Rapid Hypersonic Simulations using *US3D* and *Pointwise*

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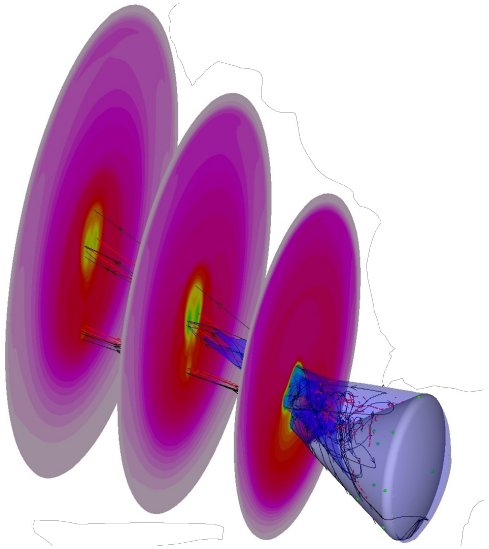
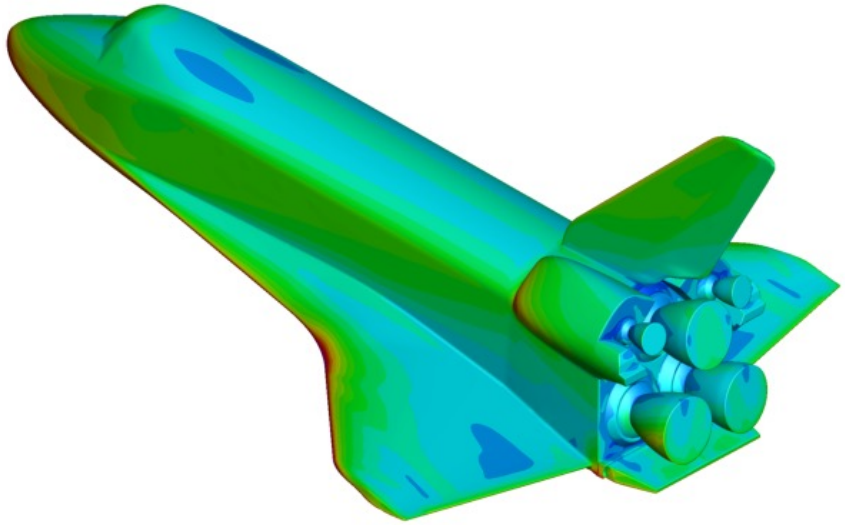
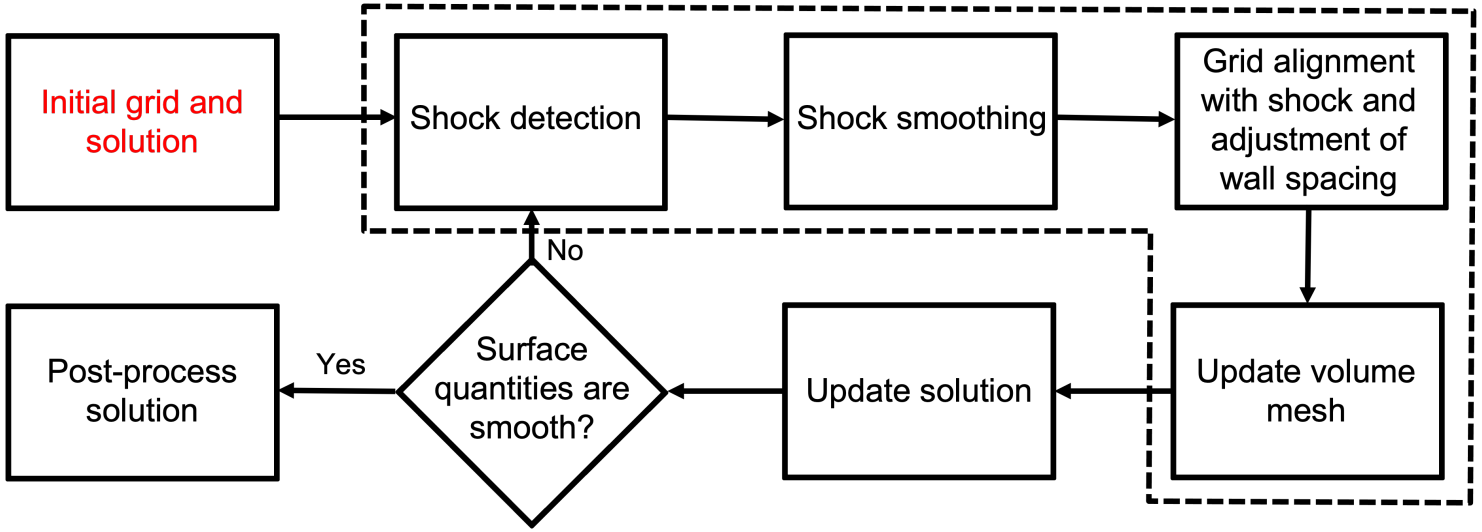
Overview



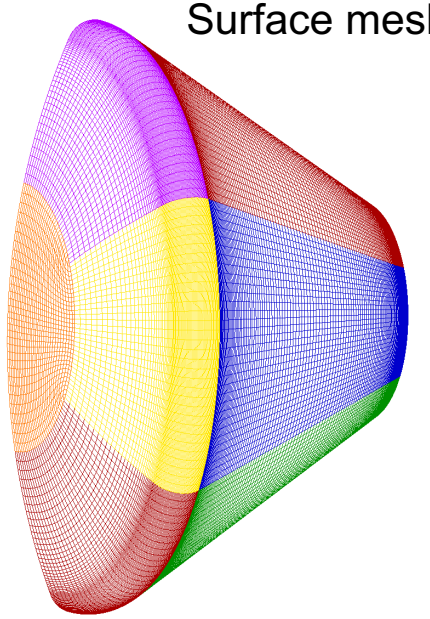


- Point-matched, structured grid flow solvers (*DPLR*, *LAURA*) have proven to provide accurate heating estimates for many hypersonic applications
- **Issue:** For complex geometries, structured grid generation is tedious and often a bottleneck in the simulation process
- **Goal:** Present an alternative framework using unstructured grid generation (*Pointwise*) and unstructured flow solver (*US3D*) that simplifies the grid generation/adaption process, resulting in faster turnaround times for hypersonic simulations
- To illustrate differences between structured vs. unstructured workflows, two examples are presented: a simple geometry (Orion capsule) and a complex geometry (Space Shuttle)

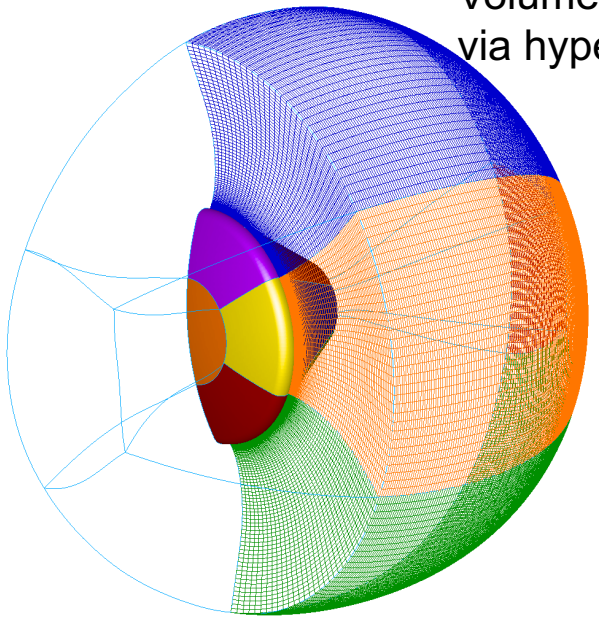
Workflow for Structured Grids (Smooth Orion Capsule)



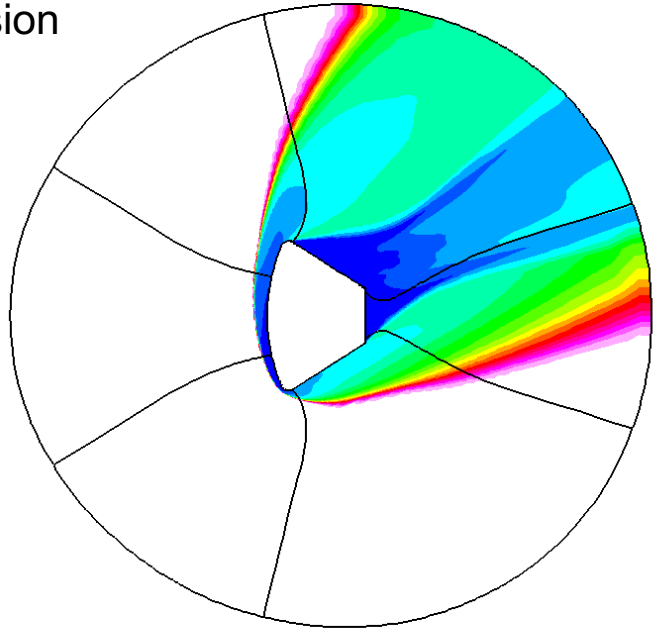
Surface mesh



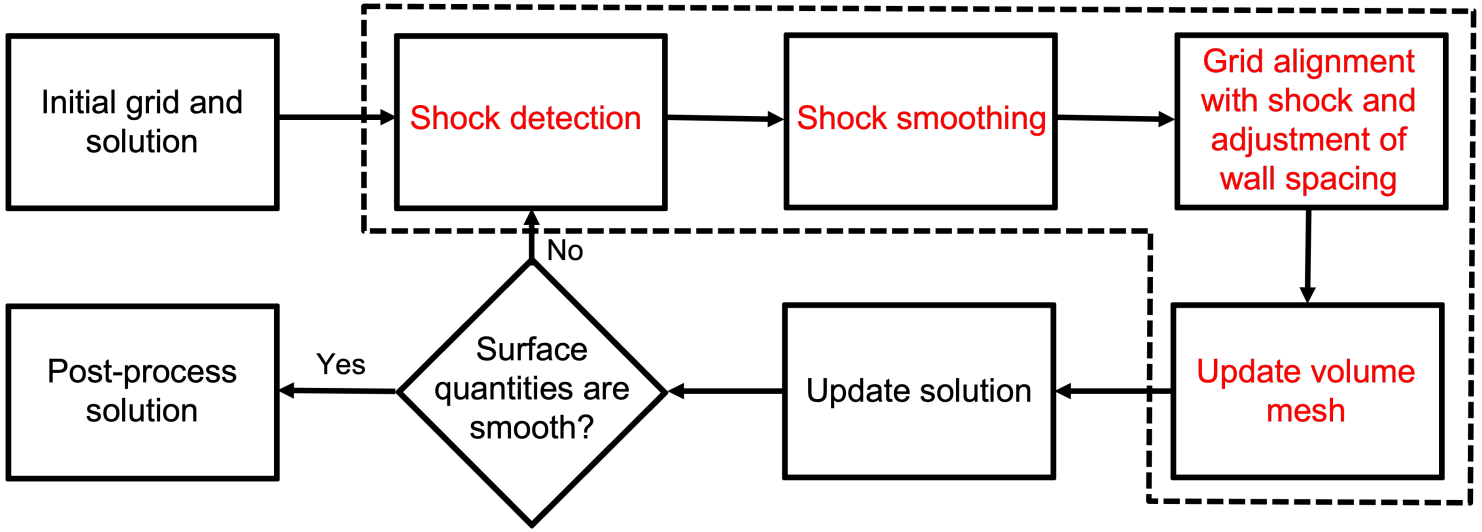
Volume mesh generation via hyperbolic extrusion



