## Summary of meshes generated

**Star-CCM+**

<table>
<thead>
<tr>
<th>Geometry</th>
<th>Mesh type</th>
<th>Grid resolution level</th>
<th>Grid resolution level</th>
<th>y+ at walls</th>
<th>Initial wall spacing, $\Delta y$ (normal dist)</th>
<th>Number of cells (Points) on trailing edges</th>
<th>Cell count (Million cells)</th>
<th>Meshing time (hours)</th>
<th>Parallel Meshing</th>
</tr>
</thead>
<tbody>
<tr>
<td>HL-CRM (full gap) Re = 3.26M Cref = 275.8 in</td>
<td>Unstructured polyhedral</td>
<td>Coarse</td>
<td>1.0</td>
<td>0.00078 inches</td>
<td>4 (5)</td>
<td>55</td>
<td>5.3</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>2/3</td>
<td>0.00078 inches</td>
<td>6 (7)</td>
<td>88</td>
<td>6.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fine</td>
<td>4/9</td>
<td>0.00078 inches</td>
<td>8 (9)</td>
<td>124</td>
<td>8.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unstructured cartesian polyhedral</td>
<td>Coarse</td>
<td>1.0</td>
<td>0.00078 inches</td>
<td>4 (5)</td>
<td>91</td>
<td>0.5</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>2/3</td>
<td>0.00078 inches</td>
<td>6 (7)</td>
<td>163</td>
<td>1.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fine</td>
<td>4/9</td>
<td>0.00078 inches</td>
<td>8 (9)</td>
<td>216</td>
<td>1.9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Aerospace and Defense applications of STAR-CCM+

- External Aerodynamics
- Rocket Propulsion
- Environmental Control Systems
- Thermal Management
- Design Exploration
- Fluid Structure interactions
- Store Separation
- Aeroacoustics
- Ice Accretion and Protection
Meshing philosophy: Automation

- STAR-CCM+ Meshing Pipeline is highly automated, easily scalable for refinement settings and massively parallel-enabled.
- The meshing “operations” are applied in a sequential pipeline.
  - CAD import and repair
  - Volume extraction operations
  - Surface meshing
  - Volume meshing
- Each operation has size controls that are scaled to a single “base” value.
- Scaling this base value scales all mesh settings accordingly, and the pipeline can be re-executed automatically in sequence.
- This allows for rapid refinement studies to be conducted once a base-line model meshing pipeline has been created.
- The surface meshing is performed in serial.
- Volume meshing is performed in parallel on large distributed memory resources.
Meshing Workflow in STAR-CCM+

- HL-CRM full-gap model
- Imported as Parasolids file
- Minor repair & sewing
- CAD-based meshing

SURFACE MESH
- Unstructured triangles
- Curvature refinements
- Proximity refinements
- Edge-Proximity controls
- Custom model-surface controls

VOLUME MESH
- Wake refinements
- Volume controls
- Function-driven sizing
- Automated scaling
- Surface conformal
- Parallel meshing

CAD
Surface Meshing
Surface meshing is the first step of the meshing pipeline in STAR-CCM+.

This surface mesh is generated upstream to the volume meshes and is common to all volume meshing tools used in this efforts, in order to standardize the surface inputs.

Automated to a common scaling size for the medium mesh and scaled up (coarse) or down (fine) by factor of 1.25.

Surface mesh type is unstructured, isotropic triangle face elements.

<table>
<thead>
<tr>
<th>Grid resolution level</th>
<th>Surface Mesh Faces (Millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>~6.8</td>
</tr>
<tr>
<td>Medium</td>
<td>~8.3</td>
</tr>
<tr>
<td>Fine</td>
<td>~9.5</td>
</tr>
</tbody>
</table>
Surface Meshing: Trailing Edges

Automated Edge Proximity Controls

- Allows users to specify number of faces between groupings of edges based on proximity
- Click edges and specify number of faces
- Simplifies TE refinement for aerospace applications

<table>
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<tr>
<th>Grid resolution level</th>
<th>Number of cells (Points) on trailing edges</th>
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<tr>
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</tr>
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</table>
Surface Meshing: Curvature & Proximity

Automated CAD-based Curvature Refinement
- User specifies CAD curvature refinement on a model surface as a function of the local refinement sizes.
- Current effort has curvature refinement set to 0.1% of the local span-wise size.
- Span-wise size can be varied based on local chord as per Gridding Guidelines.
- Generates automated LE refinements to match Guideline requirements.

