Helden Aerospace

Overview of Grids Created with HeldenMesh for HLPW5 & Meshing Lessons Learned

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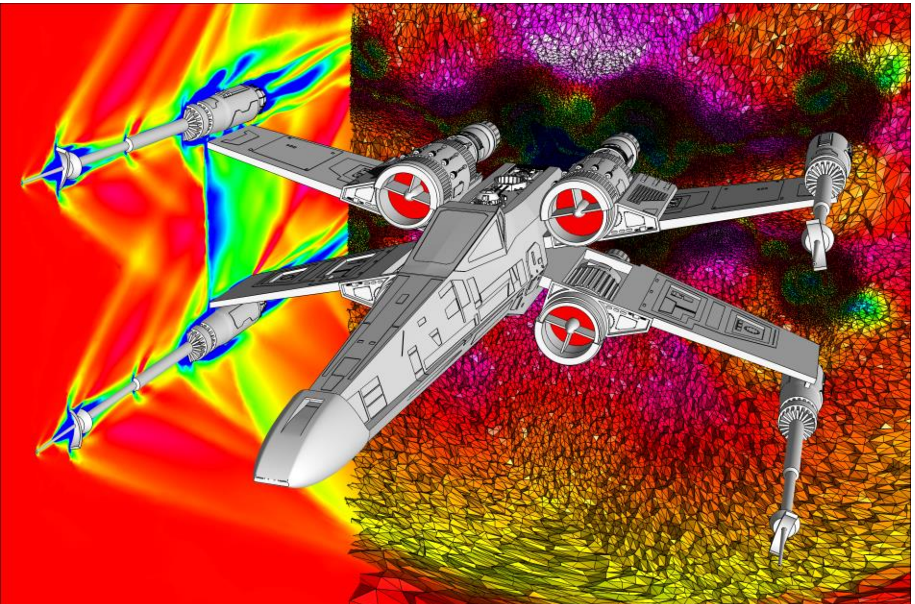
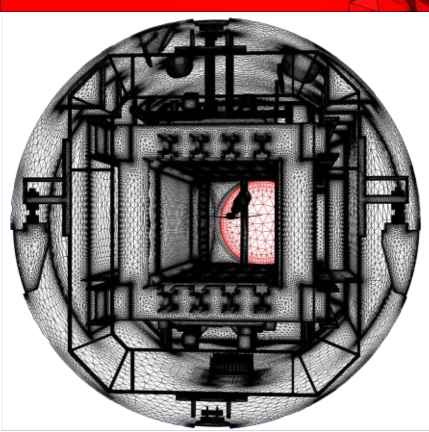
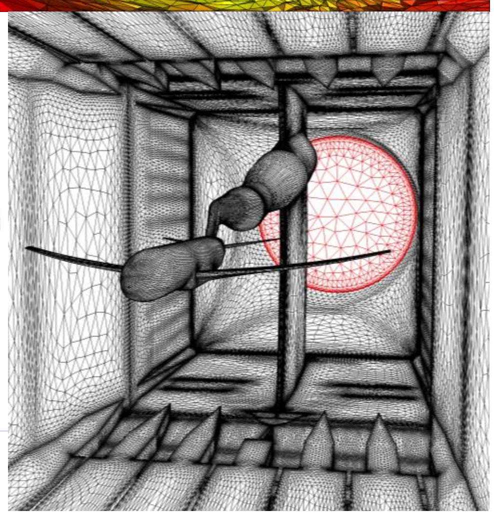
HeldenMesh Overview

Helden Aerospace





CRM in the NTF
> 10k Surfaces



- High Quality Unstructured Mesh Generator
  - Mixed element meshes (prisms, pyramids, tets, hexes, and quads)
  - Prismatic / hex elements built from surface to resolve the boundary layer
  - Smooth transition to inviscid outer mesh
- Efficient
  - Anisotropic stretching on the surface and volume
  - Automated wake and shock volume resolution
  - Reduced run times with higher accuracy
- Automated & Robust
  - Automated geometry pre-processing on complex configurations
  - Simplified input file automates mesh spacing
  - Enables rapid grid density studies
- Advanced Capabilities
  - Surface and volume mesh deformation
  - Design / optimization capability
  - Solution adaptation capability

1 Billion cells in under 10 minutes on a laptop!

HeldenMesh HLPW5 Summary

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- RANS and WMLES mesh series generated for all 3 cases, 9 sub-cases
- Adaptive Euler starting meshes developed on request
- 90 meshes released to HLPW5 committee (RANS and WMLES)
- 1,142 total meshes generated for HLPW5 by Helden Aerospace
  - 1.04 Trillion total cells generated!

Case 1 HeldenMesh RANS Grids

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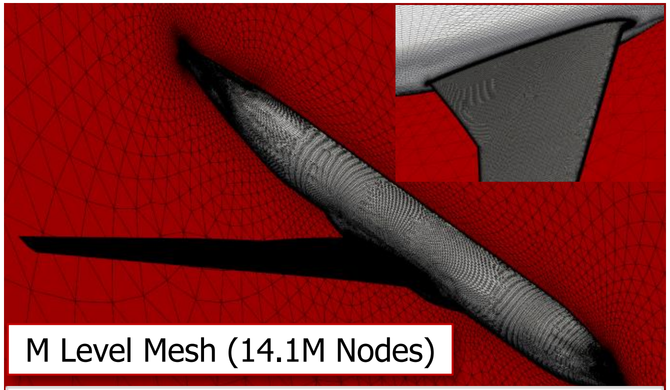
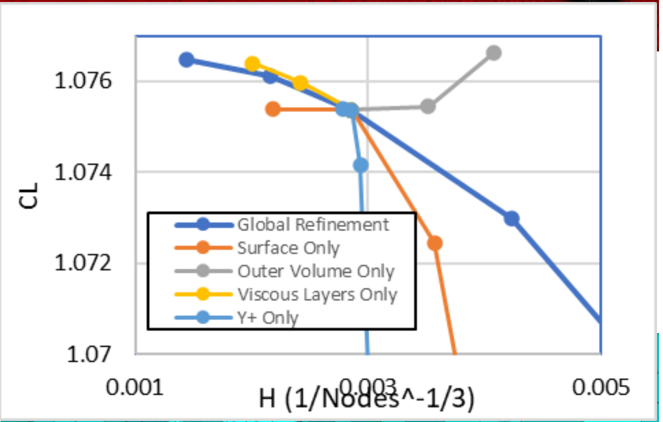
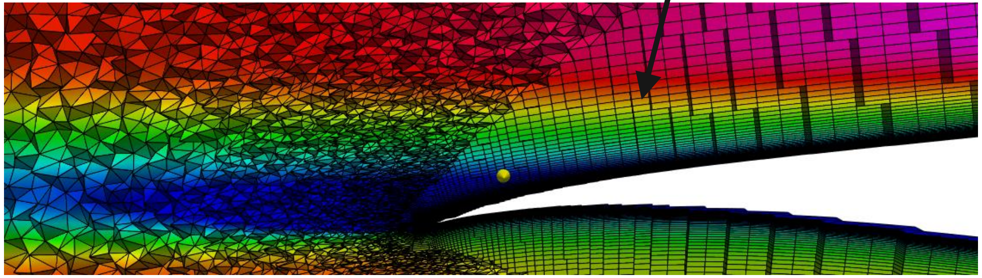
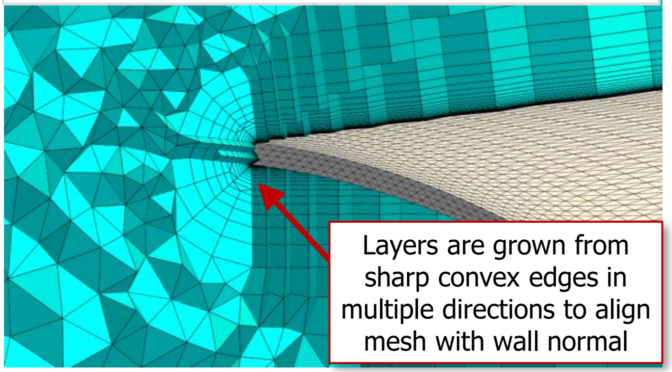
- Series 1.R.03 – 3 meshes
  - Initial meshes series was made using standard best practices only. No mesh studies were performed to tweak the mesh design.
  - Resolution was based on surface curvature + sharp edges + baseline wing upper surface refinement. No added volume refinement.
  - Prism dominant mesh in boundary layer + tetrahedral mesh in volume
  - Anisotropic stretching used to significantly reduce mesh size while maintaining accuracy
  - Meshes series (C, M, F) created from the M level by globally coarsening or globally refining the mesh spacing in all directions by a factor of 2
  - Leading edges and fuselage are significantly finer than the Pointwise workshop meshes with fewer cells across the trailing edge
  - Meshes built using multiple cells around sharp corners. This alleviates need to over-resolve the blunt trailing edge