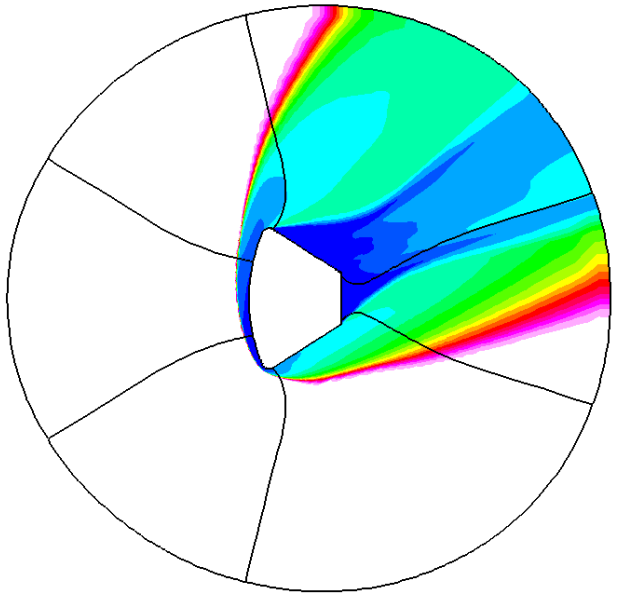
Initial solution ($M_\infty = 20$, $\alpha = 18^o$)



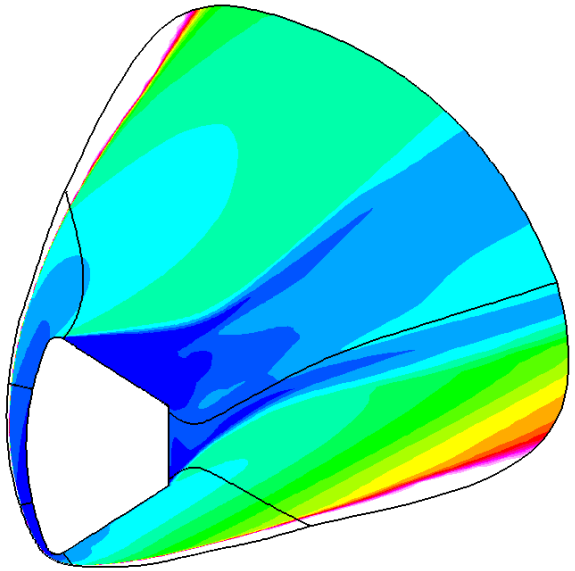
Workflow for Structured Grids (Smooth Orion Capsule)



Initial solution at pitch plane

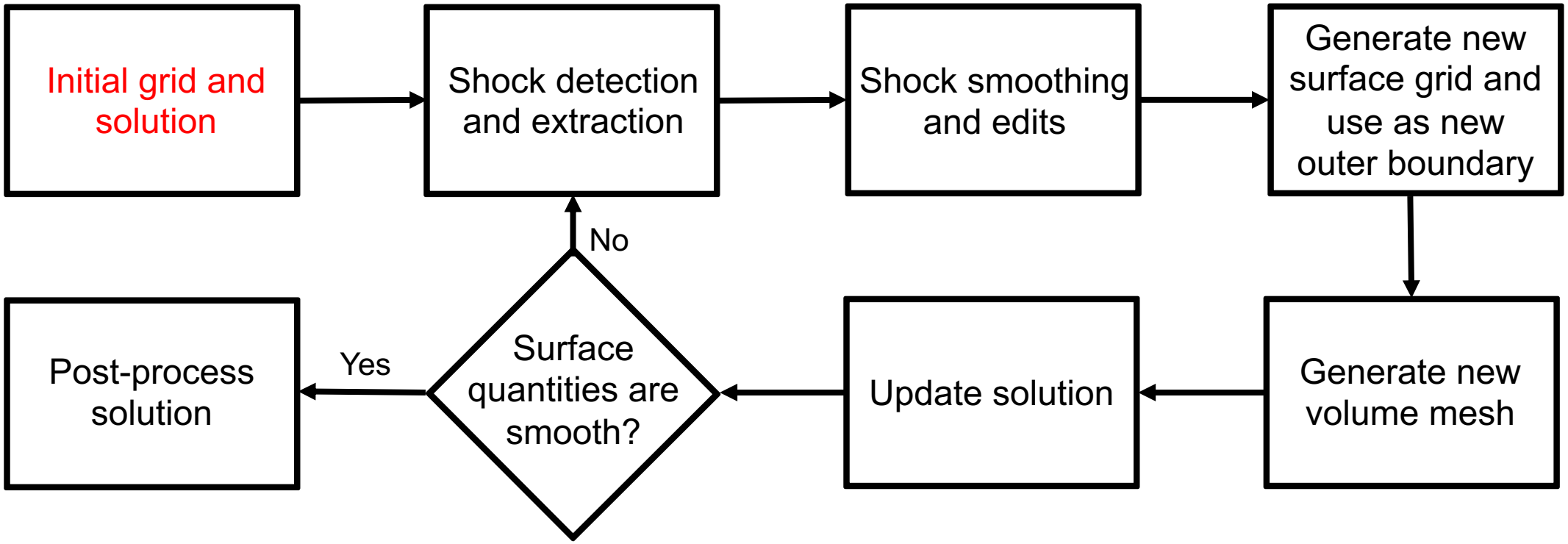


Solution after 3 adaptions

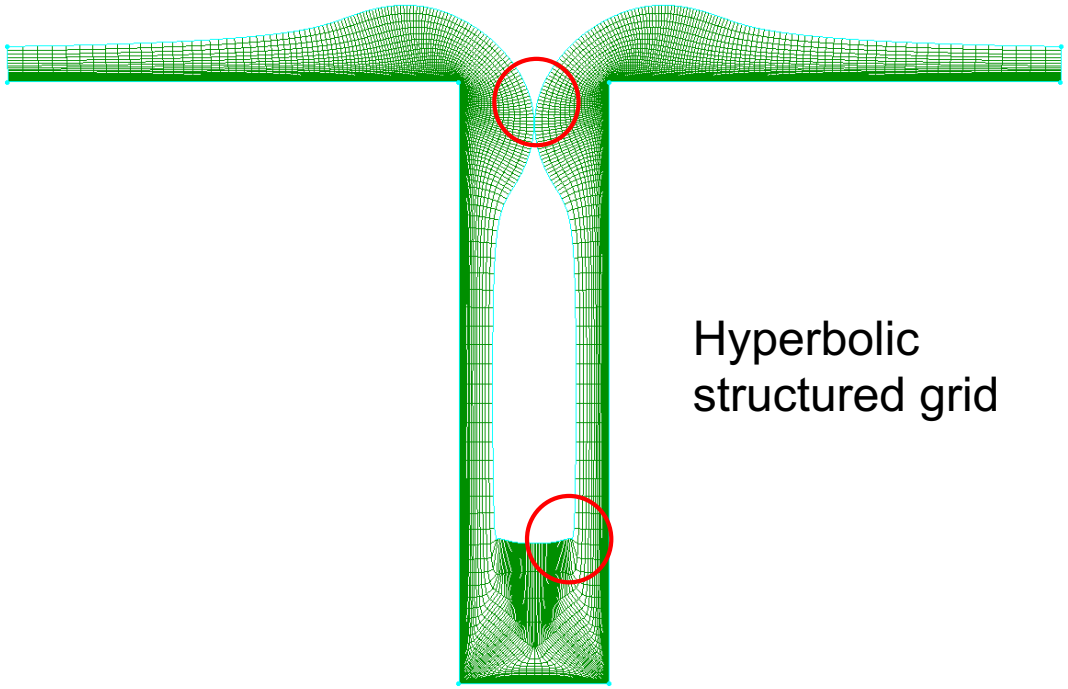


- Built-in grid adaption algorithm in *DPLR* is user-friendly and fast (~ 3-5 CPU mins)
- However, adaption algorithm only works for a very specific grid topology (a **single** layer in body-normal direction [k] that spans from wall surface to outer boundary)
- For a different grid topology, these steps need to be done outside of *DPLR*

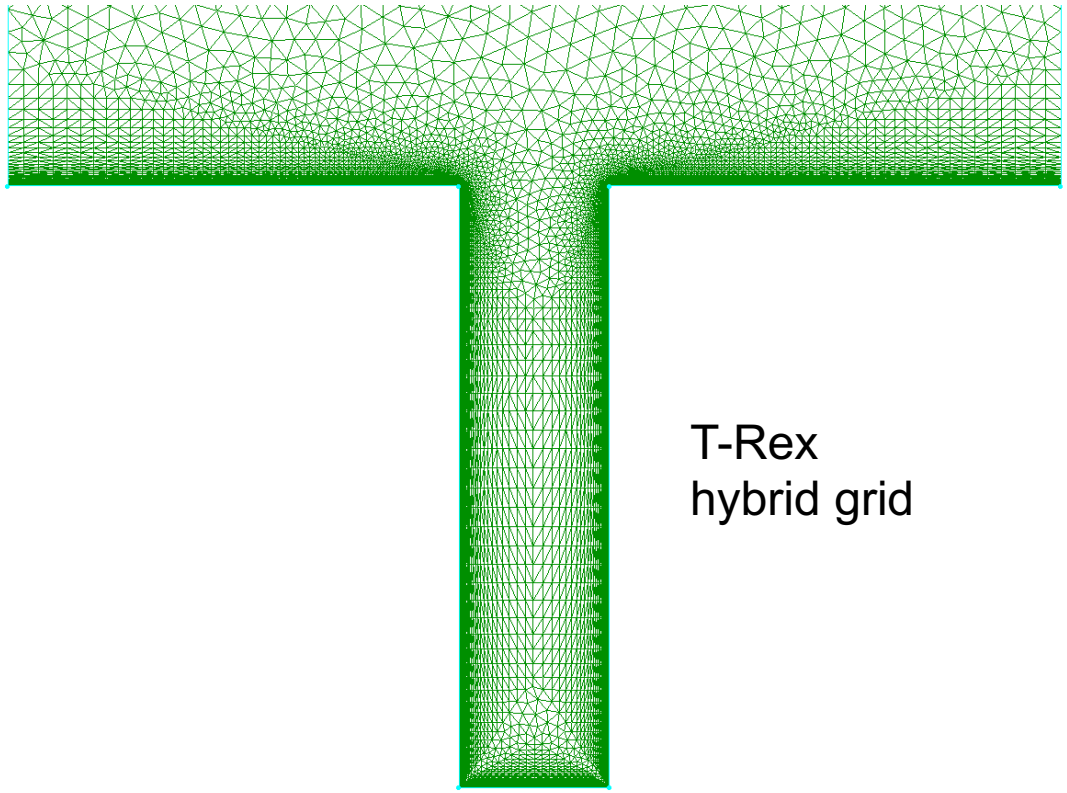
Workflow for Unstructured Grids (Smooth Orion Capsule)



T-Rex Unstructured Grid Generation (2D Cavity Example)



