LAVA Simulations for the 2nd AIAA Sonic Boom Prediction Workshop

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2nd AIAA Sonic Boom Prediction Workshop
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Outline

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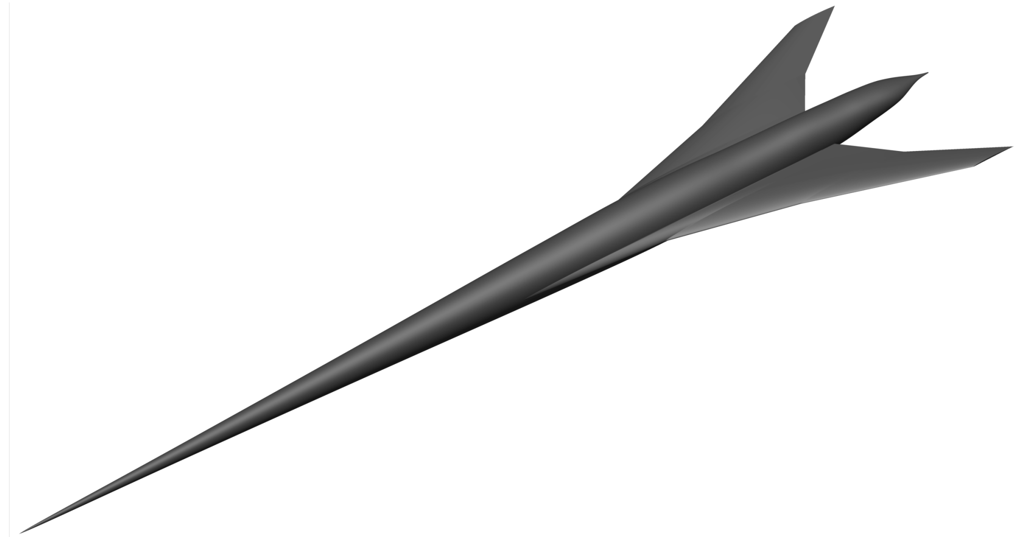
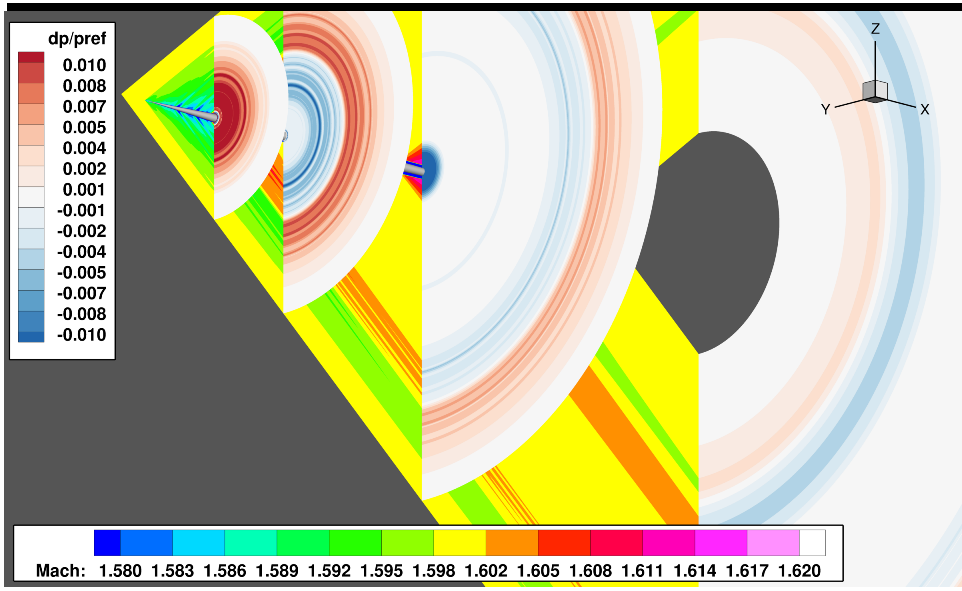
  - Axie Body of Revolution
  - JAXA Wing Body
  - C25d-Flowthru
- LAVA Solver
- Computing Requirements
- Computational Grids
- Solver Convergence
- Results
- Highlights
  - Grid Sensitivity
  - Viscous Effects
- Summary



