Session 15: Feature- and Adjoint-Based Mesh Adaptation

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Learning Goals

- A little background on adaptation
- Manual step-by-step output adaptation cycle of a turbulent flat plate
- Describe the Makefiles and Ruby scripts that automate this process
  - Turbulent flat plate output-based adaptation
  - Inviscid cut cell sonic boom output-based adaptation
  - Laminar cylinder feature-based adaptation

Local Error and Output Adaptation

Local error based

- Feature based adaptation
- Flow solver/physics agnostic
- Not as robust
- Requires more manual interaction

Output error based

Requires adjoint solution

More robust

Transport of errors

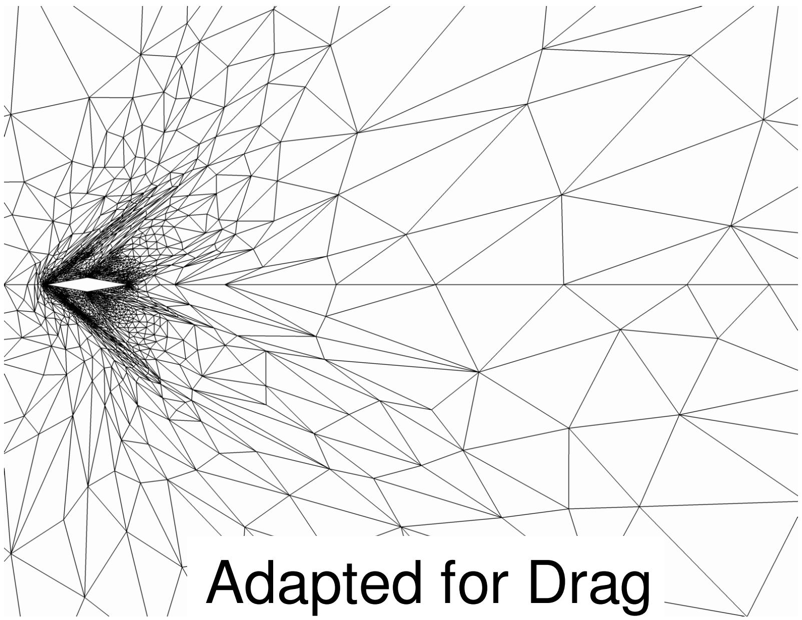
Fewer user controlled parameters

Available Adaptation Modes

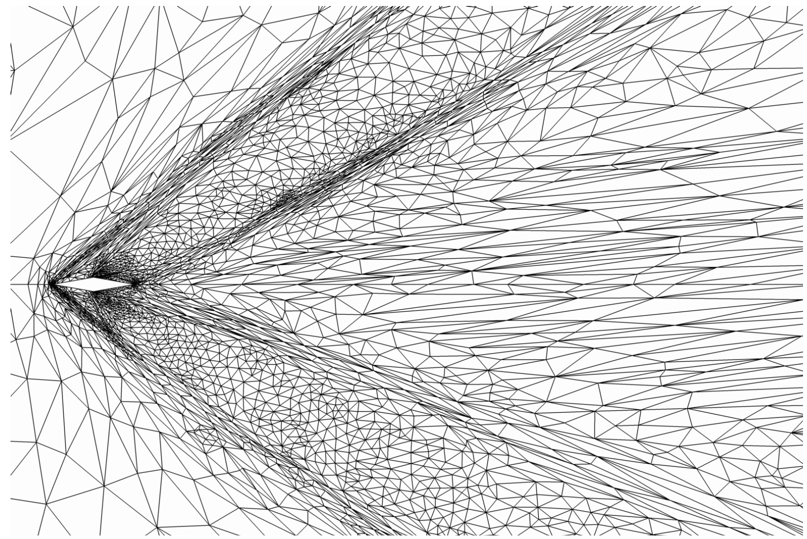
- Inviscid cut-cell output based adaptation
- Viscous body-fitted output based adaptation with frozen boundary layers
- Viscous body-fitted local error based adaptation with frozen boundary layers
- Others at various stages of development (contact us)

Output-Based Adaptation

- Mathematically rigorous approach involving the adjoint solution that reduces estimated error in an engineering output
- Uniformly reducing discretization error is not ideal from an engineering standpoint - some errors are more important to outputs