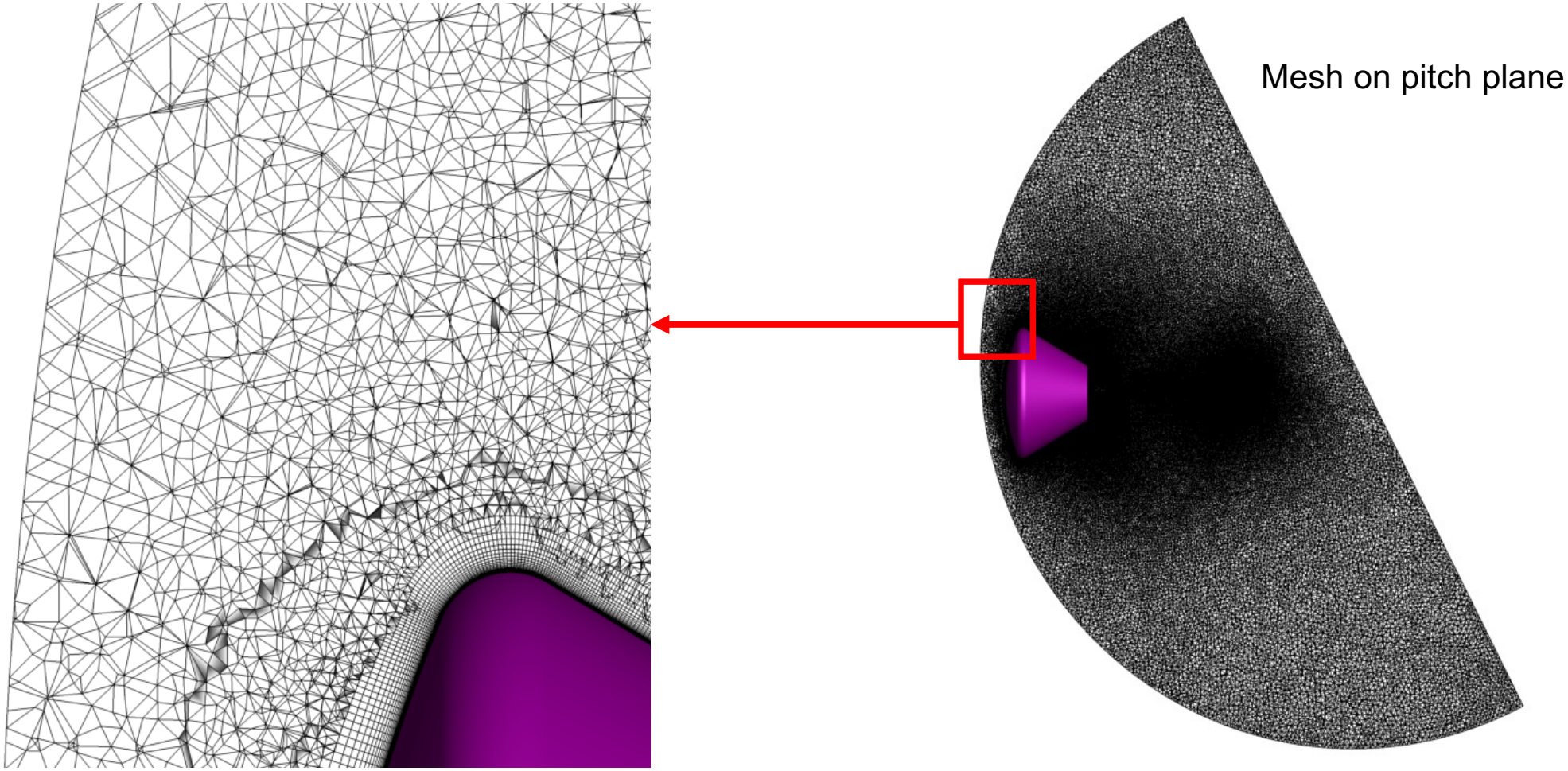
Hyperbolic
structured grid



T-Rex
hybrid grid

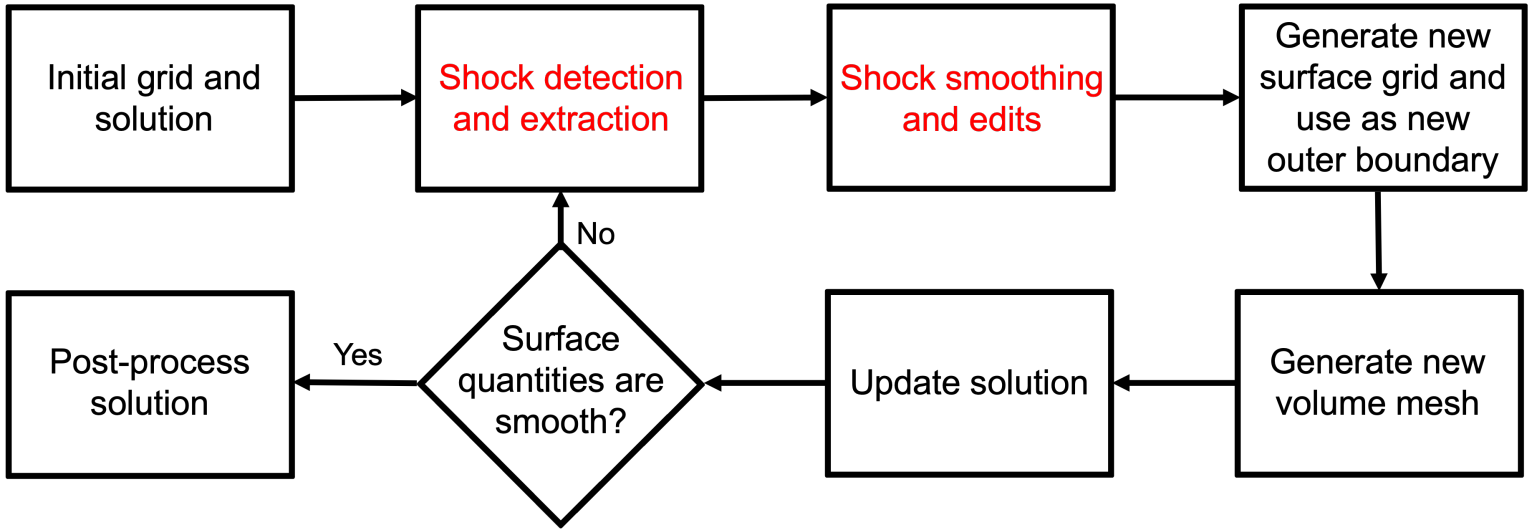
- T-Rex: Hybrid meshing using 3D anisotropic tetrahedral extrusion
- Each surface point is extruded and checked for collision. If the collision test fails, the extrusion process stops locally for that point.
- The marching front continues until all collision tests fail or user-specified number of layers is reached
- The remaining region is filled by a Delaunay-based, isotropic meshing method

Unstructured Grid Generation with T-Rex (Orion Capsule)

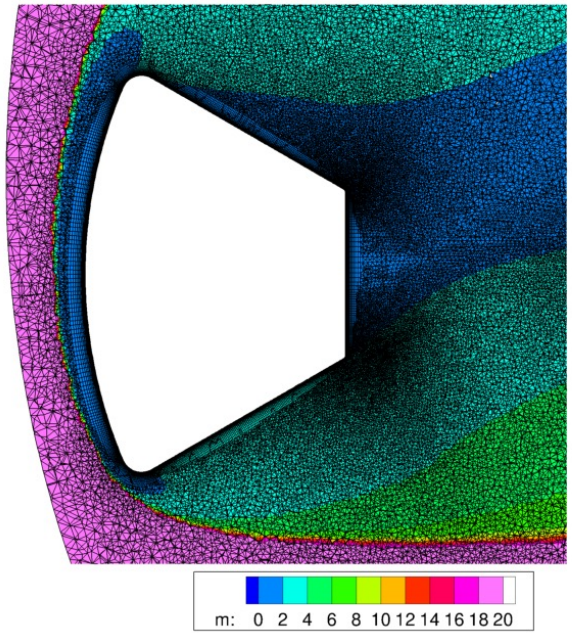


- T-Rex mesh generation is well-automated, robust, and fast (~10 CPU mins for a 10.5M nodes mesh)

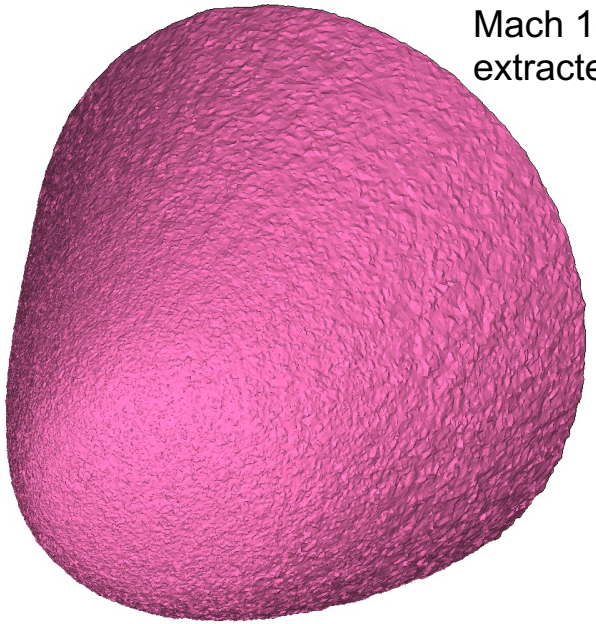
Workflow for Unstructured Grids (Smooth Orion Capsule)



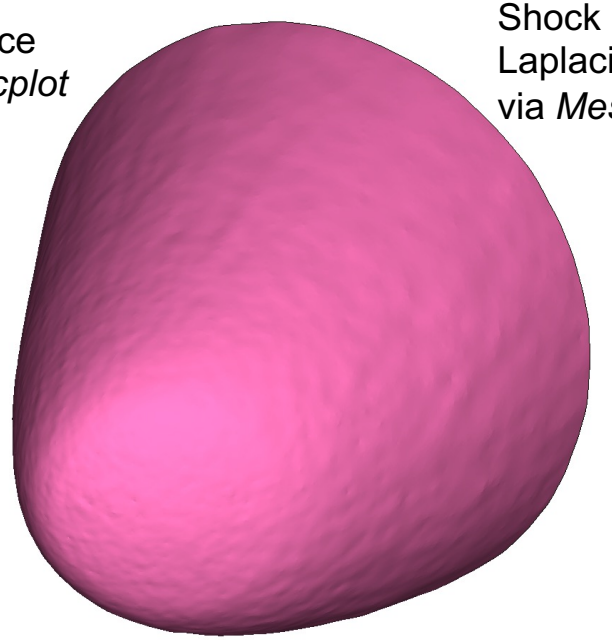
Mach contours on pitch plane



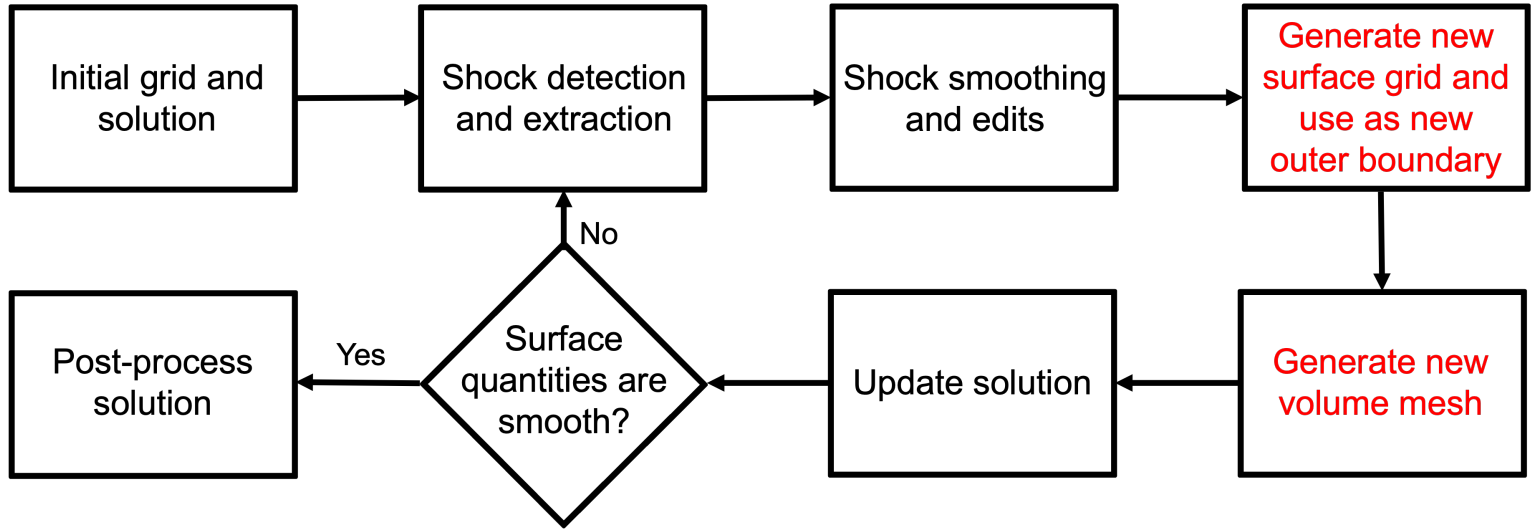
Mach 18 iso-surface extracted from *Tecplot*

