9

CHAPTER 9 Test Cases

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

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

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

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

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

9.1 Two-dimensional Test Cases

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

9.1.1 RAE 2822 Airfoil

This test case solves for the viscous flow over the RAE 2822 airfoil at $\alpha = 2.72°$ 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.

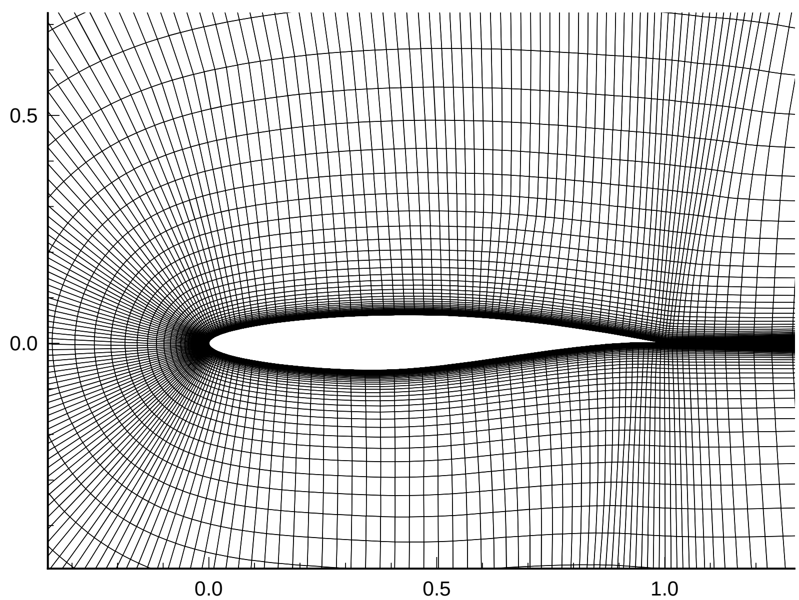

Figure 9-1. Single zone RAE 2822 airfoil grid.

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

File	Description
`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
```

Step 5

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

```
precfl3d < rae10.inp
```

Step 6

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

```
make -f makecfl3d_cray
```

Step 7

Run the CFL3D code:

```
cfl3d < rae10.inp
```

The input file for this case is:

```
FILES:
rae10.bin
plot3dg.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.turres
cfl3d.blomax
cfl3d.out15
cfl3d.prout
cfl3d.out20
ovrlp.bin
patch.bin
restart.bin
    RAE case 10, with SST model
     XMACH     ALPHA      BETA  REUE,MIL   TINF,DR     IALPH    IHSTRY
    0.7500    02.720       0.0    6.2000     460.0         0         0
      SREF      CREF      BREF       XMC       YMC       ZMC
   1.00000   1.00000    1.0000   0.00000      0.00      0.00
        DT     IREST   IFLAGTS      FMAX     IUNST    CFLTAU
   -5.0000         0       000   05.0000         0      10.0
     NGRID   NPLOT3D    NPRINT    NWREST      ICHK       I2D    NTSTEP       ITA
         1         1         1      6100         0         1      0001         1
       NCG       IEM  IADVANCE    IFORCE  IVISC(I)  IVISC(J)  IVISC(K)
         2         0         0         1         0         0         7
      IDIM      JDIM      KDIM
         2       257        97
    ILAMLO    ILAMHI    JLAMLO    JLAMHI    KLAMLO    KLAMHI
         1         2        88       159         1        97
     INEWG    IGRIDC        IS        JS        KS        IE        JE        KE
         0         0         0         0         0         0         0         0
  IDIAG(I)  IDIAG(J)  IDIAG(K)  IFLIM(I)  IFLIM(J)  IFLIM(K)
         1         1         1         3         3         3
   IFDS(I)   IFDS(J)   IFDS(K)  RKAP0(I)  RKAP0(J)  RKAP0(K)
         1         1         1    0.3333    0.3333    0.3333
      GRID     NBCI0   NBCIDIM     NBCJ0   NBCJDIM     NBCK0   NBCKDIM    IOVRLP
         1         1         1         1         1         3         1         0
I0:   GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
         1         1      1001         0         0         0         0         0
IDIM: GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
         1         1      1002         0         0         0         0         0
J0:   GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
         1         1      1002         0         0         0         0         0
JDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
         1         1      1002         0         0         0         0         0
K0:   GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
         1         1         0         0         0         1        41         0
         1         2      2004         0         0        41       217         2
                TWTYPE        CQ
                    0.        0.
         1         3         0         0         0       217       257         0
KDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
         1         1      1003         0         0         0         0         0
      MSEQ    MGFLAG    ICONSF       MTT      NGAM
         1         1         0         0        02
      ISSC EPSSSC(1) EPSSSC(2) EPSSSC(3)      ISSR EPSSSR(1) EPSSSR(2) EPSSSR(3)
         0       0.3       0.3       0.3         0       0.3       0.3       0.3
      NCYC    MGLEVG     NEMGL     NITFO
```

```
      500        03         00        000
     MIT1      MIT2       MIT3       MIT4       MIT5       MIT6       MIT7      MIT8
       01        01         01         01         01          1          1         1
   1-1 BLOCKING DATA:
     NBLI
        1
 NUMBER   GRID     :     ISTA    JSTA    KSTA    IEND    JEND    KEND   ISVA1   ISVA2
      1      1              1       1       1       2      41       1       1       2
 NUMBER   GRID     :     ISTA    JSTA    KSTA    IEND    JEND    KEND   ISVA1   ISVA2
      1      1              1     257       1       2     217       1       1       2
  PATCH SURFACE DATA:
    NINTER
        0
  PLOT3D OUTPUT:
   GRID IPTYPE ISTART    IEND    IINC JSTART    JEND    JINC KSTART    KEND    KINC
      1      0      1      01       1      01     999       1      1     999       1
  MOVIE
      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
  CONTROL SURFACE:
  NCS
    0
   GRID ISTART   IEND   JSTART   JEND   KSTART   KEND  IWALL  INORM
```

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

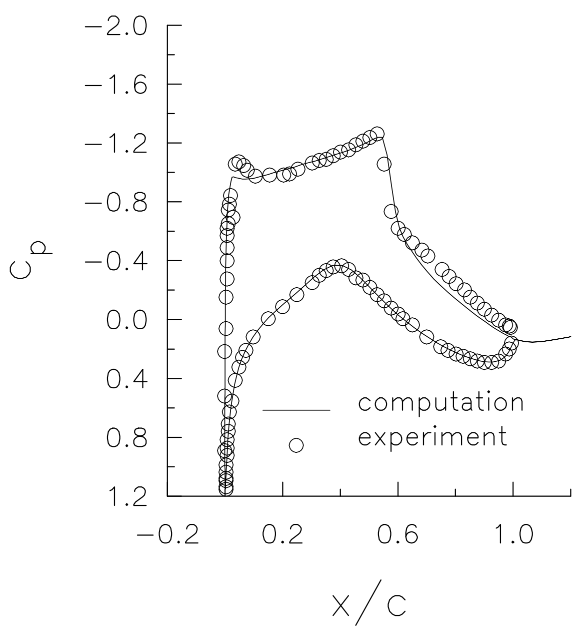

Figure 9-2. Surface pressure coefficients for RAE 2822 airfoil;
$\alpha = 2.72°$, $M_\infty = 0.75$, $Re_{\tilde{L}_R} = 6.2 \times 10^6$.

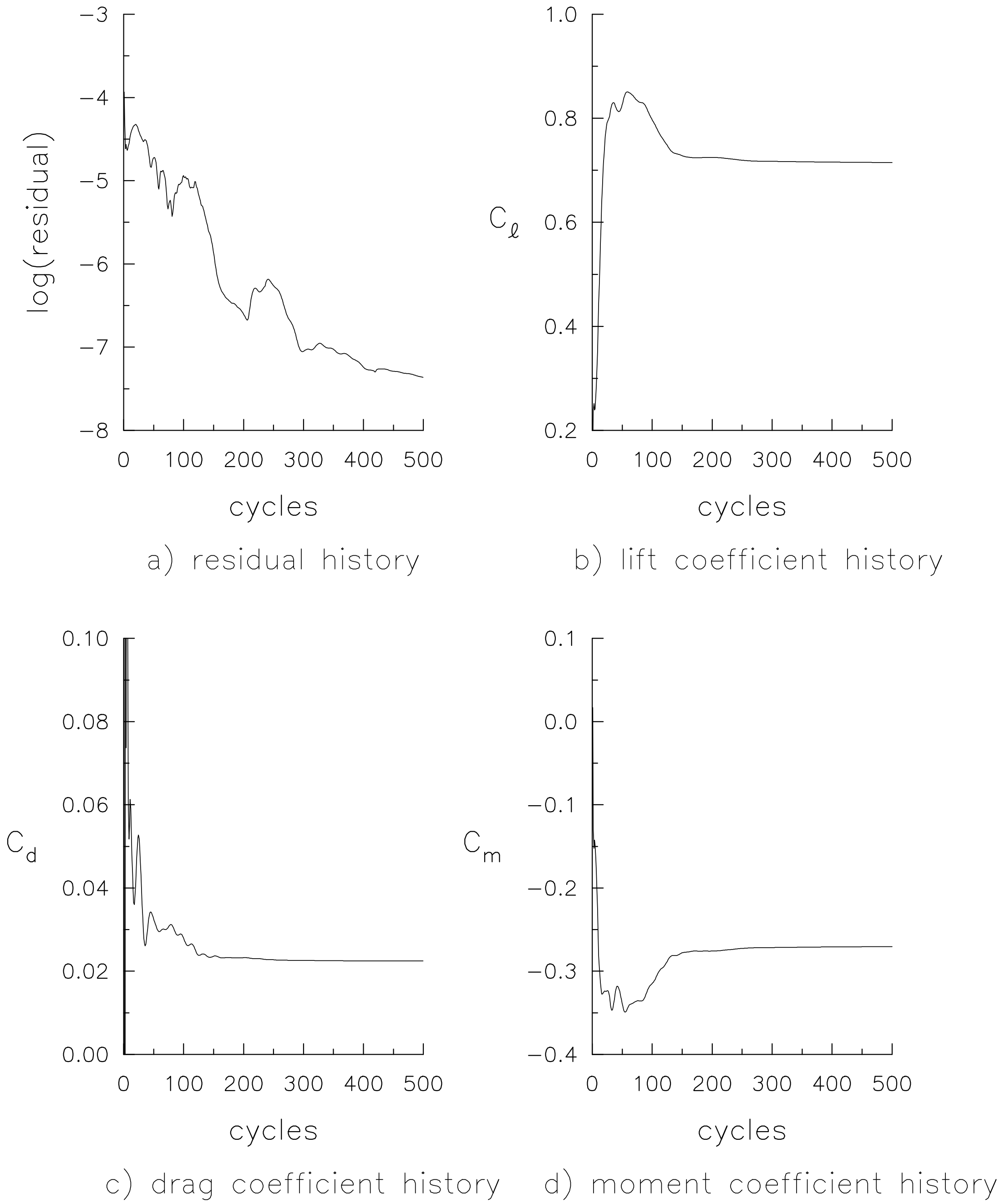

Figure 9-3. Residual and coefficient histories for RAE 2822 airfoil case;
$\alpha = 2.72°$, $M_\infty = 0.75$, $Re_{\tilde{L}_R} = 6.2 \times 10^6$

9.1.2 NACA 0012 Airfoil with Overlapped Grids

This test case solves for the inviscid flow over the NACA 0012 airfoil at $\alpha = 5°$ 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.

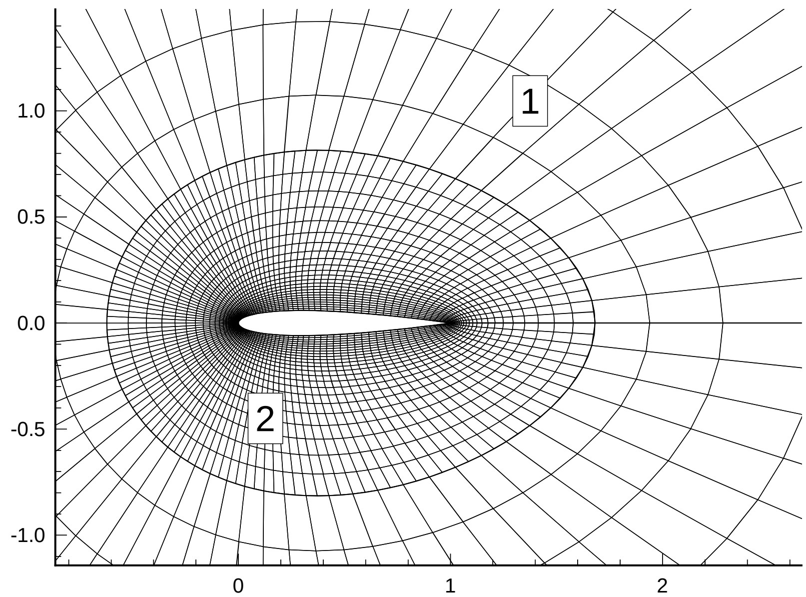

Figure 9-4. Two-zone overlapped grid system for NACA 0012 airfoil.

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

File	Description
`0012x.inp`	input for CFL3D
`0012x.fmt`	formatted grid in PLOT3D format
`fmttobin_p3d.f`	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 `precfl3d` code (the `cflx.h` files will be output):

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

Step 8

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

```
make -f makecfl3d_cray
```

Step 9

Run the CFL3D code:

```
cfl3d < 0012x.inp
```

The input file for this case is:

```
I/O FILES
0012x.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
  2-block 0012 airfoil as simple chimera test
     XMACH     ALPHA      BETA  REUE,MIL   TINF,DR     IALPH    IHSTRY
      .200     5.000       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      FMAX     IUNST    CFLTAU
     -5.00         0       000      1.00         0       10.
     NGRID   NPLOT3D    NPRINT    NWREST      ICHK       I2D    NTSTEP       ITA
        -2         2         0       100         0         1         1         1
       NCG       IEM  IADVANCE    IFORCE  IVISC(I)  IVISC(J)  IVISC(K)
         2         0         0         0         0         0         0
         2         0         0         1         0         0         0
      IDIM      JDIM      KDIM
       002        65        25
       002       129        25
    ILAMLO    ILAMHI    JLAMLO    JLAMHI    KLAMLO    KLAMHI
        00        00       000       000         0      0000
        00        00       000       000         0      0000
     INEWG    IGRIDC        IS        JS        KS        IE        JE        KE
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
  IDIAG(I)  IDIAG(J)  IDIAG(K)  IFLIM(I)  IFLIM(J)  IFLIM(K)
         1         1         1         0         0         0
         1         1         1         0         0         0
   IFDS(I)   IFDS(J)   IFDS(K)  RKAP0(I)  RKAP0(J)  RKAP0(K)
         1         1         1     .3333     .3333     .3333
         1         1         1     .3333     .3333     .3333
      GRID     NBCI0   NBCIDIM     NBCJ0   NBCJDIM     NBCK0   NBCKDIM    IOVRLP
         1         1         1         1         1         1         1         1
         2         1         1         1         1         1         1         1
I0:   GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
         1         1      1002         0         0         0         0         0
         2         1      1002         0         0         0         0         0
IDIM: GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
         1         1      1002         0         0         0         0         0
         2         1      1002         0         0         0         0         0
J0:   GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
         1         1         0         0         0         0         0         0
         2         1         0         0         0         0         0         0
JDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
         1         1         0         0         0         0         0         0
         2         1         0         0         0         0         0         0
K0:   GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
         1         1         0         0         0         0         0         0
         2         1      1005         0         0         0         0         0
KDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
         1         1      1003         0         0         0         0         0
         2         1         0         0         0         0         0         0
      MSEQ    MGFLAG    ICONSF       MTT      NGAM
         1         1         1         0        01
      ISSC  EPSSC(1)  EPSSC(2)  EPSSC(3)      ISSR  EPSSR(1)  EPSSR(2)  EPSSR(3)
         0        .3        .3        .3         0        .3        .3        .3
```

