CHAPTER 9  

Test Cases

CFL3D provides multiple options for solving CFD problems. A variety of 0-equation, 1-equation, and 2-equation turbulence models are available. The code has static or dynamic mesh capabilities. If the grid has multiple zones, there are several choices for communication between the zones which can be used independently or in conjunction with one another. For convergence acceleration, multigrid and mesh sequencing are available.

The test cases described in this chapter provide a sampling of CFL3D’s capabilities. After studying the test cases, the user will hopefully be able to choose the best strategy for his or her particular applications. For information on how to obtain the files needed for the test cases see “Acquiring the Code and Example Files” on page 7.

Several two-dimensional test cases discussed in this chapter involve airfoils and flat plates. The use of a single block is exemplified with a RAE 2822 airfoil case. A NACA 0012 airfoil case is used as an example for both grid patching and grid overlapping. Also included is a multielement airfoil case, involving grid overlapping. The flat plate examples include a turbulent flat plate case and a vibrating flat plate case which illustrates the dynamic mesh capabilities of CFL3D. Also included are a multistream nozzle case and a rotor-stator case.

One three-dimensional example is for an axisymmetric bump. By taking advantage of periodicity, it is solved on a grid with only two planes in the circumferential direction. Three of the three-dimensional examples are for wing topologies. A single block case is set up for an F-5 wing. A case solving for the viscous flow over the Onera M-6 wing is also set up using a single block. A delta wing case with laminar flow is also available. Keep in mind that, in order to have cases that are “quick” to run, the three-dimensional grids used in some of these examples are relatively coarse compared to what one should use to adequately resolve the flow.

Note: you may see slight differences in your results, due to errors in CFL3D that have been corrected since the plots in this chapter were generated.

9.1 Two-dimensional Test Cases

CFL3D solves for the primitive variables at the cell centers of a grid. Therefore, for two-dimensional cases, two grid planes are needed for one plane of cell-center points to exist. The “2-d direction” is the i direction designated by setting idim = 2 (and i2d = 1). Typically, after a 2-d grid is generated, it is simply duplicated such that identical planes
exist at $i = 1$ and $i = 2$ with a constant value in the third direction. For example, if $x$ is the third direction, $x$ is typically set to 0.0 at $i = 1$ and $x$ might equal 1.0 or −1.0 at $i = 2$. When setting up the third direction by duplicating the grid plane, keep in mind that the right-hand rule must be satisfied. See “The Right-Hand Rule” on page 67. Also note that, while this step is doubling the number of grid points, only one plane of data is actually computed. Therefore, the number of points in one plane of the grid should be used when estimating the time required to run the code.

9.1.1 RAE 2822 Airfoil

This test case solves for the viscous flow over the RAE 2822 airfoil at $\\alpha = 2.72^\circ$ with $M_\infty = 0.75$. These are corrected conditions from Case 10 of Cook et al.\textsuperscript{15} The grid consists of a single zone with 24929 points in one plane. Menter’s $k-\omega$ SST model is used to solve the turbulent flow with a Reynolds number of 6.2 million. The memory requirement for this example is 5.7 million words. A typical timing for this case is 382 CPU seconds on a CRAY YMP (NASA LaRC’s Sabre as of June 1996). A close-up of the grid near the airfoil is shown in Figure 9-1.

Figure 9-1. Single zone RAE 2822 airfoil grid.
Besides the CFL3D code, the following files are needed to run this test case:

<table>
<thead>
<tr>
<th>File</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>rae10.inp</td>
<td>input for CFL3D</td>
</tr>
<tr>
<td>rae10.grd</td>
<td>formatted single plane grid</td>
</tr>
<tr>
<td>grid2dto3d.f</td>
<td>converter for creating 2 grid planes</td>
</tr>
</tbody>
</table>

The steps for running this case on the YMP are as follows:

**Step 1**
Compile the grid converter code:
```
cft77 grid2dto3d.f
```

**Step 2**
Link the grid converter object file:
```
segldr -o grid2dto3d grid2dto3d.o
```

**Step 3**
Run the grid converter program (the binary file rae10.bin will be output):
```
grid2dto3d
```
In answer to the questions, type:
```
rae10.grd
rae10.bin
2
0
```

**Step 4**
Use the makefile to compile, link, and create the executable for the precfl3d code (be sure precfl.h is in the current directory):
```
make -f makeprecfl3d_cray
```

**Step 5**
Run the precfl3d code (the cflx.h files will be output):
```
 precfl3d < rae10.inp
```

**Step 6**
Use the makefile to compile, link, and create the executable for the CFL3D code:
Step 7

Run the CFL3D code:

cfl3d < rae10.inp

The input file for this case is:

FILES:
rae10.bin
plot3dg.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d. sécur
plot3doutl5
cfl3d.prout
cfl3d.out20
ovrlp.bin
patch.bin
restart.bin

RAE case 10, with SST model

XMACH     ALPHA      BETA  REUE,MIL   TINF,DR     IALPH    IHSTRY
0.7500    02.720       0.0    6.2000     460.0         0         0

SREF      CREF      BREF       XMC       YMC       ZMC
1.00000   1.00000    1.0000   0.00000      0.00      0.00

DT     IREST   IFLAGTS      FMAX     IUNST     CFLTAU
-5.0000         0       000   05.0000         0      10.0

NGRID   NPLOT3D    NPRINT    NWREST      ICHK       I2D    NTSTEP       ITA
1         1         1      6100         0         1      0001         1

NCG       IEM  IADVANCE    IFORCE  IVISC(I)  IVISC(J)  IVISC(K)
2         0         0         1         0         0         7

IDIM     JDIM     KDIM
2         257        97

ILAMLO    ILAMHI    JLAMLO    JLAMHI    KLAMLO    KLAMHI
1         2        88       159       1        97

INEWG    IGRIDC    IS       JS       KS       IE       JE       KE
0         0         0         0         0         0         0         0

I0:   GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
1         1      1001         0         0         0         0         0

IDIM: GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
1         1      1002         0         0         0         0         0

J0:   GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
1         1      1002         0         0         0         0         0

JDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
1         1      1002         0         0         0         0         0

K0:   GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
1         1         0         0         1        41         0         0

1         1         2        2004         0         0        41        217       2

TWTYPE        CQ
0.        0.

1         3         0         0         0        217       257         0

KDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
1         1      1003         0         0         0         0         0

MSEQ    MGFLAG    ICONSF       MTT      NGAM
1         1         0         0         0         0

ISSC EPSSSC(1) EPSSSC(2) EPSSSC(3) ISSR EPSSSR(1) EPSSSR(2) EPSSSR(3)
0       0.3       0.3       0.3         0       0.3       0.3      0.3

NCYC    MGLEVG    NEMGL    NITFO
After running this test case a result such as that shown in Figure 9-2 should be obtained. In the figure, surface pressure coefficients are plotted along with experimental data for this case. The computational surface pressures can be obtained from file cfl3d.prout. Experimental surface pressure coefficients from Cook et. al.\textsuperscript{15} are included with this test case for comparison purposes. The file is called rae10.cpexp. The residual plots shown in Figure 9-3 should also be duplicated. These convergence histories can be found in cfl3d.res.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{Figure9-2}
\caption{Surface pressure coefficients for RAE 2822 airfoil; \(\alpha = 2.72^\circ, M_\infty = 0.75, Re_\ell_R = 6.2 \times 10^6\).}
\end{figure}
Figure 9-3. Residual and coefficient histories for RAE 2822 airfoil case;
\[
\alpha = 2.72^\circ, M_\infty = 0.75, \Re_{\text{e}_R} = 6.2 \times 10^6
\]
9.1.2 NACA 0012 Airfoil with Overlapped Grids

This test case solves for the inviscid flow over the NACA 0012 airfoil at $\alpha = 5^\circ$ with $M_\infty = 0.2$. The grid has a total of 4850 points on two grid zones which communicate with one another through overlapped grid stencils. Therefore, the MaGGiE code is used in addition to CFL3D. The memory requirement for this case is 1.8 million words. A typical timing for this case is 43 CPU seconds on a CRAY YMP (NASA LaRC’s Sabre as of June 1996). A close-up of the grid near the airfoil is shown in Figure 9-4.

![Figure 9-4. Two-zone overlapped grid system for NACA 0012 airfoil.](image)

Besides the CFL3D and MaGGiE codes the following files are needed to run this test case:

<table>
<thead>
<tr>
<th>File</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0012x.inp</td>
<td>input for CFL3D</td>
</tr>
<tr>
<td>0012x.fmt</td>
<td>formatted grid in PLOT3D format</td>
</tr>
<tr>
<td>fmttobin_p3d.f</td>
<td>grid converter</td>
</tr>
<tr>
<td>mag1.h</td>
<td>parameters for MaGGiE makefile</td>
</tr>
<tr>
<td>maggie.inp</td>
<td>input for MaGGiE</td>
</tr>
</tbody>
</table>

The steps for running this case on the YMP are as follows:
**Step 1**

Compile the grid converter code:

```
cft77 fmttobin_p3d.f
```

**Step 2**

Link the grid converter object file:

```
segldr -o fmttobin_p3d fmttobin_p3d.o
```

**Step 3**

Run the grid converter program (the binary file `0012x.bin` will be output):

```
fmttobin_p3d
```

**Step 4**

Use the makefile to compile, link, and create the executable for the MaGGiE code (be sure `mag1.h` is in the current directory):

```
make -f makemaggie_cray
```

**Step 5**

Run the MaGGiE code (the file `ovrlp.bin` will be output):

```
maggie < maggie.inp
```

**Step 6**

Use the makefile to compile, link, and create the executable for the `precfl3d` code (be sure `precfl1.h` is in the current directory):

```
make -f makeprecfl3d_cray
```

**Step 7**

Run the `precfl3d` code (the `cflx.h` files will be output):

```
precfl3d < 0012x.inp
```

**Step 8**

Use the makefile to compile, link, and create the executable for the CFL3D code:

```
make -f makecfl3d_cray
```

**Step 9**

Run the CFL3D code:
The input file for this case is:

```plaintext
I/O FILES
0012x.bin
plot3dq.bin
plot3dout.bin
cfl3d.res
cfl3d.tures
utf3d.blomax
cfl3d.out15
utf3d.out
ovrlp.bin
patch.bin
restart.bin

2-block 0012 airfoil as simple chimera test

XMACH  ALPHA  BETA  REUE,MIL  TINF,DR  IALPH  IHSTRY
0.200  5.000  0.00  0.00  520.0  1  0

SREF  CREF  BREF  XMC  YMC  ZMC
1.00000  1.00000  1.00000  0.25000  0.00  0.00

DT  IREST  IFLAGTS  FMAX  IUNST  CFLTAU
-5.00  0  0  100  0  1

NGRID  NPRINT  NWREST  ICHK  I2D  NTSTEP  ITA
-2  2  100  0  1  1

NGC  IEM  IADVANCE  IFORCE  IVISC(I)  IVISC(J)  IVISC(K)
2  0  0  0  0  0

IDIM  JDIM  KDIM
002  65  25
002  129  25

ILAMLO  ILAMHI  JIAMLO  JIAMHI  KLAMLO  KLAMHI
00  000000  000000  000000
00  000000  000000  000000

INEWG  IGRIDC  IS  JS  KS  IE  JE  KE
0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0

IDIM: GRID  SEGMENT  BCTYPE  JSTA  JEND  KSTA  KEND  NDATA
1  1  1002  0  0  0  0  0
2  1  1002  0  0  0  0  0

IDIM: GRID  SEGMENT  BCTYPE  JSTA  JEND  KSTA  KEND  NDATA
1  1  1002  0  0  0  0  0
2  1  1002  0  0  0  0  0

K0: GRID  SEGMENT  BCTYPE  ISTA  IEND  JSTA  JEND  NDATA
1  1  0  0  0  0  0  0
2  1  0  0  0  0  0  0

KDIM: GRID  SEGMENT  BCTYPE  ISTA  IEND  JSTA  JEND  NDATA
1  1  0  0  0  0  0  0
2  1  0  0  0  0  0  0

MSEQ  MGFLAG  ICONSF  MTT  NGAM
1  1  1  0  0

ISSC  EPSSC(I)  EPSSC(J)  EPSSC(K)  ISSR  EPSSR(I)  EPSSR(J)  EPSSR(K)
0  0.3  0.3  0.3  0  0.3  0.3  0.3
```
The residual and coefficient histories for this case are plotted in Figure 9-5.
Figure 9-5. NACA 0012 with overlapped grids residual and coefficient histories; \( \alpha = 5^\circ, M_\infty = 0.2 \).
9.1.3 NACA 0012 Airfoil with Patched Grids

This test case solves for the inviscid flow over the NACA 0012 airfoil at $\alpha = 1.25^\circ$ with $M_\infty = 0.8$. The grid has a total of 4949 points in seven zones which communicate with one another utilizing the patching option. Therefore, the ronnie code is used in addition to CFL3D. An advantage of using patched grids is that finer grids can be placed in high gradient regions while relatively coarser grids can be placed elsewhere thus reducing the CPU time and memory needed. In this case, the finest grids are located in the regions where the upper and lower shocks are expected to occur in order to better resolve these flow phenomena. The memory requirement for this example is 1.9 million words. A typical timing is 87 CPU seconds on a CRAY YMP (NASA LaRC’s Sabre as of June 1996). A close-up of the grid near the airfoil is shown in Figure 9-6. In the figure, the grids are labelled one through seven and this is the grid order in which the information is set up in the input file.