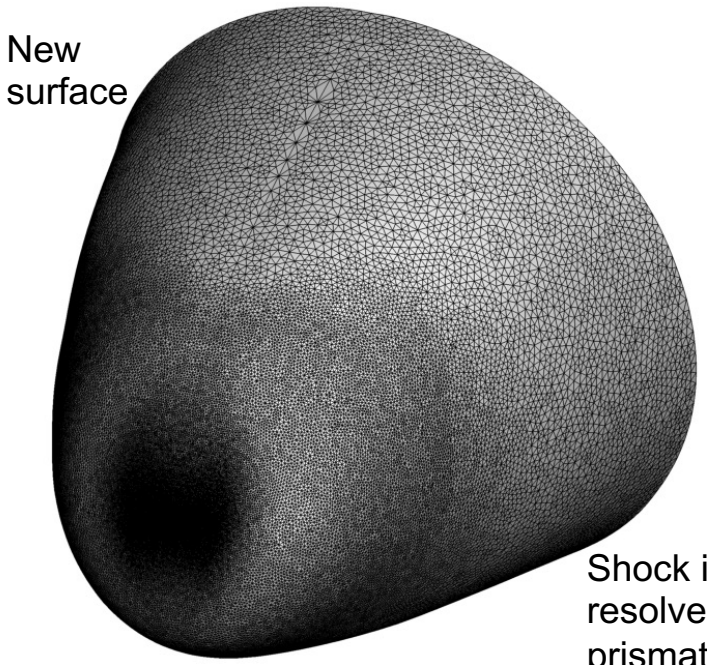


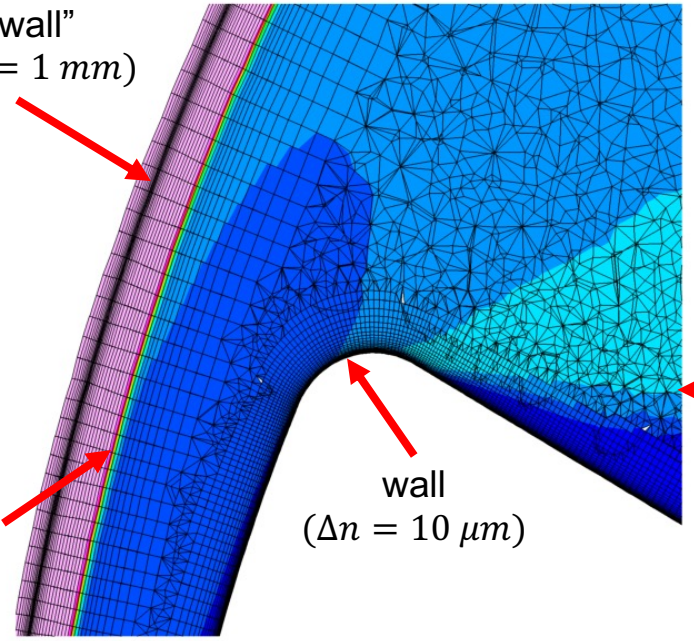
Shock surface with Laplacian smoothing via *MeshLab*

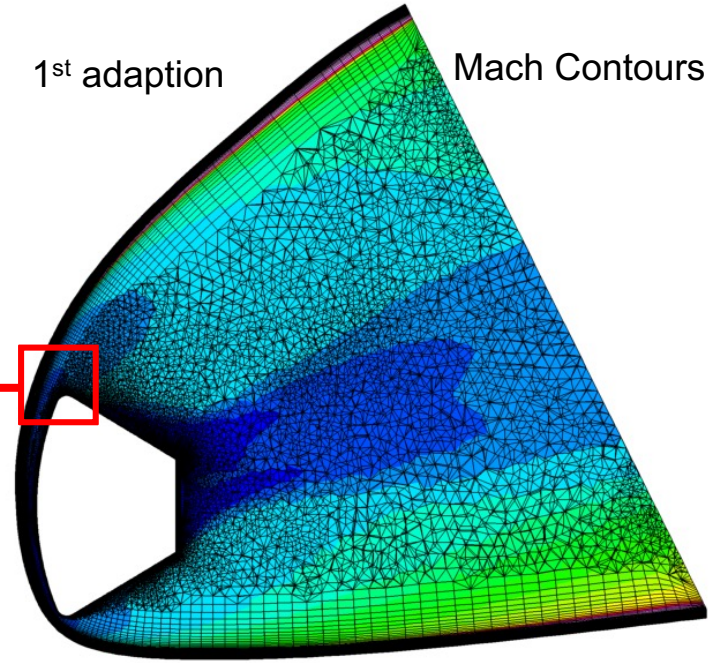


Workflow for Unstructured Grids (Smooth Orion Capsule)

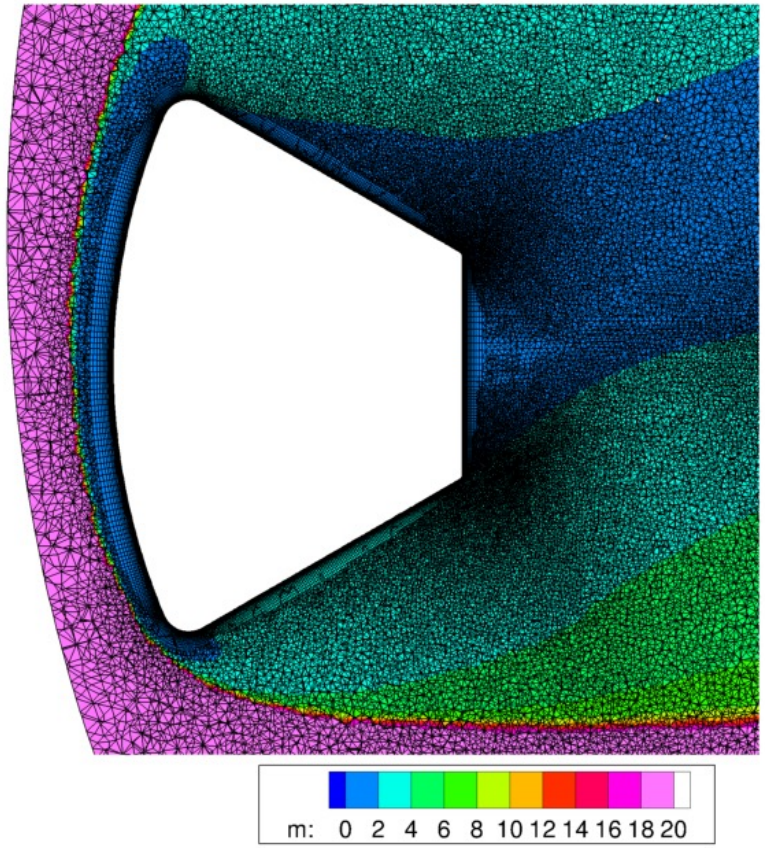




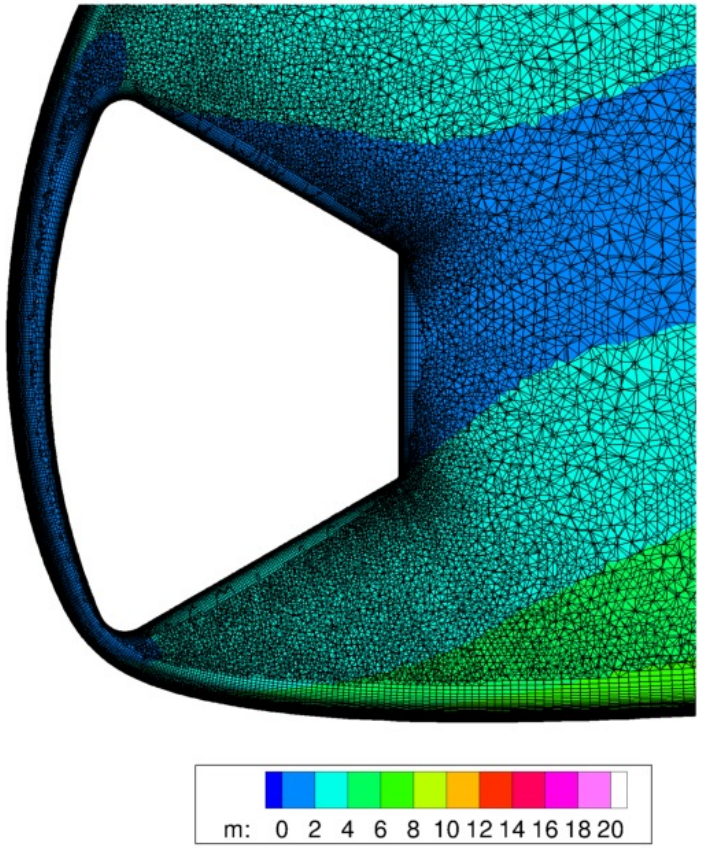




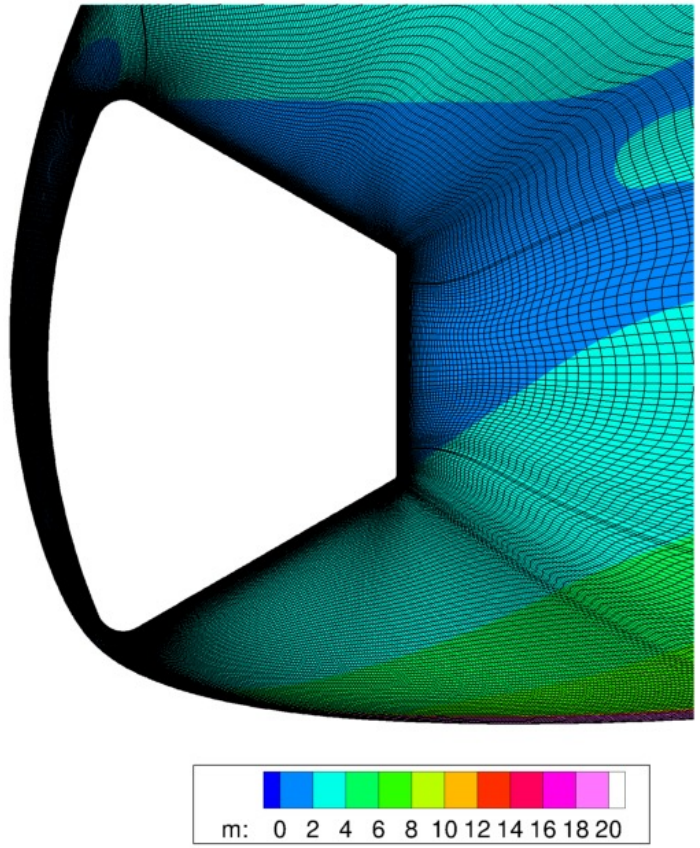
Comparison of Centerline Mach Contours



Initial unstructured grid
(*US3D*)