```
      NCYC    MGLEVG      NEMGL      NITFO
       500        03         00        000
      MIT1      MIT2       MIT3       MIT4       MIT5
        01        01         01         01         01
   1-1 BLOCKING DATA:
      NBLI
         2
 NUMBER   GRID     :     ISTA   JSTA   KSTA   IEND   JEND   KEND  ISVA1  ISVA2
      1      1              1      1      1      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 SURFACE DATA:
    NINTER
         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
  CONTROL SURFACE:
  NCS
    0
   GRID ISTART   IEND   JSTART   JEND   KSTART   KEND  IWALL   INORM
```

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

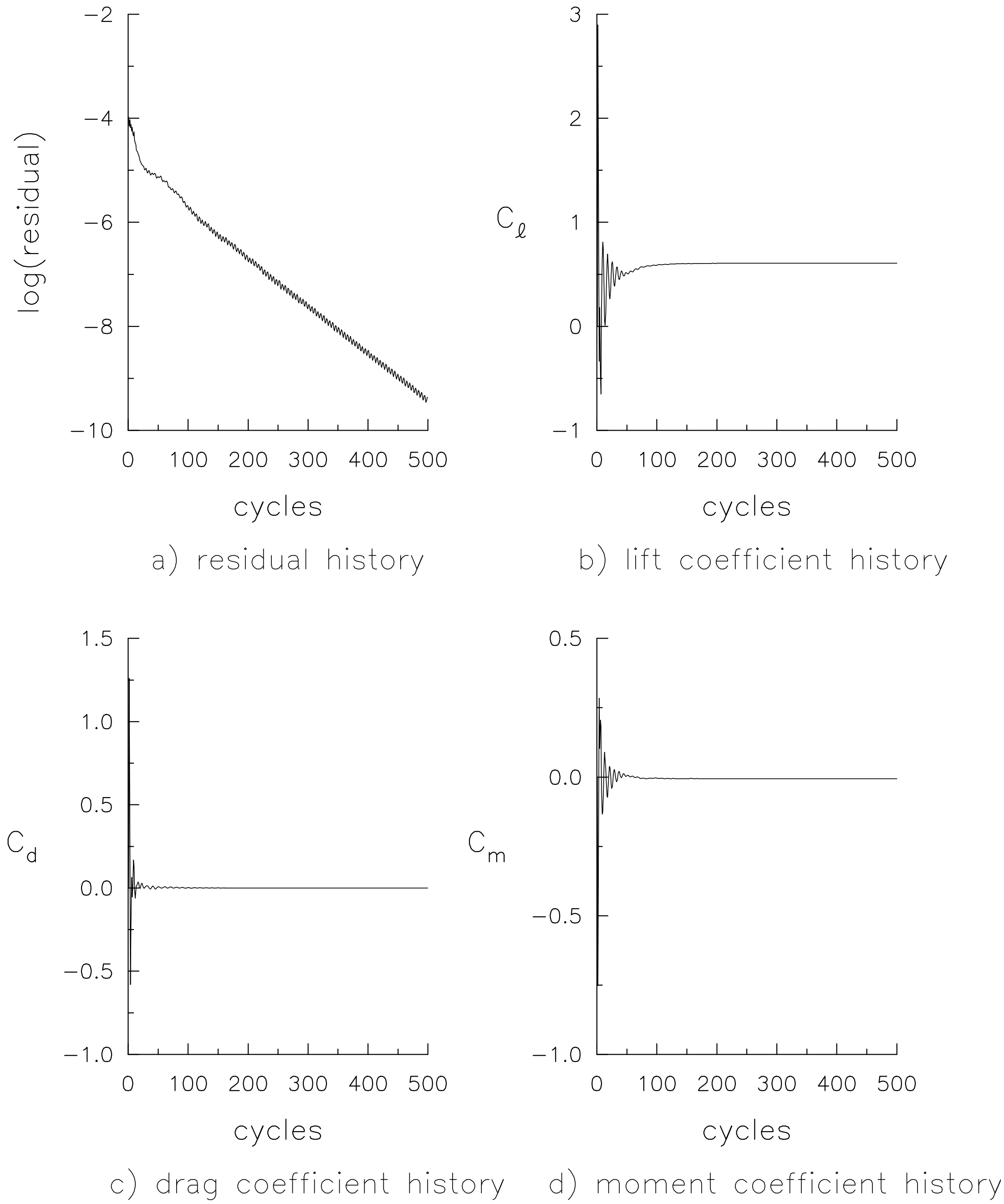

Figure 9-5. NACA 0012 with overlapped grids residual and coefficient histories; $\alpha = 5°, M_\infty = 0.2$.

9.1.3 NACA 0012 Airfoil with Patched Grids

This test case solves for the inviscid flow over the NACA 0012 airfoil at $\alpha = 1.25°$ 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.

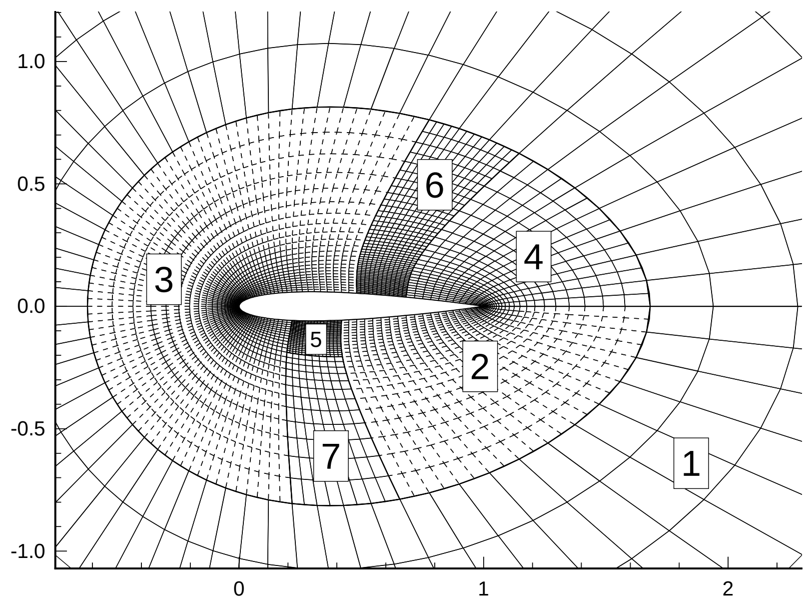

Figure 9-6. Seven-zone patched grid system for NACA 0012 airfoil.

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

File	Description
`0012.inp`	input for CFL3D
`0012.fmt`	formatted grid
`fmttobin.f`	grid converter

File	Description
`ron1.h`	parameters for ronnie makefile
`ronnie.inp`	input for ronnie

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

Step 1

Compile the grid converter code:

```
cft77 fmttobin.f
```

Step 2

Link the grid converter object file:

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

Step 3

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

```
fmttobin
```

Step 4

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

```
make -f makeronnie_cray
```

Step 5

Run the ronnie code (the file `patch.bin_0012` will be output):

```
ronnie < ronnie.inp
```

Step 6

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

```
make -f makeprecfl3d_cray
```

Step 7

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

```
precfl3d < 0012.inp
```

Step 8

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

```
make -f makecfl3d_cray
```

Step 9

Run the CFL3D code:

```
cfl3d < 0012.inp
```

The input file for this case is:

```
I/O FILES
0012.bin
plot3dg.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.turres
cfl3d.blomax
cfl3d.out15
cfl3d.prout
cfl3d.out20
ovrlp.bin
patch.bin_0012
restart.bin
input for 7 block patched 0012 grids - iopt = 1 in assemble.f
     XMACH     ALPHA      BETA  REUE,MIL   TINF,DR     IALPH    IHSTRY
      0.80      1.25       0.0     0.000     122.0         0         0
      SREF      CREF      BREF       XMC       YMC       ZMC
   1.00000   1.00000    1.0000   0.25000      0.00      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
         7         7         0       100         0         1         1         1
       NCG       IEM  IADVANCE    IFORCE  IVISC(I)  IVISC(J)  IVISC(K)
         1         0         0         0         0         0         0
         1         0         0         1         0         0         0
         1         0         0         1         0         0         0
         1         0         0         1         0         0         0
         1         0         0         1         0         0         0
         1         0         0         1         0         0         0
         1         0         0         0         0         0         0
      IDIM      JDIM      KDIM
         2        65        13
         2        23        25
         2        79        25
         2        15        25
         2        17        25
         2        13        49
         2         9        13
    ILAMLO    ILAMHI    JLAMLO    JLAMHI    KLAMLO    KLAMHI
        00        00       000       000         0      0000
        00        00       000       000         0      0000
        00        00       000       000         0      0000
        00        00       000       000         0      0000
        00        00       000       000         0      0000
        00        00       000       000         0      0000
        00        00       000       000         0      0000
     INEWG    IGRIDC        IS        JS        KS        IE        JE        KE
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         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)  IDIAG(J)  IDIAG(K)  IFLIM(I)  IFLIM(J)  IFLIM(K)
         0         0         0         3         3         3
         0         0         0         3         3         3
         0         0         0         3         3         3
         0         0         0         3         3         3
         0         0         0         3         3         3
         0         0         0         3         3         3
         0         0         0         3         3         3
   IFDS(I)   IFDS(J)   IFDS(K)  RKAP0(I)  RKAP0(J)  RKAP0(K)
         0         0         0     .3333     .3333     .3333
         0         0         0     .3333     .3333     .3333
         0         0         0     .3333     .3333     .3333
         0         0         0     .3333     .3333     .3333
         0         0         0     .3333     .3333     .3333
         0         0         0     .3333     .3333     .3333
         0         0         0     .3333     .3333     .3333
      GRID     NBCI0   NBCIDIM     NBCJ0   NBCJDIM     NBCK0   NBCKDIM    IOVRLP
         1         1         1         1         1         1         1         0
         2         1         1         1         1         1         1         0
         3         1         1         1         1         1         1         0
         4         1         1         1         1         1         1         0
         5         1         1         1         1         1         1         0
         6         1         1         1         1         1         1         0
         7         1         1         1         1         1         1         0
I0:   GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
         1         1      1002         0         0         0         0         0
         2         1      1002         0         0         0         0         0
         3         1      1002         0         0         0         0         0
         4         1      1002         0         0         0         0         0
         5         1      1002         0         0         0         0         0
         6         1      1002         0         0         0         0         0
         7         1      1002         0         0         0         0         0
IDIM: GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
         1         1      1002         0         0         0         0         0
         2         1      1002         0         0         0         0         0
         3         1      1002         0         0         0         0         0
         4         1      1002         0         0         0         0         0
         5         1      1002         0         0         0         0         0
         6         1      1002         0         0         0         0         0
         7         1      1002         0         0         0         0         0
J0:   GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
         1         1         0         0         0         0         0         0
         2         1         0         0         0         0         0         0
         3         1         0         0         0         0         0         0
         4         1         0         0         0         0         0         0
         5         1         0         0         0         0         0         0
         6         1         0         0         0         0         0         0
         7         1         0         0         0         0         0         0
JDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
         1         1         0         0         0         0         0         0
         2         1         0         0         0         0         0         0
         3         1         0         0         0         0         0         0
         4         1         0         0         0         0         0         0
         5         1         0         0         0         0         0         0
         6         1         0         0         0         0         0         0
         7         1         0         0         0         0         0         0
K0:   GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
         1         1         0         0         0         0         0         0
         2         1      1005         0         0         0         0         0
         3         1      1005         0         0         0         0         0
         4         1      1005         0         0         0         0         0
         5         1      1005         0         0         0         0         0
         6         1      1005         0         0         0         0         0
         7         1         0         0         0         0         0         0
KDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
         1         1      1003         0         0         0         0         0
         2         1         0         0         0         0         0         0
         3         1         0         0         0         0         0         0
         4         1         0         0         0         0         0         0
         5         1         0         0         0         0         0         0
```

```
         6         1         0         0         0         0         0         0
         7         1         0         0         0         0         0         0
      MSEQ    MGFLAG    ICONSF       MTT      NGAM
         2         1         1         0        02
      ISSC  EPSSC(1)  EPSSC(2)  EPSSC(3)      ISSR  EPSSR(1)  EPSSR(2)  EPSSR(3)
         0        .3        .3        .3         0        .3        .3        .3
      NCYC    MGLEVG     NEMGL     NITFO
      0300        01        00       000
      0300        02        00       000
      MIT1      MIT2      MIT3      MIT4      MIT5
        01        01        01        01        01
        01        01        01        01        01
   1-1 BLOCKING DATA:
      NBLI
         1
 NUMBER   GRID     :    ISTA   JSTA   KSTA   IEND   JEND   KEND  ISVA1  ISVA2
      1      1             1      1      1      2      1     13      1      3
 NUMBER   GRID     :    ISTA   JSTA   KSTA   IEND   JEND   KEND  ISVA1  ISVA2
      1      1             1     65      1      2     65     13      1      3
  PATCH SURFACE DATA:
    NINTER
        -1
  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
      3      0      1    001      1     01    999      1      1    999      1
      4      0      1    001      1     01    999      1      1    999      1
      5      0      1    001      1     01    999      1      1    999      1
      6      0      1    001      1     01    999      1      1    999      1
      7      0      1    001      1     01    999      1      1    999      1
  MOVIE
      0
  PRINT OUT:
   GRID IPTYPE ISTART   IEND   IINC JSTART   JEND   JINC KSTART   KEND   KINC
  CONTROL SURFACE:
  NCS
    0
   GRID ISTART   IEND   JSTART   JEND   KSTART   KEND  IWALL   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`.

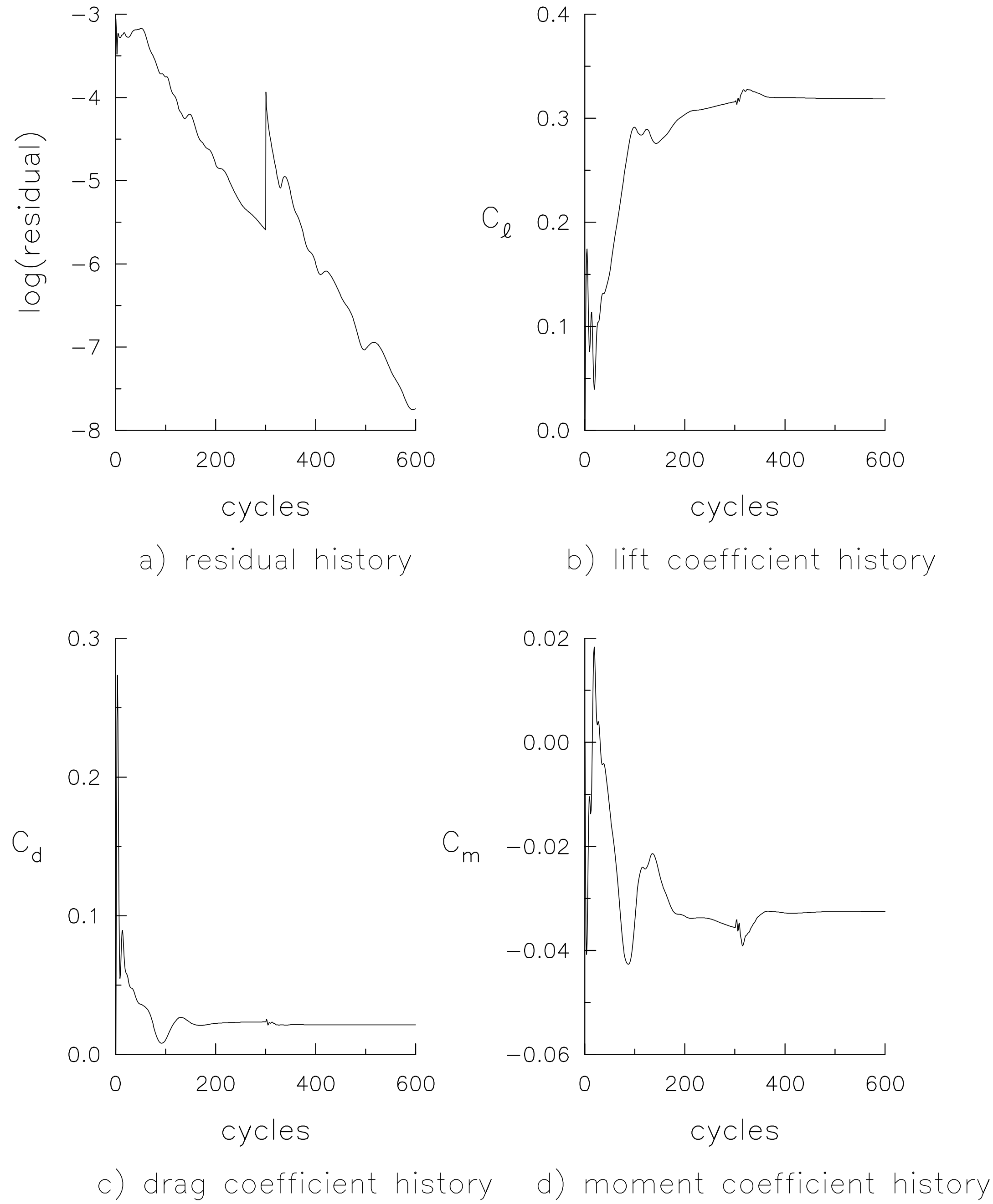

Figure 9-7. Seven-zone NACA 0012 case residual and coefficient histories; $\alpha = 1.25°$, $M_\infty = 0.8$.

9.1.4 Multielement Airfoil with Overlapped Grids

This test case solves for the viscous, turbulent flow over a three-element airfoil with $M_\infty = 0.2$, $\alpha = 8.109°$, 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.

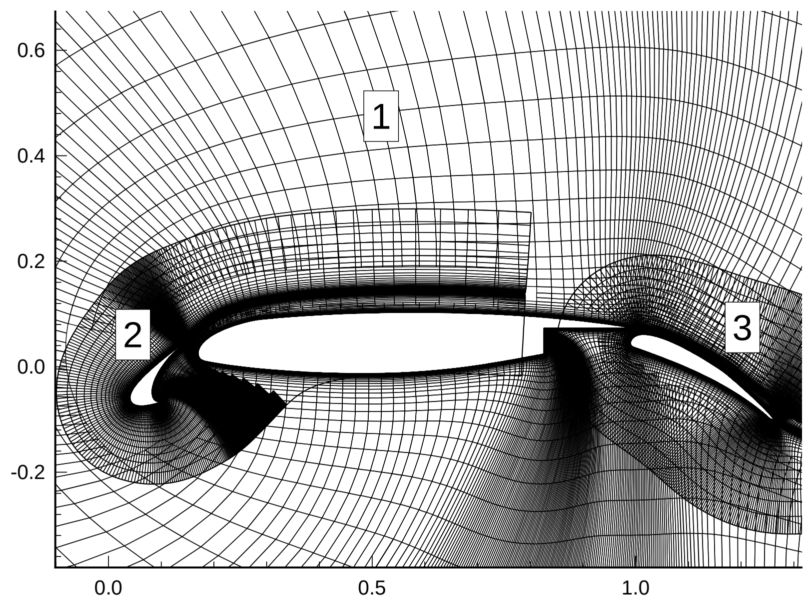

Figure 9-8. Three-zone overlapped grid system for a three-element airfoil.

