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NAVIER-STOKES CALCULATION OF TRANSONIC FLOW PAST THE NTF 65-DEGREE DELTA WING

by

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Abstract

This project is a continuation of the research initiated in summer last year. Viscous flow past a wind tunnel model of a 65-degree swept angle Delta wing at transonic speeds is being studied. The model was tested in the 8-foot cryogenic transonic wind tunnel at the National Transonic Facility. Aerodynamic forces and wing surface pressure data were obtained at various angles of attack, Mach numbers and Reynold's numbers for four different leading edges of the wing. The objectives of the present investigation are:

1. To perform numerical modelling of the flow around the wing.
2. To validate the experimental data with a Navier-Stokes computational fluid dynamics code and vice versa.
3. To investigate the effects of the sting mount of the wing.
4. To evaluate the effects of leading edge radius on the flow.
5. To explain the Reynold's number effect as indicated by the test data.

Several computer programs were developed to define the surfaces of the wing, the four leading edges and the sting mount. Based on these geometric databases, the surface grids of a single-block computational domain was generated interactively on the IRIS workstation using the GRIDGEN2D module of GRIDGEN. To refine the grids and to avoid excessive loss of grid points due to collapsed edges, a 9-block computational domain containing approximately 750,000 grid points was developed with the GRIDBLOCK module to replace the single-block grid:

Block No.	Model Surface Contained	Dimension
1	Fore Upper Wing	49x13x65
2	Leading Edge	49x49x65
3	Fore Lower Wing	49x13x65
4	Sting	49x49x65
5	Wing Apex	25x25x65
6	Upper Sting Joint	49x25x65
7	Rear Upper Wing	49x25x65
8	Rear Lower Wing	49x25x65
9	Lower Sting Joint	49x25x65

Fig. 1 shows the wing and sting surfaces, and the block edges near the model, while Fig. 2 shows all the blocks in the entire computational domain encompassing a space of 20 chord lengths from the wing in all directions.

The double-precision version of GRIDGEN2D was then used to generate the surface grids of every block. Grid point-clustering was performed on high-curvature portions of the apex, the leading edge, the trailing edge and the sting joint. To facilitate thin-layer Navier-Stokes calculation at high Reynold's numbers, a very tight spacing of 10-6 was specified on the wing surface. Fig. 3 shows some typical surface grids on the model and the plane of symmetry. Figs. 4 and 5 show some typical 2-D grids on block interfaces. Upon minor modification of the blocks containing the wing apex and the leading edge, the surface grids of these two blocks can be generated for other leading edge profiles without disturbing the other blocks.

Job files and input files were created to read the multiple-block surface grids into the GRIDGEN3D module on the Cray super-computer to generate the internal volume grid of each block. A typical output file summarizing successful generation of satisfactory volume grids is given in Appendix A. The resulting volume grids were finally examined by the GRIDVUE3D module or the FAST software on the IRIS workstation.

The CFL3D computational fluid dynamics code, developed by the Computational Aerodynamics Branch, is to be applied. A typical input file which sets up the code to read the volume grids and specifies the boundary conditions for each block is given in Appendix B. Calculations for both laminar and turbulent flows are being conducted, and preliminary solutions are expected in the immediate future.