![Figure 9-6. Seven-zone patched grid system for NACA 0012 airfoil.](image)

Besides the CFL3D and ronnie codes the following files are needed to run this test case:

<table>
<thead>
<tr>
<th>File</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0012.inp</td>
<td>input for CFL3D</td>
</tr>
<tr>
<td>0012.fmt</td>
<td>formatted grid</td>
</tr>
<tr>
<td>fmttobin.f</td>
<td>grid converter</td>
</tr>
</tbody>
</table>
The steps for running this case on the YMP are as follows:

**Step 1**
Compile the grid converter code:
```
cft77 fmttobin.f
```

**Step 2**
Link the grid converter object file:
```
segldr -o fmttobin fmttobin.o
```

**Step 3**
Run the grid converter program (the binary file 0012.bin will be output):
```
fmttobin
```

**Step 4**
Use the makefile to compile, link, and create the executable for the ronnie code (be sure ron1.h is in the current directory):
```
make -f makeronnie_cray
```

**Step 5**
Run the ronnie code (the file patch.bin_0012 will be output):
```
ronnie < ronnie.inp
```

**Step 6**
Use the makefile to compile, link, and create the executable for the precfl3d code (be sure precfl.h is in the current directory):
```
make -f makeprecfl3d_cray
```

**Step 7**
Run the precfl3d code (the cfix.h files will be output):
```
precfl3d < 0012.inp
```
**Step 8**

Use the makefile to compile, link, and create the executable for the CFL3D code:

```
make -f makecfl3d_cray
```

**Step 9**

Run the CFL3D code:

```
cfl3d < 0012.inp
```

The input file for this case is:

```
I/O FILES
0012.bin
plot3dg.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.turres
cfl3d.blomax
cfl3d.out15
cfl3d.prout
cfl3d.out20
ovrlp.bin
patch.bin_0012
restart.bin

input for 7 block patched 0012 grids - iopt = 1 in assemble.f

XMACH    ALPHA  BETA    REUE,MIL    TINF,DR    IALPH  IHSTRY
 0.80     1.25   0.0      0.000       122.0      0        0

SREF     CREF     BREF     XMC      YMC      ZMC
 1.00000  1.00000   0.25000   0.00      0.00

DT    IREST    IFLAGTS      FMAX     IUNST    CFLTAU
-5.00    0       000       1.000       0     10.0

NGRID    NPLOT3D    NPRINT    NWREST      ICHK       I2D   NTSTEP       ITA
    7        7         0       100         0         1        1         1

NCG    IEM  IADVANCE    IFORCE  IVISC(I)  IVISC(J)  IVISC(K)
 1      0         0        0          0         0         0

IDIM    JDIM    KDIM
 2        65       13

ILAMLO    ILAMHI    JLAMLO    JLAMHI    Klamlo    KLAMHI
 00        00       000       000      0       0000
 00        00       000       000      0       0000
 00        00       000       000      0       0000
 00        00       000       000      0       0000
 00        00       000       000      0       0000
 00        00       000       000      0       0000

INWG    IGRIDC        IS        JS        KS        IE        JE        KE
 0         0         0        0          0         0         0         0
 0         0         0        0          0         0         0         0
 0         0         0        0          0         0         0         0
 0         0         0        0          0         0         0         0
 0         0         0        0          0         0         0         0
 0         0         0        0          0         0         0         0
```
### 9.1.3 NACA 0012 Airfoil with Patched Grids

<table>
<thead>
<tr>
<th>IDIAG(I)</th>
<th>IDIAG(J)</th>
<th>IDIAG(K)</th>
<th>IFLIM(I)</th>
<th>IFLIM(J)</th>
<th>IFLIM(K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IFDS(I)</th>
<th>IFDS(J)</th>
<th>IFDS(K)</th>
<th>RKAP0(I)</th>
<th>RKAP0(J)</th>
<th>RKAP0(K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GRID</th>
<th>NBCI0</th>
<th>NBCIDIM</th>
<th>NBCJ0</th>
<th>NBCJDIM</th>
<th>NBCK0</th>
<th>NBCKDIM</th>
<th>IOVRLP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>I0: GRID</th>
<th>SEGMENT</th>
<th>BCTYPE</th>
<th>JSTA</th>
<th>JEND</th>
<th>KSTA</th>
<th>KEND</th>
<th>NDATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IDIM: GRID</th>
<th>SEGMENT</th>
<th>BCTYPE</th>
<th>JSTA</th>
<th>JEND</th>
<th>KSTA</th>
<th>KEND</th>
<th>NDATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>J0: GRID</th>
<th>SEGMENT</th>
<th>BCTYPE</th>
<th>ISTA</th>
<th>IEND</th>
<th>KSTA</th>
<th>KEND</th>
<th>NDATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>JDIM: GRID</th>
<th>SEGMENT</th>
<th>BCTYPE</th>
<th>ISTA</th>
<th>IEND</th>
<th>KSTA</th>
<th>KEND</th>
<th>NDATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>K0: GRID</th>
<th>SEGMENT</th>
<th>BCTYPE</th>
<th>ISTA</th>
<th>IEND</th>
<th>JSTA</th>
<th>JEND</th>
<th>NDATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KDIM: GRID</th>
<th>SEGMENT</th>
<th>BCTYPE</th>
<th>ISTA</th>
<th>IEND</th>
<th>JSTA</th>
<th>JEND</th>
<th>NDATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1003</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
The residual and force coefficient history plots for this case is shown in Figure 9-7. The sharp spike in the residual history plot depicts the iteration at which the grid levels changed for mesh sequencing. These convergence histories can be found in cfl3d.res.
Figure 9-7. Seven-zone NACA 0012 case residual and coefficient histories; \( \alpha = 1.25^\circ \), \( M_\infty = 0.8 \).
9.1.4 Multielement Airfoil with Overlapped Grids

This test case solves for the viscous, turbulent flow over a three-element airfoil with \( M_\infty = 0.2 \), \( \alpha = 8.109^\circ \), and a Reynolds number of 9 million. The Spalart-Allmaras turbulence model is used. The grid, with a total of 59051 points, consists of three zones, one for each element. The grid zones communicate with one another utilizing the grid overlapping option. Therefore, the MaGGiE code is used in addition to CFL3D. The memory requirement for this case is 9.5 million words. A typical timing is 2849 CPU seconds on a CRAY YMP (NASA LaRC’s Sabre as of June 1996). A close-up of the grid near the airfoil is shown in Figure 9-8. In the figure, the grids are labelled one through three and this is the grid order in which the information is set up in the input file.

![Figure 9-8. Three-zone overlapped grid system for a three-element airfoil.](image)

Besides the CFL3D and MaGGiE codes the following files are needed to run this test case:

<table>
<thead>
<tr>
<th>File</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>multi.inp</td>
<td>input for CFL3D</td>
</tr>
<tr>
<td>grid.fmt</td>
<td>formatted grid</td>
</tr>
<tr>
<td>fmttobin.f</td>
<td>grid converter</td>
</tr>
<tr>
<td>magi.h</td>
<td>parameters for MaGGiE makefile</td>
</tr>
<tr>
<td>mag.inp_multi</td>
<td>input for MaGGiE</td>
</tr>
</tbody>
</table>
The steps for running this case on the YMP are as follows:

**Step 1**

Compile the grid converter code:

```
cft77 fmttobin.f
```

**Step 2**

Link the grid converter object file:

```
segldr -o fmttobin fmttobin.o
```

**Step 3**

Run the grid converter program (the binary file `multi.bin` will be output):

```
fmttobin
```

**Step 4**

Use the makefile to compile, link, and create the executable for the MaGGiE code (be sure `mag1.h` is in the current directory):

```
make -f makenaggie_cray
```

**Step 5**

Run the MaGGiE code (the file `ovrlp.bin` will be output):

```
maggie < mag.inp_multi
```

**Step 6**

Use the makefile to compile, link, and create the executable for the `precfl3d` code (be sure `precfl1.h` is in the current directory):

```
make -f makeprecfl3d_cray
```

**Step 7**

Run the `precfl3d` code (the `cflx.h` files will be output):

```
precfl3d < multi.inp
```

**Step 8**

Use the makefile to compile, link, and create the executable for the CFL3D code:

```
make -f makecfl3d_cray
```
**Step 9**

Run the CFL3D code:

```
cfl3d < multi.inp
```

The input file for this case is:

```
I/O FILES
multi.bin
plot3dg.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.blomax
cfl3d.out15
cfl3d.prout
ovrlp.bin
patch.bin
restart.bin
```

3 element airfoil - chimera-type grids - Spalart-Allmaras turb model

```
XMACH     ALPHA      BETA  REUE,MIL   TINF,DR     IALPH    IHSTRY
  .2000     8.109       0.0       9.0     520.0         0         0

SREF      CREF      BREF       XMC       YMC       ZMC
  1.0000    1.0000   0.25000   0.0000     0.0000       0.0000

DT IREST IFLAGTS FMAX IUNST CFLTAU
-5.00     0       000   1.000     0       10.0

NGRID NPRINT NWREST ICHK I2D NTSTEP ITA
  3   3     100   0     1         1         1

NCG IEM IADVANCE IFORCE IVISC(I) IVISC(J) IVISC(K)
  2   0       001     0          0         0         5
  2   0       001     0          0         0         5
  2   0       001     0          0         0         5

IDIM JDIM KDIM
  002   357   65
  002   359   57
  002   397   49

ILAMLO ILAMHI JAMLO JAMHI KLAMLO KLAMHI
  00     000      000      0000
  00     000      0000     0000
  00     0000     0000     0000

INEWG IGRIDC IS JS KS IE JE KE
  0     0     0     0     0     0     0     0
  0     0     0     0     0     0     0     0
  0     0     0     0     0     0     0     0

IDIAG(I) IDIAG(J) IDIAG(K) IFLIM(I) IFLIM(J) IFLIM(K)
  1   1       1      3      3      3
  1   1       1      3      3      3
  1   1       1      3      3      3

IFDS(I) IFDS(J) IFDS(K) RKAP0(I) RKAP0(J) RKAP0(K)
  1   1      .3333   .3333    .3333
  1   1      .3333   .3333    .3333
  1   1      .3333   .3333    .3333

GRID NBCI0 NBCIDIM NBCJ0 NBCJDIM NBCK0 NBCKDIM IOVRLP
  1   1       1      1      3      1      1
  1   1       1      1      3      1      1
  1   1       1      1      3      1      1

IO: GRID SEGMENT BCTYPE JSTA JEND KSTA KEND NDATA
  1   1    1002     0     0     0     0
  2   1    1002     0     0     0     0
  3   1    1002     0     0     0     0

IDIM: GRID SEGMENT BCTYPE JSTA JEND KSTA KEND NDATA
  1   1    1002     0     0     0     0
  2   1    1002     0     0     0     0
  3   1    1002     0     0     0     0

JO: GRID SEGMENT BCTYPE ISTA IEND KSTA KEND NDATA
  1   1    1003     0     0     0     0
```
After running this test case, the residual and force coefficient convergence histories should look like those in Figure 9-9. These convergence histories can be found in file cfl3d.res. Note the unusually high number of multigrid cycles required to converge this case. While quite large, this is the behavior typically seen (with CFL3D) for multielement airfoil cases, even when one-to-one blocking is employed.
Figure 9-9. Convergence histories for three-element airfoil case;
\[ \alpha = 8.109^\circ, \quad Re_{L_R} = 9 \times 10^6. \]
9.1.5 Flat Plate

The viscous, turbulent flow with a Reynolds number of 6 million over a flat plate is solved in this test case. The grid consists of a single grid zone with 6305 points. Menter’s $k-\omega$ SST turbulence model is utilized in this example. The memory requirement is 2.3 million words. A typical timing for this case is 157 CPU seconds on a CRAY YMP (NASA LaRC’s Sabre as of June 1996). The entire flat plate grid is illustrated in Figure 9-10.

![Figure 9-10. Single zone flat plate grid.](image)

Besides the CFL3D code the following files are needed to run this test case:

<table>
<thead>
<tr>
<th>File</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>grdflat5.inp</td>
<td>input for CFL3D</td>
</tr>
<tr>
<td>grdflat5.grd</td>
<td>formatted grid</td>
</tr>
<tr>
<td>grid2dto3d.f</td>
<td>grid converter</td>
</tr>
</tbody>
</table>

The steps for running this case on the YMP are as follows:

**Step 1**

Compile the grid converter code:

```
cft77 grid2dto3d.f
```
Step 2

Link the grid converter object file:

```
segldr -o grid2dto3d grid2dto3d.o
```

Step 3

Run the grid converter program (the binary file `grdflat5.bin` will be output):

```
grid2dto3d
```

In answer to the questions, type:

```
grdflat5.grd
grdflat5.bin
2
0
```

Step 4

Use the makefile to compile, link, and create the executable for the `precfl3d` code (be sure `precfl.h` is in the current directory):

```
make -f makeprecfl3d_cray
```

Step 5

Run the `precfl3d` code (the `cflx.h` files will be output):

```
precfl3d < grdflat5.inp
```

Step 6

Use the makefile to compile, link, and create the executable for the CFL3D code:

```
make -f makecfl3d_cray
```