- Series 1.R.05 / 1.R.06 (Tet) – 8 meshes
  - Mesh sensitivity studies on meshing parameters were performed with USM3DME to optimize the mesh design. No targeted refinement of areas or locations in the volume.
  - New series was generated based on this optimization effort
  - Resulted in more viscous layers / finer normal spacing off the body. Believe this was to resolve edge of boundary layer near the trailing edge





Case 2 HeldenMesh RANS Grids

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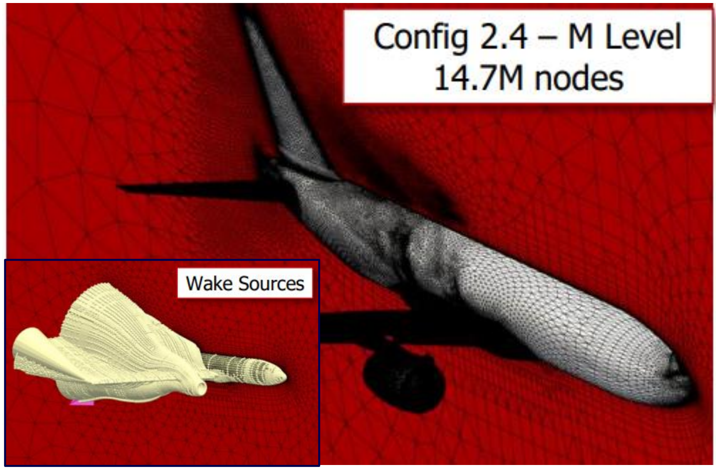
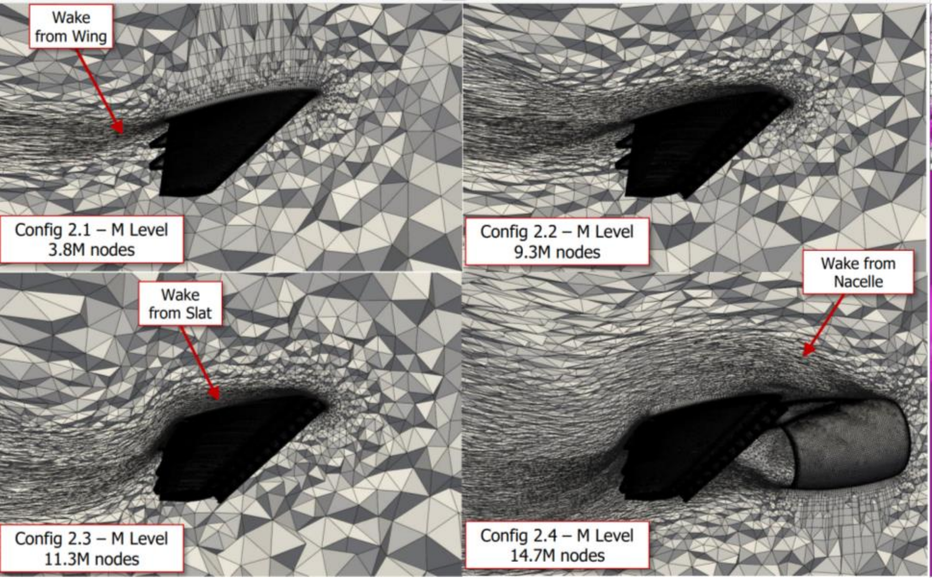
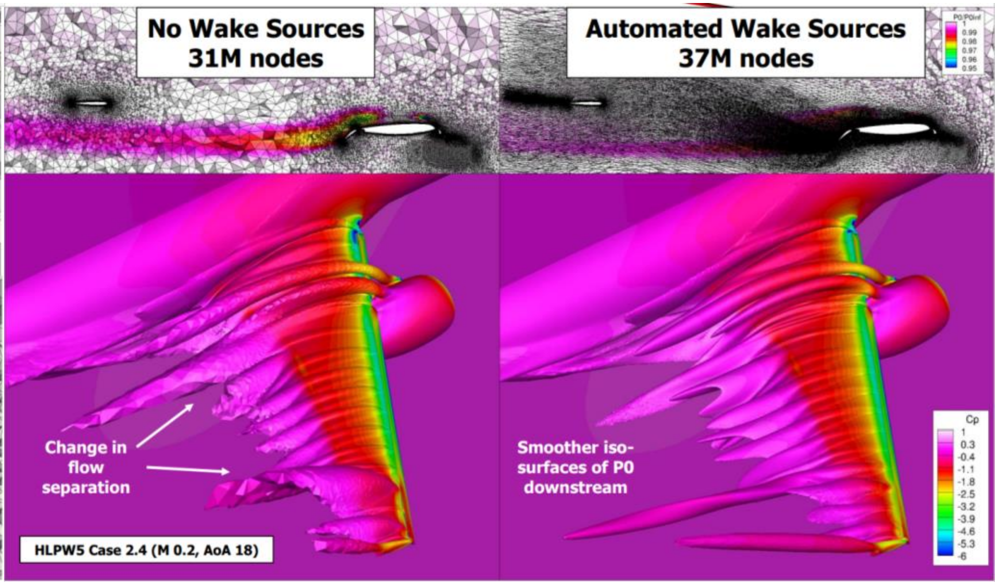
- Series 2.R.01 / 2.R.02 (Tet) – 40 meshes total
  - Meshes were generated using similar strategy as Case 1: surface curvature + sharp edges + wing/slat/flap/tail upper surface refinement
  - Resolution was also added to the wing/slat/flap/tail wakes using an estimated wake path and anisotropic resolution in the volume mesh
  - Same spacing parameters were applied to all Case 2 geometries (2.1 – 2.4) but each with custom wake sources (geometry dependent)
    - Wake sources designed to expand downstream to cover range of angles of attack
    - Goal was to resolve any effect of wing/flap wake on the horizontal tail
  - Prism dominant mesh in boundary layer + tetrahedral mesh in volume
  - Meshes series (C, M, F, G, R) for each geometry was created from the F level by globally coarsening or globally refining the mesh spacing in all directions by a factor of 2







