Initial Implementation of Near-Body Grid Adaption in OVERFLOW

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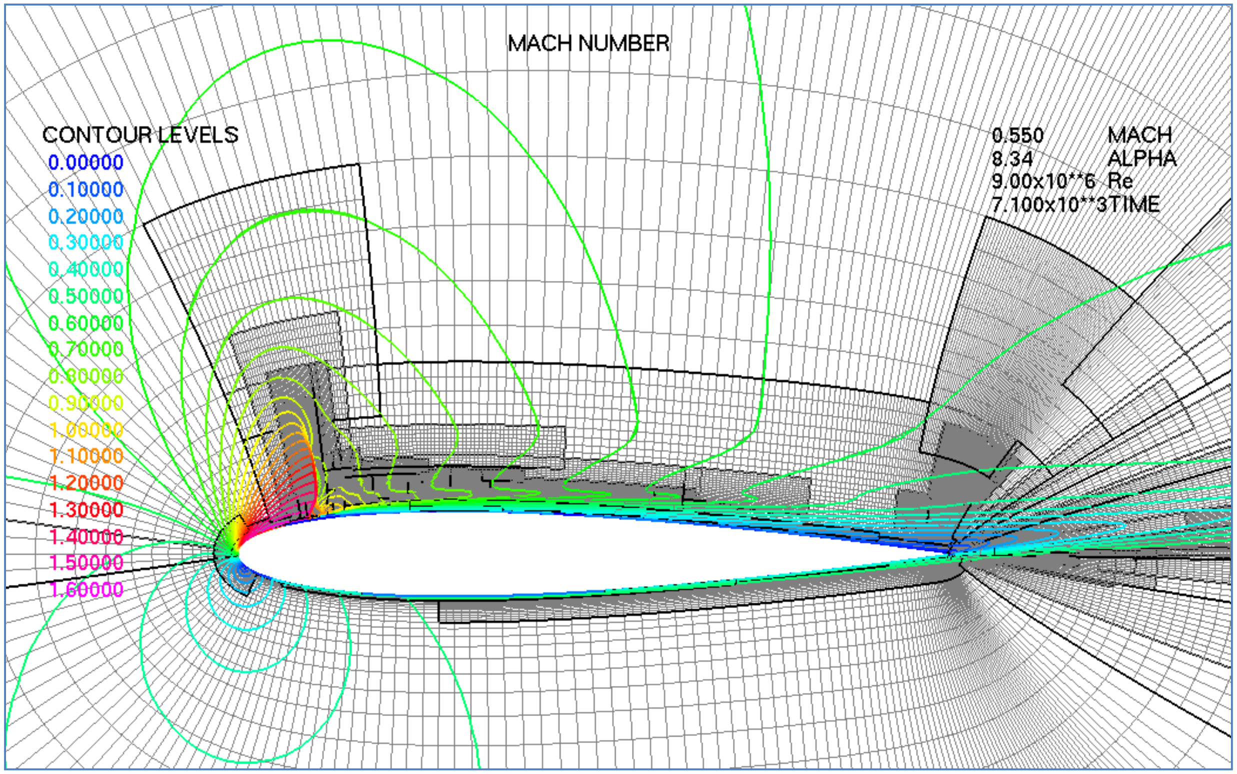
Goal

- Extend off-body solution adaption approach to near-body grids
  - Make it an integral part of the OVERFLOW solution procedure
  - Efficient enough for time-accurate moving grids!

Off-body adaption reported in: P.G. Buning and T.H. Pulliam, "Cartesian Off-body Grid Adaption for Viscous Time-Accurate Flow Simulation," AIAA 2011-3693, June 2011

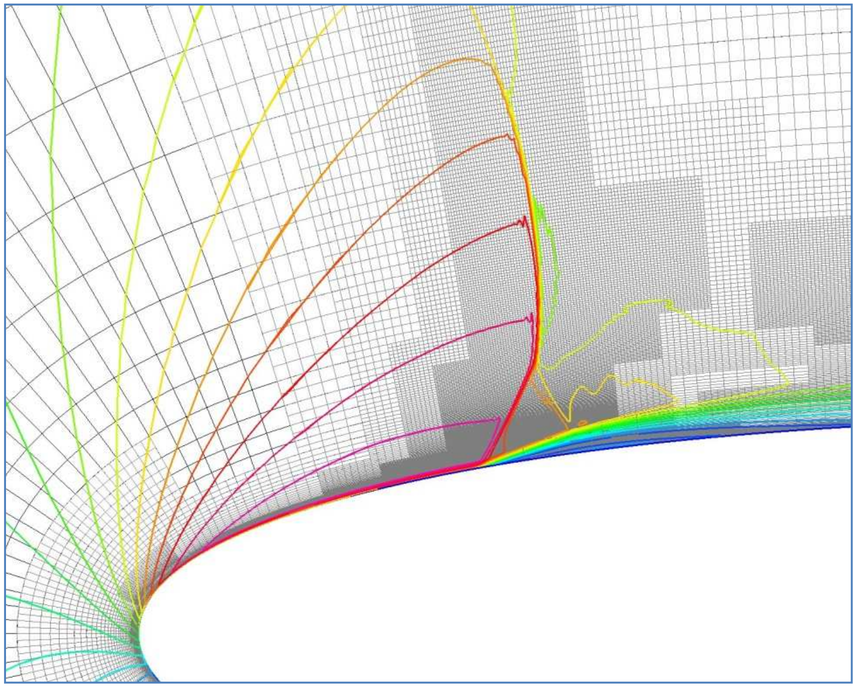


Outline

- (Goal)
- Approach
  - Sensor function and marking
  - Grid generation and connectivity
  - Grid and solution interpolation
- Examples
- Issues
  - Topology limitations
  - Parametric cubic interpolation
- Summary and future work

Approach

- Use the same approach as for off-body adaption, just in computational space instead of Cartesian space
  - Refinement is isotropic
  - Where we have refinement regions, blank out coarser-level regions
  - Neighboring refinement regions differ by only 2x in spacing
  - Use parametric cubic interpolation to form refined grids (more later)



Approach

Controls:

- NREFINE – maximum number of refinement levels
    - **NBREFINE – number of near-body refinement levels, if different**
- ETYPE – sensor function (undivided 2^{nd} difference, vorticity, undivided vorticity...)
- EREFINE – sensor value above which we mark for refinement
- ECOARSEN – sensor value below which we mark for coarsening
- **Specify near-body regions to explicitly refine**
- **Specify near-body regions to limit refinement**

Sensor Function and Marking

- Undivided 2nd difference of (elements of) Q=(ρ, ρu, ρv, ρw, ρe_0)
- Actually computed as
  (normalized and squared;
  take max over Q variables)

$$\max_{i=j,k,l}\left\{\left[\frac{q_i-\frac{1}{2}\left(q_{i-1}+q_{i+1}\right)}{q_{ref}}\right]^2\right\}$$

- This function
  - Is non-dimensional
  - Is independent of grid units
  - Gets smaller as the grid is refined (where Q is smooth)

