CFS Contribution to GMGW-1

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1st June 2017 [v3]
Summary of Grids generated using **BOXER**

- The core philosophy underpinning **BOXER** is to develop a coupled meshing & geometry editing & management system, implemented in parallel, which can handle geometries of arbitrary scale & size and which scales well to billion cell meshes & beyond
  - **BOXER**’s key advantage is ability to be run automatically, scripted, very tolerant of geometry defects
  - The challenge is to keep the cell-count low

- **BOXER** imports the geometry direct and then generates a body-fitted, hybrid unstructured mesh, with layers, subject to various geometry & spatial refinement criteria
  - **BOXER** first uses its Digital Geometry model to capture the imported geometry, then builds a volume mesh which is made conformal to the geometry, then layers are added – the “wrapped” surface mesh emerges as an output
  - Cell quality is managed dynamically with the aim of being able to start up any COTS solver first time

- For GMGW we generated meshes from each of the supplied geometry formats; although each had some issues, very little work was needed to fix, and **BOXER** successfully meshed all

<table>
<thead>
<tr>
<th>Resolution</th>
<th>#Layers</th>
<th>y+</th>
<th>Y Spacing</th>
<th>Growth rate</th>
<th>Cell Count</th>
<th>Time (min)</th>
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</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>25</td>
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<td>0.00175</td>
<td>1.25</td>
<td>114M</td>
<td>380.92</td>
</tr>
<tr>
<td>Medium_A</td>
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<td>~2/3</td>
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<td>1.16</td>
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<tr>
<td>Medium_B</td>
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<td>0.00117</td>
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<td>~200M</td>
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</tr>
<tr>
<td>Fine</td>
<td>~50</td>
<td>~4/9</td>
<td>0.00078</td>
<td>1.1</td>
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Overview
CFS meshing history...

- In the late 1990’s we worked on conventional, unstructured mesh generation based on standard Delaunay algorithms & we put in place a process chain
  - 3Dgeo (fixed up the CAD) => NEWTsurfsmh (surface mesh) => NEWTvolmsh (volume mesh)
- In 1999 we successfully generated a mesh for a complete racing car, from CAD
In the late 1990’s we worked on conventional, unstructured mesh generation based on standard Delaunay algorithms & we put in place a process chain:

- 3Dgeo (fixed up the CAD) => NEWTsurfMsh (surface mesh) => NEWTvolMsh (volume mesh)

In 1999 we successfully generated a mesh for a complete racing car, from CAD.

It took one person three months – which is too long...so we asked the question:

- what would it take to do this in one day?
BOXER process summary

1. Setup Distance Field
2. Octree Mesh
3. Hybridisation
4. Body-Fitting
5. Viscous Layer Extrusion
6. Continue layer extrusion
BOXERMesg – typical complex geometry

An HP turbine rotor including cooling air system, shroud and under-hub

Mesh of the main gas path and cooling passages
Geometry import & preparation
1. Setup Distance Field

- Region seed point
- Internal cells
- Cut cells

\[ \phi = 3, \quad \phi = 2, \quad \phi = 1 \]
Geometry Import and Preparation (1)

- Downloaded all the available CAD geometries and tried each

- Imported CAD into BOXER
  - With fine tessellation and angle refinement
  - Checked imported CAD for issues
    - Large gaps / missing faces
    - Inexact Edges
    - Obvious errors

- Resolved any issues
  - Missing faces on fuselage (see image)
    - Imported CAD with reduced tessellation and missing patch is included
    - Take the missing area and import this into finer CAD model
  - Inexact edges (see image)
    - Increasing tolerance
    - Not usually an issue but the refinement captured the incorrect alignment in some cases – see image
Geometry Import and Preparation (2)

Inexact TE Issue

- Edge at TE is not connected and there’s a tiny step between surfaces
- Zoom on mesh shows it captures this false step in some areas
- Not possible for layers to grow
- inset shows “layer coverage”
  - (RED = OK)

Curvature Repair

- Causes issue with TE – small gaps
- Wouldn’t be an issue, however refinement is on same size as the gap
- Outcome is not to use curvature repair in this case.
Geometry Import and Preparation (3)

▶ Missing Faces
  • Some imports have this area missing
  • It appears with a coarser import
  • Can extract it and import it into the finer import as a patch