Case 3 HeldenMesh RANS Grids

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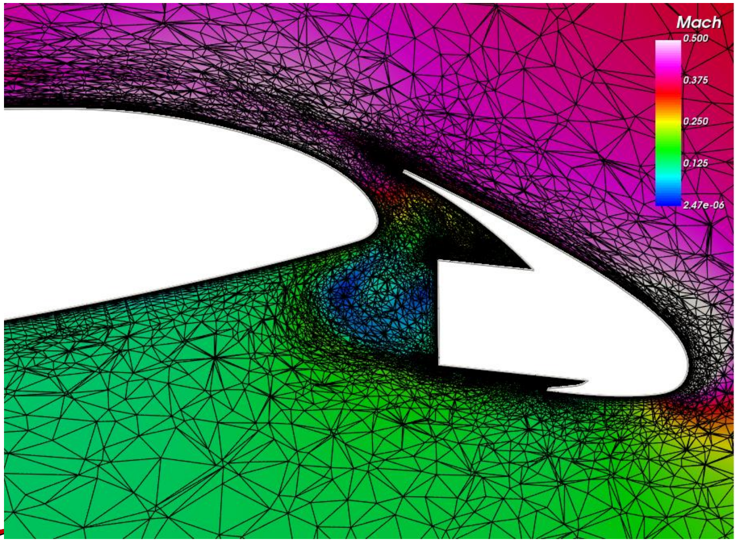
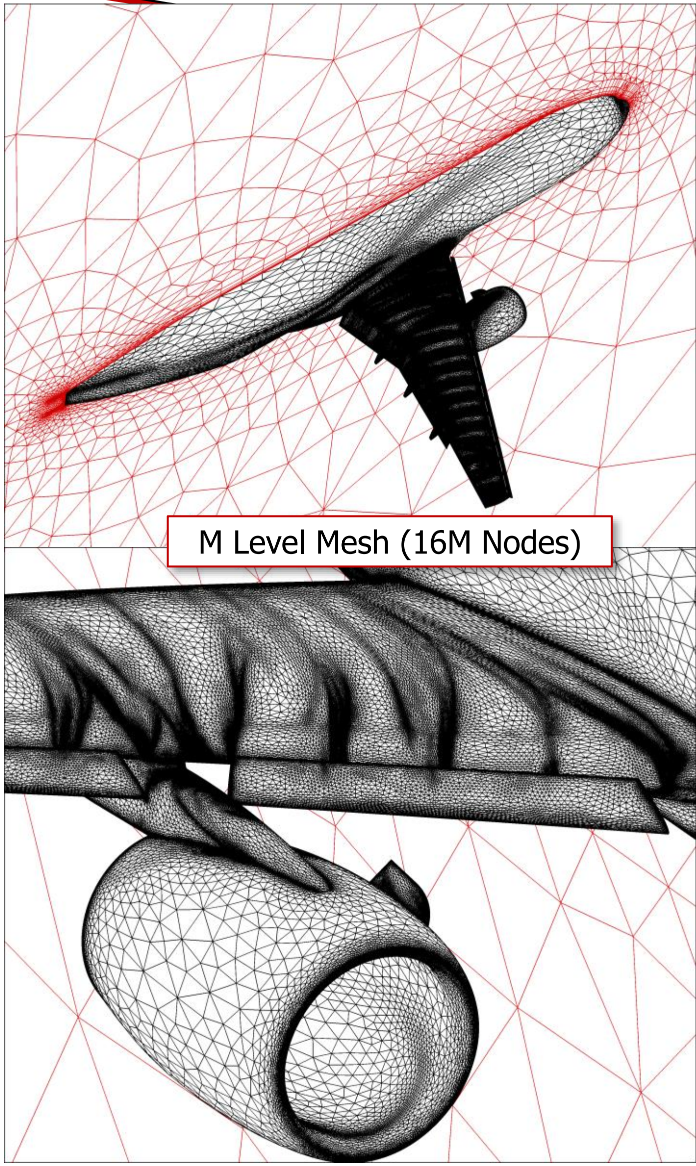
- Series 3.R.02 – 20 meshes total
  - New Adaptive Sourcing approach was used to generate this series
  - Solutions were run at RE30M Alpha 6, 12, 18 degrees. Mach Hessian of all 3 solutions was used to generate a spacing field. New mesh was regenerated with this spacing field to match the flow features.
  - Goal was to get better resolution of slat bracket wakes, etc. than can be achieved reasonably with fixed meshing
  - 5 iterations of solve/remesh were performed to create final G level mesh
  - Meshes series (C, M, F, G, R) for each geometry was created from the G level by globally coarsening or globally refining the mesh spacing in all directions by a factor of 2
  - Separate mesh series was created for each Reynolds Number with Constant Y+1 spacing (based on mid-point of average chord).
  - Prism dominant mesh in boundary layer + tetrahedral mesh in volume





M Level Mesh (16M Nodes)

RANS Meshing Lessons Learned

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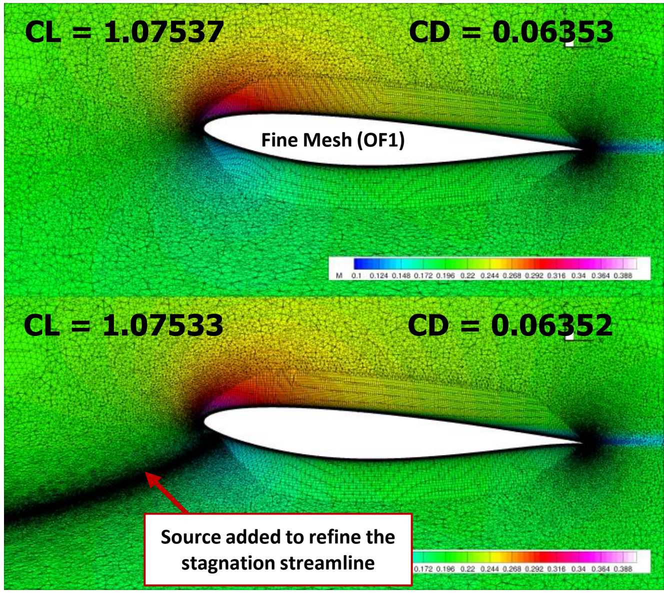
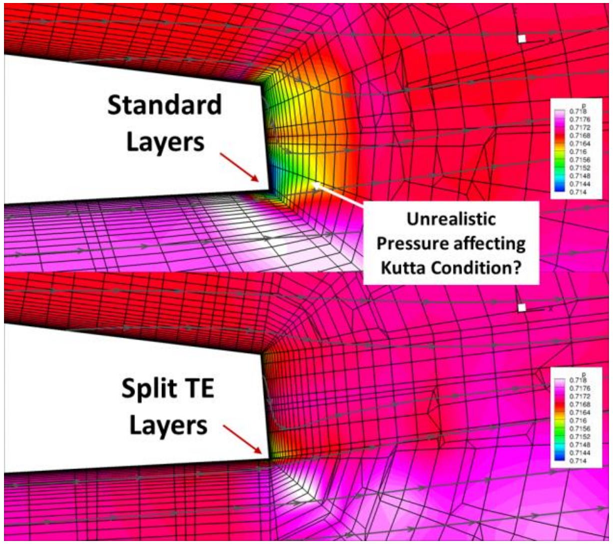
- Resolving the leading edge stagnation streamline is unnecessary
  - Many goal-oriented mesh adaptation approaches end up resolving the leading edge stagnation streamline
    - Is it needed for solution accuracy?
  - Study was performed with HeldenMesh to determine whether adding resolution to the stagnation streamline improved the solution accuracy and efficiency
  - Stagnation streamline was extracted from fine mesh solution and resolved across the entire wing leading edge
  - Resulted in no difference in lift or drag at coarse or fine levels



