FUN3D v12.7 Training

Session 4: Gridding, Solution, and Visualization Basics

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Learning Goals

What we will cover

- Basic gridding requirements and formats
- Nondimensionalizations and axis conventions
- Basic environment for running FUN3D
- FUN3D user inputs
- Running FUN3D for typical steady-state RANS cases
  - Compressible transonic turbulent flow over a wing-body using a tetrahedral VGRID mesh
  - Turbulent flow over a NACA 0012 airfoil section
- Things to help diagnose problems
- Visualization overview

What we will *not* cover

- Other speed regimes
- Unsteady flows

Gridding Considerations

- FUN3D is a **node-based** discretization
  - To get similar resolution when comparing with a cell-centered code, you must use a finer grid
    - E.g., on a tetrahedral grid, the grid for FUN3D must be ~2 times finer on the surface, and ~6 times finer in the volume mesh to be fair
  - This is critical when comparing with cell-centered solvers
  - Hanging nodes are not currently supported
- FUN3D integrates all of the way to the wall for turbulent flows
  - Wall function grids are not adequate
  - Goal is to place first grid point at $y^+=1$
    - Base Δy on a flat plate estimate using your Reynolds number; can examine result in solver output and tweak as necessary
- Users employ all of the common grid generators – VGRID, AFLR2/AFLR3/SolidMesh, ICEM, Pointwise, etc.
- FUN3D also supports point-matched, multiblock structured grids through Plot3D file input
  - Subject to certain grid topologies:
    - Singularities treated – i.e., hexes with collapsed faces converted to prisms
    - But hexes with 180° internal angles cause FUN3D discretization to break down (LSQ)
- FUN3D can convert tetrahedral VGRID meshes to mixed elements
- FUN3D can convert any mixed element grid into tetrahedra using command line option '`--make_tets`'

Supported Grid Formats

Grid Format	Formatted	Unformatted	Supports mixed elements	Direct load or converter	File extension(s)
FAST	X	X		Direct	.fgrid, .mapbc
VGRID (single or multisegment)		X		Direct	.cogsg, .bc, .mapbc
AFLR3	X	X Also Binary	X	Direct	.ugrid/.(l)r8.ugrid/.(l)b8.ugrid, .mapbc
FUN2D	X			Direct	.faces
Fieldview v2.4, v2.5, v3.0	X	X	X	Direct (Some details of format not supported)	.fvgrid_fmt, .fvgrid_unf, .mapbc
Felisa	X			Direct	.gri, .fro, .bco
Point-matched, multiblock Plot3D	X	X	Hexes, degenerates	Converter	.p3d, .nmf
CGNS		Binary	X	Converter	.cgns

The development team can work with you to handle other formats as needed

Boundary Condition Input File

- Where required, the FUN3D .mapbc file takes the form:

```
Number of boundary patches
Boundary patch index    BC index     Family name
```

- The BC index may be either a 4-digit FUN3D-style index or a GridTool-style index
- The family name is optional, but must be present if the user requests patch lumping by family

```
3
1  4000    Wing
2  5000    Farfield
3  6662    Symmetry plane
```

- Exception: The .mapbc format for VGRID meshes follows the GridTool/VGRID format

Nondimensionalization

- Notation: * indicates a dimensional variable, otherwise dimensionless; the reference flow state is ***usually*** free stream ("∞"), but need not be
- Define reference values:
  - L^*_{ref} = reference length of the physical problem (e.g. chord in ft)
  - L_{ref} = corresponding length in your grid (*dimensionless*)
  - ρ^*_{ref} = reference density (e.g. slug/ft^3)
  - μ^*_{ref} = reference molecular viscosity (e.g. slug/ft-s)
  - T^*_{ref} = reference temperature (e.g. ^{o}R, compressible only)
  - a^*_{ref} = reference sound speed (e.g. ft/s, compressible only)
  - U^*_{ref} = reference velocity (e.g. ft/s)
- Space and time are made dimensionless in FUN3D by:
  - $\vec{x} = \vec{x}^* / (L^*_{ref} / L_{ref})$ $\quad t = t^* a^*_{ref} / (L^*_{ref} / L_{ref})$ (compressible) $\quad t = t^* U^*_{ref} / (L^*_{ref} / L_{ref})$ (incompressible)

Nondimensionalization (cont)

- For the ***compressible flow*** equations the dimensionless variables are:
  - $\vec{u} = \vec{u}^* / a^*_{ref}$ so $|\vec{u}|_{ref} = |\vec{u}|^*_{ref} / a^*_{ref} = M_{ref}$
  - $P = P^* / (\rho^*_{ref} a^{*2}_{ref})$ so $P_{ref} = P^*_{ref} / (\rho^*_{ref} a^{*2}_{ref}) = 1/\gamma$
  - $a = a^* / a^*_{ref}$ so $a_{ref} = 1$
  - $T = T^* / T^*_{ref}$ so $T_{ref} = 1$
  - $e = e^* / (\rho^*_{ref} a^{*2}_{ref})$ so $e_{ref} = e^*_{ref} / (\rho^*_{ref} a^{*2}_{ref}) = 1/(\gamma(\gamma-1)) + M^2_{ref}/2$
  - $\rho = \rho^* / \rho^*_{ref}$ so $\rho_{ref} = 1$
  - From the equation of state and the definition of sound speed:

$$T = \gamma P / \rho = a^2$$

- The input Reynolds number in FUN3D is related to the Reynolds number of the physical problem by

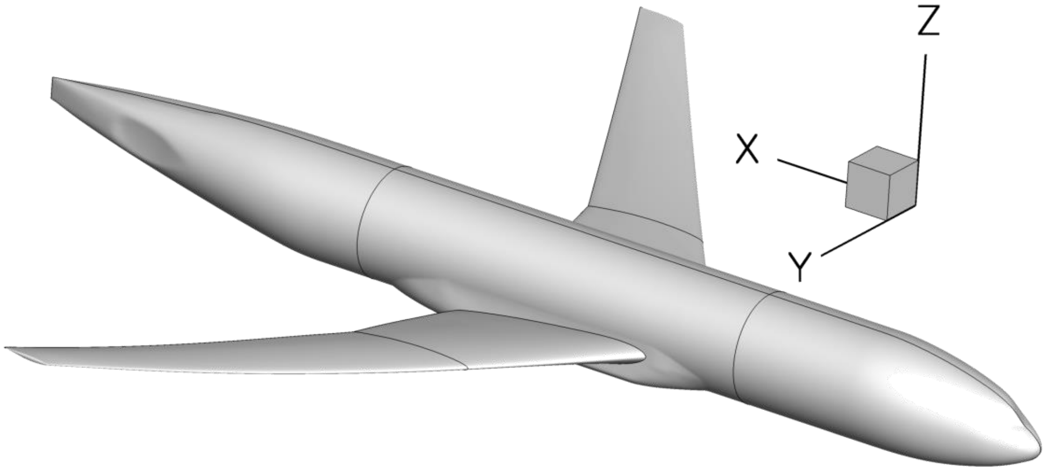
reynolds_number = $\mathrm{Re}_{ref} / L_{ref}$ where $\mathrm{Re}_{ref} = \rho^*_{ref} U^*_{ref} L^*_{ref} / \mu^*_{ref}$

