

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 $\mathbf{idim} = 2$ (and $\mathbf{i2d} = 1$). 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. 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.

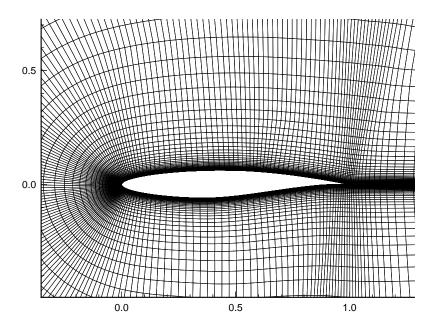


Figure 9-1. Single zone RAE 2822 airfoil grid.

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

<u>File</u>	<u>Description</u>
rae10.inp	input for CFL3D
rae10.grd	formatted single plane grid
grid2dto3d.f	converter for creating 2 grid planes

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
```

<u>Step 5</u>

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

```
precfl3d < rae10.inp</pre>
```

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 < rae10.inp

```
FILES:
rae10.bin
plot3dg.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.turres
cfl3d.blomax
cfl3d.out15
cfl3d.prout
cf13d.out20
ovrlp.bin
patch.bin
restart.bin
    RAE case 10, with SST model
                                                 TINF, DR
     XMACH
                 ALPHA
                              BETA
                                     REUE, MIL
                                                               IALPH
                                                                          IHSTRY
    0.7500
                                                    460.0
                02.720
                               0.0
                                       6.2000
                                                                    Λ
                                                                                Ω
       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
                               000
                                      05.0000
                      0
                                                        0
                                                                 10.0
                                                                          NTSTEP
     NGRID
               NPLOT3D
                           NPRINT
                                       NWREST
                                                     ICHK
                                                                  I2D
                                                                                         ITA
                                         6100
                                                                            0001
                                                IVISC(I)
                                                            IVISC(J)
                         IADVANCE
        NCG
                   IEM
                                       IFORCE
                                                                        IVISC(K)
          2
                     0
                                 0
                                             1
                                                        0
                                                                    0
       IDIM
                  JDIM
                              KDIM
                                97
          2
                   257
    ILAMLO
                ILAMHI
                           JLAMLO
                                       JLAMHI
                                                   KLAMLO
                                                              KLAMHI
                                88
                                          159
                                                                   97
          1
                      2
                                                        1
     INEWG
                IGRIDC
                                IS
                                            JS
                                                       KS
                                                                   IE
                                                                               JΕ
                                                                                          KE
          0
                      0
                                 0
                                             0
                                                        0
                                                                    0
                                                                                0
                                                                                           0
  IDIAG(I)
              IDIAG(J)
                         IDIAG(K)
                                     IFLIM(I)
                                                IFLIM(J)
                                                            IFLIM(K)
   IFDS(I)
               IFDS(J)
                          IFDS(K)
                                                RKAP0(J)
                                                            RKAPO(K)
                                     RKAPO(I)
                                       0.3333
                                                   0.3333
                                                              0.3333
       GRID
                 NBCI0
                          NBCIDIM
                                        NBCJ0
                                                                         NBCKDIM
                                                                                      IOVRLP
                                                 NBCJDIM
                                                               NBCK0
          1
                      1
                                 1
                                             1
                                                        1
                                                                    3
                                                                                1
                                                                                           0
I0:
       GRID
               SEGMENT
                           BCTYPE
                                         JSTA
                                                     JEND
                                                                 KSTA
                                                                            KEND
                                                                                       NDATA
                              1001
                                             Λ
                                                        Ω
                                                                    Λ
          1
                      1
                                                                                n
                                                                                           n
IDIM:
      GRID
               SEGMENT
                            BCTYPE
                                         JSTA
                                                     JEND
                                                                 KSTA
                                                                            KEND
                                                                                       NDATA
                                             0
                                                                    0
                                                                                           0
                              1002
                                                        0
                                                                                0
          1
                      1
J0:
       GRID
               SEGMENT
                            BCTYPE
                                         ISTA
                                                     IEND
                                                                 KSTA
                                                                            KEND
                                                                                       NDATA
          1
                      1
                              1002
                                             0
                                                        0
                                                                    0
                                                                                0
                                                                                           0
JDIM: GRID
               SEGMENT
                                         ISTA
                                                                 KSTA
                                                                            KEND
                                                                                       NDATA
                            BCTYPE
                                                     IEND
                              1002
                                             0
                                                        0
                                                                    0
                                                                                0
                                                                                           0
               SEGMENT
                                         ISTA
K0:
       GRID
                                                     IEND
                                                                 JSTA
                                                                            JEND
                                                                                       NDATA
                            BCTYPE
          1
                      1
                                 0
                                             0
                                                        0
                                                                    1
                                                                               41
                                                                                           0
                      2
                                             0
                                                        0
                                                                                            2
          1
                              2004
                                                                   41
                                                                              217
                TWTYPE
                                CQ
                    0.
                                0.
                                 0
                                             0
                                                        0
                                                                  217
                                                                             257
                                                                                           0
          1
                      3
KDIM: GRID
               SEGMENT
                            BCTYPE
                                         ISTA
                                                     IEND
                                                                 JSTA
                                                                            JEND
                                                                                       NDATA
          1
                     1
                              1003
                                             0
                                                        0
                                                                    0
                                                                                0
                                                                                           0
      MSEQ
                MGFLAG
                            ICONSF
                                           MTT
                                                     NGAM
                      1
                                 0
                                             0
                                                       02
            EPSSSC(1)
                                                           EPSSSR(1) EPSSSR(2) EPSSSR(3)
       ISSC
                        EPSSSC(2)
                                   EPSSSC(3)
                                                     ISSR
          0
                   0.3
                               0.3
                                           0.3
                                                                  0.3
                                                                             0.3
      NCYC
                MGLEVG
                             NEMGL
                                        NITFO
```

MI	00 T1 01 LOCKING	03 MIT2 01 DATA:	00 MIT3 01		000 MIT4 01	rim O	:5 i	MIT6 1	MIT7 1	MIT8 1
NB										
	1									
NUMBER	GRID	:	ISTA	JSTA	KSTA			KEND	ISVA1	ISVA2
1	1		_ 1	1	1	2		1	1	2
NUMBER	GRID	:	ISTA	JSTA	KSTA			KEND	ISVA1	ISVA2
1	1		1	257	1	2	217	1	1	2
	SURFACE	DATA:								
NINT	ък 0									
חניתיאט	OUTPUT	٠.								
		ISTART	IEND	TINC	JSTART	JEND	TINC	KSTART	KEND	KINC
GRID 1	0	1	01	1	031AK1	999		1	999	1
MOVIE	O	_	01	_	01		_	_	222	_
0										
PRINT	OUT:									
GRID	IPTYPE	ISTART	IEND	IINC	JSTART	JEND) JINC	KSTART	KEND	KINC
1	0	1	01	1	41	217	1	1	1	1
CONTRO NCS 0	L SURFA	CE:								
ū	ISTART	IEND	JSTART	JEI	ND KS	TART	KEND I	WALL IN	IORM	

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. al¹⁵ are included with this test case for comparison purposes. The file is called rael0.cpexp. The residual plots shown in Figure 9-3 should also be duplicated. These convergence histories can be found in cfl3d.res.

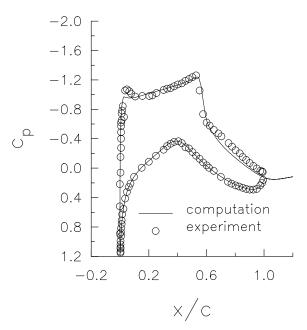


Figure 9-2. Surface pressure coefficients for RAE 2822 airfoil;

$$\alpha = 2.72^{\circ}, M_{\infty} = 0.75, Re_{\tilde{L}_R} = 6.2 \times 10^{6}.$$

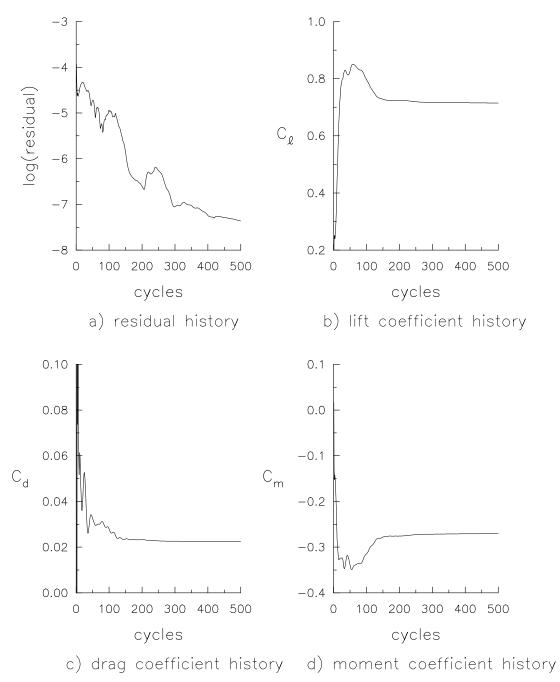


Figure 9-3. Residual and coefficient histories for RAE 2822 airfoil case;

 $\alpha = 2.72^{\circ}, M_{\infty} = 0.75, Re_{\tilde{L}_R} = 6.2 \times 10^{6}$

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.

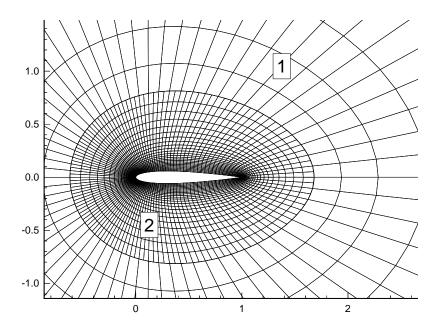


Figure 9-4. Two-zone overlapped grid system for NACA 0012 airfoil.

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

<u>File</u>	<u>Description</u>
0012x.inp	input for CFL3D
0012x.fmt	formatted grid in PLOT3D format
<pre>fmttobin_p3d.f</pre>	grid converter
mag1.h	parameters for MaGGiE makefile
maggie.inp	input for MaGGiE

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 precfl.h is in the current directory):

```
make -f makeprecfl3d_cray
```

Step 7

Run the precf13d 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:

cfl3d < 0012x.inp

```
I/O FILES
0012x.bin
plot3dg.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.turres
cfl3d.blomax
cfl3d.out15
cfl3d.prout
cf13d.out20
ovrlp.bin
patch.bin
restart.bin
  2-block 0012 airfoil as simple chimera test
                                                    TINF, DR
                                                                             IHSTRY
      XMACH
                  ALPHA
                               BETA
                                      REUE, MIL
                                                                  IALPH
                  5.000
       .200
                                0.0
                                            0.0
                                                      520.0
                                                                       1
                                                                                   0
       SREF
                   CREF
                               BREF
                                            XMC
                                                        YMC
                                                                     ZMC
   1.00000
               1.00000
                            1.0000
                                       0.25000
                                                       0.00
                                                                   0.00
         DT
                  IREST
                            IFLAGTS
                                           {\sf FMAX}
                                                      IUNST
                                                                 CFLTAU
      -5.00
                       0
                                000
                                           1.00
                                                           0
                                                                     10.
               NPLOT3D
      NGRID
                            NPRINT
                                        NWREST
                                                       ICHK
                                                                     I2D
                                                                             NTSTEP
                                                                                             ITA
         -2
                       2
                                   0
                                            100
                                                           0
                                                              IVISC(J)
        NCG
                                                  IVISC(I)
                          IADVANCE
                                         IFORCE
                                                                           IVISC(K)
                    IEM
           2
                       0
                                   0
                                               0
                                                           0
                                                                       0
                                                                                   0
           2
                       0
                                   0
                                                           0
                                                                       0
                                                                                   0
                                               1
       IDIM
                   JDIM
                               KDIM
        002
                     65
                                 25
                    129
                                 25
        002
     ILAMLO
                 ILAMHI
                             JLAMLO
                                         JLAMHI
                                                     KLAMLO
                                                                 KLAMHI
         00
                     00
                                000
                                            000
                                                           0
                                                                   0000
         0.0
                     00
                                000
                                            000
                                                           0
                                                                   0000
      INEWG
                 IGRIDC
                                 IS
                                             JS
                                                          KS
                                                                      ΙE
                                                                                              KE
                                                                                  JΕ
                       0
                                  0
                                               0
                                                           0
                                                                       0
                                                                                   0
                                                                                               0
          0
           0
                       0
                                   0
                                               0
                                                           0
                                                                       0
                                                                                   0
              IDIAG(J)
                          IDIAG(K)
  IDIAG(I)
                                      IFLIM(I)
                                                  IFLIM(J)
                                                              IFLIM(K)
                                                           0
                                                                       0
                                      RKAPO(I)
                                                              RKAPO(K)
   IFDS(I)
               IFDS(J)
                           IFDS(K)
                                                  RKAPO(J)
                                          .3333
                                                      .3333
                                                                  .3333
                                          .3333
                                                      .3333
                                                                   .3333
           1
                       1
                                   1
       GRID
                 NBCI0
                           NBCIDIM
                                         NBCJ0
                                                   NBCJDIM
                                                                 NBCK0
                                                                           NBCKDIM
                                                                                        IOVRLP
           1
                                   1
                                                                       1
                                                                                   1
           2
                       1
                                               1
                                                                       1
                                                                                   1
                                                                                               1
IO:
       GRID
               SEGMENT
                             BCTYPE
                                           JSTA
                                                       JEND
                                                                   KSTA
                                                                               KEND
                                                                                         NDATA
                                               0
                                                           0
                                                                       0
                               1002
                                                                                   0
                                                                                              0
                       1
           1
           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
                               1002
                                               0
                                                           0
                                                                       0
                                                                                   0
                                                                                              0
J0:
                             BCTYPE
                                                                   KSTA
       GRID
               SEGMENT
                                           ISTA
                                                       IEND
                                                                               KEND
                                                                                         NDATA
                       1
                                   0
                                               0
                                                           0
                                                                       0
                                                                                   0
                                                                                              0
                                   0
                                                                                   0
                                                                                              0
           2
                       1
                                               0
                                                           0
                                                                       0
                                                                   KSTA
                                                                               KEND
                                                                                         NDATA
JDIM: GRID
               SEGMENT
                            BCTYPE
                                           ISTA
                                                       IEND
           1
                       1
                                   0
                                               0
                                                           0
                                                                       0
                                                                                   0
                                                                                              0
           2
                       1
                                   0
                                               0
                                                           0
                                                                       0
                                                                                   0
                                                                                              0
K0:
       GRID
               SEGMENT
                             BCTYPE
                                           ISTA
                                                       IEND
                                                                   JSTA
                                                                               JEND
                                                                                         NDATA
                                                           0
                                                                       0
                                                                                   0
                                                                                              0
                      1
                                   0
                                               0
           1
                               1005
           2
                       1
                                               0
                                                           0
                                                                       0
                                                                                   0
                                                                                              0
KDIM: GRID
               SEGMENT
                             BCTYPE
                                           ISTA
                                                       IEND
                                                                   JSTA
                                                                               JEND
                                                                                         NDATA
                                               0
                                                                       0
                                                                                   0
                                                                                              0
           1
                       1
                               1003
                                                           n
           2
                                   0
                                               0
                                                           0
                                                                       0
                                                                                   0
                                                                                              0
       MSEQ
                MGFLAG
                             ICONSF
                                            MTT
                                                       NGAM
                       1
                                               0
                                                          01
       ISSC
              EPSSC(1)
                          EPSSC(2)
                                      EPSSC(3)
                                                       ISSR
                                                              EPSSR(1)
                                                                           EPSSR(2)
                                                                                       EPSSR(3)
           0
                                                           0
                      . 3
                                  . 3
                                              . 3
                                                                      . 3
                                                                                  . 3
                                                                                              . 3
```

MI	00 T1 01 LOCKING	IGLEVG 03 MIT2 01 DATA:	NEMGL 00 MIT3 01	1	NITFO 000 MIT4 01	MIT5 01				
NUMBER	GRID	:	ISTA	JSTA	KSTA	IEND	JEND	KEND	ISVA1	ISVA2
1	1		1	1	1	2	1	25	1	3
2	2		1	1	1	2	1	25	1	3
NUMBER	GRID	:	ISTA	JSTA	KSTA	IEND	JEND	KEND	ISVA1	ISVA2
1	1		1	65	1	2	65	25	1	3
2	2		1	129	1	2	129	25	1	3
PATCH S	SURFACE	DATA:	_		_	_			_	
NINT	ER									
	0									
PLOT3D	OUTPUT	·:								
GRID :	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
MOVIE										
0										
PRINT (OUT:									
GRID :	IPTYPE	ISTART	IEND	IINC	JSTART	JEND	JINC	KSTART	KEND	KINC
CONTRO	L SURFA	CE:								
NCS										
0										
GRID :	ISTART	IEND	JSTART	JEI	ND KST	'ART KE	II D	WALL IN	ORM	

The residual and coefficient histories for this case are plotted in Figure 9-5.

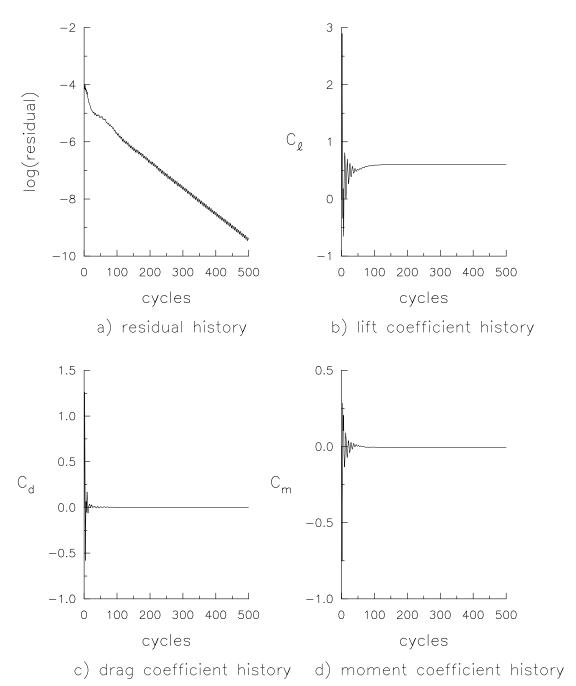


Figure 9-5. NACA 0012 with overlapped grids residual and coefficient histories; $\alpha=5^{\circ}$, $M_{\infty}=0.2$.

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.

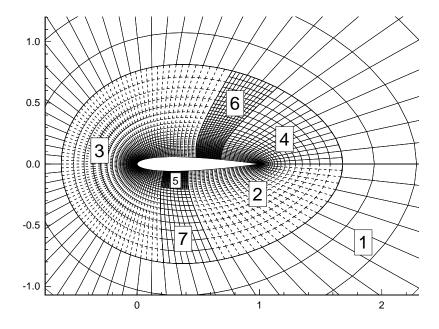


Figure 9-6. Seven-zone patched grid system for NACA 0012 airfoil.

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

<u>File</u>	<u>Description</u>
0012.inp	input for CFL3D
0012.fmt	formatted grid
fmttobin.f	grid converter

<u>File</u> <u>Description</u>

ron1.h parameters for ronnie makefile

ronnie.inp input for ronnie

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

<u> Step 1</u>

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</pre>
```