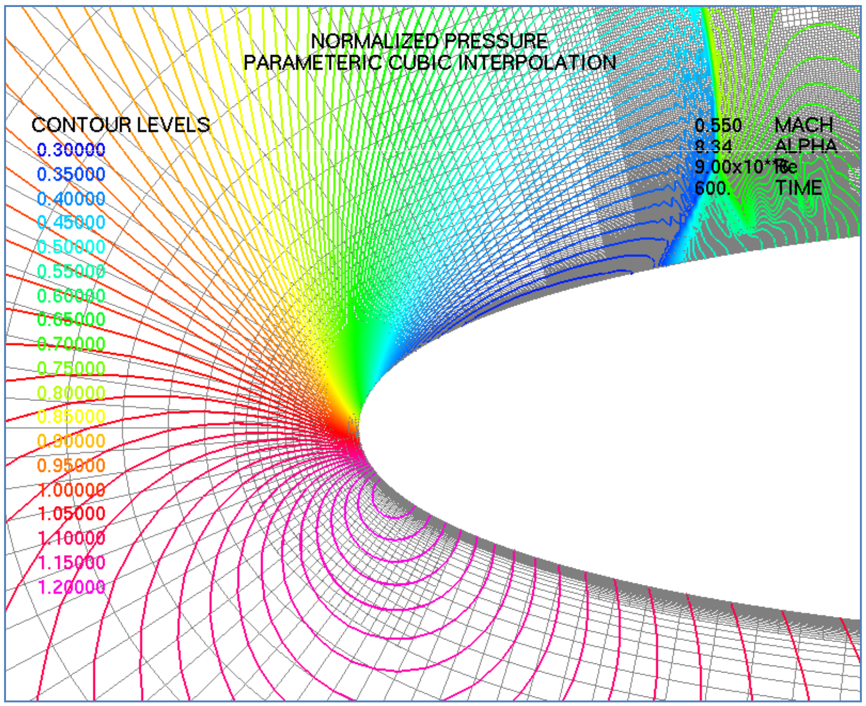
Sensor Function and Marking

- At each grid point
  - If the sensor function value exceeds a refinement tolerance, mark for grid refinement;
  - If it falls below a coarsening tolerance, mark for grid coarsening
- Within an 8x8x8 grid cube, or “box”
  - If any point votes for refinement, the box is marked for refinement;
  - If all points vote for coarsening, the box is marked for coarsening
- Regions can only coarsen or refine by one level at a time

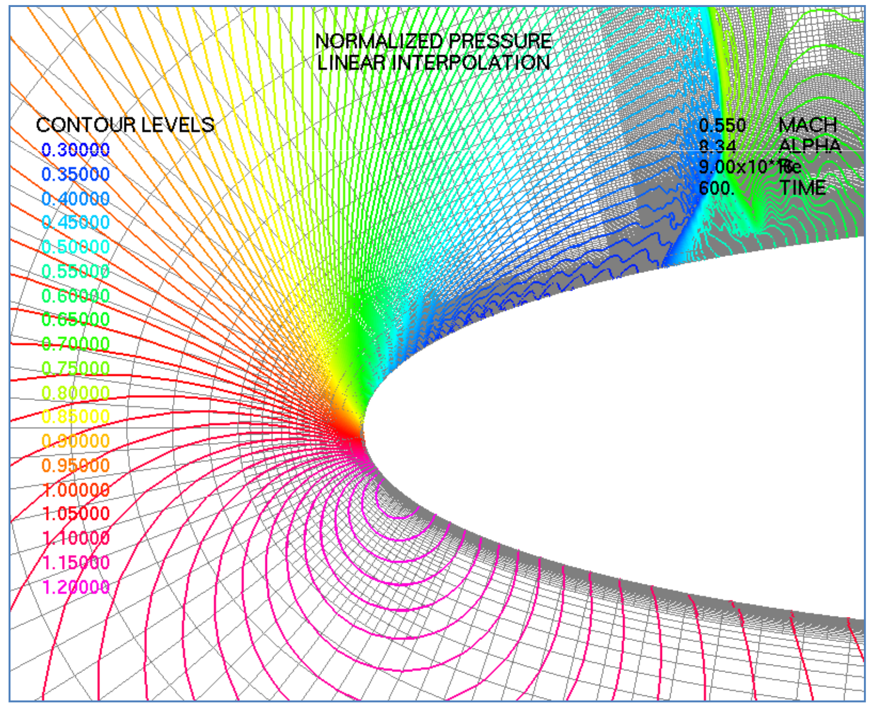
Grid Generation

- Parametric cubic interpolation vs. linear interpolation
  - Preserves smooth geometry

