Suggar++: Current Status and Improvements

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Outline

- Brief Overview of Suggar++ Capabilities
- New Features
  - Interpolation Using Unstructured Dual Grid
  - Immersed Boundary Capability
  - Reorder To Improve Performance
- Summary

Overview of Suggar++ Capabilities

Suggar++

- A general overset grid assembly code
- Useable with most any solver/grid system
- Available world wide
  - EAR-99 export license

Suggar++® is a registered trademark of Celeritas Simulation Technology, LLC

Suggar++ Grid Types

- Structured
  - Curvilinear
  - Analytic
    - Cartesian (uniform and non-uniform)
      - Uniform can be defined in input file
    - Cylindrical
    - Spherical
    - Faster, less storage
- Unstructured
  - Tetrahedron
  - Mixed element
    - Tet, Hex, Prism, Pyramid
    - Hanging Nodes (NEW)
  - General polyhedral
  - Octree-based Cartesian

Suggar++ Solver Support

- Node- and/or cell-centered assembly
  - Has been used to couple different solvers
    - Overflow (node-centered) & Octree (cell-centered)
- Support for arbitrary structured solver stencil
  - Mark fringes required by flow solver spatial discretization
- High-order discretization support
  - Arbitrary number of fringes
  - High-order interpolation for structured grids

Suggar++ Overview

- Hole cutting
  - Direct cut, analytic, octree, hybrid, manual
- Overlap minimization using general Donor Suitability Function
  - DSF: is this donor suitable for the fringe?
    - Element volume, diagonal, min edge length
    - Element size (bounding box diagonal)
    - Distance-to-wall
      - Switch to d-to-wall near surfaces

Suggar++ Support for Overlapping Surfaces

- Integrated surface assembly
  - “Project” fringe grid onto donor grid
  - Structured and/or mixed element grids
    - Unstructured grid must have layers
  - Overlapping surfaces with relative motion
- Integrated USURP to support Force & Moment integration
  - Integration weights available via file, API to transfer without file I/O

Suggar++ Parallel Execution

- Threads for shared memory machines
  - Thread loops over grids
  - Thread loops over elements/nodes
- MPI for distributed memory machines
- Hybrid parallel execution
  - Use MPI to distribute memory across nodes
  - Use threads within a node

Suggar++ Library

- Suggar++ is designed for moving body simulations
- Link into flow solver for integrated dynamic OGA
- libSuggar++ API
  - Control execution
  - Provide moving body transformations
  - Transfer DCI
    - With or without DiRTlib
    - Improved capability to send DCI to flow ranks

Unstructured Dual Grid Donor

Node Centered Donor Interpolation

- Flow solver data is collocated with grid points
- Use parametric/trilinear interpolation from data at cell corners
    - Donor weights are between [0-1] if fringe is inside the donor cell

Cell Centered Donor Interpolation

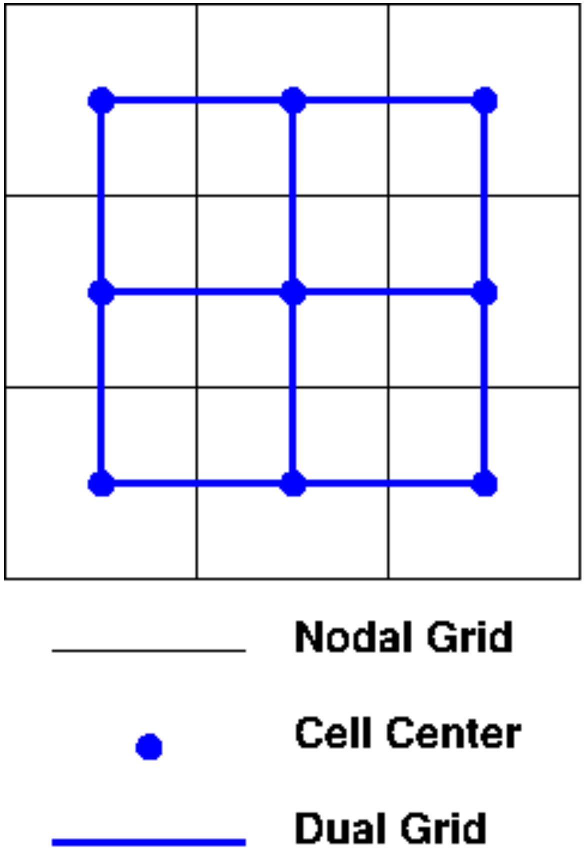
- Flow solver data is collocated with cell centers
- Standard donor members
  - Donor cell and its neighbors
  - Use Least Square approach to compute interpolation weights
    - Donor weights are NOT between [0-1]: Interpolation is non-monotonic
    - DiRTlib has option to clip interpolated data
      - Cannot build clipping into pressure matrix
- New: Unstructured dual grid donor
  - Details in AIAA-2020-1407