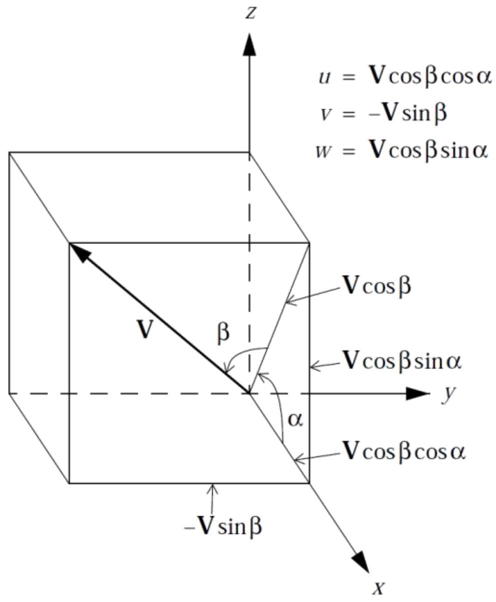
i.e. reynolds_number is a Reynolds number ***per unit grid length***

Setting the Reynolds Number Input

- Frequent cause of confusion, even for developers
- Need to know what characteristic length your Reynolds number is based on – mean aerodynamic chord, diameter, etc.
- Your input Reynolds number is based on the corresponding length of that “feature” in your computational grid
- Example: You want to simulate a Reynolds number of 2.5 million based on the MAC:
  - If the length of the MAC in your grid is 1.0 grid units, you would input Re=2500000 into FUN3D
  - If the length of the MAC in your grid is 141.2 grid units (perhaps these physically correspond to millimeters), you would input 2500000/141.2, or Re=17705.4 into FUN3D

FUN3D Axis Convention





- FUN3D coordinate system differs from the standard wind coordinate system by a 180º rotation about the y-axis
  - Positive x-axis is toward the “back” of the vehicle (downstream)
  - Positive y-axis is out the “right wing”
  - Positive z-axis is “upward”
- The freestream angle of attack and yaw angle are defined as shown

Runtime Environment

- "Unlimit" your shell (also good idea to put this in any queue scripts):

```
$ ulimit unlimited # for bash
$ unlimit          # for c shell
```

- If unformatted or binary, what "endianness" does your grid file have?
  - E.g., VGRID files are always big endian, regardless of platform
  - If your compiler supports it, FUN3D will attempt to open files using an `open(convert=…)` syntax
  - Most compilers support some means of conversion
    - Either an environment variable or compile-time option, depending on what compiler you're using
    - E.g., Intel compiler can be controlled with an environment variable `F_UFMTENDIAN = big`
- Memory required by solver: *rough* rule of thumb is 3-3.5 GB per million points (not cells!)
  - Conversely, 200k-300k points per 1 GB of memory
    - Users generally partition into smaller domains than this, but be aware of these numbers
  - This memory estimate will be higher if visualization options are used, etc

User Inputs for FUN3D

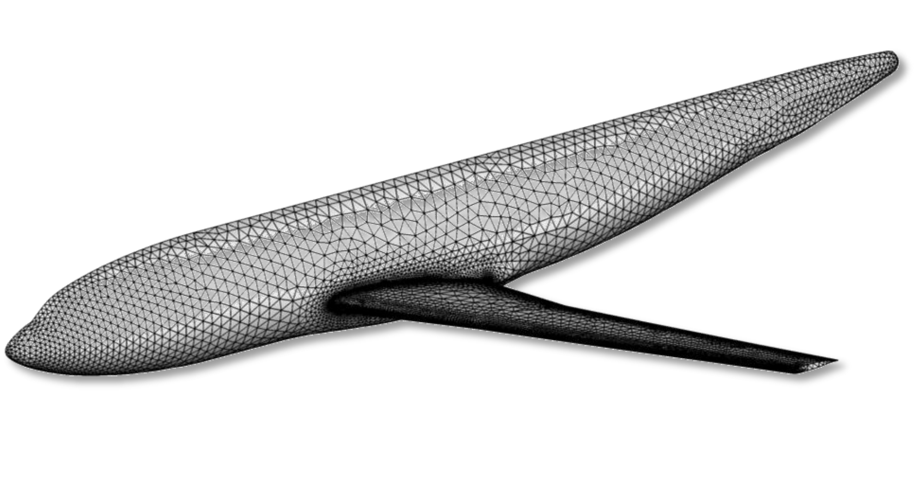
Input deck `fun3d.nml`

- The user is required to supply an input deck for FUN3D named `fun3d.nml` (fixed name)
- This filename contains a collection of Fortran namelists that control FUN3D execution – all namelist variables have default values as documented
- But user will need to set at least some high-level variables, such as the project name

Command Line Options (CLOs)

- CLOs always take the form `--command_line_option` after the executable name
  - Some CLOs may require trailing auxiliary data such as integers and/or reals
- User may specify as many CLOs as desired
- CLOs always trump `fun3d.nml` inputs
- CLOs available for a given code in the FUN3D suite may be viewed by using `--help` after the executable name
- Most CLOs are for developer use; namelist options are preferred where available

Transonic Turbulent Flow on a Tetrahedral Wing-Body Mesh



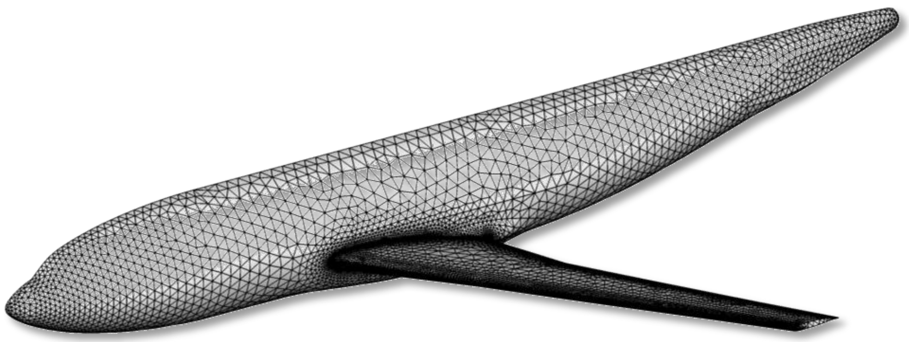
- For this case, we will assume that someone has provided a set of VGRID files containing the mesh
  - f6fx2b_trn.cogsg, f6fx2b_trn.bc, and f6fx2b_trn.mapbc
- It is always a good idea to examine the .mapbc file first to check the boundary conditions and any family names
  - Note that specific boundary conditions will be covered in a separate session

Transonic Turbulent Flow on a Tetrahedral Wing-Body Mesh

- For this case, the VGRID/GridTool-style .mapbc file is as shown
- Surface grid consists of 51 patches
- Note that VGRID/GridTool-style BC's are specified
- Family names are also as shown (required in this format)
- FUN3D does not use the other columns of data
- If you cannot easily visualize your mesh to set appropriate boundary conditions, one easy approach is to set them all to inflow/outflow, then run a single time step of FUN3D with boundary visualization activated – then set patch BC's as needed for actual simulation

```
#Thu Mar 11 13:42:40 2010
#bc.map
Patch #        BC             Family   #surf   surfIDs        Family
#------------------------------------------------------------------------
1              3              3              0              0       Box
2              3              3              0              0       Box
3              3              3              0              0       Box
4              3              3              0              0       Box
5              3              3              0              0       Box
6              4              4              1              15      Wing
7              4              4              1              15      Wing
8              4              4              1              17      Wing
9              4              4              1              17      Wing
10             4              4              1              15      Wing
11             4              4              1              13      Fuselage
12             4              4              1              21      Fuselage
13             4              4              1              11      Fuselage
14             4              4              1              11      Fuselage
15             4              4              1              12      Fuselage
16             4              4              1              12      Fuselage
17             4              4              1              15      Wing
18             4              4              1              15      Wing
19             4              4              1              15      Wing
20             4              4              1              15      Wing
21             4              4              1              17      Wing
22             4              4              1              17      Wing
23             4              4              1              16      Wing
24             4              4              1              15      Wing
25             4              4              1              17      Wing
26             4              4              1              8       Fuselage
27             4              4              1              16      Wing
28             4              4              1              16      Wing
29             4              4              1              16      Wing
30             4              4              1              16      Wing
31             4              4              1              18      Wing
32             4              4              1              18      Wing
33             4              4              1              17      Wing
34             4              4              1              18      Wing
35             4              4              1              18      Wing
36             4              4              1              1       Wing
37             4              4              1              18      Wing
38             4              4              1              18      Wing
39             4              4              1              18      Wing
40             4              4              1              22      Fuselage
41             1              1              0              0       Symmetry
42             4              4              1              10      Fuselage
43             4              4              1              9       Fuselage
44             4              4              1              14      Fuselage
45             4              4              1              23      Fuselage
46             4              4              1              19      Wing
47             4              4              1              20      Wing
48             4              4              1              27      Fairing
49             4              4              1              29      Fairing
50             4              4              1              28      Fairing
51             4              4              1              30      Fairing
```