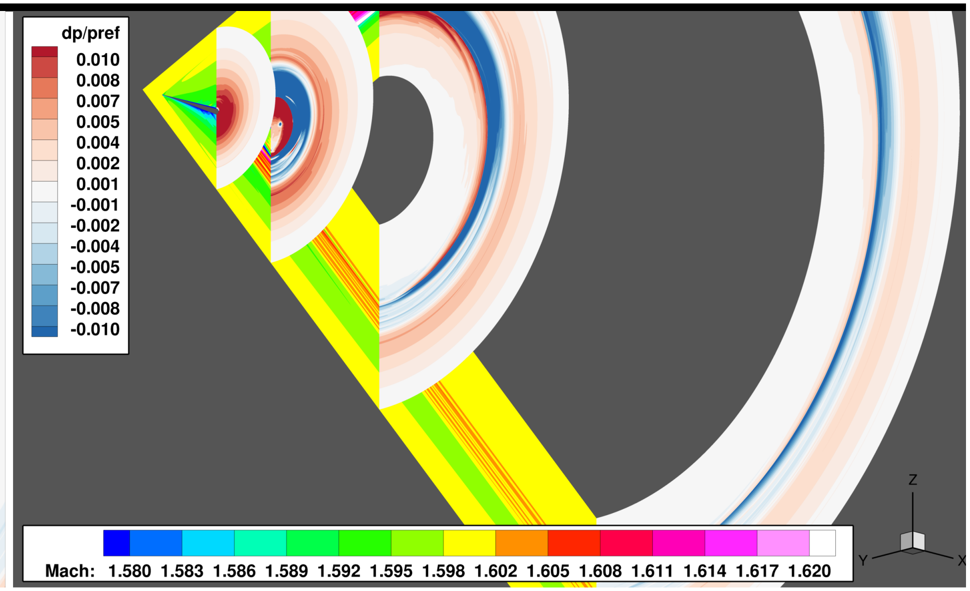
JAXA Wing Body

C25d-Flowthru

Summary of Cases

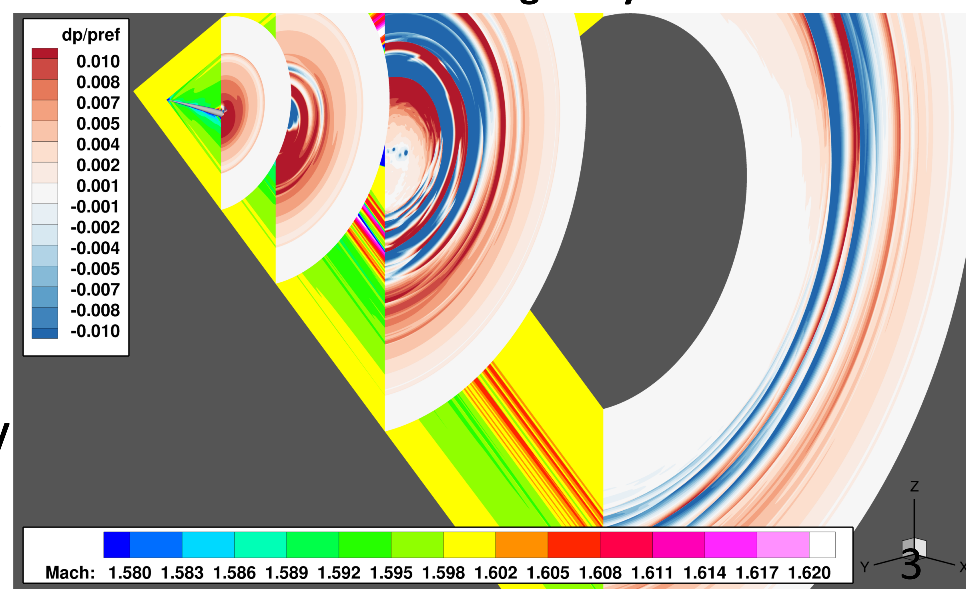


Axie



JAXA Wing Body

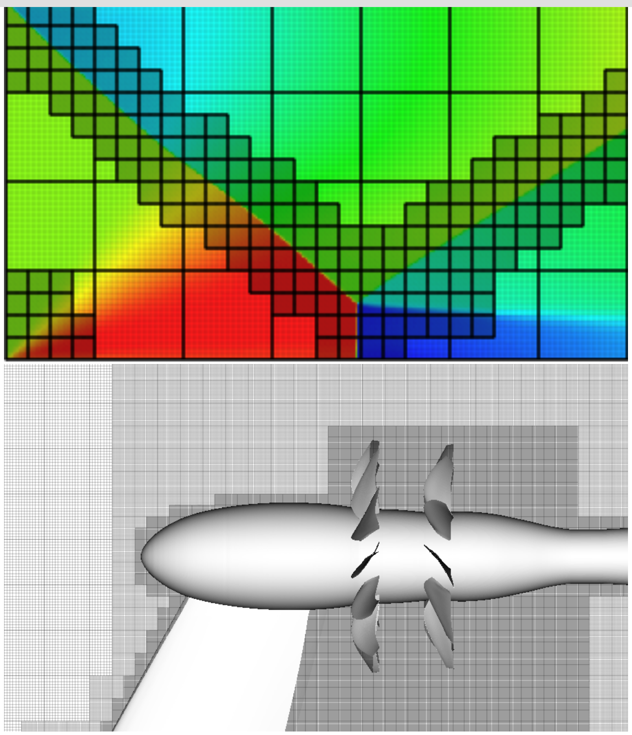
- Axie (Euler and RANS)
- JAXA Wing Body (Euler and RANS)
- C25d-Flowthru (Euler and RANS)
  - Mach = 1.6
  - Re = 5.7x10^{6} (per meter)
  - $\alpha = 0$ $\beta = 0$ degrees (geometry includes angle of attack, 2.3067^{o} JWB, 3.375^{o} C25d)