▶ CREO file
  • Poor TE and Flap surfaces
  • Not fixable without altering the CAD
  • Not much detail is captured
Geometry Import and Preparation (4)

The different CAD Files
- Native: NX (prt) – Missing face and non-geometry patches (deleted)
- CREO file – Issue with flaps and TE’s. (ignored due to poor quality geometry)
- IGS file – Inexact TE’s
- STP file – Missing face
- Parasolid (x_t) – Scaled to inches, missing face

BOXER was able to mesh all the supplied geometries
- CREO export was very poor - was mesh-able but output is as bad as input
- All the rest had some different issues but generally output was very similar
- Little to no modification required
- Time taken was minimal

Lessons learned
- Realising the inexact edges were cause for initial mesh quality issues and could be simply fixed with increased tolerances on import
- Next time would import the CAD parts separately (wing, flaps, etc.) in order to get better quality surfaces for individual parts
Mesh generation
BOXER process summary

2. Octree Mesh

3. Hybridisation

4. Body-Fitting

5. Viscous Layer Extrusion

6. Continue layer extrusion

Region seed point

Body Normals

Integer Front
Mesh Generation (1)

▶ Algorithms Used
  • See previous summary slide

▶ Resolution controlled
  • Length scale – Background Size
  • Refinements – Surface, Edges, Volumes – Cell Spacings
  • Layering – Initial Height, Growth Rate – Viscous Layers
  • Bounding Box Extrusions – Total Distance - Farfield

▶ Export
  • Various formats
    • BOX, CFD++, CGNS, MSH, UNS, XDMF
Difficulties Encountered - CAD

- TE’s not captured correctly
- Due to inexact edges – fixed with some tolerance adjustments
- Gaps filled in
  - Initial refinements around the flap-flap, root-flap and the wing-slat were not sufficient to capture the gaps
- Adjustment to refinement levels in these areas cleaned this up
- Curvature LE’s
  - Initial curvatures were ‘poor’ on the LE’s
  - Fixed again by adjusting the level of refinement and oversampling the initial geometry
- Edges around thin areas
  - Reducing the angle for feature capture helped in these areas
  - As well as adjusting the refinement level in these areas
Mesh Generation (3)

Difficulties Encountered – Guidelines

- Number of Nodes on TE
  - Can set a refinement level to a size that is length of the edge divided by number of nodes required.
- The high refinements required on the TE’s leads to higher cell counts
- Spacing based on local chord
  - Not accurately followed, simply set a general spacing.
  - Some more detailed setup could most likely adhere to the specific local chord length for each part as it varies along the span of the wing
Mesh Generation (4)

Images of Mesh Setup
Reworks and Iterations

• Because BOXER is an automated meshing process it’s very easy to make adjustments and rework based on the output.
• For this workshop the initial mesh was created within a couple of hours of downloading the CAD
• From this we could identify what areas require certain refinements an overall estimation of the size and complexity and how best to setup the project
• Most of the iterations carried out were to perform optimisation of the cell count and level of refinement in specific areas

Mesh Time

• Typical mesh time was initial ~ 2-3 hours for a coarse mesh and up to ~6 hours for medium and excess of 12 hours for fine
• Once a decent mesh for a specific resolution created, the settings could be adjusted to go to a higher/lower resolution as well as sticking to the guidelines for that resolution
Lessons Learned

- This workshop helped improve understanding of the basic mesh requirements for a high lift wing and also how these requirements translate into the BOXER setup.
- Also learnt various new ways to tackle specific problems using the tools available to us in BOXER; there were several ways to setup the problem and can apply this to future projects.
- The mesh process could still be improved as the topology/smoothing calculations within BOXER are still being optimised and as these develop the output mesh will reflect these changes.
- If we were to do this again we could take a much better approach on how to setup the problem and what difficulties to expect and solve ahead of time.
# Mesh Statistics

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## CFD Settings

<table>
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<tr>
<th>CFD Setting</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Pressure</td>
<td>1 Bar</td>
</tr>
<tr>
<td>Velocity</td>
<td>0.2 Mach</td>
</tr>
<tr>
<td>Angle of Attack</td>
<td>8 deg</td>
</tr>
<tr>
<td>Mesh</td>
<td>Coarse</td>
</tr>
</tbody>
</table>