Pressure contours



Parametric cubic interpolation

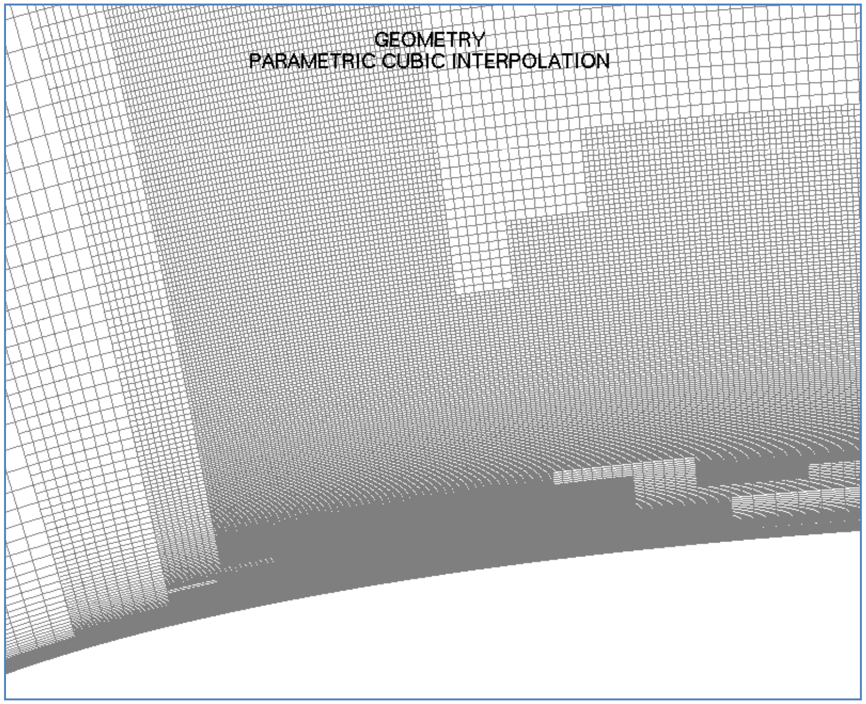


Linear interpolation

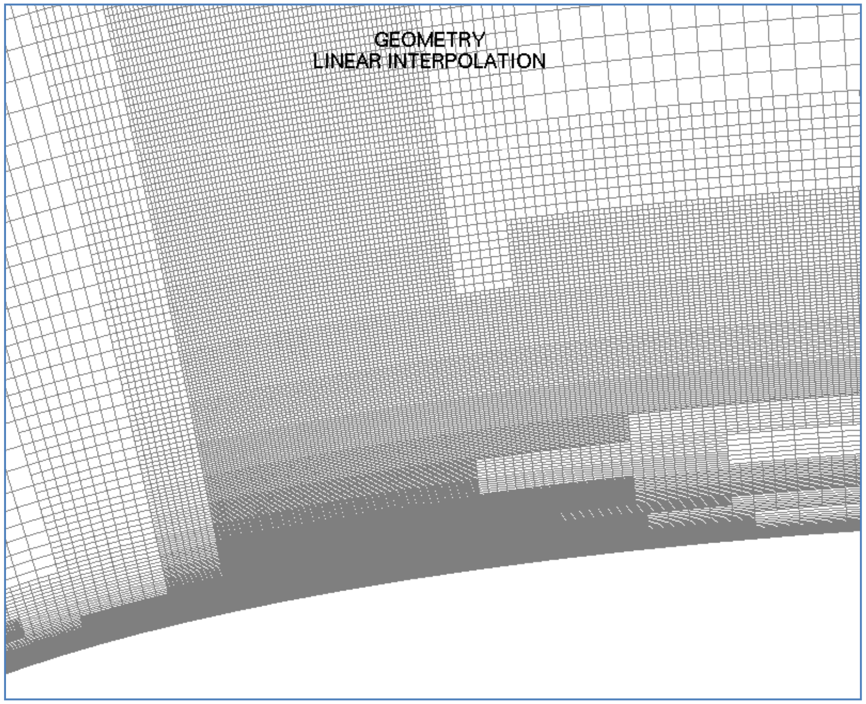
Grid Generation

- Parametric cubic interpolation vs. linear interpolation
  - Preserves grid stretching

Computational grid



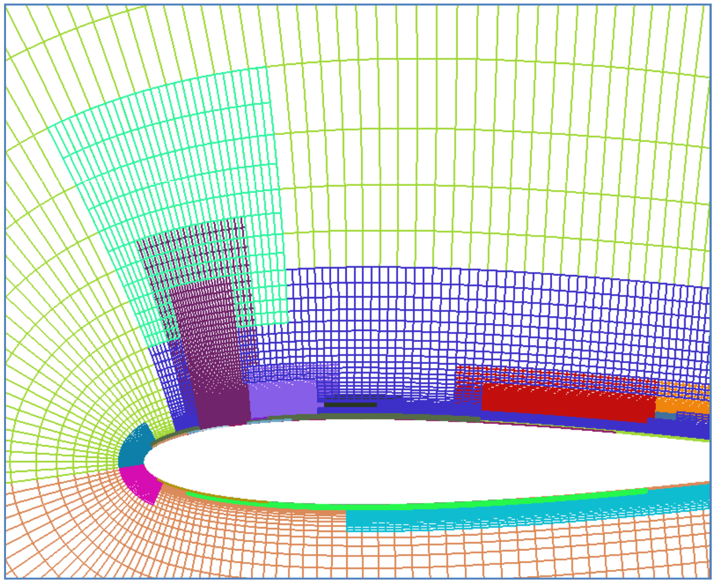
Parametric cubic interpolation



Linear interpolation

Grid Connectivity

- Hole cutting
  - All refinement regions get cut by geometry (just like original near-body grid)
- Blanking for refinement
  - Next-finer grid level explicitly blanks out regions in current level
- Connectivity
  - Refinement regions can have
    - Hole boundary points from geometry cuts
    - Hole boundary points from finer refinement grids
    - Outer boundary points (connecting to same- or coarser-level regions)
    - Outer boundary points (connecting to other near-body or off-body grids)
    - Boundary conditions inherited from original near-body grid



Sample grid blanking for refinement regions

Grid and Solution Interpolation

- Use parametric cubic interpolation of *original* near-body grid to form any level refinement region
  - For parallel execution, only have to send necessary part of original grid to processor creating refined region
- Near-body grid and solution interpolation:
  - All MPI groups exchange (pieces of) the original near-body grids to generate original or refinement grids, using non-blocking sends and blocking receives
  - All MPI groups loop through old near-body grids, coarse-to-fine, transferring and interpolating solution onto new grids

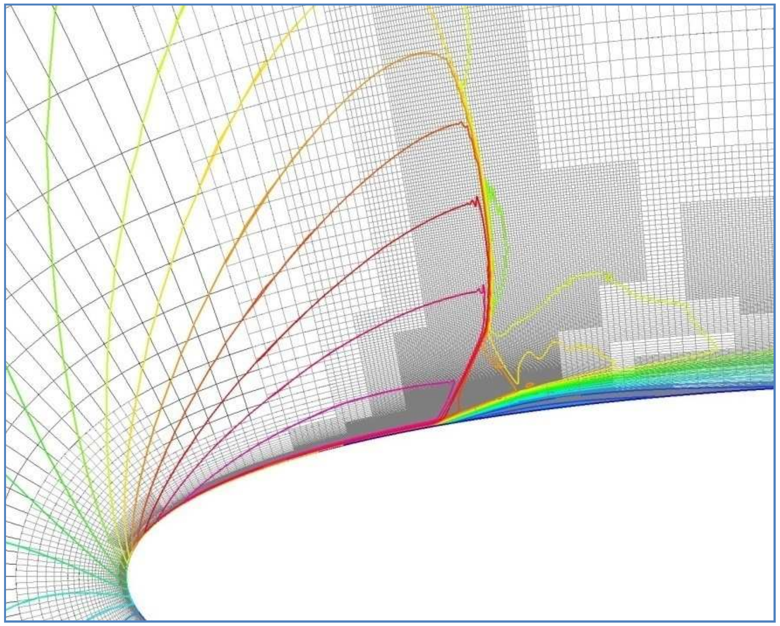
Example Applications

- NACA 0012 airfoil
- 2D supersonic inlet
- Leading/trailing wing interaction
- Vortex generator on a flat plate