Step 7

Run the CFL3D code:

```
cfl3d < grdflat5.inp
```

The input file for this case is:

```
I/O FILES
grdflat5.bin
plot3dg.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.turres
cfl3d.blomax
cfl3d.out15
cfl3d.prout
```
turbulent flat plate (plate from j=17-65, prior to 17 is symmetry)

```
XMACH     ALPHA      BETA  REUE,MIL   TINF,DR     IALPH    IHSTRY
0.2000    00.000       0.0    06.000     460.0         0         0
SREF      IGRIDC       IS     IE     KE
1         0          1         1
1         0          1         1
IDIM      JDIM       KDIM
02      65       97
ILAMLO   ILAMHI   JLAMLO   JLAMHI   Klamlo   KLMHI
1         2         1         17         1       97
INEWG    IEM    İADVANCE    IFORCE  IVISC(I)  IVISC(J)  IVISC(K)
2         0         001         0         0         12
DT     IREST      IFLAGTS      FMAX     IUNST    CFLTAU
-5.000        1        000   05.0000         0        10.
NGRID   NPLOT3D      NPRINT    NWREST      ICHK       I2D
1         1         2      1200         0         1
1         1         2      1200         0         1
NCG     IE       IADVANCE    IFORCE  IVISC(I)  IVISC(J)  IVISC(K)
 2         0         001         0         0         12
IDIM      JDIM       KDIM
 0          2         1    02      65       97
0:  GRID SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
1         1          1001        0         0         0        0
IDIM: GRID SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
1         1          1002        0         0         0        0
J0:  GRID SEGMENT    BCTYPE      Ista      IEND      KSTA      KEND     NDATA
1         1          1008        0         0         0        0
JDIM: GRID SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
1         1          1002        0         0         0        0
K0:  GRID SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
1         1          1001        0         0         1       17
1         1          2004        0         0       17       65
1         1          2004        0         0       17       65
TWTYPE   CQ
1         1          2004        0         0       17       65
1         1          2004        0         0       17       65
1         1          2004        0         0       17       65
1         1          2004        0         0       17       65
1         1          2004        0         0       17       65
KDIM: GRID SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
1         1          1003        0         0         0        0
MSEQ    MGFLAG      ICONSF       MTT      NGAM
1         1          1003        0         0         0        0
ISSC    EPSSSC(1)   EPSSSC(2)   EPSSSC(3)   ISSR    EPSSSR(1)   EPSSSR(2)   EPSSSR(3)
0         0.3     0.3     0.3        0       0.3        0.3
NCYC    MGLEVG     NEWGL    NITPO
0500        00       0000
01         01         01     01         01     1       1
1      1-1 BLOCKING DATA:
    NBLI
    NUMBER : GRID     ISTA   JSTA   KSTA   IEND   JEND   KEND  ISVA1  ISVA2
 0
    NUMBER : GRID     ISTA   JSTA   KSTA   IEND   JEND   KEND  ISVA1  ISVA2
 0
    PATCH SURFACE DATA:
    NINTER
 0
    PLOT3D OUTPUT:
    GRID IPTYPE ISTART   IEND   IINC JSTART   JEND   JINC KSTART   KEND   KINC
1         0         0         0         0         0         0         0         0
IMOVIE
0
PRINT OUT:
    GRID IPTYPE ISTART   IEND   IINC JSTART   JEND   JINC KSTART   KEND   KINC
1         0         0         0         0         0         0         0         0
1         0         0         0         0         49       49       1       0       0
CONTROL SURFACE:
    NCS
0
    GRID ISTART   IEND   JSTART   JEND   KSTART   KEND   IWALL   INORM
```
After this test case is run, the residual history, found in file cfl3d.res, should look like that plotted in Figure 9-11. In Figure 9-12, values of $u^+$ versus $y^+$ are plotted at two cross sections of the flat plate and compared with theoretical values. The $u^+$ and $y^+$ values were extracted from the PLOT3D grid and q files using a postprocessor currently not available for general use.

![Figure 9-11. Residual history for single grid flat plate case.](image)

![Figure 9-12. Flat plate calculation compared with experiment; $Re_{L_R} = 6 \times 10^6$.](image)
This flat plate case has been studied with all the turbulence models currently available in CFL3D and a summary of the timings is tabulated below:

<table>
<thead>
<tr>
<th>Turbulence Model</th>
<th>$ivisc$</th>
<th>Approximate CPU seconds per cycle</th>
<th>Percent increase over Baldwin-Lomax per cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baldwin-Lomax</td>
<td>2</td>
<td>0.153</td>
<td>0</td>
</tr>
<tr>
<td>Baldwin-Lomax with Degani-Schiff</td>
<td>3</td>
<td>0.153</td>
<td>0</td>
</tr>
<tr>
<td>Baldwin-Barth</td>
<td>4</td>
<td>0.177</td>
<td>16</td>
</tr>
<tr>
<td>Spalart-Allmaras</td>
<td>5</td>
<td>0.182</td>
<td>19</td>
</tr>
<tr>
<td>Wilcox $k - \omega$</td>
<td>6</td>
<td>0.186</td>
<td>22</td>
</tr>
<tr>
<td>SST $k - \omega$</td>
<td>7</td>
<td>0.196</td>
<td>28</td>
</tr>
<tr>
<td>$k - \omega$ EASM Gatski-Speziale (Linear)</td>
<td>8</td>
<td>0.218</td>
<td>43</td>
</tr>
<tr>
<td>$k - \varepsilon$ EASM Girimaji (Linear)</td>
<td>9</td>
<td>0.236</td>
<td>54</td>
</tr>
<tr>
<td>$k - \varepsilon$ (Abid version)</td>
<td>10</td>
<td>0.197</td>
<td>29</td>
</tr>
<tr>
<td>$k - \varepsilon$ EASM Gatski-Speziale (Nonlinear)</td>
<td>11</td>
<td>0.236</td>
<td>54</td>
</tr>
<tr>
<td>$k - \omega$ EASM Gatski-Speziale (Nonlinear)</td>
<td>12</td>
<td>0.236</td>
<td>54</td>
</tr>
<tr>
<td>$k - \varepsilon$ EASM Girimaji (Nonlinear)</td>
<td>13</td>
<td>0.254</td>
<td>66</td>
</tr>
</tbody>
</table>

This case requires between 800 to 1800 cycles to converge, depending on the turbulence model employed and the convergence criterion chosen. Generally, $k - \varepsilon$ models take longer than $k - \omega$ models and two-equation models tend to take longer than one-equation models. (See Appendix H.) Memory requirements also depend on which turbulence model is being used, varying from 2.2 to 2.4 million words.

9.1.6 Vibrating Flat Plates

This test case solves for the unsteady, time-accurate inviscid flow through an “infinite” row of vibrating flat plates. The plates, located from $x = 0.0$ to $x = 1.0$, are vibrating up and down with a sinusoidal motion. The maximum displacement is $h = 0.001$ and the nominal distance between the plates is 1.0. The reduced frequency, defined by $k_r = \bar{\omega}c/2|\bar{V}|_\infty$, where $\bar{\omega}$ is in radians/second, is 4.0. (Note that the input to CFL3D defines $\bar{\omega}$ in cycles/second; therefore, $r\text{freq} = 0.63662$.) The plate vibration generates acoustic waves which propagate both downstream and upstream. The solution invokes periodicity at both the upper and lower boundaries (except between $x = 0.0$ and $x = 1.0$), thus mimicking an infinite row of flat plates.
This example also employs a second block downstream of \( x = 2.0 \). This block is a “sliding block” that is used to test the effect of a sliding block interface (such as might be used in a rotor-stator computation) on the transmission of acoustic waves. Currently, it is set to translate “up” with speed \( w/a_\infty = 1/\pi = 0.31831 \).

This test problem is set up to run for 961 time steps, using three multigrid sub-iterations per time step. The time step is \( \pi/320 = 0.0098175 \). At this time step, 160 time steps yield one complete cycle of plate oscillation, so 961 steps yield six complete cycles of plate oscillations. The code, taking advantage of the periodicity of the solution, “resets” the sliding zone (zone 2) whenever its motion exceeds \( dz_{\text{max}} = 1.0 \). At the end of time step 961, zone 2 is again physically aligned with zone 1. If the number of steps taken is such that \( nt_{\text{step}}-1 \) is not evenly divisible by 160, then zone 2 will appear displaced some distance “up” from zone 1 when looking at the solution. While this is not a problem since the solution is periodic, it is easier to visualize the whole flow field when the two zones are aligned.

The grid consists of two grid zones with a total of 5502 points. The memory requirement for this case is 2.1 million words. A typical timing for six cycles of plate oscillation is 422 CPU seconds on a CRA Y YMP (NASA LaRC’s Sabre as of July 1996).

Besides the CFL3D code the following files are needed to run this test case:

<table>
<thead>
<tr>
<th>File</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>vibrate.inp</td>
<td>input for CFL3D</td>
</tr>
<tr>
<td>cartesian.f</td>
<td>grid generator</td>
</tr>
</tbody>
</table>

The steps for running this case on the YMP are as follows:

**Step 1**

Compile the grid generator code:

```
cft77 cartesian.f
```

**Step 2**

Link the grid converter object file:

```
segldr -o cartesian cartesian.o
```

**Step 3**

Run the grid generator program (the binary file grid.bin will be output):

```
cartesian
```

In answer to the questions, type
9.1.6 Vibrating Flat Plates

Step 4

Use the makefile to compile, link, and create the executable for the precf13d code (be sure precfl.h is in the current directory):

```
make -f makeprecf13d_cray
```

Step 5

Run the precf13d code (the cflx.h files will be output):

```
precf13d < vibrate.inp
```

Step 6

Use the makefile to compile, link, and create the executable for the CFL3D code:

```
make -f makecfl3d_cray
```

Step 7

Run the CFL3D code:

```
cfl3d < vibrate.inp
```

The input file for this case is:

```
I/O FILES
grid.bin
plot3dq.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.tures
cfl3d.blomax
cfl3d.out15
cfl3d.prout
cfl3d.out20
ovrlp.bin
patch.bin
restart.bin

Flat plate vibrating cascade with sliding interface downstream

XMACH  ALPHA  BETA  REUE,MIL  TINF,DR  IALPH  IHSTRY
0.50   0.00   0.0   1.07      520.0    0       0
SREF  CREF  BREF  XMC  YMC  ZMC
1.00000 1.00000 1.00000 0.250000 0.00 0.00
DT  IREST  IFLAGS  FMAX  IUNST  CFLTAU
0.0098175 0   0000   1.0000   1   5.
```
CHAPTER 9  Test Cases

NGRID  NPLOT3D  NPRINT  NWREST  ICHK  I2D  NTSTEP  ITA
2        2        2      2000         0         1        961   -2
NCG    IEM    IADVANCE  IFORCE  IVISC(I)  IVISC(J)  IVISC(K)
2        0        0      001         0         0         0
2        0        0      001         0         0         0
IDIM    JDIM    KDIM
2      161      21
2      101      21
ILAMLO  ILAMHI  JLAMLO  JLAMHI  KLANLO  KLAMHI
00      0000      0000      0000      0000      0000
INEWG  IGRIDC  IS  JS  KS  IE  JE  KE
0        0        0        0        0        0        0        0
IDIA(I)  IDIA(J)  IDIA(K)  IFILM(I)  IFILM(J)  IFILM(K)
1        1        1         0         0         0
1        1        1         0         0         0
IFDS(I)  IFDS(J)  IFDS(K)  RKAP0(I)  RKAP0(J)  RKAP0(K)
1        1        1      .3333     .3333     .3333
1        1        1      .3333     .3333     .3333
GRID    NBCI0  NBCIDIM  NBCJ0  NBCJDIM  NBCK0  NBCKDIM  IOVRLP
1        1        1         1         1         3         3         0
2        1        1         1         1         1         1         0
I0:  GRID SEGMENT  BCTYPE  JSTA  JEND  KSTA  KEND  NDATA
1        1      1001         0         0         0         0
2        1      1001         0         0         0         0
IDIM:  GRID SEGMENT  BCTYPE  JSTA  JEND  KSTA  KEND  NDATA
1        1      1002         0         0         0         0
2        1      1002         0         0         0         0
JO:  GRID SEGMENT  BCTYPE  ISTA  IEND  KSTA  KEND  NDATA
1        1      1003         0         0         0         0
2        1        1         0         0         0         0
JDIM:  GRID SEGMENT  BCTYPE  ISTA  IEND  KSTA  KEND  NDATA
1        1        0         0         0         0         0
2        1      1003         0         0         0         0
KO:  GRID SEGMENT  BCTYPE  ISTA  IEND  JSTA  JEND  NDATA
1        1      2005         1         2         1       121        4
2        1        0         0         0         0         0
KDIM:  GRID SEGMENT  BCTYPE  ISTA  IEND  JSTA  JEND  NDATA
1        1      2005         1         2         1       121        4
NBLP    DTHTX  DTHTY  DTHTZ
1        1        0.0        0.        0.
1        2      1005         1         2       121       141        0
1        3      2005         1         2       141       161        4
NBLP    DTHTX  DTHTY  DTHTZ
1        1        0.0        0.        0.
2        1        0.0        0.        0.
2        1      2005         0         0         0         0
2        2        0.0        0.        0.
MSEQ    MGFLAG  ICONSF  MTT  NGAM
1        1         0         0
ISSC  EPSSC(1)  EPSSC(2)  EPSSC(3)  ISSR  EPSSR(1)  EPSSR(2)  EPSSR(3)
0        .3        .3        .3         0        .3        .3        .3
NCYC    MGLEVG  NEMGL  NITFO
3        03        00       0000
MIT1  MIT2  MIT3  MIT4  MIT5
0        01        01        01
1-1 BLOCKING DATA:
NBLI  0
NUMBER GRID : ISTA  JSTA  KSTA  IEND  JEND  KEND  ISVA1  ISVA2
NUMBER GRID : ISTA  JSTA  KSTA  IEND  JEND  KEND  ISVA1  ISVA2
PATCH SURFACE DATA:
NINTER
9.1.6 Vibrating Flat Plates

The resulting residual and lift coefficient histories for this case are shown in Figure 9-13 and Figure 9-14, respectively. The oscillatory nature of the flow is clearly evident. Figure 9-15 shows a profile of the flow as defined by pressure contours.
Figure 9-13. Residual history for inviscid flow through vibrating flat plates.

Figure 9-14. Lift coefficient history for inviscid flow through vibrating flat plates; 
\( M_\infty = 0.5 \).
Figure 9-15. Pressure contours for inviscid flow through vibrating flat plates; $M_\infty = 0.5$. 
9.1.7 Multistream Nozzle

This case simulates, in two dimensions, the flow through a converging/diverging nozzle with multiple streams. The case is meant to model the exhaust from an engine (with a hot core and cooler outer flow modeled as a “top hat” temperature profile) entering an s-shaped converging/diverging nozzle. Two additional streams are injected downstream of the throat to provide additional cooling of the exhaust.

The grid consists of thirteen patched zones with a total of 15897 points in one plane. The memory requirement for this example is 3.2 million words. A typical timing for this case is 1550 CPU seconds on a CRAY YMP (NASA LaRC’s Sabre as of October 1996). A cross-section of the grid is shown in Figure 9-16.