Transonic Turbulent Flow on a Tetrahedral Wing-Body Mesh



- Now we will look at the minimum set of user inputs needed in `fun3d.nml` to run this case

Transonic Turbulent Flow on a Tetrahedral Wing-Body Mesh

```
&project
  project_rootname = 'f6fx2b_trn'
/
&raw_grid
  grid_format = 'vgrid'
/
&reference_physical_properties
  mach_number       = 0.75
  reynolds_number   = 17705.40
  angle_of_attack   = 1.0
  temperature       = 580.0
  temperature_units = "Rankine"
/
&code_run_control
  restart_read = 'off'
  steps        = 500
/
&force_moment_integ_properties
  area_reference   = 72700.0
  x_moment_length = 141.2
  y_moment_length = 585.6
  x_moment_center = 157.9
  z_moment_center = -33.92
/
&nonlinear_solver_parameters
  schedule_cfl     = 10.0 200.0
  schedule_cflturb = 1.0 30.0
/
```

project_rootname	Project name
grid_format	Read a set of VGRID files
mach_number	Sets freestream Mach number
reynolds_number	Sets Reynolds number
angle_of_attack	Sets freestream angle of attack
temperature	Sets freestream temperature
temperature_units	Uses Rankine temperature units for input
restart_read	Perform a cold start
steps	Perform 500 time steps
area_reference	Sets reference area
x_moment_length	Sets length for normalizing y-moments
y_moment_length	Sets length for normalizing x-, z-moments
x_moment_center	Sets x-moment center
z_moment_center	Sets z-moment center
schedule_cfl	CFL for meanflow is ramped from 10.0 to 200.0
schedule_cflturb	CFL for turbulence is ramped from 1.0 to 30.0

$\left.\begin{array}{l}\text{Sets reference area}\\\text{Sets length for normalizing y-moments}\\\text{Sets length for normalizing x-, z-moments}\\\text{Sets x-moment center}\\\text{Sets z-moment center}\end{array}\right\}$ All in grid units

Transonic Turbulent Flow on a Tetrahedral Wing-Body Mesh

- We now have the boundary conditions and input deck set up to run FUN3D
- To execute FUN3D, we use the following basic command line syntax:

```
mpirun ./nodet_mpi
```

  - Note your environment may require slightly different syntax:
    - `mpirun` vs `mpiexec` vs `aprun` vs …
    - May need to specify various MPI runtime options:
      - `-np #`
      - `-machinefile filename`
      - `-nolocal`
      - Others

Transonic Turbulent Flow on a Tetrahedral Wing-Body Mesh

- Using 1 Intel Haswell node (24 cores), this case runs in 2-3 minutes
- The top of the screen output will include an echo of your `fun3d.nml`, as well as some preprocessing information:

```
FUN3D 12.7-74063 Flow started 05/18/2015 at 06:09:15 with 24 processes
        [Echo of fun3d.nml]
 The default "unformatted" data format is being
   used for the grid format "vgrid".
... nsegments,ntet,nnodesg            1      2994053      513095
cell statistics: type,      min volume,      max volume, max face angle
cell statistics:  tet,  0.41152313E-06,  0.66593449E+11,  179.973678915
cell statistics:  all,  0.41152313E-06,  0.66593449E+11,  179.973678915

     ... PM (64,skip_do_min) :            0 F
     ... Calling ParMetis (ParMETIS_V3_PartKway) ....           0 F
 ... edgeCut       140453
     ... Time for ParMetis: .2 s
     ... Constructing partition node sets for level-0...              2994053 T
     ... Edge Partitioning ....
     ... Boundary partitioning....
     ... Reordering for cache efficiency....
     ... Write global grid information to f6fx2b.grid_info
     ... Time after preprocess TIME/Mem(MB):      1.60     180.52     180.52
  NOTE: kappa_umuscl set by grid: .00

 Grid read complete
  Repaired 82 nodes of symmetry plane 6662, max deviation: 0.172E-03
  y-symmetry metrics modified/examined: 23601/23601
  Distance_function unique ordering  T    20000000
  construct partial boundary...nloop=          1
  find closer surface edge...
  find closer surface face...

 Wall spacing: 0.766E-03 min, 0.120E-02 max, 0.115E-02 avg
```

FUN3D version, start time, job size

VGRID input is being used
Grid contains 2,994,053 tets and 513,095 points
Min/max cell volumes, max internal face angles

# of edges cut by partitioning (measure of communication)

1.6 secs required to preprocess the mesh

Min/max/avg wall spacing statistics

Transonic Turbulent Flow on a Tetrahedral Wing-Body Mesh

- At this point, time stepping commences
- For each time step:
  - The L2-norm of the density|turbulence equation is red|blue; max and location are also included
  - Lift and drag are reported in green
- "`Done.`" indicates execution is complete

```
Iter             density_RMS  density_MAX   X-location   Y-location   Z-location
                    turb_RMS     turb_MAX   X-location   Y-location   Z-location
   1  0.567457404772944E+00  0.28035E+02  0.16377E+03 -0.16562E+03  0.20117E+02
      0.764159584901413E+04  0.13249E+07  0.79654E+04 -0.88280E+04  0.25675E+02
      Lift  0.103226565173772E+00        Drag  0.646513396068887E+00
   2  0.300679598726331E+00  0.12718E+02  0.29226E+03 -0.72487E+02 -0.12411E+02
      0.753354470463467E+04  0.12868E+07  0.79654E+04 -0.88280E+04  0.25675E+02
      Lift  0.146829230859457E+00        Drag  0.721243167013704E+00
.
.
.
 999  0.383370843514542E-05  0.13909E-03  0.35380E+03 -0.58429E+02 -0.16200E+02
      0.318320572426105E-02  0.19891E+00  0.36848E+03 -0.68458E+02  0.31074E+01
      Lift  0.556387990643583E+00        Drag  0.388233647462313E-01
1000  0.382497896407724E-05  0.13871E-03  0.35380E+03 -0.58429E+02 -0.16200E+02
      0.317436044959994E-02  0.19835E+00  0.36848E+03 -0.68458E+02  0.31074E+01
      Lift  0.556387923023456E+00        Drag  0.388233658091165E-01

Writing f6fx2b.flow (version 11.8) lmpi_io 2
 inserting current history iterations 1000
Time for write: .1 s
Done.
```

Transonic Turbulent Flow on a Tetrahedral Wing-Body Mesh

- At this point, time stepping commences
- For each time step:
  - The L2-norm of the density|turbulence equation is red|blue; max and location are also included
  - Lift and drag are reported in green
- "`Done.`" indicates execution is complete