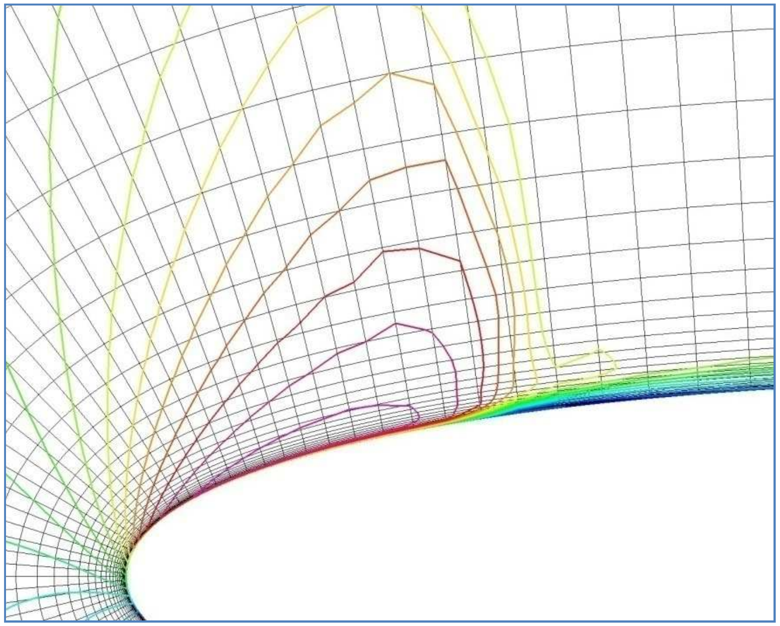
NACA 0012 Airfoil

- Refinement shows additional flow features, resolves pressure details

Mach contours



4 levels of grid adaption
Total grid size 450K points



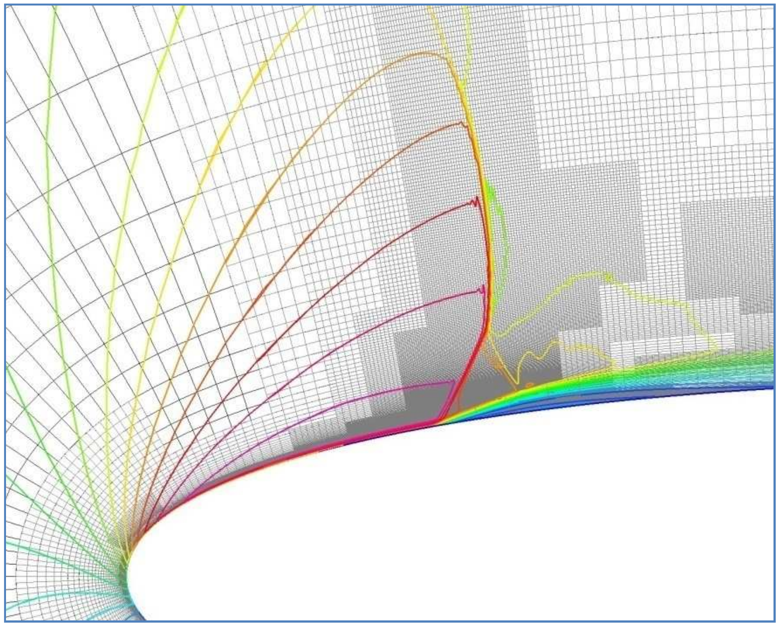
Original 253x73 O-grid
Total grid size 18K points

Flow conditions: Mach 0.55, alpha 8.34 deg, Re=9M/chord

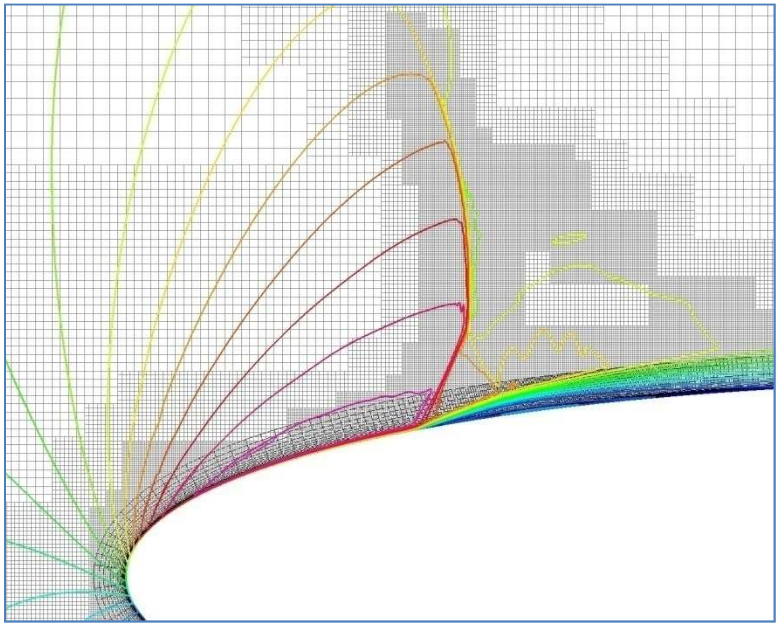
NACA 0012 Airfoil

- Similar answer is obtained using previous approach of off-body grid adaption with thin (fine) near-body grid

Mach contours



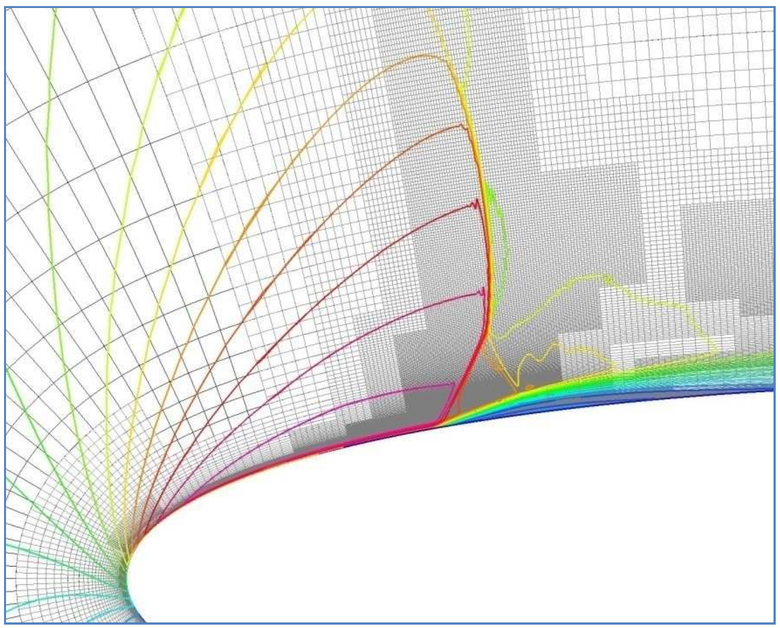
4 levels of near-body grid adaption
Total grid size 450K points



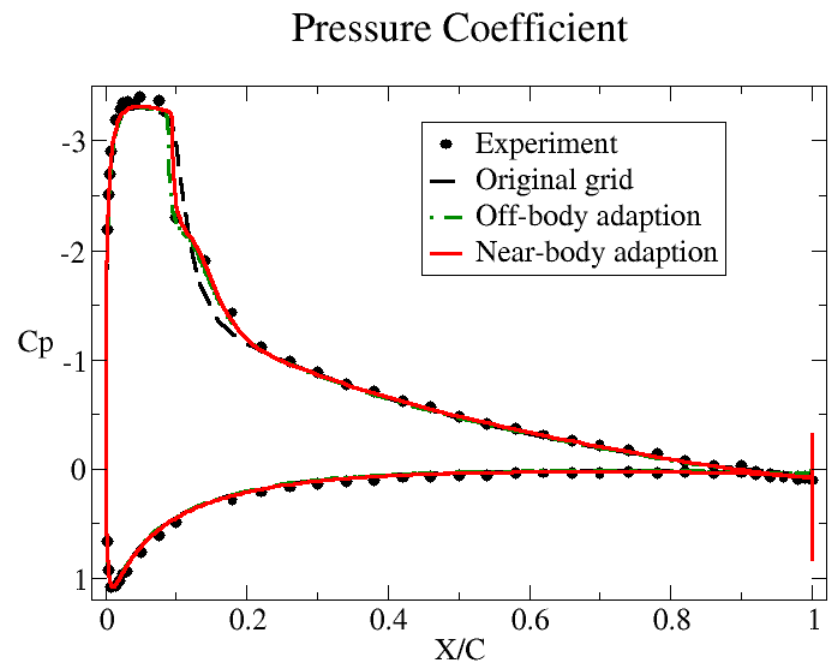
Off-body adaption with thin near-body grid
Total grid size 550K points