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

```
precfl3d < 0012.inp</pre>
```

<u>Step 8</u>

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
```

```
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
                                                                           IHSTRY
     XMACH
                 ALPHA
                              BETA
                                     REUE, MIL
                                                  TINF, DR
                                                                IALPH
                 1.25
       0.80
                               0.0
                                         0.000
                                                     122.0
                                                                     Λ
                                                                                 0
       SREF
                   CREF
                              BREF
                                           XMC
                                                       YMC
                                                                   ZMC
               1.00000
   1.00000
                            1.0000
                                      0.25000
                                                      0.00
                                                                  0.00
         DT
                 IREST
                           IFLAGTS
                                          FMAX
                                                     IUNST
                                                               CFLTAU
      -5.00
                                000
                      0
                                          1.00
                                                         0
                                                                  10.0
               NPLOT3D
                                                                          NTSTEP
     NGRID
                            NPRINT
                                        NWREST
                                                      ICHK
                                                                   I2D
                                                                                         ITA
                                           100
                                                             IVISC(J)
        NCG
                          IADVANCE
                                                 IVISC(I)
                                                                         IVISC(K)
                                        IFORCE
                    IEM
          1
                      0
                                  0
                                            0
                                                         0
                                                                     0
                                                                                 0
                      0
                                  0
                                                         0
                                                                     0
                                                                                 0
          1
                                            1
          1
                      0
                                  0
                                            1
                                                         0
                                                                     0
                                                                                 0
          1
                      0
                                  0
                                            1
                                                         0
                                                                     0
                      0
                                  0
                                                         0
                                                                     0
                                                                                 0
          1
                                            1
          1
                      0
                                  0
                                            1
                                                         0
                                                                     0
                                                                                 0
          1
                      0
                                  0
                                            0
                                                          0
       IDIM
                  JDIM
                              KDIM
          2
                     65
                                 13
          2
                     23
                                 25
          2
                     79
                                 25
          2
                                 25
                     15
          2
                     17
                                 25
          2
                     13
                                 49
          2
                      9
                                 13
    ILAMLO
                ILAMHI
                            JLAMLO
                                        JLAMHI
                                                   KLAMLO
                                                               KLAMHI
                     00
         0.0
                                000
                                           000
                                                         0
                                                                  0000
         00
                     00
                                000
                                           000
                                                         0
                                                                  0000
                                000
                                                         0
                                                                  0000
         00
                     00
                                           000
                     00
                                000
                                           000
                                                         0
                                                                  0000
         0.0
         00
                     00
                                000
                                           000
                                                         0
                                                                  0000
                     00
                                                         0
         0.0
                                000
                                           000
                                                                  0000
         00
                     00
                                000
                                           000
                                                         0
                                                                  0000
                                IS
      INEWG
                IGRIDC
                                            JS
                                                        KS
                                                                    ΙE
                                                                                JΕ
                                                                                           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 IDIAG(I)	0 0 1DIAC(I)	0 0 IDIAG(K)	0 0 IFLIM(I)	0 0 TELTM(T)	0 0 IFLIM(K)	0 0	0
Ó	0	0	3	3	3		
0	0	0 0	3	3	3 3		
0	0	0	3	3	3		
0	0	0	3	3	3		
0 IFDS(I)	0 IFDS(J)	0 IFDS(K)	3 RKAPO(I)	3 RKAPO(J)	3 RKAPO(K)		
0	0	0	.3333	.3333	.3333		
0	0	0	.3333	.3333	.3333		
0	0	0 0	.3333	.3333	.3333		
0	0	0	.3333	.3333	.3333		
GRID	NBCI0	NBCIDIM	NBCJ0	NBCJDIM	NBCK0	NBCKDIM	IOVRLP
1 2	1 1	1 1	1 1	1 1	1 1	1 1	0
3 4	1 1	1 1	1 1	1 1	1 1	1 1	0
5	1	1	1	1	1	1	0
6 7	1 1	1 1	1 1	1 1	1 1	1 1	0 0
IO: GRID	SEGMENT 1	BCTYPE 1002	JSTA 0	JEND 0	KSTA 0	KEND 0	NDATA 0
2	1	1002	0	0	0	0	0
3 4	1 1	1002 1002	0	0	0 0	0 0	0
5 6	1 1	1002 1002	0	0	0	0	0
7	1	1002	0	0	0	0	0
IDIM: GRID 1	SEGMENT 1	BCTYPE 1002	JSTA 0	JEND 0	KSTA 0	KEND 0	NDATA 0
2 3	1 1	1002 1002	0	0	0	0	0
4	1	1002	0	0	0	0	0
5 6	1 1	1002 1002	0	0	0 0	0 0	0
J0: GRID	1 SEGMENT	1002 BCTYPE	0 ISTA	0 IEND	0 KSTA	0 KEND	0 NDATA
1	1	0	0	0	0	0	0
2	1 1	0 0	0	0	0 0	0 0	0
4 5	1 1	0	0	0	0	0	0
6	1	0	0	0	0	0	0
7 JDIM: GRID		0 BCTYPE	0 ISTA	0 IEND	0 KSTA	0 KEND	0 NDATA
1 2		0	0	0	0	0	0
3 4	1 1	0	0	0	0	0	0
5	1	0	0	0	0	0	0
6 7	1 1	0	0	0	0 0	0	0 0
K0: GRID		BCTYPE 0	ISTA 0	IEND 0	JSTA 0	JEND 0	NDATA 0
2	1	1005	0	0	0	0	0
3 4	1 1	1005 1005	0	0	0 0	0	0 0
5 6	1 1	1005 1005	0	0	0	0	0
7	1	0	0	0	0	0	0
KDIM: GRID		BCTYPE 1003	ISTA 0	IEND 0	JSTA 0	JEND 0	NDATA 0
2 3		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
MS	~	MGFLAG	ICONSF		MTT	NGAM					
T-0	2	1	1		0	02		- / 1 \	===== (
15		SSC(1)	EPSSC(2)	EPSS	SC(3)	ISSR 0	EPSSI	. ,	EPSSR(2)	EPSSR (
NC	0	.3 MGLEVG	.3 NEMGL	7	.3 NITFO	U		. 3	.3		. 3
03	-	MGLEVG 01	00	1	000						
03		02	00		000						
MI		MIT2	MIT3		MIT4	MIT5					
	01	01	01		01	01					
	01	01	01		01	01					
		G DATA:	0.2		0.1	0.2					
NB	LI										
	1										
NUMBER	GRID	:	ISTA	JSTA	KSTA	IEND	JEND	KEN		ISVA2	
1	1		1	1	1	2	1	1	3 1	3	
NUMBER	GRID	:	ISTA	JSTA	KSTA	IEND	JEND	KEN		ISVA2	
1	1		1	65	1	2	65	1	3 1	3	
_		E DATA:									
NINT											
	-1										
	OUTPU'	ISTART	IEND	TIMO	JSTART	JEND	TIMO	KSTAR	T KEND	KINC	
GRID 1	O TAILTEE	ISTART		1 INC	USTART 01	999	JINC 1		1 KEND	KINC 1	
2	0	1	001	1	01	999	1		1 999	1	
3	0	1		1	01	999	1		1 999	1	
4	0	1		1	01	999	1		1 999	1	
5	0	1		1	01	999	1		1 999	1	
6	0	1		1	01	999	1		1 999	1	
7	0	1	001	1	01	999	1		1 999	1	
MOVIE											
0											
PRINT											
-		ISTART	IEND	IINC	JSTART	JEND	JINC	KSTAR	T KEND	KINC	
	L SURF	ACE:									
NCS											
0 CD TD	T.C	T 1737	T.C		TD 17.0m	*DIII ***	T		TATODA		
GRID	ISTART	IEND	JSTART	JEI	ND KST	art Ke	ND I	WALL	INORM		

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.

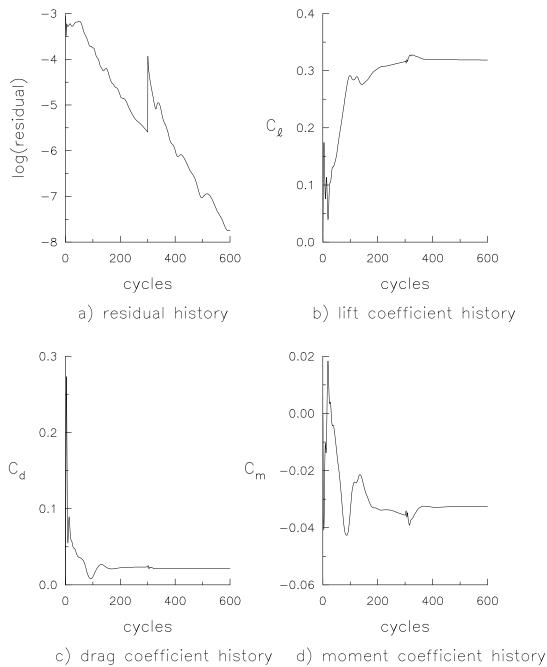


Figure 9-7. Seven-zone NACA 0012 case residual and coefficient histories; $\alpha=1.25^{\circ}$, $M_{\infty}=0.8$.

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.

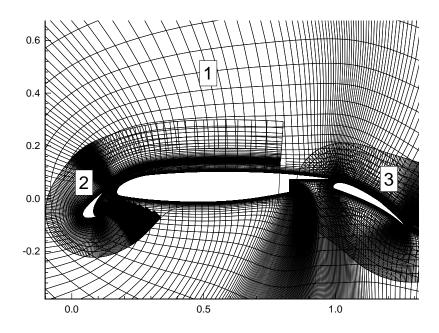


Figure 9-8. Three-zone overlapped grid system for a three-element airfoil.

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

<u>File</u>	<u>Description</u>
multi.inp	input for CFL3D
grid.fmt	formatted grid
fmttobin.f	grid converter
mag1.h	parameters for MaGGiE makefile
mag.inp_multi	input for MaGGiE

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 makemaggie_cray
```

Step 5

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

```
maggie < mag.inp_multi</pre>
```

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

```
precfl3d < multi.inp</pre>
```

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

```
I/O FILES
multi.bin
plot3dg.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.turres
cf13d.blomax
cfl3d.out15
cfl3d.prout
cf13d.out20
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
                                                                      Λ
                                                                                  0
       SREF
                   CREF
                              BREF
                                            XMC
                                                       YMC
                                                                   ZMC
   1.00000
               1.00000
                                       0.25000
                                                                  0.00
                            1.0000
                                                      0.00
         DT
                  IREST
                           IFLAGTS
                                          FMAX
                                                     IUNST
                                                                CFLTAU
      -5.00
                      0
                                000
                                           1.00
                                                          0
                                                                  10.0
     NGRID
               NPLOT3D
                            NPRINT
                                        NWREST
                                                      ICHK
                                                                   I2D
                                                                            NTSTEP
                                                                                           ITA
                                            100
                                                             IVISC(J)
                          IADVANCE
                                                 IVISC(I)
                                        IFORCE
                                                                         IVISC(K)
        NCG
                    IEM
          2
                      0
                                  0
                                            001
                                                          0
                                                                      0
                                                                                  5
          2
                      0
                                  0
                                            001
                                                          0
                                                                      0
                                                                                  5
                                                                                  5
          2
                      0
                                  0
                                            001
                                                          0
                                                                      0
       IDIM
                   JDIM
                              KDIM
        002
                    361
                                 65
        002
                    369
                                 57
                                 49
        002
                    297
     ILAMLO
                ILAMHI
                            JLAMLO
                                        JLAMHI
                                                    KLAMLO
                                                                KLAMHI
                                            000
                                                                  0000
         00
                     00
                                000
                                                          0
                                000
                                            000
                                                                  0000
         0.0
                     0.0
                                                          0
         00
                     00
                                000
                                            000
                                                          0
                                                                  0000
                                                                                JΕ
                                                                                            KE
      INEWG
                IGRIDC
                                 IS
                                                         KS
                                             JS
                                                                     ΙE
          0
                      0
                                  0
                                              Λ
                                                          0
                                                                      0
                                                                                  0
                                                                                             0
          0
                      0
                                  0
                                              0
                                                          0
                                                                      0
                                                                                  0
                                                                                             0
                      Ω
                                  Ω
                                                          Ω
                                                                      Ω
                                                                                  0
                                                                                             0
          n
                                              0
  IDIAG(I)
              IDIAG(J)
                          IDIAG(K)
                                      IFLIM(I)
                                                  IFLIM(J)
                                                             IFLIM(K)
                                  1
                                              3
                                                                      3
                      1
                                                          3
          1
                      1
                                  1
                                              3
                                                          3
                                                                      3
                      1
                                  1
                                                          3
          1
   IFDS(I)
                                                 RKAPO(J)
               IFDS(J)
                           IFDS(K)
                                      RKAPO(I)
                                                             RKAPO(K)
                                         .3333
                                                     .3333
                                                                 .3333
                                                     .3333
                                         .3333
                                                                 .3333
                      1
                                  1
          1
                                          .3333
                                                      .3333
                                                                 .3333
       GRID
                 NBCI0
                           NBCIDIM
                                         NBCJ0
                                                   NBCJDIM
                                                                 NBCK0
                                                                          NBCKDIM
                                                                                        IOVRLP
          1
                      1
                                  1
                                              1
                                                          1
                                                                      3
                                                                                  1
          2
                      1
                                  1
                                                          1
                                                                                  1
          3
                                                                      3
                                                                                  1
                      1
                                              1
                                                          1
                                                                                             1
I0:
       GRID
               SEGMENT
                            BCTYPE
                                          JSTA
                                                      JEND
                                                                  KSTA
                                                                              KEND
                                                                                         NDATA
                               1002
                                              0
                                                          0
                                                                      0
                                                                                             0
          1
                      1
                                                                                  0
          2
                      1
                              1002
                                              0
                                                          0
                                                                      0
                                                                                  0
                                                                                             0
          3
                      1
                              1002
                                              0
                                                          0
                                                                      0
                                                                                  0
                                                                                             0
IDIM: GRID
                                          JSTA
                                                                  KSTA
                                                                                         NDATA
               SEGMENT
                            BCTYPE
                                                      JEND
                                                                              KEND
                               1002
                                              0
                                                          0
                                                                      0
                                                                                             0
          2
                      1
                                              0
                                                          0
                                                                      0
                                                                                  0
                                                                                             0
                               1002
          3
                      1
                              1002
                                              0
                                                          0
                                                                      0
                                                                                  0
                                                                                             0
J0:
       GRID
               SEGMENT
                            BCTYPE
                                           ISTA
                                                      IEND
                                                                  KSTA
                                                                              KEND
                                                                                         NDATA
                                              0
                                                          0
          1
                               1003
```

JDIM:	_	1 SEGMENT	. 0 BCTYPE		0 0 ISTA	0 0 IEND	K	0 0 STA	0 0 KEND	0 0 NDATA
к0:	1 2 3 GRID 1	1 1 1 SEGMENT	. 0 . 0 . BCTYPE		0 0 0 ISTA 0	0 0 0 IEND 0	ā	0 0 0 STA 1	0 0 0 JEND 73	0 0 0 NDATA 0
	1	TWTYPE 0.	CQ 0.		0	0		73	289	2
	1 2 2	TWTYPE	. 0 2004 CQ		0 0 0	0 0 0		289 1 65	361 65 305	0 0 2
	2 3 3	0. 3 1 2 TWTYPE	0 0 2004		0 0 0	0 0 0		305 1 49	369 49 249	0 0 2
KDIM:	1 2	0. 3 SEGMENT 1	BCTYPE 1003		0 ISTA 0 0	0 IEND 0		249 ISTA 0 0	297 JEND 0 0	0 NDATA 0
	3 MSEQ 1	1 MGFLAC 1	ICONSF		0 MTT 0	0 NGAM 01		0	0	0
	ISSC 0 NCYC 2000	EPSSC(1) .3 MGLEVO	NEMGL	I	SC(3) .3 NITFO 000	ISSR 0	EPSSF		PSSR(2) .3	EPSSR(3)
1-	MIT1 01 1 BLOC NBLI 3	MIT2 01 CKING DATA	. 01		MIT4 01	MIT5 01				
NUMB:		RID : 1 2 3	ISTA 1 1 1	JSTA 1 1 1	KSTA 1 1 1	IEND 2 2 2	JEND 73 65 49	KEND 1 1	ISVA1 1 1 1	ISVA2 2 2 2
NUMB:	ER 0 1 2 3	RID : 1 2 3	ISTA 1 1 1	JSTA 361 369 297	KSTA 1 1 1	IEND 2 2 2	JEND 289 305 249	KEND 1 1 1	ISVA1 1 1 1	ISVA2 2 2 2
N	CH SUF INTER 0 T3D OU	RFACE DATA	ι:							
	ID IPT 1 2	TYPE ISTAF 1 1	1 001 1 001	1 1		JEND 999 999	1 1	KSTART 1 1	KEND 999 999	KINC 1 1
MOV:	3 IE 0 NT OUT	1	1 001	1	01	999	1	1	999	1
	TROL S	TYPE ISTAF SURFACE:	T IEND	IINC	JSTART	JEND	JINC	KSTART	KEND	KINC
	ID IST	CART IEN	ID JSTART	JEI	ND KST	ART KE	ND IV	ALL IN	IORM	

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.

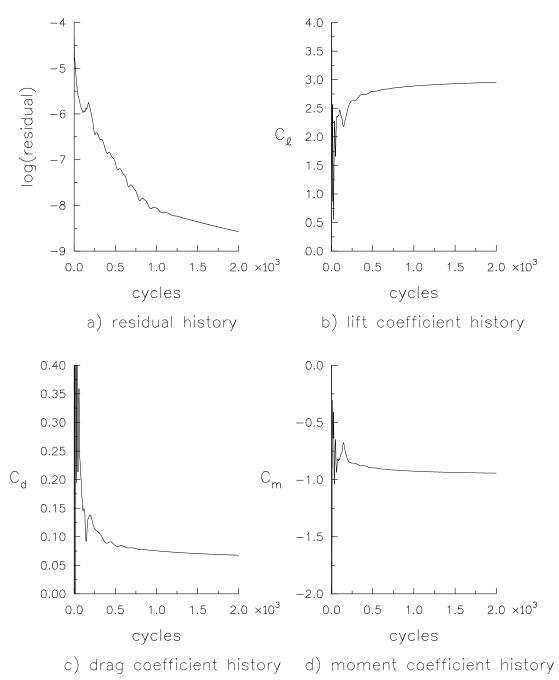


Figure 9-9. Convergence histories for three-element airfoil case;

$$\alpha = 8.109^{\circ}, Re_{\tilde{L}_R} = 9 \times 10^6.$$

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.

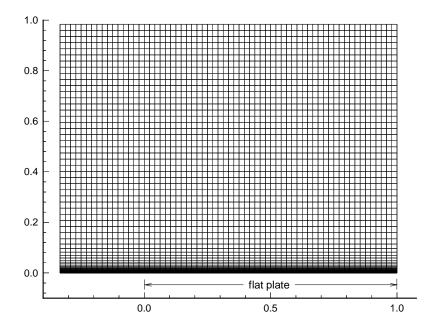


Figure 9-10. Single zone flat plate grid.

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

<u>File</u>	<u>Description</u>
grdflat5.inp	input for CFL3D
grdflat5.grd	formatted grid
grid2dto3d.f	grid converter

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

<u>Step 1</u>

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