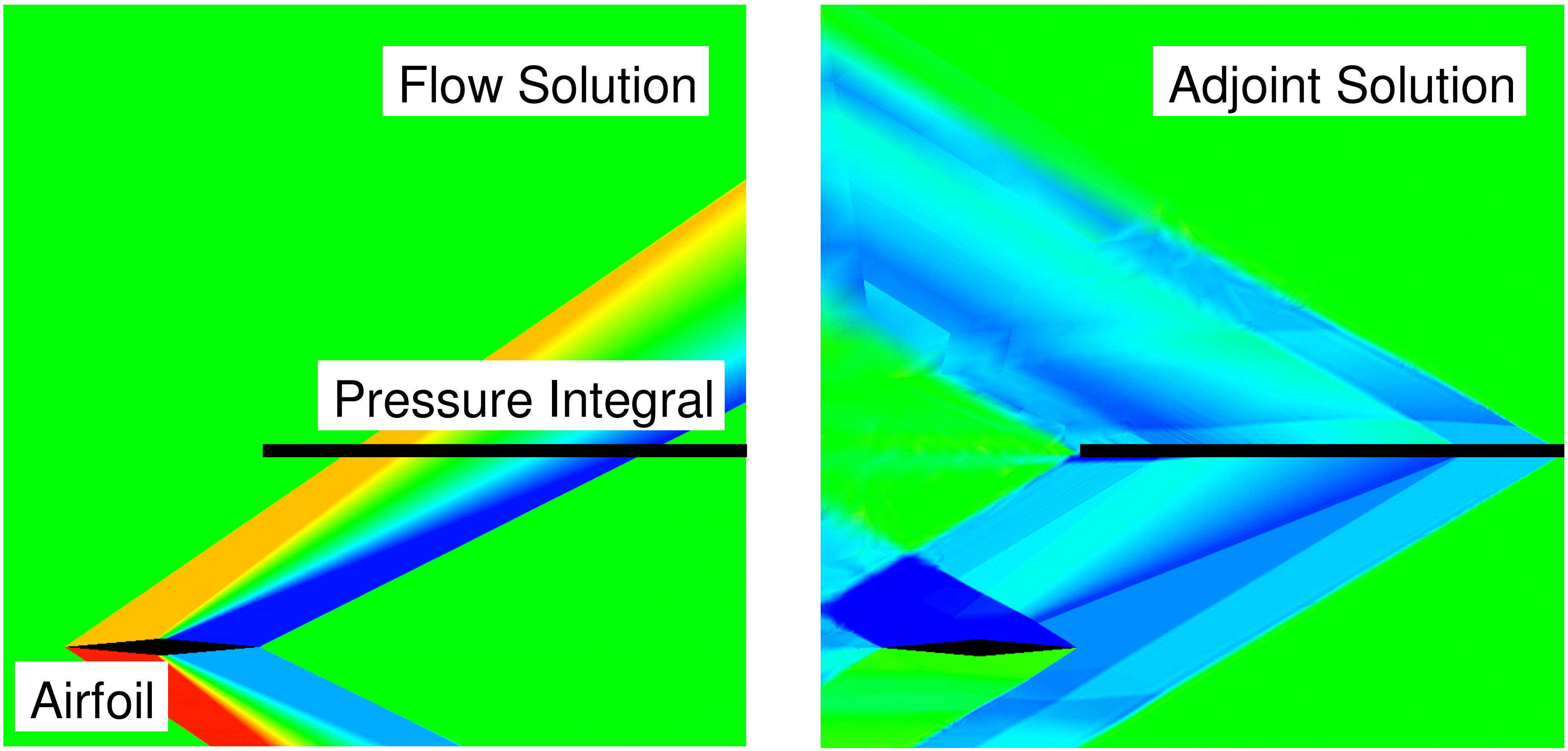
Adapted for Drag



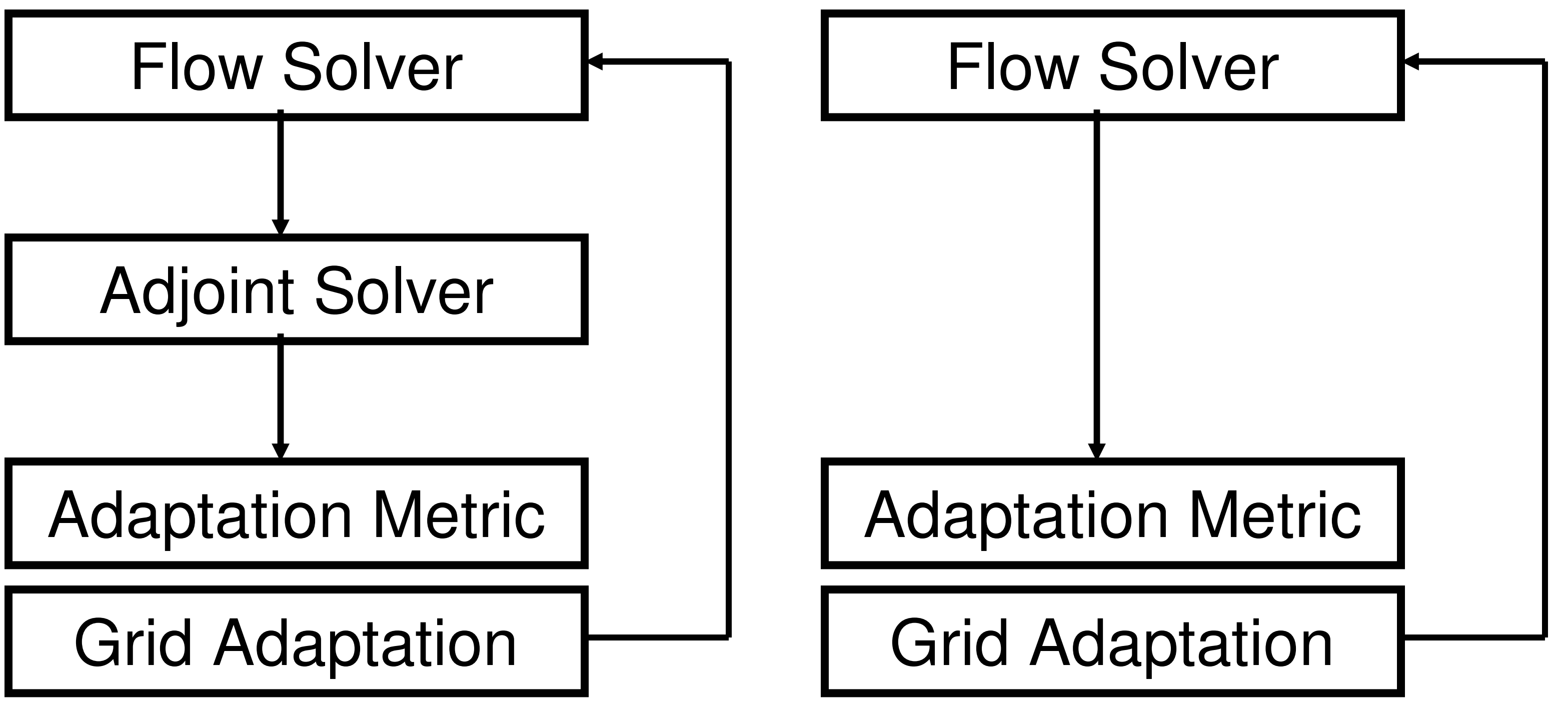
Adapted for Shock Propagation

Shock Propagation Example

- Adaptation is targeted to improve off-body pressure integral output for diamond airfoil

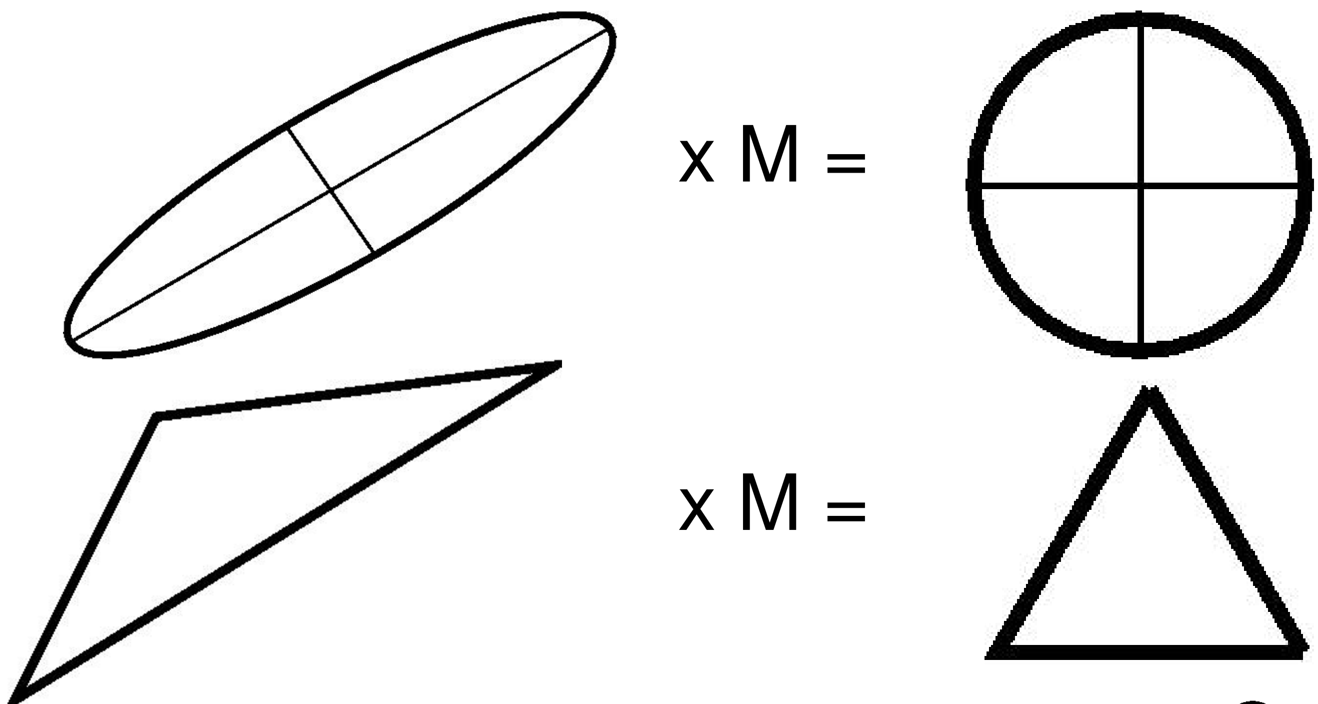


Adaptation Process



Adaptation Mechanics

- Parallel node insertion, node movement, element collapse, and element swap
  - Very general approach to iteratively drive mesh to satisfy an anisotropic metric M