NACA 0012 Airfoil

- Grid refinement gives resolution of bounce in Cp due to lambda shock

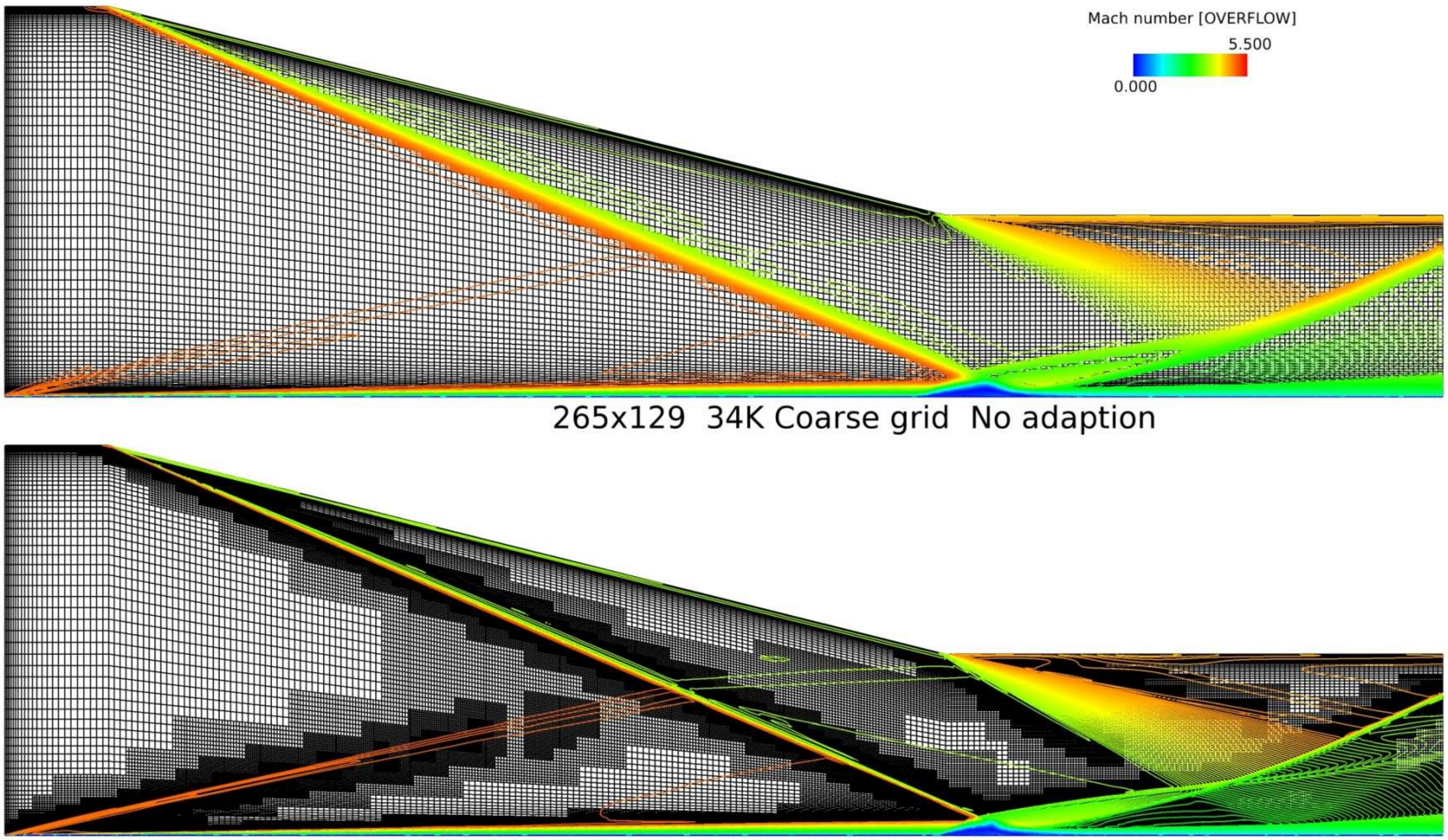


Mach contours with 4 levels of near-body grid adaption



2D Supersonic Inlet

- Grid adapts to shocks, expansion fans, and boundary layer



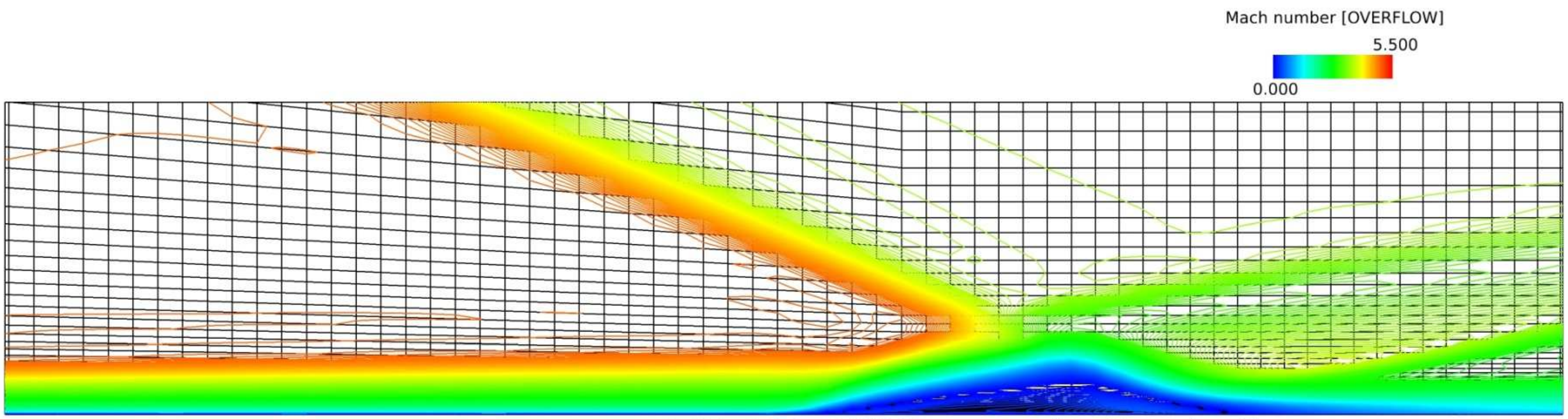
265x129 34K Coarse grid No adaption

635K Points 567 grids : Adapted grid 4 levels

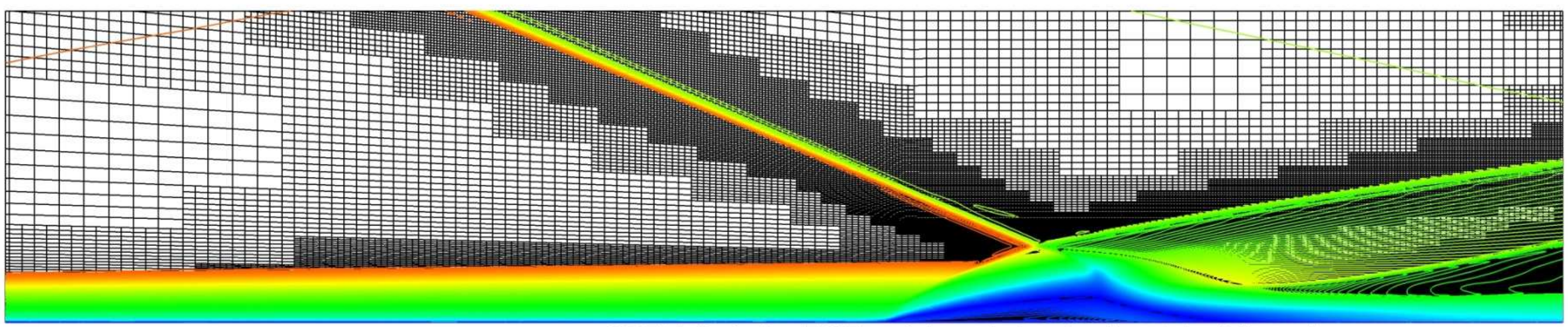
Flow conditions: Mach 5.0, Re=0.9M, inviscid upper wall