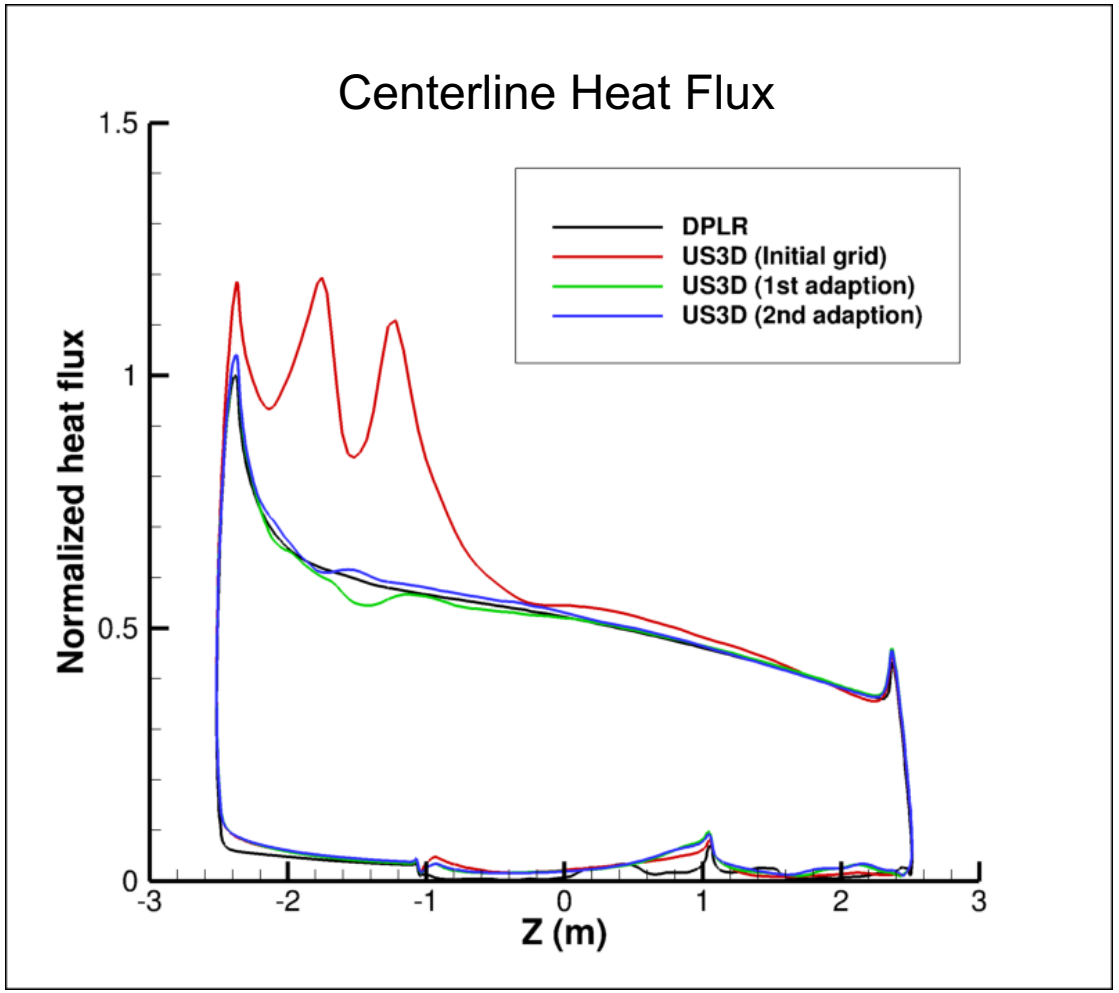


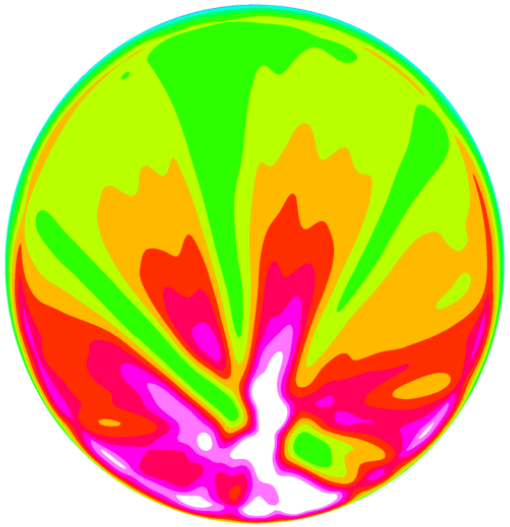
Final adapted unstructured grid
(*US3D*)



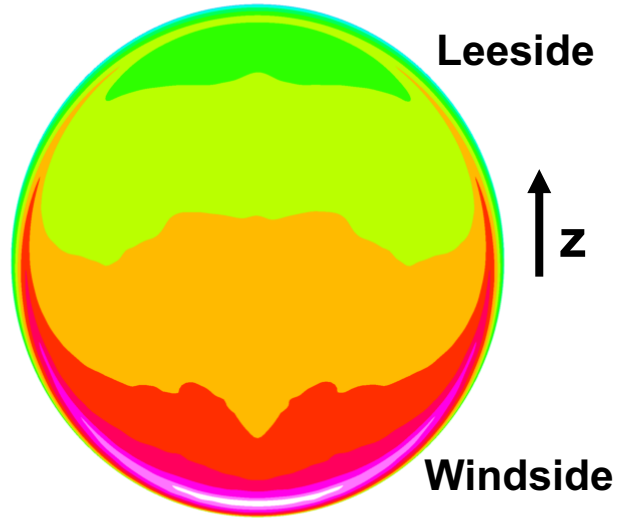
Final adapted structured grid
(*DPLR*)

Comparison of Surface Heating (Laminar, 5-sp Air, M_∞= 20, α = 18º)

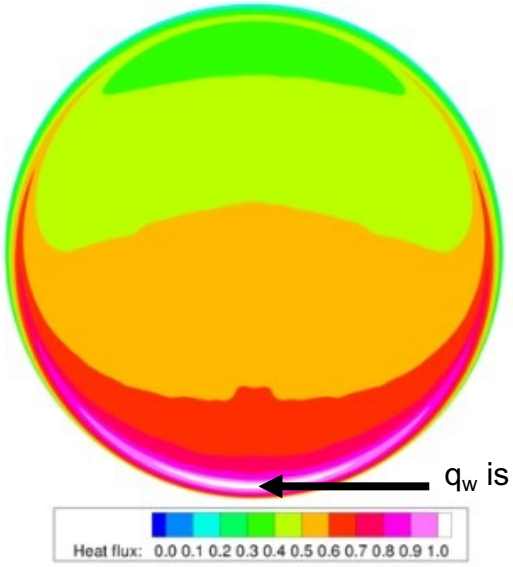




Initial solution (*US3D*)

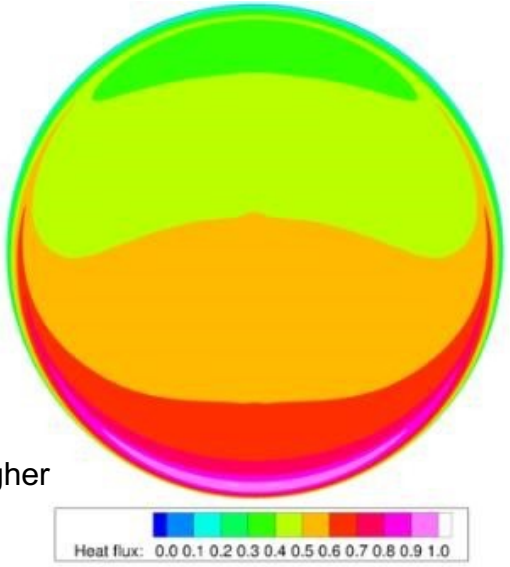


1st adaption (*US3D*)



q_w is 4% higher

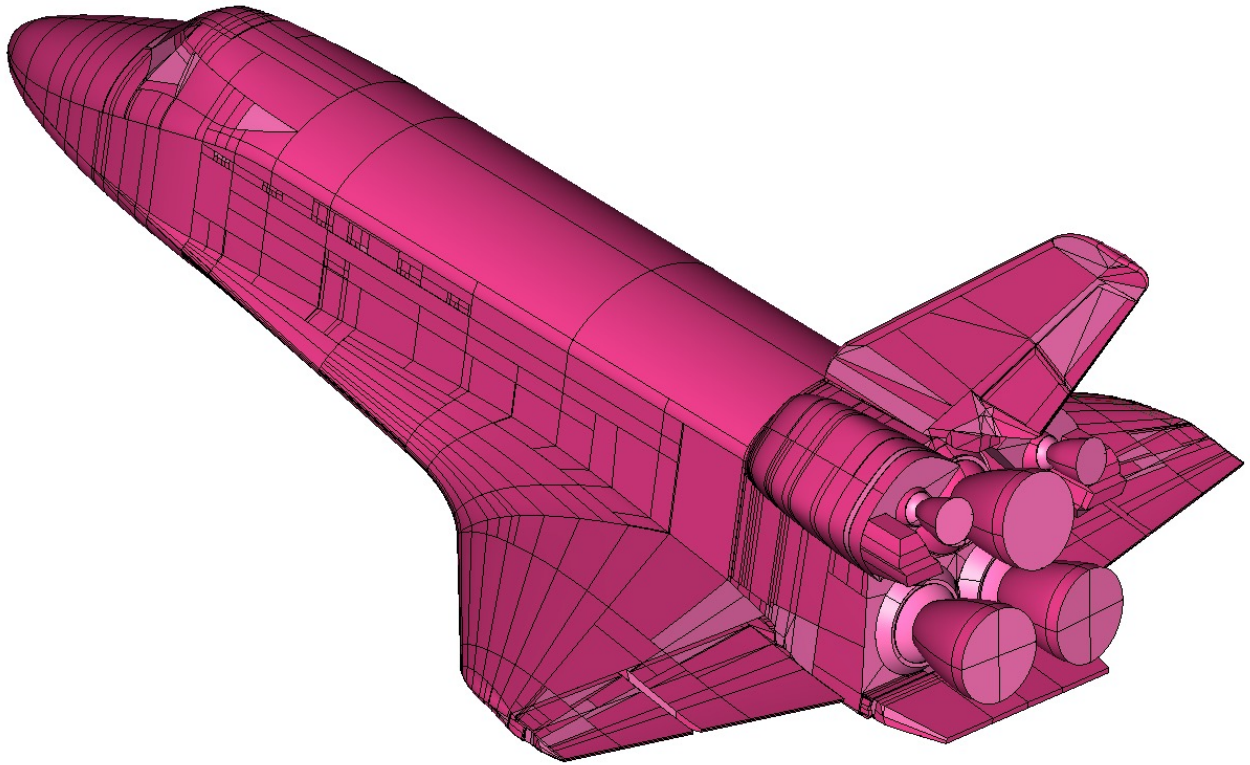
2nd adaption (*US3D*)