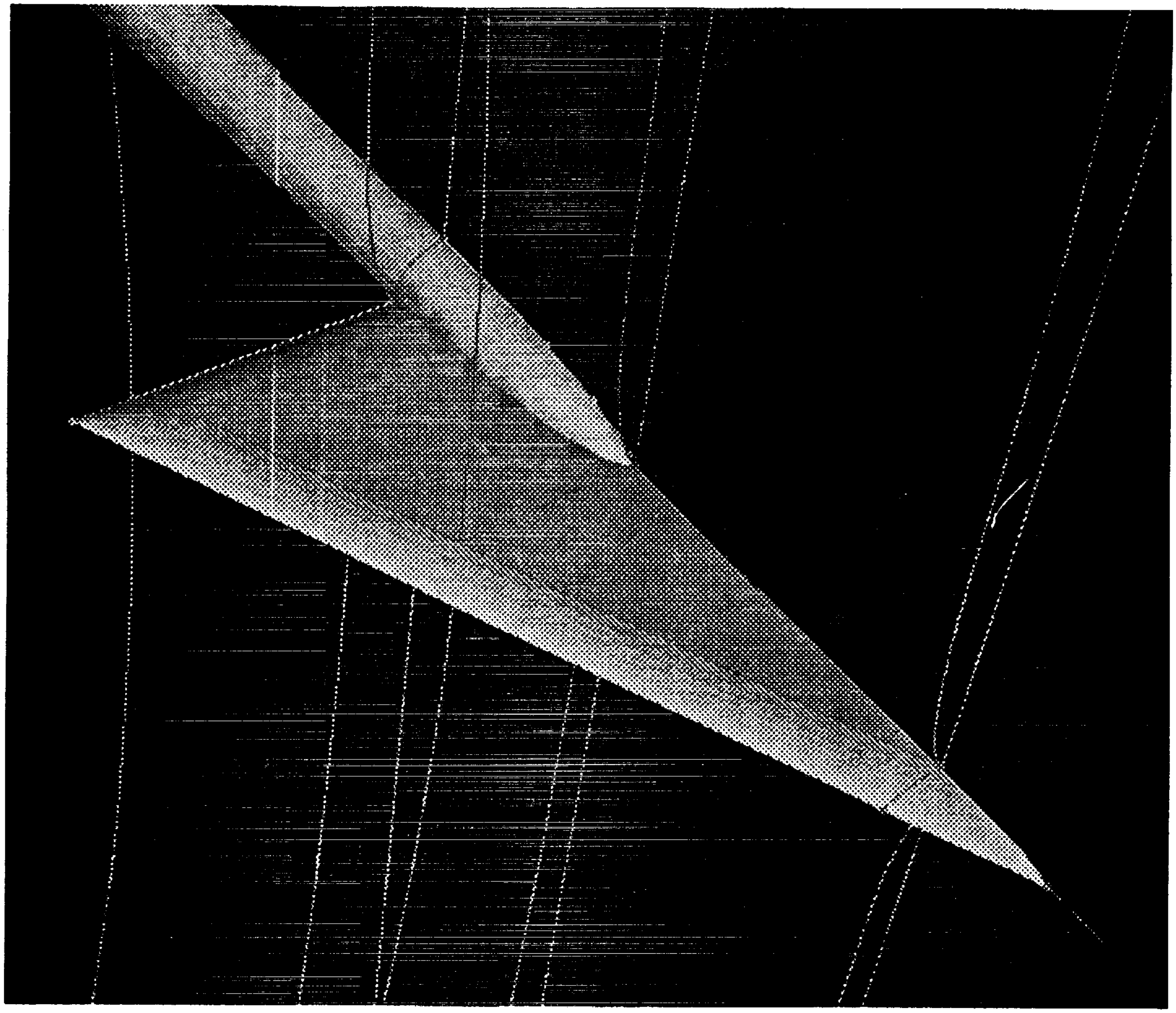

Fig. 1 Wing Model and Block Edges - Near Field

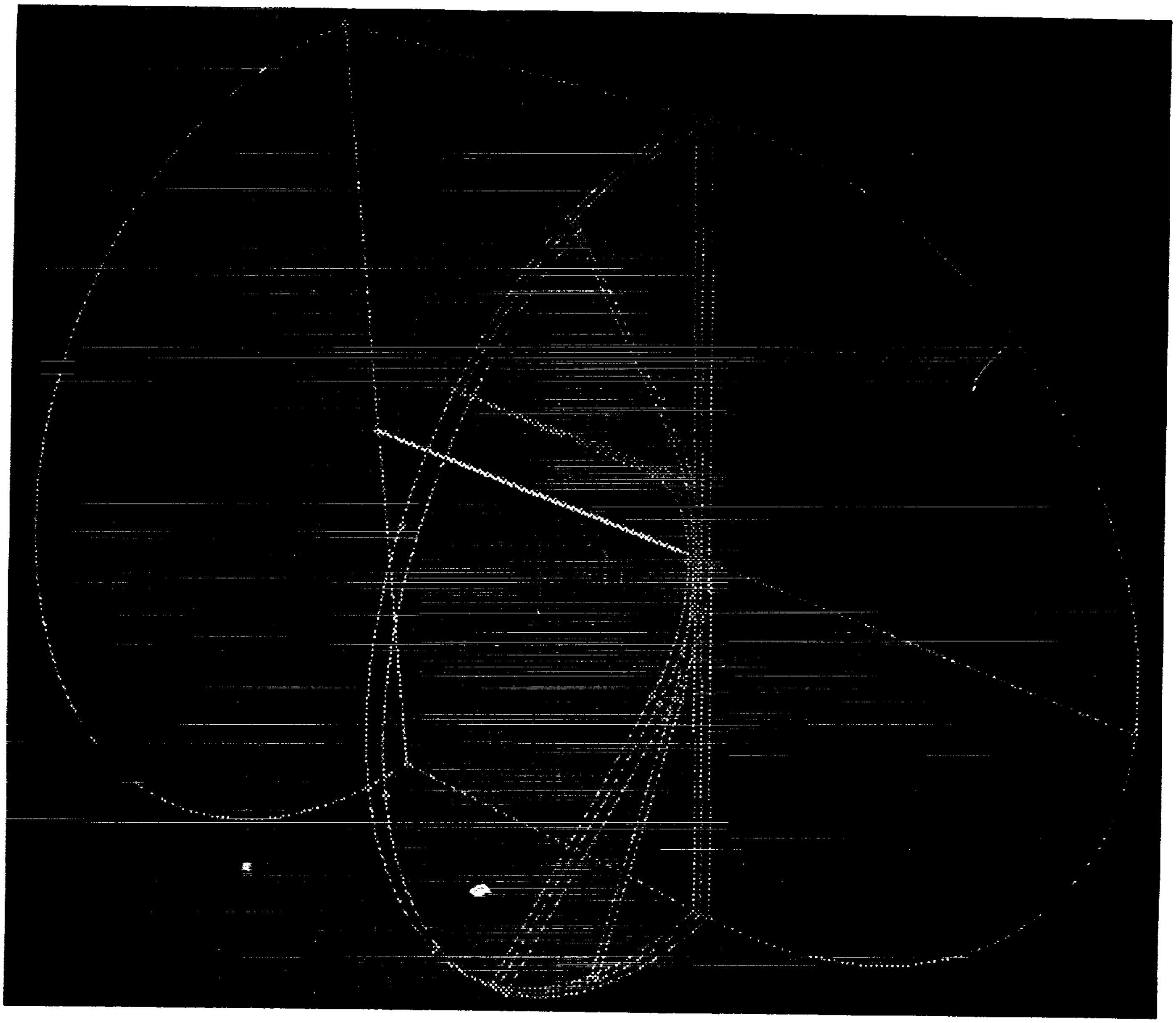

Fig. 2 Block Edges - Far Field

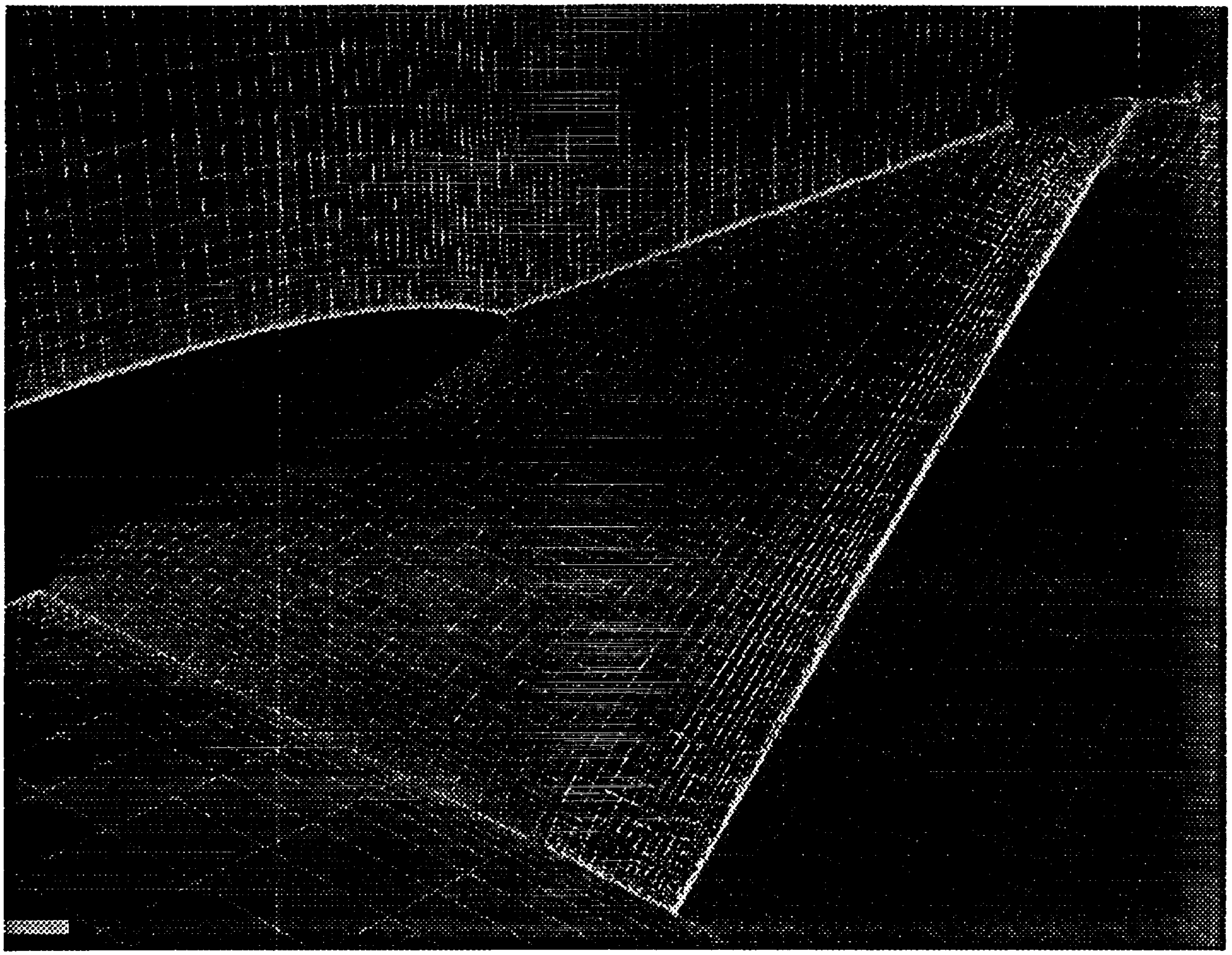

Fig. 3 Surface Grids on the Model and Plane of Symmetry

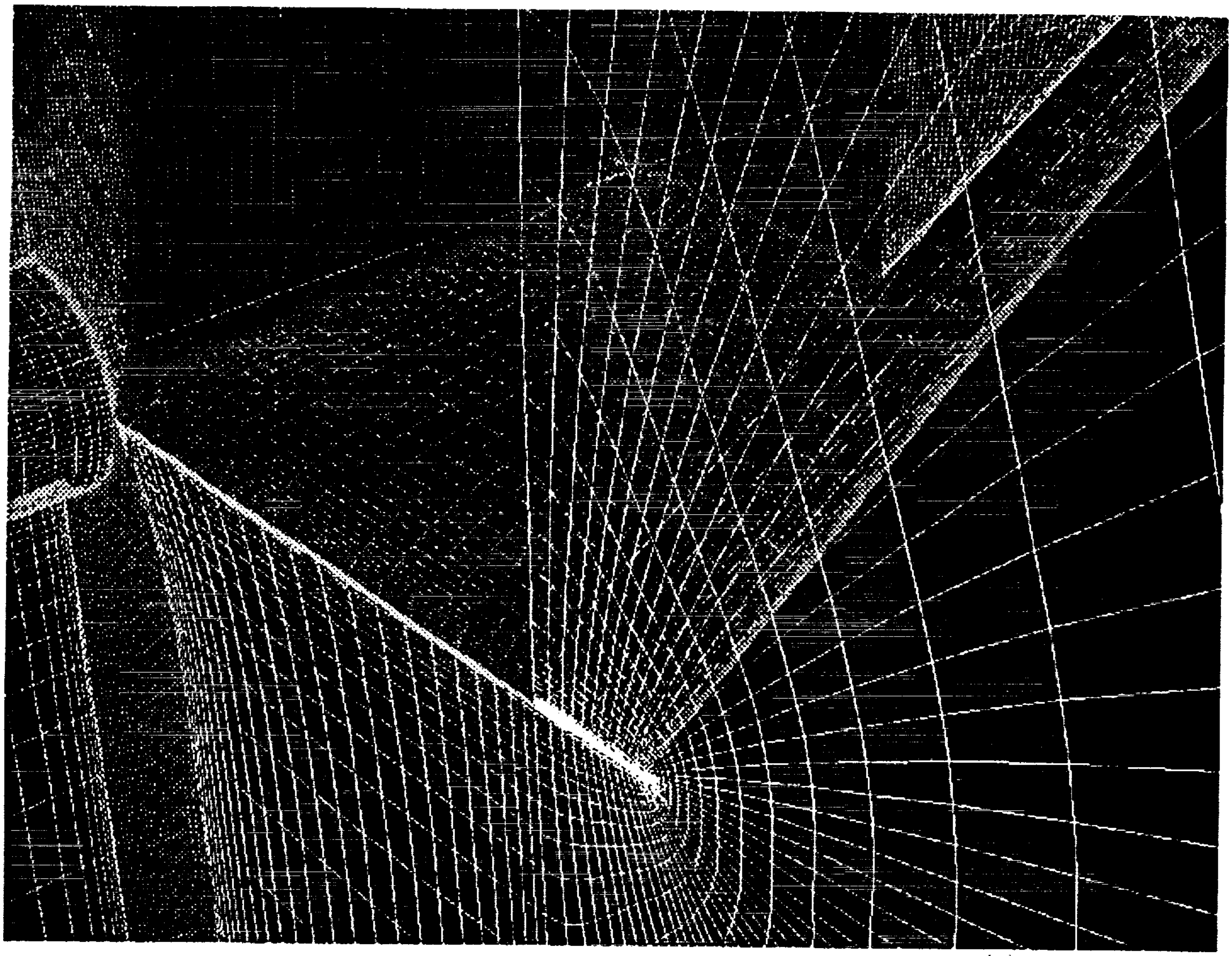

Fig. 4 Surface Grids on Block Interfaces

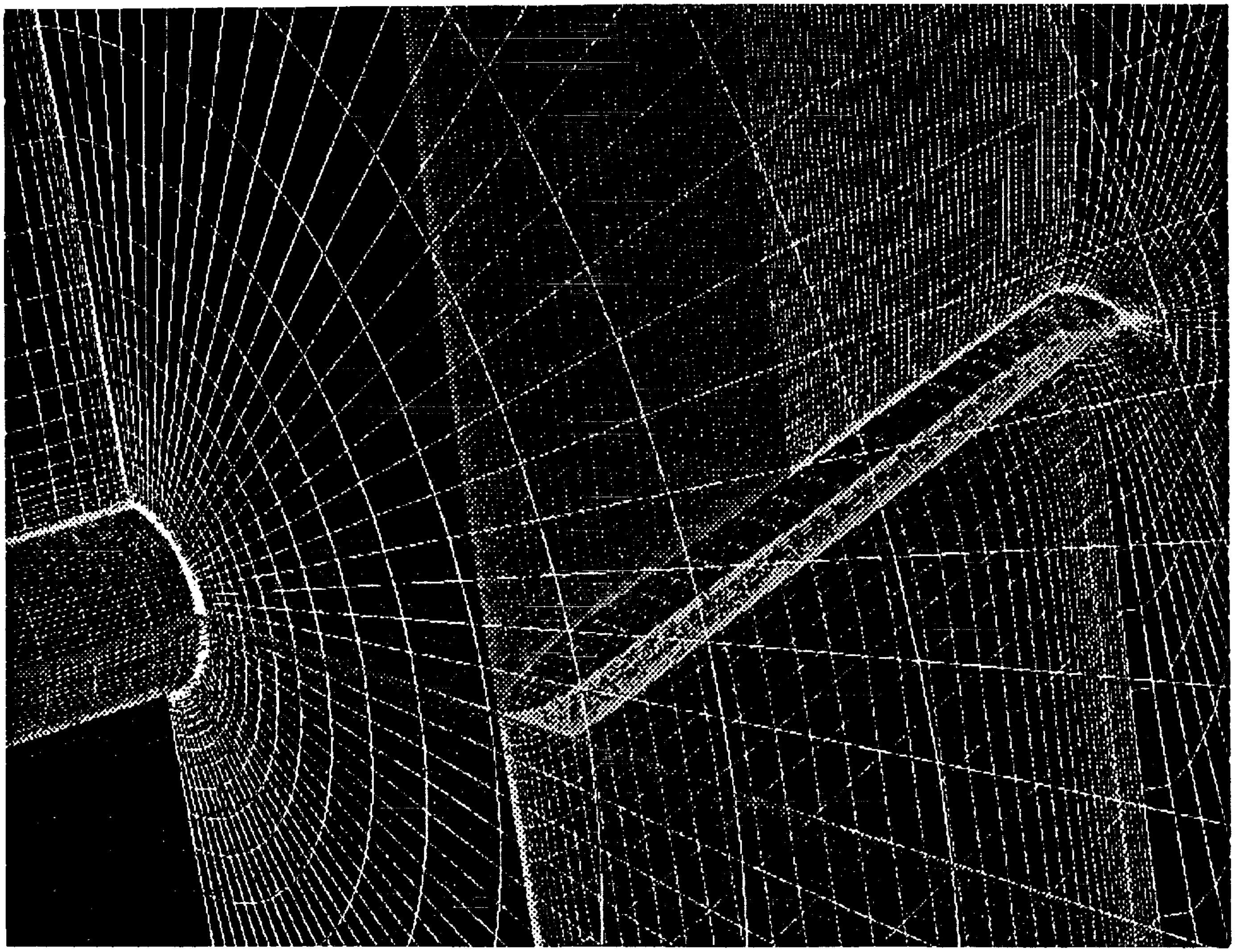

Fig. 5 Surface Grids on Block Interfaces

```
GGGGG  RRRRR  I  DDDDD  GGGGG  EEEEE  N   N  33333  DDDDD
G      R   R  I  D   D  G      E      NN  N      3  D   D
G GGG  RRRRR  I  D   D  G GGG  EEEEE  N N N  33333  D   D
G   G  R R    I  D   D  G   G  E      N  NN      3  D   D
GGGGG  R   R  I  DDDDD  GGGGG  EEEEE  N   N  33333  DDDDD

                  $Revision: 8.6.3.4 $

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*********************************************************************