Dual Grid

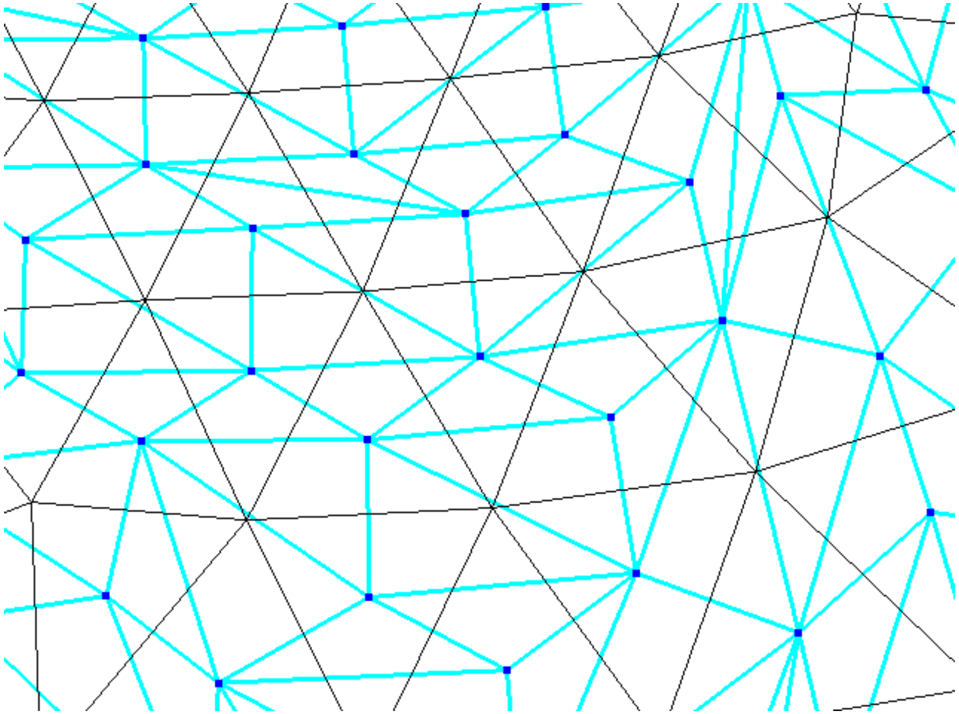
- Primal grid
  - Grid points and cells connecting grid points
- Dual Grid
  - Primal cell centers (PCC) and cells connecting PCC
    - Implicit for structured grids
    - Must be generated for unstructured grid
  - Global Dual Grid
    - Single grid connecting all primal cell centers
  - Local Dual Grid covering each primal cell
    - Independent of neighboring primal cells
    - Requirement: completely cover primal cell

Dual Grid

- Structured



- Unstructured



Generation of Tetrahedral Dual Grid

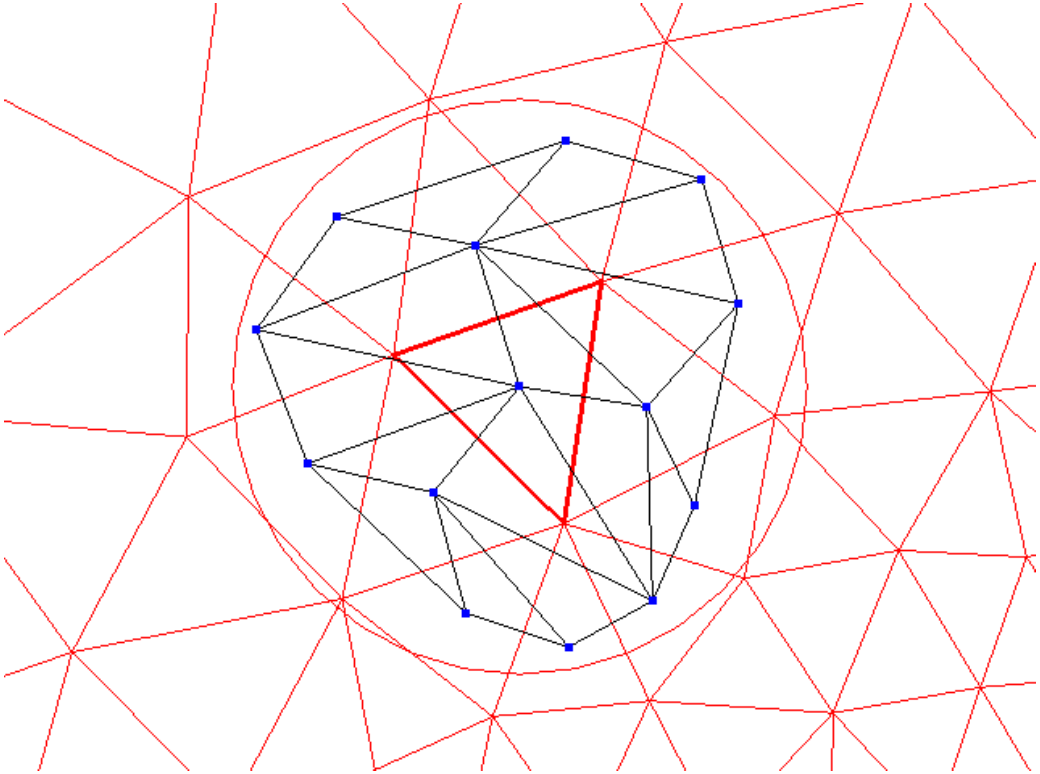
- Delaunay tetrahedralization of primal grid cell centers
  - Uses Pointwise meshing software
  - Option to add boundary points & face centers
  - Anisotropic primal meshes can lead to performance issues
  - Can produce sliver cells with planar data

Local Dual Grid

- Global Dual can be expensive
  - Serial process to generate
  - Large grid to generate and store
- Local Dual Grid at each primal cell
  - Requirement: completely cover primal cell
  - Independent of neighboring primal cells
    - Task parallel generation
  - Only need to load dual cells that are needed
    - Overhead/time required to loading local dual