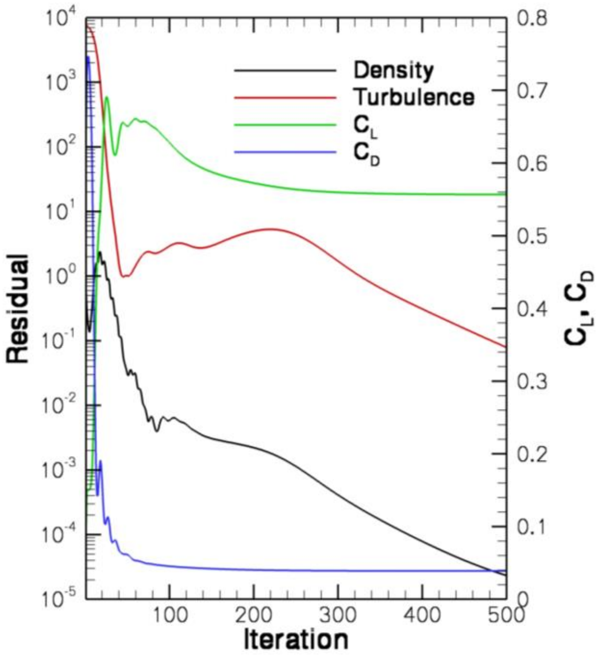
```
Iter           density_RMS  density_MAX   X-location   Y-location   Z-location
                  turb_RMS     turb_MAX   X-location   Y-location   Z-location
   1 0.567454200028342E+00  0.28035E+02  0.16377E+03 -0.16562E+03  0.20117E+02
     0.764159584901741E+04  0.13249E+07  0.79654E+04 -0.88280E+04  0.25675E+02
     Lift  0.103222129717669E+00          Drag  0.646514468368827E+00
   2 0.300676687726037E+00  0.12718E+02  0.29226E+03 -0.72487E+02 -0.12411E+02
     0.753354469872627E+04  0.12868E+07  0.79654E+04 -0.88280E+04  0.25675E+02
     Lift  0.146830367737086E+00          Drag  0.721243419758588E+00
.
.
.
499 0.235098406158263E-04  0.44827E-02  0.63496E+04 -0.38199E+04  0.18712E+04
    0.799698877237297E-01  0.12961E+02  0.46732E+04 -0.15204E+04  0.26710E+03
    Lift  0.556610229549889E+00          Drag  0.388376897833650E-01
500 0.232908407834686E-04  0.44201E-02  0.63496E+04 -0.38199E+04  0.18712E+04
    0.789246351974423E-01  0.12785E+02  0.46732E+04 -0.15204E+04  0.26710E+03
    Lift  0.556607946389416E+00          Drag  0.388374809483346E-01

Writing f6fx2b_trn.flow (version 11.8) lmpi_io 2
 inserting current history iterations 500
Time for write: .0 s

Done.
```

Transonic Turbulent Flow on a Tetrahedral Wing-Body Mesh

- FUN3D provides a couple of text files with basic statistics and summary data:
  - `f6fx2b_trn.grid_info` File containing basic mesh statistics and partitioning info
  - `f6fx2b_trn.forces` File containing force breakdowns by boundary and totals
- FUN3D also produces:

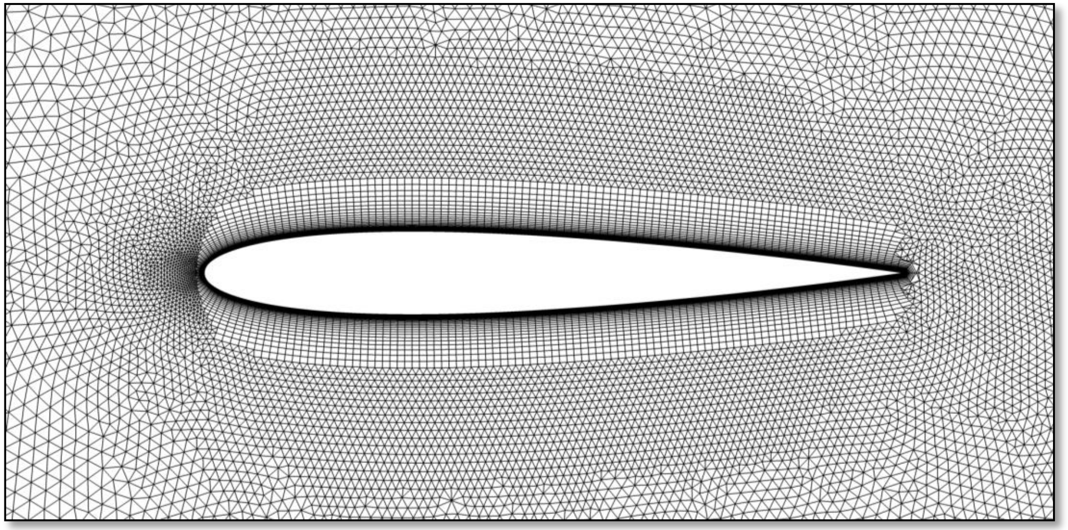
  `f6fx2b_trn_hist.dat` Tecplot file with residual, force convergence histories

  `f6fx2b_trn.flow` Solver restart information



- For this particular case, the mean flow and turbulence residuals are reduced by ~5 orders of magnitude over 500 time steps
- Lift and drag come in after a few hundred time steps

NACA 0012 Airfoil



- For this case, we have been given a set of binary, big endian AFLR3 files
  - 0012.b8.ugrid, 0012.mapbc
  - For computations in 2D mode
    - Grid must be one-element wide in the y-direction (except when using FUN2D format)
    - Grid must contain only prisms and/or hexes
- First check the .mapbc file
  - The y-planes must be separate boundary patches and should be given BC 6662

0012.mapbc

```
4
1 4000
2 5000
3 6662
4 6662
```

NACA 0012 Airfoil

- `fun3d.nml` is shown here
- FUN2D grid format will automatically be executed in 2D mode; all others must be explicitly put in 2D mode

```
&project
  project_rootname = '0012'
/
&raw_grid
  grid_format = 'aflr3'
  twod_mode   = .true.
/
&reference_physical_properties
  mach_number         = 0.80
  reynolds_number     = 1.e6
  angle_of_attack     = 1.25
  temperature         = 580.0
  temperature_units = "Rankine"
/
&code_run_control
  restart_read = 'off'
  steps        = 5000
/
&force_moment_integ_properties
  area_reference   = 0.1
  x_moment_center = 0.25
/
&nonlinear_solver_parameters
  schedule_cfl      = 10.0 200.0
  schedule_cflturb = 1.0 10.0
/
&global
  boundary_animation_freq = -1
/
```