```
precfl3d < grdflat5.inp</pre>
```

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
```

```
I/O FILES grdflat5.bin plot3dg.bin plot3dq.bin cfl3d.out cfl3d.res cfl3d.turres cfl3d.blomax cfl3d.out15 cfl3d.prout
```

```
cfl3d.out20
ovrlp.bin
patch.bin
restart.bin
    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
                                                   460.0
                              0.0
                                      06.000
                                                                  Λ
      SREF
                  CREF
                             BREF
                                         XMC
                                                     YMC
                                                                ZMC
   1.00000
              1.00000
                           1.0000
                                     0.00000
                                                    0.00
                                                               0.00
        DT
                 IREST
                          IFLAGTS
                                        FMAX
                                                   IUNST
                                                             CFLTAU
     -5.000
                     1
                              000
                                     05.0000
                                                       0
                                                                10.
              NPLOT3D
                                                                                       ITA
     NGRID
                           NPRINT
                                      NWREST
                                                    ICHK
                                                                I2D
                                                                        NTSTEP
          1
                     1
                                2
                                        1200
                                                       0
                                                                  1
       NCG
                                                                      IVISC(K)
                        IADVANCE
                                      IFORCE
                                               IVISC(I)
                                                           IVISC(J)
                   IEM
          2
                     0
                                0
                                          001
                                                       0
                                                                  0
    IDIM
             JDIM
                      KDIM
      02
                65
                        97
                ILAMHI
                                      JLAMHI
    ILAMLO
                           JLAMLO
                                                 KLAMLO
                                                             KLAMHI
                                                                 97
          1
                     2
                                1
                                           17
                                                       1
     INEWG
                IGRIDC
                               IS
                                           JS
                                                      KS
                                                                 ΙE
                                                                            JE
                                                                                        KE
                     0
                                0
                                                       0
                                                                                         0
          0
                                            0
                                                                  0
                                                                             0
  IDIAG(I)
             IDIAG(J)
                         IDIAG(K)
                                    IFLIM(I)
                                               IFLIM(J)
                                                           IFLIM(K)
                                            0
                                                       0
          1
                                1
   TFDS(T)
                          IFDS(K)
                                    RKAPO(I)
                                               RKAPO(J)
                                                          RKAPO(K)
              IFDS(J)
                                      0.3333
                                                 0.3333
                                                             0.3333
                NBCI0
                                       NBCJ0
                                                              NBCK0
                                                                       NBCKDIM
       GRID
                          NBCIDIM
                                                NBCJDIM
                                                                                   TOVRLP
          1
                     1
                                1
                                            1
                                                       1
                                                                  2
                                                                              1
I0:
       GRID
              SEGMENT
                           BCTYPE
                                        JSTA
                                                    JEND
                                                               KSTA
                                                                          KEND
                                                                                    NDATA
                             1001
                                           Ω
                                                       0
                                                                             0
          1
                     1
                                                                  0
                                                                                         Λ
IDIM: GRID
              SEGMENT
                           BCTYPE
                                                    JEND
                                                                          KEND
                                        JSTA
                                                               KSTA
                                                                                    NDATA
                     1
                             1002
                                            0
                                                       0
                                                                  0
                                                                             0
                                                                                         0
          1
.TO:
       GRID
              SEGMENT
                           BCTYPE
                                        ISTA
                                                    IEND
                                                               KSTA
                                                                          KEND
                                                                                    NDATA
          1
                     1
                             1008
                                            0
                                                       0
                                                                  0
                                                                             0
                                                                                         0
JDIM: GRID
              SEGMENT
                           BCTYPE
                                        ISTA
                                                    IEND
                                                               KSTA
                                                                          KEND
                                                                                    NDATA
          1
                     1
                             1002
                                                       0
                                                                  0
                                                                             0
                                                                                         0
κO:
       GRID
              SEGMENT
                           BCTYPE
                                        TSTA
                                                    TEND
                                                               JSTA
                                                                          JEND
                                                                                    NDATA
          1
                     1
                             1001
                                            0
                                                       0
                                                                  1
                                                                            17
                                                                                         0
          1
                     2
                             2004
                                            0
                                                       0
                                                                 17
                                                                             65
                                                                                         2
                TWTYPE
                               CQ
                    0.
                               0.
KDIM: GRID
              SEGMENT
                           BCTYPE
                                        ISTA
                                                    IEND
                                                               JSTA
                                                                          JEND
                                                                                    NDATA
                     1
                             1003
                                            0
                                                       0
          1
                           ICONSF
                                         MTT
                                                    NGAM
      MSEQ
               MGFTAG
          1
                     1
                                0
                                            0
                                                      02
            EPSSSC(1) EPSSSC(2) EPSSSC(3)
       ISSC
                                                    ISSR EPSSSR(1) EPSSSR(2) EPSSSR(3)
          Λ
                   0.3
                              0.3
                                          0.3
                                                       0
                                                                0.3
                                                                           0.3
      NCYC
               MGLEVG
                            NEMGL
                                       NITFO
       0500
                    03
                               0.0
                                         000
      MIT1
                  MIT2
                             MIT3
                                        MIT4
                                                   MTT5
                                                               MIT6
                                                                          MIT7
                                                                                    мтт8
        01
                    01
                               01
                                           01
                                                      01
                                                                  1
   1-1 BLOCKING DATA:
      NBLI
          0
 NUMBER
          GRID
                           ISTA
                                   JSTA
                                           KSTA
                                                   IEND
                                                           JEND
                                                                  KEND
                                                                         ISVA1
                                                                                 ISVA2
 NUMBER
                           ISTA
                                          KSTA
                                                   IEND
                                                          JEND
                                                                  KEND
                                                                         ISVA1
                                                                                 ISVA2
           GRID
                                   JSTA
  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
                                                                              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
                                                                      1
                                                                              1
                                                                                      1
              0
                      0
                              0
                                      0
                                             49
                                                     49
                                                              1
                                                                      0
                                                                              0
                                                                                      0
       1
  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^+ verses 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.

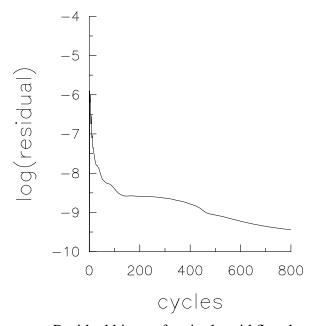


Figure 9-11. Residual history for single grid flat plate case.

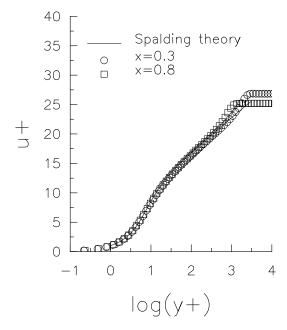


Figure 9-12. Flat plate calculation compared with experiment; $Re_{\tilde{L}_R} = 6 \times 10^6$.

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:

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

This case requires between 800 to 1800 cycles to converge, depending on the turbulence model employed and the convergence criterion chosen. Generally, $k-\epsilon$ 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 $k_r = \tilde{\omega}\tilde{c}/2|\tilde{\mathbf{V}}|_{\infty}$, where ω is in radians/second, is 4.0. (Note that the input to CFL3D defines $\tilde{\omega}$ in cycles/second; therefore, **rfreq** = 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 **dzmax** = 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 **ntstep**-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 CRAY YMP (NASA LaRC's Sabre as of July 1996).

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

<u>File</u>	<u>Description</u>
vibrate.inp	input for CFL3D
cartesian.f	grid generator

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

<u>Step 1</u>

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

```
2
-6,2,0,1
.05,.05
0
2,7,0,1
.05,.05
```

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

```
precfl3d < vibrate.inp</pre>
```

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
```

```
I/O FILES
grid.bin
plot3dg.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.turres
cfl3d.blomax
cfl3d.out15
cfl3d.prout
cf13d.out20
ovrlp.bin
patch.bin
restart.bin
  Flat plate vibrating cascade with sliding interface downstream
     XMACH
                ALPHA
                           BETA REUE, MIL
                                              TINF,DR
                                                          IALPH
                                                                    IHSTRY
      .500
                 0.00
                            0.0
                                      1.07
                                                520.0
                                                              0
                 CREF
                                       XMC
                                                            ZMC
      SREF
                           BREF
                                                  YMC
   1.00000
              1.00000
                         1.0000
                                   0.25000
                                                 0.00
                                                           0.00
                IREST
                                      {\tt FMAX}
                                                IUNST
        DT
                        IFLAGTS
                                                         CFLTAU
  .0098175
                             000
                                      1.00
```

NGRID	NPLOT3D	NPRINT	NWREST 2000 IFORCE	ICHK O	I2D 1	NTSTEP	ITA -2
NCG	IEM	IADVANCE	IFORCE	IVISC(I)	IVISC(J)	IVISC(K)	2
2 2	0	0	001 001	0	0	0	
IDIM	JDIM	KDIM	001	0	0	O	
2	161	21					
Z ILAMLO	TUL TIJAMHI	JLAMLO	JLAMHI	KLAMLO	KLAMHI		
00	00	000	000	0	0000		
00	00 TCPTDC	000	000 000 JS 0	, KG	0000	.т.г	V F
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
IDIAG(I) 1	IDIAG(J) 1	IDIAG(K) 1	IFLIM(I)	U TF.PTW(1)	TF.PTW(K)		
1	1	1	1FLIM(1) 0 0 RKAP0(I)	0	0		
IFDS(I)	IFDS(J)	IFDS(K)	RKAPO(I)	RKAPO(J)	RKAPO(K)		
1	1	1	.3333	.3333	.3333		
GRID	NBCI0	NBCIDIM	NBCJ0	NBCJDIM	NBCK0	NBCKDIM	IOVRLP
1	1	1	1	1	3	3	0
IO: GRID	SEGMENT	BCTYPE	JSTA	JEND	KSTA	KEND	NDATA
1	1	1001	0	0	0	0	0
GRID 1 2 10: GRID 1 2 IDIM: GRID 1 2 JO: GRID 1 2 JDIM: GRID 1 2 KO: GRID 1	SEGMENT	BCTYPE 1001	U ATRT.	U TEND	U KSTA	KEND 0	0 ATACIN
1	1	1002	0	0	0	0	0
2	1	1002	0	0	0	0	0
JU: GRID	SEGMENI 1	1003	151A 0	0 TEND	KSIA 0	VEND	NDATA 0
2	1	0	0	0	0	0	0
JDIM: GRID	SEGMENT 1	BCTYPE	ISTA	IEND	KSTA	KEND	NDATA
2	1	1003	0	0	0	0	0
K0: GRID	SEGMENT	BCTYPE	ISTA	IEND	JSTA	JEND	NDATA
1	1 NRI.D	2005 TTHTX	DTHTV	2 DTHT7	1	121	4
	1	0.0	0.	0.			
1	2	1005	DTHTY 0. 1	2	121	141 161	0
1	NBLP	DTHTX	DTHTY	Z DTHTZ	141	101	4
	1	0.0	DTHTY 0. 0 DTHTY	0.			
2	1 NDT D	2005	סיינוייט 0	סיייטייט 0	0	0	4
	2	0.0	0.	0.			
KDIM: GRID	SEGMENT	BCTYPE	ISTA	IEND	JSTA	JEND	NDATA
1	_		1 DTHTY	2 DTHTZ		121	4
	1	0.0	0.	0.			
1	2 3	1005 2005		2 2		141	0 4
1	NBLP	DTHTX	DTHTY	DTHTZ	141	161	4
	1	0.0	0.	0.	_	_	_
2	1 NBLP	2005 DTHTX	0 DTHTY	0 DTHTZ	0	0	4
	2	0.0	0.	0.			
MSEQ	MGFLAG 1	ICONSF	MTT 0	NGAM 02			
ISSC	EPSSC(1)	EPSSC(2)	EPSSC(3)	ISSR	EPSSR(1)	EPSSR(2)	EPSSR(3)
0	.3	.3	.3		.3	.3	.3
NCYC 3	MGLEVG 03	NEMGL 00	NITFO 000				
MIT1	MIT2		мтт4	MIT5			
01	01	01	01	01			
1-1 BLOC NBLI	KING DATA:						
0							
			JSTA KST JSTA KST				
	FACE DATA:		IGA AIGU	Y TEND	овил Кр	TPANT חוזי	TOVAZ
NINTER							