Adapted *DPLR* Solution

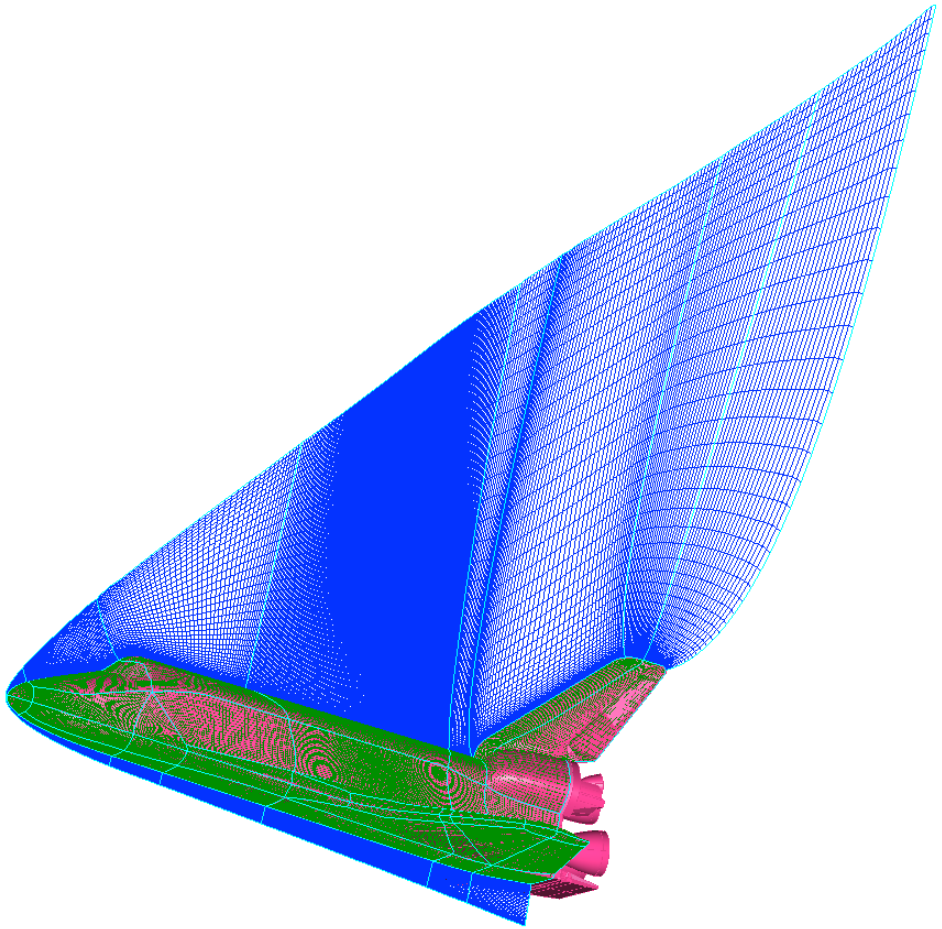
Example of a Complex Geometry (Space Shuttle)

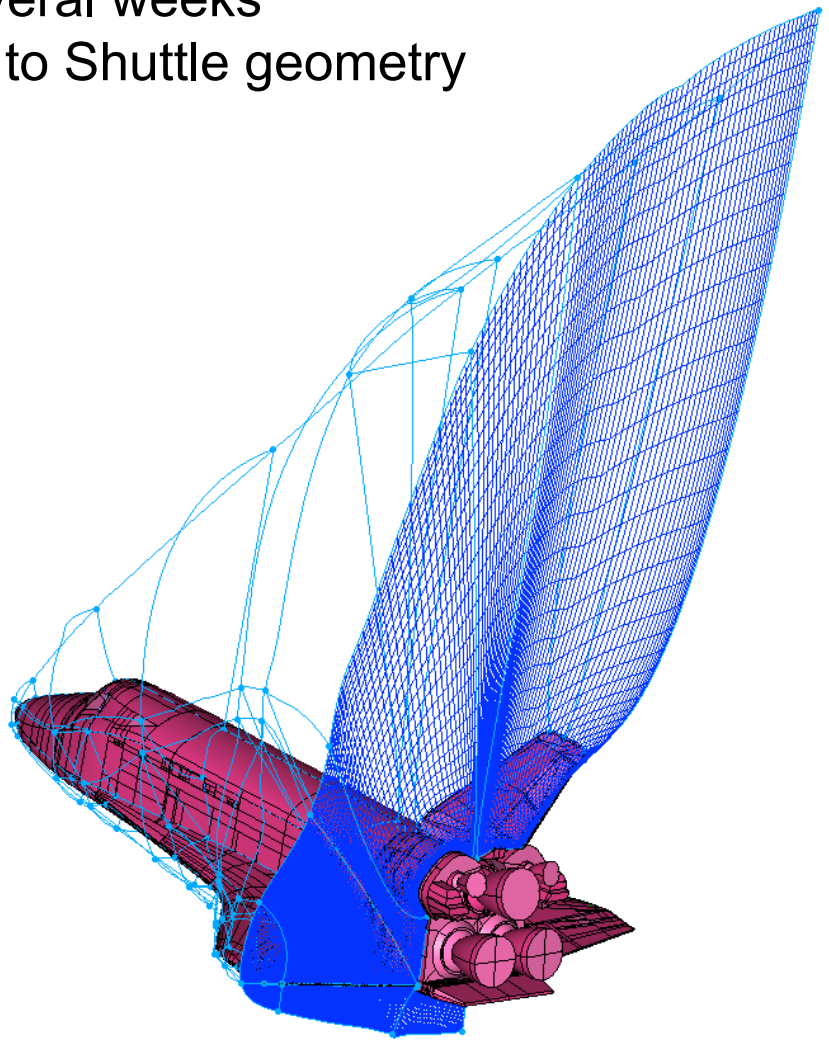
- Back in 2004, ARC and LaRC team members were tasked with running hypersonic Shuttle simulations to support Return-to-Flight and subsequent missions
- The goal was to have CFD solutions at various points along nominal trajectories so we can use them during mission support
- How do you generate a single-layer, structured grid for this complex geometry?



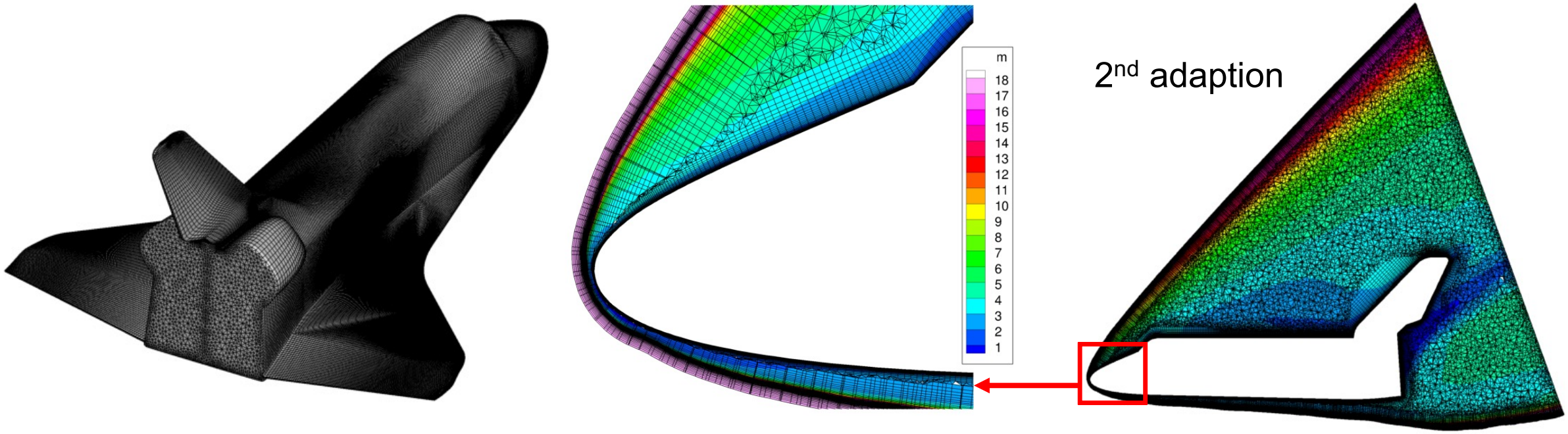
Structured Grid for Space Shuttle

- Geometry was simplified (e.g., aft end was not modeled) to enable the creation of a single-layer structured grid
- Grid was handcrafted by skilled users, and it took several weeks
- A leap in skill level required to go from Orion capsule to Shuttle geometry