Read an AFLR3 grid
Execute in 2D mode

NACA 0012 Airfoil

```
FUN3D 12.7-74063 Flow started 05/18/2015 at 09:06:46 with 24 processes
        [Echo of fun3d.nml]
 The default "stream" data format is being
   used for the grid format "aflr3".
Preparing to read binary AFLR3 grid: 0012.b8.ugrid

  nnodes              116862
  ntface,nqface       204510 14607
  ntet,npyr,nprz,nhex 0 0 102255 7047

cell statistics: type,      min volume,      max volume, max face angle
cell statistics:  prz,  0.16960303E-06,  0.52577508E-01,  164.861624007
cell statistics:  hex,  0.83173480E-09,  0.12843645E-04,  123.906431556
cell statistics:  all,  0.83173480E-09,  0.52577508E-01,  164.861624007

 ... PM (64,skip_do_min) :            0 F
     ... Calling ParMetis (ParMETIS_V3_PartKway) ....           0 F
     ... edgeCut        11490
     ... Time for ParMetis: .1 s
     ... checking for spanwise edge cuts.
     ... Constructing partition node sets for level-0...               109302 T
     ... Edge Partitioning ....
     ... Boundary partitioning....
     ... Euler numbers Grid:1 Boundary:0 Interior:0
     ... Reordering for cache efficiency....
     ... ordering edges for 2D.
     ... Write global grid information to 0012.grid_info
     ... Time after preprocess TIME/Mem(MB):      0.31     90.82     90.82
  NOTE: kappa_umuscl set by grid: .00

 Grid read complete

 Using 2D Mode (Node-Centered)

Distance_function unique ordering  T    20000000
  construct partial boundary...nloop=           1
  find closer surface edge...
  find closer surface face...
 Wall spacing: 0.100E-03 min, 0.100E-03 max, 0.100E-03 avg
```

Binary AFLR3 format is the default

Binary AFLR3 grid being read

Grid contains 116,862 points

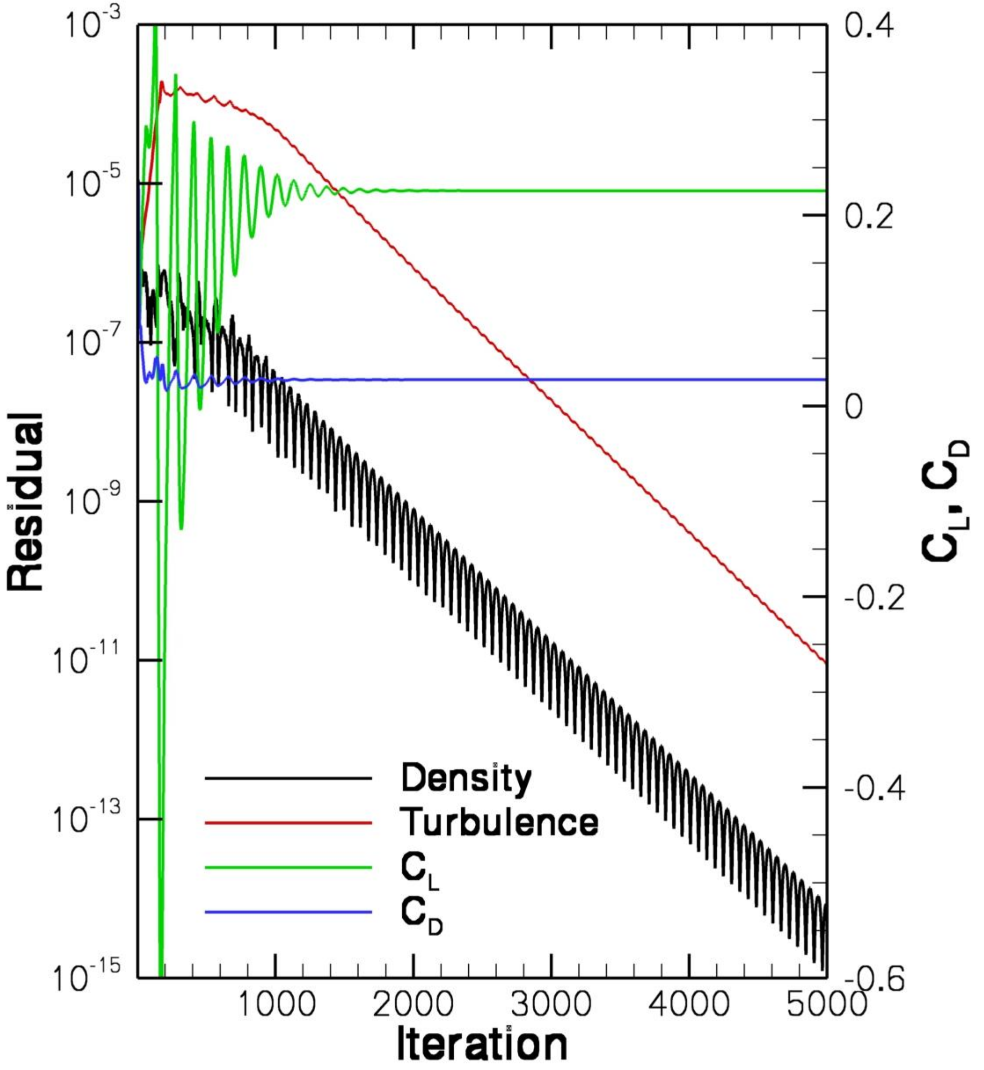
Grid contains 204,510 tris, 14,607 quads

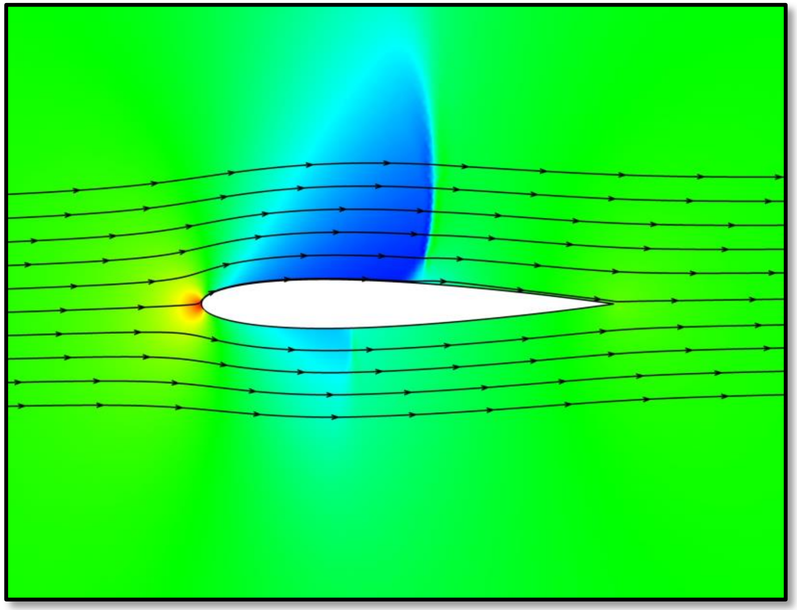
Grid contains 102,255 prisms, 7,047 hexes

Cell stats now broken out by cell type

Solver running in 2D mode

NACA 0012 Airfoil





List of Key Input/Output Files

- Input
  - Grid files (prefixed with project name, suffixes depend on grid format)
  - `fun3d.nml`
- Output
  - `[project].grid_info`
  - `[project].forces`
  - `[project]_hist.dat`
  - `[project].flow`

What Could Possibly Go Wrong?

<u>Problem</u>

- Common complaint from VGRID meshes during initial preprocessing phase at front end of solver:

```
Checking volume-boundary connectivity...

stopping...unable to find common element for face       1 of
boundary       3
boundary nd array      46   17368 334315

node,locvc          46*******************************
node,locvc_type     46    tet    tet    tet    tet    tet

node,locvc       17368*************************************
node,locvc_type  17368    tet    tet    tet    tet    tet    tet
```

- This is due to a very old VGRID bug that causes an incompatibility between the `.cogsg` and `.bc` files
  - Compile and run `utils/repair_vgrid_mesh.f90` to generate a valid `.bc` file to replace your original one

What Could Possibly Go Wrong?

Problem

- Common complaint from unformatted/binary meshes during initial preprocessing phase at front end of solver:

```
Read/Distribute Grid.
forrtl: severe (67): input statement requires too much data, unit 16100,
file /misc/work14/user/FUN3D/project.cogsg
```

- Check the endianness of the grid and your environment/executables

Problem

- Unexpected termination, especially during preprocessing or first time step
  - Are your shell limits set?
  - Do you have enough local memory for what you are trying to run?