*****                         I N P U T                         *****
*********************************************************************
&ASSEM   IASSEM =  0,  IDEBUG =  0,  IFORM =  1,  NOBOCON =  0,  NBLOCKS =  9,  MMII
2*49,  65,  13,  49,  65,  49,  25,  65,  25,  49,  65,  25,  49,  65,  25,  49,  65
 IAUTO =  0,  IBPW =  7009149136318496768,  FNBOCI =  'interle4.bnda          ',  FNSUR
 FNVOLI =  'interle4.vol          ',  PATHTMP =  '.
     ----------------------------------------------------
         Grid contains   9 block(s)
     ----------------------------------------------------
       nb      imax      jmax      kmax      name
     ----------------------------------------------------
        1       49        65        13       inter2.blk
        2       49        65        49       inter3.blk
        3       49        65        13       inter4.blk
        4       49        65        49       inter7.blk
        5       25        65        25       inter1.blk
        6       49        65        25       upjoint
        7       49        65        25       wingup
        8       49        65        25       winglo
        9       49        65        25       jointlo
     ----------------------------------------------------
*********************************************************************
*****             A L G E B R A I C   S O L V E R               *****
*********************************************************************
 &INIT   INITIAL =  9*2,  TOLER =  1.E-9,  ITSONI =  16,  IJACA =  1  &END
     ----------------------------------------------------
     Jacobians for block #  1: inter2.blk
       number of positive volumes :  36864 (100.00%)
       number of  skewed  volumes :      0 (  0.00%)
       number of negative volumes :      0 (  0.00%)
       minimum volume at (  2,  2, 13) is   0.5158E-12
       maximum volume at ( 17, 65,  7) is   0.8509E-01
     ----------------------------------------------------
     Jacobians for block #  2: inter3.blk