2D Supersonic Inlet

- Visible details of shock/boundary layer interaction, allowing better evaluation of turbulence model response to physics



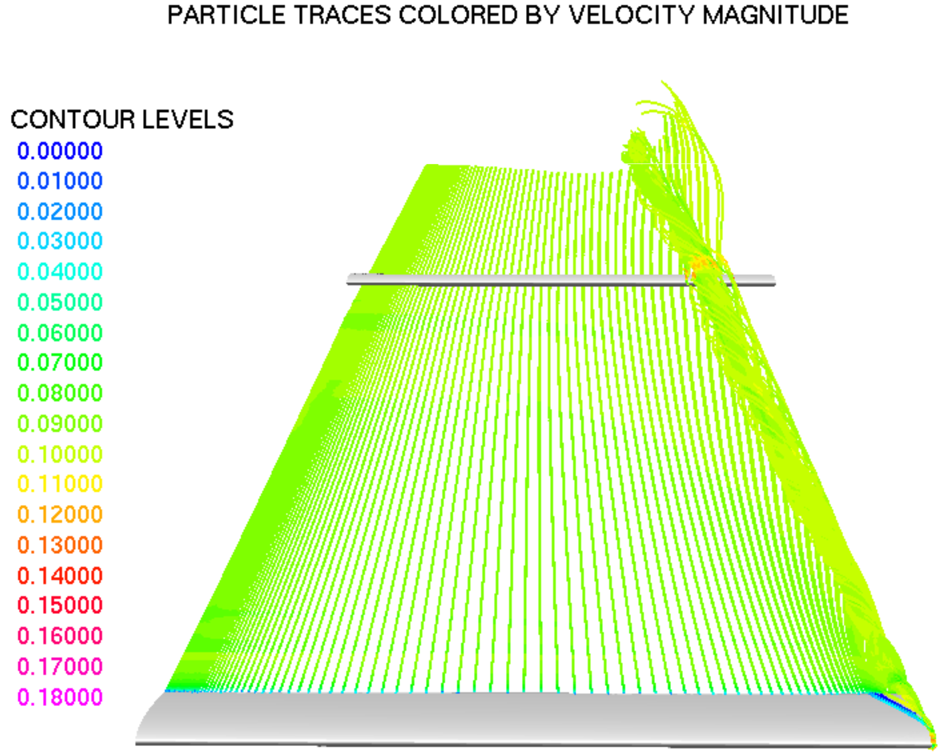
265x129 34K Coarse grid No adaption



635K Points 567 grids : Adapted grid 4 levels

Leading/Trailing Wing Interaction

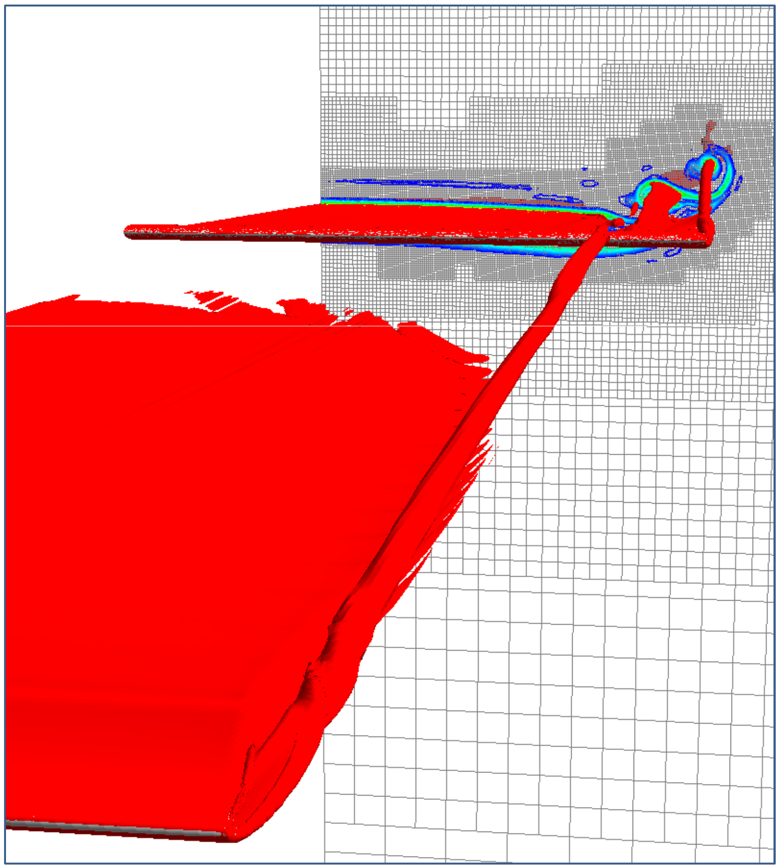
- Wake and tip vortex of leading wing impinges on trailing wing
- Experiment performed at Virginia Tech:
  – K.S. Wittmer, W.J. Devenport, M.C. Rife, and S.A.L. Glegg, “Perpendicular Blade Vortex Interaction”, AIAA 94-0526, Jan. 1994.



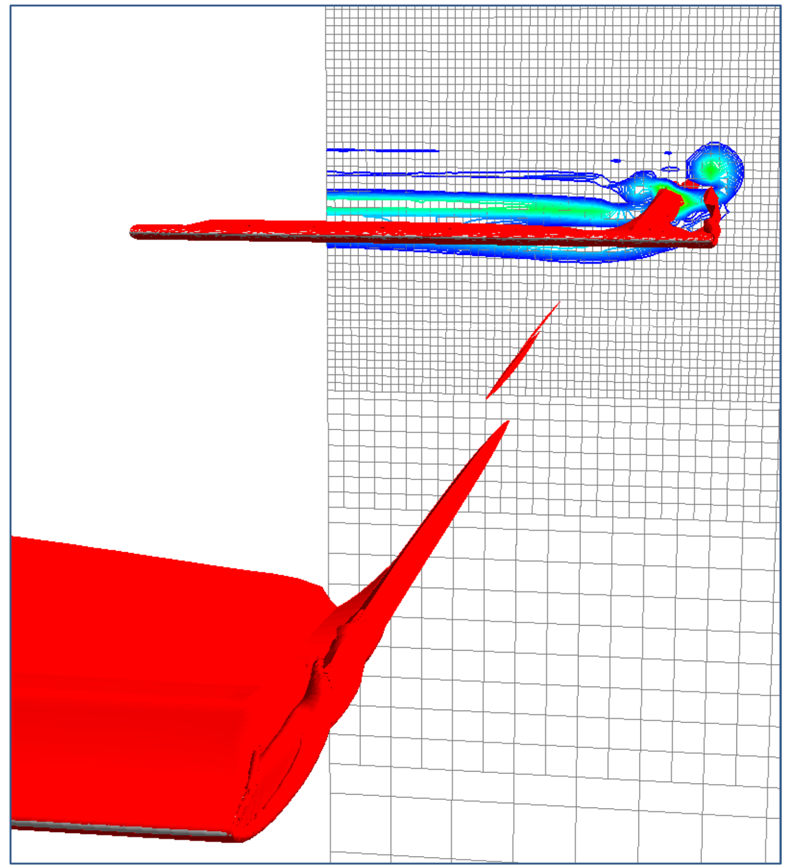
Flow conditions: Mach 0.1, Re=0.26M/chord, both wings at 5 deg angle-of-attack

