Generation of Curved Meshes for the High-Lift Common Research Model

Eloi Ruiz-Gironés and Xevi Roca

2022 AIAA Aviation Forum
Simulate the flow around the CRM-HL: Technology focus groups

High-order technology focus group: Geometry & flow

Mesh curving questions: Curving feasibility and mesh quality

1. Can 3D curved meshes be generated for the CRM-HL?  
   Without a mesh, there is no simulation

2. What quality metrics are used to evaluate high-order meshes?  
   Is the mesh good, *a priori*?

3. How well do the curved meshes conform to the actual geometry?  
   Does increasing polynomial degree increases geometric accuracy?
Prepare the geometry and generate the linear mesh:
Create curving-friendly inputs

- **Geometry repair and virtual model**
  - Water-tight geometry
  - **Virtual model:** virtually join entities according to simulation intent

- **Linear mesh generation requirements:**
  - **Simulation:** element size and shape
  - **Geometry:** enough resolution to obtain desired accuracy
  - **Curving:** curving-friendly mesh leads to easy curving process

- **Convert sequential inputs to parallel inputs**
  - Sequential inputs are bottlenecks
  - Create a hdf5 parallel input
Mesh Curving Methodology: curving step

Curve the linear mesh

• **Constrained optimization problem:**
  Minimize mesh distortion while approximating the virtual model

• **Mesh is always valid:**
  No need to introduce untangling

• **Virtual geometry aware:**
  Elements span several entities

• **Tight tolerances:**
  Fully converged meshes avoids element oscillations

• **Newton’s method with backtracking line-search:**
  Ensures quadratic convergence near solution

• **Distributed parallel:**
  All meshes curved with 768 processors
Check the curved mesh and create output file

- Mesh validity and quality:
  - **Mesh validity**: required for simulation
  - **Mesh quality**: facilitates simulation

- Visual inspection: Paraview in distributed parallel
  - **Location of low-quality elements**: remesh area
  - **Boundary mesh accuracy**: increase resolution

- Curving iterative process:
  - **Geometric accuracy and element quality**: Candidates to remesh

- Create output file
  - **cgns output**: python wrapper of cgns library
CRM-HL virtual model

- **Virtually join surfaces**: Simulation intent
  Decouple geometry and mesh topology
  - **One virtual surface on**: fuselage, nacelle, wings, ...

- **Surfaces**: From 415 original surfaces to 215 virtual surfaces
  - **Keep leading edges**: improves the mesh
  - **Mesh smoothness**: Smooth virtual surfaces → smooth curved mesh

Virtual surfaces: top view

Virtual surfaces: bottom view
Mesh curving results

- **Two sets of meshes:** $Q = 2$ and $Q = 3$, with same linear mesh
  - **Boundary layer:** Isotropic, $Y^+ = 800$, $Y^+ = 200$ and $Y^+ = 100$

- **Mesh analysis** (see paper for full analysis)
  - **Element quality:** Valid mesh & high-quality elements
  - **Accuracy:** relative to aircraft length $\sim 10^{-7} - 10^{-6}$
  - **Computational resources:** order of minutes with 768 processors
Mesh curving difficulties: geometry and mesh

Difficulties when curved mesh is low-quality or inverted

- **Thin regions**: small feasible region $\rightarrow$ high distorted elements  
  **Solution**: Match element resolution with region width

- **Unfeasible to curve**: tangent curves (e.g. WUSS) $\rightarrow$ tangled element  
  **Solution**: Keep straight-edged triangle
Can 3D curved meshes be generated for the CRM-HL?

Yes, we can! But we need curving-friendly:

1. Virtual models:
   • No curve/surface tangencies → valid curved meshes
   • Smooth virtual surfaces → smooth curved mesh surfaces

2. Linear meshes:
   • Accounting for thin regions and tangencies → Facilitates curving

Bottlenecks: Geometry and linear meshing

• 1. + 2. takes days of tunning:
  Curving a single mesh takes minutes

• Sequential linear mesh generation: Only sequential part
  Largest mesh determined by the workstation memory
What quality metrics are used to evaluate high-order meshes?

1. Mesh validity and element quality:
   - **Scaled Jacobian**: Check the element linearity
   - **Relative shape distortion**: Check the element distortion
   Both qualities check validity

2. Geometric accuracy: Three equivalent measures
   - **Max point-wise distance**: largest distance, target triangles to refine
   - **Average point-wise distance**: average distance, global view
   - **L₂-average point-wise distance**: average, penalizes large values

Use all of them to obtain more information
How well do the curved meshes conform to the actual geometry?

- **Relative to aircraft length** ($\ell_c = 2470$):
  - Max: $\sim 10^{-5} - 10^{-4}$
  - Average: $\sim 10^{-7}$
  - $L_2$-Average: $\sim 10^{-7} - 10^{-6}$

- **Higher polynomial degree, better accuracy**:
  - Function space is richer

- **Geometric accuracy depends on the boundary mesh**:
  - Element size and topology of the surface linear mesh
  - Consequently, no $Y+$ influence

- **We need tools to predict element size**:
  - Otherwise, trial & error
  - For a given $Q$, which $h$ do I need?
Concluding Remarks

- We must improve pre-process time because mesh curving time is negligible

- Preparing curving-friendly inputs for the CRM-HL takes days

- Mesh curving for the CRM-HL takes minutes
Thank you for your attention!

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme under grant agreement No 715546.