![Mach Contours](image)

**Figure 9-16.** Cross-section of multistream nozzle zonal patching and Mach contours.

Boundary conditions with user-defined input, including constant data supplied via the main input deck and variable (point-to-point) data supplied via an auxiliary boundary condition data file are exemplified. Control surfaces are used to monitor mass-flow convergence (here, two control surfaces are used to measure the “difference” between mass in...
and mass out). In addition, the case illustrates how one can define reference conditions for CFL3D in the case of a purely internal flow, as discussed below.

### 9.1.7.1 Nondimensionalization

The conditions provided for this case are that the total pressure of the primary inflow is 50 psi, with a total temperature of 1960°R in the core and 760°R in the outer region. The flow enters the s-duct with zero angle. The secondary cooling flows also have a total pressure of 50 psi and a uniform total temperature of 760°R. The cooling flow enters at –9 degrees relative to horizontal. The exhaust from the nozzle system is supersonic. The throat height is 1 foot. The primary inflow height is 1.449 feet; the core flow region (i.e. where the total temperature is 1960°R) spans the central 0.769 feet.

Although inflow stagnation conditions would be a natural reference state for this problem, the associated Mach number is zero. Since the viscous terms are scaled with the reference Mach number, another reference state is needed. A second natural reference state for nozzle flows is the sonic point. From isentropic relations, the sonic conditions can be obtained once the inflow total conditions are known. However, for this problem there are two total conditions owing to the “top hat” temperature profile. Thus, to have just one reference state, the total temperature of the inflow is area-averaged and the resulting average total temperature, together with the given total pressure, is used to determine the sonic conditions at the throat.

In what follows, stagnation conditions are denoted by 0, sonic conditions by *, and dimensional quantities by ~. First, determine the average inflow total temperature:

\[
\tilde{T}_0 = \frac{0.769}{1.449(1960)} + \frac{(1.449 - 0.769)}{1.449(760)} = 1397°R
\]

Next, determine the stagnation density and speed of sound:

\[
\tilde{\rho}_0 = \frac{\tilde{p}_0}{\tilde{R}\tilde{T}_0} = \frac{50(144)}{1716(1397)} = 0.00300 \text{ slugs/feet}^3
\]

\[
\tilde{a}_0 = \sqrt{\gamma\tilde{R}\tilde{T}_0} = \sqrt{1.4(1716)(1397)} = 1832 \text{ feet/second}
\]

where \( \tilde{R} = 1716 \text{ feet}^2/(\text{second}^2\cdot°R) \). From the isentropic relations,

\[
\frac{p}{p_0} = 0.528, \quad \frac{T}{T_0} = 0.833, \quad \frac{\tilde{\rho}}{\tilde{\rho}_0} = 0.634, \quad \frac{a}{a_0} = 0.913
\]

Thus, the desired reference pressure, temperature, speed of sound and density are
\[ \tilde{p} = 50(0.528) = 26.4 \text{ psi} \]
\[ \tilde{T} = 1397(0.833) = 1164^\circ R \]  
\[ \tilde{\rho} = 0.003(0.634) = 0.0019 \text{ slug/feet}^3 \]
\[ \tilde{a} = 1832(0.913) = 1673 \text{ feet/second} \]  

Assuming a molecular viscosity coefficient of $3.7 \times 10^{-7}$ slugs/(feet-seconds) for a temperature of $520^\circ R$, then the power law \[ \mu_2 / \mu_1 = (T_2 / T_1)^{0.76} \] gives

\[ \tilde{\mu}^* = 3.7 \times 10^{-7} \left( \frac{1164}{520} \right)^{0.76} = 6.82 \times 10^{-7} \text{ slugs/(feet-seconds)} \]  

The reference Reynolds number based on throat height and the reference sonic values is

\[ \text{Re}^* = \frac{\tilde{\rho}^* \tilde{u}^* \text{(throat height)}}{\tilde{\mu}^*} = 0.0019(1673) \frac{1}{6.82 \times 10^{-7}} = 4.66 \times 10^6 \]  

In the grid, the throat height is 12 inches, so the input parameter \text{reue} is

\[ \text{reue} = \frac{\text{Re}^* \times 10^{-6}}{12} = \frac{4.66}{12} = 0.388 \]  

Finally, the nondimensional input values for boundary condition type 2003 are determined from the reference sonic conditions (note that in CFL3D parlance, in this problem the * conditions are the “infinity” conditions):

\[ p_t = 50 \text{ psi} \rightarrow \frac{p_t}{p^*} = \frac{p_t}{p_\infty} = \frac{50}{26.4} = 1.894 \]
\[ T_t = 760^\circ R \rightarrow \frac{T_t}{T^*} = \frac{T_t}{T_\infty} = \frac{760}{1164} = 0.653 \]  

\[ T_t = 1960^\circ R \rightarrow \frac{T_t}{T^*} = \frac{T_t}{T_\infty} = \frac{1960}{1164} = 1.684 \]  

Boundary condition type 2003 also needs an estimate of the local Mach number. For the primary inflow, the inlet height (area) to throat height (area) is 1.449/1. The isentropic relations give a corresponding Mach number of approximately 0.45. The local Mach number for the cooling inflow cannot be determined a priori; 1.0 is used in the boundary condition. The computations give the cooling inflow Mach number as approximately 0.85; 1.0 is deemed as a sufficiently close estimate since the solution does not change perceptibly if 0.85 is used instead of 1.0.
The auxiliary boundary condition data file provided for this example (inflow.data) contains the data for the primary inflow:

\[
M = 0.45 \\
\frac{\rho_t}{\rho_\infty} = 1.894 \\
\frac{T_t}{T_\infty} = 0.653
\] (9-10)

in top hat distribution, \(\alpha = 0, \beta = 0\). The cooling inflow:

\[
M = 1.0 \\
\frac{\rho_t}{\rho_\infty} = 1.894 \\
\frac{T_t}{T_\infty} = 0.653 \\
\alpha = -9 \\
\beta = 0
\] (9-11)

is specified explicitly in the main data file.

9.1.7.2 Running CFL3D

Besides the CFL3D and ronnie codes the following files are needed to run this test case:

<table>
<thead>
<tr>
<th>File</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>multistream.inp</td>
<td>input for CFL3D</td>
</tr>
<tr>
<td>grid_multistream.fmt</td>
<td>formatted grid</td>
</tr>
<tr>
<td>formtobin.f</td>
<td>grid converter</td>
</tr>
<tr>
<td>inflow.data</td>
<td>auxiliary boundary condition data</td>
</tr>
<tr>
<td>ron1.h</td>
<td>parameters for ronnie makefile</td>
</tr>
<tr>
<td>ronnie.inp</td>
<td>input for ronnie</td>
</tr>
</tbody>
</table>

The steps for running this case on the YMP are as follows:

**Step 1**

Compile the grid converter code:

```plaintext
cft77 formtobin.f
```
**Step 2**

Link the grid converter object file:

```
segldr -o formtobin formtobin.o
```

**Step 3**

Run the grid generator program (the binary file `grid_multistream.bin` will be output):

```
formtobin
```

**Step 4**

Use the makefile to compile, link, and create the executable for the ronnie code (be sure `ron1.h` is in the current directory):

```
make -f makeronnie_cray
```

**Step 5**

Run the ronnie code (the file `patch_multistream.bin` will be output):

```
ronnie < ronnie.inp
```

**Step 6**

Use the makefile to compile, link, and create the executable for the precfl3d code (be sure `precfl.h` is in the current directory):

```
make -f makeprecfl3d_cray
```

**Step 7**

Run the precfl3d code (the `cflx.h` files will be output):

```
precfl3d < multistream.inp
```

**Step 8**

Use the makefile to compile, link, and create the executable for the CFL3D code:

```
make -f makecfl3d_cray
```

**Step 9**

Run the CFL3D code (be sure the `inflow.data` file is available and correct for this case):

```
cfl3d < multistream.inp
```

The input file for this case is:

I/O FILES
grid_multistream.p3d
plot3dg.bin
### Multistream Nozzle

Multistream Nozzle (sonic conditions as reference state)

<table>
<thead>
<tr>
<th>XMACH</th>
<th>ALPHA</th>
<th>BETA</th>
<th>REUE,MIL</th>
<th>TINF,DR</th>
<th>IALPH</th>
<th>IHIST</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.000</td>
<td>0.00</td>
<td>0.0</td>
<td>0.388</td>
<td>1163.0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SREF</th>
<th>CREF</th>
<th>BREF</th>
<th>XMIL</th>
<th>YMIL</th>
<th>ZMIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.000</td>
<td>1.000</td>
<td>0.2500</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DT</th>
<th>IREST</th>
<th>IFLAGTS</th>
<th>FMAX</th>
<th>IUNST</th>
<th>CFL_TAU</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1.0000</td>
<td>0</td>
<td>000</td>
<td>1.0</td>
<td>+1</td>
<td>5.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NGRID</th>
<th>NPLOT3D</th>
<th>NPRINT</th>
<th>NWREST</th>
<th>ICHK</th>
<th>I2D</th>
<th>NTSTEP</th>
<th>ITA</th>
</tr>
</thead>
<tbody>
<tr>
<td>-13</td>
<td>13</td>
<td>0</td>
<td>500</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>-2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NCG</th>
<th>IEM</th>
<th>IADVANCE</th>
<th>IFORCE</th>
<th>IVISC(I)</th>
<th>IVISC(J)</th>
<th>IVISC(K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>000</td>
<td>0</td>
<td>0</td>
<td>+7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IDIM</th>
<th>JDIM</th>
<th>KDIM</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>23</td>
<td>41</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ILAMLO</th>
<th>ILAMHI</th>
<th>JLAMLO</th>
<th>JLAMHI</th>
<th>KLAMLO</th>
<th>KLAMHI</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>00</td>
<td>000</td>
<td>000</td>
<td>0</td>
<td>0000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INENG</th>
<th>IGRIDC</th>
<th>IS</th>
<th>JS</th>
<th>KS</th>
<th>IE</th>
<th>JE</th>
<th>KE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

---

The above table provides the initial conditions and parameters for the multistream nozzle simulation, including Mach number, angles, and various flow conditions and settings for the simulation run.
<table>
<thead>
<tr>
<th>IDIAG(I)</th>
<th>IDIAG(J)</th>
<th>IDIAG(K)</th>
<th>IFLIM(I)</th>
<th>IFLIM(J)</th>
<th>IFLIM(K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IFDS(I)</th>
<th>IFDS(J)</th>
<th>IFDS(K)</th>
<th>RKAP0(I)</th>
<th>RKAP0(J)</th>
<th>RKAP0(K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
<td>.3333</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GRID</th>
<th>NBCIO</th>
<th>NBCIDIM</th>
<th>NBCJO</th>
<th>NBCJDIM</th>
<th>NBCKO</th>
<th>NBCKDIM</th>
<th>IOVRLP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IO: GRID</th>
<th>SEGMENT</th>
<th>BCTYPE</th>
<th>JSTA</th>
<th>JEND</th>
<th>KSTA</th>
<th>KEND</th>
<th>NDATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IDIM: GRID</th>
<th>SEGMENT</th>
<th>BCTYPE</th>
<th>JSTA</th>
<th>JEND</th>
<th>KSTA</th>
<th>KEND</th>
<th>NDATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>J0: GRID SEGMENT BCTYPE ISTA IEND KSTA KEND NDATA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 1 2003 0 0 0 0 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mach Pt/Pinf Tt/Tinf alpha beta</th>
</tr>
</thead>
<tbody>
<tr>
<td>inflow.data</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mach Pt/Pinf Tt/Tinf alpha beta</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00 1.894 0.653 -9.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>JDIM: GRID SEGMENT BCTYPE ISTA IEND KSTA KEND NDATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1 0 0 0 0 0 0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tw Cq</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.</td>
</tr>
<tr>
<td>2.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tw Cq</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.</td>
</tr>
<tr>
<td>0.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tw Cq</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.</td>
</tr>
<tr>
<td>0.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tw Cq</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.</td>
</tr>
<tr>
<td>0.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tw Cq</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.</td>
</tr>
<tr>
<td>0.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tw Cq</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.</td>
</tr>
<tr>
<td>0.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tw Cq</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.</td>
</tr>
<tr>
<td>0.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tw Cq</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.</td>
</tr>
<tr>
<td>0.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tw Cq</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.</td>
</tr>
<tr>
<td>0.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tw Cq</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.</td>
</tr>
<tr>
<td>0.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tw Cq</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.</td>
</tr>
<tr>
<td>0.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tw Cq</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.</td>
</tr>
<tr>
<td>0.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tw Cq</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.</td>
</tr>
<tr>
<td>0.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tw Cq</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.</td>
</tr>
<tr>
<td>0.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tw Cq</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.</td>
</tr>
<tr>
<td>0.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tw Cq</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.</td>
</tr>
<tr>
<td>0.</td>
</tr>
</tbody>
</table>
```
CHAPTER 9  Test Cases

KDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND    NDATA
 1       Tw     Cq    2004         0         0         0         0        2
   2      Cq   0.     0.         0         0         0         0        2
   3      Cq   0.     0.         0         0         0         0        2
   4      Cq   0.     0.         0         0         0         0        2
   5      Cq   0.     0.         0         0         0         0        2
   6      Cq   0.     0.         0         0         0         0        2
   7      Cq   0.     0.         0         0         0         0        2
   8      Cq   0.     0.         0         0         0         0        2
   9      Cq   0.     0.         0         0         0         0        2
  10      Cq   0.     0.         0         0         0         0        2
  11      Cq   0.     0.         0         0         0         0        2
  12      Cq   0.     0.         0         0         0         0        2
  13      Cq   0.     0.         0         0         0         0        2

MSEQ    MGFLAG    ICONSF       MTT      NGAM
 1       1         1         0        02
  2

ISSC  EPSSC(1)  EPSSC(2)  EPSSC(3)      ISSR  EPSSR(1)  EPSSR(2)  EPSSR(3)
 0        .3        .3        .3         0        .3        .3        .3

NCYC    MGLEVG     NEMGL     NITFO
 3000        02        00         0

MIT1      MIT2      MIT3      MIT4      MIT5
 01        01        01        01        01

1-1 BLOCKING DATA:
NBLI
 0

NUMBER   GRID   : ISTA   JSTA   KSTA   IEND   JEND   KEND ISVA1 ISVA2
 0

NUMBER   GRID   : ISTA   JSTA   KSTA   IEND   JEND   KEND ISVA1 ISVA2
 0

PATCH SURFACE DATA:
NINTER
 1

PLOT3D OUTPUT:
grid iiptyp  ista  iend  iinc  jsta  jend  jinc  ksta  kend  kinc
 0        0        0        0        0        0        0        0        0        0
 1        0        0        0        0        0        0        0        0        0
 2        0        0        0        0        0        0        0        0        0
 3        0        0        0        0        0        0        0        0        0
 4        0        0        0        0        0        0        0        0        0
 5        0        0        0        0        0        0        0        0        0
 6        0        0        0        0        0        0        0        0        0
 7        0        0        0        0        0        0        0        0        0
 8        0        0        0        0        0        0        0        0        0
 9        0        0        0        0        0        0        0        0        0
10        0        0        0        0        0        0        0        0        0
11        0        0        0        0        0        0        0        0        0
12        0        0        0        0        0        0        0        0        0
13        0        0        0        0        0        0        0        0        0

MOVIE
 0

PRINT OUT:
GRID IPTYPE ISTART  IEND  IINC  JSTART  JEND  JINC  KSTART  KEND  KINC
CONTROL SURFACES:
```
The *inflow.data* file is:

```
auxiliary bc data, j-face of block 1, multistream nozzle
40,  2*1
5
40*0.4499999999999993, 40*1.893999999999998, 16*0.653000000000001, 8*1.685000000000004, 16*0.653000000000001, 40*0., 40*0.
```

After running this test case, the residual history and mass flow convergence history shown in Figure 9-17 results. Also, a plot of Mach contours should have the flow features of those plotted in Figure 9-16.