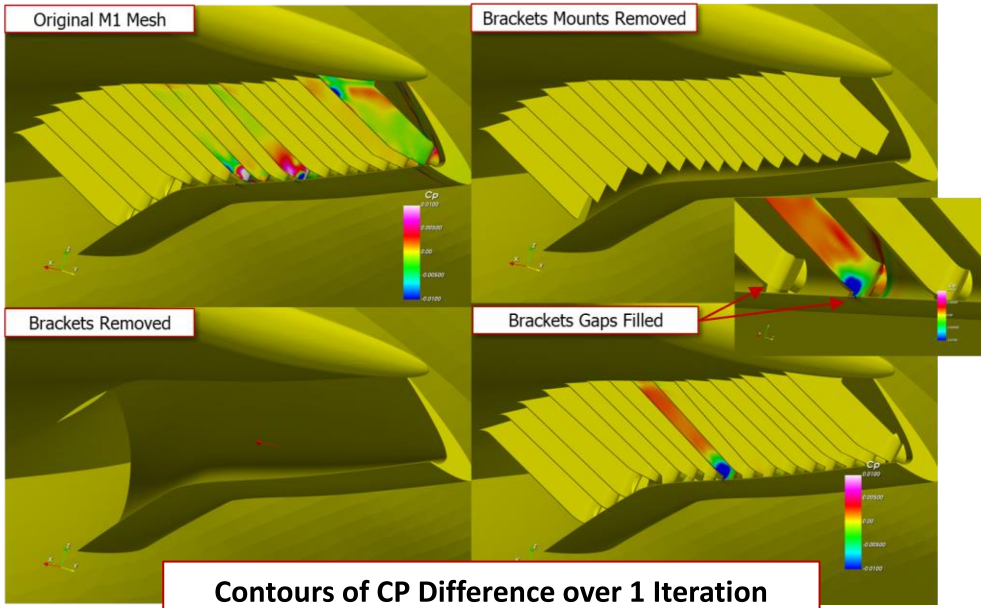
- Trailing edge mesh topology in the layers can make a big difference with lift/drag
  - Most grid generation approaches use a standard extrusion of cells around sharp corners, resulting in 2 no-slip faces 90 degrees apart
  - This can lead the flow solver to impost an unrealistic boundary condition which affects the kutta condition
  - Adding additional points around the corners by splitting the grid into multiple growth vectors can relieve this effect
  - Splitting the mesh growth vectors also means you don't need a bazillion points across the trailing edge to get grid resolved answers



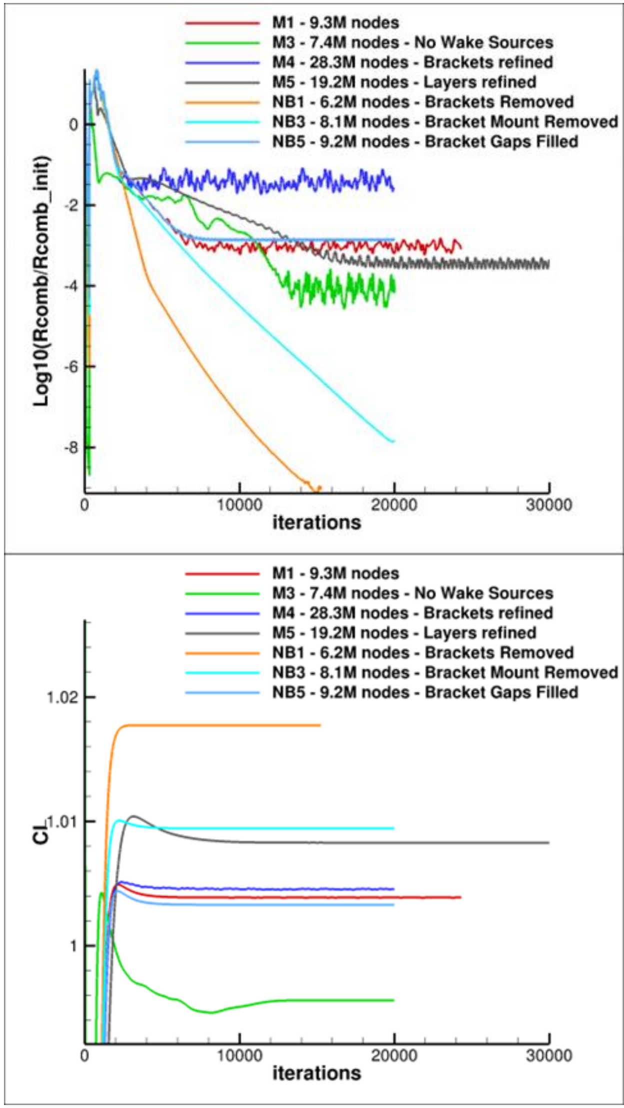
RANS Meshing Lessons Learned

Helden Aerospace

- Slat bracket geometry plays a role in solution convergence and why it can be difficult
  - – Achieving machine convergence was difficult for many codes when the slat geometry was present (Case 2.2, 2.3, 2.4)
  - – Mesh sensitivity study was performed with HeldenMesh on Case 2.2, looking at modifying the mesh density and modifying the geometry
  - x Increasing the grid resolution of the brackets (surface, layers, and outer volume) did not result in USM3DME achieving machine convergence
  - x Adding fillets and removing the tight corners from the slat brackets did not result in machine zero convergence
  - ✓ Removing the slat brackets entirely did result in convergence to machine zero with USM3DME
  - ✓ Removing just the mounting geometry but leaving the majority of the brackets also resulted in machine zero convergence with USM3DME