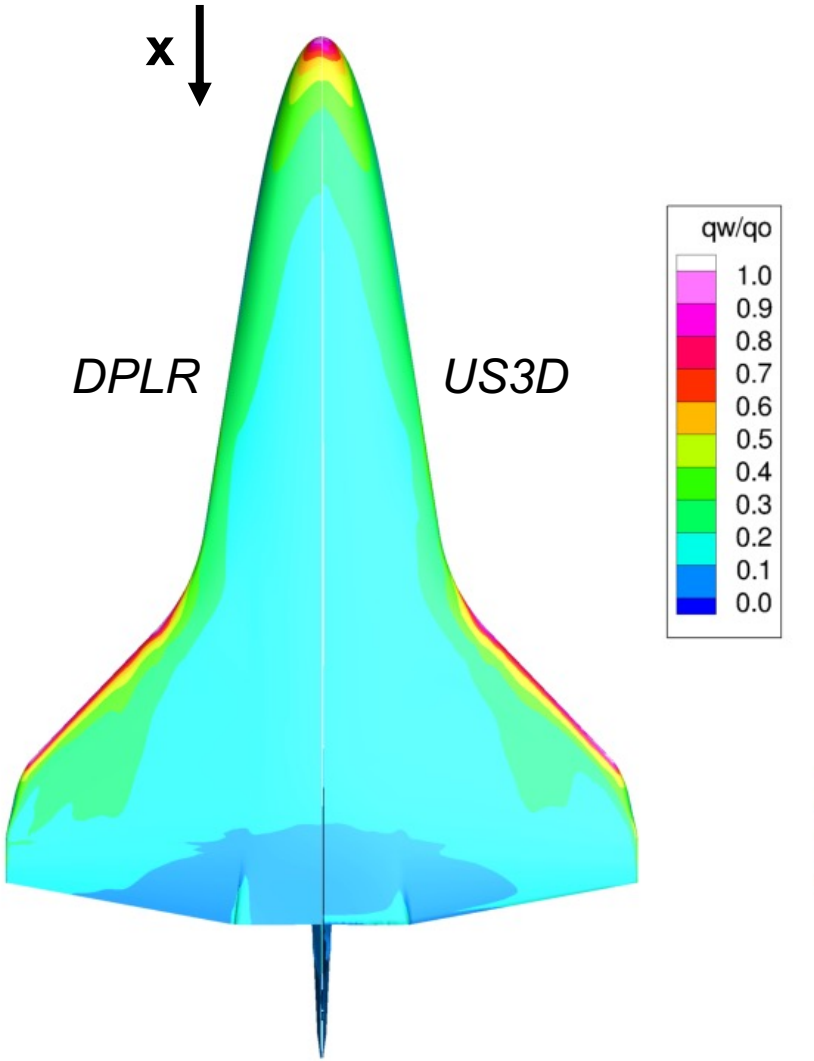


Unstructured Grid for Space Shuttle

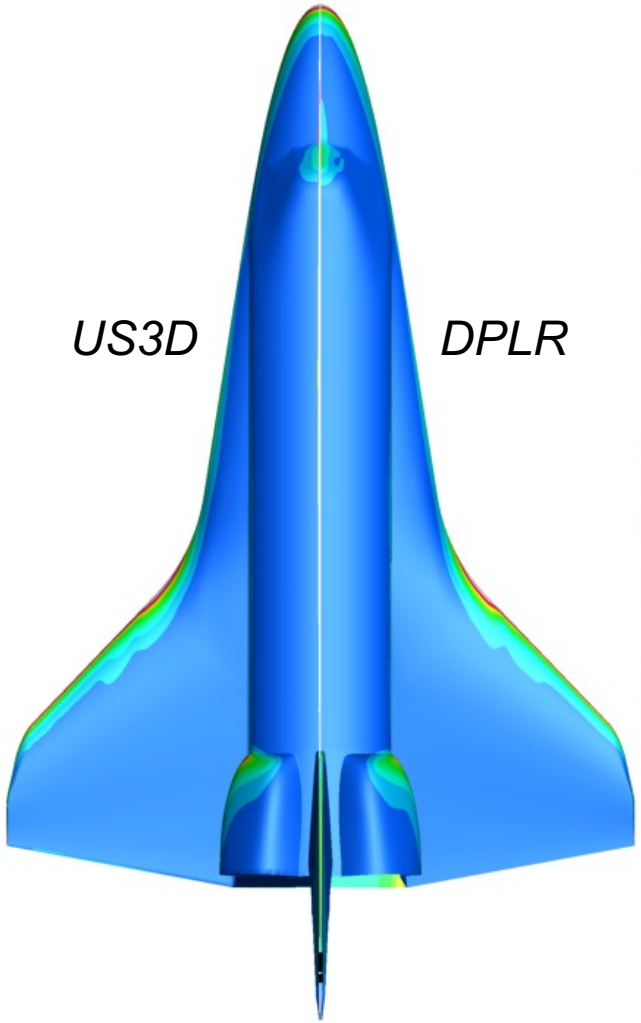


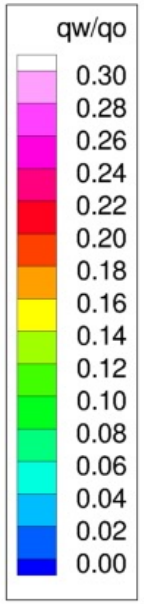
- Grid is closed off to form a watertight surface
- Same workflow using T-Rex to generate hybrid volume grid (~18 CPU mins for 14.6M nodes grid)
- In general, unstructured hybrid grids are less stable numerically than single-layer, structured grids because the solver switches from implicit line relaxation (in the boundary layer) to point relaxation (outside the BL). Lower maximum CFL permitted so slower convergence.

Comparison of Surface Heating (Laminar, M_∞= 17.9, α = 40º)