What Could Possibly Go Wrong?

Problem

- Solver diverges or does not converge
  - Problem-dependent, very tough to give general advice here
  - Sometimes require first-order iterations (primarily for high speeds)
  - Sometimes require smaller CFL numbers
  - Sometimes require alternate flowfield initialization (not freestream) in some subregion of the domain: e.g., chamber of an internal jet
  - Check your boundary conditions and gridding strategy
  - Perhaps your problem is simply unsteady

Problem

- Solver suddenly dies during otherwise seemingly healthy run
  - Sometimes useful to visualize solution just before failure
  - Is it a viscous case on a VGRID mesh? Try turning on `large_angle_fix` in `&special_parameters` namelist (viscous flux discretization degenerates in sliver cells common to VGRID meshes)
  - Is it a turbulent flow on a mesh generated using AFLR3? Look for "eroded" boundary layer grids near geometric singularities – AFLR3 sometimes has trouble adding viscous layers near complex corners, etc

What Could Possibly Go Wrong?

In General…

- Do not hesitate to send questions to *fun3d-support@lists.nasa.gov* ; we are happy to try to diagnose problems
  - Please send as much information about the problem/inputs/environment that you can, as well as all screen output, any error output, and `config.log`
  - In extreme cases, we may request your grid and attempt to run a case for you to track down the problem
  - If you cannot send us a case due to restrictions, size, etc, a generic/smaller representative case that behaves similarly can be useful
  - Check the manual for guidance
- Ask the FUN3D user community, *fun3d-users@lists.nasa.gov*

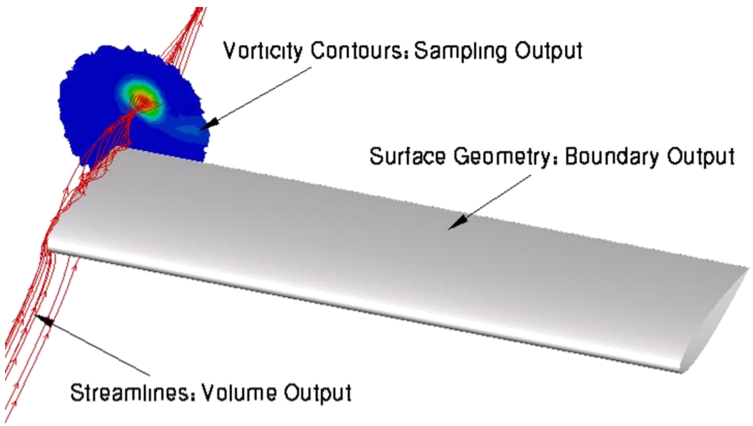
Visualization Learning Goals

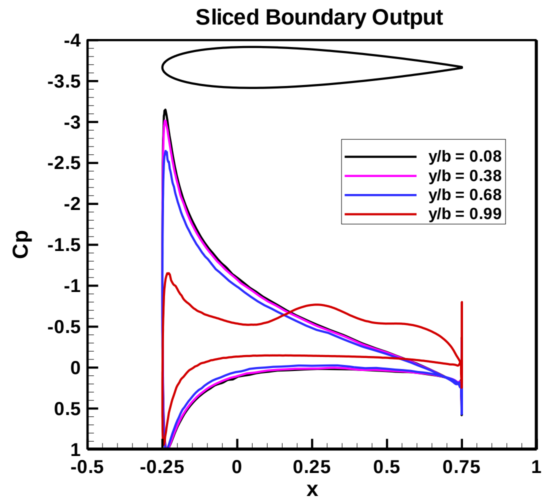
- What this will teach you
  - Run-time flow visualization output
    - Output on boundary surfaces
    - Output on user-specified "sampling" surfaces within the volume
    - Output of full volume data
    - Output generated by "slicing" boundary data - "sectional" output
- What you will not learn
  - The plethora of output options available for visualization
  - Tecplot usage
- What should you already know
  - Basic flow solver operation and control

Background

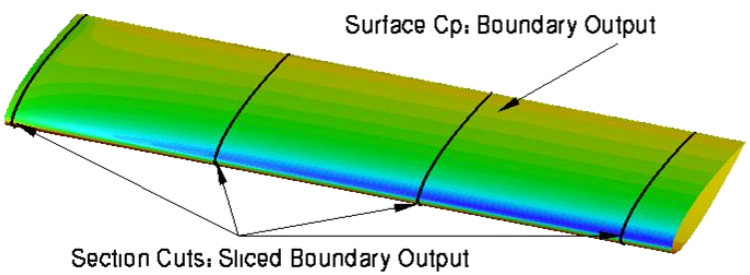
- Datasets are getting simply too large to post-process in a traditional manner
- FUN3D allows visualization data to be generated as the solver is running
    - User specified frequency and output type
    - User specified output variables from a fairly extensive list
- Majority of output options are Tecplot-based
    - Volume output may also be generated in Fieldview, CGNS formats
- Note FUN3D also supports true in-situ visualization at scale using the DoE VisIt package; however, this is not covered here
    - Intelligent Light is currently integrating VisIt's in-situ capabilities with Fieldview

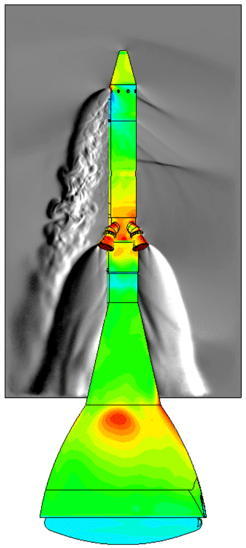
Selected Visualization Output Examples





Iso-surfaces





Schlieren,
boundary output

Visualization Overview

- All of the visualization outputs require similar namelist-specified "frequency" N to activate:
  - In all cases, N = 0, 1, 2, 3, …
    - N = 0 generates no output
    - N < 0 generates output only at the ***end*** of the run - typically used for steady-state cases. The actual value of N is ignored
    - N > 0 generates output every N^{th} time step - typically used to generate animation for unsteady flows; can also be used to observe how a steady flow converges

Visualization Overview

- Customizable output variables (except sliced boundary data):
  - Most variables are the same between the boundary surface, sampling and volume output options; boundary surface has a few extra
  - See manual for lists of all available variables
  - Default variables always include x, y, z, and the “primitive” flow variables u, v, w, and p (plus density if compressible)
  - Several “shortcut” variables: e.g.,

    `primitive_variables = rho, u, v, w, p`
  - Must explicitly turn off the default variables if you don’t want them (e.g. **`primitive_variables = .false.`**)
  - Variable selection for each co-processing option done with a different namelist to allow “mix and match”

Visualization Overview

- For boundary surface output, default is all solid boundaries in 3D and one y=const plane in 2D; alternate output boundaries selected with, e.g.:

```
&boundary_output_variables
   number_of_boundaries = 3
   boundary_list = '3,5,9'    ! blanks OK as
                                delimiter too: '3 5 9'
                              ! dashes OK as delimiter
                                too: '3-9'
 /
```

- If you already have a converged solution and don't want to advance the solution any further, can do a "pass through" run:
  - set **`steps = 0`** in **`&code_run_control`**
  - You must have a restart file (**`[project].flow`**)
  - Run the solver with the appropriate namelist input to get desired output
  - **`[project].flow`** will remain unaltered after completion