       number of positive volumes : 147455 (100.00%)
       number of  skewed  volumes :      1 (  0.00%)
       number of negative volumes :      0 (  0.00%)
       minimum volume at ( 49,  2, 25) is   0.1773E-14
       maximum volume at ( 25, 65, 25) is   0.1046E+00
     ----------------------------------------------------
     Jacobians for block #  3: inter4.blk
       number of positive volumes :  36864 (100.00%)
       number of  skewed  volumes :      0 (  0.00%)
       number of negative volumes :      0 (  0.00%)
       minimum volume at (  2,  2, 13) is   0.8873E-12
       maximum volume at ( 17, 65,  7) is   0.6504E-01
     ----------------------------------------------------
     Jacobians for block #  4: inter7.blk
       number of positive volumes : 147456 (100.00%)
       number of  skewed  volumes :      0 (  0.00%)
       number of negative volumes :      0 (  0.00%)
       minimum volume at (  2,  2,  4) is   0.4317E-11
       maximum volume at ( 49, 65, 47) is   0.2896E+02
     ----------------------------------------------------
     Jacobians for block #  5: inter1.blk
       number of positive volumes :  36337 ( 98.57%)
       number of  skewed  volumes :    527 (  1.43%)
       number of negative volumes :      0 (  0.00%)
       minimum volume at (  2,  2, 13) is   0.1768E-13
       maximum volume at ( 25, 65,  2) is   0.1002E+02
     ----------------------------------------------------
     Jacobians for block #  6: upjoint
       number of positive volumes :  73728 (100.00%)
       number of  skewed  volumes :      0 (  0.00%)
       number of negative volumes :      0 (  0.00%)
       minimum volume at (  2,  2,  2) is   0.5358E-12
       maximum volume at ( 31, 65, 25) is   0.2172E-01
     ----------------------------------------------------
     Jacobians for block #  7: wingup
       number of positive volumes :  73728 (100.00%)
       number of  skewed  volumes :      0 (  0.00%)
       number of negative volumes :      0 (  0.00%)
       minimum volume at ( 49,  2, 25) is   0.2288E-11
       maximum volume at ( 29, 65,  2) is   0.2060E-01
     ----------------------------------------------------
     Jacobians for block #  8: winglo
       number of positive volumes :  73728 (100.00%)
       number of  skewed  volumes :      0 (  0.00%)
       number of negative volumes :      0 (  0.00%)
       minimum volume at ( 49,  2,  2) is   0.2181E-11
       maximum volume at ( 29, 65, 16) is   0.2763E-01
     ----------------------------------------------------
     Jacobians for block #  9: jointlo
       number of positive volumes :  73728 (100.00%)
       number of  skewed  volumes :      0 (  0.00%)
       number of negative volumes :      0 (  0.00%)
       minimum volume at (  2,  2, 25) is   0.4156E-12
       maximum volume at ( 19, 65, 25) is   0.1394E-01
     ----------------------------------------------------
     Jacobian summary for entire grid
```