Automated Surface Proximity Refinement
- Bi-directional Proximity detection is used to control TE refinement.
- Similar to Curvature Refinement, Proximity can be scaled to local chord sizes as well.
- Automated for the model as a whole.
### Unstructured Polyhedra

#### Core Mesh
- Polyhedra generated via dualization of underlying Tetrahedra cells.
- Highly automated and pipelined.
- High quality feature retention
- Better quality meshes for aerospace applications.

#### Meshing Controls
- Core volume cell growth rates
- Blending factors
- Volume controls and sources
- Conformal surface meshes
- Custom surface sizes
- Automated wake refinements
Unstructured Polyhedra: Far-Field
Unstructured Polyhedra: Fuselage
Workflow: Volume Controls

Custom Part Shapes used to create unique volume controls for each model surface
Workflow: Volume Controls
Unstructured Polyhedra + Prismatic near-wall cells
Near-wall Prismatic Cell Layers

Near-wall Prismatic Cells
- Wall surfaces offset from the surface to create the near-wall prismatic layers by extrusion.
- Highly automated and pipelined.
- Conformal to underlying surface mesh
- Choice of Advancing-front layer or Extrusion-type layers

Meshing Controls
- Prism layer thickness automated and scaled with local chord sizes
- Near wall thickness specifications ($y+$ defined)
- Stretching Distributions / Ratios
- Near-Core Layer Aspect Ratio
- Custom surface sizes
- Automated layer transitions and layer reductions
Trailing Edge Refinement

Trailing Edges

- Polyhedra at the TE is dualized from the underlying tetrahedra mesh, which in turn is surface mesh conformal.
- Therefore, all TE refinements applied using Edge Proximity tools translate over to the tetrahedra and then over to polyhedra, but with a dualization factor to be applied.
Unstructured Cartesian Meshing
Cartesian Polyhedra

Core Mesh
- Cartesian octree cells converted to unstructured cells.
- Cells cut with complex faces at the model surface boundaries to create body-fitted meshes.
- Compatible with near-wall prismatic cell layers
- Easily scalable refinements using octree-sizing controls
- Highly automated and pipelined.
- High speed mesh generation compared dualized-tetrahedral cells
- Robust mesh generation

Meshing Controls
- Core volume cell growth rates
- Volume controls and sources
- Custom surface sizes
- Automated wake refinements
Cartesian Polyhedra: Automated Wake Refinement
Cartesian Polyhedra: Automated Wake Refinement
STAR-CCM+ has massively scalable parallel volume meshing tools.

This allows for increased leverage over commercially available distributed computing hardware resources.

Tests have shown scalability up to mesh sizes of billions of cells and over 1,000+ computing cores.

This capability has the potential to reduce overall meshing times dramatically and eventually make it an invisible cost to the simulation process.

For this effort, the Cartesian Meshes were generated in parallel on a distributed memory cluster using 16 cores with a serial-relative scalability of ~8.

<table>
<thead>
<tr>
<th>Unstructured Cartesian Meshing Process (Medium Mesh; 120 Million cells)</th>
<th>Mesh generation time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serial</td>
<td>~4</td>
</tr>
<tr>
<td>Parallel (4 cores)</td>
<td>~1.5</td>
</tr>
<tr>
<td>Parallel (16 cores)</td>
<td>~0.5</td>
</tr>
<tr>
<td>Parallel ( &gt; 64 cores)</td>
<td>~0.4</td>
</tr>
</tbody>
</table>
Mesh Quality Optimization
Mesh Quality: Poly + Prisms

Cell Quality

Skewness Angle
Mesh Quality: Trimmer + Prisms

Cell Quality

Skewness Angle
Summary

- Six meshes generated using two different meshing approaches
  - Both unstructured
  - Near wall prismatic layers

- High degree of complete automation in the meshing process

- Isotropic meshing created more mesh cells than warranted
  - Upcoming anisotropic meshing capabilities will reduce overall mesh count

- Parallel meshing shows great promise for all future meshing work
  - Applied to unstructured trimmer core meshing tools
  - Applied to near-wall prism meshing tools
  - Being applied to Tet/Poly meshers this year
  - Complete meshing pipeline to be massively parallel-scalable within the next year
Questions?
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