Adaptation Metric

- Output-based size specification scales the stretching and orientation of the Mach Hessian grid metric (Venditti and Darmofal)

$$M = \left| \frac{\partial^2 \mathrm{Mach}}{\partial x^2} \right| = X \begin{bmatrix} \left(\frac{1}{h_1}\right)^2 & & \\ & \left(\frac{1}{h_2}\right)^2 & \\ & & \left(\frac{1}{h_3}\right)^2 \end{bmatrix} X^T$$

Adaptation Metric

- Output-based size specification scales the stretching and orientation of the Mach Hessian grid metric (Venditti and Darmofal)

$$e_\kappa = \frac{|(\hat{\lambda} - \bar{\lambda}) R(\hat{u})| + |(\hat{u} - \bar{u}) R_\lambda(\hat{\lambda})|}{2}$$

$$\frac{h_{\text{request}}}{h_{\text{current}}} = \left(\frac{e_{\text{tol}}}{\sum e_\kappa} \frac{e_{\text{tol}}}{N e_\kappa} \right)^\omega$$

Turbulent Flat Plate

- Change directory to the example
  - **cd**
  - **cd Adaptation_Demos**
  - **cd flat-plate**

Turbulent Flat Plate Contents

- rubber.data is for the adjoint cost function
  - ‘cd’ is specified as the output
- Flow/ is where the flow solve will be performed
- Adjoint/ is where the adjoint solve and adaptation will be performed

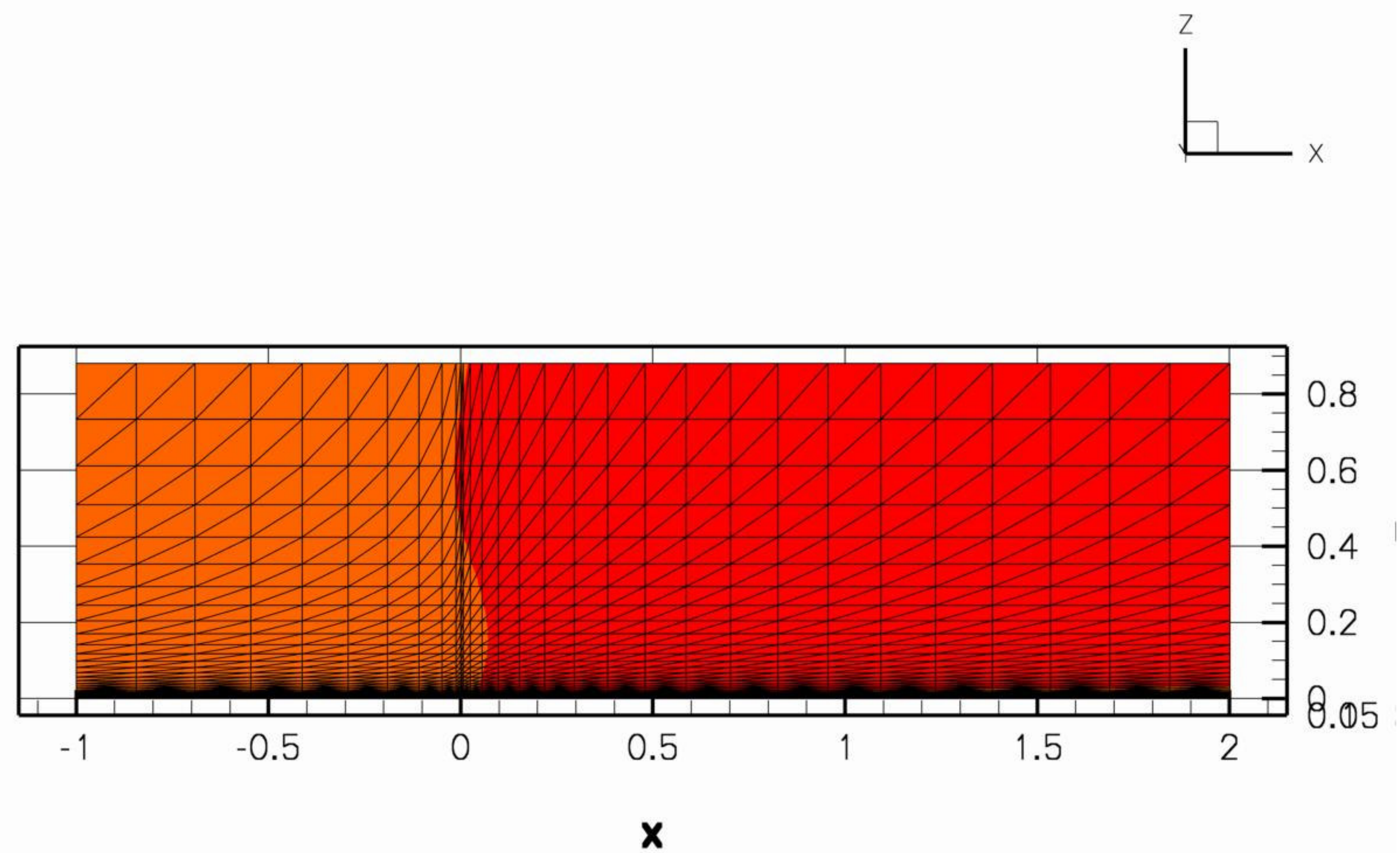
Turbulent Flat Plate Flow Solve

- **cd Flow**
- **qsub flow-solver.pbs**
- **tail –F flow-solver.output**
- box01.fgrid and box01.mapbc is the grid and boundary conditions
- box01_flow_fun3d.nml is the input file