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Appendix A   GRIDGEN3D Output File

```
dspl.g2dgrd
p3dx.d25mac
p3dq.d25mac
d25mac.out
d25mac.plt
d25mac.info
d25mac.prout
d25mac.press
d25mac.restrt
d25mac.jkturb
65-deg Delta Wing with Sting - Medium Leading Edge
   XMACH     ALPHA      BETA  REUE,MIL   TINF,DR      ISND     C2SPE      IRUN
    0.85      13.3       0.0      9.00     527.0         0      0.00        85
    SREF      CREF      BREF       XMC       YMC       ZMC   XLTRANS   XUTRANS
 0.22315   1.00000    0.9326      0.25      0.00      0.00      0.01      0.01
      DT     IREST   IFLAGTS      FMAX     IUNST     RFREQ    ALPHAU      CLOC
  -1.000        01      0200        07         0      0.00      0.00    0.0000
   NGRID   NPLOT3D    NPRINT    NWREST      ICHK       I2D     ITURB      CFLG
       9         9         0       100         1         0         0       1.5
     NCG       IEM  IADVANCE    IFORCE     IMESH  IVISC(I)  IVISC(J)  IVISC(K)
       1         0         0         1         1         0         0         1
       1         0         0         1        11         0         0         1
       1         0         0         1         0         0         0         1
       1         0         0        -1        11         0         0         1
       1         0         0         0        11         0         0         1
       1         0         0         0                   0         0         1
       1         0         0         0         0         0         0         1
       1         0         0         0         0         0         0         1
       1         0         0         0                   0         0         1
    IDIM      JDIM      KDIM      ITE1      ITE2      JTE1      JTE2
      49        17       065         1        49         1        17
      49        49       065         1        49         1        49
      49        17       065         1        49         1        17
      49        49       065         1        49         1        49
      25        25       065         1        25         1        25
      49        25       065         1        49         1        25
      49        25       065         1        49         1        25
      49        25       065         1        49         1        25
      49        25       065         1        49         1        25
   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
IDIAG(I)  IDIAG(J)  IDIAG(K)  IFLIM(I)  IFLIM(J)  IFLIM(K)
       1         1         1        00        04        04
       1         1         1        00        04        04
       1         1         1        00        04        04
       1         1         1        00        04        04
       1         1         1        00        04        04
       1         1         1        00        04        04
       1         1         1        00        04        04
       1         1         1        00        04        04
       1         1         1        00        04        04
 IFDS(I)   IFDS(J)   IFDS(K)  RKAPO(I)  RKAPO(J)  RKAPO(K)
       1         1         1  -3.00000  0.333333  0.333333
       1         1         1  -3.00000  0.333333  0.333333
       1         1         1  -3.00000  0.333333  0.333333
       1         1         1  -3.00000  0.333333  0.333333
       1         1         1  -3.00000  0.333333  0.333333
       1         1         1  -3.00000  0.333333  0.333333
       1         1         1  -3.00000  0.333333  0.333333
       1         1         1  -3.00000  0.333333  0.333333
       1         1         1  -3.00000  0.333333  0.333333
MTYPEI(1) MTYPEI(2) MTYPEJ(1) MTYPEJ(2) MTYPEK(1) MTYPEK(2)
      200       200      1001       200        10      1003
      200       200       200       200        10      1003
      200       200       200      1001        10      1003
      200      1003      1001      1001        10      1003
      702       200      1001      1001        10      1003
      200       200      1001       200        10      1003
      200       200       200       200        10      1003
      200       200       200       200        10      1003
      200       200       200      1001        10      1003
     MSEQ    MGFLAG    ICONSF       MTT      NGAM
        1         1         0         0        01
     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
     1000        03        00      0000
     MIT1      MIT2      MIT3      MIT4      MIT5      MIT6      MIT7      MIT8
       01        01        01        01
  1-1 BLOCKING DATA:
     NBLI
        0
    NBLON   NBLK(1)   NBLK(2)
LIMBLK(1) LIMBLK(2) LIMBLK(3) LIMBLK(4) LIMBLK(5) LIMBLK(6) ISVA(1,1) ISVA(1,2)
LIMBLK(1) LIMBLK(2) LIMBLK(3) LIMBLK(4) LIMBLK(5) LIMBLK(6) ISVA(2,1) ISVA(2,2)
 PATCH SURFACE DATA:
   NINTER
       26
    IIFIT    LLIMIT    IITMAX     MMCXI    MMCETA
        3         5        20         0         0
        4         5        20         0         0
        3         5        20         0         0
        3         5        20         0         0
        3         5        20         0         0
        4         5        20         0         0
        4         5        20         0         0
        3         5        20         0         0
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        3         5        20         0         0
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        3         5        20         0         0
        4         5        20         0         0
        4         5        20         0         0
        3         5        20         0         0
        3         5        20         0         0
        4         5        20         0         0
        4         5        20         0         0
        3         5        20         0         0
```

Appendix B CFL3D Input File