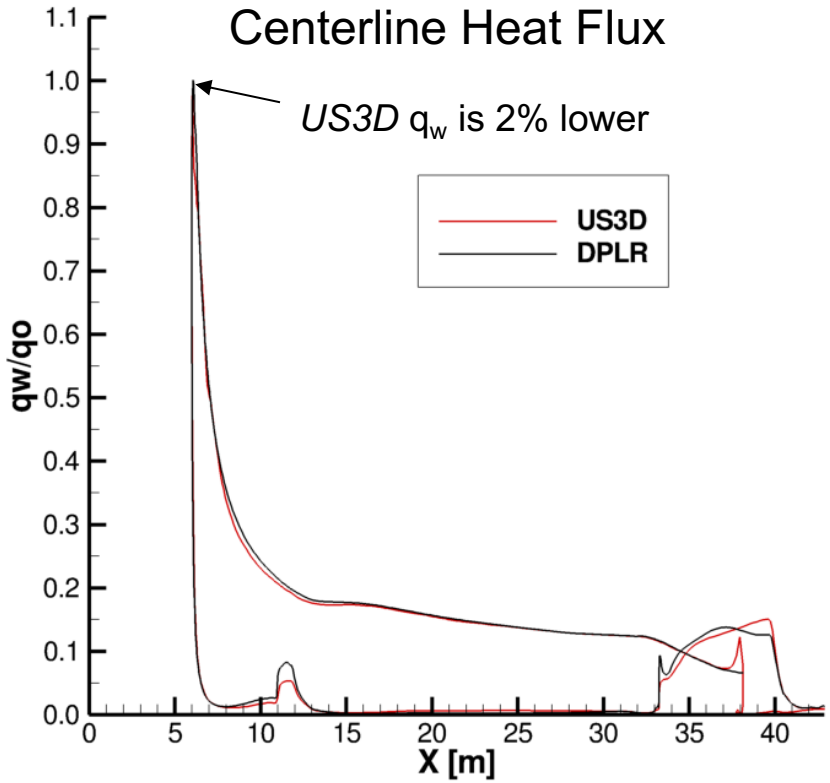


Windside

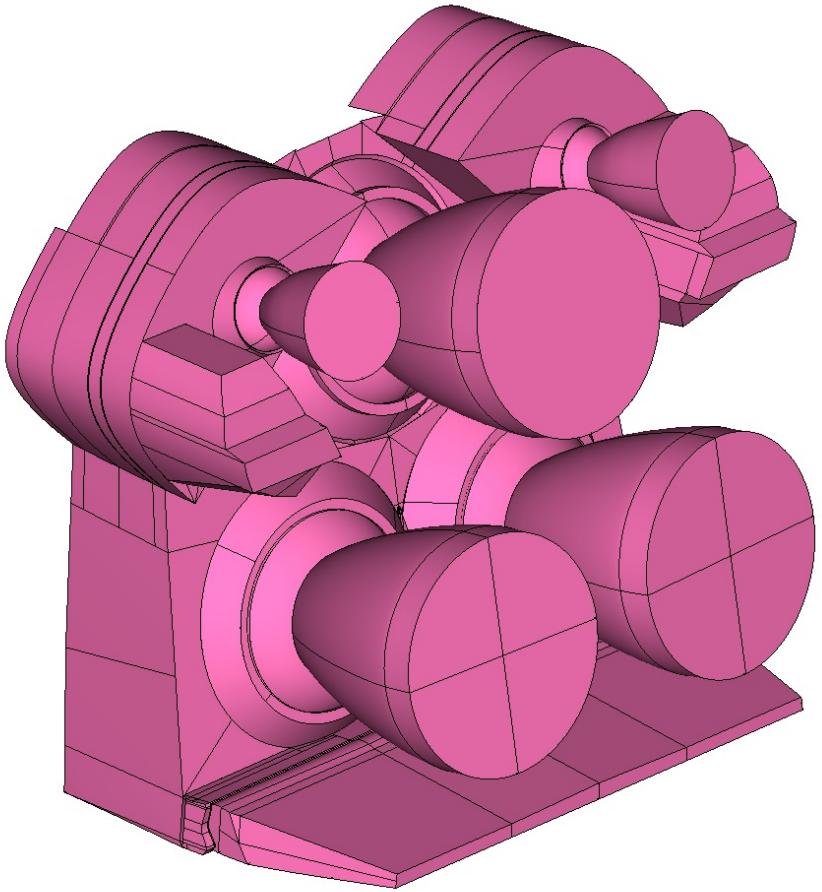




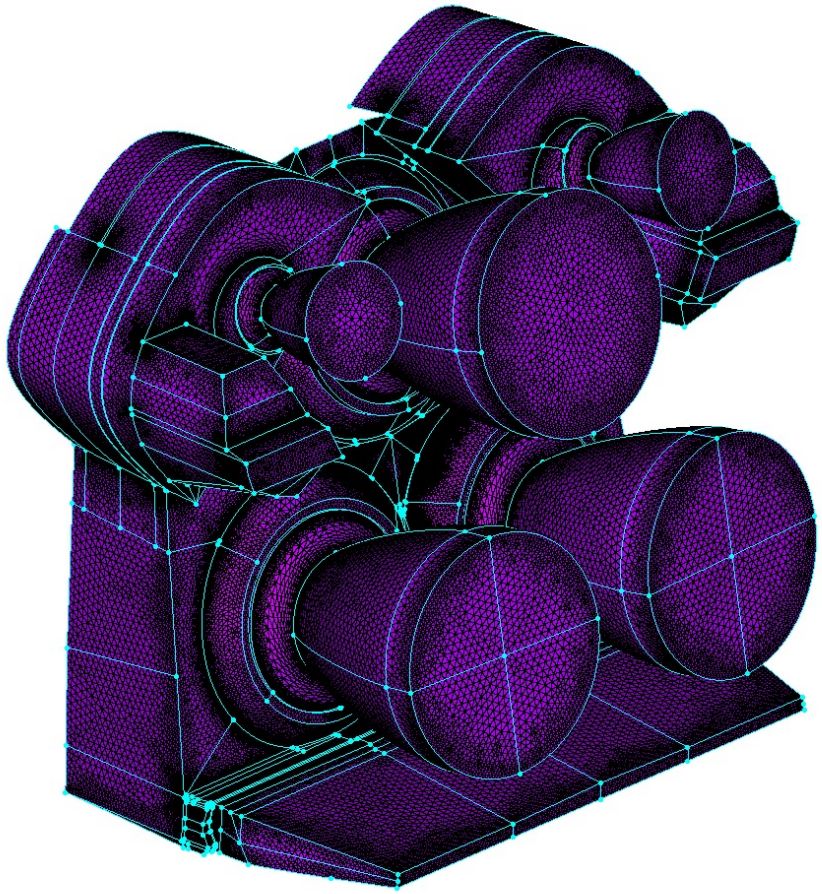
Leeside



Automatic Surface Mesh Generation in *Pointwise*

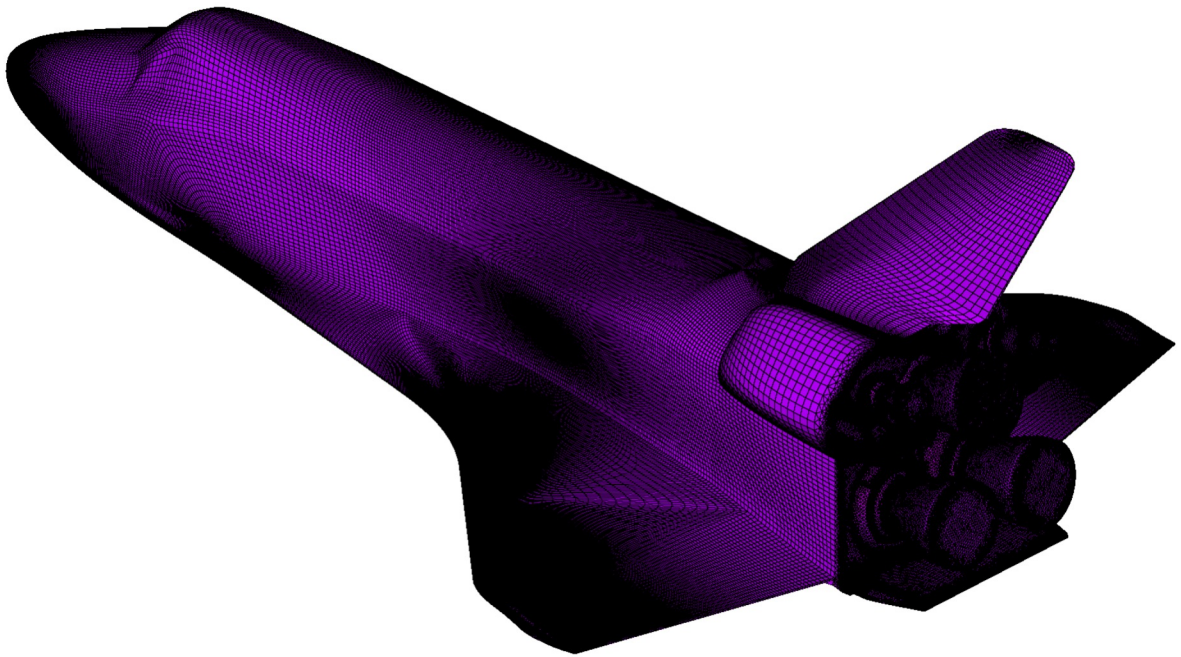


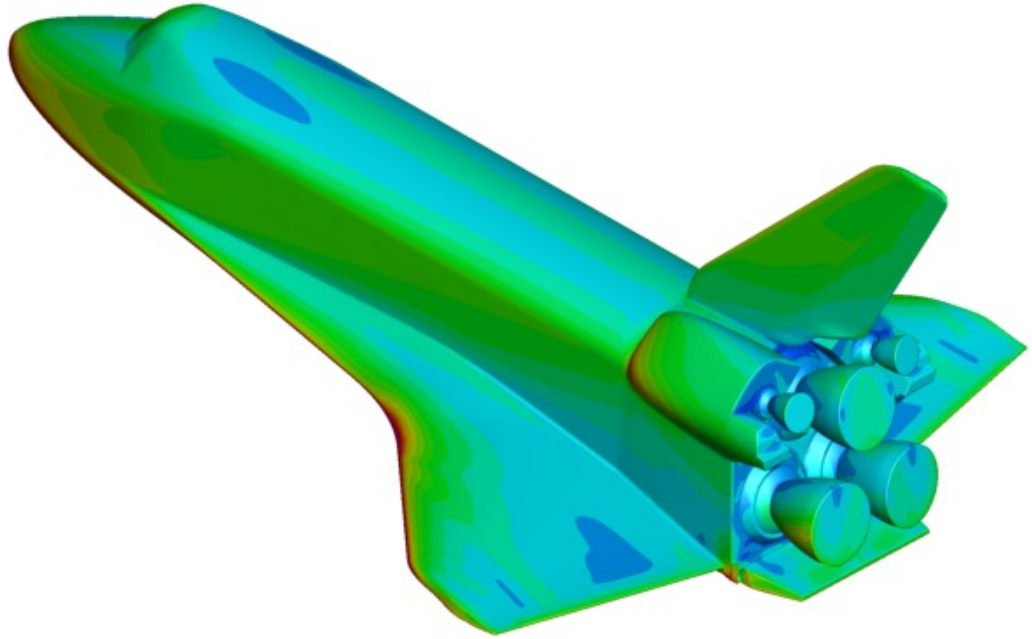
CAD Geometry

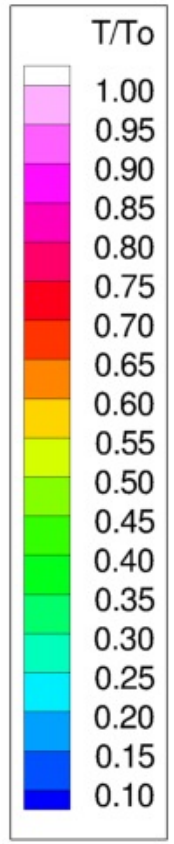


- Automatic surface mesh generation (~ 90 CPU sec)
- Additional time to remove surface features and adjust cell size (~ 2-3 hours)

New Unstructured Shuttle Grid and Solution

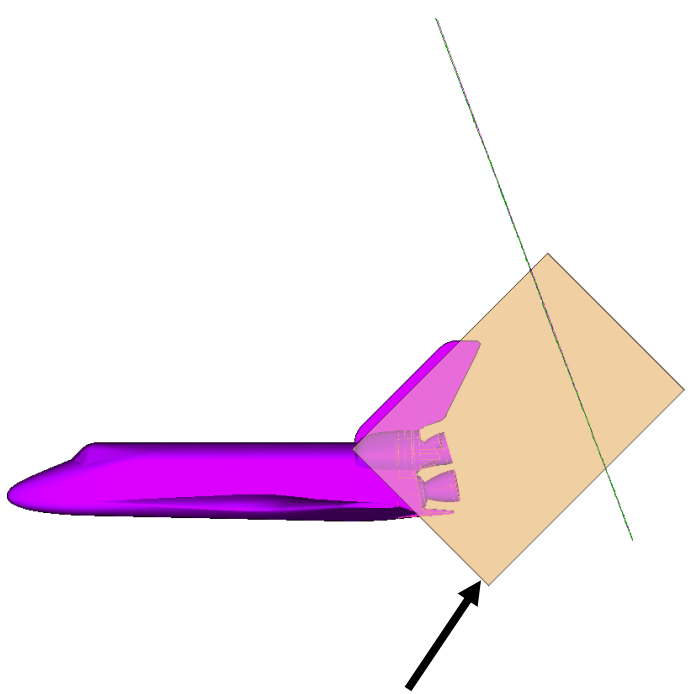


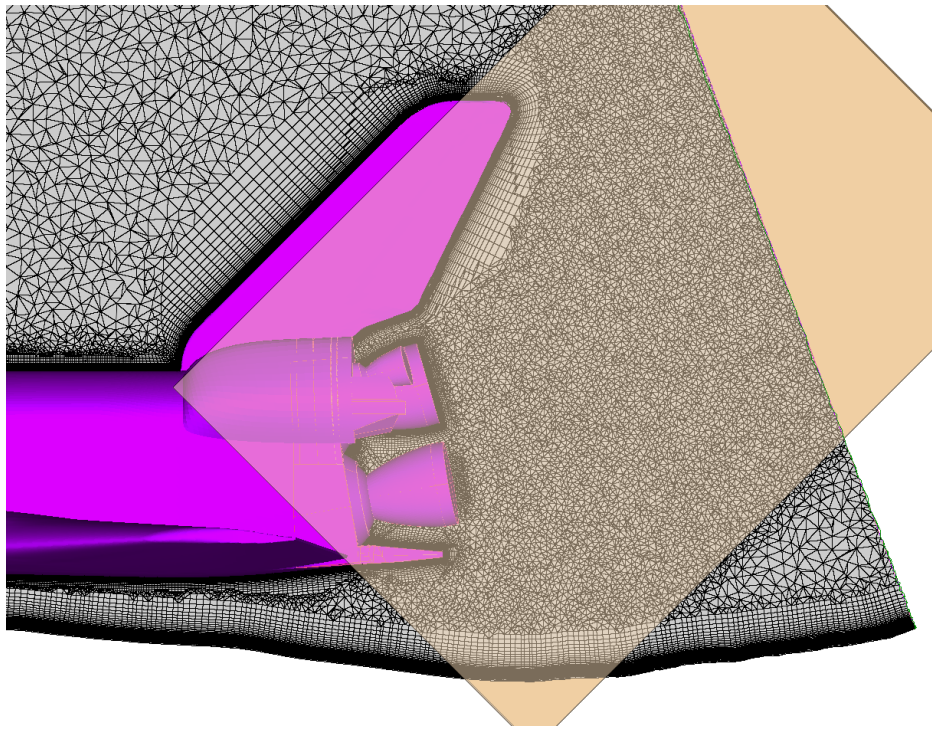


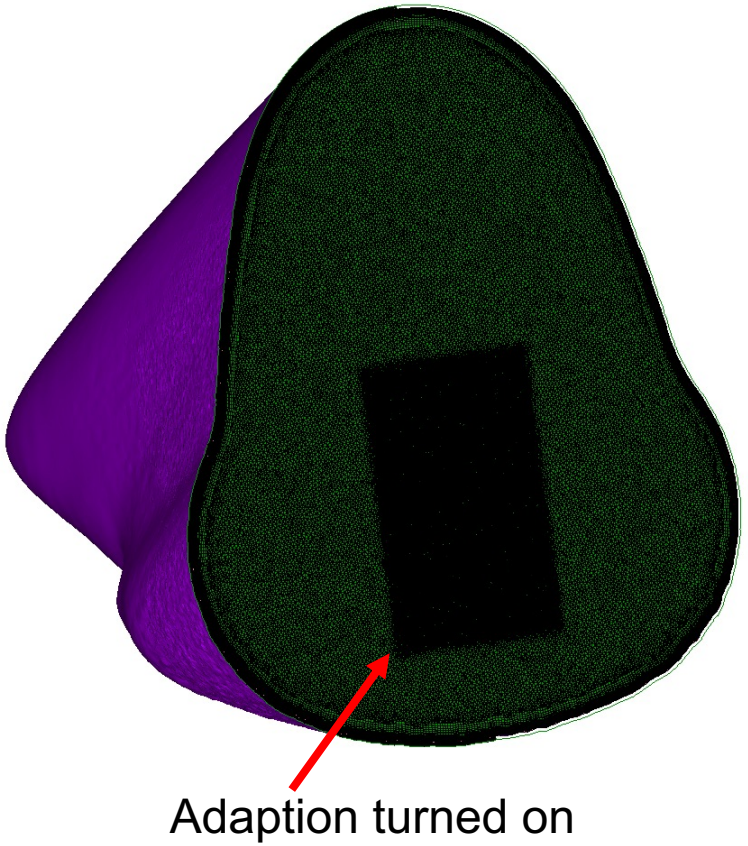


- Easy to combine structured and unstructured surfaces
- T-Rex used to create hybrid volume grid (~ 21 CPU mins for 17.9M nodes mesh)
- Total wall-clock time to generate a hybrid volume grid from CAD file ~ 1 day
- How long to generate a point-matched, structured volume grid?

Mesh Refinement Using Sources







- Sources can be added in T-Rex to refine regions of interest
- Surfaces can be selected to adapt to sources
- Since wall surfaces are defined by CAD, refined surface grids match CAD geometry
- Well-suited for adding automatic mesh refinement to unstructured workflow

Concluding Remarks

- Proposed workflow using unstructured grids/solver offers a viable and promising alternative to traditional structured grid methods
- For complex geometries, unstructured grid generation is fast and simplifies the mesh generation/adaption process
  - Automatic surface mesh generation in *Pointwise* is well-automated
  - Even for complex geometries, T-Rex hybrid grid generation is easy to implement
  - Method is fast and robust
- Unstructured grids allow for great flexibility in modifying existing grids and mesh refinement
  - Well-suited for adding or deleting grid points to existing meshes
  - Mesh refinement can be incorporated in grid generation process via sources
  - Since geometry is defined by CAD database, refined surface grids are guaranteed to match CAD geometry

Forward Work

- Refinements to the workflow for unstructured grids
  - Determine best parameter settings in T-Rex to reduce grid skewness and small cell volumes
  - Better integration of shock detection/smoothing/remeshing tools to make process more automated
  - Accelerate convergence using grid sequencing
- Incorporate automatic mesh refinement into workflow
  - Extract flow features or use error indicators to create sources
  - Use sources during grid generation process for mesh refinement

Questions?