Visualization Overview

- Sampling output requires additional data to describe the desired sampling surface(s)
  - Specified in namelist **`&sampling_parameters`**
  - Surfaces may be planes, quadrilaterals or circles of arbitrary orientation, or may be spheres or boxes
  - Isosurfaces and schlierens also available
  - Points may also be sampled
  - See manual for complete info
- Sliced boundary surface output requires additional data to describe the desired slice section(s)
  - Specified in namelist **`&slice_data`**
  - Always / only outputs x, y, z, C_p, C_{fx}, C_{fy}, C_{fz}
  - User specifies which (solid) boundaries to slice, and where
  - See manual for complete info

Visualization Overview

- Output files will be ASCII unless you have built FUN3D against the Tecplot library (exception: sliced boundary data is always ASCII)
  - ASCII files have .dat extension
  - Binary files have .plt extension - smaller files; load into Tecplot faster
  - Boundary output file naming convention (T = time step counter):
    - **`[project]_tec_boundary_timestepT.dat`** if N > 0
    - **`[project]_tec_boundary.dat`** if N < 0
  - Volume output file naming convention (note: 1 file *per processor* P)
    - **`[project]_partP_tec_volume_timestepT.dat`** if N > 0
    - **`[project]_partP_tec_volume.dat`** if N < 0
  - Sampling output file naming convention (one file per sampling geometry G):
    - **`[project]_tec_sampling_geomG_timestepT.dat`** if N > 0
    - **`[project]_tec_sampling_geomG.dat`** if N < 0

Boundary Output Visualization Example

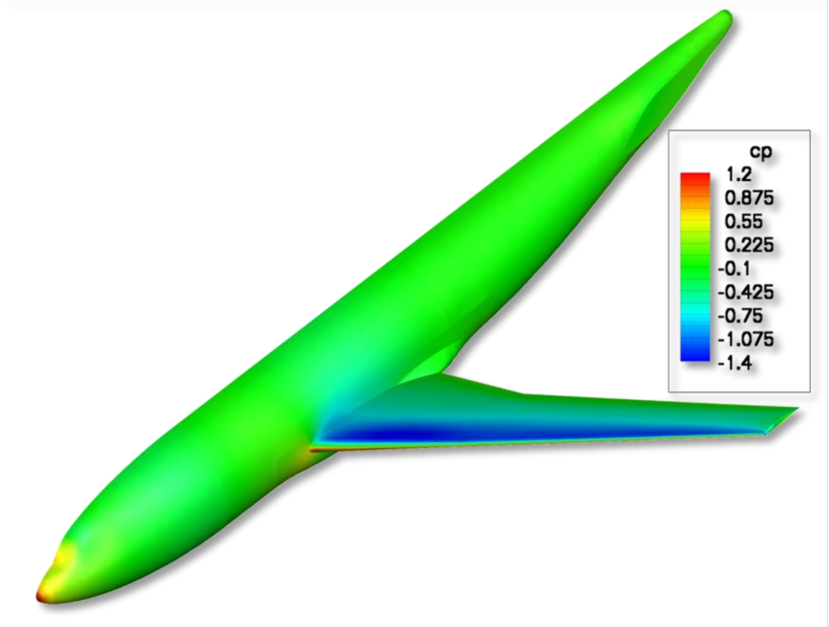
```
&global
  boundary_animation_freq = -1
/
&boundary_output_variables
  primitive_variables = .false.
  cp                  = .true.
  yplus               = .true.
/
```

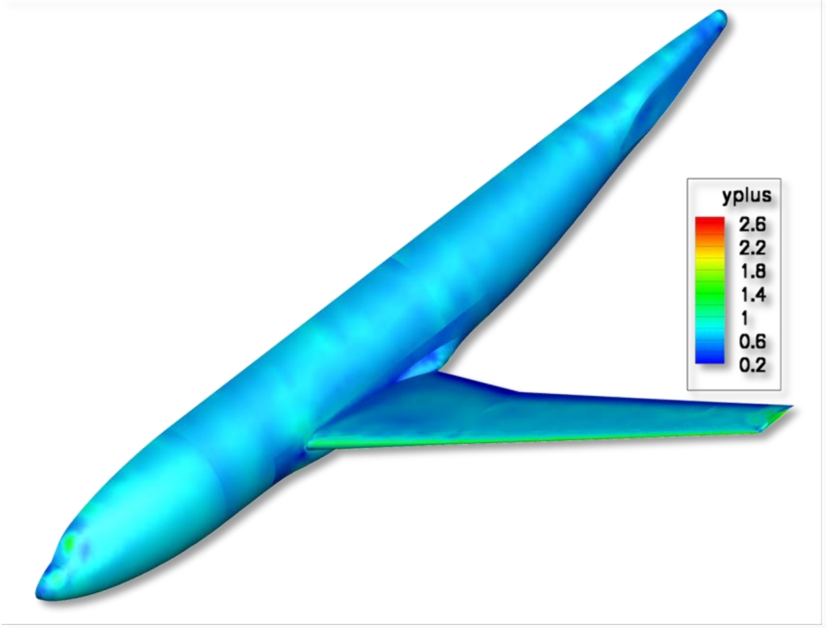
Dump boundary vis at end of run

Turn off rho, u, v, w, p

Turn on C_p

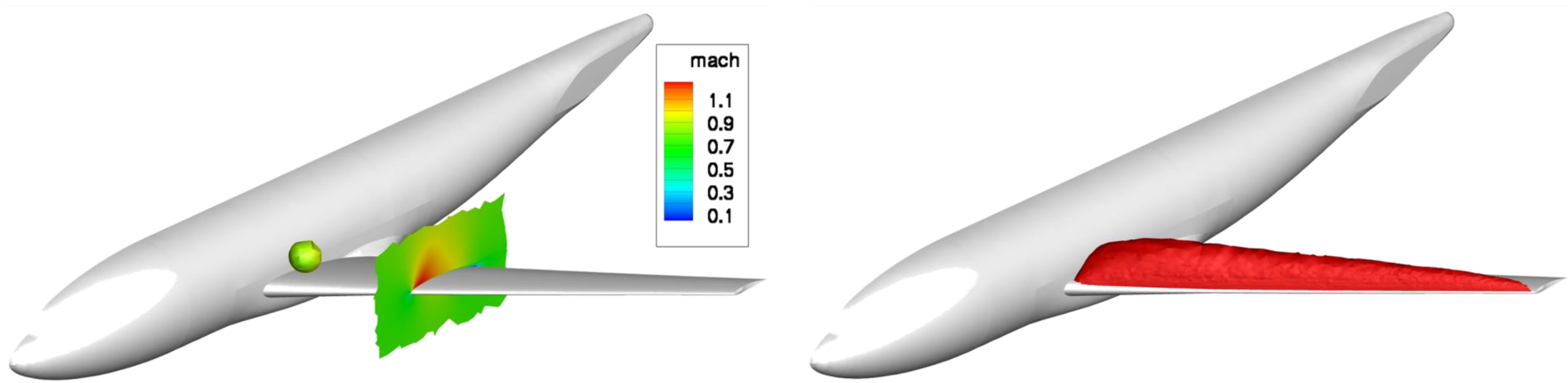
Turn on y^+





Sampling Visualization Example

`&sampling_parameters`	
`number_of_geometries  = 3`	Want 3 sampling geometries
`type_of_geometry(1)   = 'plane'`	First geometry is a plane
`plane_center(2,1)     = -234.243`	Plane y-coordinate
`plane_normal(2,1)     = 1.0`	Plane y-normal
`sampling_frequency(1) = -1`	Write at end of run
`type_of_geometry(2)   = 'sphere'`	Second geometry is a sphere
`sphere_center(1,2)    = 74.9`	Center x-coordinate
`sphere_center(2,2)    = -107.7`	Center y-coordinate
`sphere_center(3,2)    = 50.0`	Center z-coordinate
`sphere_radius(2)      = 20.0`	Sphere radius
`sampling_frequency(2) = -1`	Write at end of run
`type_of_geometry(3)   = 'isosurface'`	Third geometry is an isosurface
`isosurf_variable(3)   = 'mach'`	Isosurface will be based on Mach number
`isosurf_value(3)      = 1.00`	Isosurface defined by Mach=1
`sampling_frequency(3) = -1`	Write at end of run
`/`	
`&sampling_output_variables`	
`primitive_variables = .false.`	Turn off rho, u, v, w, p
`mach                = .true.`	Turn on Mach number
`/`	