	0									
	D OUTPUT									
GRID	IPTYPE	ISTART	IEND	IINC JST	CART	JEND	JINC	KSTART	KEND	KINC
2	0	1 1	999	1	01	999	1	1	999	1
MOVIE		_		_	0.1		_	_		_
0										
PRINT		ISTART	TEND	TINC JST	TART	JEND	JINC	KSTART	KEND	KINC
1	1	1 1	2	1	999	999	1	1	999	1
			2	1	1	1	1	1	999	1
NCS	OL SURFA	CE.								
0										
		IEND TA - TRA			KSTAI	RT KI	END IV	VALL IN	IORM	
NTRAN		IA - IKA	NSLATION							
LRE										
GRI	D ITRA	NS RF	REQ	XMAG	YMAG	ZI	MAG			
:	1	2 .31 1	831	0.	0.	0.001	100			
GR TI	2 מצח מא	iya da. T	0. may d	0. ZMAX	0.	0.318	831			
GICI	$\frac{1}{1}$	IAX DY	0. 0	.000						
	2		0. 1	.000						
MOVING NROTA		TA - ROT	ATTON							
_										
	0									
LRE	F	יס סי די אי	DEO TU	·VM7C T	THVMAC	ייעייי	MAC	VORTC	VODI	C ZORIC
LREI GRII	F D IROT	'AT RF	REQ TH MAX TH	XMAG T	THYMAG	THZ	MAG	XORIG	YORIO	G ZORIG
LREI GRII GRII DYNAMI	F D IROT D THXM IC PATCH	AT RF. IAX THY.	MAX TH	XMAG T	THYMAG	THZI	MAG	XORIG	YORI	G ZORIG
LREI GRII GRII DYNAMI NIN	F D IROT D THXM IC PATCH TER	IAX THY. I INPUT D.	MAX TH ATA	ZMAX						
LREI GRII GRII DYNAMI NIN	F D IROT D THXM IC PATCH TER	IAX THY. I INPUT D.	MAX TH ATA	ZMAX						
LREI GRII GRII DYNAMI NIN	F D IROT D THXM IC PATCH TER	IAX THY. I INPUT D.	MAX TH ATA	ZMAX						
LREI GRII GRII DYNAMI NIN	F D IROT D THXM IC PATCH TER	IAX THY. I INPUT D.	MAX TH ATA	ZMAX						
LREI GRII GRII DYNAMI NIN	F D IROT D THXM IC PATCH TER	IAX THY. I INPUT D.	MAX TH ATA	ZMAX						
LREI GRII GRII DYNAMI NIN	F D IROT D THXM IC PATCH TER 2 IFIT -1 -1 TO 122 FROM	IAX THY. INPUT D. LIMIT 5 5 XIE1 0 XIE1	MAX TH ATA ITMAX 20 20 XIE2 0 XIE2	ZMAX MCXIE 0 ETA1 0 ETA1	. Mo) 	CETA 0 0 ETA2 0 ETA2	C-(((NFI 2 FACT:) IOF)) 3 2 J FAC	RPH : 0 0	
LREI GRII GRII DYNAMI NIN	F D IROT D THXM IC PATCH TER	LIMIT 5 5 XIE1 0 XIE1 0	MAX TH ATA ITMAX 20 20 XIE2 0 XIE2	ZMAX MCXIE 0 ETA1 0 ETA1	. Mo) 	CETA 0 0 ETA2 0 ETA2	C-(((NFI 2 FACT:) IOF)) 3 2 J FAC	RPH : 0 0	
LREI GRII GRII DYNAMI NIN	F D IROT D THXM IC PATCH TER 2 IFIT -1 -1 TO 122 FROM	LIMIT LIMIT 5 XIE1 0 XIE1 0 DX 0.	MAX THATA ITMAX 20 20 XIE2 0 XIE2 0 DY 0.	ZMAX MCXIE 0 ETA1 0 ETA1 0 DD	. M()) . 1) . 1	CETA 0 0 ETA2 0 ETA2 0 ETA2 0 HETX	C-((NF 2 FACTO DTHET)	O IOF	RPH : 0 0 0 CTK 0.	
LREI GRII GRII DYNAMI NIN	FD IROT D THXM IC PATCH TER 2 IFIT -1 -1 TO 122 FROM 221 FROM	LIMIT 5 5 XIE1 0 XIE1 0 XXIE1 0 XXIE1	MAX TH ATA ITMAX 20 20 XIE2 0 XIE2 0 DY 0. XIE2	MCXIE 0 0 ETA1 0 ETA1 0 DZ 0 ETA1	G M())) 1) () Triangle of the control of the co	CETA 0 0 ETA2 0 ETA2 0 HETX 0.	C-(((NFF FACTO DTHET)) IOF) 3 2 J FAC , DTHE	RPH : 0 0 0 CTK 0. CTK 0. CTK	
LREI GRII GRII DYNAMI NIN	F D IROT D THXM IC PATCH TER 2 IFIT -1 -1 TO 122 FROM 221	LIMIT 5 5 XIE1 0 XIE1 0 XIE1 0 XIE1 0 0	MAX TH ATA ITMAX 20 20 XIE2 0 XIE2 0 DY 0. XIE2	MCXIE 0 0 ETA1 0 ETA1 0 DZ 0 ETA1	G M())) 1) () Triangle of the control of the co	CETA 0 0 ETA2 0 ETA2 0 HETX 0. ETA2	C-(((NFF FACTO DTHET)) IOF) 3 2 J FAC , DTHE	RPH : 0 0 0 CTK 0. CTK 0. CTK	
LRE GRI GRI DYNAM NIN' INT 1 2 INT 1	FD IROT D THXM IC PATCH FER 2 IFIT -1 TO 122 FROM 221 FROM 221	LIMIT 5 5 XIE1 0 XIE1 0 XIE1 0 DX 0. XIE1 0 0.	MAX TH ATA ITMAX 20 20 XIE2 0 XIE2 0 DY 0. XIE2 0 DY 0. DY 0. 0.	MCXIE 0 0 ETA1 0 ETA1 0 DZ 0. ETA1 0	G M()))) () () () () () () () () () () (CETA 0 0 ETA2 0 ETA2 0 HETX 0. ETA2 0 HETX	C-(() () NFF 2 FACTO 0. DTHETY 0. DTHETY	O IOF O O O O O O O O O O O O O O O O O O O	RPH 0 0 0 CTK 0. CTK 0. CTK 0. CTK 0. CTK	
LRE: GRI: GRI: DYNAM: NIN' INT 1 2 INT 1	FD IROT D THXM IC PATCH FER 2 IFIT -1 TO 122 FROM 221 FROM 221	LIMIT 5 5 XIE1 0 XIE1 0 XIE1 0 XXIE1 0 XXIE1 0 XXIE1 0 XXIE1 0 XXIE1	MAX TH ATA ITMAX 20 20 XIE2 0 XIE2 0 DY 0. XIE2 0 DY 0. XIE2 0 XIE2	MCXIE 0 0 ETA1 0 ETA1 0 DZ 0. ETA1 0 DZ	G M())))) 1) TITC TI	CETA 0 0 ETA2 0 ETA2 0 HETX 0 HETX 0 HETX 0 HETX	C-(() () () () () () () () () () () () ()	O IOF O O O O O O O O O O O O O O O O O O O	RPH 0 0 0 CTK 0. CTK 0. CTK 0. CTK 0. CTK	
LRE GRI GRI DYNAM NIN' INT 1 2 INT 1	FD IROT D THXM IC PATCH FER 2 IFIT -1 TO 122 FROM 221 FROM 221	LIMIT 5 5 XIE1 0 XIE1 0 XIE1 0 DX 0. XIE1 0 0.	MAX TH ATA ITMAX 20 20 XIE2 0 XIE2 0 DY 0. XIE2 0 DY 0. DY 0. 0.	MCXIE 0 0 ETA1 0 ETA1 0 DZ 0. ETA1 0	G M())) 1) TTI TTI TTI TTI	CETA 0 0 ETA2 0 ETA2 0 HETX 0. ETA2 0 HETX 0.	C-C () () () () () () () () () () () () ()	O IOF O O O O O O O O O O O O O O O O O O O	RPH 0 0 0 CTK 0. CTZ 0. CTK 0. CTZ 0. CTZ 0. CTZ 0. CTZ 0.	
LRE: GRI: GRI: DYNAM: NIN' INT 1 2 INT 1	FD IROT D IROT D THXM IC PATCH IER 2 IFIT -1 TO 122 FROM 221 FROM 221 TO 221	LIMIT 5 5 XIE1 0 XIE1	MAX TH ATA ITMAX 20 20 XIE2 0 XIE2 0 DY 0. XIE2 0 DY 0. XIE2 0 XIE2 0 XIE2 0 XIE2 0 XIE2 0 XIE2	MCXIE 0 0 ETA1	G M()) 1) 1) 1) 1) 1) 1) 1) 1) 1) 1)	CETA 0 0 ETA2 0 ETA2 0 HETX 0. ETA2 0 HETX 0. ETA2 0 HETX 0. ETA2 0	C-(() () () () () () () () () () () () ()	O IOF O O O O O O O O O O O O O O O O O O O	RPH 0 0 0 CTK 0.	
LRE: GRI: GRI: DYNAM: NIN' INT 1 2 INT 1	FD IROT D IROT D THXM IC PATCH TER 2 IFIT -1 -1 TO 122 FROM 221 FROM 221 TO 221 FROM	LIMIT 5 5 XIE1 0 XIE1 0 XIE1 0 XIE1 0 XIE1 0 DX 0. XIE1 0 DX 0. XIE1 0 DX	MAX TH ATA ITMAX 20 20 XIE2 0 XIE2 0 DY 0.	MCXIE 0 0 ETA1 0 ETA1 0 ETA1 0 ETA1 0 ETA1 0 ETA1 0 DZ -1. ETA1 0 ETA1	G M())) 1) TI DTI	CETA 0 0 ETA2 0 ETA2 0 HETX 0. ETA2 0 HETX 0. ETA2 0 HETX	C-(() () () () () () () () () () () () ()	O IOF O O O O O O O O O O O O O O O O O O O	RPH 0 0 0 CTK 0. CTK 0. CTZ 0. CTZ 0. CTZ 0.	
LRE: GRI: GRI: DYNAM: NIN' INT 1 2 INT 1	FD IROT D IROT D THXM IC PATCH TER 2 IFIT -1 -1 TO 122 FROM 221 FROM 221 TO 221 FROM	LIMIT 5 5 XIE1 0 XIE1	MAX TH ATA ITMAX 20 20 XIE2 0 XIE2 0 DY 0. XIE2 0 DY 0. XIE2 0 XIE2 0 XIE2 0 XIE2 0 XIE2 0 XIE2	MCXIE 0 0 ETA1	G M())) 1) TI DTI	CETA 0 0 ETA2 0 ETA2 0 HETX 0. ETA2 0 HETX 0. ETA2 0 HETX	C-(() () () () () () () () () () () () ()	O IOF O O O O O O O O O O O O O O O O O O O	RPH 0 0 0 CTK 0. CTZ 0. CTK 0. CTZ 0. CTK 0. CTZ 0. CTTZ 0.	
LRE: GRI: GRI: DYNAM: NIN' INT 1 2 INT 1	FD IROT D IROT D THXM IC PATCH TER 2 IFIT -1 -1 TO 122 FROM 221 FROM 221 TO 221 FROM 122	LIMIT 5 XIE1 0 XIE1	MAX TH ATA ITMAX 20 20 XIE2 0 XIE2 0 DY 0. XIE2 0 DY 0. XIE2 0 DY 0. XIE2 0 XIE2	MCXIE 0 0 ETA1 0 ETA1 0 ETA1 0 DZ 0. ETA1 0 DZ -1. ETA1 0 ETA1 0 ETA1	G M())))) TI DTI DTI DTI DTI DTI D	CETA 0 0 ETA2 0 ETA2 0 HETX 0. ETA2 0 HETX 0. ETA2 0 HETX 0. ETA2 0 ETA2 0 HETX 0 O HETX 0	C-(() () () () () () () () () () () () ()	DTHE	RPH 0 0 CTK 0. CTK 0. CTZ 0. CTK 0. CTZ 0. CTK 0. CTK 0.	
LRE: GRI: GRI: DYNAM: NIN' INT 1 2 INT 1	FD IROT D IROT D THXM IC PATCH TER 2 IFIT -1 TO 122 FROM 221 FROM 221 FROM 122 FROM 122 FROM 122	LIMIT 5 XIE1 0 XIE1	MAX TH ATA ITMAX 20 20 XIE2 0 XIE2 0 DY 0. XIE2 0 DY 0. XIE2 0 DY 0. XIE2 0 DY 0. XIE2 0 XIE2	MCXIE 0 0 ETA1 0 ETA1 0 ETA1 0 ETA1 0 ETA1 0 DZ -1. ETA1 0 ETA1 0 ETA1	G M())))) TI DTI DTI DTI DTI DTI D	CETA 0 0 ETA2 0 ETA2 0 HETX 0. ETA2 0 HETX 0. ETA2 0 HETX 0. ETA2 0 HETX	C-() () () () () () () () () () () () () (DTHE	RPH 0 0 CTK 0. CTK 0. CTZ 0. CTK 0. CTZ 0. CTK 0. CTK 0.	

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.

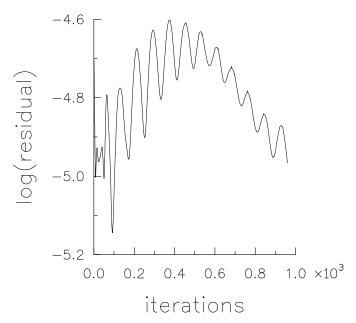


Figure 9-13. Residual history for inviscid flow through vibrating flat plates.

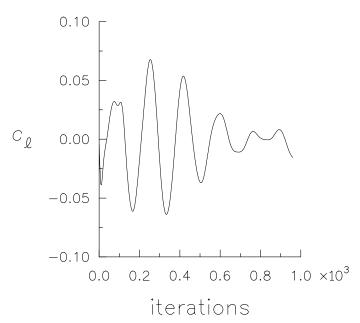


Figure 9-14. Lift coefficient history for inviscid flow through vibrating flat plates; $M_{\infty}=0.5$.

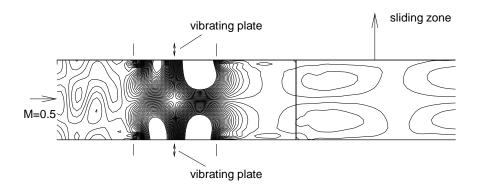


Figure 9-15. Pressure contours for inviscid flow through vibrating flat plates; $M_{\infty} = 0.5$.

9.1.7 Multistream Nozzle

This case simulates, in two dimensions, the flow though 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.

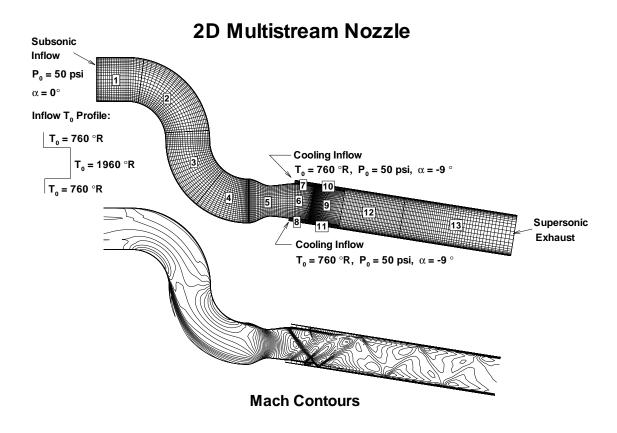


Figure 9-16. Cross-section of multistream nozzle zonal patching and Mach contours.