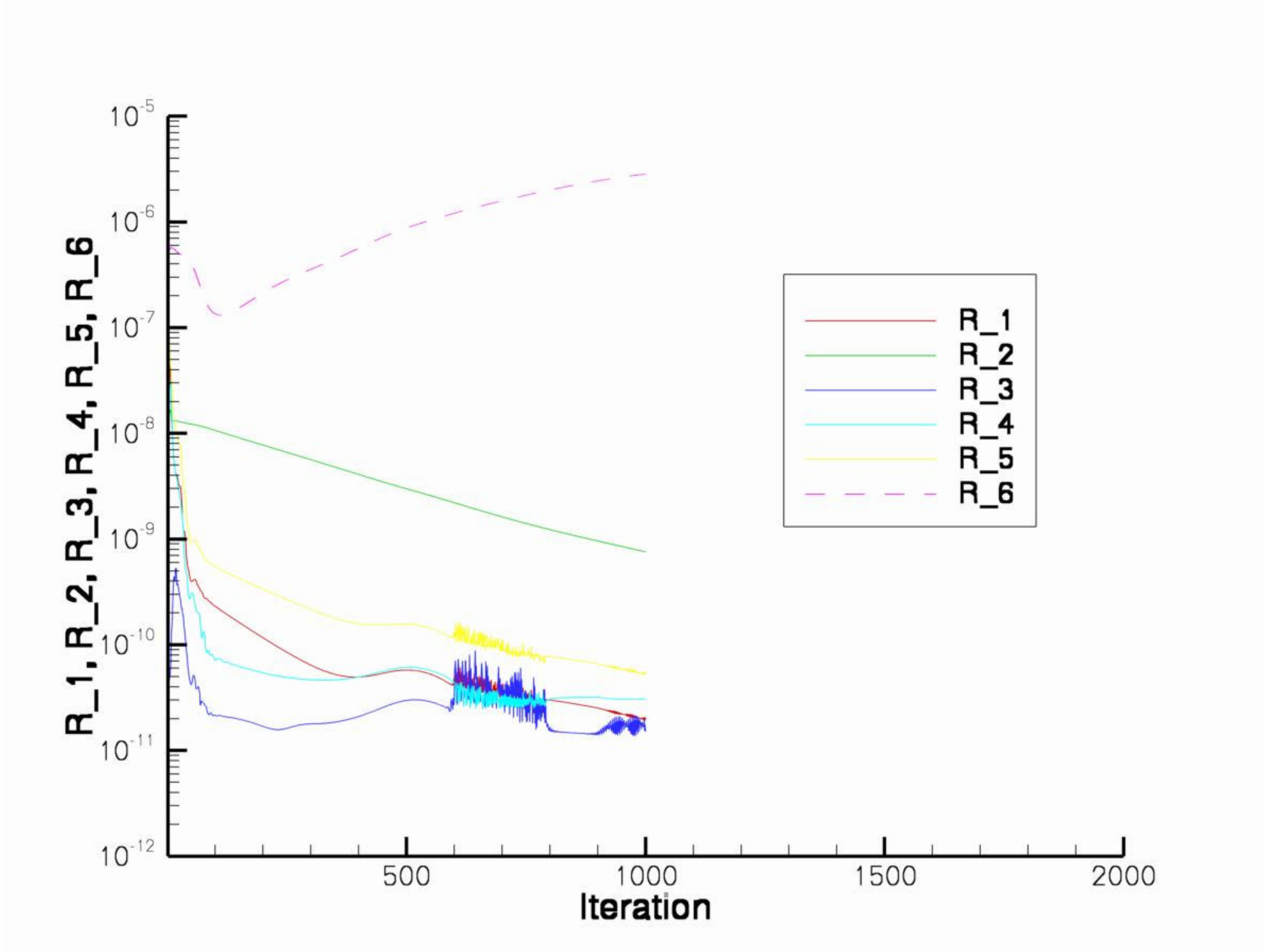
Turbulent Flat Plate Flow Solve

- In the flow-solver.pbs script the command line arguments are specified.
  - --linear_projection wraps the standard linear solver
    - Kick out tolerance
    - Stabilizes unstable linear solves
  - --animation_freq -1 and –sampling_freq -1 produce tecplot output
- The box01_flow_fun3d.nml is copied to fun3d.nml