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

File	Description
`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
```

Step 6

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

```
make -f makeprecfl3d_cray
```

Step 7

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

```
precfl3d < multi.inp
```

Step 8

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

```
make -f makecfl3d_cray
```

Step 9

Run the CFL3D code:

```
cfl3d < multi.inp
```

The input file for this case is:

```
I/O FILES
multi.bin
plot3dg.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.turres
cfl3d.blomax
cfl3d.out15
cfl3d.prout
cfl3d.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         0         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         0       000      1.00         0      10.0
      NGRID   NPLOT3D    NPRINT    NWREST      ICHK       I2D    NTSTEP       ITA
          3         3         0       100         0         1         1         1
        NCG       IEM  IADVANCE    IFORCE  IVISC(I)  IVISC(J)  IVISC(K)
          2         0         0       001         0         0         5
          2         0         0       001         0         0         5
          2         0         0       001         0         0         5
       IDIM      JDIM      KDIM
        002       361        65
        002       369        57
        002       297        49
     ILAMLO    ILAMHI    JLAMLO    JLAMHI    KLAMLO    KLAMHI
         00        00       000       000         0      0000
         00        00       000       000         0      0000
         00        00       000       000         0      0000
      INEWG    IGRIDC        IS        JS        KS        IE        JE        KE
          0         0         0         0         0         0         0         0
          0         0         0         0         0         0         0         0
          0         0         0         0         0         0         0         0
   IDIAG(I)  IDIAG(J)  IDIAG(K)  IFLIM(I)  IFLIM(J)  IFLIM(K)
          1         1         1         3         3         3
          1         1         1         3         3         3
          1         1         1         3         3         3
    IFDS(I)   IFDS(J)   IFDS(K)  RKAP0(I)  RKAP0(J)  RKAP0(K)
          1         1         1     .3333     .3333     .3333
          1         1         1     .3333     .3333     .3333
          1         1         1     .3333     .3333     .3333
       GRID     NBCI0   NBCIDIM     NBCJ0   NBCJDIM     NBCK0   NBCKDIM    IOVRLP
          1         1         1         1         1         3         1         1
          2         1         1         1         1         3         1         1
          3         1         1         1         1         3         1         1
I0:    GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
          1         1      1002         0         0         0         0         0
          2         1      1002         0         0         0         0         0
          3         1      1002         0         0         0         0         0
IDIM:  GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
          1         1      1002         0         0         0         0         0
          2         1      1002         0         0         0         0         0
          3         1      1002         0         0         0         0         0
J0:    GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
          1         1      1003         0         0         0         0         0
```

```
          2         1         0         0         0         0         0         0
          3         1         0         0         0         0         0         0
JDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
          1         1      1003         0         0         0         0         0
          2         1         0         0         0         0         0         0
          3         1         0         0         0         0         0         0
K0:   GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
          1         1         0         0         0         1        73         0
          1         2      2004         0         0        73       289         2
             TWTYPE        CQ
                 0.        0.
          1         3         0         0         0       289       361         0
          2         1         0         0         0         1        65         0
          2         2      2004         0         0        65       305         2
             TWTYPE        CQ
                 0.        0.
          2         3         0         0         0       305       369         0
          3         1         0         0         0         1        49         0
          3         2      2004         0         0        49       249         2
             TWTYPE        CQ
                 0.        0.
          3         3         0         0         0       249       297         0
KDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
          1         1      1003         0         0         0         0         0
          2         1         0         0         0         0         0         0
          3         1         0         0         0         0         0         0
       MSEQ    MGFLAG    ICONSF       MTT      NGAM
          1         1         1         0        01
       ISSC  EPSSC(1)  EPSSC(2)  EPSSC(3)      ISSR  EPSSR(1)  EPSSR(2)  EPSSR(3)
          0        .3        .3        .3         0        .3        .3        .3
       NCYC    MGLEVG     NEMGL     NITFO
       2000        03        00       000
       MIT1      MIT2      MIT3      MIT4      MIT5
         01        01        01        01        01
    1-1 BLOCKING DATA:
       NBLI
          3
  NUMBER   GRID     :    ISTA   JSTA   KSTA   IEND   JEND   KEND  ISVA1  ISVA2
       1      1             1      1      1      2     73      1      1      2
       2      2             1      1      1      2     65      1      1      2
       3      3             1      1      1      2     49      1      1      2
  NUMBER   GRID     :    ISTA   JSTA   KSTA   IEND   JEND   KEND  ISVA1  ISVA2
       1      1             1    361      1      2    289      1      1      2
       2      2             1    369      1      2    305      1      1      2
       3      3             1    297      1      2    249      1      1      2
   PATCH SURFACE DATA:
     NINTER
          0
   PLOT3D OUTPUT:
    GRID IPTYPE ISTART   IEND   IINC JSTART   JEND   JINC KSTART   KEND   KINC
       1      1      1    001      1     01    999      1      1    999      1
       2      1      1    001      1     01    999      1      1    999      1
       3      1      1    001      1     01    999      1      1    999      1
   MOVIE
       0
   PRINT OUT:
    GRID IPTYPE ISTART   IEND   IINC JSTART   JEND   JINC KSTART   KEND   KINC
   CONTROL SURFACE:
   NCS
     0
    GRID ISTART   IEND   JSTART   JEND   KSTART   KEND  IWALL  INORM
```

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.

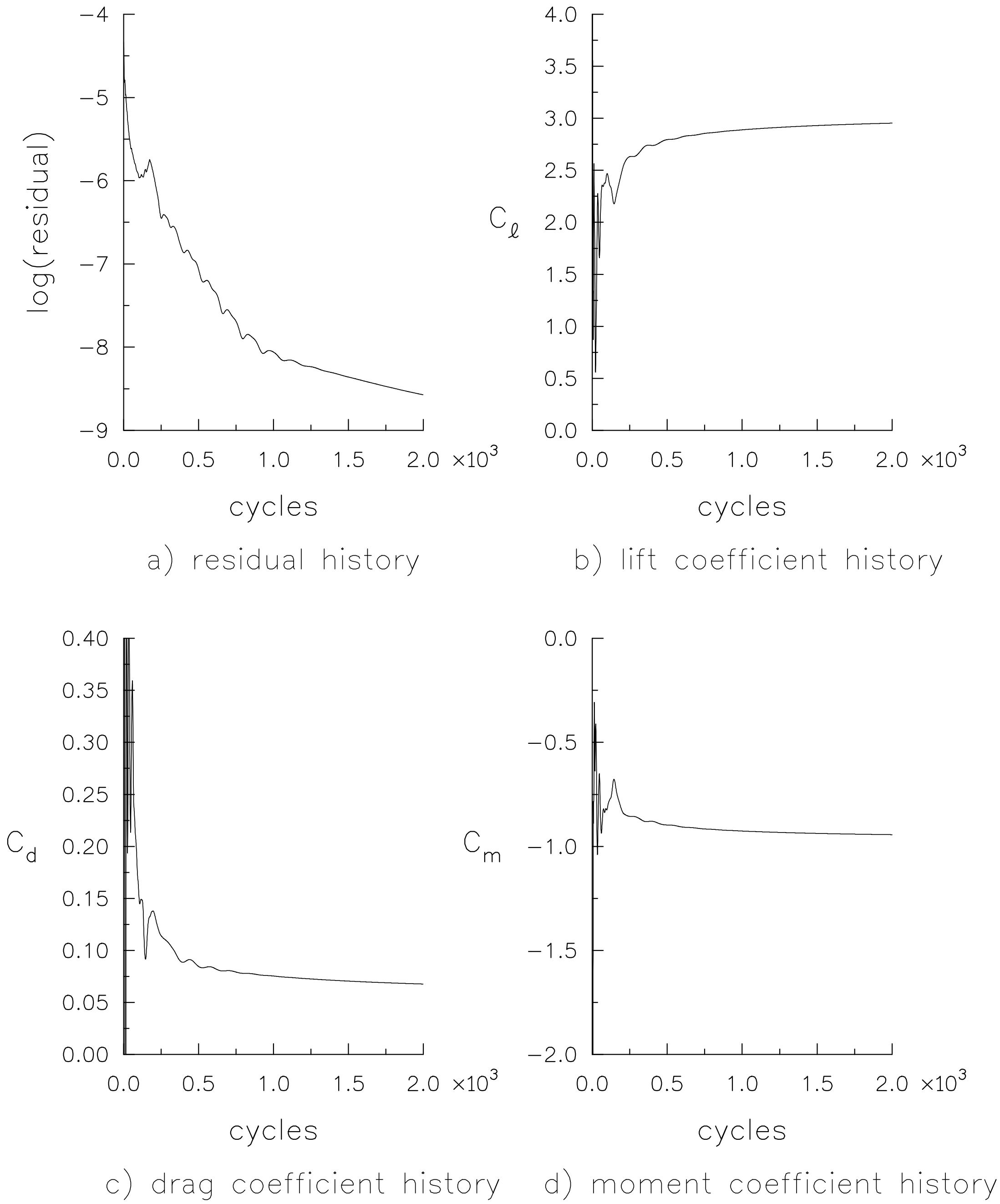

Figure 9-9. Convergence histories for three-element airfoil case; $\alpha = 8.109°$, $Re_{\tilde{L}_R} = 9 \times 10^6$.

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.

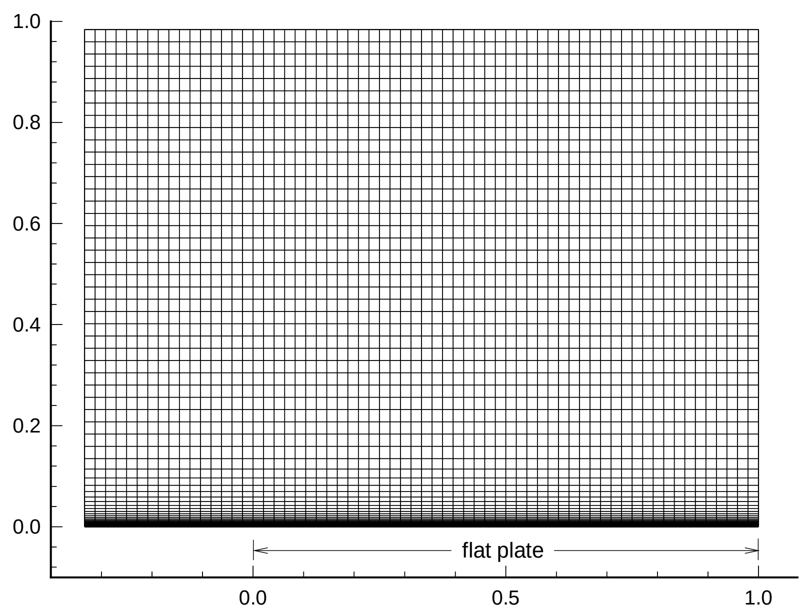

Figure 9-10. Single zone flat plate grid.

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

File	Description
`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:

Step 1

Compile the grid converter code:

```
cft77 grid2dto3d.f
```

Step 2

Link the grid converter object file:

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

Step 3

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

```
grid2dto3d
```

In answer to the questions, type:

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

Step 4

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

```
make -f makeprecfl3d_cray
```

Step 5

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

```
precfl3d < grdflat5.inp
```

Step 6

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

```
make -f makecfl3d_cray
```

Step 7

Run the CFL3D code:

```
cfl3d < grdflat5.inp
```

The input file for this case is:

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

```
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       0.0    06.000     460.0         0         0
      SREF      CREF      BREF       XMC       YMC       ZMC
   1.00000   1.00000    1.0000   0.00000      0.00      0.00
        DT     IREST   IFLAGTS      FMAX     IUNST    CFLTAU
    -5.000         1       000   05.0000         0       10.
     NGRID   NPLOT3D    NPRINT    NWREST      ICHK       I2D    NTSTEP       ITA
         1         1         2      1200         0         1         1         1
       NCG       IEM  IADVANCE    IFORCE  IVISC(I)  IVISC(J)  IVISC(K)
         2         0         0       001         0         0        12
    IDIM    JDIM    KDIM
      02      65      97
    ILAMLO    ILAMHI    JLAMLO    JLAMHI    KLAMLO    KLAMHI
         1         2         1        17         1        97
     INEWG    IGRIDC        IS        JS        KS        IE        JE        KE
         0         0         0         0         0         0         0         0
  IDIAG(I)  IDIAG(J)  IDIAG(K)  IFLIM(I)  IFLIM(J)  IFLIM(K)
         1         1         1         0         0         0
   IFDS(I)   IFDS(J)   IFDS(K)  RKAP0(I)  RKAP0(J)  RKAP0(K)
         1         1         1    0.3333    0.3333    0.3333
      GRID     NBCI0   NBCIDIM     NBCJ0   NBCJDIM     NBCK0   NBCKDIM    IOVRLP
         1         1         1         1         1         2         1         0
I0:   GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
         1         1      1001         0         0         0         0         0
IDIM: GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
         1         1      1002         0         0         0         0         0
J0:   GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
         1         1      1008         0         0         0         0         0
JDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
         1         1      1002         0         0         0         0         0
K0:   GRID   SEGMENT    BCTYPE      ISTA      IEND      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         1      1003         0         0         0         0         0
      MSEQ    MGFLAG    ICONSF       MTT      NGAM
         1         1         0         0        02
      ISSC EPSSSC(1) EPSSSC(2) EPSSSC(3)      ISSR EPSSSR(1) EPSSSR(2) EPSSSR(3)
         0       0.3       0.3       0.3         0       0.3       0.3       0.3
      NCYC    MGLEVG     NEMGL     NITFO
      0500        03        00       000
      MIT1      MIT2      MIT3      MIT4      MIT5      MIT6      MIT7      MIT8
        01        01        01        01        01         1         1         1
   1-1 BLOCKING DATA:
      NBLI
         0
 NUMBER   GRID     :     ISTA    JSTA    KSTA    IEND    JEND    KEND   ISVA1   ISVA2
 NUMBER   GRID     :     ISTA    JSTA    KSTA    IEND    JEND    KEND   ISVA1   ISVA2
  PATCH SURFACE DATA:
    NINTER
         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
      1      0      0      0      0     49     49      1      0      0      0
  CONTROL SURFACE:
  NCS
    0
   GRID ISTART   IEND   JSTART   JEND   KSTART   KEND  IWALL  INORM
```

After this test case is run, the residual history, found in file `cfl3d.res`, should look like that plotted in Figure 9-11. In Figure 9-12, values of u^+ 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.

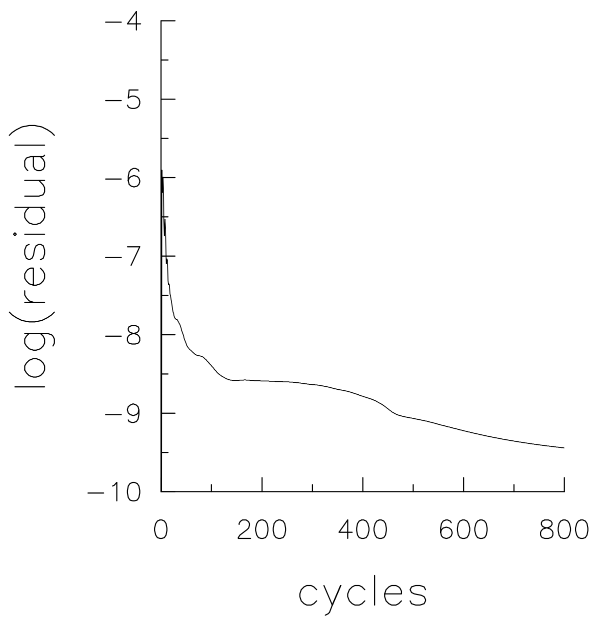

Figure 9-11. Residual history for single grid flat plate case.

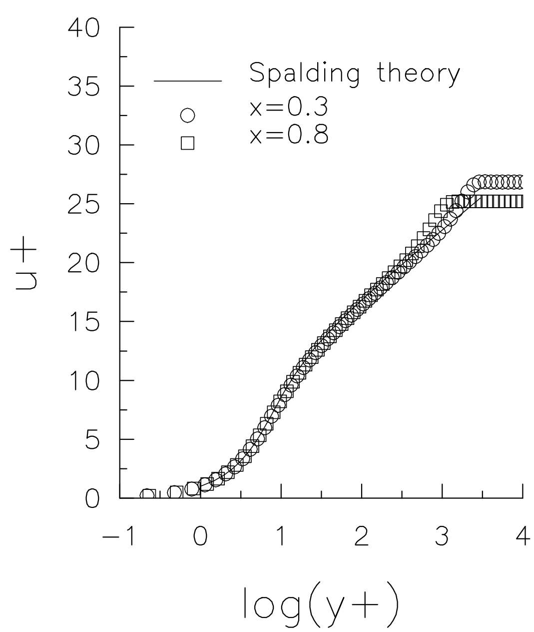

Figure 9-12. Flat plate calculation compared with experiment; $Re_{\tilde{L}_R} = 6 \times 10^6$.

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
$k-\omega$ EASM Gatski-Speziale (Linear)	8	0.218	43
$k-\varepsilon$ 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
$k-\varepsilon$ 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, $\mathrm{k}-\varepsilon$ models take longer than $\mathrm{k}-\omega$ 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 $\mathrm{k}_r = \tilde{\omega}\tilde{c}/2|\tilde{\mathbf{V}}|_\infty$, 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:

File	Description
`vibrate.inp`	input for CFL3D
`cartesian.f`	grid generator

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

Step 1

Compile the grid generator code:

```
cft77 cartesian.f
```

Step 2

Link the grid converter object file:

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

Step 3

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

```
cartesian
```

In answer to the questions, type

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

Step 4

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

```
make -f makeprecfl3d_cray
```

Step 5

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

```
precfl3d < vibrate.inp
```

Step 6

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

```
make -f makecfl3d_cray
```

Step 7

Run the CFL3D code:

```
cfl3d < vibrate.inp
```

The input file for this case is:

```
I/O FILES
grid.bin
plot3dg.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.turres
cfl3d.blomax
cfl3d.out15
cfl3d.prout
cfl3d.out20
ovrlp.bin
patch.bin
restart.bin
  Flat plate vibrating cascade with sliding interface downstream
     XMACH     ALPHA      BETA  REUE,MIL   TINF,DR     IALPH    IHSTRY
      .500      0.00       0.0      1.07     520.0         0         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
  .0098175         0       000      1.00         1        5.
```