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 $1960^{\circ}R$ in the core and $760^{\circ}R$ 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 $760^{\circ}R$. 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 $1960^{\circ}R$) 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:

$$\tilde{T}_0 = \frac{0.769}{1.449(1960)} + \frac{(1.449 - 0.769)}{1.449(760)} = 1397^{\circ} R$$
 (9-1)

Next, determine the stagnation density and speed of sound:

$$\tilde{\rho}_0 = \frac{\tilde{p}_0}{\tilde{R}\tilde{T}_0} = \frac{50(144)}{1716(1397)} = 0.00300 \text{ slugs/feet}^3$$
 (9-2)

$$\tilde{a}_0 = \sqrt{\gamma \tilde{R} \tilde{T}_0} = \sqrt{1.4(1716)(1397)} = 1832 \text{ feet/second}$$
 (9-3)

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

$$\frac{p}{p_0} = 0.528, \frac{T}{T_0} = 0.833, \frac{\rho}{\rho_0} = 0.634, \frac{a}{a_0} = 0.913$$
 (9-4)

Thus, the desired reference pressure, temperature, speed of sound and density are

$$\tilde{p} = 50(0.528) = 26.4 \text{ psi}$$
 $\tilde{T} = 1397(0.833) = 1164^{\circ}\text{R}$
 $\tilde{\rho} = 0.003(0.634) = 0.0019 \text{ slug/feet}^3$
 $\tilde{a} = 1832(0.913) = 1673 \text{ feet/second}$
(9-5)

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

$$\tilde{\mu}^* = 3.7 \times 10^{-7} \left(\frac{1164}{520}\right)^{0.76} = 6.82 \times 10^{-7} \text{ slugs/(feet-seconds)}$$
 (9-6)

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

$$Re^* = \frac{\tilde{\rho}^* \tilde{u}^* (\text{throat height})}{\tilde{\mu}^*} = 0.0019(1673) \frac{1}{6.82 \times 10^{-7}} = 4.66 \times 10^6$$
 (9-7)

In the grid, the throat height is 12 inches, so the input parameter **reue** is

reue =
$$\frac{Re^* \times 10^{-6}}{12} = \frac{4.66}{12} = 0.388$$
 (9-8)

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):

$$p_{t} = 50 \text{ psi} \rightarrow \frac{p_{t}}{p^{*}} = \frac{p_{t}}{p_{\infty}} = \frac{50}{26.4} = 1.894$$

$$T_{t} = 760^{\circ} \text{R} \rightarrow \frac{T_{t}}{T^{*}} = \frac{T_{t}}{T_{\infty}} = \frac{760}{1164} = 0.653$$

$$T_{t} = 1960^{\circ} \text{R} \rightarrow \frac{T_{t}}{T^{*}} = \frac{T_{t}}{T_{\infty}} = \frac{1960}{1164} = 1.684$$
(9-9)

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:

$$M = 0.45$$

$$\frac{p_t}{p_{\infty}} = 1.894$$
 (9-10)
$$\frac{T_t}{T_{\infty}} = \frac{0.653}{1.684}$$

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

$$M=1.0$$

$$\frac{p_t}{p_{\infty}}=1.894$$

$$\frac{T_t}{T_{\infty}}=0.653$$

$$\alpha=-9$$

$$\beta=0$$
 (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:

<u>File</u>	<u>Description</u>
multistream.inp	input for CFL3D
<pre>grid_multistream.fmt</pre>	formatted grid
formtobin.f	grid converter
inflow.data	auxiliary boundary condition data
ron1.h	parameters for ronnie makefile
ronnie.inp	input for ronnie

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

<u>Step 1</u>

Compile the grid converter code:

cft77 formtobin.f

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</pre>
```

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

```
precfl3d < multistream.inp</pre>
```

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
```

```
I/O FILES
grid_multistream.p3d
plot3dg.bin
```

```
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.turres
cfl3d.blomax
cfl3d.out15
cfl3d.prout
cfl3d.out20
ovrlp.bin
patch_multistream.bin
restart.bin
 Multistream Nozzle (sonic conditions as reference state)
      XMACH
                 ALPHA
                               BETA REUE, MIL
                                                    TINF, DR
                                                                  IALPH
                                                                              IHIST
                                0.0
      1.000
                   0.00
                                          0.388
                                                     1163.0
                                                                       1
                                                                                   1
       SREF
                   CREF
                               BREF
                                            XMC
                                                         YMC
                                                                     ZMC
   1.00000
               1.00000
                             1.0000
                                                                   0.00
                                        0.25000
                                                        0.00
         DT
                  IREST
                            IFLAGTS
                                           FMAX
                                                      IUNST
                                                                CFL_TAU
     -1.0000
                       0
                                000
                                                          +1
                                                                      5.
                                            1.0
               NPLOT3D
                             NPRINT
                                         NWREST
     NGRID
                                                        ICHK
                                                                     I2D
                                                                             NTSTEP
                                                                                             ITA
        -13
                     13
                                   0
                                             500
                                                           0
                                                                       1
                                                                                              -2
        NCG
                          IADVANCE
                                         IFORCE
                                                  IVISC(I)
                                                               IVISC(J)
                                                                           IVISC(K)
                    IEM
          1
                       0
                                   0
                                             000
                                                           0
                                                                       0
                                                                                  +7
           1
                       0
                                   0
                                             000
                                                           0
                                                                       0
                                                                                  +7
                       0
                                   0
                                             000
                                                           0
                                                                       0
                                                                                  +7
           1
                       0
                                   0
                                             000
                                                           0
                                                                       0
                                                                                  +7
                       0
                                   0
                                             000
                                                           0
                                                                       0
                                                                                  +7
          1
           1
                       0
                                   0
                                             000
                                                           0
                                                                       0
                                                                                  +7
                       0
                                                                       0
                                                                                  +7
           1
                                   0
                                             000
                                                           0
                       0
                                   0
                                             000
                                                           0
                                                                       0
                                                                                  +7
           1
                       0
                                   0
                                             000
                                                           0
                                                                       0
                                                                                  +7
           1
                       0
                                   0
                                             000
                                                           0
                                                                       0
           1
                       0
                                   0
                                             000
                                                           0
                                                                       0
                                                                                  +7
                                                                                  +7
                       0
                                   0
                                             000
                                                                       0
           1
                                                           0
                       0
                                   0
                                             000
                                                                       0
                                                                                  +7
           1
                                                           0
       IDIM
                   JDIM
                               KDIM
           2
                      23
                                  41
           2
                      23
                                  41
           2
                      23
                                  41
           2
                      23
                                  41
           2
                      25
                                  41
           2
                      25
                                  41
           2
                      17
                                  21
           2
                      17
                                  21
           2
                      49
                                  41
           2
                      49
                                  21
           2
                      49
                                  2.1
           2
                      41
                                  61
           2
                      49
                                  57
                                         JLAMHI
                                                     KLAMLO
    ILAMLO
                 ILAMHI
                             JLAMLO
                                                                 KLAMHI
         00
                      00
                                000
                                             000
                                                                   0000
                                                           0
                                                                   0000
         00
                      00
                                000
                                             000
                                                           0
         00
                      00
                                000
                                             000
                                                                    0000
         00
                      00
                                000
                                             000
                                                                   0000
                                                           0
         00
                      00
                                000
                                             000
                                                           0
                                                                   0000
         00
                      00
                                000
                                             000
                                                           0
                                                                   0000
         00
                      00
                                000
                                             000
                                                           0
                                                                   0000
         00
                      00
                                000
                                             000
                                                           0
                                                                   0000
         0.0
                                000
                                                           0
                                                                   0000
                      00
                                             000
         00
                      00
                                000
                                             000
                                                           0
                                                                   0000
                      00
         00
                                000
                                             000
                                                           0
                                                                   0000
         00
                      00
                                000
                                             000
                                                           0
                                                                   0000
         00
                      00
                                000
                                             000
                                                           0
                                                                   0000
                 IGRIDC
                                              JS
                                                                                  JΕ
      INEWG
                                  IS
                                                          KS
                                                                      ΙE
                                                                                              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
                                                                                               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 IDIAG(I) 1 1 1 1 1 1 1 1	0 0 0 0 IDIAG(J) 1 1 1 1 1 1 1 1 1 1	0 0 0 0 IDIAG(K) 1 1 1 1 1 1 1 1 1 1	0 0 0 0 IFLIM(I) 3 3 3 3 3 3 3 3 3 3 3	0 0 0 0 IFLIM(J) 3 3 3 3 3 3 3 3 3 3 3	0 0 0 0 IFLIM(K) 3 3 3 3 3 3 3 3 3 3 3	0 0 0 0	0 0 0 0
1 IFDS(I) 1 1 1 1 1 1 1 1 1 1 1 1 1 2 3 4 5 6 7	1 1 IFDS(J) 1 1 1 1 1 1 1 1 1 1 NBCIO 1 1 1 1	1 1 IFDS(K) 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	3 RKAPO(I) .3333 .3333 .3333 .3333 .3333 .3333 .3333 .3333 .3333 .3333 .3333 .31333	3 3 RKAPO(J) .3333 .3333 .3333 .3333 .3333 .3333 .3333 .3333 .3333 .3333 .3333 .31333	3 RKAPO(K) .3333 .3333 .3333 .3333 .3333 .3333 .3333 .3333 .3333 .3333 .3333 .3333 .31	NBCKDIM 1 1 1 1 1 1	IOVRLP 0 0 0 0 0
7 8 9 10 11 12 13 IO: GRID 2 3 4 5 6 7 8 9 10 11 12 13 IDIM: GRID 1 2 3 4 5 6 7 7 8 9 10 11 12 13 13 10 10 10 10 10 10 10 10 10 10 10 10 10	SEGMENT 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	BCTYPE 1002 1002 1002 1002 1002 1002 1002 100	JSTA 0 0 0 0 0 0 0 0 0 0 0 0 0 JSTA 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	JEND O O O O O O O O O O O O O	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0	1 1 1 1 1 1 1 1 1 1 1 1 1 1 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

J0: Mach	12 13 GRID 1 Pt/Pi	1 1 SEGMENT 1 .nf Tt/Tinf	1002 1002 BCTYPE 2003 alpha k	0 0 ISTA 0	0 0 IEND 0	0 0 KSTA 0	0 0 KEND 0	0 0 NDATA -5
inflo	ow.data 2	1	0	0	0	0	0	0
	3	1 1	0	0	0	0	0	0
	5 6	1 1	0 0	0 0	0 0	0 0	0	0 0
Mad		1 'Pinf Tt/Tir		0 beta	0	0	0	5
1.0	00 1. 8	894 0.653 1	2003	0.	0	0	0	5
Mad		Pinf Tt/Tin 894 0.653	nf alpha 3 -9.	beta 0.				
	9 10	1 1	0 0	0 0	0 0	0	0	0
	11 12	1 1	0	0 0	0	0	0	0
	13	1	0	0	0	0	0	0
JDIM	GRID 1	SEGMENT 1	BCTYPE 0	ISTA 0	IEND 0	KSTA 0	KEND 0	NDATA 0
	2	1	0	0	0	0	0	0
	3 4	1 1	0	0	0	0	0	0
	5	1	0	0	0	0	0	0
	6 7	1 1	0 0	0	0	0	0	0
	8	1	0	0	0	0	0	0
	9 10	1 1	0 0	0	0	0	0	0
	11	1	0	0	0	0	0	0
	12 13	1 1	0 1002	0	0	0	0	0
к0:	GRID	SEGMENT	BCTYPE	ISTA	IEND	JSTA	JEND	NDATA
Tw	1 Cq	1	2004	0	0	0	0	2
0.	0.							
Tw	2 Cq	1	2004	0	0	0	0	2
0.	0.							
Tw	3 Cq	1	2004	0	0	0	0	2
0.	0.							
Tw	4 Cq	1	2004	0	0	0	0	2
0.	0.							
Tw	5 Cq	1	2004	0	0	0	0	2
0.	0.							
Tw	6 Cq	1	2004	0	0	0	0	2
0.	0.					_	_	_
Tw	7 Cq	1	2004	0	0	0	0	2
0.	0.							
Tw	8 Cq	1	2004	0	0	0	0	2
0.	0.							
	9 10	1 1	0 2004	0 0	0 0	0	0	0 2
Tw	Cq	Δ.	2001	O	O	O	0	۷
0.	0. 11	1	0	0	0	0	0	0
	12	1	2004	0	0	0	0	0 2
Tw 0.	Cq 0.							
	13	1	2004	0	0	0	0	2
Tw 0.	Сq 0.							
٠.	٠.							

KDIM:	GRID 1	SEGMENT	BCTYPE 2004	I	STA 0	IENI	D 0	JSTA 0	JEND 0	NDATA 2
Tw	Cq									
0.	0. 2	1	2004		0	(0	0	0	2
Tw	Cq									
0.	0. 3	1	2004		0	(0	0	0	2
Tw	Cq	_	2001		Ü	·	O	Ü	· ·	2
0.	0. 4	1	2004		0	,	0	0	0	2
Tw	Cq	1	2004		U	,	U	U	U	۷
0.	0.	_			_			_	_	
Tw	5 Cq	1	2004		0	(0	0	0	2
0.	0.									
_	6	1	2004		0	(0	0	0	2
Γw O.	Сq 0.									
<i>.</i>	7	1	2004		0	(0	0	0	2
Γw	Cq									
0.	0. 8	1	2004		0	(0	0	0	2
Γw	Cq	1	2001		J	`	•	U	O	2
Ο.	0.	-	•		0		0	_	-	-
	9 10	1 1	0		0 0		0 0	0 0	0	0
	11	1	2004		0		0	0	0	2
Γw	Cq									
0.	0. 12	1	2004		0	(0	0	0	2
Γw	Cq	_	2001		O	`	O	O	· ·	2
0.	0.	-	0004				•			
Γw	13 Cq	1	2004		0	(0	0	0	2
0.	0.									
	MSEQ	MGFLAG	ICONSF	1	MTT	NGAI				
	1 ISSC	1 EPSSC(1)	1 EPSSC(2)	EPSSC	0 (3)	0: ISSI		R(1)	EPSSR(2)	EPSSR(3)
	0	.3	.3		.3		0	.3	.3	.3
	NCYC 3000	MGLEVG 02	NEMGL 00	NI'	TFO 0					
	MIT1	MIT2	MIT3	М	IT4	MIT!	5			
	01	01	01		01	0:	1			
1-1	L BLOC: NBLI	KING DATA:								
	0									
	MBER	GRID :			KSTA KSTA	IEND IEND	JEND JEND	KEN		ISVA2
		FACE DATA:		JSTA I	KSIA	TEND	OFIND	KEN	D ISVAI	ISVA2
N	INTER									
PLOT:	-1 3D OUT:	PUT:								
grid	d ipty	p ista i		_	jend	jinc		kend		
		0 0	0 0	0	0	0 0	0 0	0 0	0 0	
		0 0	0 0	0	0	0	0	0	0	
4	4	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	
	3	0 0	0 0	0	0	0	0	0	0	
8		0 0	0 0	0	0	0 0	0 0	0 0	0 0	
9		Λ Λ	0 0			U	U	U	U	
8)	0 0 0 0	0 0	0 0	Ö	0	0	0	0	
10 12 12) 1 2	0 0 0	0 0	0	0	0 0	0	0	0	
10 11 12 13	0 1 2 3	0 0	0 0	0	0	0				
10 12 12	0 1 2 3	0 0 0	0 0	0	0	0 0	0	0	0	
10 11 12 13 MOVI	O 1 2 3 IE 0 NT OUT	0 0 0 0 0 0	0 0 0 0 0 0	0	0 0 0	0 0 0	0	0	0	KINC

NCS								
4								
GRID	ISTA	IEND	JSTA	JEND	KSTA	KEND	IWALL	INORM
1	0	0	1	1	0	0	0	-1
7	0	0	1	1	0	0	0	-1
8	0	0	1	1	0	0	0	-1
13	0	0	49	49	0	0	0	1

The inflow.data file is:

```
auxiliary bc data, j-face of block 1, multistream nozzle
40, 2*1
5
40*0.44999999999999, 40*1.893999999999, 16*0.65300000000001,
8*1.685000000000004, 16*0.6530000000001, 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.

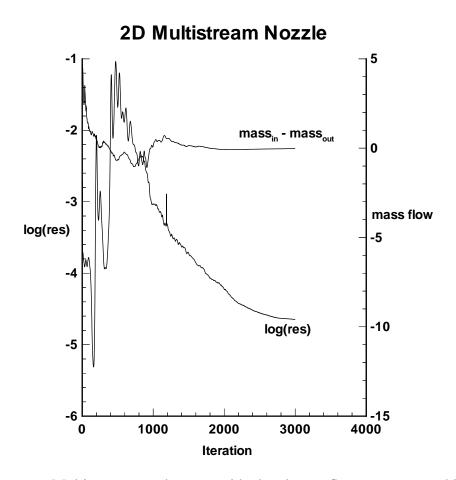


Figure 9-17. Multistream nozzle case residual and mass flow convergence history.

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. Dorney¹⁷ 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

 $M_{inlet} = 0.07 \text{ Re/L} = 100,000 \text{ U}_{axia}/\text{U}_{rotor} = 0.78$

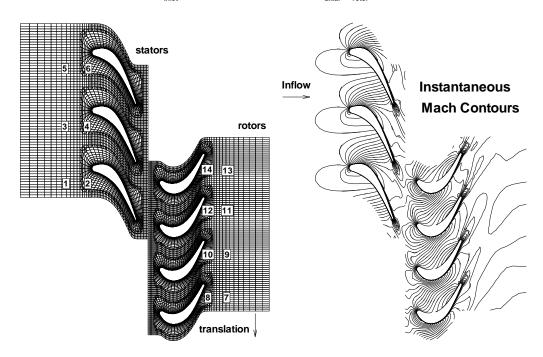


Figure 9-18. Fourteen zone rotor-stator grid system and Mach contours.

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.al¹⁸). 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 **xmach** = 0.07. The grid is full scale, with dimensions in inches. Therefore, **reue** = 0.1. The inlet temperature was assumed to be $60^{\circ}F$, so **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,

$$M_{inlet} = 0.07$$

$$\frac{p_{t, inlet}}{p_{\infty}} = 1.0035$$

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

Also, alphae = betae = 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

$$\frac{p_{exit}}{p_{\infty}} = \frac{p_{exit}}{p_{t,inlet}} \frac{p_{t,inlet}}{p_{\infty}} = 0.963 \times 1.0035 = 0.967$$
 (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" direction (**ialph** = 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 simulation corresponding to the mid-span radius is

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

This gives

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

The input value **wtrans** is $\tilde{w}_{trans}/\tilde{a}_{\infty}$, so with the reference Mach number 0.07, **wtrans** = 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 $\mathbf{dzmax} = 24.23514$. Thus the rotor zones are reset whenever the displacement exceeds 24.23514 inches.

9.1.8.3 Running CFL3D

T'1

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

<u>F11e</u>	Description
lsrr.inp	input for CFL3D
lsrr_coarse.p3d_fmt	formatted single plane grid
fmttobin_p3d.f	converter for creating 2 grid planes
mag1.h	parameters for MaGGiE makefile
maggie.inp	input for MaGGiE

D . ..