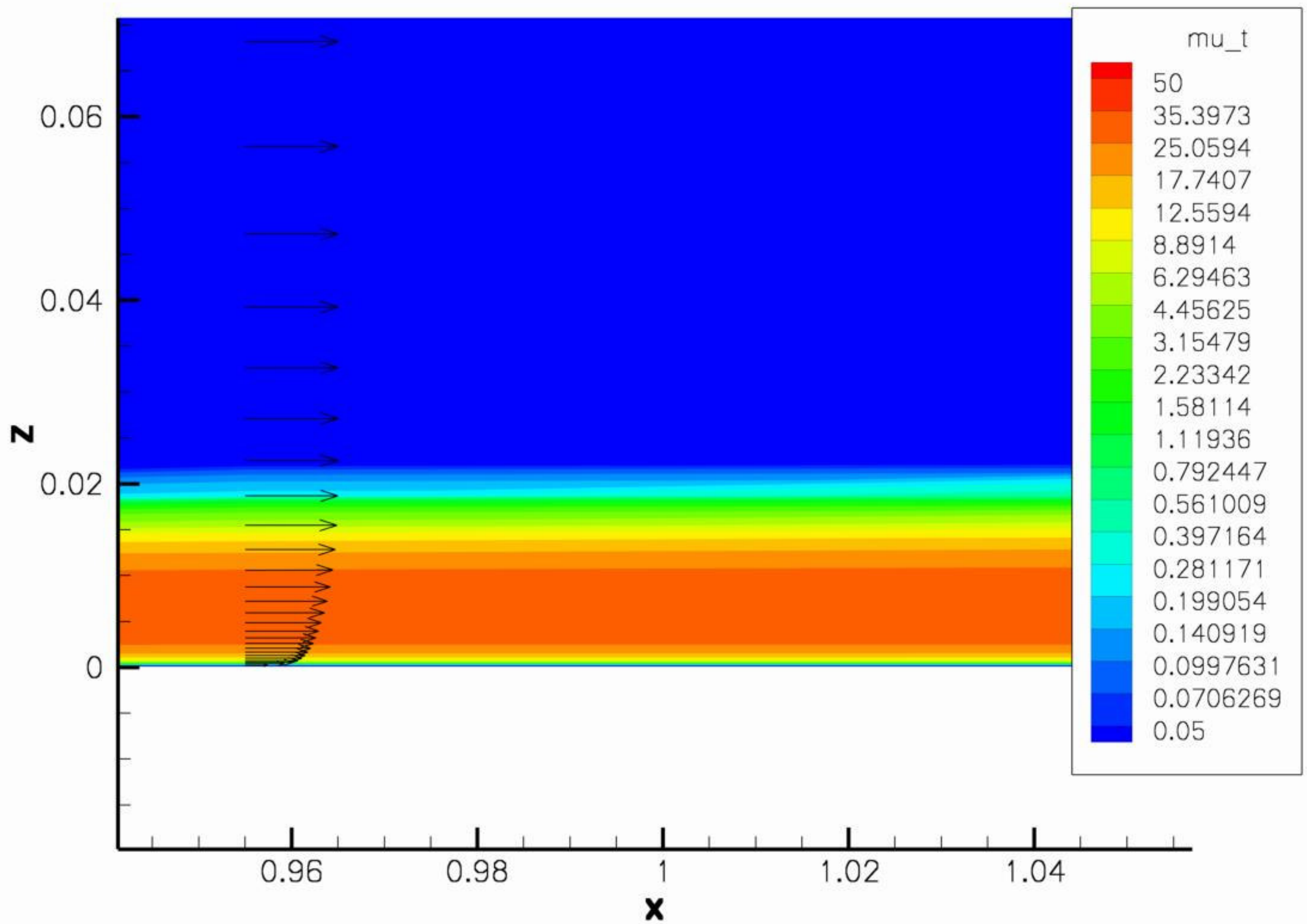
Turbulent Flat Plate Grid



Turbulent Flat Plate History



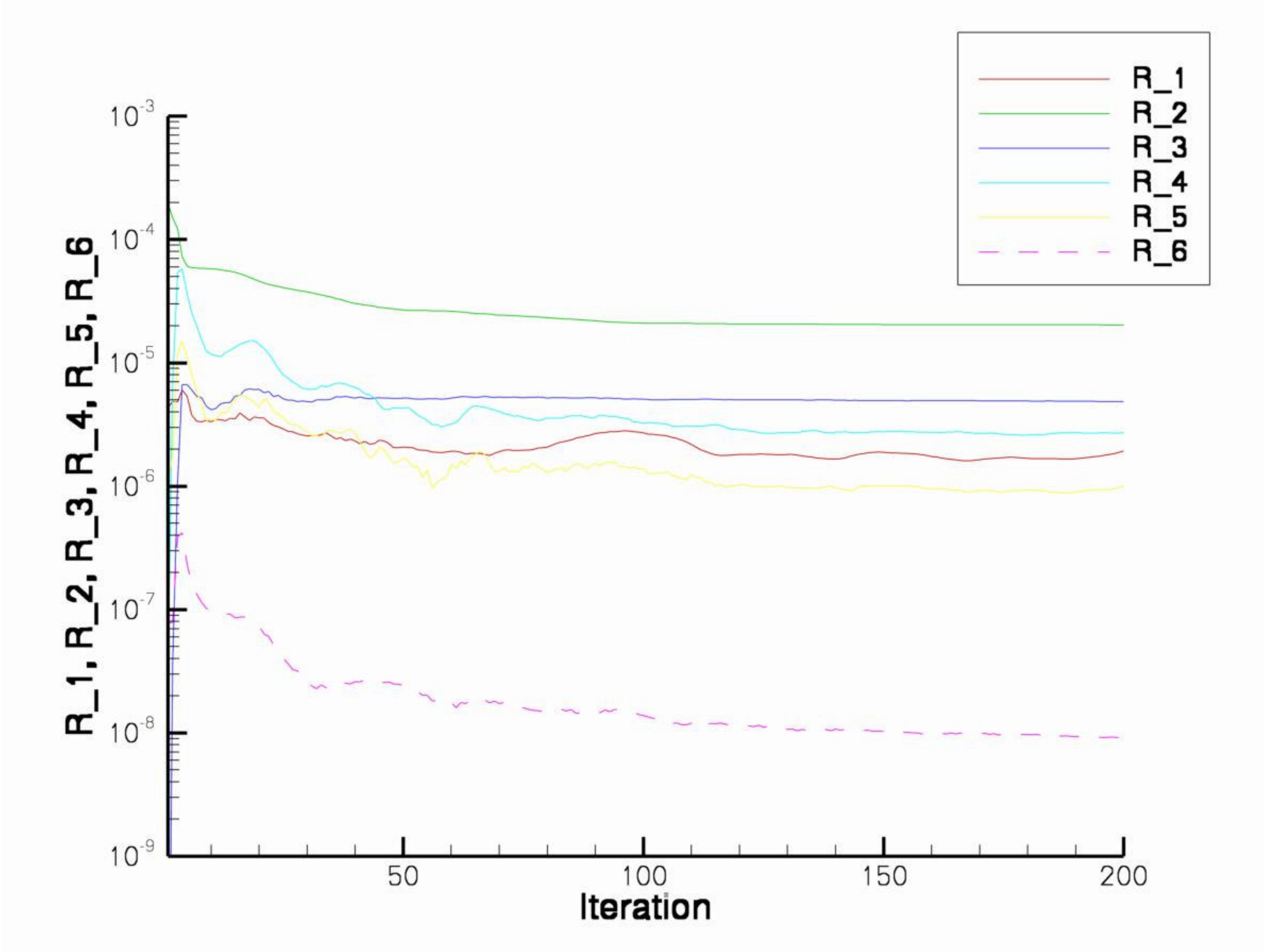
Turbulent Flat Plate Solution



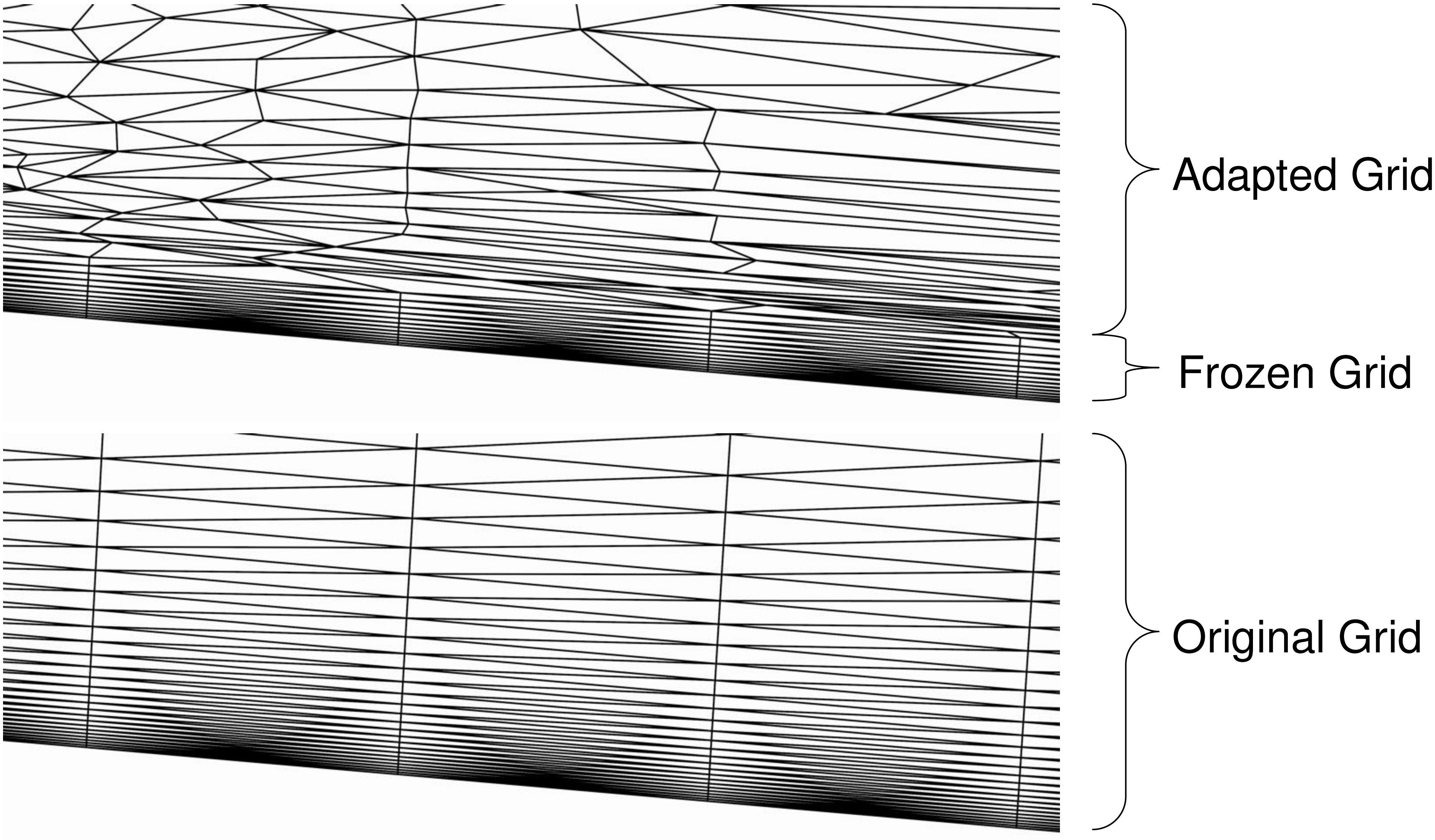
Turbulent Flat Plate Adjoint Solve

- **cd ../Adjoint**
- **qsub adjoint-solver.pbs**
- **tail –F adjoint-solver.output**
- In the adjoint-solver.pbs script the command line arguments are specified.
  - --linear_projection wraps the standard linear solver
    - Kick out tolerance
    - Stabilizes unstable linear solves
  - --outer_loop_krylov stabilizes and accelerates adjoint iterative convergence (linear problem)
- The box01_adjoint_fun3d.nml is copied to fun3d.nml (in the ../Flow directory)