![2D Multistream Nozzle](image)

**Figure 9-17.** Multistream nozzle case residual and mass flow convergence history.
9.1.8 Rotor Stator

This case simulates, in two dimensions, the unsteady flow through a single stage turbine in which the ratio of stator to rotor blades is 3:4. The axial gap between the two blades is 50% of the blade chord. The case exercises a number of capabilities of CFL3D including unsteady flow, moving (translating) zones, dynamic patching between zones in relative motion, grid overlapping, and boundary conditions with user-defined input.

The original grid for this case was provided by D. J. Dorney\textsuperscript{17} of Western Michigan University, although the grid given out for the test case contains only half the number of points of the original grid. The grid consists of fourteen zones with a total of 18374 points in one plane. A close-up of the grid near the airfoil is shown in Figure 9-18. The grid zones communicate with one another through both patching and overlapping. At a time step of 1.0, it takes 270 time steps for the eight rotor zones (containing four blades) to completely traverse the six stator zones (containing three blades). The rotor zones are reset after each complete traverse. The input file is set for 1500 time steps (using five multigrid sub-iterations per time step), which is sufficient to establish a time-periodic solution. The memory requirement for this example is 4.0 million words. A typical timing for this case (1500 time steps) is 4205 CPU seconds on a Cray YMP (NASA LaRC’s Sabre as of October 1996). On a DEC Alpha workstation, the timing is 18303 CPU seconds, using single precision (as of June 1996).

![2D Large Scale Rotating Rig](image)

**Figure 9-18.** Fourteen zone rotor-stator grid system and Mach contours.
9.1.8 Rotor Stator

9.1.8.1 Experimental Conditions

The experimental blade count was 22 stator blades and 28 rotor blades. In order to run an exact simulation, a minimum of 11 stator blades and 14 rotor blades would be required (Dring et.al\textsuperscript{18}). To reduce the problem size in the computation, the ratio of stator to rotor blades was reduced to 3:4 (equivalent to 21:28), and the stators were scaled by a factor of 22/21 to maintain the same pitch-to-chord ratio as in the experiment. The experimental set-up was a three-dimensional configuration; the corresponding 2-d simulation was set up from conditions at the mid-span radius of 27 inches, for a rotor speed of 410 rpm, with a nominal axial velocity of 75 feet/second. The inlet Mach number in the experiment was approximately 0.07, and the Reynolds number/inch was approximately 100,000.

9.1.8.2 Input Setup

Inlet conditions are used as the reference conditions, so $\text{xmach} = 0.07$. The grid is full scale, with dimensions in inches. Therefore, $\text{reue} = 0.1$. The inlet temperature was assumed to be $60^\circ F$, so $\text{tinf} = 520^\circ R$.

Boundary condition type 2003 is used to specify total pressure and total temperature at the inlet. From isentropic flow relations or tables, for an inlet flow Mach number of 0.07,

$$
M_{inlet} = 0.07
$$

$$
\frac{p_{t,\text{inlet}}}{p_\infty} = 1.0035 \quad \text{(9-12)}
$$

$$
\frac{T_{t,\text{inlet}}}{T_\infty} = 1.0010
$$

Also, $\alpha e = \beta e = 0$ (purely axial flow is assumed).

Boundary condition type 2002 is used to specify an exit pressure. Dorney gives a ratio of static pressure to inlet total pressure $= 0.963$ at the rotor trailing edge plane. Assuming this value to hold at the exit as well gives

$$
\frac{p_{exit}}{p_\infty} = \frac{p_{exit}}{p_{t,\text{inlet}}} \cdot \frac{p_{t,\text{inlet}}}{p_\infty} = 0.963 \times 1.0035 = 0.967 \quad \text{(9-13)}
$$

Note that the inflow Mach number used in boundary condition type 2003 is an estimate; if the exit pressure were not set correctly, the computed inflow Mach number would not be close to the specified inflow value (when a time-periodic state is reached or at convergence in steady state). By specifying control surfaces at the inflow plane, the user is able to verify after the computation is complete that the average inflow Mach number is approximately 0.071; this was deemed to be close enough to the desired value. If desired,
the exit pressure could be adjusted (raised in this case) and the solution re-run until a new
time-periodic solution (and a new inlet Mach number) is established.

It should be noted that the input grid is in PLOT3D format, with $y$ as the “up” direc-
tion ($i_{\text{alph}} = 1$; $z$ is the spanwise, 2-d direction). However, the grid motion parameters
must be set as if $z$ is the up direction. Recall that if the input grid has $y$ as the up direction,
CFL3D will internally swap $y$ and $z$ so that the code always computes on a grid in which
$z$ is up. (See the caution in “LT35 - Translational Information and Velocities” on page 44.)

Given the rotor speed and mid-span radius, the translational velocity for a 2-d simula-
tion corresponding to the mid-span radius is

$$\tilde{w}_{\text{trans}} = \omega r = (410/60 \times 2\pi)(27/12) = 96.6 \text{ feet/second} \quad (9-14)$$

This gives

$$\frac{\tilde{u}_{\text{axial}}}{\tilde{w}_{\text{trans}}} = \frac{75}{96.6} = 0.78 \quad (9-15)$$

The input value $w_{\text{trans}}$ is $\tilde{w}_{\text{trans}}/\tilde{a}_\infty$, so with the reference Mach number 0.07, $w_{\text{trans}} = 0.07/0.78 = (-) 0.0897$ (the negative gives a downward rotor motion).

In order to be able to run an arbitrarily long simulation, the grid resetting option was
employed. The top-to-bottom length of the grid is 24.23514 inches and the rotor and stator
zones start out in alignment, so $dz_{\text{max}} = 24.23514$. Thus the rotor zones are reset whenever the displacement exceeds 24.23514 inches.

9.1.8.3 Running CFL3D

Besides the CFL3D code, the following files are needed to run this test case:

<table>
<thead>
<tr>
<th>File</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>lsrr.inp</td>
<td>input for CFL3D</td>
</tr>
<tr>
<td>lsrr_coarse.p3d_fmt</td>
<td>formatted single plane grid</td>
</tr>
<tr>
<td>fmttobin_p3d.f</td>
<td>converter for creating 2 grid planes</td>
</tr>
<tr>
<td>mag1.h</td>
<td>parameters for MaGGiE makefile</td>
</tr>
<tr>
<td>maggie.inp</td>
<td>input for MaGGiE</td>
</tr>
</tbody>
</table>

The steps for running this case on the DEC are as follows:
Step 1
Compile the grid converter code:
   cft77 fmttobin_p3d.f

Step 2
Link the grid converter object file:
   segldr -o fmttobin_p3d fmttobin_p3d.o

Step 3
Run the grid converter program (the binary file lsrr_coarse.p3d will be output):
   fmttobin_p3d

Step 4
Use the makefile to compile, link, and create the executable for the MaGGiE code (be sure mag1.h is in the current directory):
   make -f makemaggie_cray

Step 5
Run the MaGGiE code (the file ovrlp.bin will be output):
   maggie < maggie.inp

Step 6
Use the makefile to compile, link, and create the executable for the precfl3d code (be sure precfl.h is in the current directory):
   make -f makeprecfl3d_cray

Step 7
Run the precfl3d code (the cflx.h files will be output):
   precfl3d < lsrr.inp

Step 8
Use the makefile to compile, link, and create the executable for the CFL3D code:
   make -f makecfl3d_cray

Step 9
Run the CFL3D code:
cfl3d < lsrr.inp

The input file for this case is:

I/O FILES
lsrr_coarse.p3d
plot3dg.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.turess
cfl3d.blomax
cfl3d.out15
cfl3d.prout
cfl3d.out20
ovrlp.bin
patch.bin
restart.bin

2D model of Pratt & Whitney Large Scale Rotating Rig (LSRR) - 50% Axial Gap

<table>
<thead>
<tr>
<th>XMACH</th>
<th>ALPHA</th>
<th>BETA</th>
<th>REUE,MIL</th>
<th>TINF,DR</th>
<th>IALPH</th>
<th>IHSTRY</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.070</td>
<td>0.000</td>
<td>0.0</td>
<td>0.1</td>
<td>520.0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SREF</th>
<th>CREF</th>
<th>BREF</th>
<th>XMC</th>
<th>YMC</th>
<th>ZMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.000000</td>
<td>1.000000</td>
<td>1.000000</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DT</th>
<th>IREST</th>
<th>IFLAGTS</th>
<th>FMAX</th>
<th>IUNST</th>
<th>CFL_TAU</th>
</tr>
</thead>
<tbody>
<tr>
<td>+1.0000</td>
<td>0</td>
<td>0</td>
<td>1.00</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NGRID</th>
<th>NPLOT3D</th>
<th>NPRINT</th>
<th>NWREST</th>
<th>ICHK</th>
<th>I2D</th>
<th>NTSTEP</th>
<th>ITA</th>
</tr>
</thead>
<tbody>
<tr>
<td>-14</td>
<td>14</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>1</td>
<td>1500</td>
<td>-2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NCG</th>
<th>IEM</th>
<th>IADVANCE</th>
<th>IFORCE</th>
<th>IVISC(I)</th>
<th>IVISC(J)</th>
<th>IVISC(K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IDIM</th>
<th>JDIM</th>
<th>KDIM</th>
</tr>
</thead>
<tbody>
<tr>
<td>002</td>
<td>55</td>
<td>23</td>
</tr>
<tr>
<td>002</td>
<td>61</td>
<td>21</td>
</tr>
<tr>
<td>002</td>
<td>55</td>
<td>23</td>
</tr>
<tr>
<td>002</td>
<td>55</td>
<td>23</td>
</tr>
<tr>
<td>002</td>
<td>55</td>
<td>23</td>
</tr>
<tr>
<td>002</td>
<td>61</td>
<td>21</td>
</tr>
<tr>
<td>002</td>
<td>61</td>
<td>23</td>
</tr>
<tr>
<td>002</td>
<td>61</td>
<td>23</td>
</tr>
<tr>
<td>002</td>
<td>61</td>
<td>21</td>
</tr>
<tr>
<td>002</td>
<td>61</td>
<td>23</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ILAMLO</th>
<th>ILAMHI</th>
<th>JLAMLO</th>
<th>JLAMHI</th>
<th>KLAMLO</th>
<th>KLAMHI</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>00</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>00</td>
<td>00</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>00</td>
<td>00</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>00</td>
<td>00</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>00</td>
<td>00</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>00</td>
<td>00</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>00</td>
<td>00</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>00</td>
<td>00</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>00</td>
<td>00</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>00</td>
<td>00</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>00</td>
<td>00</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
<td>0000</td>
</tr>
</tbody>
</table>
9.1.8 Rotor Stator