## Cell Quality % of Total Cells

<table>
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<th>Coarse</th>
<th>Medium</th>
</tr>
</thead>
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<tr>
<td>0.00 - 0.10</td>
<td>1.03%</td>
<td>0.55%</td>
</tr>
<tr>
<td>0.10 - 0.20</td>
<td>5.97%</td>
<td>5.15%</td>
</tr>
<tr>
<td>0.20 - 0.30</td>
<td>3.86%</td>
<td>3.33%</td>
</tr>
<tr>
<td>0.30 - 0.40</td>
<td>3.50%</td>
<td>3.03%</td>
</tr>
<tr>
<td>0.40 - 0.50</td>
<td>3.37%</td>
<td>2.94%</td>
</tr>
<tr>
<td>0.50 - 0.60</td>
<td>3.36%</td>
<td>3.00%</td>
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<tr>
<td>0.60 - 0.70</td>
<td>3.42%</td>
<td>3.21%</td>
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<tr>
<td>0.70 - 0.80</td>
<td>3.63%</td>
<td>3.42%</td>
</tr>
<tr>
<td>0.80 - 0.90</td>
<td>4.67%</td>
<td>4.07%</td>
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<tr>
<td>0.90 - 1.00</td>
<td>67.19%</td>
<td>71.30%</td>
</tr>
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“Quality” = weighted average of Cell Skewness, Face-Warp, Jacobian and Orthogonality
Medium_A Mesh Images
Wing Upper Surface
Wing Lower Surface
Wing Slat LE at Root
Wing Flap TE at Root
Wing Tip LE
Wing Tip TE
Flap Gap Upper Surface
Volume Mesh Cut at y=277.5
Volume Mesh Cut at y=638
Volume Mesh Cut at y=1050
Repeats with deeper layers...

~40 layers; Y=227

~50 layers; Y=638
Mesh evaluation
Mesh Evaluation (1)

Summary

• Can first check in the output file of the mesh generated what the cell count is, quality of cells, number of layers etc.
• The second step is to visually review the mesh by loading it back in to Boxer (mesh was generated through script .lua) looking for key areas
• Feature capture along TE – ensure that it’s correct and distribution of cells is within the guidelines
• Other Edges – checking if the have been captured
• Layering – can get rendered view of the depth of layers over the mesh surface
• Spacings – Ensure that for the resolution specified the cell spacings are reasonable

Import into Fluent™

• Another check was to ensure the mesh could be imported into Fluent™ – additional quality checks are also available in Fluent™
• Some solutions successfully carried out with the meshes with no indication of any issues
Mesh Evaluation (2)

- Adherence to mesh guidelines; from the guidelines the import factors were assumed to be
  - Initial wall spacing
  - Number of cells across trailing edges
  - 2 layers minimum
  - Grid growth ~ 3X for each resolution
  - Layer Growth ~ 1.25, 1.16, 1.1 for each resolution
  - Spacing's based on ~% of local chord
    - TE’s and LE’s ~ 0.27in
    - Body, Nose and Tail ~ 2.75in
    - Root and Tip ~ 1.15in
    - Wing, Flaps, Slat ~ < 1.0in

- Able to follow the guidelines fairly well, however not to exact specification
Mesh adaptation from solution

- Running CFD on the mesh
  - Get a solution after several hundred iterations
  - Not converged but allows extraction of Iso-Surface of key areas
  - Export this Iso-Surface (the wake behind wing) - turbulent viscosity ratio
  - Import this as a refinement region in BOXER

- BOXER Setup with Wake
  - Right shows mesh with volume refinement in the Wake region
  - Further refinements can be made easily from more iso-surfaces from CFD
Additional Topics

Future Technology

• We expect continued emphasis on automated, human-free meshing
• We expect continued emphasis on scalable meshing with no real limit on the complexity of geometry or size of mesh needed to resolve it & support the flow
• We expect continued integration of meshing with the supporting geometry engine driving it
• We expect geometry, meshing, conjugate aero-thermal-mechanical simulation – with post-processing – to be integrated in an end-to-end in parallel workflow
• Our BOXER activity illustrates our thinking in these areas and our progress towards these goals

Summary

• We are looking forward to comparing our meshes, from a deliberately general purpose mesh generator with strong tolerance to geometry defects, with meshes from very specialised & customised meshing systems targeted directly at aerospace
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