Turbulent Flat Plate History



Hybrid Adaptation



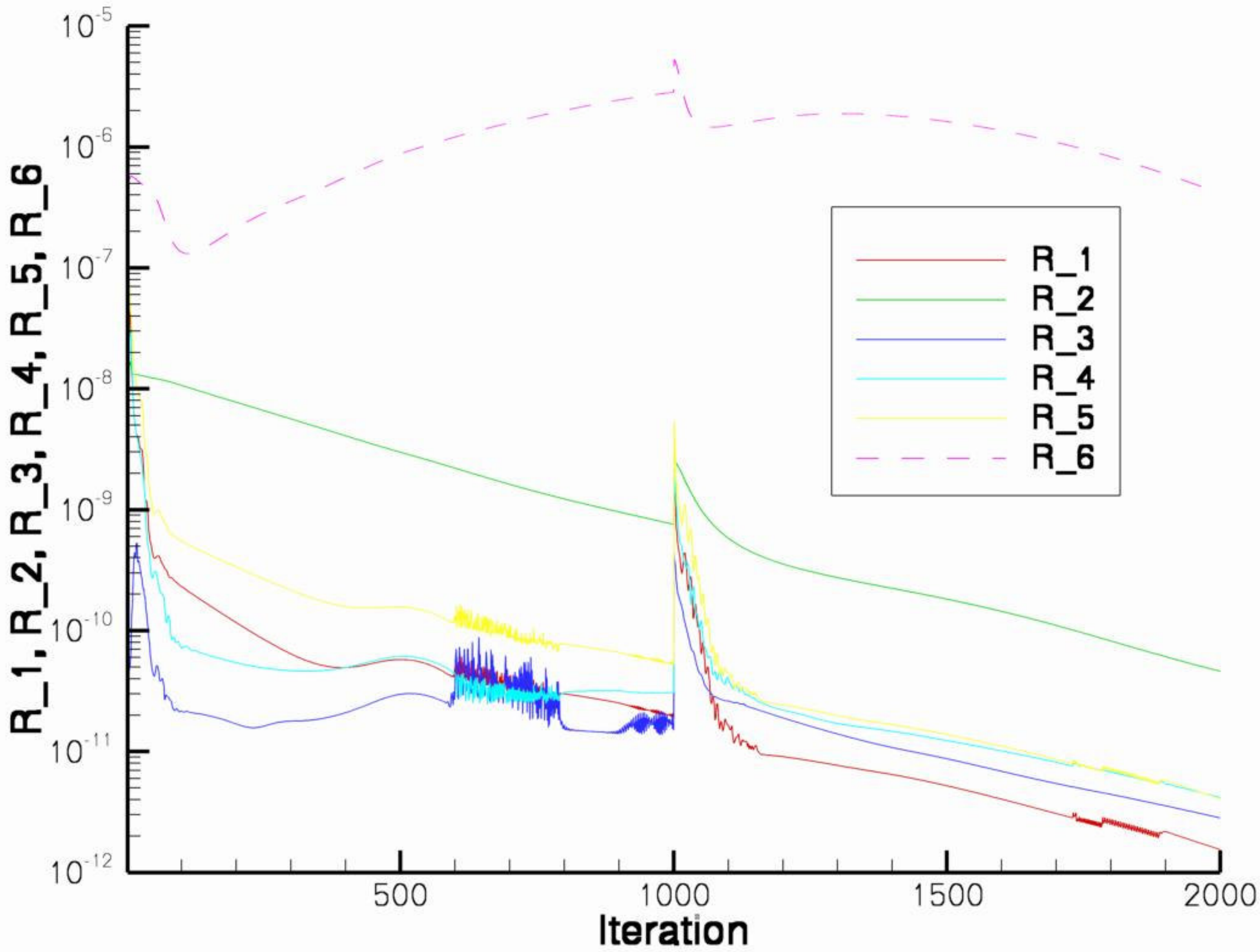
Turbulent Flat Plate Adaptation

- **qsub adaptation.pbs**
- **tail –F adaptation.output**
- In the adaptation.pbs script the command line arguments are specified.
  - --adapt activates adaptation with refine
  - --embedrad embeds that grid and forms the output-based adaptation metric
  - --adaptation_project box02 is the name of the new project that is produced by adaptation
  - --adapt_freezebl 0.001 thickness of the frozen boundary layer grid
- The faux_input file specifies the geometry of adaptation planar faces
- The box01_adjoint_fun3d.nml is copied to fun3d.nml (in the ../Flow directory)