<table>
<thead>
<tr>
<th>I (NEWG)</th>
<th>IGRIDC</th>
<th>IS</th>
<th>JS</th>
<th>KS</th>
<th>IE</th>
<th>JE</th>
<th>KE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INEWG</th>
<th>IGRIDC</th>
<th>IS</th>
<th>JS</th>
<th>KS</th>
<th>IE</th>
<th>JE</th>
<th>KE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IDIAG(I)</th>
<th>IDIAG(J)</th>
<th>IDIAG(K)</th>
<th>IFLIM(I)</th>
<th>IFLIM(J)</th>
<th>IFLIM(K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IFDS(I)</th>
<th>IFDS(J)</th>
<th>IFDS(K)</th>
<th>RKAP0(I)</th>
<th>RKAP0(J)</th>
<th>RKAP0(K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3.333</td>
<td>3.333</td>
<td>3.333</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3.333</td>
<td>3.333</td>
<td>3.333</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3.333</td>
<td>3.333</td>
<td>3.333</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3.333</td>
<td>3.333</td>
<td>3.333</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3.333</td>
<td>3.333</td>
<td>3.333</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3.333</td>
<td>3.333</td>
<td>3.333</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3.333</td>
<td>3.333</td>
<td>3.333</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3.333</td>
<td>3.333</td>
<td>3.333</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3.333</td>
<td>3.333</td>
<td>3.333</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3.333</td>
<td>3.333</td>
<td>3.333</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GRID</th>
<th>NBCI0</th>
<th>NBCIDIM</th>
<th>NBCJ0</th>
<th>NBCJDIM</th>
<th>NBCK0</th>
<th>NBCKDIM</th>
<th>IOVRLP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>I0:</th>
<th>GRID</th>
<th>SEGMENT</th>
<th>BCTYPE</th>
<th>JSTA</th>
<th>JEND</th>
<th>KSTA</th>
<th>KEND</th>
<th>NDATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>1002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
CHAPTER 9  Test Cases

```
10  1  1002  0  0  0  0  0  0
11  1  1002  0  0  0  0  0  0
12  1  1002  0  0  0  0  0  0
13  1  1002  0  0  0  0  0  0
14  1  1002  0  0  0  0  0  0

IDIM: GRID  SEGMENT  BCTYPE  JSTA  JEND  KSTA  KEND  NDATA
1  1  1002  0  0  0  0  0  0
2  1  1002  0  0  0  0  0  0
3  1  1002  0  0  0  0  0  0
4  1  1002  0  0  0  0  0  0
5  1  1002  0  0  0  0  0  0
6  1  1002  0  0  0  0  0  0
7  1  1002  0  0  0  0  0  0
8  1  1002  0  0  0  0  0  0
9  1  1002  0  0  0  0  0  0
10 1  1002  0  0  0  0  0  0
11 1  1002  0  0  0  0  0  0
12 1  1002  0  0  0  0  0  0
13 1  1002  0  0  0  0  0  0
14 1  1002  0  0  0  0  0  0

J0: GRID  SEGMENT  BCTYPE  ISTA  IEND  KSTA  KEND  NDATA
1  1  2003  0  0  0  0  5
Mach  Pt/Pinf  Tt/Tinf  alpha  beta
0.07  1.0035  1.0010  0.  0.
2  1  0  0  0  0  0  0
3  1  2003  0  0  0  0  5
Mach  Pt/Pinf  Tt/Tinf  alpha  beta
0.07  1.0035  1.0010  0.  0.
4  1  0  0  0  0  0  0
5  1  2003  0  0  0  0  5
Mach  Pt/Pinf  Tt/Tinf  alpha  beta
0.07  1.0035  1.0010  0.  0.
6  1  0  0  0  0  0  0
7  1  0  0  0  0  0  0
8  1  0  0  0  0  0  0
9  1  0  0  0  0  0  0
10 1  0  0  0  0  0  0
11 1  0  0  0  0  0  0
12 1  0  0  0  0  0  0
13 1  0  0  0  0  0  0
14 1  0  0  0  0  0  0

JDIM: GRID  SEGMENT  BCTYPE  ISTA  IEND  KSTA  KEND  NDATA
1  1  0  0  0  0  0  0
2  1  0  0  0  0  0  0
3  1  0  0  0  0  0  0
4  1  0  0  0  0  0  0
5  1  0  0  0  0  0  0
6  1  0  0  0  0  0  0
7  1  2002  0  0  0  0  1
peexit/pinf  0.967
8  1  0  0  0  0  0  0
9  1  2002  0  0  0  0  1
peexit/pinf  0.967
10  1  0  0  0  0  0  0
11  1  2002  0  0  0  0  1
peexit/pinf  0.967
12  1  0  0  0  0  0  0
13  1  2002  0  0  0  0  1
peexit/pinf  0.967
14  1  0  0  0  0  0  0

K0: GRID  SEGMENT  BCTYPE  ISTA  IEND  JSTA  JEND  NDATA
1  1  0  0  0  0  0  0
2  1  2004  0  0  0  0  2
Tw/Tinf  C_q
0.
3  1  0  0  0  0  0  0
4  1  2004  0  0  0  0  2
Tw/Tinf  C_q
```
0.        0.
5  1  0  0  0  0  0  0  0  0
6  1  2004  0  0  0  0  2  2

Tw/Tinf  C_q
0.        0.
7  1  0  0  0  0  0  0  0  0
8  1  2004  0  0  0  0  2  2

Tw/Tinf  C_q
0.        0.
9  1  0  0  0  0  0  0  0  0
10  1  2004  0  0  0  0  2  2

Tw/Tinf  C_q
0.        0.
11  1  0  0  0  0  0  0  0  0
12  1  2004  0  0  0  0  2  2

Tw/Tinf  C_q
0.        0.
13  1  0  0  0  0  0  0  0  0
14  1  2004  0  0  0  0  2  2

KDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND    NDATA
1         1         0         0         0         0         0        0
2         1         0         0         0         0         0        0
3         1         0         0         0         0         0        0
4         1         0         0         0         0         0        0
5         1         0         0         0         0         0        0
6         1         0         0         0         0         0        0
7         1         0         0         0         0         0        0
8         1         0         0         0         0         0        0
9         1         0         0         0         0         0        0
10        1         0         0         0         0         0        0
11        1         0         0         0         0         0        0
12        1         0         0         0         0         0        0
13        1         0         0         0         0         0        0
14        1         0         0         0         0         0        0

MSEQ    MGFLAG    ICONSF       MTT      NGAM
1         1         1         0        01

ISSC  EPSSC(1)  EPSSC(2)  EPSSC(3)      ISSR  EPSSR(1)  EPSSR(2)  EPSSR(3)
0        .3        .3        .3         0        .3        .3        .3

NCYC    MGLEVG     NEMGL     NITFO
5        02        00       000

MIT1      MIT2      MIT3      MIT4      MIT5
01        01        01        01        01

1-1 BLOCKING DATA:
NBL1    14

NUMBER   GRID   :   ISTA   JSTA   KSTA   IEND   JEND   KEND   ISVA1   ISVA2
1        2        1        1        1        1        1        1        1        3
2        4        1        1        1        2        1        21       1        3
3        6        1        1        1        2        1        21       1        3
4        8        1        1        1        2        1        21       1        3
5        10       1        1        1        2        1        21       1        3
6        12       1        1        1        2        1        21       1        3
7        14       1        1        1        2        1        21       1        3
8        1        1        1        2        55       1        1        2
9        7        1        1        1        2        61       1        1        2
10       1        1        1        24       2        55       23       1        2
11       3        1        1        24       2        55       23       1        2
12       7        1        1        24       2        61       23       1        2
13       9        1        1        24       2        61       23       1        2
14       11       1        1        24       2        61       23       1        2

NUMBER   GRID   :   ISTA   JSTA   KSTA   IEND   JEND   KEND   ISVA1   ISVA2
1        2        1        61       1        2        61       21       1        3
2        4        1        61       1        2        61       21       1        3
3        6        1        61       1        2        61       21       1        3
4        8        1        61       1        2        61       21       1        3
5        10       1        61       1        2        61       21       1        3
6        12       1        61       1        2        61       21       1        3
7        14       1        61       1        2        61       21       1        3
8        1        1        24       2        55       23       1        2
9        13       1        1        24       2        61       23       1        2
CHAPTER 9 Test Cases

10 3 1 1 1 2 55 1 1 2
11 5 1 1 1 2 55 1 1 2
12 9 1 1 1 2 61 1 1 2
13 11 1 1 1 2 61 1 1 2
14 13 1 1 1 2 61 1 1 2

PATCH SURFACE DATA:
NINTER

PLOT3D OUTPUT:
BLOCK IPTYPE ISTART IEND IINC JSTART JEND JINC KSTART KEND KINC
1 0 1 001 1 01 999 1 1 999 1
2 0 1 001 1 01 999 1 1 999 1
3 0 1 001 1 01 999 1 1 999 1
4 0 1 001 1 01 999 1 1 999 1
5 0 1 001 1 01 999 1 1 999 1
6 0 1 001 1 01 999 1 1 999 1
7 0 1 001 1 01 999 1 1 999 1
8 0 1 001 1 01 999 1 1 999 1
9 0 1 001 1 01 999 1 1 999 1
10 0 1 001 1 01 999 1 1 999 1
11 0 1 001 1 01 999 1 1 999 1
12 0 1 001 1 01 999 1 1 999 1
13 0 1 001 1 01 999 1 1 999 1
14 0 1 001 1 01 999 1 1 999 1

MOVIE
0

PRINT OUT:
BLOCK IPTYPE ISTART IEND IINC JSTART JEND JINC KSTART KEND KINC

CONTROL SURFACES:
NCS
7
GRID ISTA IEND JSTA JEND KSTA KEND IWALL INORM
7 1 2 999 999 0 0 0 1
9 1 2 999 999 0 0 0 1
11 1 2 999 999 0 0 0 1
13 1 2 999 999 0 0 0 1
1 1 2 1 1 0 0 0 0
3 1 2 1 1 0 0 0 0
5 1 2 1 1 0 0 0 0

MOVING GRID DATA - TRANSLATION
NTRANS
9
LREF
1.0
GRID ITRANS RFREQ UTRANS VTRANS WTRANS
7 1 0. 0. 0. 0. -0.0897
8 1 0. 0. 0. 0. -0.0897
9 1 0. 0. 0. 0. -0.0897
10 1 0. 0. 0. 0. -0.0897
11 1 0. 0. 0. 0. -0.0897
12 1 0. 0. 0. 0. -0.0897
13 1 0. 0. 0. 0. -0.0897
14 1 0. 0. 0. 0. -0.0897
0 1 0. 0. 0. 0. -0.0897
GRID DXMAX DYMAY DZMAX
7 0. 0. -24.23514
8 0. 0. -24.23514
9 0. 0. -24.23514
10 0. 0. -24.23514
11 0. 0. -24.23514
12 0. 0. -24.23514
13 0. 0. -24.23514
14 0. 0. -24.23514
0 0. 0. -24.23514

MOVING GRID DATA - ROTATION
NROTAT
0
LREF
GRID IROTAT RFREQ OMEGAX OMEGAY OMEGAZ XORIG YORIG ZORIG
GRID THXMAX THYMAX THZMAX
DYNAMIC PATCH INPUT DATA
NINTER
9.1.8 Rotor Stator

INT IFIT LIMIT ITMAX MCXIE MCETA C-0 IORPH ITOS
1 1 1 30 0 0 0 0 1
2 1 1 30 0 0 0 0 1
3 1 1 30 0 0 0 0 1
4 1 1 30 0 0 0 0 1
5 1 1 30 0 0 0 0 1
6 1 1 30 0 0 0 0 1
7 1 1 30 0 0 0 0 1

INT TO XIE1 XIE2 ETA1 ETA2 NFB
1 122 0 0 0 0 6

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
721 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
921 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
1121 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
1321 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
721 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
921 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
1121 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
1321 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
721 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
921 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
1121 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
1321 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

INT TO XIE1 XIE2 ETA1 ETA2 NFB
2 322 0 0 0 0 6

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
921 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
1121 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
1321 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
721 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
921 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
721 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
921 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
1121 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
1321 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

INT TO XIE1 XIE2 ETA1 ETA2 NFB
3 522 0 0 0 0 6

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
1121 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
1321 0 0 0 0 0 0.

DX DY D2 DTHETX DTHETY DTHETZ
0. 0. 0. 0. 0. 0.

FROM XIE1 XIE2 ETA1 ETA2 FACTJ FACTK
|    |    |    |    |    |    |    |    |
|----|----|----|----|----|----|----|
| 721 | 0  | 0  | 0  | 0  | 0  | 0.  | 0.  |
| DX  | DY | DZ | DTHETX | DTHETY | DTHETZ |
| 0.  | 0. | 24.23514 | 0.  | 0.  | 0.  |
| FROM | XIE1 | XIE2 | ETA1 | ETA2 | FACTJ | FACTK |
| 921 | 0  | 0  | 0  | 0  | 0  | 0.  | 0.  |
| DX  | DY | DZ | DTHETX | DTHETY | DTHETZ |
| 0.  | 0. | 24.23514 | 0.  | 0.  | 0.  |
| FROM | XIE1 | XIE2 | ETA1 | ETA2 | FACTJ | FACTK |
| 1121 | 0  | 0  | 0  | 0  | 0  | 0.  | 0.  |
| DX  | DY | DZ | DTHETX | DTHETY | DTHETZ |
| 0.  | 0. | 24.23514 | 0.  | 0.  | 0.  |
| FROM | XIE1 | XIE2 | ETA1 | ETA2 | FACTJ | FACTK |
| 1321 | 0  | 0  | 0  | 0  | 0  | 0.  | 0.  |
| DX  | DY | DZ | DTHETX | DTHETY | DTHETZ |
| 0.  | 0. | 24.23514 | 0.  | 0.  | 0.  |
| INT  TO | XIE1 | XIE2 | ETA1 | ETA2 | NFB |
| 4   | 721 | 0  | 0  | 0  | 0  | 0  | 4  |
| FROM | XIE1 | XIE2 | ETA1 | ETA2 | FACTJ | FACTK |
| 122 | 0  | 0  | 0  | 0  | 0  | 0.  | 0.  |
| DX  | DY | DZ | DTHETX | DTHETY | DTHETZ |
| 0.  | 0. | 0.  | 0.  | 0.  | 0.  |
| FROM | XIE1 | XIE2 | ETA1 | ETA2 | FACTJ | FACTK |
| 522 | 0  | 0  | 0  | 0  | 0  | 0.  | 0.  |
| DX  | DY | DZ | DTHETX | DTHETY | DTHETZ |
| 0.  | 0. | -24.23514 | 0.  | 0.  | 0.  |
| FROM | XIE1 | XIE2 | ETA1 | ETA2 | FACTJ | FACTK |
| 322 | 0  | 0  | 0  | 0  | 0  | 0.  | 0.  |
| DX  | DY | DZ | DTHETX | DTHETY | DTHETZ |
| 0.  | 0. | -24.23514 | 0.  | 0.  | 0.  |
| FROM | XIE1 | XIE2 | ETA1 | ETA2 | FACTJ | FACTK |
| 122 | 0  | 0  | 0  | 0  | 0  | 0.  | 0.  |
| DX  | DY | DZ | DTHETX | DTHETY | DTHETZ |
| 0.  | 0. | -24.23514 | 0.  | 0.  | 0.  |
| INT  TO | XIE1 | XIE2 | ETA1 | ETA2 | NFB |
| 5   | 921 | 0  | 0  | 0  | 0  | 0  | 5  |
| FROM | XIE1 | XIE2 | ETA1 | ETA2 | FACTJ | FACTK |
| 122 | 0  | 0  | 0  | 0  | 0  | 0.  | 0.  |
| DX  | DY | DZ | DTHETX | DTHETY | DTHETZ |
| 0.  | 0. | 0.  | 0.  | 0.  | 0.  |
| FROM | XIE1 | XIE2 | ETA1 | ETA2 | FACTJ | FACTK |
| 322 | 0  | 0  | 0  | 0  | 0  | 0.  | 0.  |
| DX  | DY | DZ | DTHETX | DTHETY | DTHETZ |
| 0.  | 0. | 0.  | 0.  | 0.  | 0.  |
| FROM | XIE1 | XIE2 | ETA1 | ETA2 | FACTJ | FACTK |
| 522 | 0  | 0  | 0  | 0  | 0  | 0.  | 0.  |
| DX  | DY | DZ | DTHETX | DTHETY | DTHETZ |
| 0.  | 0. | -24.23514 | 0.  | 0.  | 0.  |
| FROM | XIE1 | XIE2 | ETA1 | ETA2 | FACTJ | FACTK |
| 322 | 0  | 0  | 0  | 0  | 0  | 0.  | 0.  |
| DX  | DY | DZ | DTHETX | DTHETY | DTHETZ |
| 0.  | 0. | -24.23514 | 0.  | 0.  | 0.  |
| FROM | XIE1 | XIE2 | ETA1 | ETA2 | FACTJ | FACTK |
| 122 | 0  | 0  | 0  | 0  | 0  | 0.  | 0.  |
| DX  | DY | DZ | DTHETX | DTHETY | DTHETZ |
| 0.  | 0. | -24.23514 | 0.  | 0.  | 0.  |
| INT  TO | XIE1 | XIE2 | ETA1 | ETA2 | NFB |
| 6   | 1121 | 0  | 0  | 0  | 0  | 0  | 5  |
| FROM | XIE1 | XIE2 | ETA1 | ETA2 | FACTJ | FACTK |
| 322 | 0  | 0  | 0  | 0  | 0  | 0.  | 0.  |
| DX  | DY | DZ | DTHETX | DTHETY | DTHETZ |
| 0.  | 0. | 0.  | 0.  | 0.  | 0.  |
| FROM | XIE1 | XIE2 | ETA1 | ETA2 | FACTJ | FACTK |
| 522 | 0  | 0  | 0  | 0  | 0  | 0.  | 0.  |
| DX  | DY | DZ | DTHETX | DTHETY | DTHETZ |
| 0.  | 0. | 0.  | 0.  | 0.  | 0.  |
| FROM | XIE1 | XIE2 | ETA1 | ETA2 | FACTJ | FACTK |
| 122 | 0  | 0  | 0  | 0  | 0  | 0.  | 0.  |
| DX  | DY | DZ | DTHETX | DTHETY | DTHETZ |
| 0.  | 0. | 0.  | 0.  | 0.  | 0.  |
| FROM | XIE1 | XIE2 | ETA1 | ETA2 | FACTJ | FACTK |
| 522 | 0  | 0  | 0  | 0  | 0  | 0.  | 0.  |
| DX  | DY | DZ | DTHETX | DTHETY | DTHETZ |
The convergence histories for residual, mass flow, and rotor lift coefficient as shown in Figure 9-19 should be obtained.
9.2 Three-dimensional Test Cases

