03    0.1105735E-02    0.3944950E-03
0.1105735E-02    0.3944950E-03
  130     0.0000000E+00    -0.5204091E-03    0.1199971E-02    0.4023478E-03
0.1199971E-02    0.4023478E-03
  140     0.0000000E+00    -0.6564953E-03    0.1343964E-02    0.4022762E-03
0.1343964E-02    0.4022762E-03
  150     0.0000000E+00    -0.7627857E-03    0.1428600E-02    0.3854224E-03
0.1428600E-02    0.3854224E-03
  160     0.0000000E+00    -0.8344739E-03    0.1440121E-02    0.3498787E-03
0.1440121E-02    0.3498787E-03
  170     0.0000000E+00    -0.8683233E-03    0.1411837E-02    0.3144878E-03
0.1411837E-02    0.3144878E-03
  180     0.0000000E+00    -0.8628094E-03    0.1441719E-02    0.3215582E-03
0.1441719E-02    0.3215582E-03
  190     0.0000000E+00    -0.8181817E-03    0.1466631E-02    0.3400078E-03
0.1466631E-02    0.3400078E-03
  200     0.0000000E+00    -0.7364561E-03    0.1396880E-02    0.3251915E-03
0.1396880E-02    0.3251915E-03
  300     0.0000000E+00     0.7869449E-03   -0.9389608E-03   -0.1546807E-03
-0.9389608E-03   -0.1546807E-03
  400     0.0000000E+00    -0.1014595E-03   -0.3143718E-03   -0.1135785E-03
-0.3143718E-03   -0.1135785E-03
  500     0.0000000E+00    -0.6801117E-03    0.1274294E-02    0.2756665E-03
0.1274294E-02    0.2756665E-03
  600     0.0000000E+00     0.8269683E-03   -0.1046632E-02   -0.1808268E-03
-0.1046632E-02   -0.1808268E-03
  700     0.0000000E+00    -0.2006272E-03   -0.1633620E-03   -0.8417629E-04
-0.1633620E-03   -0.8417629E-04
  800     0.0000000E+00    -0.6144505E-03    0.1219364E-02    0.2697954E-03
0.1219364E-02    0.2697954E-03
  900     0.0000000E+00     0.8562813E-03   -0.1139753E-02   -0.2042098E-03
-0.1139753E-02   -0.2042098E-03
 1000     0.0000000E+00    -0.2976673E-03   -0.7904521E-05   -0.5269619E-04
-0.7904521E-05   -0.5269619E-04
 1100     0.0000000E+00    -0.5403253E-03    0.1148615E-02    0.2607508E-03
0.1148615E-02    0.2607508E-03
 1190     0.0000000E+00     0.8358155E-03   -0.1065932E-02   -0.1852415E-03
-0.1065932E-02   -0.1852415E-03
 1191     0.0000000E+00     0.8414243E-03   -0.1083511E-02   -0.1896380E-03
-0.1083511E-02   -0.1896380E-03
 1192     0.0000000E+00     0.8466506E-03   -0.1100574E-02   -0.1939406E-03
```

```
-0.1100574E-02    -0.1939406E-03
 1193       0.0000000E+00      0.8514918E-03      -0.1117106E-02     -0.1981483E-03
-0.1117106E-02    -0.1981483E-03
 1194       0.0000000E+00      0.8559459E-03      -0.1133120E-02     -0.2022628E-03
-0.1133120E-02    -0.2022628E-03
 1195       0.0000000E+00      0.8600107E-03      -0.1148572E-02     -0.2062550E-03
-0.1148572E-02    -0.2062550E-03
 1196       0.0000000E+00      0.8636845E-03      -0.1163501E-02     -0.2101399E-03
-0.1163501E-02    -0.2101399E-03
 1197       0.0000000E+00      0.8669655E-03      -0.1177901E-02     -0.2139311E-03
-0.1177901E-02    -0.2139311E-03
 1198       0.0000000E+00      0.8698523E-03      -0.1191825E-02     -0.2176559E-03
-0.1191825E-02    -0.2176559E-03
 1199       0.0000000E+00      0.8723435E-03      -0.1205166E-02     -0.2212571E-03
-0.1205166E-02    -0.2212571E-03
 1200       0.0000000E+00      0.8744380E-03      -0.1217933E-02     -0.2247393E-03
-0.1217933E-02    -0.2247393E-03
```

Note: A plot of the pitching amplitudes (3rd column) showed that the amplitudes are increasing with time, and the response of the two blades are in 180 degrees out of phase. This is expected for this example (Ref.5).

## 8. PROGRAM CALLING TREE

This section gives the static calling tree for ECAP2D and PRIC programs.

### 8.1 Static calling tree for ECAP2D code:

```
ECAP2D------BMFFT

        |------COEFFS

        |------FFTCP
        |------FFTMB

        |------FORCE---------CPINT

        |------GROUT
        |------INFLNC

        |------INICON--------BLDMCK
                       |------INIACC-------GMTMLT

        |------INPUT  ---------DPMAP
        |------PERF
        |------PVAR

        |------RDGRID-------GRIDGEN------VARDXS
        |------RESTRT
        |------SAVEIT--------INTERP
        |------SAVRST

        |------START---------BC
                       |------ EIGENV
                       |------ GRIDP
                       |------ GRIDV
                       |------ IC
                       |------ METRIC

        |------STEPHI--------BC
                       |------DOO
                       |------FJMAT
                       |------GETJPTS
                       |------GRIDP
                       |------GRIDV
                       |------METRIC
                       |------RESID----------MINMOD
                                      |------RLVECS
                                      |------SUPBEE
                                      |------VL
                       |------EIGENV
                       |------SETPTS
```

```
|------STEPPM------BC
                   |------DOO
                   |------FJMAT
                   |------GETJPTS
                   |------GRIDP
                   |------GRIDV
                   |------METRIC
                   |------RESID----------MINMOD
                                   |------RLVECS
                                   |------SUPBEE
                                   |------VL
                   |------EIGENV
                   |------SETPTS

|------STEPTD------BC
                   |------DOO
                   |------FJMAT
                   |------GETJPTS
                   |------GRIDP
                   |------GRIDV
                   |------METRIC
                   |------RESID----------MINMOD
                                   |------RLVECS
                                   |------SUPBEE
                                   |------VL
                   |------EIGENV
                   |------SETPTS

|------STRDAT------BLDDAT
                   |------DINVS

|------STRUCT------BLDMCK
                   |-----FLTR23------GMTMLT

|------TSFLTR------BLDDAT
```

## 8.2 Static calling tree for PRIC code:

```
PRIC
     |------CFDSOL------INFLNC
     |------COEFFS
     |------EULER
     |------RDCFD------CHECK
```

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**13. ABSTRACT** ***(Maximum 200 words)***
This guide describes the input data required for using ECAP2D (Euler Cascade Aeroelastic Program—Two Dimensional). ECAP2D can be used for steady or unsteady aerodynamic and aeroelastic analysis of two dimensional cascades. Euler equations are used to obtain aerodynamic forces. The structural dynamic equations are written for a rigid typical section undergoing pitching (torsion) and plunging (bending) motion. The solution methods include harmonic oscillation method, influence coefficient method, pulse response method, and time integration method. For harmonic oscillation method, example inputs and outputs are provided for pitching motion and plunging motion. For the rest of the methods, input and output for pitching motion only are given.

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