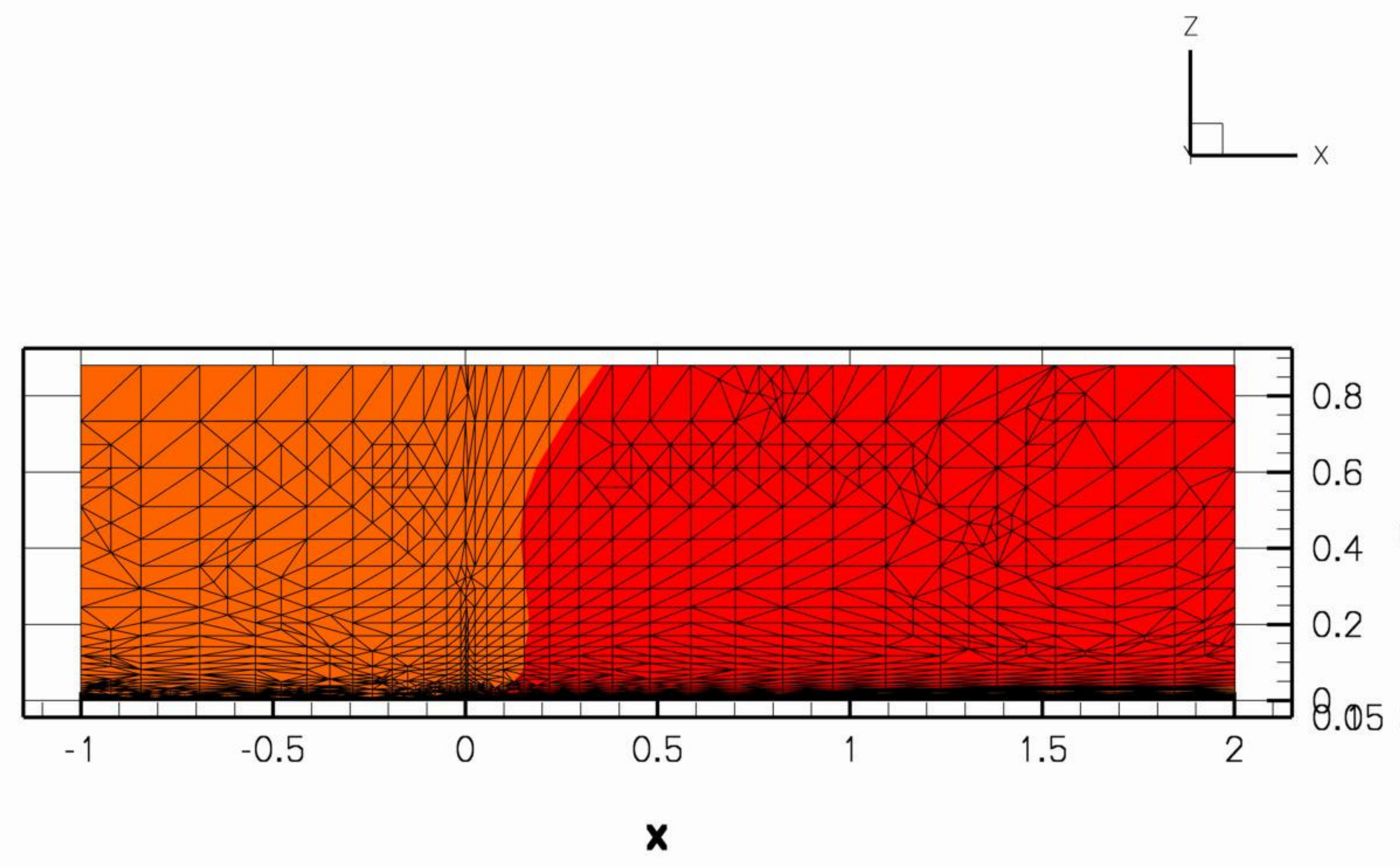
Adapted Turbulent Flat Plate Flow Solve

- **cd ../Flow**
- **qsub adapted-restart.pbs**
- **tail –F adapted-restart.pbs**
- In the adapted-restart.pbs script the command line arguments are specified.
  - --linear_projection wraps the standard linear solver
    - Kick out tolerance
    - Stabilizes unstable linear solves
  - --animation_freq -1 and –sampling_freq -1 produce tecplot output
- The box02_flow_fun3d.nml is copied to fun3d.nml

Turbulent Flat Plate History



Turbulent Flat Plate Solution



refine and knife

- refine
  - Grid adaptation library
  - Called by FUN3D through an API
- knife
  - Cut cell library
  - Utilities for extracting and visualizing cut surface from volume grids

refine and knife

- Linked into the version of FUN3D we will use today
- Require separate user agreements
- Use the same autotool process to build
  - ./configure
  - make
  - make install
- See the README and INSTALL files in each package

Git the Tutorial

- Obtain a copy of the examples with git
  - **cd**
  - **git clone ../funshop-files/grid-adaptation-tutorial.git**

Start the flat plate case running

- Go to the testcase
  - **cd**
  - **cd grid-adaptation-tutorial**
  - **cd flat-plate-frozen-bl**
  - **cd case**
- Start it running
  - **make test**
- Is it running?
  - **make view**
  - [press ctrl-c to exit]

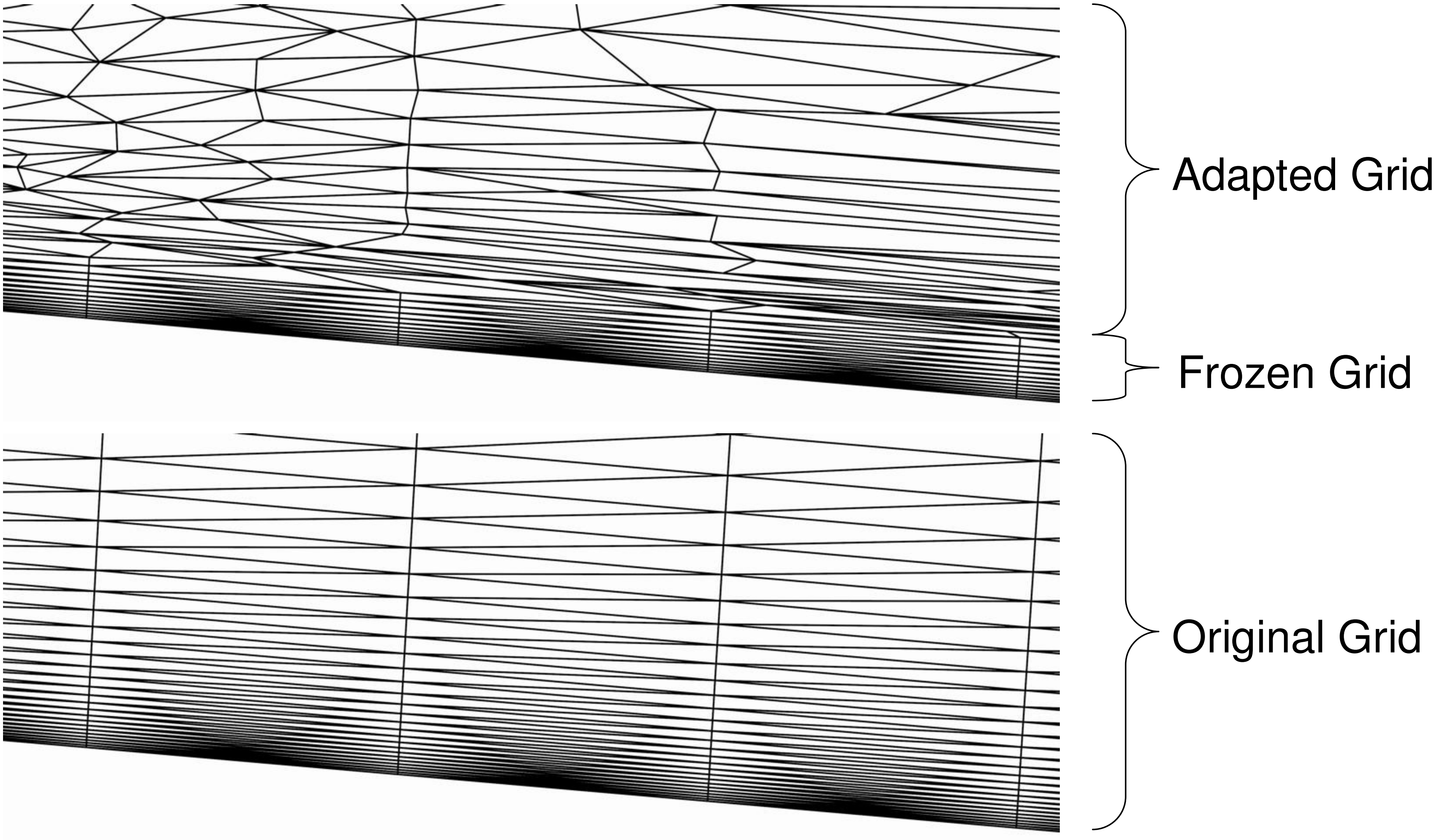
Input files

- **fun3d.nml**
  - Standard fun3d input file
- **rubber.data**
  - Standard adjoint input file
  - Quiz… what is the adjoint output function?
    - Hint: line 76

Grids

- Flat plate grid (body-fitted)
  - Created by **box01.f90** and **box01.sh**
  - See the ‘**grid**' directory
- **faux_input** (background grid geometry)
  - Number of background grid faces
  - Face id, type, position
- Frozen to a height listed in “**case_specifics**”
  - **rad_cl “—adapt_freezebl 0.001”**

Hybrid Adaptation



pbs_run

- Ruby wrapper to make pbs “act like” mpirun/mpiexec
  - See **grid-adaptation-tutorial/pbs_job**
  - Specified in **case_specifics**
    - **mpirun_command '../../../pbs_job/bin/pbs_run'**
  - Generates a pbs job with xMoDaHrMnS.pbs
    - Month, Day, Hour, Min, tens of Sec.
  - Output is in xMoDaHrMnS, xMoDaHrMnS.pbsout, xMoDaHrMnS.pbserr

Makefile

- Provides targets
  - **make test** starts the adaptation
  - **make shutdown** abruptly stops adaptation (may require qdel)
  - **make view** watch the status of the case
  - **make hist** plot the convergence history
  - **make nodes** grid size
  - **make remain** remaining error estimate in output

Status

- **output**
  - Lists the commands as they are executed
- **Flow/flow_out**
  - flow solver
- **Adjoint/dual_out**
  - Adjoint solve
- **Adjoint/rad_out**
  - Output-based adaptation