Leading/Trailing Wing Interaction

- Entropy contours and downstream grid cut show difference in resolution of tip vortex interaction with trailing wing



With 2 levels of near-body and off-body grid adaption
Grid size 121M points

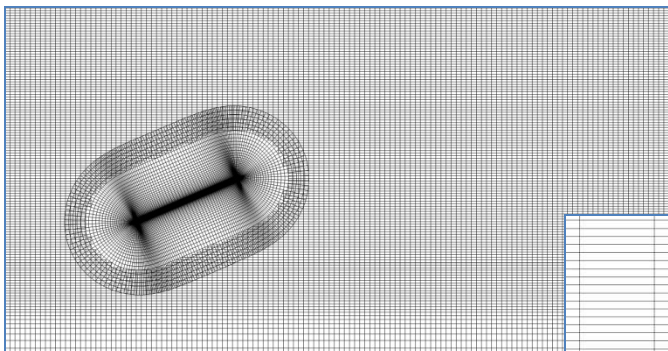


With no grid adaption
Grid size 8M points

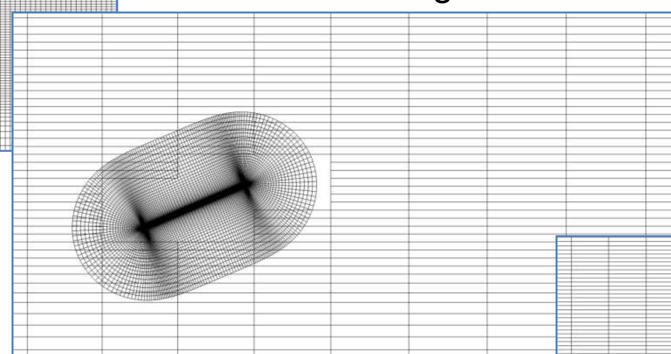
Vortex Generator on a Flat Plate

- Original grid system included plate grid, box grid, and vortex generator grids
- Throw away box grid and let adaption resolve grid communication

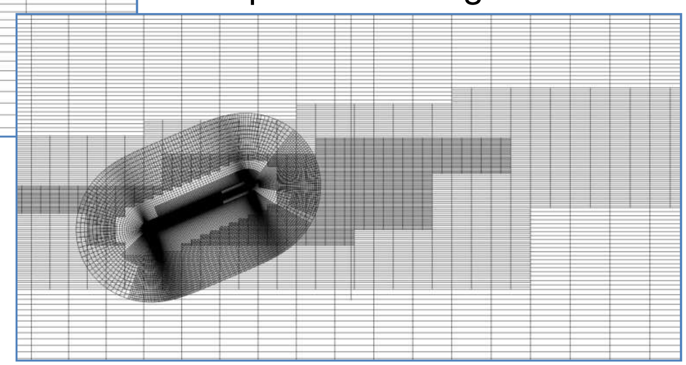
Original surface grids



Without box grid



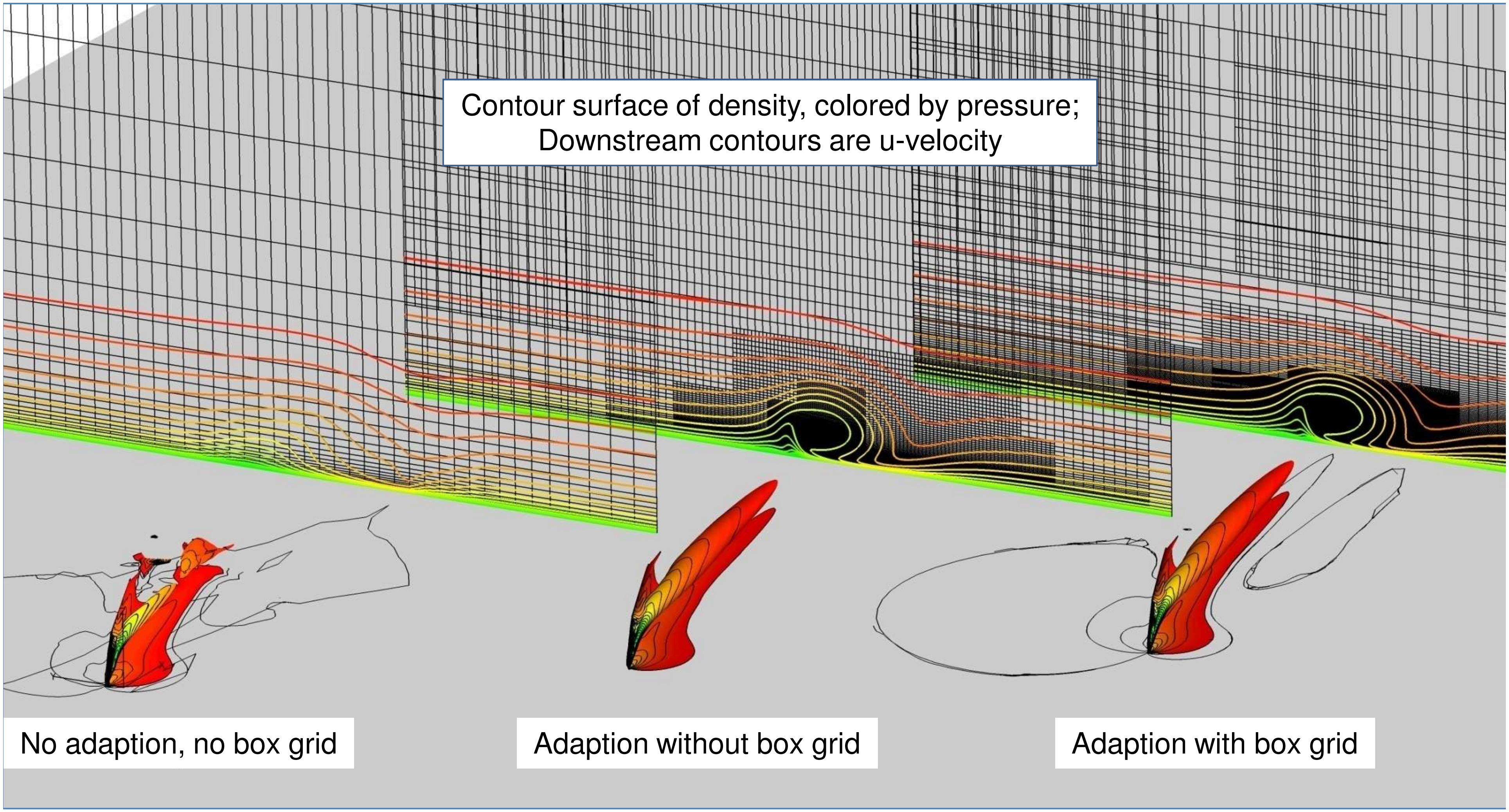
Adapted surface grids



Reference for original vortex generator analysis:
B.G. Allan, C.-S. Yao, and J.C. Lin, “Numerical Simulations of Vortex Generator Vanes and Jets on a Flat Plate,” AIAA 2002-3160, June 2002