Local Dual:
Points within 2R Bounding Sphere

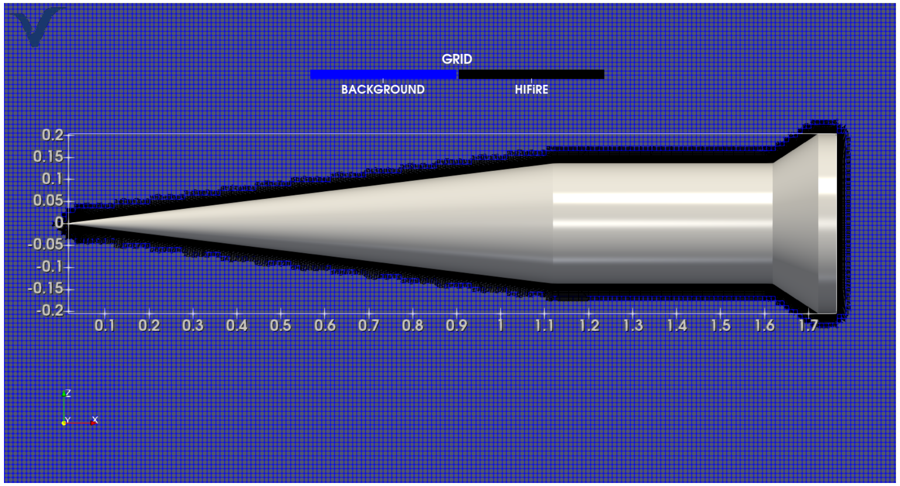
- Covers primal cell
- Generates unneeded dual cells
  - Remove points/cells that are outside of primal cell



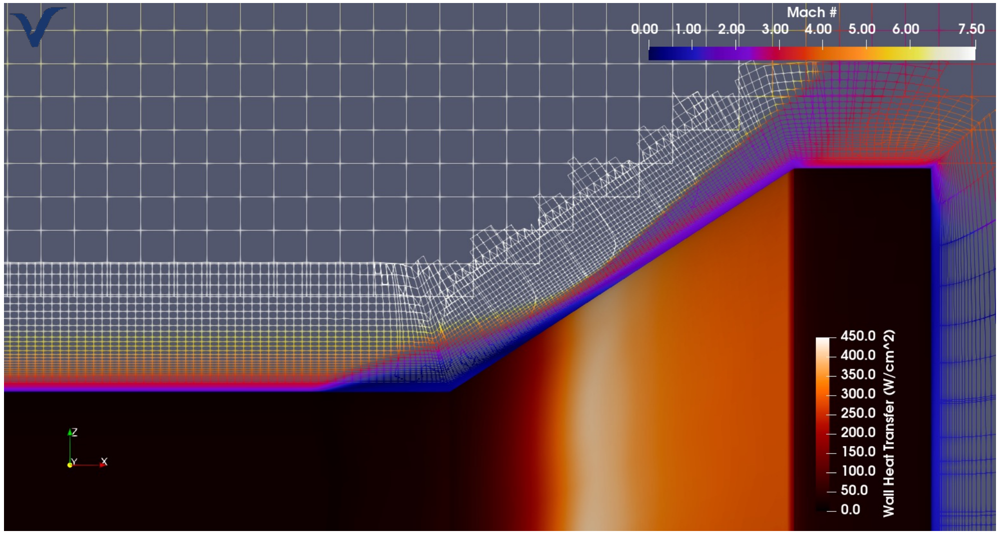
HIFiRE-1

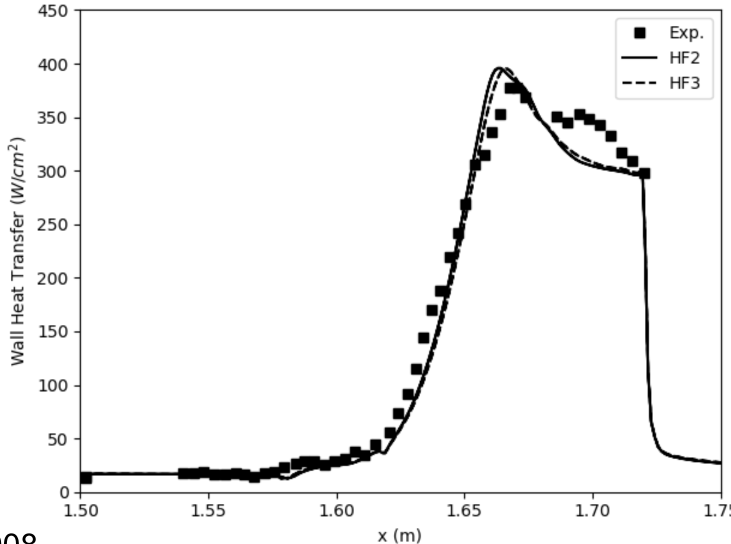
$Mach = 7.16$
$\alpha = 0°$
$T_{wall} = 300\ K$

Slide courtesy of Cameron Brown, Corvid Technologies



- **<u>HF1:</u> Least squares weighting** *without* interpolation function clipping (simulation crashed)
- **<u>HF2:</u> Least squares weighting** *with* interpolation function clipping
- **<u>HF3:</u> Dual-grid donor weighting** *without* interpolation function clipping