9.2.1 Axisymmetric Bump Flow

This test case solves for the turbulent flow over an axisymmetric bump. The flow is modeled in 3-d using two computational planes (separated by an angle of 1 degree), with periodic boundary conditions; hence \texttt{bctype} is 2005 and \texttt{dhtx} is –1.0 and 1.0 on the IO and IDIM boundaries, respectively. The grid consists of a single zone with a total of 36562 points. The memory requirement for this example is 4.9 million words. A typical timing for this case is 1026 CPU seconds on a CRAY YMP (NASA LaRC’s Sabre as of October 1996). A close-up of the grid near the bump is shown in Figure 9-20.

![Axisymmetric bump grid](image)

**Figure 9-20.** Axisymmetric bump grid.

Besides the CFL3D code, the following files are needed to run this test case:

<table>
<thead>
<tr>
<th>File</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>bumpv5periodic.inp</td>
<td>input for CFL3D</td>
</tr>
<tr>
<td>bump.grd</td>
<td>formatted single plane grid</td>
</tr>
<tr>
<td>gridaxi.f</td>
<td>converter for creating 2 grid planes</td>
</tr>
</tbody>
</table>

The steps for running this case on the YMP are as follows:
**Step 1**

Compile the grid converter code:

```bash
cft77 gridaxi.f
```

**Step 2**

Link the grid converter object file:

```bash
segldr -o gridaxi gridaxi.o
```

**Step 3**

Run the grid converter program (the binary file `bumpgrd.bin` will be output):

```bash
gridaxi
```

In answer to the question, type:

```bash
bump.grd
```

**Step 4**

Use the makefile to compile, link, and create the executable for the `precfl3d` code (be sure `precfl1.h` is in the current directory):

```bash
make -f makeprecfl3d_cray
```

**Step 5**

Run the `precfl3d` code (the `cflx.h` files will be output):

```bash
precfl3d < bumpv5periodic.inp
```

**Step 6**

Use the makefile to compile, link, and create the executable for the CFL3D code:

```bash
make -f makecfl3d_cray
```

**Step 7**

Run the CFL3D code:

```bash
cfl3d < bumpv5periodic.inp
```

The input file for this case is:

```
I/O FILES
bumpgrd.bin
plot3dq.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.turres
cfl3d.blomax
```
Axisymmetric bump flow, 3-d, using 2 planes and periodic BCs

<table>
<thead>
<tr>
<th>XMACH</th>
<th>ALPHA</th>
<th>BETA</th>
<th>REUE,MIL</th>
<th>TINF,DR</th>
<th>IALPH</th>
<th>IHIST</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8750</td>
<td>00.000</td>
<td>0.0</td>
<td>02.660</td>
<td>460.0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SREF</th>
<th>CREF</th>
<th>BREF</th>
<th>XMC</th>
<th>YMC</th>
<th>ZMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00000</td>
<td>1.00000</td>
<td>1.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DT</th>
<th>IREST</th>
<th>IFLAGTS</th>
<th>FMAX</th>
<th>IUNST</th>
<th>CFLTAU</th>
</tr>
</thead>
<tbody>
<tr>
<td>-05.000</td>
<td>0</td>
<td>0</td>
<td>5.0000</td>
<td>0</td>
<td>10.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NGRID</th>
<th>NPRINT</th>
<th>NWREST</th>
<th>ICHK</th>
<th>I2D</th>
<th>NTSTEP</th>
<th>ITA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NCG</th>
<th>IEM</th>
<th>IADVANCE</th>
<th>IFORCE</th>
<th>IVISC(I)</th>
<th>IVISC(J)</th>
<th>IVISC(K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IDIM</th>
<th>JDIM</th>
<th>KDIM</th>
</tr>
</thead>
<tbody>
<tr>
<td>02</td>
<td>181</td>
<td>101</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ILAGLO</th>
<th>ILAMHI</th>
<th>JLAGLO</th>
<th>JLAGHI</th>
<th>KLAGLO</th>
<th>KLAGHI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INEWG</th>
<th>IGRIDC</th>
<th>IS</th>
<th>JS</th>
<th>KS</th>
<th>IE</th>
<th>JE</th>
<th>KE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IDIAG(I)</th>
<th>IDIAG(J)</th>
<th>IDIAG(K)</th>
<th>IFLIM(I)</th>
<th>IFLIM(J)</th>
<th>IFLIM(K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IFSDS(I)</th>
<th>IFDS(J)</th>
<th>IFDS(K)</th>
<th>RAKPO(I)</th>
<th>RAKPO(J)</th>
<th>RAKPO(K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.3333</td>
<td>0.3333</td>
<td>0.3333</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GRID</th>
<th>NBCI0</th>
<th>NBCJ0</th>
<th>NBCK0</th>
<th>NBCDIM</th>
<th>NBCJDIM</th>
<th>NBCKDIM</th>
<th>IOVRLP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>I0: GRID</th>
<th>SEGMENT</th>
<th>BCTYPE</th>
<th>JSTA</th>
<th>JEND</th>
<th>KSTA</th>
<th>KEND</th>
<th>NDATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2005</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NBLP</th>
<th>DTHTX</th>
<th>DTHTY</th>
<th>DTHTZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-1.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IDIM: GRID</th>
<th>SEGMENT</th>
<th>BCTYPE</th>
<th>JSTA</th>
<th>JEND</th>
<th>KSTA</th>
<th>KEND</th>
<th>NDATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2005</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NBLP</th>
<th>DTHTX</th>
<th>DTHTY</th>
<th>DTHTZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>+1.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>J0: GRID</th>
<th>SEGMENT</th>
<th>BCTYPE</th>
<th>ISTA</th>
<th>IEND</th>
<th>JSTA</th>
<th>JEND</th>
<th>KSTA</th>
<th>NDATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1003</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>JDIM: GRID</th>
<th>SEGMENT</th>
<th>BCTYPE</th>
<th>ISTA</th>
<th>IEND</th>
<th>JSTA</th>
<th>JEND</th>
<th>KSTA</th>
<th>NDATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1003</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>K0: GRID</th>
<th>SEGMENT</th>
<th>BCTYPE</th>
<th>ISTA</th>
<th>IEND</th>
<th>JSTA</th>
<th>JEND</th>
<th>KSTA</th>
<th>NDATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2004</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TWTYPE</th>
<th>CQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KDIM: GRID</th>
<th>SEGMENT</th>
<th>BCTYPE</th>
<th>ISTA</th>
<th>IEND</th>
<th>JSTA</th>
<th>JEND</th>
<th>NDATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1003</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MSEQ</th>
<th>MGFLAG</th>
<th>ICONSF</th>
<th>MTT</th>
<th>NGAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>02</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ISSC</th>
<th>EPSSSC(1)</th>
<th>EPSSSC(2)</th>
<th>EPSSSC(3)</th>
<th>ISSR</th>
<th>EPSSSR(1)</th>
<th>EPSSSR(2)</th>
<th>EPSSSR(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NCYC</th>
<th>MGLEVG</th>
<th>NEMGL</th>
<th>NTFO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1100</td>
<td>03</td>
<td>000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MIT1</th>
<th>MIT2</th>
<th>MIT3</th>
<th>MIT4</th>
<th>MIT5</th>
<th>MIT6</th>
<th>MIT7</th>
<th>MIT8</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>01</td>
<td>01</td>
<td>01</td>
<td>01</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

1-1 BLOCKING DATA:

<table>
<thead>
<tr>
<th>NBLI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NUMBER GRID</th>
<th>: ISTA</th>
<th>JSTA</th>
<th>KSTA</th>
<th>IEND</th>
<th>JEND</th>
<th>KEND</th>
<th>ISVA1</th>
<th>ISVA2</th>
</tr>
</thead>
<tbody>
<tr>
<td>NUMBER GRID</td>
<td>: ISTA</td>
<td>JSTA</td>
<td>KSTA</td>
<td>IEND</td>
<td>JEND</td>
<td>KEND</td>
<td>ISVA1</td>
<td>ISVA2</td>
</tr>
</tbody>
</table>

PATCH SURFACE DATA:

<table>
<thead>
<tr>
<th>NINTER</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PLOT3D OUTPUT</th>
<th>BLOCK IPTYPE</th>
<th>ISTART</th>
<th>IEND</th>
<th>IINC</th>
<th>JSTART</th>
<th>JEND</th>
<th>JINC</th>
<th>KSTART</th>
<th>KEND</th>
<th>KINC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

| IMovie | 0 |

PRINT OUT:

<table>
<thead>
<tr>
<th>BLOCK IPTYPE</th>
<th>ISTART</th>
<th>IEND</th>
<th>IINC</th>
<th>JSTART</th>
<th>JEND</th>
<th>JINC</th>
<th>KSTART</th>
<th>KEND</th>
<th>KINC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

CONTROL SURFACE:
After running this test case, the convergence history plots shown in Figure 9-21 should be duplicated.

![Residual and Coefficient Histories](image)

**Figure 9-21.** Residual and coefficient histories for axisymmetric bump flow case

\[
M_\infty = 0.875, \quad Re_{L_R} = 2.66 \times 10^6.
\]
Also, a result such as that shown in Figure 9-22 should be obtained. In the figure, surface pressure coefficients are plotted along with experimental data for this case. The computational surface pressures can be obtained from file `cfl3d.prout`. Experimental surface pressure coefficients from Bachalo et al. are included with this test case for comparison purposes. The file is called `bumpcpdata.dat`.

![Figure 9-22. Pressure coefficients for axisymmetric bump case](image)

$M_\infty = 0.875$, $Re_{LR} = 2.66 \times 10^6$. 
9.2.2 F-5 Wing

The inviscid flow over an F-5 wing is solved in this test case. The grid consists of a single grid zone with a C-H mesh topology and is composed of 210,177 points. The memory requirement for this example is 10.5 million words. A typical timing for this case is 984 CPU seconds on a CRAY YMP (NASA LaRC’s Sabre as of September 1996). The wing surface grid and wake, as well as the plane of symmetry grid are illustrated in Figure 9-23.