```
      NGRID   NPLOT3D    NPRINT    NWREST      ICHK       I2D    NTSTEP       ITA
          2         2         2      2000         0         1       961        -2
        NCG       IEM  IADVANCE    IFORCE  IVISC(I)  IVISC(J)  IVISC(K)
          2         0         0       001         0         0         0
          2         0         0       001         0         0         0
       IDIM      JDIM      KDIM
          2       161        21
          2       101        21
     ILAMLO    ILAMHI    JLAMLO    JLAMHI    KLAMLO    KLAMHI
         00        00       000       000         0      0000
         00        00       000       000         0      0000
      INEWG    IGRIDC        IS        JS        KS        IE        JE        KE
          0         0         0         0         0         0         0         0
          0         0         0         0         0         0         0         0
   IDIAG(I)  IDIAG(J)  IDIAG(K)  IFLIM(I)  IFLIM(J)  IFLIM(K)
          1         1         1         0         0         0
          1         1         1         0         0         0
    IFDS(I)   IFDS(J)   IFDS(K)  RKAP0(I)  RKAP0(J)  RKAP0(K)
          1         1         1     .3333     .3333     .3333
          1         1         1     .3333     .3333     .3333
       GRID     NBCI0   NBCIDIM     NBCJ0   NBCJDIM     NBCK0   NBCKDIM    IOVRLP
          1         1         1         1         1         3         3         0
          2         1         1         1         1         1         1         0
  I0:   GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
          1         1      1001         0         0         0         0         0
          2         1      1001         0         0         0         0         0
  IDIM: GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
          1         1      1002         0         0         0         0         0
          2         1      1002         0         0         0         0         0
  J0:   GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
          1         1      1003         0         0         0         0         0
          2         1         0         0         0         0         0         0
  JDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
          1         1         0         0         0         0         0         0
          2         1      1003         0         0         0         0         0
  K0:   GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
          1         1      2005         1         2         1       121         4
                 NBLP     DTHTX     DTHTY     DTHTZ
                    1       0.0        0.        0.
          1         2      1005         1         2       121       141         0
          1         3      2005         1         2       141       161         4
                 NBLP     DTHTX     DTHTY     DTHTZ
                    1       0.0        0.        0.
          2         1      2005         0         0         0         0         4
                 NBLP     DTHTX     DTHTY     DTHTZ
                    2       0.0        0.        0.
  KDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
          1         1      2005         1         2         1       121         4
                 NBLP     DTHTX     DTHTY     DTHTZ
                    1       0.0        0.        0.
          1         2      1005         1         2       121       141         0
          1         3      2005         1         2       141       161         4
                 NBLP     DTHTX     DTHTY     DTHTZ
                    1       0.0        0.        0.
          2         1      2005         0         0         0         0         4
                 NBLP     DTHTX     DTHTY     DTHTZ
                    2       0.0        0.        0.
       MSEQ    MGFLAG    ICONSF       MTT      NGAM
          1         1         1         0        02
       ISSC  EPSSC(1)  EPSSC(2)  EPSSC(3)      ISSR  EPSSR(1)  EPSSR(2)  EPSSR(3)
          0        .3        .3        .3         0        .3        .3        .3
       NCYC    MGLEVG     NEMGL    NITFO
          3        03        00       000
       MIT1      MIT2      MIT3      MIT4      MIT5
         01        01        01        01        01
    1-1 BLOCKING DATA:
       NBLI
          0
   NUMBER   GRID     :    ISTA   JSTA   KSTA   IEND   JEND   KEND  ISVA1  ISVA2
   NUMBER   GRID     :    ISTA   JSTA   KSTA   IEND   JEND   KEND  ISVA1  ISVA2
    PATCH SURFACE DATA:
     NINTER
```

```
       0
 PLOT3D OUTPUT:
  GRID IPTYPE ISTART   IEND   IINC JSTART   JEND   JINC KSTART   KEND   KINC
     1      0      1    999      1     01    999      1      1    999      1
     2      0      1    999      1     01    999      1      1    999      1
 MOVIE
     0
 PRINT OUT:
  GRID IPTYPE ISTART   IEND   IINC JSTART   JEND   JINC KSTART   KEND   KINC
     1      1      1      2      1    999    999      1      1    999      1
     2      1      1      2      1      1      1      1      1    999      1
 CONTROL SURFACE:
 NCS
   0
  GRID ISTART   IEND   JSTART   JEND   KSTART   KEND  IWALL  INORM
MOVING GRID DATA - TRANSLATION
 NTRANS
      2
   LREF
    0.5
   GRID   ITRANS    RFREQ     XMAG     YMAG     ZMAG
      1        2   .31831       0.       0.  0.00100
      2        1       0.       0.       0.  0.31831
   GRID    DXMAX    DYMAX    DZMAX
      1       0.       0.    0.000
      2       0.       0.    1.000
MOVING GRID DATA - ROTATION
 NROTAT
      0
  LREF
   GRID   IROTAT    RFREQ   THXMAG   THYMAG   THZMAG    XORIG    YORIG    ZORIG
   GRID   THXMAX   THYMAX   THZMAX
 DYNAMIC PATCH INPUT DATA
   NINTER
       2
  INT  IFIT    LIMIT    ITMAX    MCXIE    MCETA      C-0    IORPH    ITOSS
    1    -1        5       20        0        0        0        0        1
    2    -1        5       20        0        0        0        0        1
  INT    TO     XIE1     XIE2     ETA1     ETA2      NFB
    1   122        0        0        0        0        2
       FROM     XIE1     XIE2     ETA1     ETA2    FACTJ    FACTK
        221        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
        221        0        0        0        0       0.       0.
                  DX       DY       DZ   DTHETX   DTHETY   DTHETZ
                  0.       0.      -1.       0.       0.       0.
  INT    TO     XIE1     XIE2     ETA1     ETA2      NFB
    2   221        0        0        0        0        2
       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
        122        0        0        0        0       0.       0.
                  DX       DY       DZ   DTHETX   DTHETY   DTHETZ
                  0.       0.      +1.       0.       0.       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.

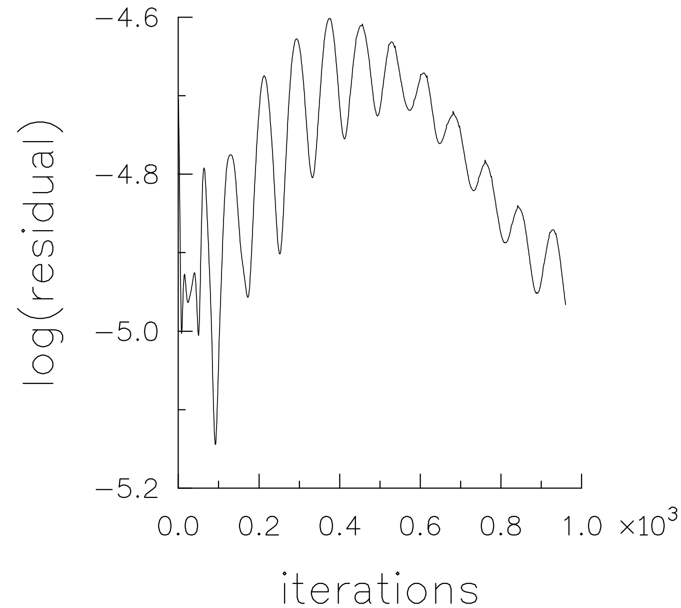

Figure 9-13. Residual history for inviscid flow through vibrating flat plates.

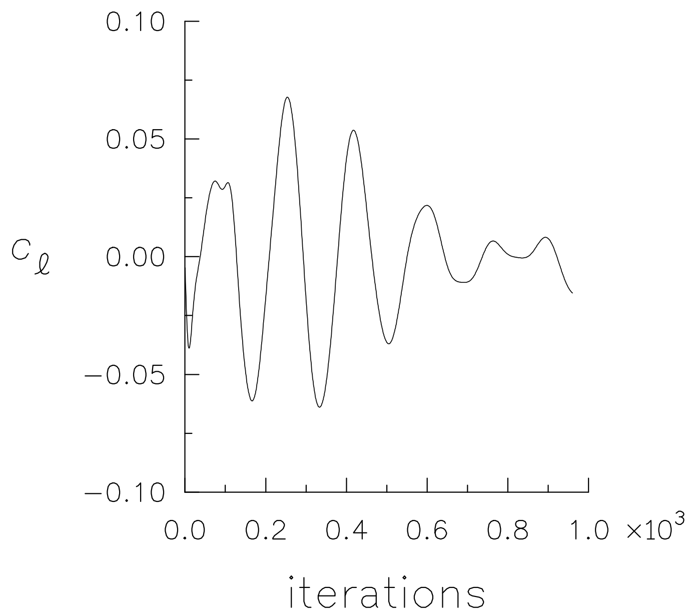

Figure 9-14. Lift coefficient history for inviscid flow through vibrating flat plates; $M_\infty = 0.5$.

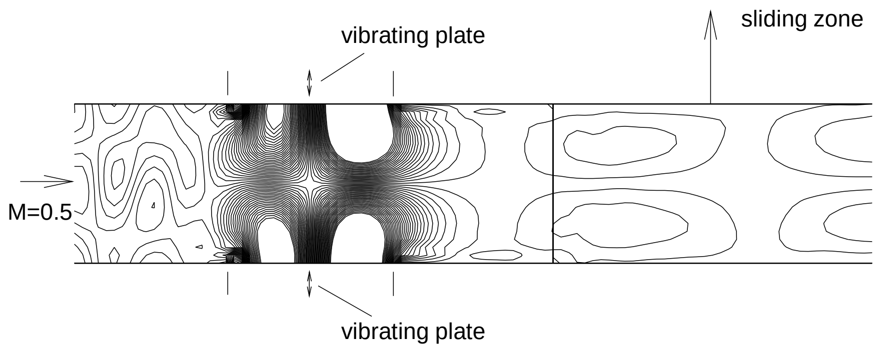

Figure 9-15. Pressure contours for inviscid flow through vibrating flat plates; $M_\infty = 0.5$.

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.

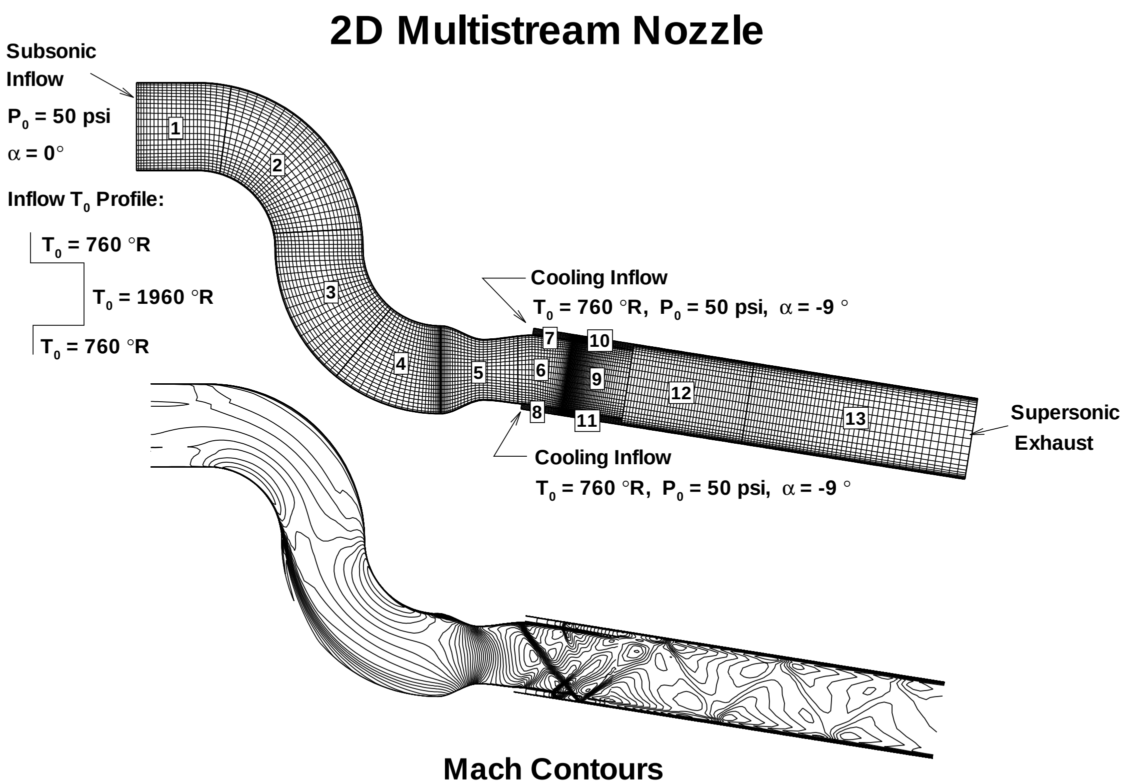

Figure 9-16. Cross-section of multistream nozzle zonal patching and Mach contours.

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 $1960°\mathrm{R}$ in the core and $760°\mathrm{R}$ 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 $760°\mathrm{R}$. 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 $1960°\mathrm{R}$) 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:

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

Next, determine the stagnation density and speed of sound:

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

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

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

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

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

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

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

$$\tilde{\mu}^* = 3.7\times10^{-7}\left(\frac{1164}{520}\right)^{0.76} = 6.82\times10^{-7} \text{ slugs/(feet-seconds)} \tag{9-6}$$

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

$$Re^* = \frac{\tilde{\rho}^*\tilde{u}^*(\text{throat height})}{\tilde{\mu}^*} = 0.0019(1673)\frac{1}{6.82\times10^{-7}} = 4.66\times10^6 \tag{9-7}$$

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

$$\mathbf{reue} = \frac{Re^*\times10^{-6}}{12} = \frac{4.66}{12} = 0.388 \tag{9-8}$$

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):

$$\begin{aligned}p_t &= 50 \text{ psi} \rightarrow \frac{p_t}{p^*} = \frac{p_t}{p_\infty} = \frac{50}{26.4} = 1.894\\ T_t &= 760°\text{R} \rightarrow \frac{T_t}{T^*} = \frac{T_t}{T_\infty} = \frac{760}{1164} = 0.653\\ T_t &= 1960°\text{R} \rightarrow \frac{T_t}{T^*} = \frac{T_t}{T_\infty} = \frac{1960}{1164} = 1.684\end{aligned} \tag{9-9}$$

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:

$$\begin{aligned} M &= 0.45 \\ \frac{p_t}{p_\infty} &= 1.894 \\ \frac{T_t}{T_\infty} &= \frac{0.653}{1.684} \end{aligned} \tag{9-10}$$

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

$$\begin{aligned} M &= 1.0 \\ \frac{p_t}{p_\infty} &= 1.894 \\ \frac{T_t}{T_\infty} &= 0.653 \\ \alpha &= -9 \\ \beta &= 0 \end{aligned} \tag{9-11}$$

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:

File	Description
`multistream.inp`	input for CFL3D
`grid_multistream.fmt`	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:

Step 1

Compile the grid converter code:

```
cft77 formtobin.f
```

Step 2

Link the grid converter object file:

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

Step 3

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

```
formtobin
```

Step 4

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

```
make -f makeronnie_cray
```

Step 5

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

```
ronnie < ronnie.inp
```

Step 6

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

```
make -f makeprecfl3d_cray
```

Step 7

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

```
precfl3d < multistream.inp
```

Step 8

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

```
make -f makecfl3d_cray
```

Step 9

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

```
cfl3d < multistream.inp
```

The input file for this case is:

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

```
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
     1.000      0.00       0.0     0.388    1163.0         1         1
      SREF      CREF      BREF       XMC       YMC       ZMC
   1.00000   1.00000    1.0000   0.25000      0.00      0.00
        DT     IREST   IFLAGTS      FMAX     IUNST   CFL_TAU
    -1.0000         0       000       1.0        +1        5.
     NGRID   NPLOT3D    NPRINT    NWREST      ICHK       I2D    NTSTEP       ITA
       -13        13         0       500         0         1         2        -2
       NCG       IEM  IADVANCE    IFORCE  IVISC(I)  IVISC(J)  IVISC(K)
         1         0         0       000         0         0        +7
         1         0         0       000         0         0        +7
         1         0         0       000         0         0        +7
         1         0         0       000         0         0        +7
         1         0         0       000         0         0        +7
         1         0         0       000         0         0        +7
         1         0         0       000         0         0        +7
         1         0         0       000         0         0        +7
         1         0         0       000         0         0        +7
         1         0         0       000         0         0        +7
         1         0         0       000         0         0        +7
         1         0         0       000         0         0        +7
         1         0         0       000         0         0        +7
      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        21
         2        41        61
         2        49        57
    ILAMLO    ILAMHI    JLAMLO    JLAMHI    KLAMLO    KLAMHI
        00        00       000       000         0      0000
        00        00       000       000         0      0000
        00        00       000       000         0      0000
        00        00       000       000         0      0000
        00        00       000       000         0      0000
        00        00       000       000         0      0000
        00        00       000       000         0      0000
        00        00       000       000         0      0000
        00        00       000       000         0      0000
        00        00       000       000         0      0000
        00        00       000       000         0      0000
        00        00       000       000         0      0000
        00        00       000       000         0      0000
     INEWG    IGRIDC        IS        JS        KS        IE        JE        KE
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         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         0         0         0         0         0
  IDIAG(I)  IDIAG(J)  IDIAG(K)  IFLIM(I)  IFLIM(J)  IFLIM(K)
         1         1         1         3         3         3
         1         1         1         3         3         3
         1         1         1         3         3         3
         1         1         1         3         3         3
         1         1         1         3         3         3
         1         1         1         3         3         3
         1         1         1         3         3         3
         1         1         1         3         3         3
         1         1         1         3         3         3
         1         1         1         3         3         3
         1         1         1         3         3         3
         1         1         1         3         3         3
         1         1         1         3         3         3
   IFDS(I)   IFDS(J)   IFDS(K)  RKAP0(I)  RKAP0(J)  RKAP0(K)
         1         1         1     .3333     .3333     .3333
         1         1         1     .3333     .3333     .3333
         1         1         1     .3333     .3333     .3333
         1         1         1     .3333     .3333     .3333
         1         1         1     .3333     .3333     .3333
         1         1         1     .3333     .3333     .3333
         1         1         1     .3333     .3333     .3333
         1         1         1     .3333     .3333     .3333
         1         1         1     .3333     .3333     .3333
         1         1         1     .3333     .3333     .3333
         1         1         1     .3333     .3333     .3333
         1         1         1     .3333     .3333     .3333
         1         1         1     .3333     .3333     .3333
      GRID     NBCI0   NBCIDIM     NBCJ0   NBCJDIM     NBCK0   NBCKDIM    IOVRLP
         1         1         1         1         1         1         1         0
         2         1         1         1         1         1         1         0
         3         1         1         1         1         1         1         0
         4         1         1         1         1         1         1         0
         5         1         1         1         1         1         1         0
         6         1         1         1         1         1         1         0
         7         1         1         1         1         1         1         0
         8         1         1         1         1         1         1         0
         9         1         1         1         1         1         1         0
        10         1         1         1         1         1         1         0
        11         1         1         1         1         1         1         0
        12         1         1         1         1         1         1         0
        13         1         1         1         1         1         1         0
I0:   GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
         1         1      1002         0         0         0         0        0
         2         1      1002         0         0         0         0        0
         3         1      1002         0         0         0         0        0
         4         1      1002         0         0         0         0        0
         5         1      1002         0         0         0         0        0
         6         1      1002         0         0         0         0        0
         7         1      1002         0         0         0         0        0
         8         1      1002         0         0         0         0        0
         9         1      1002         0         0         0         0        0
        10         1      1002         0         0         0         0        0
        11         1      1002         0         0         0         0        0
        12         1      1002         0         0         0         0        0
        13         1      1002         0         0         0         0        0
IDIM: GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
         1         1      1002         0         0         0         0        0
         2         1      1002         0         0         0         0        0
         3         1      1002         0         0         0         0        0
         4         1      1002         0         0         0         0        0
         5         1      1002         0         0         0         0        0
         6         1      1002         0         0         0         0        0
         7         1      1002         0         0         0         0        0
         8         1      1002         0         0         0         0        0
         9         1      1002         0         0         0         0        0
        10         1      1002         0         0         0         0        0
        11         1      1002         0         0         0         0        0
```

```
        12         1      1002         0         0         0         0         0
        13         1      1002         0         0         0         0         0
J0:   GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
         1         1      2003         0         0         0         0        -5
Mach  Pt/Pinf  Tt/Tinf  alpha  beta
inflow.data
         2         1         0         0         0         0         0         0
         3         1         0         0         0         0         0         0
         4         1         0         0         0         0         0         0
         5         1         0         0         0         0         0         0
         6         1         0         0         0         0         0         0
         7         1      2003         0         0         0         0         5
  Mach  Pt/Pinf  Tt/Tinf  alpha  beta
  1.00   1.894    0.653    -9.    0.
         8         1      2003         0         0         0         0         5
  Mach  Pt/Pinf  Tt/Tinf  alpha  beta
  1.00   1.894    0.653    -9.    0.
         9         1         0         0         0         0         0         0
        10         1         0         0         0         0         0         0
        11         1         0         0         0         0         0         0
        12         1         0         0         0         0         0         0
        13         1         0         0         0         0         0         0
JDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
         1         1         0         0         0         0         0         0
         2         1         0         0         0         0         0         0
         3         1         0         0         0         0         0         0
         4         1         0         0         0         0         0         0
         5         1         0         0         0         0         0         0
         6         1         0         0         0         0         0         0
         7         1         0         0         0         0         0         0
         8         1         0         0         0         0         0         0
         9         1         0         0         0         0         0         0
        10         1         0         0         0         0         0         0
        11         1         0         0         0         0         0         0
        12         1         0         0         0         0         0         0
        13         1      1002         0         0         0         0         0
K0:   GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
         1         1      2004         0         0         0         0         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
0.      0.
         4         1      2004         0         0         0         0         2
Tw      Cq
0.      0.
         5         1      2004         0         0         0         0         2
Tw      Cq
0.      0.
         6         1      2004         0         0         0         0         2
Tw      Cq
0.      0.
         7         1      2004         0         0         0         0         2
Tw      Cq
0.      0.
         8         1      2004         0         0         0         0         2
Tw      Cq
0.      0.
         9         1         0         0         0         0         0         0
        10         1      2004         0         0         0         0         2
Tw      Cq
0.      0.
        11         1         0         0         0         0         0         0
        12         1      2004         0         0         0         0         2
Tw      Cq
0.      0.
        13         1      2004         0         0         0         0         2
Tw      Cq
0.      0.
```

```
KDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND    NDATA
         1         1      2004         0         0         0         0        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
0.      0.
         4         1      2004         0         0         0         0        2
Tw      Cq
0.      0.
         5         1      2004         0         0         0         0        2
Tw      Cq
0.      0.
         6         1      2004         0         0         0         0        2
Tw      Cq
0.      0.
         7         1      2004         0         0         0         0        2
Tw      Cq
0.      0.
         8         1      2004         0         0         0         0        2
Tw      Cq
0.      0.
         9         1         0         0         0         0         0        0
        10         1         0         0         0         0         0        0
        11         1      2004         0         0         0         0        2
Tw      Cq
0.      0.
        12         1      2004         0         0         0         0        2
Tw      Cq
0.      0.
        13         1      2004         0         0         0         0        2
Tw      Cq
0.      0.
      MSEQ    MGFLAG    ICONSF       MTT      NGAM
         1         1         1         0        02
      ISSC  EPSSC(1)  EPSSC(2)  EPSSC(3)      ISSR  EPSSR(1)  EPSSR(2)  EPSSR(3)
         0        .3        .3        .3         0        .3        .3        .3
      NCYC    MGLEVG     NEMGL     NITFO
      3000        02        00         0
      MIT1      MIT2      MIT3      MIT4      MIT5
        01        01        01        01        01
   1-1 BLOCKING DATA:
      NBLI
         0
   NUMBER   GRID   :   ISTA   JSTA   KSTA   IEND   JEND   KEND   ISVA1   ISVA2
   NUMBER   GRID   :   ISTA   JSTA   KSTA   IEND   JEND   KEND   ISVA1   ISVA2
  PATCH SURFACE DATA:
    NINTER
        -1
 PLOT3D OUTPUT:
  grid iptyp  ista  iend  iinc  jsta  jend  jinc  ksta  kend  kinc
     1     0     0     0     0     0     0     0     0     0     0
     2     0     0     0     0     0     0     0     0     0     0
     3     0     0     0     0     0     0     0     0     0     0
     4     0     0     0     0     0     0     0     0     0     0
     5     0     0     0     0     0     0     0     0     0     0
     6     0     0     0     0     0     0     0     0     0     0
     7     0     0     0     0     0     0     0     0     0     0
     8     0     0     0     0     0     0     0     0     0     0
     9     0     0     0     0     0     0     0     0     0     0
    10     0     0     0     0     0     0     0     0     0     0
    11     0     0     0     0     0     0     0     0     0     0
    12     0     0     0     0     0     0     0     0     0     0
    13     0     0     0     0     0     0     0     0     0     0
  MOVIE
      0
  PRINT OUT:
   GRID IPTYPE ISTART   IEND   IINC JSTART   JEND   JINC KSTART   KEND   KINC
 CONTROL SURFACES:
```

```
  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*0.4499999999999993,  40*1.893999999999998,  16*0.653000000000001,
8*1.685000000000004,  16*0.653000000000001,  40*0.,  40*0.
```

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

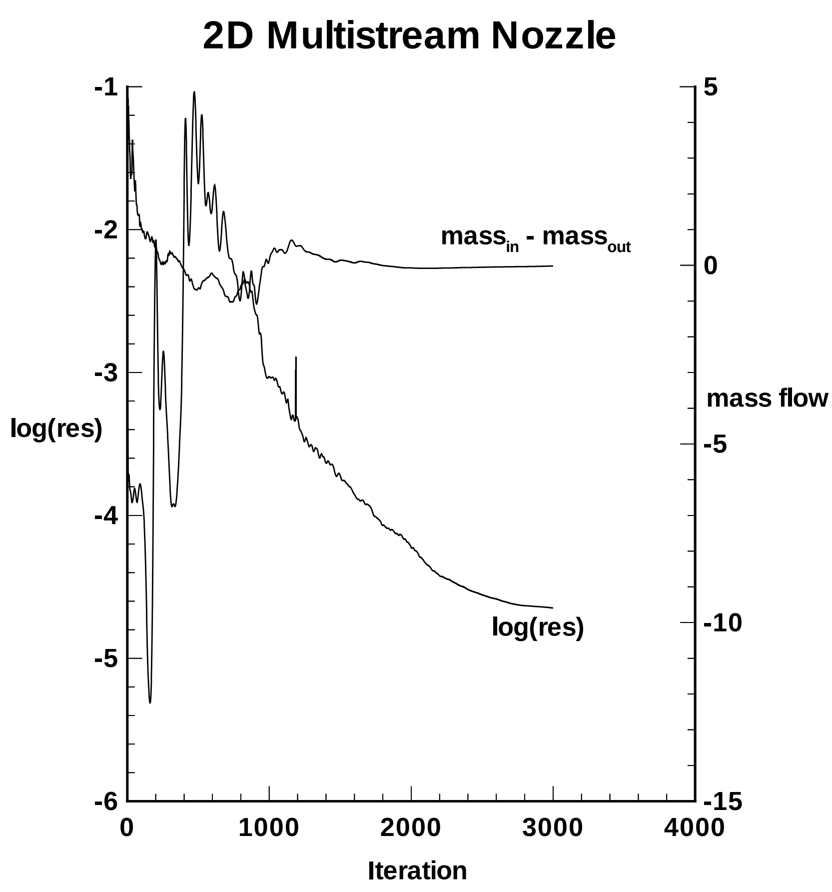

Figure 9-17. Multistream nozzle case residual and mass flow convergence history.

9.1.8 Rotor Stator

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

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

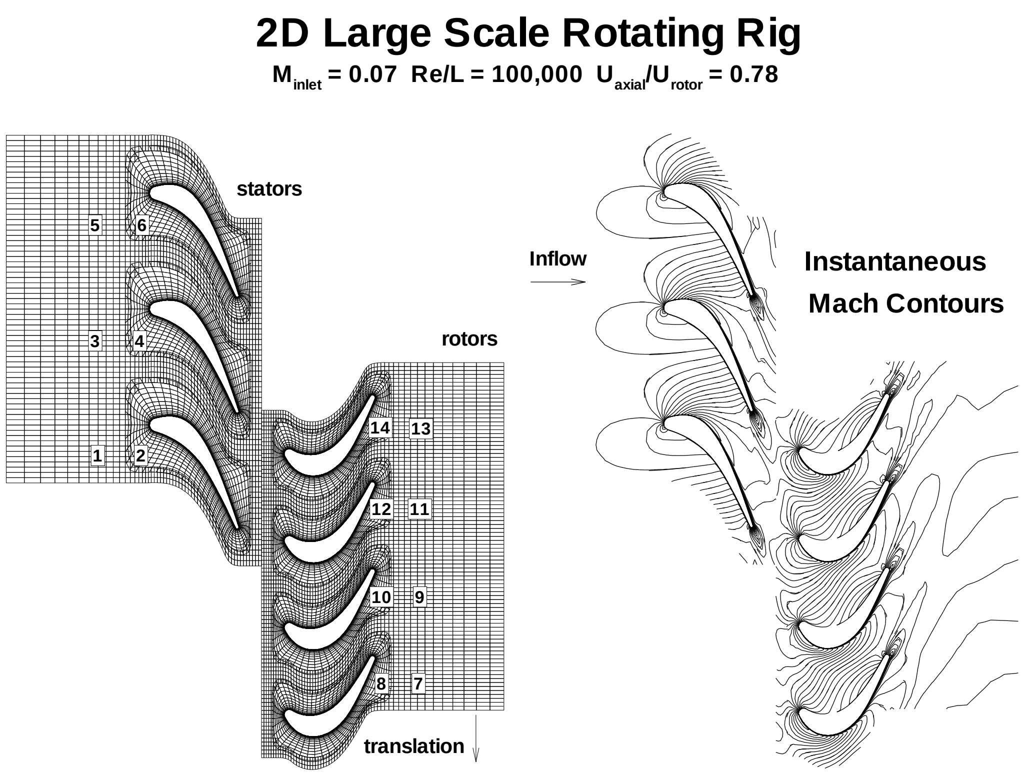

Figure 9-18. Fourteen zone rotor-stator grid system and Mach contours.

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.al[18]). To reduce the problem size in the computation, the ratio of stator to rotor blades was reduced to 3:4 (equivalent to 21:28), and the stators were scaled by a factor of 22/21 to maintain the same pitch-to-chord ratio as in the experiment. The experimental set-up was a three-dimensional configuration; the corresponding 2-d simulation was set up from conditions at the mid-span radius of 27 inches, for a rotor speed of 410 rpm, with a nominal axial velocity of 75 feet/second. The inlet Mach number in the experiment was approximately 0.07, and the Reynolds number/inch was approximately 100,000.

9.1.8.2 Input Setup

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

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,

$$M_{inlet} = 0.07$$
$$\frac{p_{t,\,inlet}}{p_\infty} = 1.0035 \qquad \text{(9-12)}$$
$$\frac{T_{t,\,inlet}}{T_\infty} = 1.0010$$

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

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

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

It should be noted that the input grid is in PLOT3D format, with y as the “up” 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

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

This gives

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

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 **dzmax** = 24.23514. Thus the rotor zones are reset whenever the displacement exceeds 24.23514 inches.

9.1.8.3 Running CFL3D

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

File	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

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

Step 1

Compile the grid converter code:

```
cft77 fmttobin_p3d.f
```

Step 2

Link the grid converter object file:

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

Step 3

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

```
fmttobin_p3d
```

Step 4

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

```
make -f makemaggie_cray
```

Step 5

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

```
maggie < maggie.inp
```

Step 6

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

```
make -f makeprecfl3d_cray
```

Step 7

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

```
precfl3d < lsrr.inp
```

Step 8

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

```
make -f makecfl3d_cray
```

Step 9

Run the CFL3D code:

```
cfl3d < lsrr.inp
```

The input file for this case is:

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

```
         00        00       000       000         0      0000
         00        00       000       000         0      0000
      INEWG    IGRIDC        IS        JS        KS        IE        JE        KE
          0         0         0         0         0         0         0         0
          0         0         0         0         0         0         0         0
          0         0         0         0         0         0         0         0
          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         0         0         0         0         0
          0         0         0         0         0         0         0         0
   IDIAG(I)  IDIAG(J)  IDIAG(K)  IFLIM(I)  IFLIM(J)  IFLIM(K)
          1         1         1         0         0         0
          1         1         1         0         0         0
          1         1         1         0         0         0
          1         1         1         0         0         0
          1         1         1         0         0         0
          1         1         1         0         0         0
          1         1         1         0         0         0
          1         1         1         0         0         0
          1         1         1         0         0         0
          1         1         1         0         0         0
          1         1         1         0         0         0
          1         1         1         0         0         0
          1         1         1         0         0         0
          1         1         1         0         0         0
    IFDS(I)   IFDS(J)   IFDS(K)  RKAP0(I)  RKAP0(J)  RKAP0(K)
          1         1         1     .3333     .3333     .3333
          1         1         1     .3333     .3333     .3333
          1         1         1     .3333     .3333     .3333
          1         1         1     .3333     .3333     .3333
          1         1         1     .3333     .3333     .3333
          1         1         1     .3333     .3333     .3333
          1         1         1     .3333     .3333     .3333
          1         1         1     .3333     .3333     .3333
          1         1         1     .3333     .3333     .3333
          1         1         1     .3333     .3333     .3333
          1         1         1     .3333     .3333     .3333
          1         1         1     .3333     .3333     .3333
          1         1         1     .3333     .3333     .3333
          1         1         1     .3333     .3333     .3333
       GRID     NBCI0   NBCIDIM     NBCJ0   NBCJDIM     NBCK0   NBCKDIM    IOVRLP
          1         1         1         1         1         1         1         1
          2         1         1         1         1         1         1         1
          3         1         1         1         1         1         1         1
          4         1         1         1         1         1         1         1
          5         1         1         1         1         1         1         1
          6         1         1         1         1         1         1         1
          7         1         1         1         1         1         1         1
          8         1         1         1         1         1         1         1
          9         1         1         1         1         1         1         1
         10         1         1         1         1         1         1         1
         11         1         1         1         1         1         1         1
         12         1         1         1         1         1         1         1
         13         1         1         1         1         1         1         1
         14         1         1         1         1         1         1         1
I0:    GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
          1         1      1002         0         0         0         0         0
          2         1      1002         0         0         0         0         0
          3         1      1002         0         0         0         0         0
          4         1      1002         0         0         0         0         0
          5         1      1002         0         0         0         0         0
          6         1      1002         0         0         0         0         0
          7         1      1002         0         0         0         0         0
          8         1      1002         0         0         0         0         0
          9         1      1002         0         0         0         0         0
```

```
        10         1      1002         0         0         0         0         0
        11         1      1002         0         0         0         0         0
        12         1      1002         0         0         0         0         0
        13         1      1002         0         0         0         0         0
        14         1      1002         0         0         0         0         0
IDIM: GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
         1         1      1002         0         0         0         0         0
         2         1      1002         0         0         0         0         0
         3         1      1002         0         0         0         0         0
         4         1      1002         0         0         0         0         0
         5         1      1002         0         0         0         0         0
         6         1      1002         0         0         0         0         0
         7         1      1002         0         0         0         0         0
         8         1      1002         0         0         0         0         0
         9         1      1002         0         0         0         0         0
        10         1      1002         0         0         0         0         0
        11         1      1002         0         0         0         0         0
        12         1      1002         0         0         0         0         0
        13         1      1002         0         0         0         0         0
        14         1      1002         0         0         0         0         0
J0:   GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
         1         1      2003         0         0         0         0         5
Mach  Pt/Pinf  Tt/Tinf  alpha  beta
0.07   1.0035   1.0010     0.    0.
         2         1         0         0         0         0         0         0
         3         1      2003         0         0         0         0         5
Mach  Pt/Pinf  Tt/Tinf  alpha  beta
0.07   1.0035   1.0010     0.    0.
         4         1         0         0         0         0         0         0
         5         1      2003         0         0         0         0         5
Mach  Pt/Pinf  Tt/Tinf  alpha  beta
0.07   1.0035   1.0010     0.    0.
         6         1         0         0         0         0         0         0
         7         1         0         0         0         0         0         0
         8         1         0         0         0         0         0         0
         9         1         0         0         0         0         0         0
        10         1         0         0         0         0         0         0
        11         1         0         0         0         0         0         0
        12         1         0         0         0         0         0         0
        13         1         0         0         0         0         0         0
        14         1         0         0         0         0         0         0
JDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
         1         1         0         0         0         0         0         0
         2         1         0         0         0         0         0         0
         3         1         0         0         0         0         0         0
         4         1         0         0         0         0         0         0
         5         1         0         0         0         0         0         0
         6         1         0         0         0         0         0         0
         7         1      2002         0         0         0         0         1
pexit/pinf
0.967
         8         1         0         0         0         0         0         0
         9         1      2002         0         0         0         0         1
pexit/pinf
0.967
        10         1         0         0         0         0         0         0
        11         1      2002         0         0         0         0         1
pexit/pinf
0.967
        12         1         0         0         0         0         0         0
        13         1      2002         0         0         0         0         1
pexit/pinf
0.967
        14         1         0         0         0         0         0         0
K0:   GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
         1         1         0         0         0         0         0         0
         2         1      2004         0         0         0         0         2
Tw/Tinf   C_q
0.        0.
         3         1         0         0         0         0         0         0
         4         1      2004         0         0         0         0         2
Tw/Tinf   C_q
```

```
0.        0.
         5         1         0         0         0         0         0         0
         6         1      2004         0         0         0         0         2
Tw/Tinf   C_q
0.        0.
         7         1         0         0         0         0         0         0
         8         1      2004         0         0         0         0         2
Tw/Tinf   C_q
0.        0.
         9         1         0         0         0         0         0         0
        10         1      2004         0         0         0         0         2
Tw/Tinf   C_q
0.        0.
        11         1         0         0         0         0         0         0
        12         1      2004         0         0         0         0         2
Tw/Tinf   C_q
0.        0.
        13         1         0         0         0         0         0         0
        14         1      2004         0         0         0         0         2
Tw/Tinf   C_q
0.        0.
KDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
         1         1         0         0         0         0         0         0
         2         1         0         0         0         0         0         0
         3         1         0         0         0         0         0         0
         4         1         0         0         0         0         0         0
         5         1         0         0         0         0         0         0
         6         1         0         0         0         0         0         0
         7         1         0         0         0         0         0         0
         8         1         0         0         0         0         0         0
         9         1         0         0         0         0         0         0
        10         1         0         0         0         0         0         0
        11         1         0         0         0         0         0         0
        12         1         0         0         0         0         0         0
        13         1         0         0         0         0         0         0
        14         1         0         0         0         0         0         0
      MSEQ    MGFLAG    ICONSF       MTT      NGAM
         1         1         1         0        01
      ISSC  EPSSC(1)  EPSSC(2)  EPSSC(3)      ISSR  EPSSR(1)  EPSSR(2)  EPSSR(3)
         0        .3        .3        .3         0        .3        .3        .3
      NCYC    MGLEVG     NEMGL     NITFO
         5        02        00       000
      MIT1      MIT2      MIT3      MIT4      MIT5
        01        01        01        01        01
   1-1 BLOCKING DATA:
      NBLI
        14
   NUMBER   GRID   :   ISTA   JSTA   KSTA   IEND   JEND   KEND   ISVA1   ISVA2
        1      2          1      1      1      2      1     21       1       3
        2      4          1      1      1      2      1     21       1       3
        3      6          1      1      1      2      1     21       1       3
        4      8          1      1      1      2      1     21       1       3
        5     10          1      1      1      2      1     21       1       3
        6     12          1      1      1      2      1     21       1       3
        7     14          1      1      1      2      1     21       1       3
        8      1          1      1      1      2     55      1       1       2
        9      7          1      1      1      2     61      1       1       2
       10      1          1      1     23      2     55     23       1       2
       11      3          1      1     23      2     55     23       1       2
       12      7          1      1     23      2     61     23       1       2
       13      9          1      1     23      2     61     23       1       2
       14     11          1      1     23      2     61     23       1       2
   NUMBER   GRID   :   ISTA   JSTA   KSTA   IEND   JEND   KEND   ISVA1   ISVA2
        1      2          1     61      1      2     61     21       1       3
        2      4          1     61      1      2     61     21       1       3
        3      6          1     61      1      2     61     21       1       3
        4      8          1     61      1      2     61     21       1       3
        5     10          1     61      1      2     61     21       1       3
        6     12          1     61      1      2     61     21       1       3
        7     14          1     61      1      2     61     21       1       3
        8      5          1      1     23      2     55     23       1       2
        9     13          1      1     23      2     61     23       1       2
```

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

```
         7
 INT  IFIT    LIMIT    ITMAX    MCXIE    MCETA      C-0    IORPH    ITOSS
   1     1        1       30        0        0        0        0        1
   2     1        1       30        0        0        0        0        1
   3     1        1       30        0        0        0        0        1
   4     1        1       30        0        0        0        0        1
   5     1        1       30        0        0        0        0        1
   6     1        1       30        0        0        0        0        1
   7     1        1       30        0        0        0        0        1
 INT    TO     XIE1     XIE2     ETA1     ETA2      NFB
   1   122        0        0        0        0        6
      FROM     XIE1     XIE2     ETA1     ETA2    FACTJ    FACTK
       721        0        0        0        0       0.       0.
        DX       DY       DZ   DTHETX   DTHETY   DTHETZ
        0.       0.       0.       0.       0.       0.
      FROM     XIE1     XIE2     ETA1     ETA2    FACTJ    FACTK
       921        0        0        0        0       0.       0.
        DX       DY       DZ   DTHETX   DTHETY   DTHETZ
        0.       0.       0.       0.       0.       0.
      FROM     XIE1     XIE2     ETA1     ETA2    FACTJ    FACTK
      1121        0        0        0        0       0.       0.
        DX       DY       DZ   DTHETX   DTHETY   DTHETZ
        0.       0.       0.       0.       0.       0.
      FROM     XIE1     XIE2     ETA1     ETA2    FACTJ    FACTK
      1321        0        0        0        0       0.       0.
        DX       DY       DZ   DTHETX   DTHETY   DTHETZ
        0.       0.       0.       0.       0.       0.
      FROM     XIE1     XIE2     ETA1     ETA2    FACTJ    FACTK
       721        0        0        0        0       0.       0.
        DX       DY       DZ   DTHETX   DTHETY   DTHETZ
        0.       0. 24.23514       0.       0.       0.
      FROM     XIE1     XIE2     ETA1     ETA2    FACTJ    FACTK
       921        0        0        0        0       0.       0.
        DX       DY       DZ   DTHETX   DTHETY   DTHETZ
        0.       0. 24.23514       0.       0.       0.
 INT    TO     XIE1     XIE2     ETA1     ETA2      NFB
   2   322        0        0        0        0        6
      FROM     XIE1     XIE2     ETA1     ETA2    FACTJ    FACTK
       921        0        0        0        0       0.       0.
        DX       DY       DZ   DTHETX   DTHETY   DTHETZ
        0.       0.       0.       0.       0.       0.
      FROM     XIE1     XIE2     ETA1     ETA2    FACTJ    FACTK
      1121        0        0        0        0       0.       0.
        DX       DY       DZ   DTHETX   DTHETY   DTHETZ
        0.       0.       0.       0.       0.       0.
      FROM     XIE1     XIE2     ETA1     ETA2    FACTJ    FACTK
      1321        0        0        0        0       0.       0.
        DX       DY       DZ   DTHETX   DTHETY   DTHETZ
        0.       0.       0.       0.       0.       0.
      FROM     XIE1     XIE2     ETA1     ETA2    FACTJ    FACTK
       721        0        0        0        0       0.       0.
        DX       DY       DZ   DTHETX   DTHETY   DTHETZ
        0.       0. 24.23514       0.       0.       0.
      FROM     XIE1     XIE2     ETA1     ETA2    FACTJ    FACTK
       921        0        0        0        0       0.       0.
        DX       DY       DZ   DTHETX   DTHETY   DTHETZ
        0.       0. 24.23514       0.       0.       0.
      FROM     XIE1     XIE2     ETA1     ETA2    FACTJ    FACTK
      1121        0        0        0        0       0.       0.
        DX       DY       DZ   DTHETX   DTHETY   DTHETZ
        0.       0. 24.23514       0.       0.       0.
 INT    TO     XIE1     XIE2     ETA1     ETA2      NFB
   3   522        0        0        0        0        6
      FROM     XIE1     XIE2     ETA1     ETA2    FACTJ    FACTK
      1121        0        0        0        0       0.       0.
        DX       DY       DZ   DTHETX   DTHETY   DTHETZ
        0.       0.       0.       0.       0.       0.
      FROM     XIE1     XIE2     ETA1     ETA2    FACTJ    FACTK
      1321        0        0        0        0       0.       0.
        DX       DY       DZ   DTHETX   DTHETY   DTHETZ
        0.       0.       0.       0.       0.       0.
      FROM     XIE1     XIE2     ETA1     ETA2    FACTJ    FACTK
```

```
      721        0        0        0        0       0.       0.
       DX       DY       DZ   DTHETX   DTHETY   DTHETZ
       0.       0. 24.23514       0.       0.       0.
     FROM     XIE1     XIE2     ETA1     ETA2    FACTJ    FACTK
      921        0        0        0        0       0.       0.
       DX       DY       DZ   DTHETX   DTHETY   DTHETZ
       0.       0. 24.23514       0.       0.       0.
     FROM     XIE1     XIE2     ETA1     ETA2    FACTJ    FACTK
     1121        0        0        0        0       0.       0.
       DX       DY       DZ   DTHETX   DTHETY   DTHETZ
       0.       0. 24.23514       0.       0.       0.
     FROM     XIE1     XIE2     ETA1     ETA2    FACTJ    FACTK
     1321        0        0        0        0       0.       0.
       DX       DY       DZ   DTHETX   DTHETY   DTHETZ
       0.       0. 24.23514       0.       0.       0.
INT    TO     XIE1     XIE2     ETA1     ETA2      NFB
  4   721        0        0        0        0        4
     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.
     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.
     FROM     XIE1     XIE2     ETA1     ETA2    FACTJ    FACTK
      122        0        0        0        0       0.       0.
       DX       DY       DZ   DTHETX   DTHETY   DTHETZ
       0.       0.-24.23514       0.       0.       0.
INT    TO     XIE1     XIE2     ETA1     ETA2      NFB
  5   921        0        0        0        0        5
     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
      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
      522        0        0        0        0       0.       0.
       DX       DY       DZ   DTHETX   DTHETY   DTHETZ
       0.       0.-24.23514       0.       0.       0.
     FROM     XIE1     XIE2     ETA1     ETA2    FACTJ    FACTK
      322        0        0        0        0       0.       0.
       DX       DY       DZ   DTHETX   DTHETY   DTHETZ
       0.       0.-24.23514       0.       0.       0.
     FROM     XIE1     XIE2     ETA1     ETA2    FACTJ    FACTK
      122        0        0        0        0       0.       0.
       DX       DY       DZ   DTHETX   DTHETY   DTHETZ
       0.       0.-24.23514       0.       0.       0.
INT    TO     XIE1     XIE2     ETA1     ETA2      NFB
  6  1121        0        0        0        0        5
     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
      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
      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.
    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.

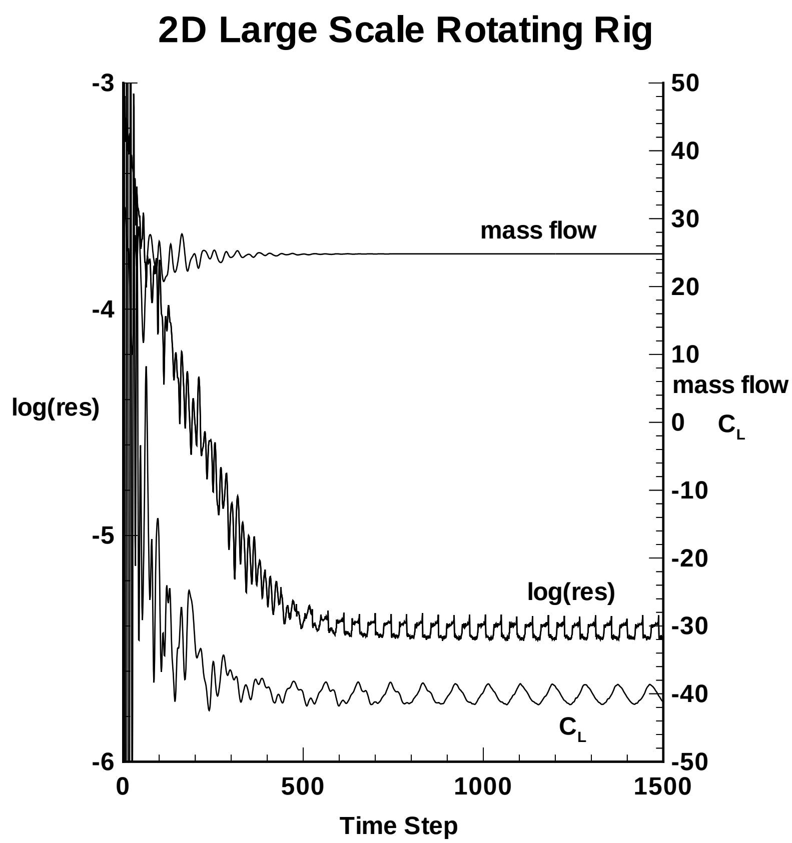

Figure 9-19. Convergence histories for rotor-stator case.

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.

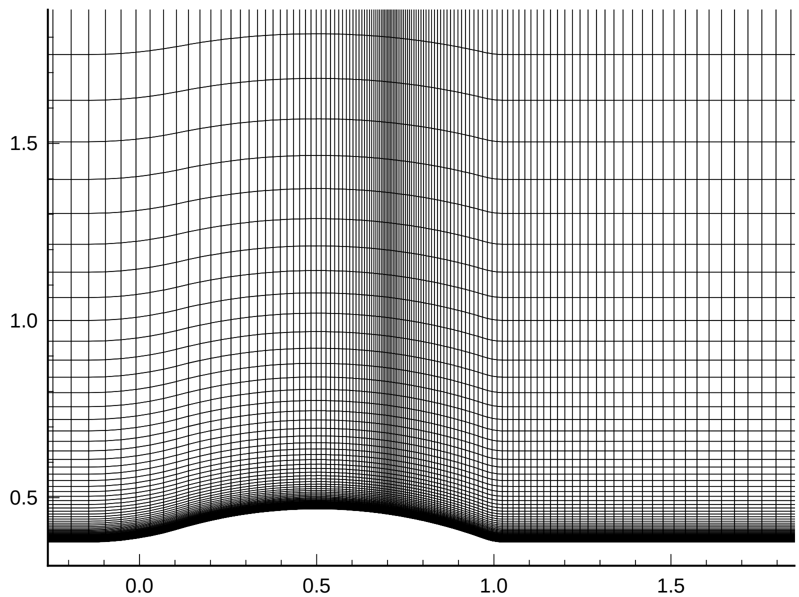

Figure 9-20. Axisymmetric bump grid.

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

File	Description
`bumpv5periodic.inp`	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:

Step 1

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

```
precfl3d < bumpv5periodic.inp
```

Step 6

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

```
make -f makecfl3d_cray
```

Step 7

Run the CFL3D code:

```
cfl3d < bumpv5periodic.inp
```

The input file for this case is:

```
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
     XMACH     ALPHA      BETA  REUE,MIL   TINF,DR     IALPH     IHIST
    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
        DT     IREST   IFLAGTS      FMAX     IUNST    CFLTAU
   -05.000         0       000    5.0000         0       10.
     NGRID   NPLOT3D    NPRINT    NWREST      ICHK       I2D    NTSTEP       ITA
         1         1         1      1200         0         0         1         1
       NCG       IEM  IADVANCE    IFORCE  IVISC(I)  IVISC(J)  IVISC(K)
         2         0         0       001         0         0        07
    IDIM    JDIM    KDIM
      02     181     101
    ILAMLO    ILAMHI    JLAMLO    JLAMHI    KLAMLO    KLAMHI
         0         0         0         0         0         0
     INEWG    IGRIDC        IS        JS        KS        IE        JE        KE
         0         0         0         0         0         0         0         0
  IDIAG(I)  IDIAG(J)  IDIAG(K)  IFLIM(I)  IFLIM(J)  IFLIM(K)
         1         1         1         3         3         3
   IFDS(I)   IFDS(J)   IFDS(K)  RKAP0(I)  RKAP0(J)  RKAP0(K)
         1         1         1    0.3333    0.3333    0.3333
      GRID     NBCI0   NBCIDIM     NBCJ0   NBCJDIM     NBCK0   NBCKDIM    IOVRLP
         1         1         1         1         1         1         1         0
I0:   GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
         1         1      2005         0         0         0         0         4
                NBLP     DTHTX     DTHTY     DTHTZ
                   1      -1.0        0.        0.
IDIM: GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
         1         1      2005         0         0         0         0         4
                NBLP     DTHTX     DTHTY     DTHTZ
                   1      +1.0        0.        0.
J0:   GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
         1         1      1003         0         0         0         0         0
JDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
         1         1      1003         0         0         0         0         0
K0:   GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
         1         1      2004         0         0         0         0         2
              TWTYPE        CQ
                  0.        0.
KDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
         1         1      1003         0         0         0         0         0
      MSEQ    MGFLAG    ICONSF       MTT      NGAM
         1         1         0         0        02
      ISSC EPSSSC(1) EPSSSC(2) EPSSSC(3)      ISSR EPSSSR(1) EPSSSR(2) EPSSSR(3)
         0       0.3       0.3       0.3         0       0.3       0.3      0.3
      NCYC    MGLEVG     NEMGL     NITFO
      1100        03        00       000
      MIT1      MIT2      MIT3      MIT4      MIT5      MIT6      MIT7      MIT8
        01        01        01        01        01         1         1        1
   1-1 BLOCKING DATA:
      NBLI
         0
 NUMBER   GRID     :    ISTA   JSTA   KSTA   IEND   JEND   KEND  ISVA1  ISVA2
 NUMBER   GRID     :    ISTA   JSTA   KSTA   IEND   JEND   KEND  ISVA1  ISVA2
  PATCH SURFACE DATA:
    NINTER
         0
  PLOT3D OUTPUT:
  BLOCK 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:
  BLOCK IPTYPE ISTART   IEND   IINC JSTART   JEND   JINC KSTART   KEND   KINC
      1      0      1      1      1      0      0      0      1      1      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.