Vortex Generator on a Flat Plate

- Comparison of no adaption, adaption, and box adaption strategies

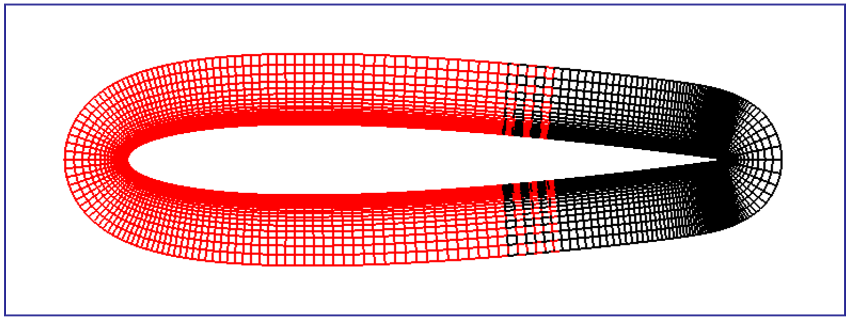


Issues

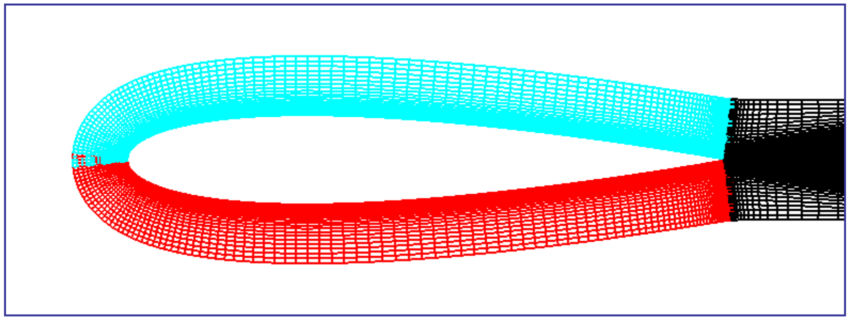
- Limitations on original grid topology
- Parametric cubic interpolation for grid refinement

Grid Topology Limitations

- Adaption indexing in computational space doesn't give overlap across O-grid periodic boundary
  - Workaround is to split O-grids into 2 grids with overlap

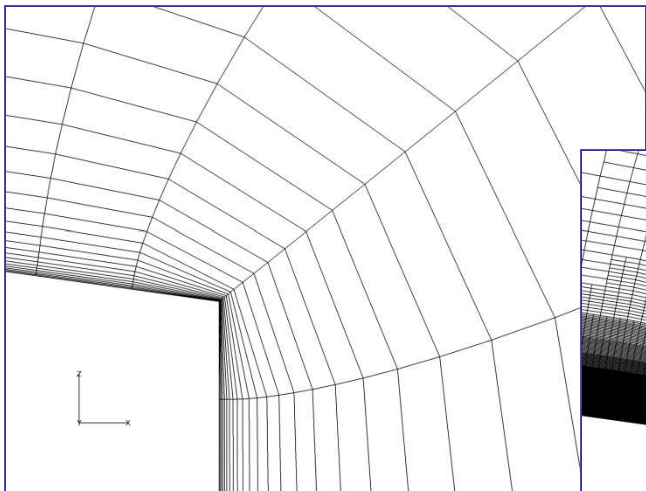


- Similar problem with C-grid wake cut
  - Sample utility splits C-grid into upper, lower, and wake grids

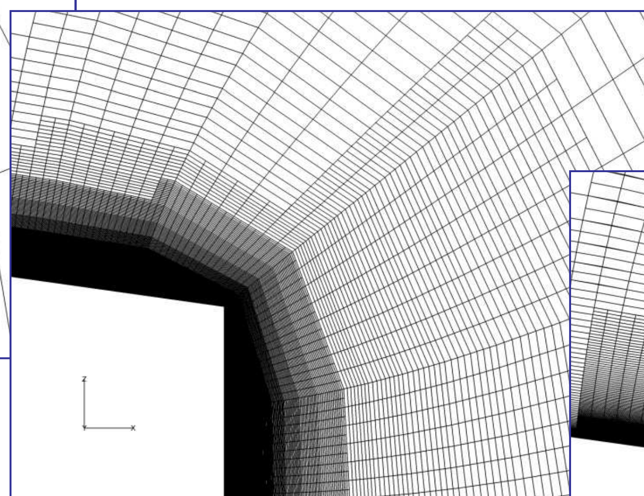


Parametric Cubic Interpolation

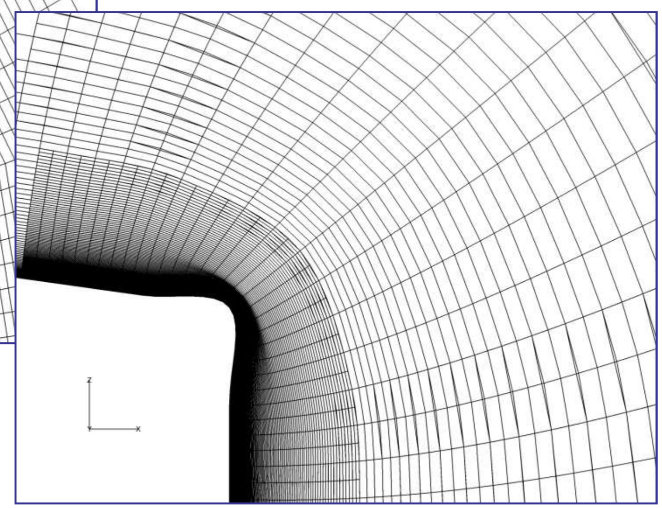
- Interpolation of grid will round sharp corners
- This is an issue for the volume grid, not just the surface grid



Original grid



Adaption with linear interpolation



Adaption with cubic interpolation

Summary and Future Work

Summary:

- A usable near-body grid adaption capability has been implemented and released in OVERFLOW
- Adaption is parallelized and fast enough for time-accurate moving-body problems

Future Work:

- Better handling of volume grids that are not smooth
- Implement O-grid (and C-grid?) adaption without the user splitting the grid
- Investigate the balance between near-body and off-body grids, with adaption
- Extend near-body adaption to work with grid systems assembled with Pegasus 5
- Implement some control on growth of grid system