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

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</pre>
```

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

```
precfl3d < lsrr.inp</pre>
```

<u>Step 8</u>

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
```

```
I/O FILES
lsrr_coarse.p3d
plot3dg.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.turres
cfl3d.blomax
cfl3d.out15
cfl3d.prout
cf13d.out20
ovrlp.bin
patch.bin
restart.bin
  2D model of Pratt & Whitney Large Scale Rotating Rig (LSRR) - 50% Axial Gap
                               BETA REUE, MIL
      XMACH
                  ALPHA
                                                   TINF, DR
                                                                  IALPH
                                                                            IHSTRY
      0.070
                  0.000
                                0.0
                                            0.1
                                                      520.0
       SREF
                   CREF
                               BREF
                                            XMC
                                                        YMC
                                                                    ZMC
               1.00000
   1.00000
                            1.0000
                                         0.00000
                                                     0.0000
                                                                0.0000
         DT
                  IREST
                           IFLAGTS
                                           {\tt FMAX}
                                                      IUNST
                                                               CFL_TAU
   +1.0000
                                000
                                                                     5.
                                           1.00
                                                          1
               NPLOT3D
      NGRID
                            NPRINT
                                        NWREST
                                                       ICHK
                                                                    I2D
                                                                            NTSTEP
                                                                                            ITA
        -14
                     14
                                            100
                                                                               1500
                                         IFORCE
        NCG
                          IADVANCE
                                                  IVISC(I)
                                                              IVISC(J)
                                                                          IVISC(K)
                    IEM
           1
                       0
                                   0
                                              0
                                                           0
                                                                      0
                       0
                                   0
                                              0
                                                           0
                                                                      0
                                                                                   5
           1
                                                                                   5
           1
                       0
                                   0
                                              0
                                                           0
                                                                      0
           1
                       0
                                   0
                                               0
                                                           0
                                                                       0
                                                                                  5
                       0
                                   0
                                              0
                                                           0
                                                                      0
           1
                                                                                  5
           1
                       0
                                   0
                                              0
                                                           0
                                                                      0
                       0
                                                                                   5
           1
                                   0
                                              0
                                                           0
                                                                      0
                                                                                   5
5
5
5
           1
                       0
                                   0
                                              1
                                                           0
                                                                      0
           1
                       0
                                   0
                                               0
                                                           0
                                                                      0
           1
                       0
                                   0
                                              0
                                                           0
                                                                      0
           1
                       0
                                   0
                                              0
                                                           0
                                                                       0
                       0
                                   0
                                                           0
                                                                      0
                                                                                   5
           1
                                              0
                                                                                   5
           1
                       0
                                   0
                                              0
                                                           0
                                                                      0
                       0
                                   0
                                                           0
                                                                                   5
           1
       IDIM
                   JDIM
                               KDIM
        002
                     55
                                  23
                                 21
        002
                     61
        002
                     55
                                 23
        002
                     61
                                  21
                                 23
        002
                     55
        002
                     61
                                  21
        002
                                  23
                     61
                                  21
        002
                     61
        002
                                 23
                     61
        002
                     61
                                  21
        002
                     61
                                  23
                                 21
        002
                     61
        002
                     61
                                  23
                                 21
        002
                     61
     ILAMLO
                 ILAMHI
                             JLAMLO
                                         JLAMHI
                                                    KLAMLO
                                                                KLAMHI
         00
                     00
                                000
                                            000
                                                           0
                                                                   0000
                                                           0
                                                                   0000
         0.0
                     00
                                000
                                            000
         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
                                000
                                            000
                                                           0
         0.0
                                                                   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
                                                           0
                     00
                                000
                                            000
                                                                   0000
         00
```

00 00 INEWG 0 0 0 0 0 0 0 0	00 00 IGRIDC 0 0 0 0 0 0 0 0 0	000 000 IS 0 0 0 0 0 0 0 0	000 000 JS 0 0 0 0 0 0	0 0 KS 0 0 0 0 0 0 0	0000 0000 IE 0 0 0 0 0 0 0	JE 0 0 0 0 0 0 0 0 0	KE 0 0 0 0 0 0 0 0 0
IDIAG(I) 1 1 1 1 1 1 1 1 1 1 1 1 1	IDIAG(J) 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	IDIAG(K) 1 1 1 1 1 1 1 1 1 1 1 1 1	IFLIM(I) 0 0 0 0 0 0 0 0 0 0 0 0 0	IFLIM(J) 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	IFLIM(K) 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0		
1 GRID 1 2 3 4 5 6 7 8 9 10 11 12 13 14 10: GRID 1 2 3 4 5 6	1 NBCIO 1 1 1 1 1 1 1 1 1 1 1 1 SEGMENT 1 1 1 1	1 NBCIDIM 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	.3333 .3333 NBCJ0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	.3333 .3333 NBCJDIM 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	.3333 .3333 NBCKO 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	NBCKDIM 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0	IOVRLP 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0

10 11 12 13 14 IDIM: GRID 1 2	1 1 SEGMENT 1	1002 1002 1002 1002 1002 BCTYPE 1002 1002	0 0 0 0 0 JSTA 0	0 0 0 0 0 JEND 0	0 0 0 0 0 KSTA 0	0 0 0 0 KEND 0	0 0 0 0 0 NDATA 0
2 3 4 5 6 7 8 9 10 11 12 13	1 1 1 1 1 1 1 1 1	1002 1002 1002 1002 1002 1002 1002 1002	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 0
J0: GRID	1	BCTYPE 2003	ISTA 0	IEND 0	KSTA 0	KEND 0	NDATA 5
Mach Pt/P 0.07 1.0 2 3	035 1.0010 1 1	alpha bo 0. 0 2003	0. 0 0	0	0	0	0 5
Mach Pt/P 0.07 1.0 4 5 Mach Pt/P	035 1.0010 1 1	alpha bo	0. 0 0	0	0 0	0	0 5
0.07 1.0 6		alpha be 0. 0 0	0. 0 0	0	0	0	0
) 8 9 10 11 12 13 14 JDIM: GRID 1 2 3 4 5 6	1 1 1 1 1 1 SEGMENT	0 0 0 0 0 0 0 0 BCTYPE 0 0 0	0 0 0 0 0 0 0 0 ISTA 0 0	0 0 0 0 0 0 0 1END 0 0 0	0 0 0 0 0 0 0 KSTA 0 0 0	0 0 0 0 0 0 0 0 KEND 0 0 0	0 0 0 0 0 0 0 0 NDATA 0 0 0
7 pexit/pinf 0.967	1	2002	0	0	0	0	1
8 9 pexit/pinf 0.967	1 1	0 2002	0 0	0 0	0 0	0 0	0 1
10 11 pexit/pinf 0.967	1 1	0 2002	0	0	0	0	0 1
12 13 pexit/pinf 0.967	1 1	0 2002	0	0 0	0 0	0	0 1
14 KO: GRID 1 2 Tw/Tinf	SEGMENT 1	0 BCTYPE 0 2004	0 ISTA 0 0	0 IEND 0 0	0 JSTA 0 0	0 JEND 0 0	0 NDATA 0 2
3 4	1	0 2004	0	0	0	0	0 2

5 6). 1 1	0 2004	0	0	0	0	0 2
0. C	C_q). 1	0	0	0	0	0	0
0.	1 C_q).	2004	0	0	0	0	2
	1 1 2_q	0 2004	0	0	0	0	0 2
11 12). 1 1	0 2004	0 0	0	0	0	0 2
	Z_q). 1 1	0 2004	0	0	0	0	0 2
Tw/Tinf C	C_q). SEGMENT	BCTYPE	ISTA	IEND	JSTA	JEND	NDATA
1 2 3 4 5 6	1 1 1 1 1	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
7 8 9 10 11 12 13	1 1 1 1 1 1	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
14 MSEQ 1 ISSC 0	1 MGFLAG 1 EPSSC(1)	0 ICONSF 1 EPSSC(2)	0 MTT 0 EPSSC(3)	0 NGAM 01 ISSR 0	0 EPSSR(1)	0 EPSSR(2)	0 EPSSR(3)
NCYC 5 MIT1 01 1-1 BLOO NBLI 14	MGLEVG 02 MIT2 01 CKING DATA:	NEMGL 00 MIT3 01	NITFO 000 MIT4 01	MIT5 01			
NUMBER 1 2 3 4 5 6 7 8 9 10 11 12 13 14 NUMBER 1	GRID : 2 4 6 8 10 12 14 1 7 1 3 7 9 11 GRID : 2	1 1 1 1 1 1 1 1 1 1 1	STA KSTA 1	IEND 2 2 2 2 2 2 2 2 2 2 2 2 2 1END 2	JEND KEN	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	
2 3 4 5 6 7 8 9	4 6 8 10 12 14 5	1 1 1 1 1 1 1	61 1 61 1 61 1 61 1 61 1 61 1 1 23 1 23	2 2 2 2 2 2 2 2 2 2	61 2 61 2 61 2 61 2 61 2 61 2 61 2 61 2	1 1 1 1 1 1 1 1 1 1 1 1 1 1 3 1	3 3 3 3 3 3 3 2 2

```
2
                         1
                               1
                                       1
                                              2
                                                     55
                                                             1
                                                                     1
      11
                                                                              2
      12
             9
                                1
                                               2
                                                     61
      13
             11
                                1
                                               2
                                                                              2
                         1
                                       1
                                                     61
                                                             1
                                                                     1
      14
             13
                         1
                                                     61
PATCH SURFACE DATA:
  NINTER
PLOT3D OUTPUT:
BLOCK IPTYPE ISTART
                       IEND
                             IINC JSTART
                                             JEND
                                                   JINC KSTART
                                                                  KEND
                                                                         KINC
                              1 01
            0
              1
                       001
                                             999
                                                    1 1
                                                                  999
                                                                         1
     2
            0
                   1
                        001
                                 1
                                        01
                                              999
                                                       1
                                                              1
                                                                   999
                                                                            1
     3
            0
                        001
                                       01
                                              999
                                                                   999
     4
                                              999
                                                                   999
            0
                   1
                        001
                                 1
                                       01
                                                       1
     5
            0
                        001
                                 1
                                       01
                                              999
                                                                   999
     6
            0
                   1
                        001
                                 1
                                       01
                                              999
                                                       1
                                                              1
                                                                   999
                                                                            1
     7
            0
                   1
                        001
                                 1
                                       01
                                              999
                                                       1
                                                                   999
     8
                                              999
            0
                        001
                                       01
     9
                                              999
            0
                   1
                        001
                                 1
                                       01
                                                       1
                                                                   999
                                                                            1
    10
            0
                        001
                                 1
                                        01
                                              999
                                                       1
                                                                   999
                                       01
                                              999
                                                                   999
   11
            0
                   1
                        0.01
                                 1
                                                       1
                                                              1
                                                                            1
   12
            0
                   1
                        001
                                 1
                                        01
                                              999
                                                       1
                                                              1
                                                                   999
                                                                            1
   13
            0
                        001
                                 1
                                        01
                                              999
                                                                   999
                   1
                                                       1
                                                              1
                                                                            1
   14
            0
                   1
                        001
                                        0.1
                                              999
                                                              1
                                                                   999
                                 1
MOVIE
    0
PRINT OUT:
BLOCK IPTYPE ISTART
                       IEND IINC JSTART
                                            JEND
                                                  JINC KSTART
                                                                  KEND
                                                                         KINC
CONTROL SURFACES:
 NCS
GRID
        ISTA IEND JSTA
                         JEND KSTA KEND IWALL INORM
        1
                                0
   7
                 2
                    999
                           999
                                       0
                                              0
                                                      1
   9
                 2
                     999
                           999
           1
                                   0
                                         0
                                                0
                                                      1
   11
                     999
                           999
                 2
                     999
                           999
                                  0
                                        0
   13
          1
                                               Ω
                                                      1
                 2
   1
           1
                       1
                             1
                                   0
                                         0
                                                0
                                                      0
                 2
                                  0
                                        0
                                               0
                                                      0
   3
          1
                       1
                             1
                 2
                                        Ο
                                              Ω
   5
          1
                       1
                             1
                                  0
MOVING GRID DATA - TRANSLATION
NTRANS
     9
  LREF
   1.0
   GRID
       ITRANS
                 RFREQ
                         UTRANS
                                  VTRANS WTRANS
                0.
                              0.
             1
                                       0. -0.0897
     8
             1
                    0.
                              0.
                                        0. -0.0897
                   0.
                                       0. -0.0897
     9
                              0.
             1
    10
             1
                   0.
                              0.
                                        0. -0.0897
                                       0. -0.0897
0. -0.0897
                              0.
     11
             1
                   0.
     12
             1
                   0.
                              0.
     13
                   0.
                              0.
                                       0. -0.0897
     14
                   0.
                              0.
                                       0. -0.0897
             1
                   0.
     Ω
             1
                              0.
                                       0. -0.0897
                 DYMAX DZMAX
   GRID
        DXMAX
                 0. -24.23514
     7
            0.
                   0. -24.23514
0. -24.23514
      8
            0.
     9
            0.
     10
            0.
                   0. -24.23514
                    0. -24.23514
0. -24.23514
     11
            0.
     12
            0.
     13
                    0. -24.23514
            0.
     14
            Ο.
                    0. -24.23514
     0
            0.
                    0. -24.23514
MOVING GRID DATA - ROTATION
NROTAT
     0
  LREF
   GRID IROTAT RFREQ OMEGAX OMEGAY OMEGAZ XORIG YORIG ZORIG
        THXMAX THYMAX
                            THZMAX
  GRID
DYNAMIC PATCH INPUT DATA
  NINTER
```

	7							
INT	IFIT	LIMIT	ITMAX	MCXIE	MCETA	C-0	IORPH	ITOSS
1 2	1 1	1 1	30 30	0	0	0	0	1 1
3	1	1	30	0	0	0	0	1
4	1	1	30	0	0	0	0	1
5 6	1 1	1 1	30 30	0	0	0	0 0	1 1
7	1	1	30	0	0	0	0	1
INT	TO		XIE2		ETA2	NFB 6		
1	122	0 vrp1	0	0	0	6		
	FROM 721	0 VIET	XIE2 0	EIAI 0	E1A2	0.	0.	
	DX	DY	DZ 0.	DTHETX	DTHETY	DTHETZ		
	0.	0.	0.	0.	0.	0.		
	FROM 921	XIE1 0	0	EIAI	E1A2	FACTJ	PACIK	
	DX	DY	DZ 0.	DTHETX	DTHETY	DTHETZ		
	0.	0.	0.	0.	0.	0.		
	FROM 1121	O VIET	XIE2 0	EIAI 0	E1A2	0.	0.	
	DX	DY	DZ 0.	DTHETX	DTHETY	DTHETZ		
	0.	0. VIE1	0.	0.	0.	0.		
	FROM 1321	0 XTFT	XIE2 0	EIAI	E1A2	PACIO 0.	PACIK	
	DX	DY	0 DZ 0.	DTHETX	DTHETY	DTHETZ		
	0.	0.	0.	0.	0.	0.		
	FROM 721	0 XTFT	XIE2 0 DZ 24.23514	EIAI	E1A2	PACIO 0.	PACIK	
	DX	DY	DZ	DTHETX	DTHETY	DTHETZ	•	
	0.	0.	24.23514	0.	0.	0.		
	FROM 921	0 XTFT	XIEZ	EIAI	E1A2	PACIO 0.	PACIK	
	DX	DY	XIE2 0 DZ 24.23514	DTHETX	DTHETY	DTHETZ		
TATO	0.	0. VIE1	24.23514	0.	0.	0.		
INT 2	TO 322	0 VIET	XIE2 0	EIAI 0	E1A2	NFB 6		
_	FROM	XIE1	XIE2	ETA1	ETA2	FACTJ	FACTK	
	921 DX	0	0 DZ 0.	0	0	0.	0.	
	0.	0.	0.	0.	0.	0.		
	FROM	XIE1	XIE2	ETA1	ETA2	FACTJ	FACTK	
	1121	0	0 DZ 0.	0	0	0.	0.	
	DX 0.	D¥	DZ 0.	O.	0. 0.	DIHEIZ 0.		
	FROM	XIE1	XTE2	ETA1	ETA2	FACTJ	FACTK	
	1321	0	0	0	0	0.	0.	
	DX 0.	D¥	DZ 0.	O.	0. 0.	DTHETZ 0.		
	FROM	XIE1	XIE2	ETA1	ETA2	FACTJ	FACTK	
	721 DX	0	0 DZ	Duffeur 0	0 0	0. DTHETZ	0.	
	0.	0.	24.23514	0.	Λ	Λ		
	FROM	XIE1	XIE2	ETA1	ETA2	FACTJ	FACTK	
	921 DX	DA 0	0 DZ	0 0	U	υ.	0.	
	0.		24.23514	0.	0	Ω		
	FROM	XIE1		ETA1	ETA2	FACTJ	FACTK	
	1121 DX	0 DY	0 DZ	0 0	0 DTHETY		0.	
	0.	0.			0.	0		
INT	TO	XIE1	XIE2	ETA1	ETA2	NFB		
3	522 FROM	0 XIE1		0 ETA1	0 ETA2		FACTK	
	1121	0	Λ	Λ	0	0.	0.	
	DX	DY	DZ	DTHETX	DTHETY			
	0. FROM	0. XIE1	0. XIE2	0. ETA1	0. ETA2	0. FACTJ	FACTK	
	1321	0	()	()	Ω	Λ	0.	
	DX	DY	DZ	DTHETX 0.	DTHETY	DTHETZ		
	0. FROM	0. XIE1	0. XIE2		0. ETA2	0. FACTJ	FACTK	
	_ 1.011						_ 110 110	