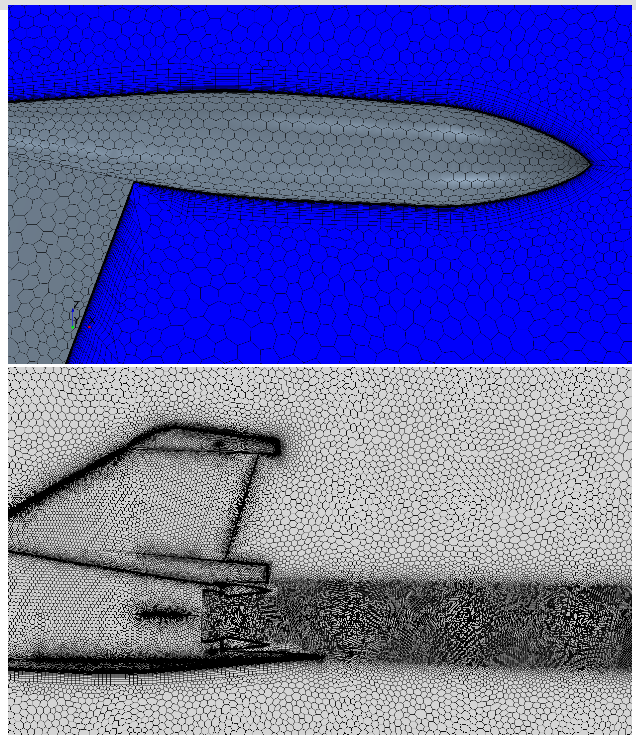
C25d-Flowthru

Launch Ascent & Vehicle Aerodynamics (LAVA) Solver

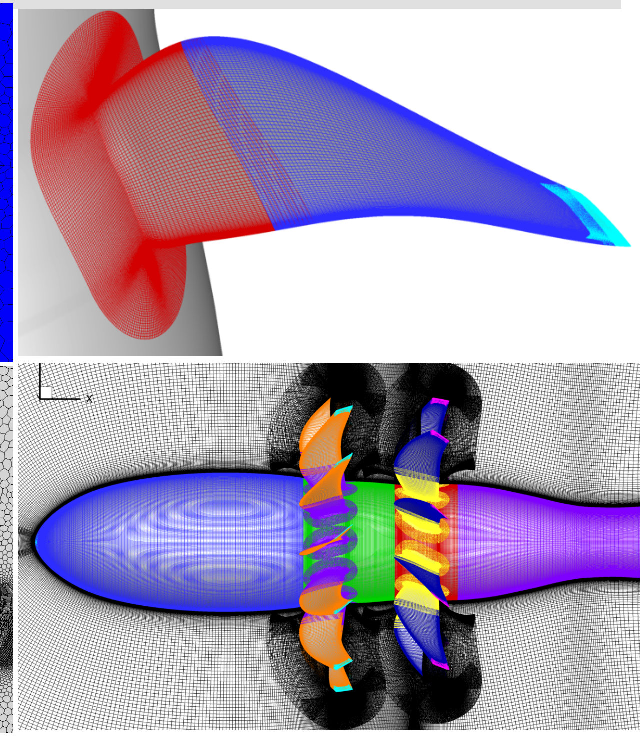
- Highly flexible with respect to computational mesh
  - Block-structured Cartesian meshes with Adaptive Mesh Refinement (AMR)
  - Unstructured arbitrary polyhedral meshes
  - Structured curvilinear overset meshes
- Overset and Immersed Boundary Methods



Cartesian Immersed Boundary



Unstructured Arbitrary Polyhedral



Overset Structured Curvilinear

Kiris et al. “Computational Framework for Launch Ascent and Vehicle Aerodynamics (LAVA)”, Aerospace Science and Technology, Volume 55, 2016

Computational Methodology

3-D Unstructured Polyhedral Mesh Solver

- Steady-state Euler or RANS using Spalart-Allmaras (SA) turbulence model
- 2nd-order AUSM-PW+ or modified Roe scheme (van Albada)
- 2nd-order blended least-squares/Green-Gauss viscous fluxes
- ILU(0)-preconditioned GMRES (PETSc)

3-D Structured Curvilinear Overset Grid Solver

- Steady-state RANS using SA turbulence model
- 6th-order Hybrid Weighted Compact Nonlinear Scheme (HWCNS)
- Numerical flux is a modified Roe scheme
- 5th order upwind biased left and right state interpolation (WENO-Z)
- 2nd-order accurate differencing used for viscous fluxes
- High-order accurate free-stream preserving metric terms
- Alternating line-Jacobi relaxation (2 sweeps)

Computing Requirements

Pleiades Supercomputer (NAS)

- Manufacturer: SGI
- 161 racks (11,472 nodes)
- 7.25 Pflops/s peak cluster
- 5.95 Pflops/s LINPACK (#13 Nov. 2016)
- Total cores: 246,048

Resources (Time per 1000 steps)