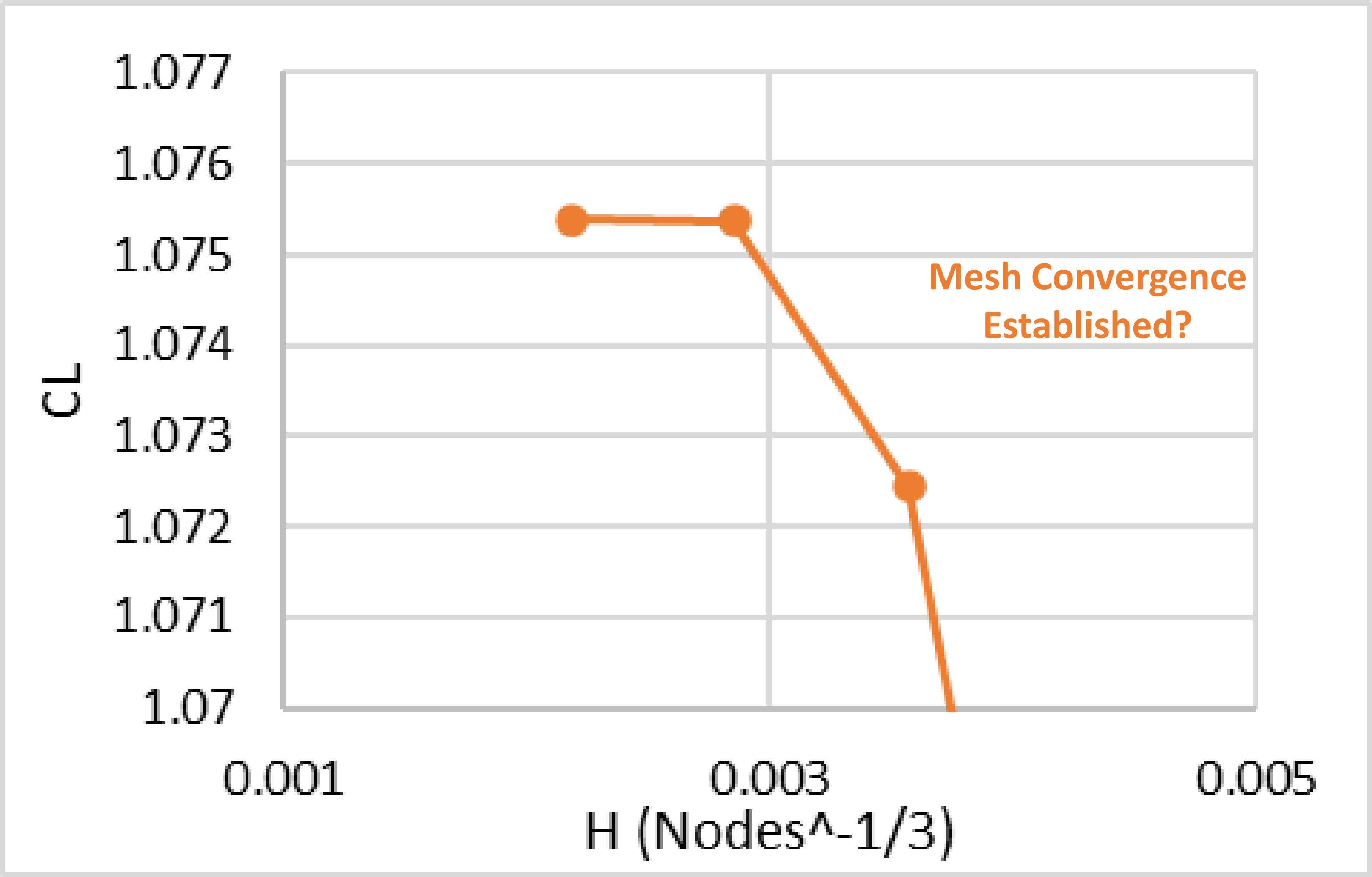


Contours of CP Difference over 1 Iteration



RANS Meshing Lessons Learned

Helden Aerospace



RANS Meshing Lessons Learned

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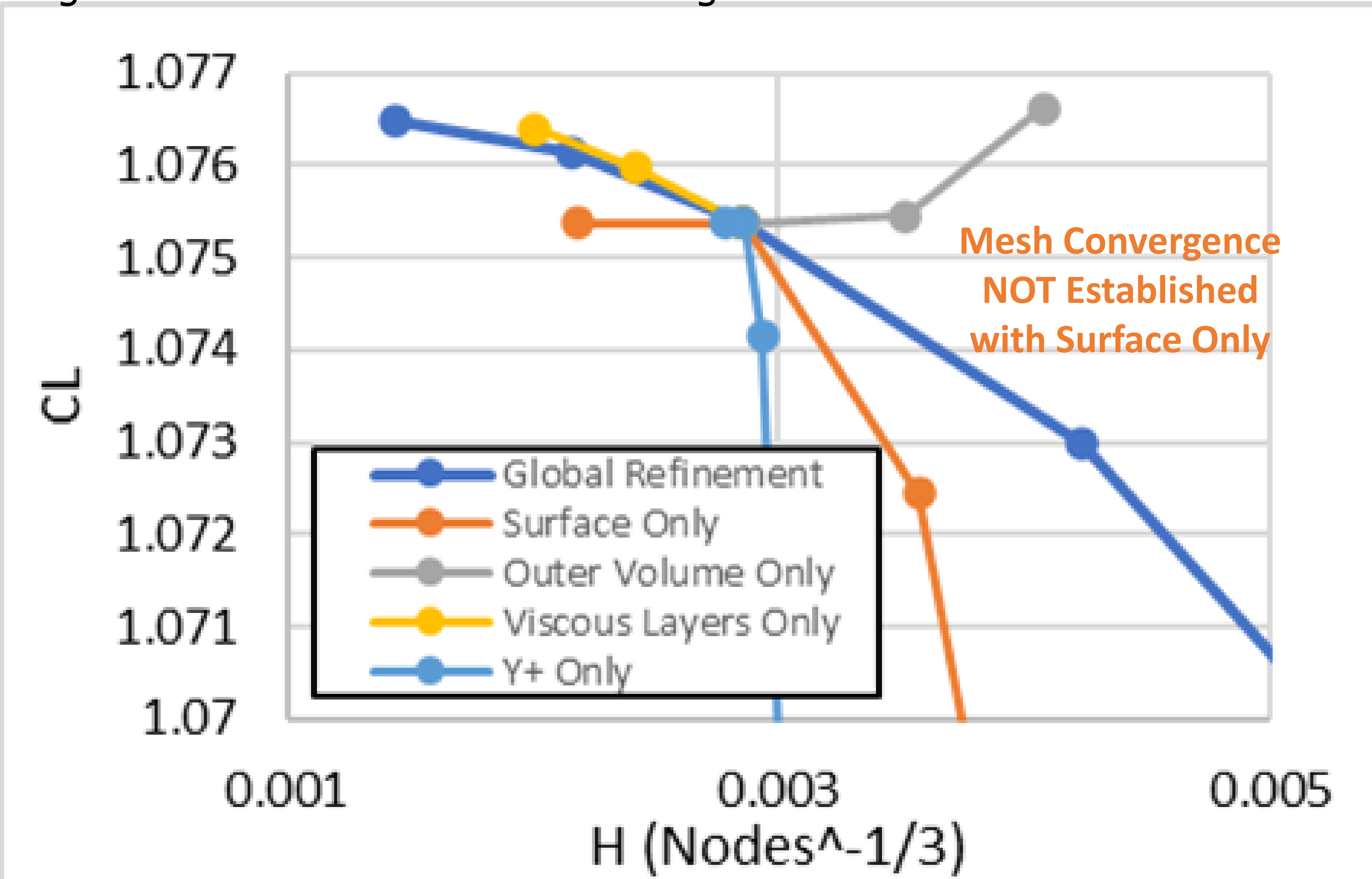
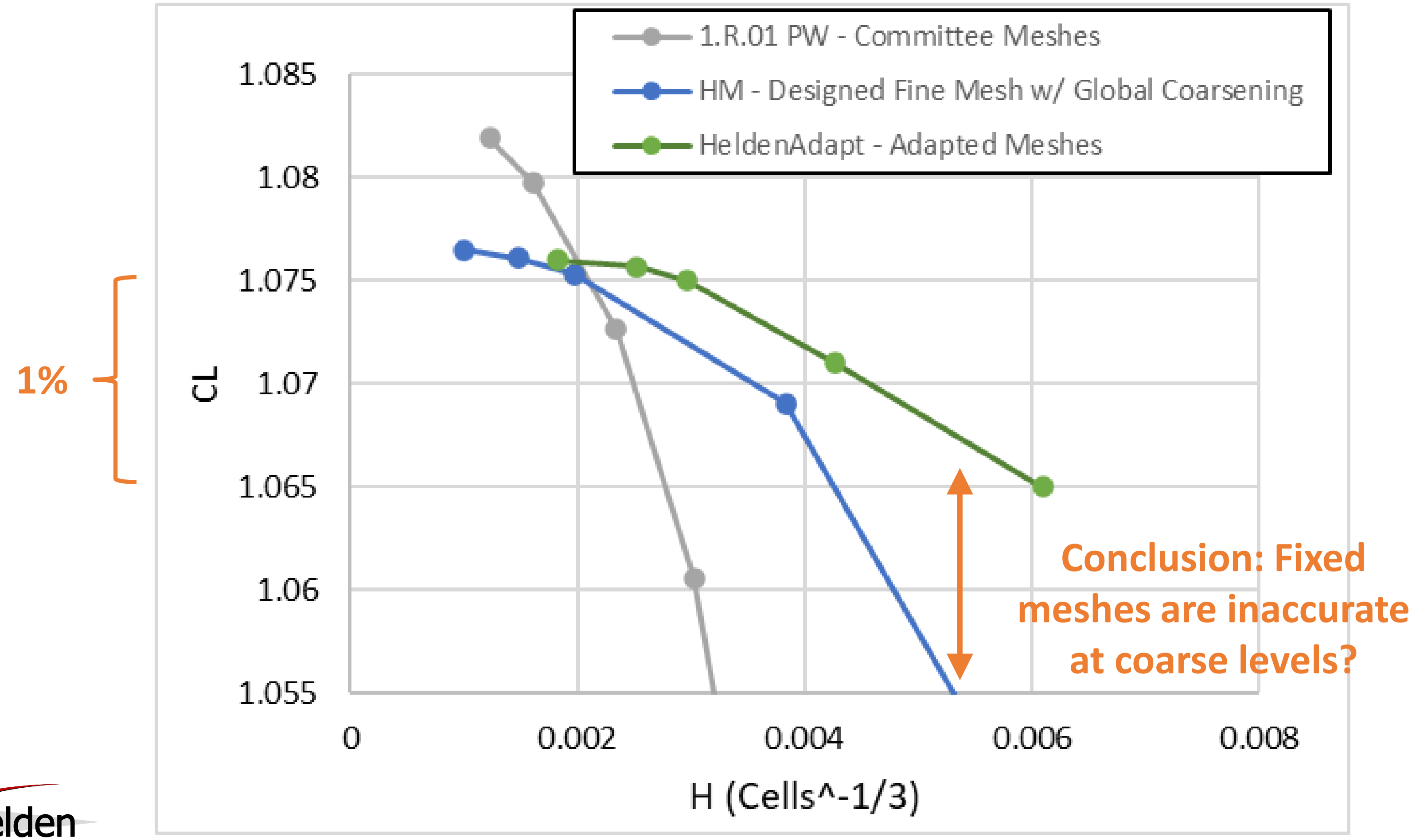
- Global refinement of series is needed to establish mesh convergence. Cannot do targeted refinement alone or risk being misled.