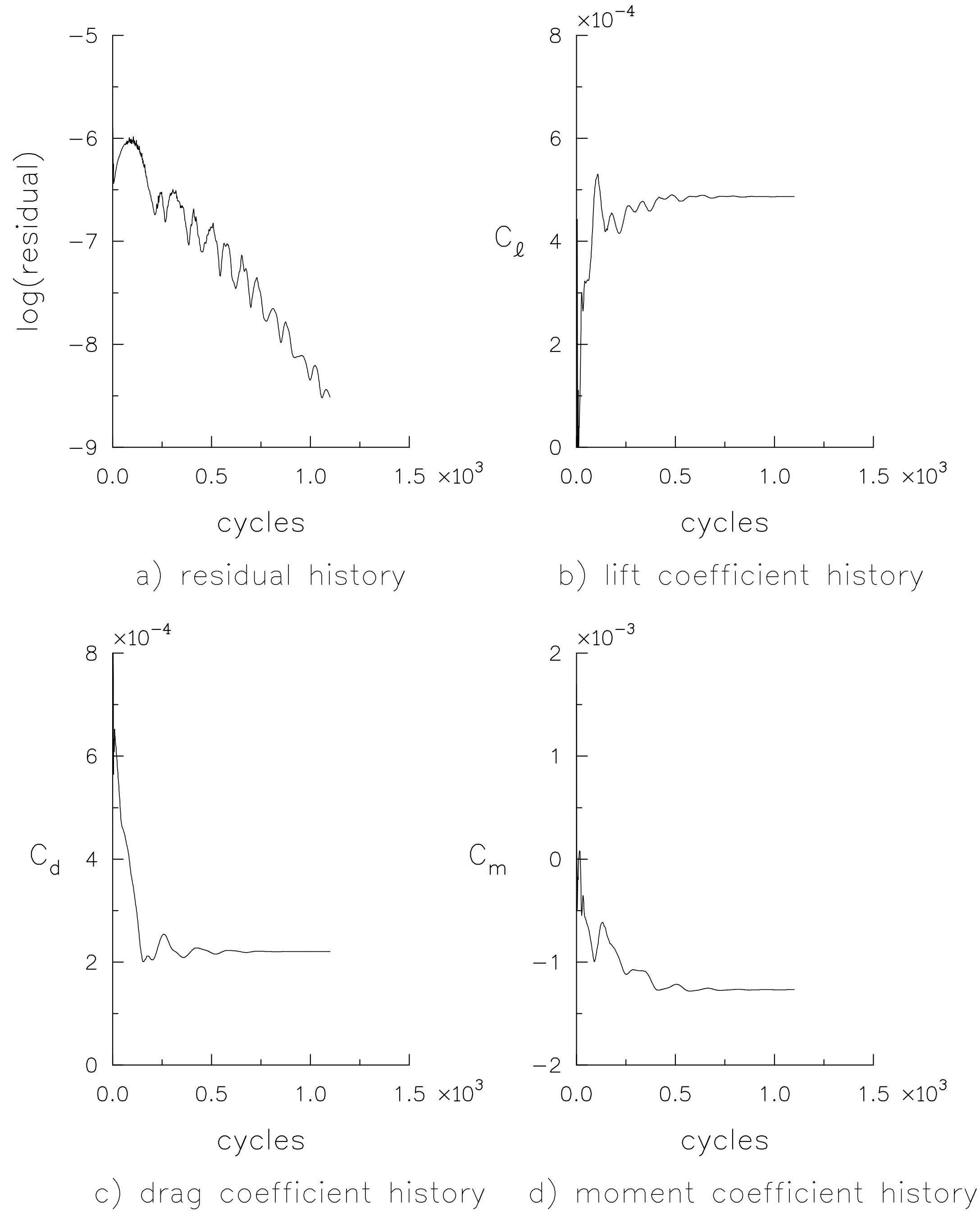

Figure 9-21. Residual and coefficient histories for axisymmetric bump flow case $M_\infty = 0.875,\ Re_{\tilde{L}_R} = 2.66 \times 10^6$.

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 `cfl3d.prout`. Experimental surface pressure coefficients from Bachalo et. al[8] are included with this test case for comparison purposes. The file is called `bumpcpdata.dat`.

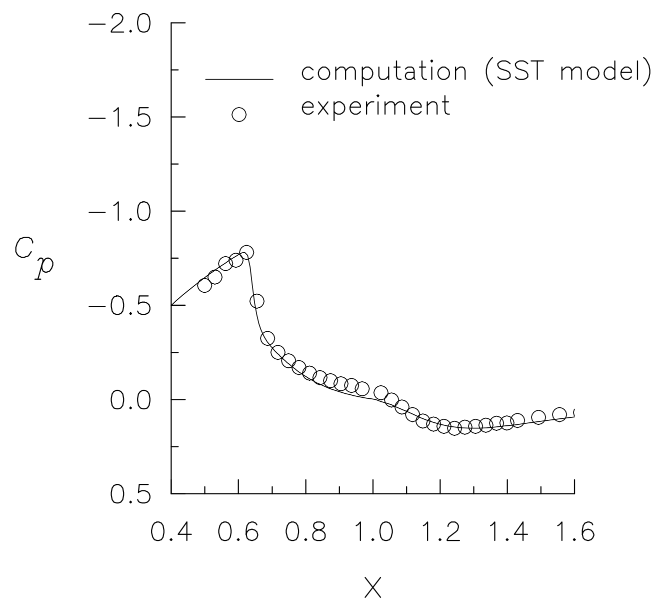

Figure 9-22. Pressure coefficients for axisymmetric bump case
$M_\infty = 0.875,\ Re_{\tilde{L}_R} = 2.66 \times 10^6$.

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.

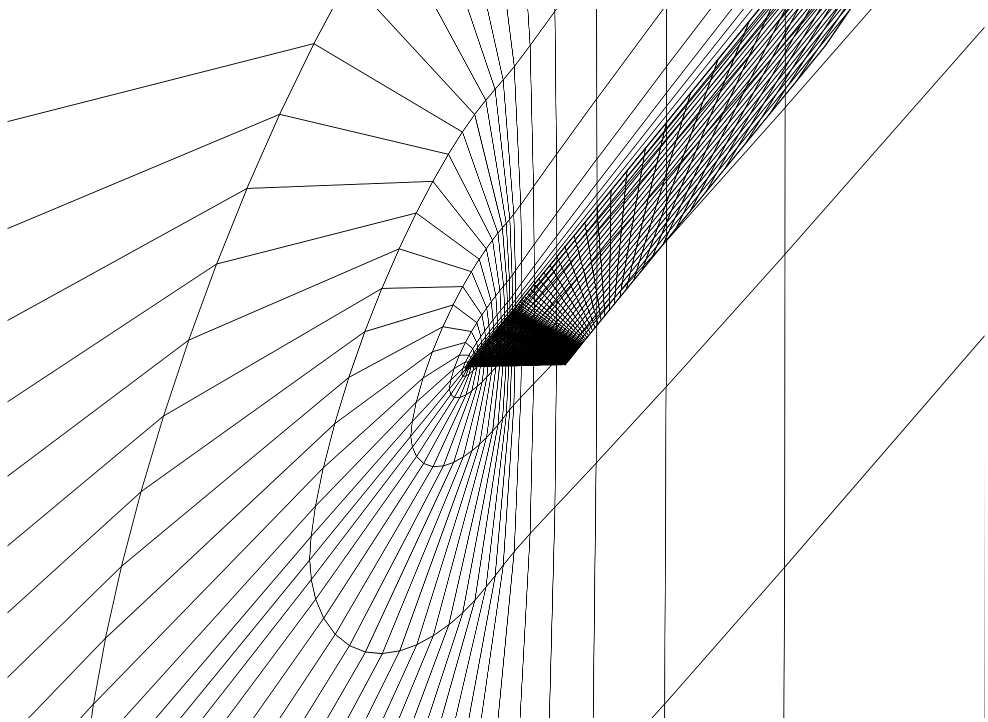

Figure 9-23. Single zone F-5 wing surface grid and plane of symmetry grid.

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

File	Description
`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
```

Step 2

Link the grid converter object file:

```
segldr -o f5wing_grid f5wing_grid.o
```

Step 3

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

```
f5wing_grid
```

Step 4

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

```
make -f makeprecfl3d_cray
```

Step 5

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

```
precfl3d < f5wing.inp
```

Step 6

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

```
make -f makecfl3d_cray
```

Step 7

Run the CFL3D code:

```
cfl3d < f5wing.inp
```

The input file for this case is:

```
 I/O FILES:
f5wing.grd
plot3dg.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.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    00.000       0.0     0.950     460.0         0         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
     -5.000         0       000     1.000         0       10.
      NGRID   NPLOT3D    NPRINT    NWREST      ICHK       I2D    NTSTEP       ITA
          1         0         0       100         0         0         1         1
        NCG       IEM  IADVANCE    IFORCE  IVISC(I)  IVISC(J)  IVISC(K)
          2         0         0         1         0         0         0
       IDIM      JDIM      KDIM
         33       193        33
     ILAMLO    ILAMHI    JLAMLO    JLAMHI    KLAMLO    KLAMHI
         00        00       000       000         0      0000
      INEWG    IGRIDC        IS        JS        KS        IE        JE        KE
          0         0         0         0         0         0         0         0
   IDIAG(I)  IDIAG(J)  IDIAG(K)  IFLIM(I)  IFLIM(J)  IFLIM(K)
          1         1         1         3         3         3
    IFDS(I)   IFDS(J)   IFDS(K)  RKAP0(I)  RKAP0(J)  RKAP0(K)
          1         1         1     .3333     .3333     .3333
       GRID     NBCI0   NBCIDIM     NBCJ0   NBCJDIM     NBCK0   NBCKDIM    IOVRLP
          1         1         1         1         1         4         1         0
I0:    GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
          1         1      1001         0         0         0         0         0
IDIM:  GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
          1         1      1002         0         0         0         0         0
J0:    GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
          1         1      1003         0         0         0         0         0
JDIM:  GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
          1         1      1003         0         0         0         0         0
K0:    GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
          1         1         0         1        33         1        41         0
          1         2      1005         1        21        41       153         0
          1         3         0        21        33        41       153         0
          1         4         0         1        33       153       193         0
KDIM:  GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
          1         1      1003         0         0         0         0         0
       MSEQ    MGFLAG    ICONSF       MTT      NGAM
          3         1         0         0        02
       ISSC EPSSSC(1) EPSSSC(2) EPSSSC(3)      ISSR EPSSSR(1) EPSSSR(2) EPSSSR(3)
          0       0.3       0.3       0.3         0       0.3       0.3       0.3
       NCYC    MGLEVG     NEMGL     NITFO
        200        01        00       000
        200        02        00       000
        200        03        00       000
       MIT1      MIT2      MIT3      MIT4      MIT5
         01        01        01        01        01
         01        01        01        01        01
         01        01        01        01        01
    1-1 BLOCKING DATA:
       NBLI
          2
 NUMBER   GRID     :    ISTA   JSTA   KSTA   IEND   JEND   KEND  ISVA1  ISVA2
      1      1             1      1      1     33     41      1      1      2
      2      1            21     41      1     33     97      1      1      2
 NUMBER   GRID     :    ISTA   JSTA   KSTA   IEND   JEND   KEND  ISVA1  ISVA2
      1      1             1    193      1     33    153      1      1      2
      2      1            21    153      1     33     97      1      1      2
  PATCH SURFACE DATA:
    NINTER
         0
  PLOT3D OUTPUT:
   GRID IPTYPE ISTART   IEND   IINC JSTART   JEND   JINC KSTART   KEND   KINC
  MOVIE
      0
  PRINT OUT:
   GRID IPTYPE ISTART   IEND   IINC JSTART   JEND   JINC KSTART   KEND   KINC
  CONTROL SURFACE:
  NCS
    0
   GRID ISTART   IEND   JSTART   JEND   KSTART   KEND  IWALL  INORM
```

After this test case is run, the convergence history, found in file `cfl3d.res`, should look like that plotted in Figure 9-24. The two sharp spikes in the residual history are at the iterations at which the grid levels change in the mesh sequencing procedure.

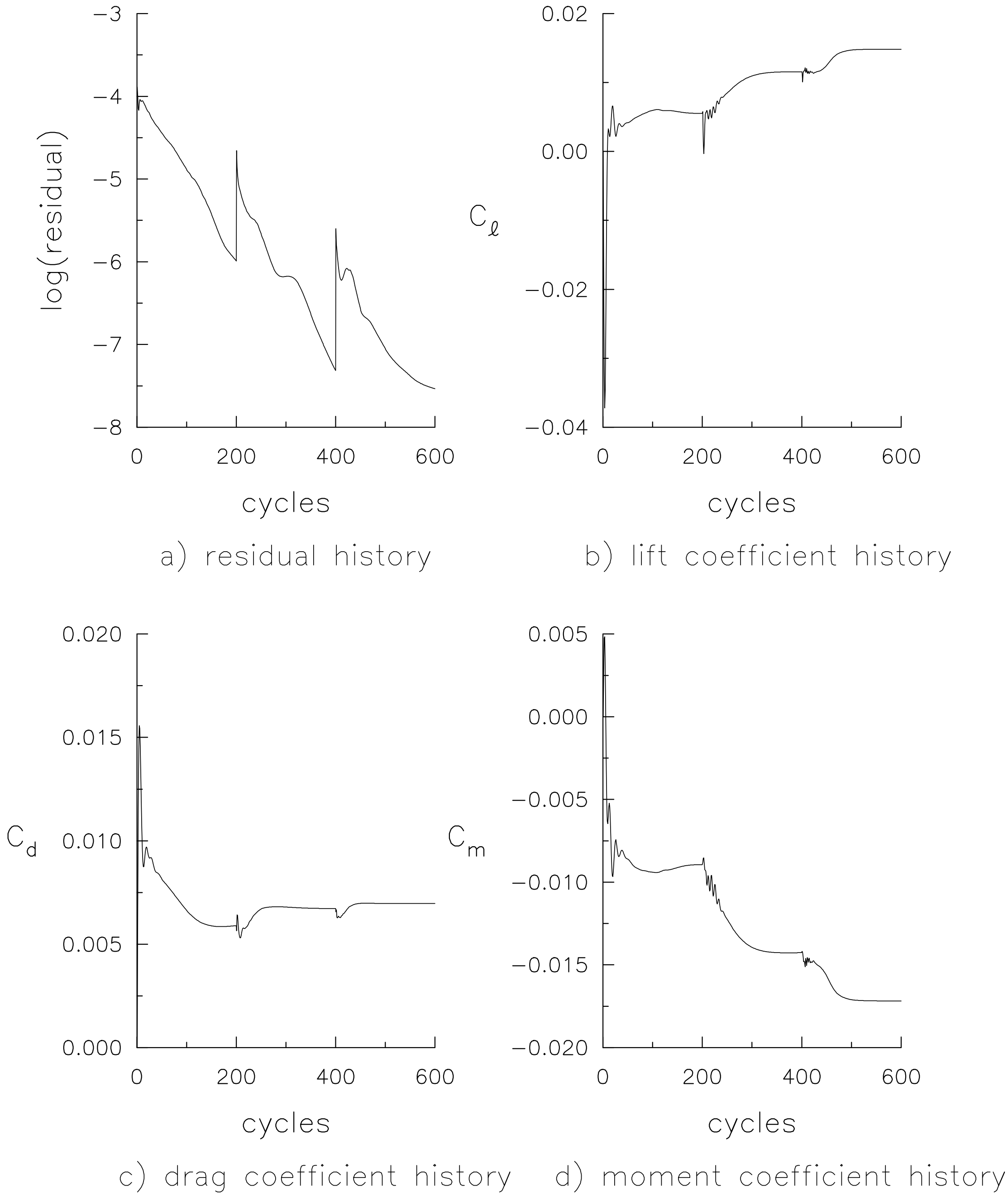

Figure 9-24. Convergence histories for single grid F-5 wing case; $\alpha = 0.0$, $M_\infty = 0.95$.

9.2.3 Onera M-6 Wing

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

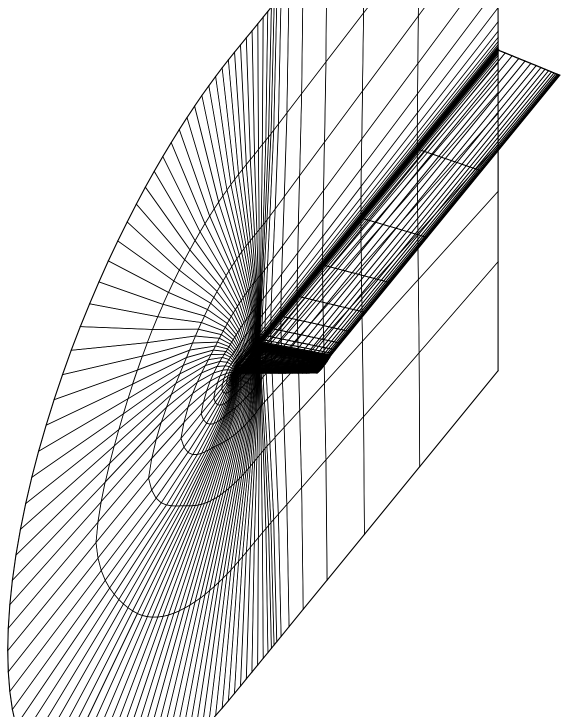

Figure 9-25. Single zone Onera wing surface grid and plane of symmetry grid.

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 seconds). 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:

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