(when using pbs_run the *_out files will list the pbs queue status and a tail command to see screen output while running)

Iterative Convergence

- **make hist**
  - Invokes a Ruby script that converts ***/*_hist.tec** to ***/*_hist.jpg**
  - Uses gnuplot under the hood
  - Lists all 5 (or 6 when turbulent)

Executing by hand

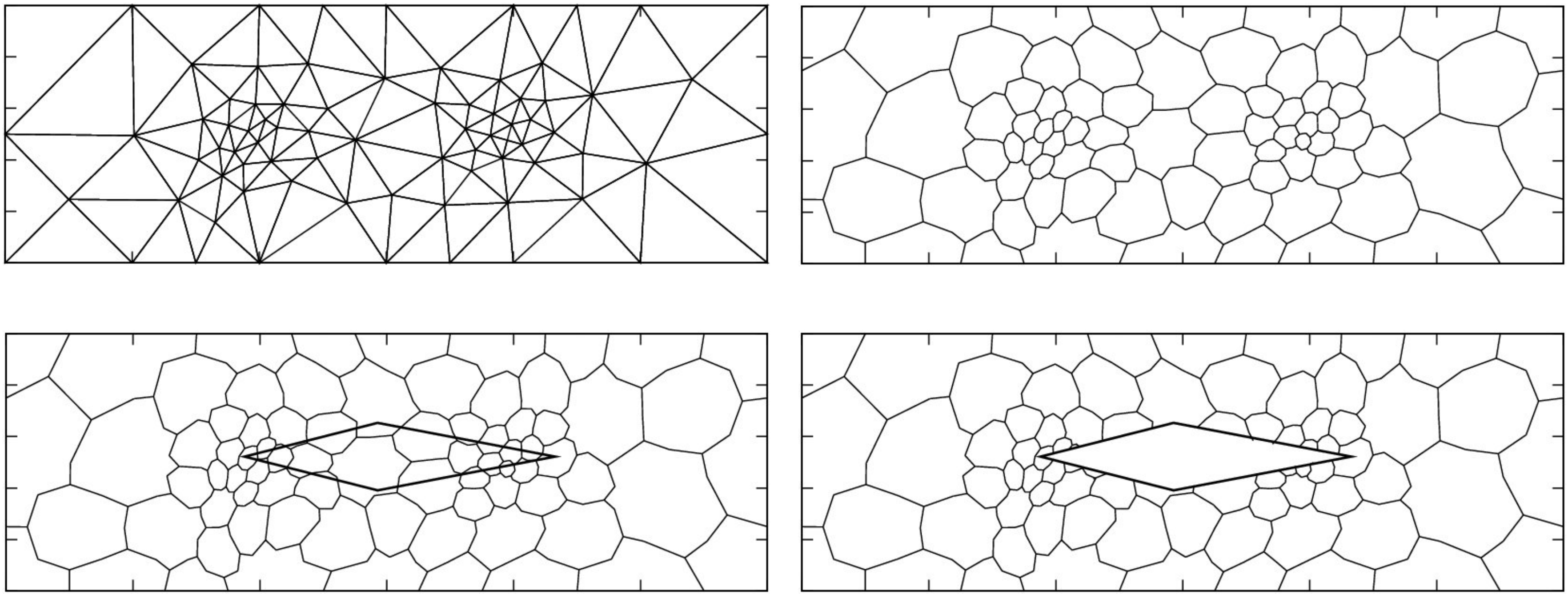
- See ‘**output**’ for command with arguments
- For namelist, see
  - **Flow/rootXX_flow_fun3d.nml**
  - **Flow/rootXX_dual_fun3d.nml**
  - **Flow/rootXX_rad_fun3d.nml**

Start the Cut Cell Case Running

- Go to the testcase
  - **cd**
  - **cd grid-adaptation-tutorial**
  - **cd diamond-airfoil**
  - **cd cutcell**
- Start it running
  - **make test**
- Is it running?
  - **make view**
  - [press ctrl-c to exit]

Cut-Cell Method

- Background volume grid
- Surface grid of geometry
  - Boolean subtracted from median dual background grid



Grids

- Surface grid
  - Describes the cut surface
  - Can come from many sources
  - VGrid in this case
  - See the '**surface**' directory and **README**
- Background grid
  - Describes the computational domain that the cut surface will intersect
  - Created by **domain01.f90** and **domain01.sh**
  - See the '**background**' directory
- **faux_input** (background grid geometry)
  - Number of background grid faces
  - Face id, type, position

Input files

- **fun3d.nml**
  - Standard fun3d input file
- **rubber.data**
  - Standard adjoint input file (only care about line 76)
- **sonic_boom.input**
  - Header is self-describing

case_specifics

- Ruby “domain specific language” input deck
  - Key-value pairs
  - **code_cl** are the command line options
  - **code_nl['key']='value'** modifies fun3d.nml for this code
  - **root_project 'root'** expects the first grid to be root01
  - **iterations first..last** run from first to last iteration
    - Each iteration uses root01, root02, etc
- Read by the grid-adaption-tutorial/fun3d.rb script

Cut cell (knife) input files

- **project01.knife**
  - Location of the cut surface grid.[tri,fgrid]
  - Do the surface normals point inward or outward
  - Optionally translate, flip, rotate surface
  - List faces to cut with, or omit to include all faces
- **project01.cutbc**
  - Fun3d boundary condition for cut surfaces
  - Overload face with boundary condition

Volume Slice

- Described in fun3d.nml **&sampling_parameters** namelist
- Produced with **–sampling_freq -1**
- Run tecplot on **Flow/domainXX_tec_sampling_geom1.dat**
  - Where **XX** is 01, 02, 03, … the series of adapted grids
  - The grid is the arbitrary intersection of a plane and the volume tetrahedra
  - The cut cells are not included

Cut surface and cut cells

- Run tecplot on **Flow/domainXX_cut_surf.t**
    - Primitive variables interpolated to cut surface grid
- Run tecplot on **Flow/domainXX_*_cut.t**
    - Primitive variables on boundaries and cut cells
    - One file per processor

Pressure signature

- Run tecplot on **Adjoint/domainXX_pressure_signature.tec**
  - Pressure at the **sonic_boom.input** specified locations

Start the feature-based supersonic cylinder case running

- Go to the testcase
  - **cd**
  - **cd grid-adaptation-tutorial**
  - **cd supersonic-cylinder**
  - **cd case**
- Start it running
  - **make test**
- Is it running?
  - **make view**
  - [press ctrl-c to exit]

Grids

- Body-fitted grid in cylindrical coordinates
  - Created by **box01.f90** and **box01.sh**
  - See the ‘**grid**' directory
- **faux_input** (background grid geometry)
  - Number of background grid faces
  - Face id, type, position
    - Cylinder faces also have radius, center, and normal
- Frozen to a height listed in “**case_specifics**”
  - **rad_cl “—adapt_freezebl 0.05**”
- The outer boundary is frozen with “**box01.freeze**”
  - Each face id is listed one per line

case_specifics

- Ruby “domain specific language” input deck
  - Overloaded the iterate method to do feature-based adaptation

```
def iterate
  iterations.each do |iter|
    iteration iter
    setup if ( 1 == iteration )
    flo
    adapt
  end
end
```

  - Adapt code gets **rad_cl** and **rad_nl**
    - **--adapt_coarsen 0.0** do not coarsen grid
    - **--output_error 0.1** target density edge jumps of 0.1