	721	0	0	0	0	0.	0.
	DX 0.	О.	DZ 24.23514	0.	0.	0.	
	FROM	XIE1	XIE2	ETA1	ETA2	FACTJ	FACTK
	921	0	0	0	0	0.	0.
	DX 0.	DY О.	DZ 24.23514	DTHETX	0.	0.	
	FROM	XIE1	XILZ	ETA1	ETA2	FACTJ	FACTK
	1121	0	0	0	0	0.	0.
	DX 0.	DY DY	DZ 24.23514	D.T.H.F.T.X	D.I.HE.I.A	DTHETZ 0.	
	FROM	XIE1	XIE2	ETA1	ETA2	FACTJ	
	1321	0	0	0	0	0.	0.
	DX 0.	DY	DZ 24.23514	DTHETX 0	DTHETY	DTHETZ 0.	
INT	TO	XIE1	XIE2	ETA1	ETA2	NFB	
4	721	0	0	0	0	4	
	FROM	XIE1	XIE2 0	ETA1	ETA2 0	FACTJ	FACTK
	122 DX	DA 0	0 DZ	U VTHETY	U VTHETY	U. DTHETZ	0.
	0.	DY 0.	0.	0.	DTHETY 0.	0.	
	FROM	XIE1	XIE2 0	ETA1	ETA2	FACTJ	_
	522 DX	0	0	0	Durreus 0	0.	0.
	0.	0.	DZ -24.23514	0.	0.	0.	
	FROM	XIE1	XIE2 0	ETA1	ETA2	FACTJ	FACTK
	322	0	0	0	0	0.	0.
	DX 0.	DY O	DZ -24.23514	D.I.HE.I.X	D.I.HE.I.A	D.I.HE.I.S	
	FROM	XIE1	XIE2	ETA1	ETA2	FACTJ	FACTK
	122	0	XIE2 0	0	0	0.	0.
	DX	DY	DZ -24.23514	DTHETX	DTHETY	DTHETZ	
INT	0. TO	V. XTE1	-24.23514 XIE2	U. ETA1	ETA2	NFB	
5	921	0	0	0	0	5	
	FROM	XIE1	XIE2 0	ETA1	ETA2	FACTJ	
	122 DX	DV	D7	טייים עייט עייים עייט	סיים בירט 0	0. DTUTT7	0.
	0.		0.	0.	DTHETY 0.	0.	
	FROM	XIE1	XIE2	ETA1	ETA2 0	FACTJ	
	322	0		0	0		0.
	DX 0.	DY 0.	DZ 0.	DTHETX 0.			
	FROM	XIE1	XIE2	ETA1	ETA2 0	FACTJ	FACTK
	522		0	0	0	0.	0.
	DX 0.	DY	DZ -24.23514	DTHETX	DTHETY 0.	DTHETZ 0.	
	FROM	XIE1	XIE2	ETA1	ETA2	FACTJ	FACTK
		0	0	0	0	0.	0.
	DX	DY	DZ	DTHETX	DTHETY	DTHETZ	
	0. FROM		-24.23514 XIE2				FACTK
	122	0		0	0	0.	0.
	DX		DZ				
INT	0. TO	0. XIE1	-24.23514 XIE2		0. ETA2		
6	1121	0		0	0		
	FROM	XIE1	XIE2	ETA1	ETA2	FACTJ	FACTK
	322	0	0	0			0.
	DX 0.	DY 0.	DZ 0.	DTHETX 0.	DTHETY 0.		
	FROM	XIE1	XIE2		ETA2		FACTK
	522	0	0	0	0		0.
	DX 0.	DY 0.	DZ 0.	DTHETX 0.	DTHETY 0.		
	FROM	XIE1	XIE2	ETA1	ETA2		FACTK
	122	0	0	0	0	0.	0.
	DX	DY	DZ	DTHETX	DTHETY		
	0. FROM	0. XIE1	0. XIE2	0. ETA1	0. ETA2		FACTK
	522		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.
	DX	DY	DZ	DTHETX	DTHETY	DTHETZ	
	0.	0.	-24.23514	0.	0.	0.	
INT	TO	XIE1	XIE2	ETA1	ETA2	NFB	
7	1321	0	0	0	0	4	
	FROM	XIE1	XIE2	ETA1	ETA2	FACTJ	FACTK
	522	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.
	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.
	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.
	DX	DY	DZ	DTHETX	DTHETY	DTHETZ	
	0.	0.	-24.23514	0.	0.	0.	

The convergence histories for residual, mass flow, and rotor lift coefficient as shown in Figure 9-19 should be obtained.

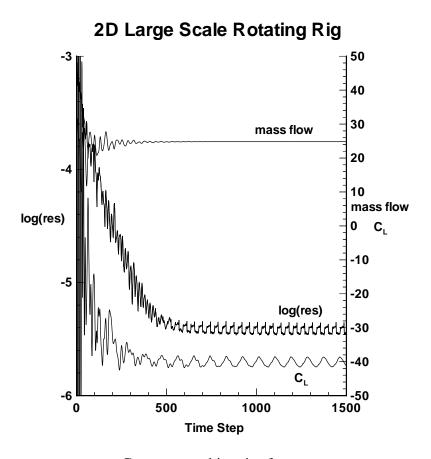


Figure 9-19. Convergence histories for rotor-stator case.

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 **bctype** is 2005 and **dthtx** is –1.0 and 1.0 on the I0 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.

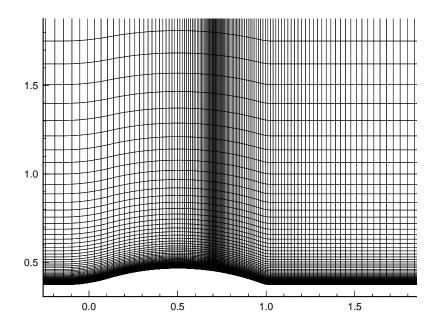


Figure 9-20. Axisymmetric bump grid.

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

<u>File</u>	<u>Description</u>
<pre>bumpv5periodic.inp</pre>	input for CFL3D
bump.grd	formatted single plane grid
gridaxi.f	converter for creating 2 grid planes

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

Compile the grid converter code:

```
cft77 gridaxi.f
```

Step 2

Link the grid converter object file:

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

Step 3

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

```
gridaxi
```

In answer to the question, type:

```
bump.grd
```

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

```
precf13d < bumpv5periodic.inp</pre>
```

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 < bumpv5periodic.inp
```

```
I/O FILES
bumpgrd.bin
plot3dg.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.turres
cfl3d.blomax
```

```
cfl3d.out15
cfl3d.prout
cfl3d.out20
ovrlp.bin
patch.bin
restart.bin
    Axisymmetric bump flow, 3-d, using 2 planes and periodic BCs
                        BETA REUE, MIL TINF, DR
    XMACH
              ALPHA
                                                         IALPH
    0.8750
              00.000
                           0.0
                                 02.660
                                             460.0
                                                           0
                                                                       0
      SREF
               CREF
                          BREF
                                      XMC
                                                YMC
                                                           ZMC
   1.00000
             1.00000
                        1.0000
                                  0.00000
                                               0.00
                                                          0.00
                       IFLAGTS
                                              IUNST
                                                        CFLTAU
       DТ
               IREST
                                     FMAX
   -05.000
                   0
                            000
                                   5.0000
                                                   0
                                                           10.
             NPLOT3D
                        NPRINT
                                   NWREST
                                                                  NTSTEP
                                                                                ITA
    NGRID
                                               ICHK
                                                           I2D
         1
                  1
                            1
                                     1200
                                                  0
                                                             0
                                                                       1
                                                                                  1
                                          IVISC(I)
                                                      IVISC(J)
       NCG
                 TEM
                     IADVANCE
                                   IFORCE
                                                                TVTSC(K)
                   0
                             0
                                      001
                                                   0
                                                                      07
            JDIM
                   KDIM
    IDIM
      0.2
             181
                     101
    ILAMLO
              ILAMHI
                        JLAMLO
                                   JLAMHI
                                             KLAMLO
                                                        KLAMHI
                 0
                            0
                                       0
         0
                                                  0
                                                            Ω
     INEWG
              IGRIDC
                             IS
                                       JS
                                                 KS
                                                            ΙE
                                                                      JΕ
                                                                                 KE
                                        0
         0
                   0
                             0
                                                  0
                                                             0
                                                                                  0
            IDIAG(J)
                      IDIAG(K)
                                 IFLIM(I)
  IDIAG(I)
                                           IFLIM(J)
                                                      IFLIM(K)
   IFDS(I)
             IFDS(J)
                                 RKAPO(I)
                                           RKAPO(J)
                                                      RKAPO(K)
                       IFDS(K)
         1
                   1
                             1
                                   0.3333
                                             0.3333
                                                        0.3333
      GRID
               NBCI0
                       NBCIDIM
                                    NBCJ0
                                            NBCJDIM
                                                        NBCK0
                                                                 NBCKDIM
                                                                             IOVRLP
                             1
                                                                                 Ω
         1
                   1
                                      1
                                                 1
                                                            1
                                                                       1
                                                                    KEND
I0:
      GRID
             SEGMENT
                        BCTYPE
                                               JEND
                                     JSTA
                                                          KSTA
                                                                              NDATA
         1
                  1
                          2005
                                     0
                                                0
                                                          0
                                                                       0
                                                                                  4
                                    DTHTY
                                              DTHTZ
                NBLP
                         DTHTX
                          -1.0
                                     0.
                                                 0.
                   1
             SEGMENT
                        BCTYPE
                                                          KSTA
IDIM: GRID
                                     JSTA
                                               JEND
                                                                    KEND
                                                                              NDATA
                  1
                          2005
                                      0
                                                 0
                                                           0
                                              DTHTZ
                NBI<sub>P</sub>
                         DTHTX
                                    DTHTY
                   1
                          +1.0
                                      0.
                                                 0.
J0:
      GRID
             SEGMENT
                        BCTYPE
                                                          KSTA
                                                                    KEND
                                     ISTA
                                               TEND
                                                                              NDATA
         1
                   1
                          1003
                                      0
                                                0
                                                             0
                                                                       0
                                                                                  0
JDIM: GRID
             SEGMENT
                        BCTYPE
                                     ISTA
                                               IEND
                                                          KSTA
                                                                    KEND
                                                                              NDATA
         1
                   1
                          1003
                                      0
                                                0
                                                             Ω
                                                                       0
                                                                                  0
к0:
      GRID
             SEGMENT
                         BCTYPE
                                               IEND
                                                          JSTA
                  1
                           2004
                                      0
                                                0
                                                             0
                                                                       0
         1
                                                                                  2
              TWTYPE
                            CQ
                 0.
                             0.
                                                                    JEND
KDTM: GRID
             SEGMENT
                        BCTYPE
                                     TSTA
                                               TEND
                                                          JSTA
                                                                              NDATA
                          1003
                                       0
                                                  0
         1
                   1
                         ICONSF
              MGFLAG
                                      MTT
                                               NGAM
      MSEO
         1
                  1
                             Ω
                                      Ω
                                                02
      ISSC EPSSSC(1) EPSSSC(2) EPSSSC(3)
                                               ISSR EPSSSR(1) EPSSSR(2) EPSSSR(3)
        0
              0.3
                          0.3
                                     0.3
                                                 Ω
                                                          0.3
                                                                     0.3
                                                                               0.3
                                    NITFO
      NCYC
              MGLEVG
                          NEMGL
                 03
      1100
                            0.0
                                      000
      MIT1
                MIT2
                          MIT3
                                     MIT4
                                               MIT5
                                                          MIT6
                                                                    MIT7
                                                                              MIT8
        01
                 01
                            01
                                      01
                                                 01
                                                             1
                                                                       1
                                                                                1
   1-1 BLOCKING DATA:
      NBLI
                :
 NUMBER
        GRID
                         ISTA
                                JSTA
                                       KSTA
                                              IEND
                                                      JEND
                                                             KEND
                                                                   ISVA1
                         ISTA
                                JSTA
                                       KSTA
                                              IEND
                                                      JEND
                                                             KEND
                                                                   ISVA1
                                                                          ISVA2
 NUMBER
         GRID
  PATCH SURFACE DATA:
   NINTER
        Ω
  PLOT3D OUTPUT:
  BLOCK IPTYPE ISTART
                         IEND
                                IINC JSTART
                                              JEND
                                                      JINC KSTART
                                                                    KEND
                                                                            KINC
      1
             0
                           0
                                   0
                                          0
                                                 0
                                                         0
                                                                        0
                                                                               0
 IMOVIE
      Λ
  PRINT OUT:
                                IINC JSTART
                                                      JINC KSTART
  BLOCK IPTYPE ISTART
                         TEND
                                              JEND
                                                                    KEND
                                                                            KINC
      1
             Ω
                    1
                           1
                                   1
                                          0
                                                 0
                                                         0
                                                                       1
  CONTROL SURFACE:
```

```
NCS
0
GRID ISTART IEND JSTART JEND KSTART KEND IWALL INORM
```

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

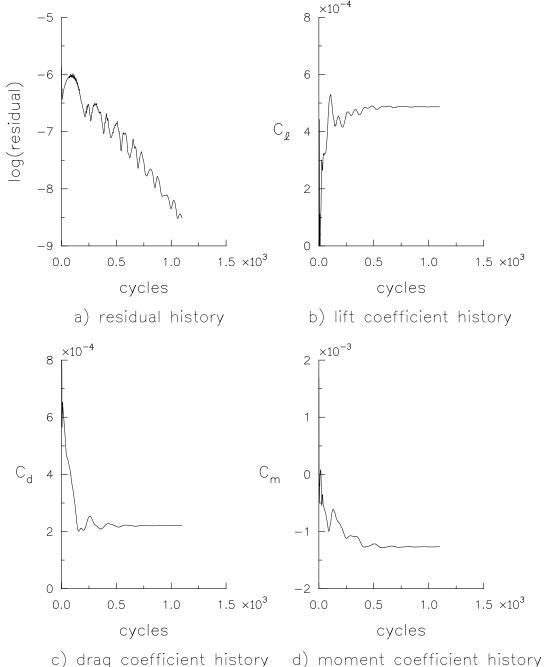


Figure 9-21. Residual and coefficient histories for axisymmetric bump flow case

 $M_{\infty} = 0.875$, $Re_{\tilde{L}_R} = 2.66 \times 10^6$.

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 cf13d.prout. Experimental surface pressure coefficients from Bachalo et. al⁸ are included with this test case for comparison purposes. The file is called bumpcpdata.dat.

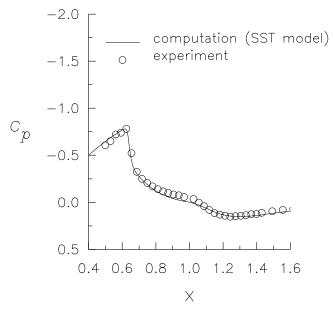


Figure 9-22. Pressure coefficients for axisymmetric bump case $M_{\infty} = 0.875 \,,\, Re_{\tilde{L}_R} = 2.66 \times 10^6 \,.$

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.

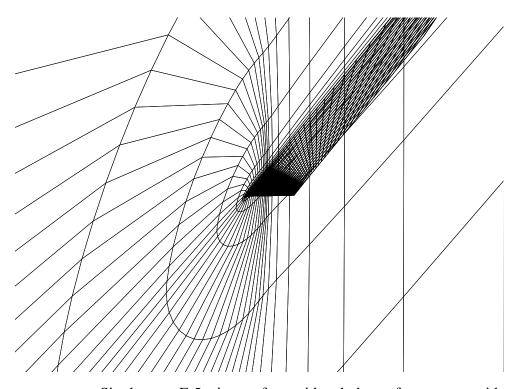


Figure 9-23. Single zone F-5 wing surface grid and plane of symmetry grid.

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

<u>File</u>	<u>Description</u>
f5wing.inp	input for CFL3D
f5grid.dat	formatted wing section grid
f5wing_grid.f	grid converter

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

Step 1

Compile the grid converter code:

```
cft77 f5wing_grid.f
```

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 precfl.h is in the current directory):

```
make -f makeprecfl3d_cray
```

Step 5

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

```
precfl3d < f5wing.inp</pre>
```

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
```

```
I/O FILES:
f5wing.grd
plot3dg.bin
plot3dq.bin
cf13d.out
cfl3d.res
cfl3d.turres
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
```