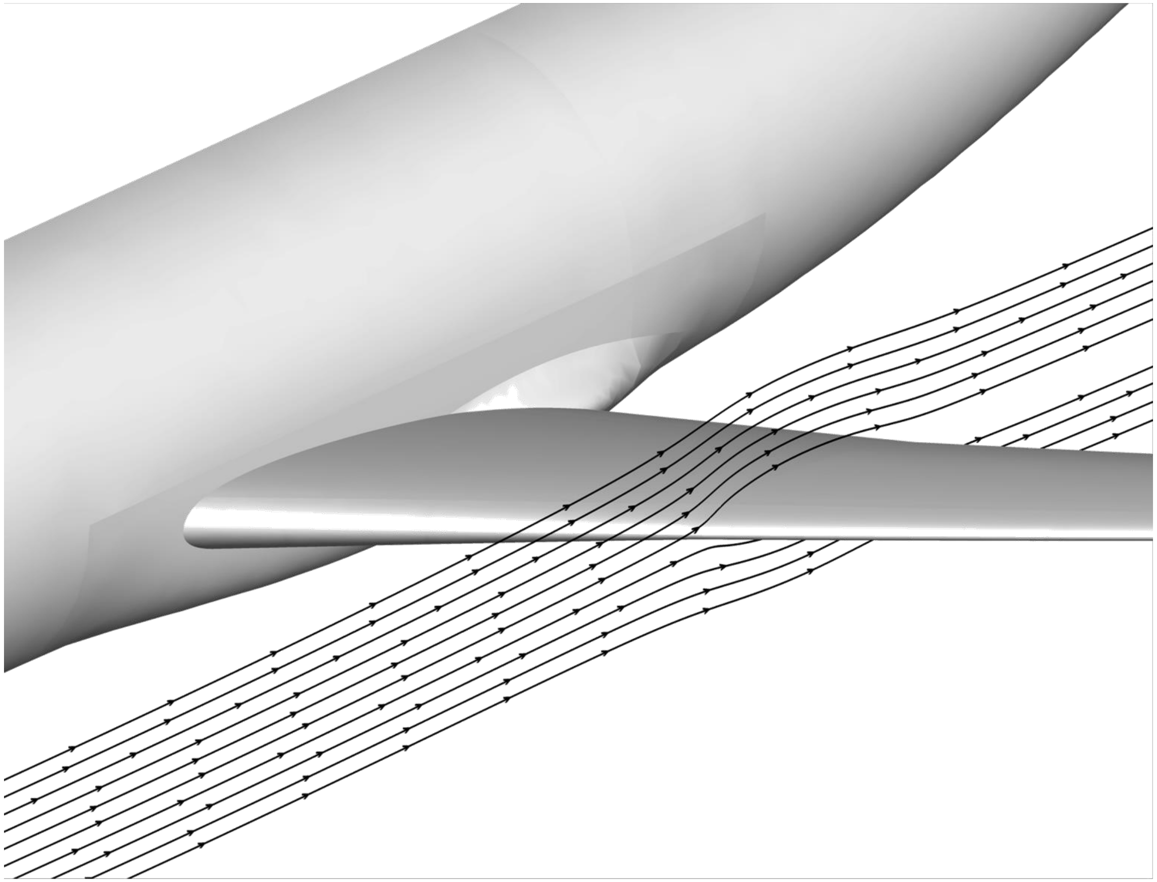


Volume Visualization Example

```
&global
  volume_animation_freq = -1
/
&volume_output_variables
  export_to='tecplot'
/
```

Dump output at end of run

Send results to Tecplot file



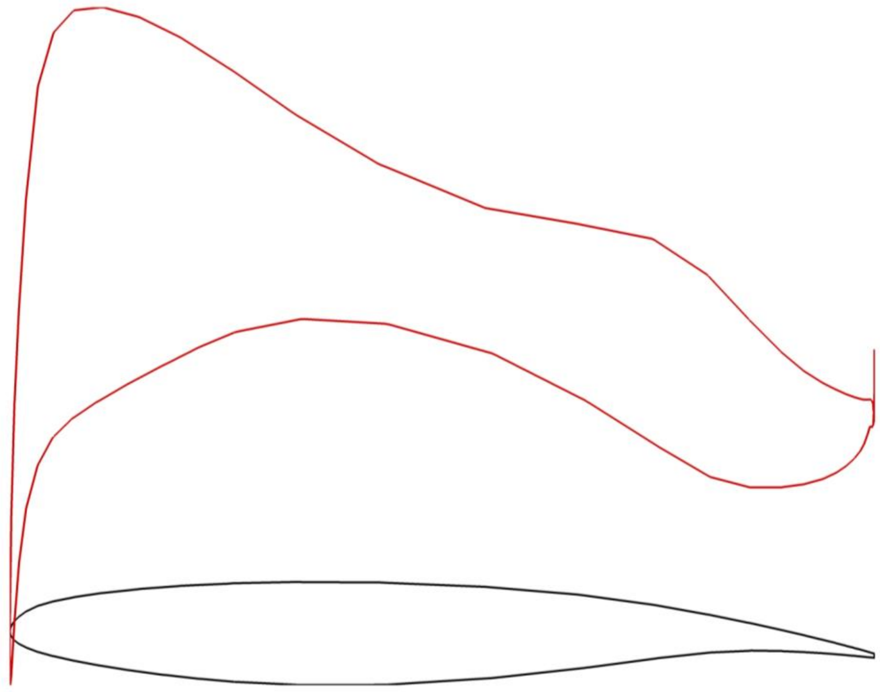
Slicing Visualization Example

```
&global
  slice_freq = -1
/
&slice_data
  nslices = 1
  slice_location(1) = -234.243
/
```

Dump output at end of run

Perform one slice

Coordinate of slice



Troubleshooting/FAQ

- I can see what look like ragged dark lines on sampling surfaces and volume data – what is that?
  - Duplicate information at partition boundaries is not removed; if surface is not completely opaque, double plotting locally doubles the opaqueness (duplicate info ***is*** removed from boundary surface output)
  - Turn off transparency in Tecplot
- When I dump out volume plot files in Tecplot format, I get a file for every processor – is there a way around this?
  - Not currently. However, Tecplot can be easily told to load all of the files at once without having to individually select them all.
  - The team is working with Tecplot to develop their next generation of I/O API's, with special focus on massively parallel needs
  - Alternative: switch to Fieldview or CGNS output, which uses a single file

What We Learned

- Basic gridding requirements and file formats
- Runtime environment
- How to set up boundary conditions and very basic FUN3D input decks
- How to run a tetrahedral RANS solution for a wing-body VGRID mesh
- How to perform a 2D mixed element airfoil solution using an AFLR3 grid
- Some unhealthy things to watch for and possible remedies
- Overview of visualization output options and examples

Don't hesitate to send questions our way!

fun3d-support@lists.nasa.gov