```
precfl3d < oneram6.inp_p3d
```

Step 6

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

```
make -f makecfl3d_cray
```

Step 7

Run the CFL3D code:

```
cfl3d < oneram6.inp_p3d
```

The input file for this case is:

```
 I/O FILES:
m6_i97.grd_p3d
plot3dg.bin
plot3dq.bin
cfl3d.out
cfl3d.res
cfl3d.turres
cfl3d.blomax
cfl3d.out15
cfl3d.prout
cfl3d.out20
ovrlp.bin
patch.bin
restart.bin
     ONERA M6 Wing, plot3d type grid, coarse grid
     XMACH     ALPHA      BETA  REUE,MIL   TINF,DR     IALPH     IHIST
    0.8400    03.060       0.0    21.660     540.0         1         0
      SREF      CREF      BREF       XMC       YMC       ZMC
   0.53080   1.00000    3.9249   0.00000      0.00      0.00
        DT     IREST   IFLAGTS      FMAX     IUNST    CFLTAU
    -5.000         0       000     1.000         0       10.
     NGRID   NPLOT3D    NPRINT    NWREST      ICHK       I2D    NTSTEP       ITA
        -1         1         0       100         0         0         0         1
       NCG       IEM  IADVANCE    IFORCE  IVISC(I)  IVISC(J)  IVISC(K)
         2         0         0        10         0         5         0
      IDIM      JDIM      KDIM
        97        25        17
    ILAMLO    ILAMHI    JLAMLO    JLAMHI    KLAMLO    KLAMHI
        00        00       000       000         0      0000
     INEWG    IGRIDC        IS        JS        KS        IE        JE        KE
         0         0         0         0         0         0         0         0
  IDIAG(I)  IDIAG(J)  IDIAG(K)  IFLIM(I)  IFLIM(J)  IFLIM(K)
         1         1         1         3         3         3
   IFDS(I)   IFDS(J)   IFDS(K)  RKAP0(I)  RKAP0(J)  RKAP0(K)
         1         1         1     .3333     .3333     .3333
      GRID     NBCI0   NBCIDIM     NBCJ0   NBCJDIM     NBCK0   NBCKDIM    IOVRLP
         1         1         1         3         1         1         1         0
I0:   GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
         1         1      1003         0         0         0         0         0
IDIM: GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
         1         1      1003         0         0         0         0         0
J0:   GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
         1         1         0         1        13         0         0         0
         1         2      2004        13        85         1        17         2
                TWTYPE        CQ
                    0.        0.
         1         3         0        85        97         0         0         0
JDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
         1         1      1003         0         0         0         0         0
K0:   GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
         1         1      1001         0         0         0         0         0
KDIM: GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
         1         1         0         0         0         0         0         0
      MSEQ    MGFLAG    ICONSF       MTT      NGAM
         2         1         0         0        02
      ISSC EPSSSC(1) EPSSSC(2) EPSSSC(3)      ISSR EPSSSR(1) EPSSSR(2) EPSSSR(3)
         0       0.3       0.3       0.3         0       0.3       0.3       0.3
      NCYC    MGLEVG     NEMGL     NITFO
```

```
       200        02        00       000
       300        02        00       000
      MIT1      MIT2      MIT3      MIT4      MIT5
        01        01        01        01        01
        01        01        01        01        01
   1-1 BLOCKING DATA:
      NBLI
         2
 NUMBER   GRID     :    ISTA   JSTA   KSTA   IEND   JEND   KEND  ISVA1  ISVA2
      1      1             1      1      1     13      1     17      1      3
      2      1             1      1     17     49     25     17      1      2
 NUMBER   GRID     :    ISTA   JSTA   KSTA   IEND   JEND   KEND  ISVA1  ISVA2
      1      1            97      1      1     85      1     17      1      3
      2      1            97      1     17     49     25     17      1      2
  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
  MOVIE
      0
  PRINT OUT:
   GRID IPTYPE ISTART   IEND   IINC JSTART   JEND   JINC KSTART   KEND   KINC
  CONTROL SURFACE:
  NCS
    0
   GRID ISTART   IEND   JSTART   JEND   KSTART   KEND  IWALL   INORM
```

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.

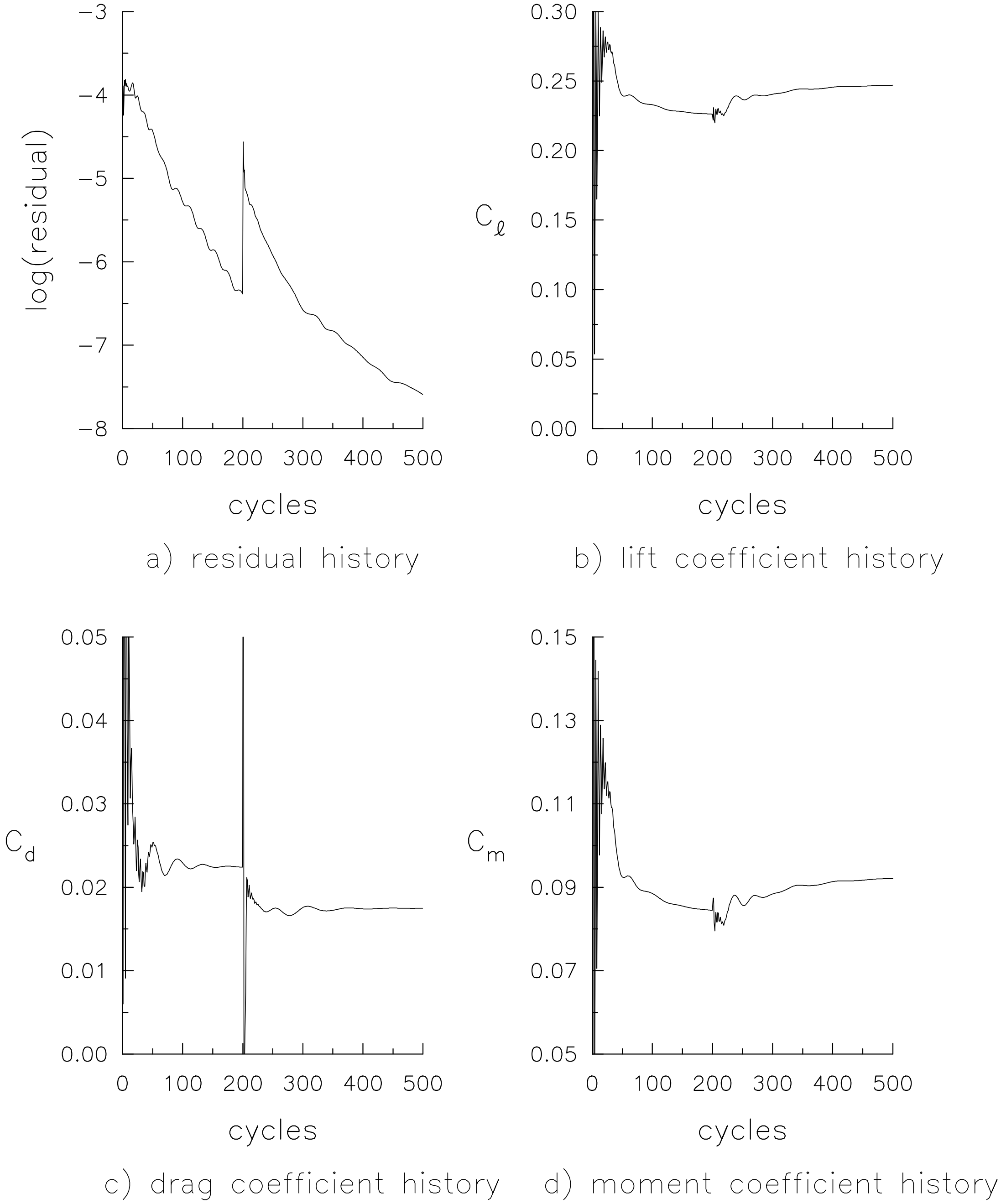

Figure 9-26. Convergence histories for single grid Onera wing case; $\alpha = 3.06$, $M_\infty = 0.84$.

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.

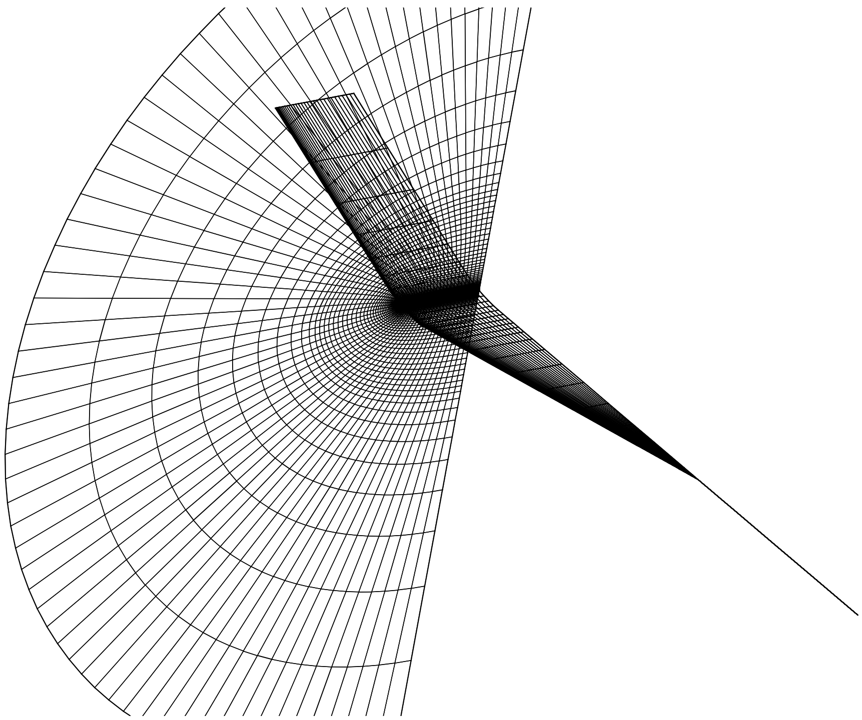

Figure 9-27. Single zone delta wing surface grid and trailing edge plane grid.

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

File	Description
`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
```

Step 2

Link the grid converter object file:

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

Step 3

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

```
form2bin
```

Step 4

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

```
make -f makeprecfl3d_cray
```

Step 5

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

```
precfl3d < delta.inp
```

Step 6

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

```
make -f makecfl3d_cray
```

Step 7

Run the CFL3D code:

```
cfl3d < delta.inp
```

The input file for this case is:

```
I/O FILES
delta.bin
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    20.500       0.0     0.500     460.0         0         0
       SREF      CREF      BREF       XMC       YMC       ZMC
     .13398   1.00000    .53590   0.25000        0.        0.
         DT     IREST   IFLAGTS      FMAX     IUNST    CFLTAU
      -10.0         0         0       1.0         0       10.
      NGRID   NPLOT3D    NPRINT    NWREST      ICHK       I2D    NTSTEP       ITA
          1         1         0      0100         0         0         1         1
        NCG       IEM  IADVANCE    IFORCE  IVISC(I)  IVISC(J)  IVISC(K)
          2         0         0       001         0         0         1
     IDIM    JDIM    KDIM
       37      65      65
     ILAMLO    ILAMHI    JLAMLO    JLAMHI    KLAMLO    KLAMHI
         00        00       000       000         0      0000
      INEWG    IGRIDC        IS        JS        KS        IE        JE        KE
          0         0         0         0         0         0         0         0
   IDIAG(I)  IDIAG(J)  IDIAG(K)  IFLIM(I)  IFLIM(J)  IFLIM(K)
          1         1         1         4         4         4
    IFDS(I)   IFDS(J)   IFDS(K)  RKAP0(I)  RKAP0(J)  RKAP0(K)
          1         1         1     .3333     .3333     .3333
       GRID     NBCI0   NBCIDIM     NBCJ0   NBCJDIM     NBCK0   NBCKDIM    IOVRLP
          1         1         1         1         1         3         1         0
I0:    GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
          1         1      1003         1        65         1        65         0
IDIM:  GRID   SEGMENT    BCTYPE      JSTA      JEND      KSTA      KEND     NDATA
          1         1      1003         1        65         1        65         0
J0:    GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
          1         1      1001         1        37         1        65         0
JDIM:  GRID   SEGMENT    BCTYPE      ISTA      IEND      KSTA      KEND     NDATA
          1         1      1001         1        37         1        65         0
K0:    GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
          1         1      1011         1         9         1        65         0
          1         2      2004         9        25         1        65         2
                 TWTYPE        CQ
                    -1.        0.
          1         3         0        25        37         1        65         0
KDIM:  GRID   SEGMENT    BCTYPE      ISTA      IEND      JSTA      JEND     NDATA
          1         1      1003         1        37         1        65         0
       MSEQ    MGFLAG    ICONSF       MTT      NGAM
          1         1         1         0        02
       ISSC EPSSSC(1) EPSSSC(2) EPSSSC(3)      ISSR EPSSSR(1) EPSSSR(2) EPSSSR(3)
          1       0.3       0.3       0.3         0       0.3       0.3       0.3
       NCYC    MGLEVG     NEMGL     NITFO
        600        03        00      0000
       MIT1      MIT2      MIT3      MIT4      MIT5      MIT6      MIT7      MIT8
         01        01        01        01        01         1         1         1
    1-1 BLOCKING DATA:
       NBLI
          1
 NUMBER   GRID     :     ISTA    JSTA    KSTA    IEND    JEND    KEND   ISVA1   ISVA2
      1      1             25       1       1      37      33       1       1       2
 NUMBER   GRID     :     ISTA    JSTA    KSTA    IEND    JEND    KEND   ISVA1   ISVA2
      1      1             25      65       1      37      33       1       1       2
   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
   MOVIE
      0
   PRINT OUT:
    GRID IPTYPE ISTART    IEND    IINC JSTART    JEND    JINC KSTART    KEND    KINC
   CONTROL SURFACE:
   NCS
     0
    GRID ISTART    IEND    JSTART    JEND    KSTART    KEND   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.

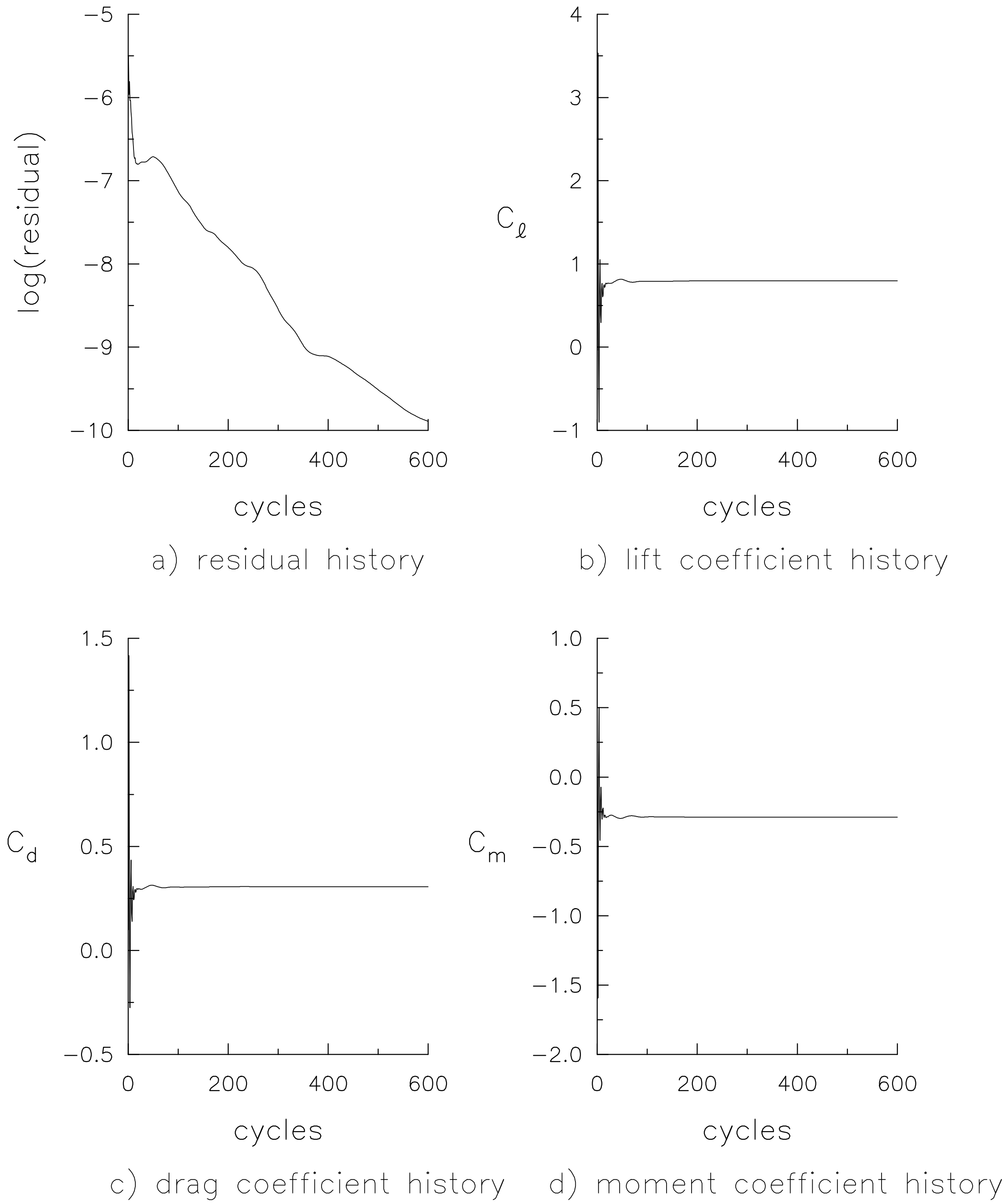

Figure 9-28. Convergence histories for single grid delta wing case; $\alpha = 20.5$.