0.950 SREF 1.00000	CREF		XMC	460.0 YMC 0.00	0 ZMC 0.00	0	
DT	IREST	IFLAGTS	FMAX	IUNST	CFLTAU		
-5.000 NGRID		000 NPRINT	1.000 NWREST	0 ICHK	10. I2D	NTSTEP	ITA
1 NCG		0 IADVANCE	100 IFORCE	0 IVISC(I)	0 IVISC(J)	1 IVISC(K)	1
2	0	0 KDIM	1	0	0	0	
IDIM 33		33					
ILAMLO 00		JLAMLO 000	JLAMHI 000	KLAMLO 0			
INEWG 0	IGRIDC	IS 0	JS 0	KS 0	IE O	ЈЕ 0	KE O
IDIAG(I)	IDIAG(J)	IDIAG(K)	IFLIM(I)	IFLIM(J)	IFLIM(K)	U	0
IFDS(I)	IFDS(J) 1	IFDS(K)	RKAP0(I)	RKAP0(J) .3333	RKAP0(K) .3333		
GRID	NBCI0	NBCIDIM	NBCJ0	NBCJDIM	NBCK0	NBCKDIM	
1 10: GRID 1	SEGMENT	1 BCTYPE 1001	1 JSTA 0	1 JEND 0	4 KSTA 0	1 KEND 0	0 NDATA 0
IDIM: GRID	SEGMENT	BCTYPE	JSTA	JEND	KSTA	KEND	NDATA
J0: GRID	SEGMENT	1002 BCTYPE	0 ISTA	0 IEND	0 KSTA	0 KEND	0 NDATA
1 JDIM: GRID		1003 BCTYPE	0 ISTA	0 IEND	0 KSTA	0 KEND	0 NDATA
K0: GRID	1	1003 BCTYPE	0 ISTA	0 IEND	0 JSTA	0 JEND	0 NDATA
1	1	0	1	33	1	41	0
1 1		1005 0	1 21	21 33	41 41	153 153	0
1	4	0	1	33	153	193	0
KDIM: GRID	1	BCTYPE 1003	ISTA 0	IEND 0	JSTA 0	JEND 0	NDATA 0
MSEQ 3		ICONSF 0	MTT 0	NGAM 02			
	EPSSSC(1)				EPSSSR(1) 0.3	EPSSSR(2) 0.3	EPSSSR(3) 0.3
NCYC	MGLEVG	NEMGL	0.3 NITFO	U	0.3	0.3	0.3
200 200		00	000 000				
200 MIT1		00 MIT3	000 MIT4	MIT5			
01	01	01	01	01			
01 01		01 01	01 01	01 01			
1-1 BLO	CKING DATA		01	01			
NBLI 2							
NUMBER 1	GRID :	ISTA 1	JSTA KST	'A IEND 1 33	JEND KI 41	END ISVA1 1 1	
2	1	21	41	1 33	97	1 1	2
NUMBER 1	GRID :	ISTA 1	JSTA KST 193	'A IEND 1 33	JEND KI 153	END ISVA1 1 1	ISVA2 2
2 DATCH SII	1 RFACE DATA	21	153	1 33	97	1 1	2
NINTER		•					
0 PLOT3D O							
GRID IP'	TYPE ISTAR	Γ IEND	IINC JSTAR	T JEND	JINC KST	ART KEND	KINC
0	- .						
CONTROL NCS	TYPE ISTAR	Γ IEND	IINC JSTAR	T JEND	JINC KST	ART KEND	KINC
0 GRID IS	TART IENI) JSTART	JEND K	START KI	END 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.

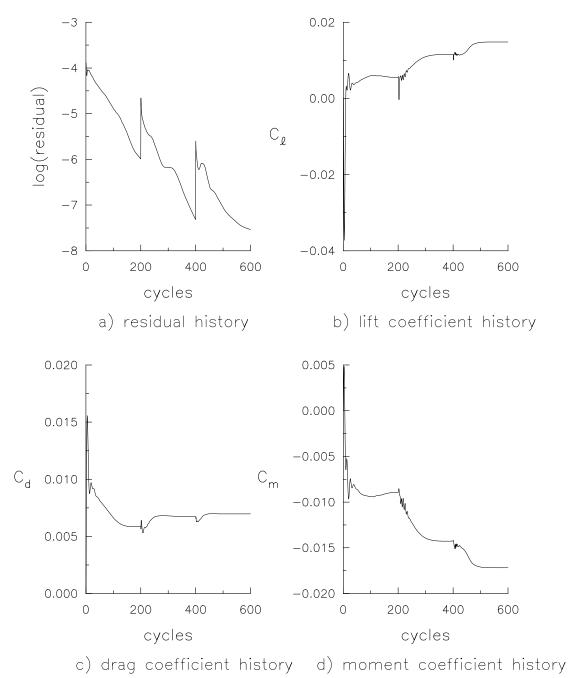


Figure 9-24. Convergence histories for single grid F-5 wing case; $\alpha = 0.0$, $M_{\infty} = 0.95$.

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).

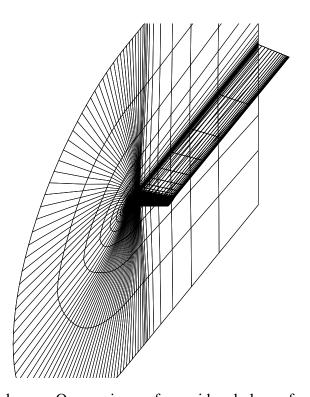


Figure 9-25. Single zone Onera wing surface grid and plane of symmetry grid.

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 iplot3d to 0 in the form2bin.f file and using the input file oneram6.inp_cfl3d instead of 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:

<u>File</u>	<u>Description</u>
oneram6.inp_p3d	input for CFL3D
m6_i97.fmt_p3d	formatted grid
form2bin.f	grid converter

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 m6_i97.grd_p3d 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 precf13d code (the cflx.h files will be output):

```
precfl3d < oneram6.inp_p3d</pre>
```

Step 6

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

```
make -f makecfl3d_cray
```

Run the CFL3D code:

cfl3d < oneram6.inp_p3d

```
I/O FILES:
m6_i97.grd_p3d
plot3dg.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.turres
cfl3d.blomax
cfl3d.out15
cfl3d.prout
cf13d.out20
ovrlp.bin
patch.bin
restart.bin
     ONERA M6 Wing, plot3d type grid, coarse grid
                 ALPHA
                                                                            IHIST
     XMACH
                              BETA
                                     REUE, MIL
                                                  TINF, DR
                                                                IALPH
    0.8400
                03.060
                               0.0
                                       21.660
                                                    540.0
                                                                    1
                                                                                0
       SREF
                  CREF
                              BREF
                                           XMC
                                                      YMC
                                                                  ZMC
   0.53080
               1.00000
                            3.9249
                                      0.00000
                                                     0.00
                                                                 0.00
         DT
                 IREST
                           IFLAGTS
                                          FMAX
                                                    IUNST
                                                               CFLTAU
     -5.000
                               000
                      0
                                         1.000
                                                         0
                                                                  10.
               NPLOT3D
                                                     ICHK
     NGRID
                           NPRINT
                                       NWREST
                                                                  I2D
                                                                          NTSTEP
                                                                                          ITA
         -1
                      1
                                 0
                                           100
                                                         0
                                                                    0
                                                                                0
                                                 IVISC(I)
                                                            IVISC(J)
                         IADVANCE
                                                                        IVISC(K)
        NCG
                   IEM
                                       IFORCE
          2
                      0
                                 0
                                            10
                                                         0
                                                                    5
                                                                                0
       IDIM
                  JDIM
                              KDIM
                     25
         97
                                17
    ILAMLO
                ILAMHI
                            JLAMLO
                                       JLAMHI
                                                   KLAMLO
                                                               KLAMHI
         0.0
                     0.0
                               000
                                           000
                                                         0
                                                                 0000
     INEWG
                IGRIDC
                                IS
                                            JS
                                                        KS
                                                                   ΙE
                                                                               JΕ
                                                                                           KE
          0
                      0
                                 0
                                             0
                                                         0
                                                                    0
                                                                                0
  IDIAG(I)
              IDIAG(J)
                         IDIAG(K)
                                     IFLIM(I)
                                                 IFLIM(J)
                                                            IFLIM(K)
               IFDS(J)
                          IFDS(K)
                                     RKAPO(I)
                                                            RKAPO(K)
   IFDS(I)
                                                 RKAPO(J)
          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
                              1003
                                             0
                                                         Λ
                                                                                Ω
          1
                      1
                                                                    0
                                                                                            0
IDIM: GRID
               SEGMENT
                            BCTYPE
                                          JSTA
                                                     JEND
                                                                 KSTA
                                                                             KEND
                                                                                       NDATA
                              1003
                                             0
                                                         0
                                                                    0
                                                                                0
                                                                                            0
          1
                      1
J0:
       GRID
               SEGMENT
                            BCTYPE
                                          ISTA
                                                     IEND
                                                                 KSTA
                                                                             KEND
                                                                                       NDATA
          1
                      1
                                 0
                                             1
                                                        13
                                                                    0
                                                                                0
                                                                                            0
                              2004
                      2
                                                                               17
                                                                                            2
          1
                                            13
                                                        85
                                                                    1
                TWTYPE
                                CQ
                                0.
                     0.
                                            85
                                                        97
          1
                      3
                                 Λ
                                                                    0
                                                                                0
                                                                                            0
JDIM: GRID
               SEGMENT
                            BCTYPE
                                          ISTA
                                                     IEND
                                                                 KSTA
                                                                             KEND
                                                                                       NDATA
          1
                      1
                              1003
                                             0
                                                         n
                                                                    0
                                                                                0
                                                                                            0
K0:
       GRID
               SEGMENT
                            BCTYPE
                                          ISTA
                                                     IEND
                                                                 JSTA
                                                                             JEND
                                                                                       NDATA
                              1001
                                             0
                                                         0
                                                                    0
                                                                                0
                                                                                            0
                      1
          1
KDIM: GRID
               SEGMENT
                            BCTYPE
                                          ISTA
                                                      IEND
                                                                 JSTA
                                                                             JEND
                                                                                       NDATA
          1
                      1
                                 0
                                             0
                                                         0
                                                                    0
                                                                                0
                                                                                            0
      MSEQ
                            ICONSF
                                           \mathsf{MTT}
                                                     NGAM
                MGFLAG
                                 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
      NCYC
                MGLEVG
                             NEMGL
                                        NITFO
```

200 300 MIT1 01 1-1 BL0 NBL1) L L L DCKING	02 02 MIT2 01 01 DATA:	00 00 MIT3 01 01		000 000 MIT4 01 01	MIT5 01 01				
NUMBER 1 2	GRID 1 1 GRID 1	:	ISTA 1 1 ISTA 97 97	JSTA 1 1 JSTA 1	KSTA 1 17 KSTA 1	IEND 13 49 IEND 85	JEND 1 25 JEND 1	KEND 17 17 KEND 17	ISVA1 1 1 ISVA1 1	ISVA2 3 2 ISVA2 3
PATCH SU NINTER (PLOT3D ()		97	1	17	49	25	17	1	2
	PTYPE 0	ISTART 0	IEND 0	IINC 0	JSTART 0	JEND 0	JINC 0	KSTART 0	KEND 0	KINC 0
	PTYPE SURF <i>I</i>		IEND JSTART	IINC JE1		JEND 'ART KE		KSTART	KEND	KINC

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.

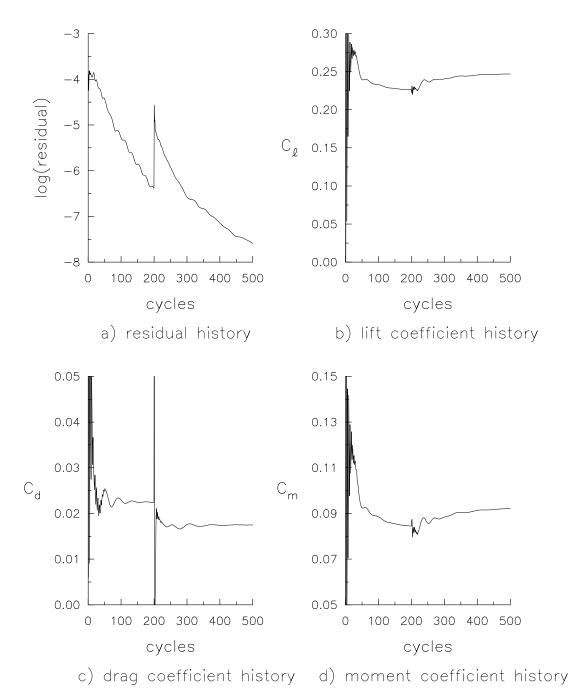


Figure 9-26. Convergence histories for single grid Onera wing case; $\alpha=3.06$, $M_{\infty}=0.84$.

9.2.4 Delta Wing

The laminar flow over a 75° 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.

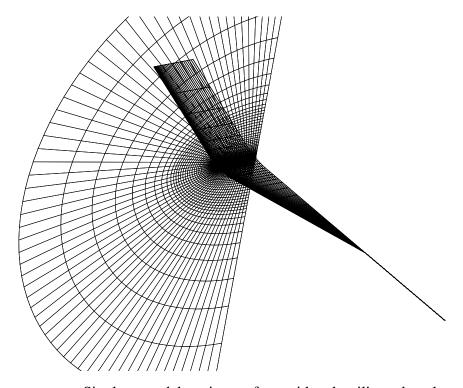


Figure 9-27. Single zone delta wing surface grid and trailing edge plane grid.

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

<u>File</u>	<u>Description</u>
delta.inp	input for CFL3D
delta.fmt	formatted grid
form2bin.f	grid converter

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

Step 1

Compile the grid converter code:

```
cft77 form2bin.f
```

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
```

<u>Step 5</u>

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

```
precfl3d < delta.inp</pre>
```

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
```

```
I/O FILES
delta.bin
plot3dg.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.turres
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
```

0.300 SREF .13398 DT	20.500 CREF 1.00000 IREST			YMC 0	0 ZMC . 0. CFLTAU	0	
-10.0 NGRID 1 NCG	0 NPLOT3D 1 IEM		1.0 NWREST 0100	0 ICHK 0 IVISC(I)	10. I2D 0	NTSTEP 1 IVISC(K)	ITA 1
2 IDIM	0 JDIM K	0 MICD		0		1	
37 ILAMLO 00	00	JLAMLO 000	JLAMHI 000	0	0000		
INEWG 0 IDIAG(I)	IGRIDC 0 IDIAG(J)		<pre>IFLIM(I)</pre>			ЈЕ 0	
IFDS(I) 1	1 IFDS(J) 1	1 IFDS(K) 1	4 RKAPO(I) .3333	RKAPO(J)			
GRID 1 10: GRID	NBCIO 1 SEGMENT		NBCJ0 1 JSTA	1		NBCKDIM 1 KEND	
1 IDIM: GRID	1 SEGMENT	1003 BCTYPE	1 JSTA	65 JEND	1 KSTA	65 KEND	0 NDATA
J0: GRID	1 SEGMENT 1	1003 BCTYPE 1001	ISTA	65 IEND 37	1 KSTA 1	65 KEND 65	0 NDATA 0
JDIM: GRID 1 K0: GRID	SEGMENT 1 SEGMENT	BCTYPE 1001 BCTYPE		IEND 37 IEND	KSTA 1 JSTA	KEND 65 JEND	NDATA 0 NDATA
1 1	1 2 TWTYPE	1011		9	1 1	65 65	0 2
1 KDIM: GRID	-1. 3 SEGMENT 1	0. 0 BCTYPE	25 ISTA 1	37 IEND	JSTA	JEND	
1 MSEQ 1	MGFLAG 1	1003 ICONSF 1	MTT 0	37 NGAM 02	1	65	0
1 NCYC	0.3 MGLEVG	0.3 NEMGL	NITFO	ISSR 0	EPSSSR(1) 0.3		EPSSSR(3) 0.3
600 MIT1 01	MIT2 01	MIT3 01	0000 MIT4 01	MIT5 01	MIT6 1		
NBLI 1	CKING DATA:						
	1	25	JSTA KSTA 1 JSTA KSTA	L 37	33	1 1	2
1 PATCH SUF NINTER 0	1 RFACE DATA:	25	65 1				
	YPE ISTART		IINC JSTART				
PRINT OUT GRID IPT CONTROL S NCS	TYPE ISTART	r IEND	IINC JSTART	r JEND	JINC KSTA	ART KEND	KINC
0 GRID IST	CART IENI) JSTART	JEND KS	START KI	END IWALL	INORM	

After this test case is run, the convergence histories, found in file cfl3d.res, should look like those plotted in Figure 9-28.

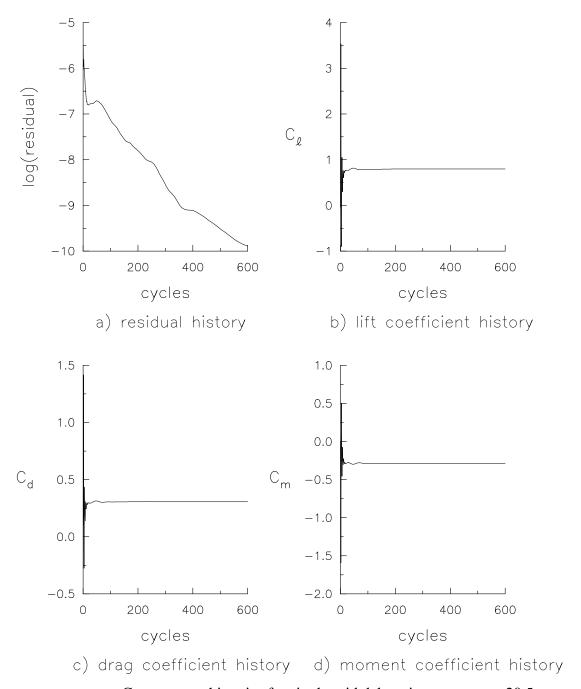


Figure 9-28. Convergence histories for single grid delta wing case; $\alpha=20.5$.

CHAPTER 9 Test Cases