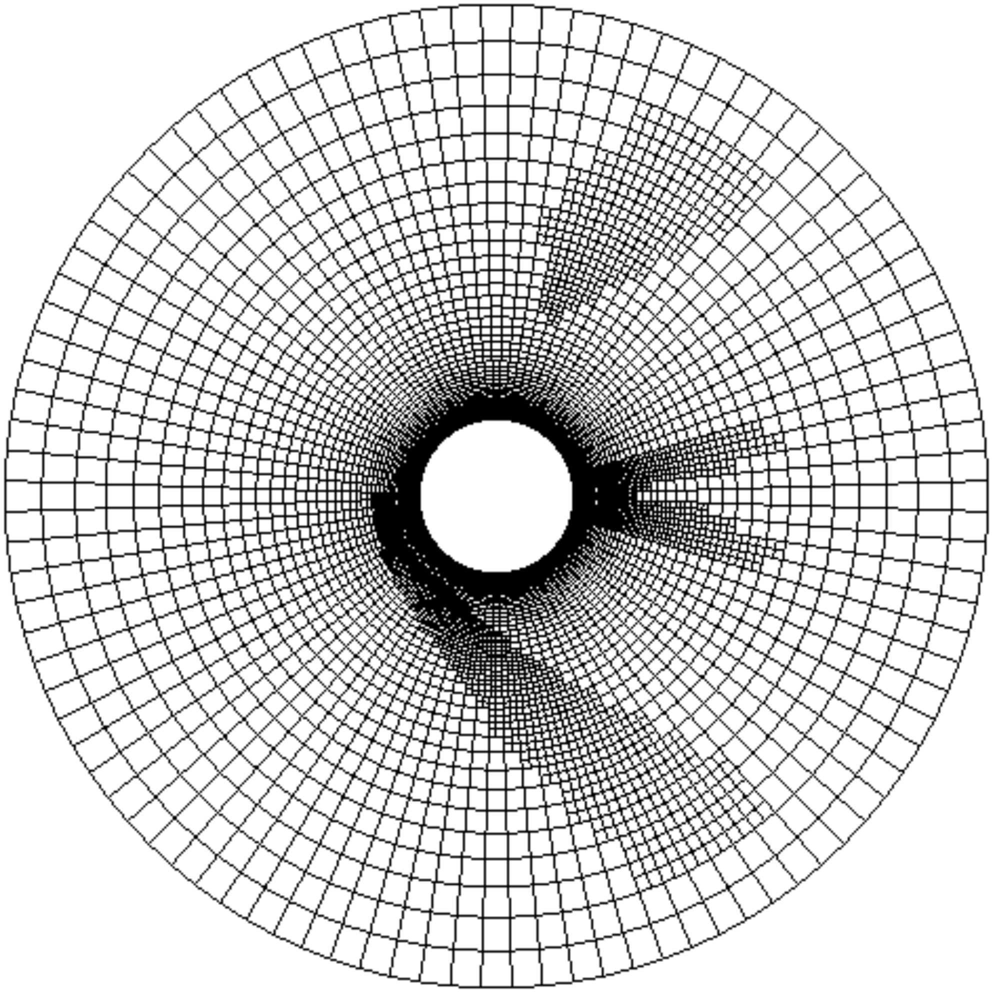
Exp. Data: Wadhams et al., J. Spacecraft and Rockets, Vol. 45, No. 6, 2008.

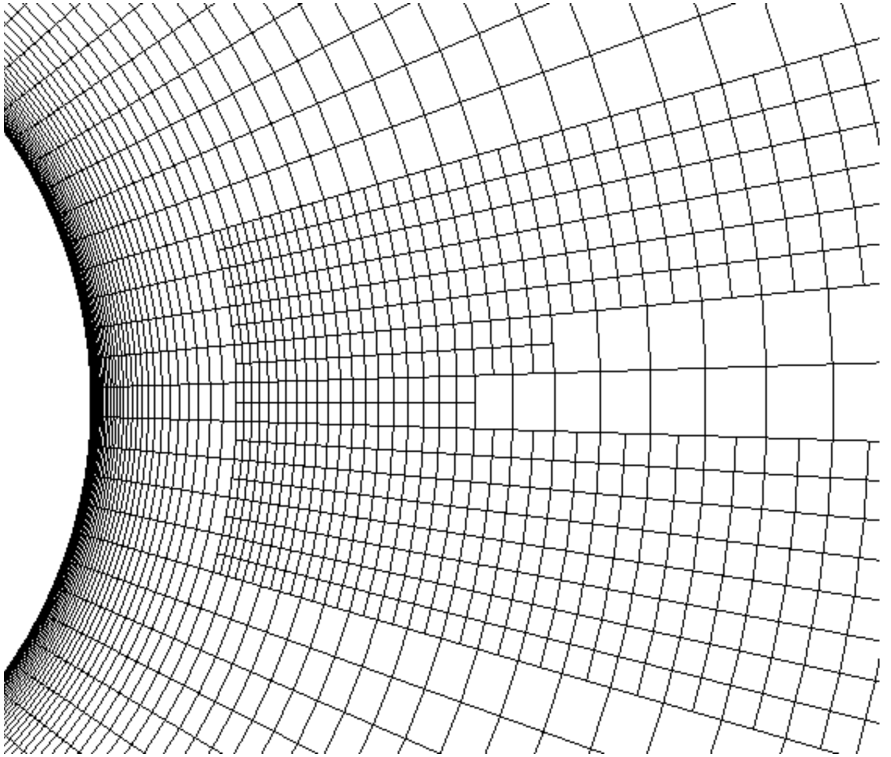
Hanging Node
Mixed Element Grid

Hanging Node Mixed Element Grid

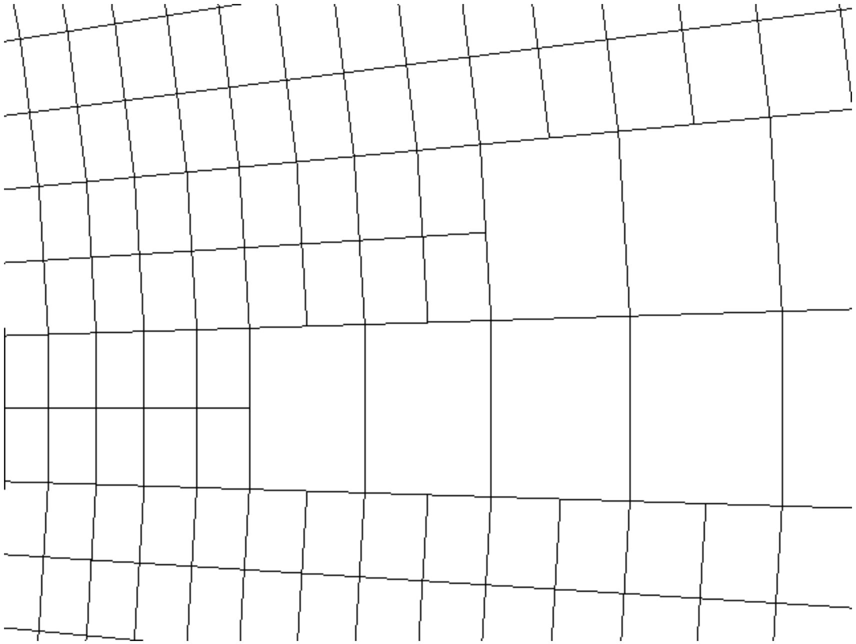
- Mixed Element Grid has specific cell types
  - Hex, Prism, Pyramid
  - Refinement requires transition elements
    - Connect refined to unrefined elements
      - LARGE number of possible refinement templates
    - AIAA 2011-3054
- Allowing hanging nodes
  - Eliminates need for transition elements
  - Simpler derefinement
- Suitable for solver using face-based connectivity

