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!

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\textsuperscript{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 2\textsuperscript{nd} difference of (elements of) $Q=(\rho, \rho u, \rho v, \rho w, \rho e_0)$

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

  (normalized and squared; take max over $Q$ variables)

- 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
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
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

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

Pressure Coefficient

- Experiment
- Original grid
- Off-body adaption
- Near-body adaption

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2D Supersonic Inlet

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

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
Leading/Trailing Wing Interaction

• Wake and tip vortex of leading wing impinges on trailing wing
• Experiment performed at Virginia Tech:

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.
Vortex Generator on a Flat Plate

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

Reference for original vortex generator analysis:
Vortex Generator on a Flat Plate

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

Contour surface of density, colored by pressure;
Downstream contours are u-velocity

No adaption, no box grid  Adaption without box grid  Adaption with box grid
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
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