RANS Meshing Lessons Learned



RANS Meshing Lessons Learned

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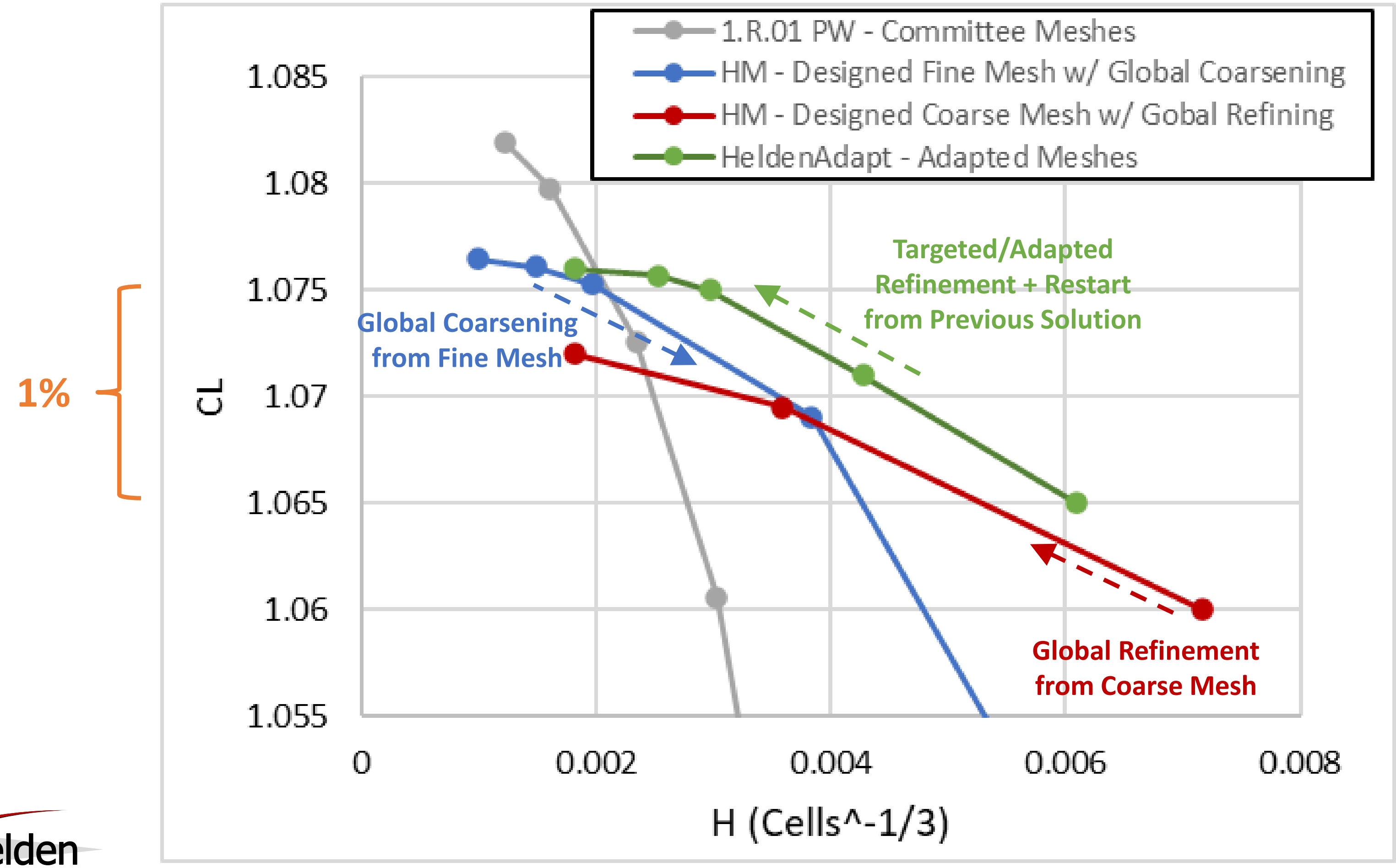
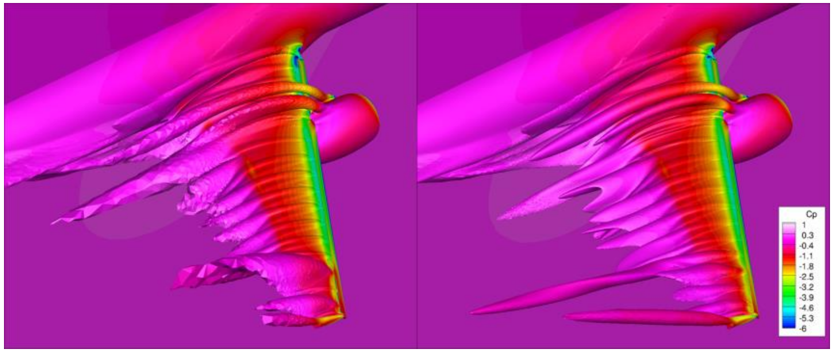
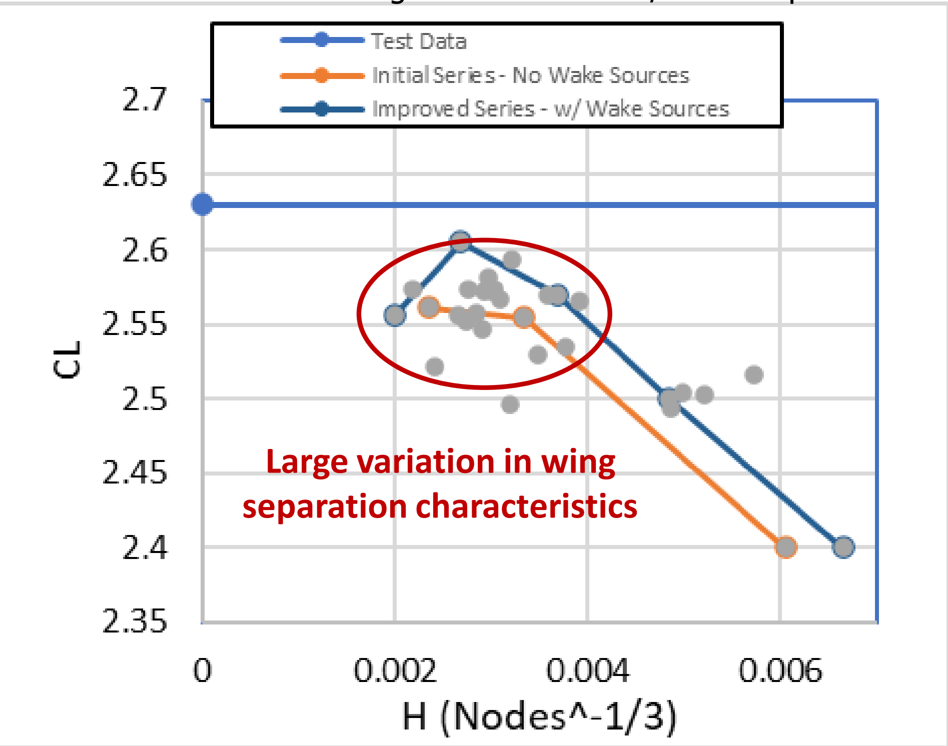
- Beware of using CL/CD/CM vs. H when making mesh efficiency comparisons
  - Well designed coarse mesh cannot be globally refined to a well-designed fine mesh. Vice versa.
  - Targeted refinement always looks better than global refinement
  - Warm restart from previous mesh will tend to look better than start from scratch