Example Hanging Node Grid

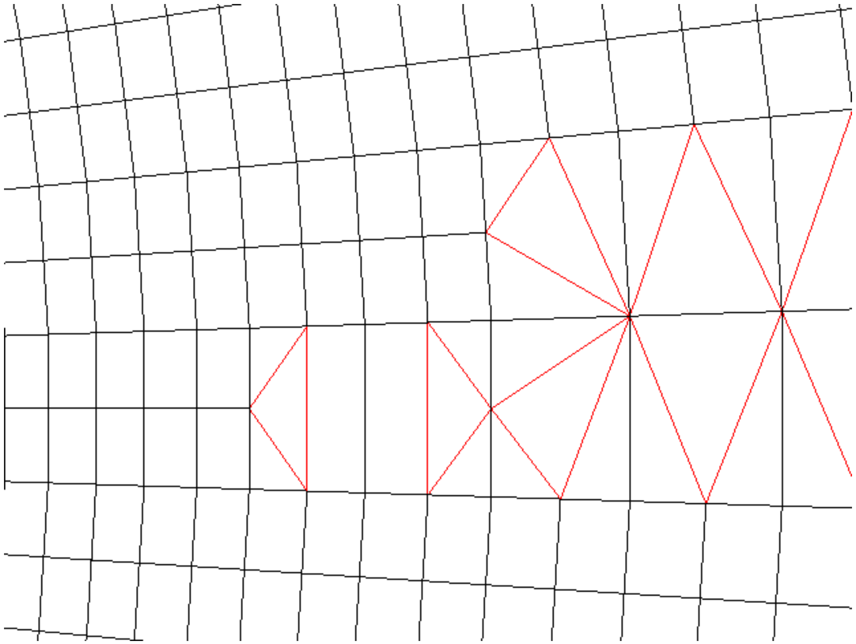




Hanging Node vs Using Transition Elements



Hanging Node



With Transition Elements

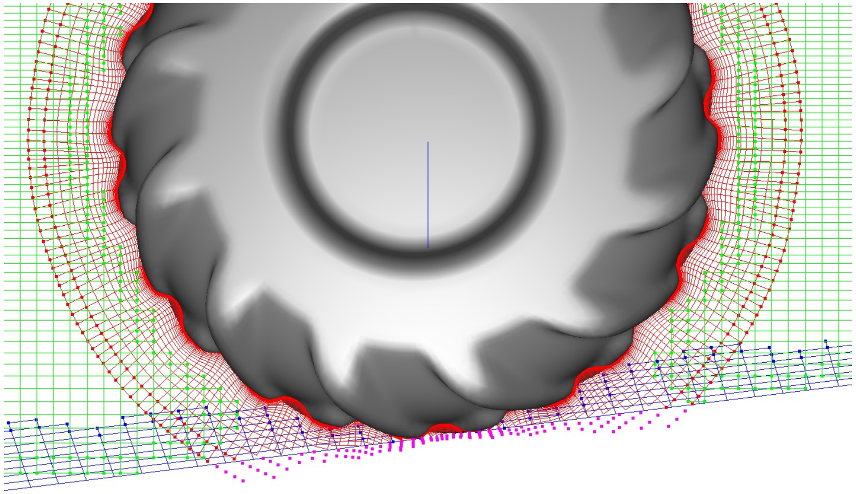
Immersed Boundary Capability

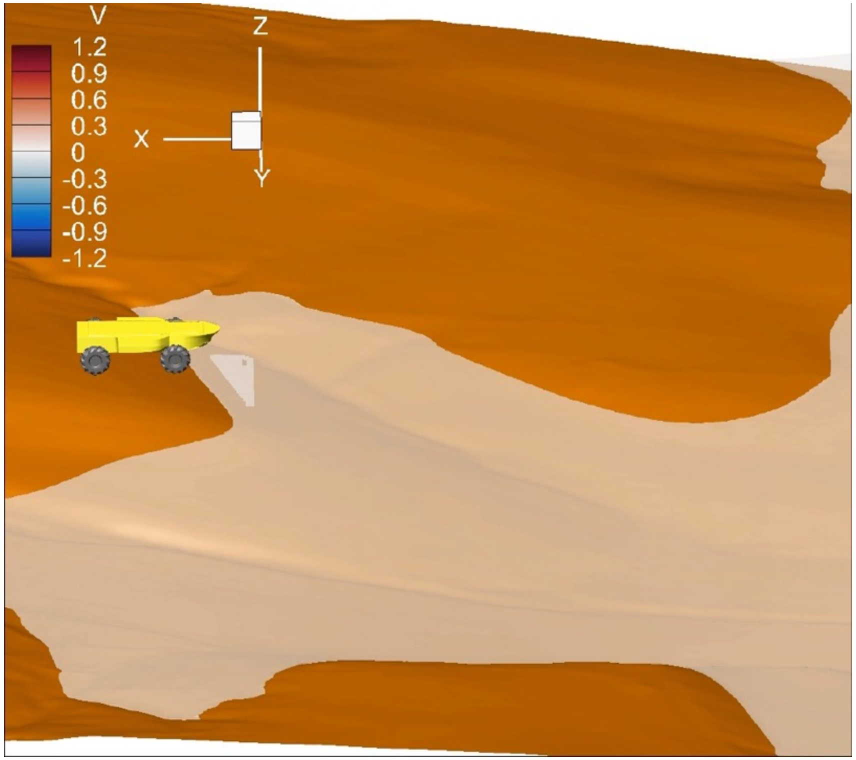
Immersed Boundary Capability

- Bodies in close proximity can may not have sufficient overlap for orphan free assembly
- Suggar++ supports two different approaches for supporting solver immersed boundary approach
  - Cutting geometry marks cells
    - OUT_immersed, ACTIVE_immersed
    - Solver treats grid interior cell face as solid boundary
    - AIAA Paper 2009-3992
  - Auxiliary grid marks points/cells
    - Locations inside grid are marked as immersed
    - Immersed locations can be used as donor members