![Figure 9-23. Single zone F-5 wing surface grid and plane of symmetry grid.](image)

Besides the CFL3D code the following files are needed to run this test case:

<table>
<thead>
<tr>
<th>File</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f5wing.inp</td>
<td>input for CFL3D</td>
</tr>
<tr>
<td>f5grid.dat</td>
<td>formatted wing section grid</td>
</tr>
<tr>
<td>f5wing_grid.f</td>
<td>grid converter</td>
</tr>
</tbody>
</table>

The steps for running this case on the YMP are as follows:

**Step 1**

Compile the grid converter code:
Chapter 9  Test Cases

Step 2

Link the grid converter object file:

segldr -o f5wing_grid f5wing_grid.o

Step 3

Run the grid converter program to generate the 3-d volume grid (the binary file f5wing.grd will be output):

f5wing_grid

Step 4

Use the makefile to compile, link, and create the executable for the precfl3d code (be sure precfl1.h is in the current directory):

make -f makeprecfl3d_cray

Step 5

Run the precfl3d code (the cflx.h files will be output):

precfl3d < f5wing.inp

Step 6

Use the makefile to compile, link, and create the executable for the CFL3D code:

make -f makecfl3d_cray

Step 7

Run the CFL3D code:

cfl3d < f5wing.inp

The input file for this case is:

I/O FILES:
f5wing.grd
plot3dg.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.turre
cfl3d.blomax
cfl3d.out15
cfl3d.prout
cfl3d.out20
ovrlp.bin
patch.bin
restart.bin
F5 Wing, cfl3d type grid
XMACH  ALPHA  BETA  REUE,MIL  TINF,DR  IALPH  IHIST
9.2.2 F-5 Wing

0.950  00.000  0.0  0.950  460.0  0  0
SREF  CREF  BREF  XMC  YMC  ZMC
1.00000  1.00000  1.00000  0.25000  0.00  0.00
DT  IREST  IFLAGS  FMAX  IUNST  CFLTAU
-5.000  0  000  1.000  0  0  10.
NGRID  NPRINT  NWREST  ICHK  ITA
1  0  100  0  0  1  1
NCG  IEM  IADVANCE  IFORCE  IVISC(I)  IVISC(J)  IVISC(K)
2  0  1  0  0  0
IDIM  KDIM
33  193  33
ILAMLO  ILAMHI  JLMLO  JLMHI  KLAMLO  KLAMHI
00  00  000  000  0000
INENG  IGRIDC  IS  JS  KS  IE  JE  KE
0  0  0  0  0  0  0  0
IDIAG(1)  IDIAG(J)  IDIAG(K)  IFLIM(I)  IFLIM(J)  IFLIM(K)
1  1  1  1  3  3  3
IFDS(I)  IFDS(J)  IFDS(K)  RKAP0(I)  RKAP0(J)  RKAP0(K)
1  1  1  1  3333  3333  3333
GRID  NBCI0  NBCIDIM  NBCJ0  NBCJDIM  NBCK0  NBCKDIM  IOVRLP
1  1  1  1  4  1  0
I0: GRID SEGMENT BCTYPE  JSTA  JEND  KSTA  KEND  NDATA
1  1  1001  0  0  0  0
IDIM: GRID SEGMENT BCTYPE  JSTA  JEND  KSTA  KEND  NDATA
1  1  1002  0  0  0  0
J0: GRID SEGMENT BCTYPE  ISTA  IEND  KSTA  KEND  NDATA
1  1  1003  0  0  0  0
JDIM: GRID SEGMENT BCTYPE  ISTA  IEND  KSTA  KEND  NDATA
1  1  1003  0  0  0  0
K0: GRID SEGMENT BCTYPE  ISTA  IEND  JSTA  JEND  NDATA
1  1  0  1  33  1  41  0
1  2  1005  1  21  41  153  0
1  3  0  21  33  41  153  0
1  4  0  1  33  153  193  0
KDIM: GRID SEGMENT BCTYPE  ISTA  IEND  JSTA  JEND  NDATA
1  1  1003  0  0  0  0
MSEQ  MGFLAG  ICONSF  MTT  NGAM
3  1  0  0  02
ISSC  EPSSSC(1)  EPSSSC(2)  EPSSSC(3)  ISSR  EPSSSR(1)  EPSSSR(2)  EPSSSR(3)
0  0.3  0.3  0.3  0  0.3  0.3  0.3
NCYC  MGLEVG  NEMGL  NITFO
200  01  00  000
200  02  00  000
200  03  00  000
MIT1  MIT2  MIT3  MIT4  MIT5
01  01  01  01  01
01  01  01  01  01
1-1 BLOCKING DATA:
NBLI
2
NUMBER  GRID :  ISTA  JSTA  KSTA  IEND  JEND  KEND  ISVA1  ISVA2
1  1  1  1  1  33  41  1  1  2
2  1  21  41  1  33  97  1  1  2
NUMBER  GRID :  ISTA  JSTA  KSTA  IEND  JEND  KEND  ISVA1  ISVA2
1  1  1  193  1  33  153  1  1  2
2  1  21  153  1  33  97  1  1  2
PATCH SURFACE DATA:
NINTER
0
PLOT3D OUTPUT:
GRID IPTYPE ISTART  IINC JSTART  JINC KSTART  KEND  KINC 
MOVIE
0
PRINT OUT:
GRID IPTYPE ISTART  IEND IINC JSTART  JEND KSTART  KEND KINC 
CONTROL SURFACE:
NCS
0
GRID ISTART  IEND  JSTART  JEND  KSTART  KEND  IWALL  INORM
After this test case is run, the convergence history, found in file cfl3d.res, should look like that plotted in Figure 9-24. The two sharp spikes in the residual history are at the iterations at which the grid levels change in the mesh sequencing procedure.

**Figure 9-24.** Convergence histories for single grid F-5 wing case; $\alpha = 0.0$, $M_\infty = 0.95$. 
9.2.3 Onera M-6 Wing

In this case, a turbulent Navier-Stokes computation is performed over the Onera M-6 wing, on a coarse grid, using a grid in PLOT3D-type format is performed. The grid consists of a single grid zone with a C-O mesh topology and is composed of 41,225 points. (Keep in mind that one needs a grid at least double this size in each direction, e.g. $193 \times 49 \times 33$ or larger, to actually resolve the flow. A coarser grid is used here to shorten the test run.) The wing surface grid and wake, as well as the plane of symmetry grid are illustrated in Figure 9-25. The memory requirement for this example is 3.4 million words. A typical timing for this case is 453 CPU seconds on a CRAY YMP (NASA LaRC’s Sabre as of September 1996).

![Figure 9-25. Single zone Onera wing surface grid and plane of symmetry grid.](image)

The viscous direction in this PLOT3D-formatted grid is taken as the $j$ direction rather than the $k$ direction as generally recommended. (Due to the order in which CFL3D approximately factors the three index directions, the CFL3D code is usually most efficient when the primary viscous direction is taken as the $k$ direction.) In this case, the convergence is not hurt by the altered directionality. (In some cases, however, it can be!) Note, however, that this case is more efficient (CPU timewise) when run on a vector machine with $k$ as the viscous direction, due to the distribution of individual $i$, $j$, $k$ index lengths and the way the code is vectorized. For this case, the difference on Sabre is a factor of 17% (with a CFL3D-type $k$ viscous grid, the code runs in 374 seconds as opposed to 453 sec-
onds). It is possible to duplicate this result by changing the hard-wired parameter \texttt{iplot3d} to 0 in the \texttt{form2bin.f} file and using the input file \texttt{oneram6.inp_cfl3d} instead of \texttt{oneram6.inp_p3d}. This exercise will demonstrate the differences between PLOT3D-type and CFL3D-type grids, as well as the corresponding differences in the input files.

Besides the CFL3D code the following files are needed to run this test case:

<table>
<thead>
<tr>
<th>File</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>oneram6.inp_p3d</td>
<td>input for CFL3D</td>
</tr>
<tr>
<td>m6_i97.fmt_p3d</td>
<td>formatted grid</td>
</tr>
<tr>
<td>form2bin.f</td>
<td>grid converter</td>
</tr>
</tbody>
</table>

The steps for running this case on the YMP are as follows:

**Step 1**

Compile the grid converter code:

```
cft77 form2bin.f
```

**Step 2**

Link the grid converter object file:

```
segldr -o form2bin form2bin.o
```

**Step 3**

Run the grid converter program to generate the 3-d volume grid (the binary file \texttt{m6_i97.grd_p3d} will be output):

```
form2bin
```

**Step 4**

Use the makefile to compile, link, and create the executable for the \texttt{precfl3d} code (be sure \texttt{precl.h} is in the current directory):

```
make -f makeprecfl3d_cray
```

**Step 5**

Run the \texttt{precfl3d} code (the \texttt{cflx.h} files will be output):

```
precfl3d < oneram6.inp_p3d
```

**Step 6**

Use the makefile to compile, link, and create the executable for the CFL3D code:
Step 7

Run the CFL3D code:

cfl3d < oneram6.inp_p3d

The input file for this case is:

```
I/O FILES:
m6_i97.grd_p3d
plot3dg.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.tures
cfl3d.out15
cfl3d.prout
ovrlp.bin
patch.bin
restart.bin

ONERA M6 Wing, plot3d type grid, coarse grid
XMACH  ALPHA  BETA  REUE,MIL  TINF,DR  IALPH  IHIST
 0.8400  03.060  0.0  21.660  540.0  1  0
SREF  CREF  XMC  YMC  ZMC
 0.53080  1.00000  3.9249  0.0000  0.00  0.00
DT  IREST  IFLAGTS  FMAX  IUNST  CFLTAU
-5.000  0  000  1.000  0  10.
NGRID  NPRINT  NWREST  ICHK  I2D  NTSTEP  ITA
-1  1  100  0  0  0  0  1
NCG  IEM  IADVANCE  IFORCE  IVISC(I)  IVISC(J)  IVISC(K)
 1  1  0  100  0  0  0  1
IDIM  JDIM  KDIM
 97  25  17
ILAMLO  ILAMHI  JLAMLO  JLAMHI  KLAMLO  KLAMHI
 00  00  000  000  000  000
INEWG  IGRIDC  IS  JS  KS  IE  JE  KE
 0  0  0  0  0  0  0  0
IDIAG(I)  IDIAG(J)  IDIAG(K)  IFLIM(I)  IFLIM(J)  IFLIM(K)
 1  1  1  3  3  3
IFDS(I)  IFDS(J)  RKAP0(I)  RKAP0(J)  RKAP0(K)
 1  1  .3333  .3333  .3333
GRID  NBCI0  NBCIDIM  NBCJ0  NBCJDIM  NBCK0  NBCKDIM  IOVRLP
 1  1  1  3  1  1  1  0
I0:  GRID  SEGMENT  BCTYPE  JSTA  JEND  KSTA  KEND  NDATA
 1  1  1003  0  0  0  0  0
IDIM:  GRID  SEGMENT  BCTYPE  JSTA  JEND  KSTA  KEND  NDATA
 1  1  1003  0  0  0  0  0
J0:  GRID  SEGMENT  BCTYPE  ISTA  IEND  KSTA  KEND  NDATA
 1  1  0  13  0  0  0  0
 1  2  2004  13  85  1  17  2
TWTYPE  CQ
 0.  0.
 1  3  0  85  97  0  0  0
JDIM:  GRID  SEGMENT  BCTYPE  ISTA  IEND  KSTA  KEND  NDATA
 1  1  1003  0  0  0  0  0
K0:  GRID  SEGMENT  BCTYPE  ISTA  IEND  JSTA  JEND  NDATA
 1  1  1001  0  0  0  0  0
KDIM:  GRID  SEGMENT  BCTYPE  ISTA  IEND  JSTA  JEND  NDATA
 1  1  0  0  0  0  0
MSEQ  MGFLAG  ICONSF  MTT  NGAM
 2  1  0  0  0  0  0  0
ISSC  EPSSSC(1)  EPSSSC(2)  EPSSSC(3)  ISSR  EPSSSR(1)  EPSSSR(2)  EPSSSR(3)
 0  0.3  0.3  0.3  0  0.3  0.3  0.3
NCYC  MGLEVG  NEMGL  NITFO
```
CHAPTER 9  Test Cases

After this test case is run, the convergence histories, found in file cfl3d.res, should look like those plotted in Figure 9-26. The sharp spikes in the plots indicate the iteration at which the grid level changes in the mesh sequencing process.
Figure 9-26. Convergence histories for single grid Onera wing case; 
\( \alpha = 3.06, M_\infty = 0.84 \).
9.2.4 Delta Wing

The laminar flow over a $75^\circ$ swept delta wing is solved in this test case. The grid consists of a single grid zone with 156,325 points. (Note that this grid is coarser than what one would normally use to resolve this flow.) The memory requirement for this example is 8.0 million words. A typical timing for this case is 2236 CPU seconds on a CRAY YMP (NASA LaRC’s Sabre as of September 1996). The surface grid ($k = 1$) and a trailing edge grid plane are shown in Figure 9-27.

![Figure 9-27. Single zone delta wing surface grid and trailing edge plane grid.](image)

Besides the CFL3D code the following files are needed to run this test case:

<table>
<thead>
<tr>
<th>File</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>delta.inp</td>
<td>input for CFL3D</td>
</tr>
<tr>
<td>delta.fmt</td>
<td>formatted grid</td>
</tr>
<tr>
<td>form2bin.f</td>
<td>grid converter</td>
</tr>
</tbody>
</table>

The steps for running this case on the YMP are as follows:

**Step 1**

Compile the grid converter code:
Step 2

Link the grid converter object file:

```
segldr -o form2bin form2bin.o
```

Step 3

Run the grid converter program to generate the 3-d volume grid (the binary file `delta.bin` will be output):

```
form2bin
```

Step 4

Use the makefile to compile, link, and create the executable for the `precfl3d` code (be sure `precfl.h` is in the current directory):

```
make -f makeprecfl3d_cray
```

Step 5

Run the `precfl3d` code (the `cflx.h` files will be output):

```
precfl3d < delta.inp
```

Step 6

Use the makefile to compile, link, and create the executable for the CFL3D code:

```
make -f makecfl3d_cray
```

Step 7

Run the CFL3D code:

```
cfl3d < delta.inp
```

The input file for this case is:

```
I/O FILES
delta.bin
plot3dq.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.turrets
cfl3d.blomax
cfl3d.out15
cfl3d.prout
cfl3d.out20
ovrlp.bin
patch.bin
restart.bin
```

75 Degree Swept Delta Wing - 37x65x65 - Laminar
XMACH ALPHA BETA REUE,MIL TINF,DR IALPH IHIST
After this test case is run, the convergence histories, found in file `cfl3d.res`, should look like those plotted in Figure 9-28.
Figure 9-28. Convergence histories for single grid delta wing case; $\alpha = 20.5$. 