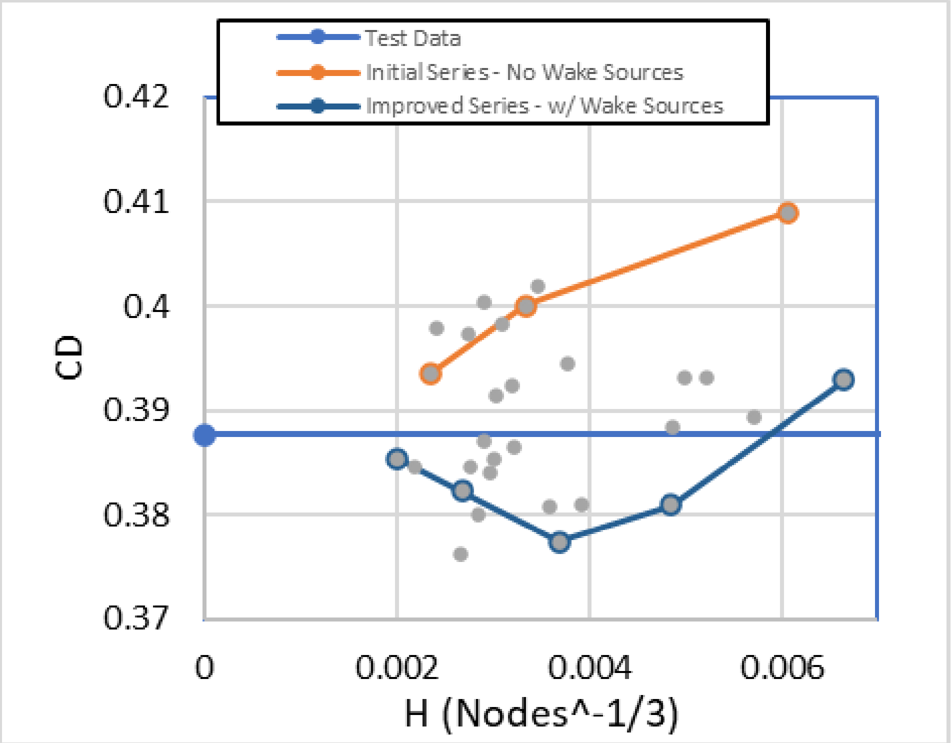


RANS Meshing Lessons Learned

- Grid convergence on Case 1 was achieved
- Grid convergence on Case 2.2 through Case 3.4 was much harder
  - Flow separation characteristics were more of a step change
  - This clouded attempts to determine optimal fixed mesh characteristics and made trends difficult to establish
  - Solution convergence was harder / more expensive







Case 2.4 Alpha 18

HeldenMesh WMLES Grids

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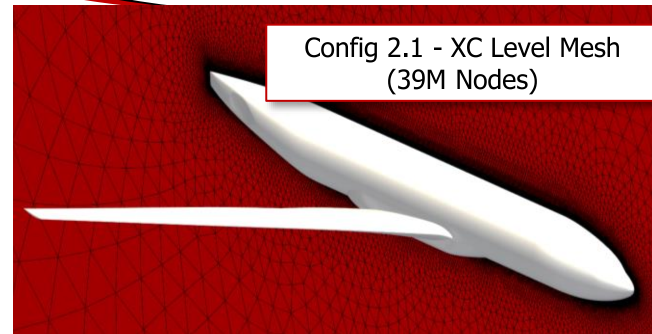
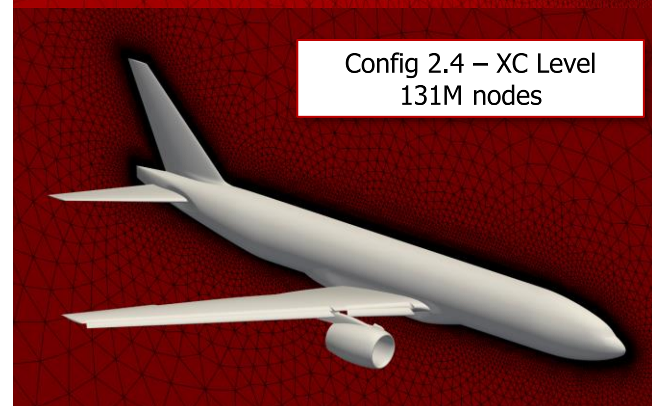
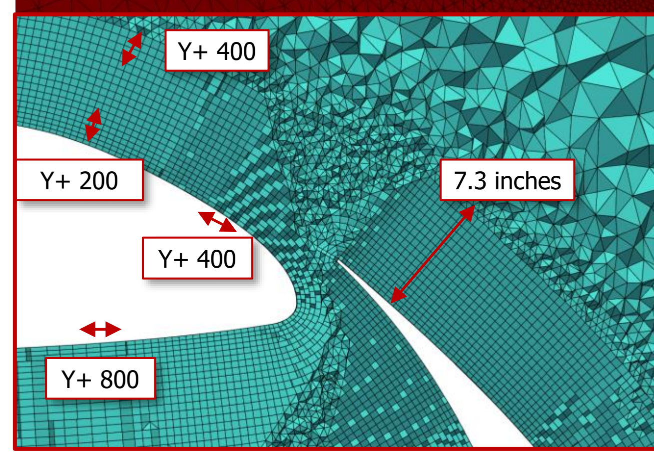
- Case 1: Series 1.W.01 – 3 meshes
  - WMLES meshes were created using best practices derived from the NASA FUN3D team's experience with HLCRM NTF
  - Prism dominant mesh in boundary layer + tetrahedral mesh in volume
  - XC, C, and M level meshes created using a series
  - Normal spacing = Y+ 160, 130, 100 (0.21, 0.17, 0.13 in)
  - Lateral spacing on Fuse = 0.8, 0.4, 0.2 in
  - Lateral spacing on Wing Upper = Fuse spacing * 0.66
  - Layer and Volume growth rates halved with each refinement level
- Case 2: Series 2.W.01 – 16 meshes
  - Following some grid sensitivity studies on Case 1 and some limited grid sensitivity studies for Case 2.4, new meshing standard were derived
  - XC, C, M, F level meshes created for all 4 geometries
  - Normal spacing = Y+ 75, 100, 150, 200 (0.09, 0.12, 0.18, 0.24 in)
  - Base spacing on the wing, nacelle, tail upper surface = 2 x normal
  - Base spacing on the fuselage / wing lower surface = 4 x normal
  - Spacing on sharp edges and curved regions (LE) = 1 x normal spacing
  - Target thickness of the prism region = 7.3 inches = flat plate boundary layer height using the inboard chord. Desire to cover the entire boundary layer in prisms of uniform size to resolve the turbulent eddies.
  - Normal spacing at the edge of the prism layer = 2 x normal spacing
- Case 3:
  - Meshes generated with FUN3D team but not posted