CFD Solution Using Suggar++ With Immersed Boundary Capability

Ocean Engineering 257 (2022) 111607

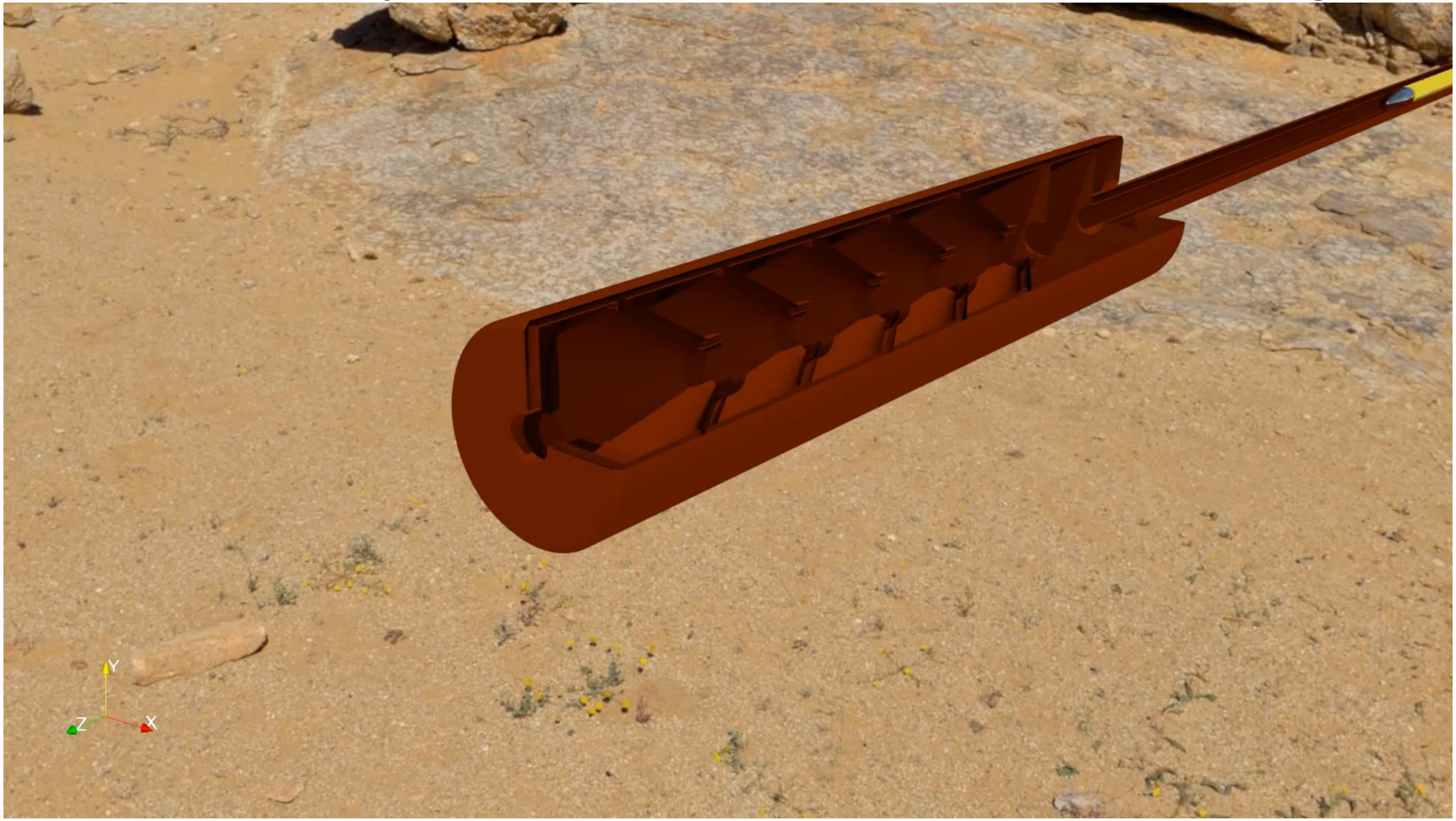




Magenta points below plane are marked as immersed

CFD Solution Using Suggar++ With Immersed Boundary Capability

Video courtesy of Cameron Brown, Corvid Technologies



Reorder To Improve Performance

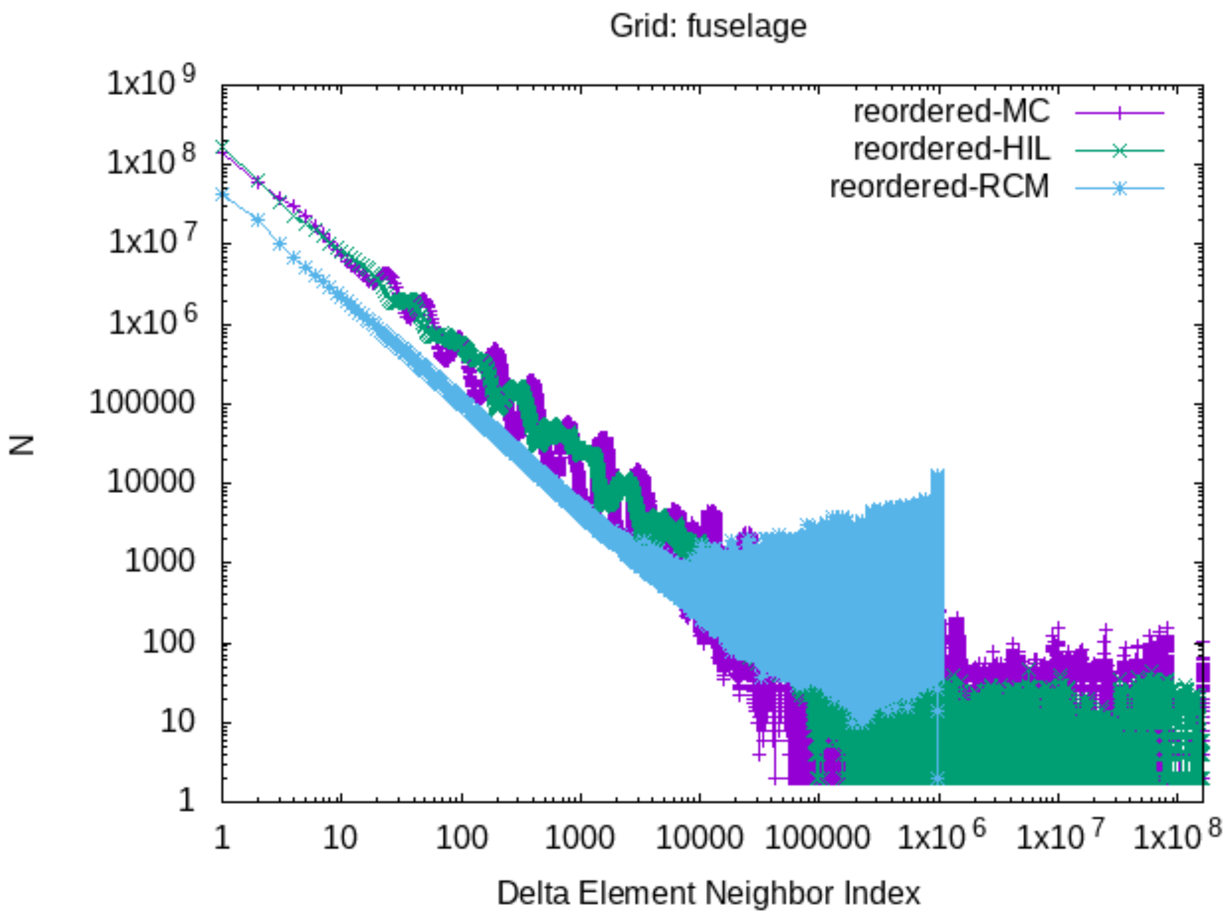
Reorder To Improve Performance

- Reordering to reduce matrix bandwidth is common for flow solvers
- Reordering to improve cache locality can improve performance for overset assembly
- Suggar++ has a utility to reorder the grid
  - Reorder grid points and cells

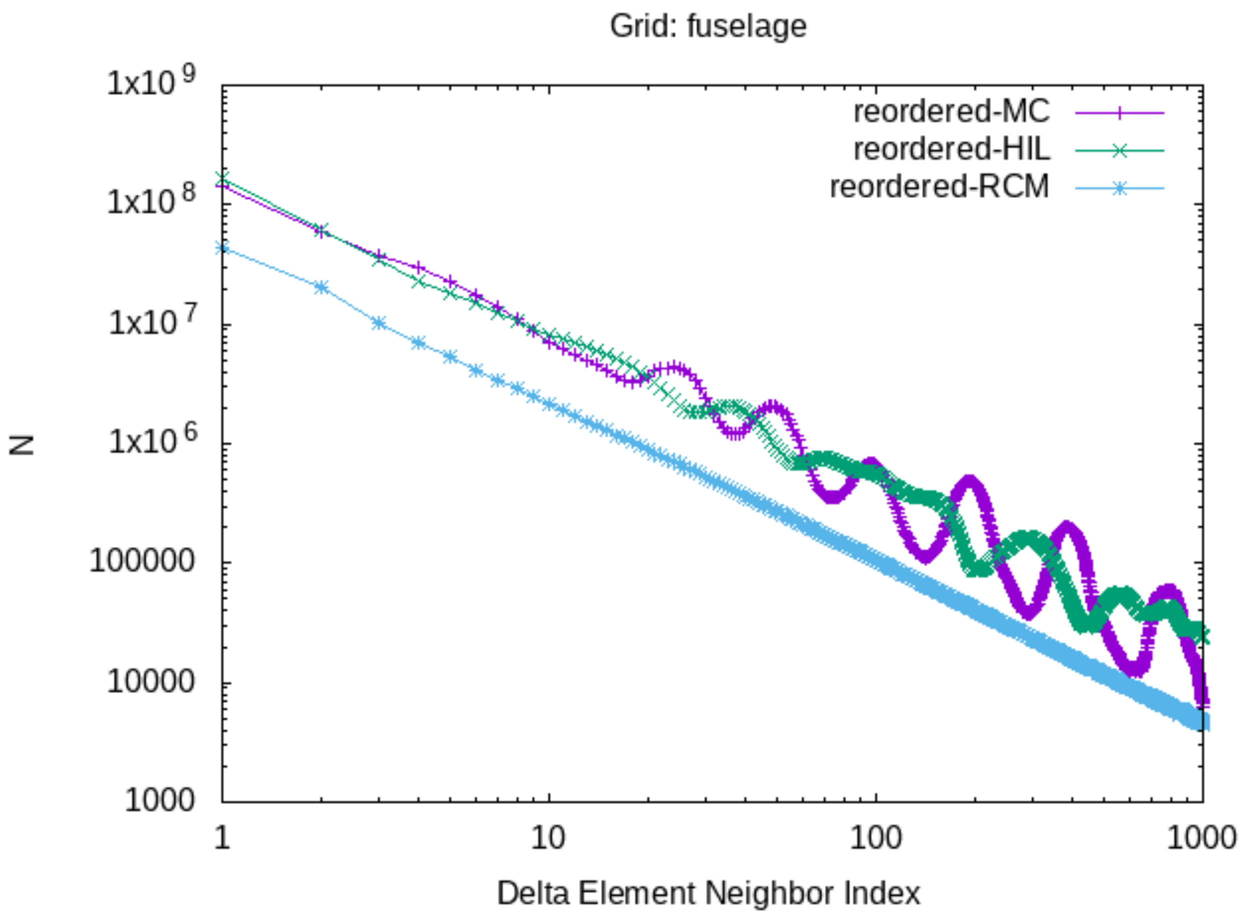
Reorder Options

- Reverse Cuthill-McKee (RCM) algorithm
  - Commonly used to reduce solver matrix bandwidth
  - Using routines from Boost Library
  - Expensive in time and memory
- Converts X,Y,Z into a single code word value
  - Space Filling Curve
  - Hilbert (HIL), Morton (MCW)
  - Fast and low storage

Locality Measure



Locality Measure

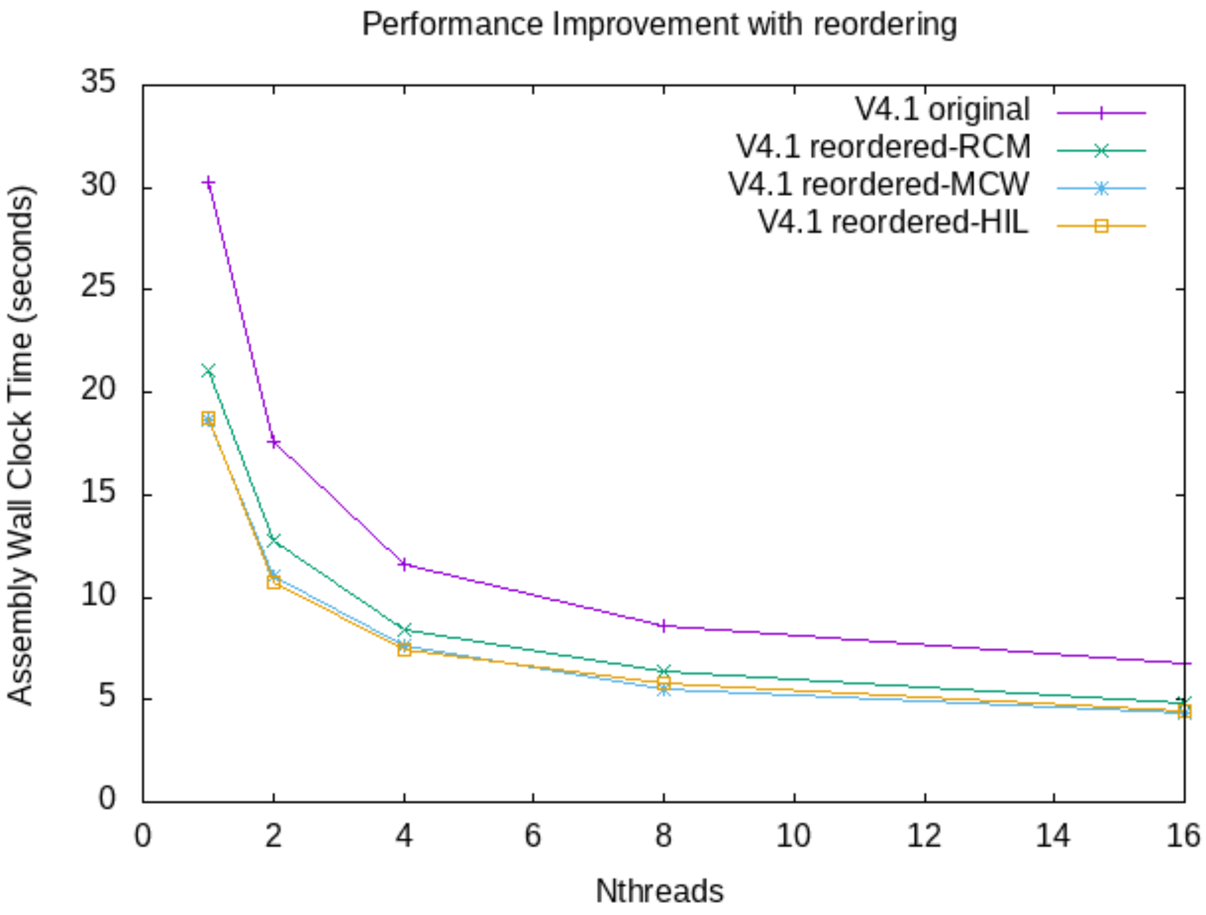


Time And Memory To Reorder

Number of grid points	27,672,611
Number of elements	162,626,774

	HILBERT	MORTON	RCM
Wall Clock Time (Seconds)	**33.2**	**74.7**	**1015.3**
Memory Used (GB)	**16**	**16**	**43**

Performance Improvement With Reordering



Summary

- Provided a brief overview of Suggar++
- Presented highlights of new features
  - Interpolation Using Unstructured Dual Grid
  - Immersed Boundary Capability
  - Reorder To Improve Performance

#Acknowledgements

- Thanks to Pointwise, Inc. for the use of tetrahedral meshing software used in the dual grid effort.

POINTWISE®

THE CHOICE FOR CFD MESHING

Questions?

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