WMLES Meshing Lessons Learned

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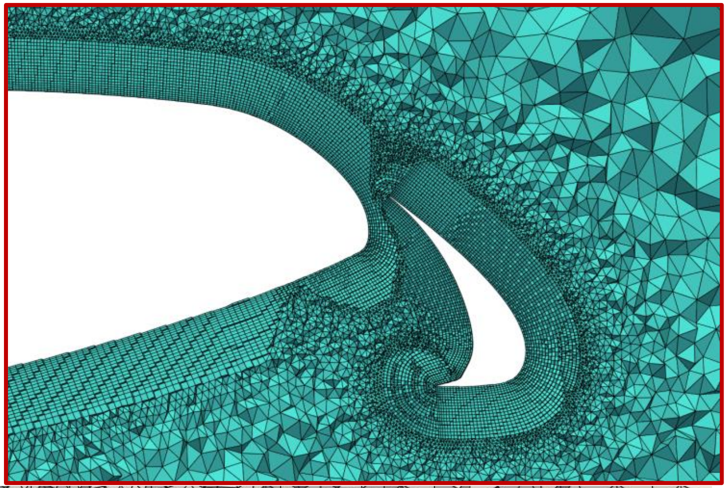
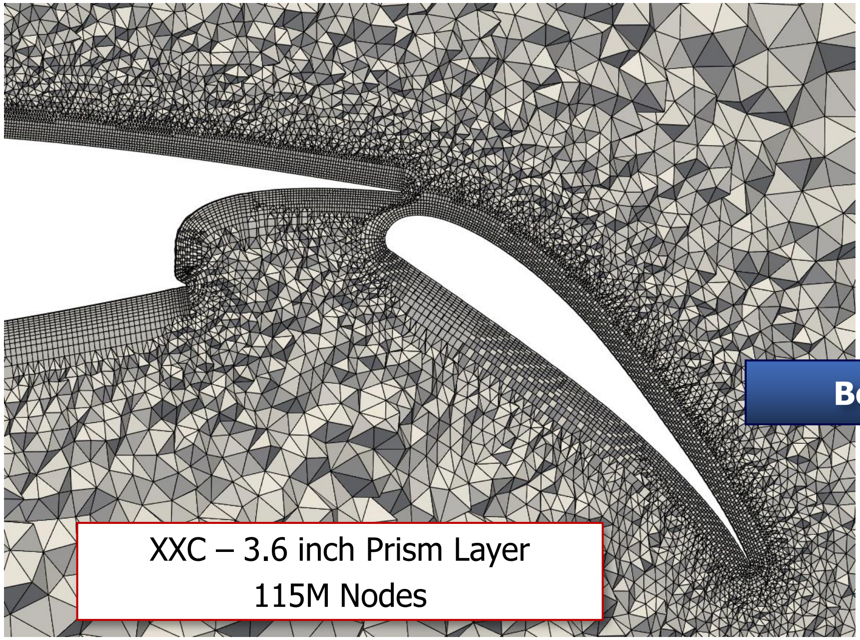
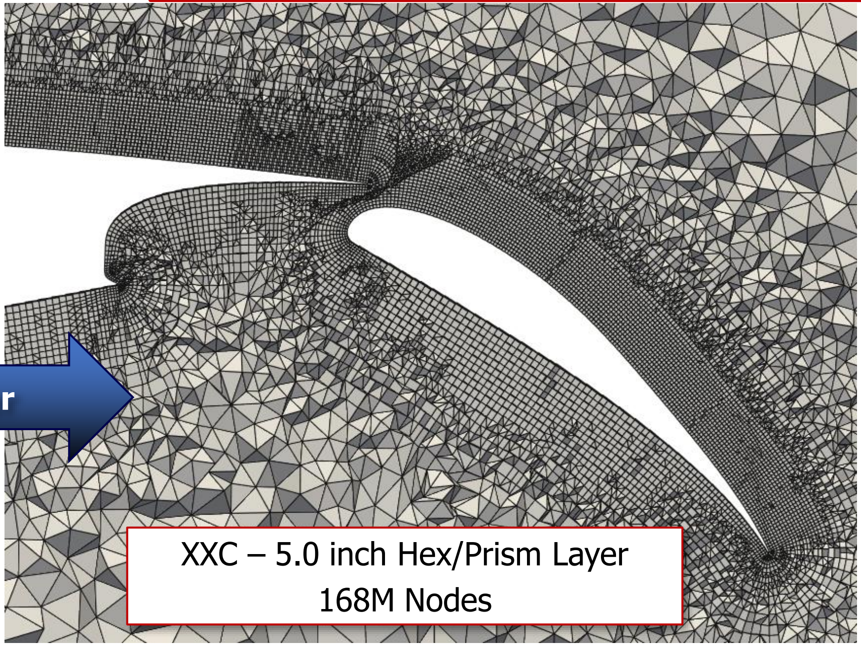
- FUN3D results seemed most accurate when the entire boundary layer was covered by prismatic elements rather than tets of the same resolution
- Flap and slat need finer resolution than the wing upper surface
- Lack of computing resources hampered full investigation / optimization of grid parameters





Better



Case 3 HeldenMesh Grids

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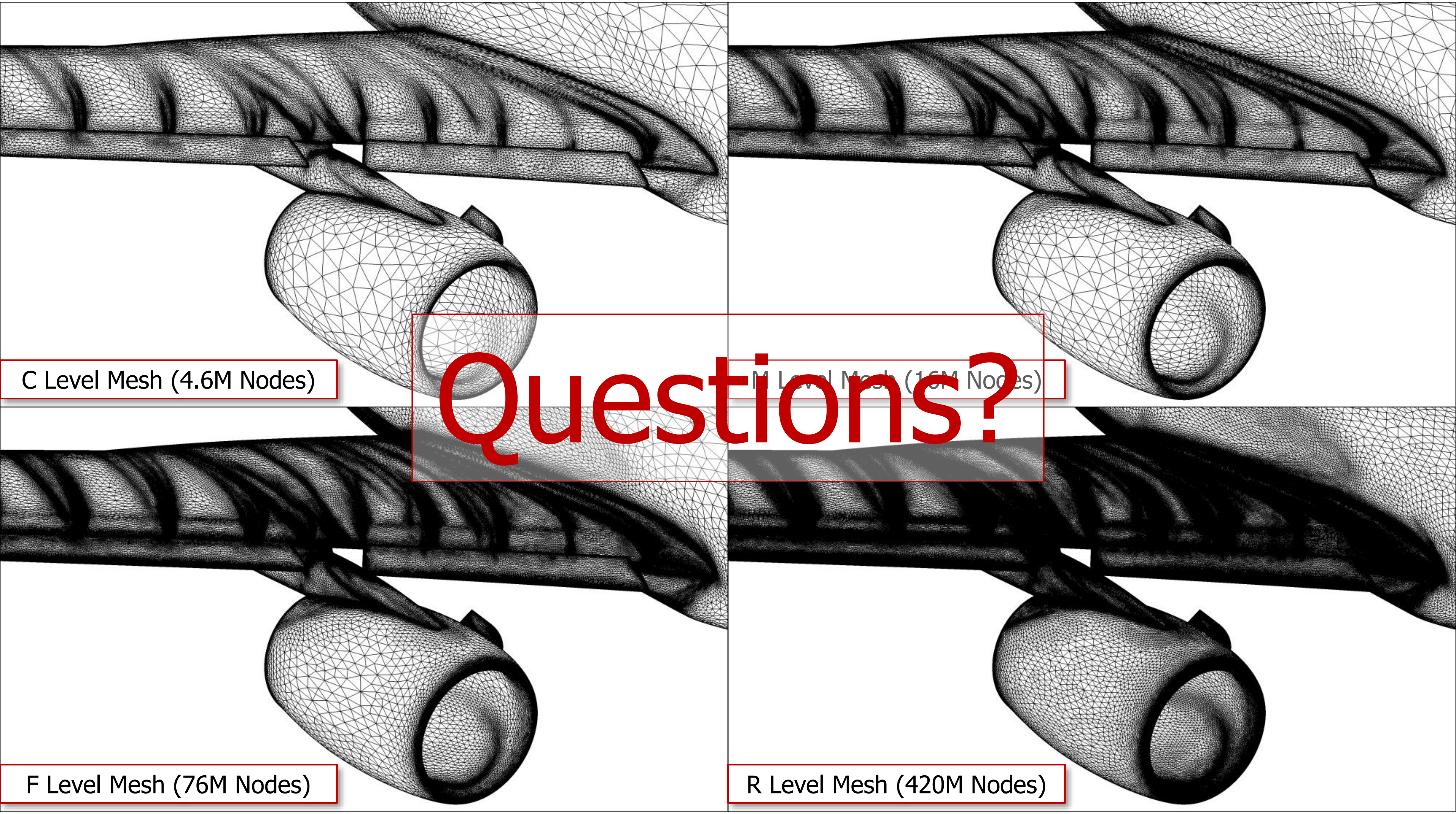

Questions?