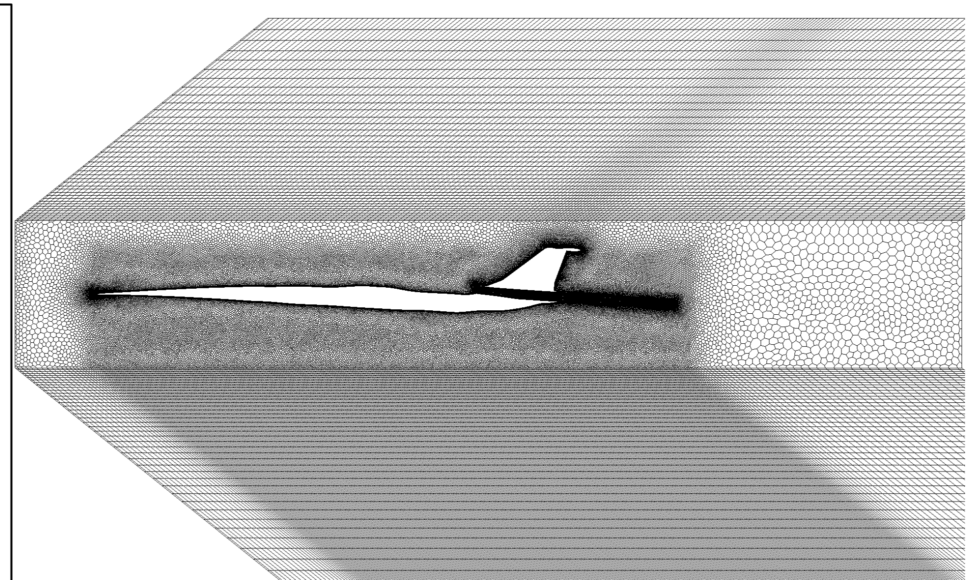
- Case 3: C25d-flowthru

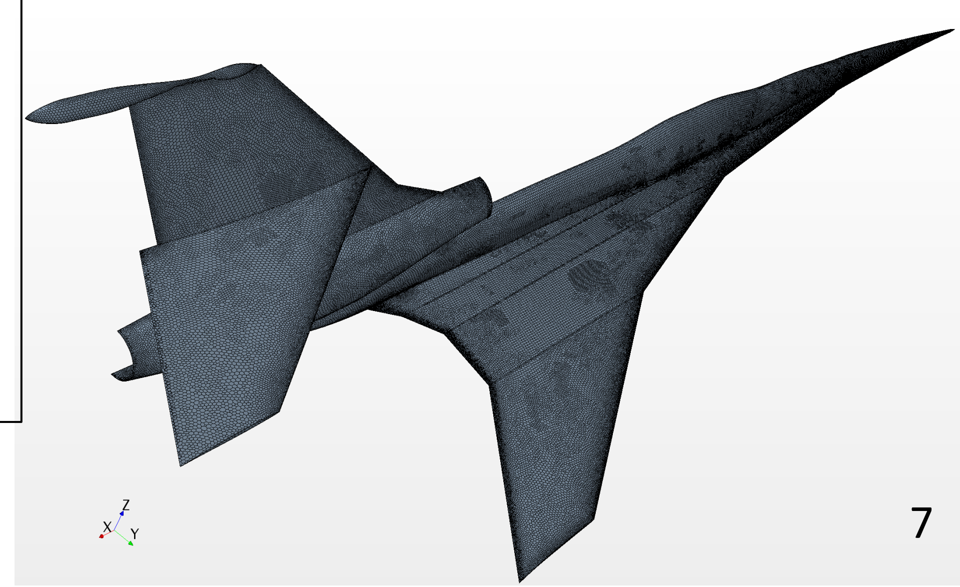
Grid ($x10^6$)	Flux	Model	Proc	Nodes (cores)	Time
U-Coarse (10.9)	Roe	RANS-SA	Haswell	50 (1200)	13 min.
U-Medium (14.2)	Roe	RANS-SA	Haswell	50 (1200)	15 min.
U-Fine (26.7)	Roe	RANS-SA	Haswell	50 (1200)	32 min.
S-Coarse (25.4)	HWCNS	RANS-SA	Ivy Bridge	11 (220)	1 hr. 30 min.
S-Medium (48.5)	HWCNS	RANS-SA	Ivy Bridge	15 (300)	2 hr. 20 min.

Computational Grids

Unstructured Grid Systems

- Axie
  - Coarse: 3.3 M
  - Medium: 3.9 M
  - Fine: 5.9 M
- JAXA Wing Body
  - Coarse: 9.2 M
  - Medium: 18.9 M
  - Fine: 40.0 M
- C25d-Flowthru
  - Coarse: 10.9 M
  - Medium: 14.2 M
  - Fine: 26.7 M

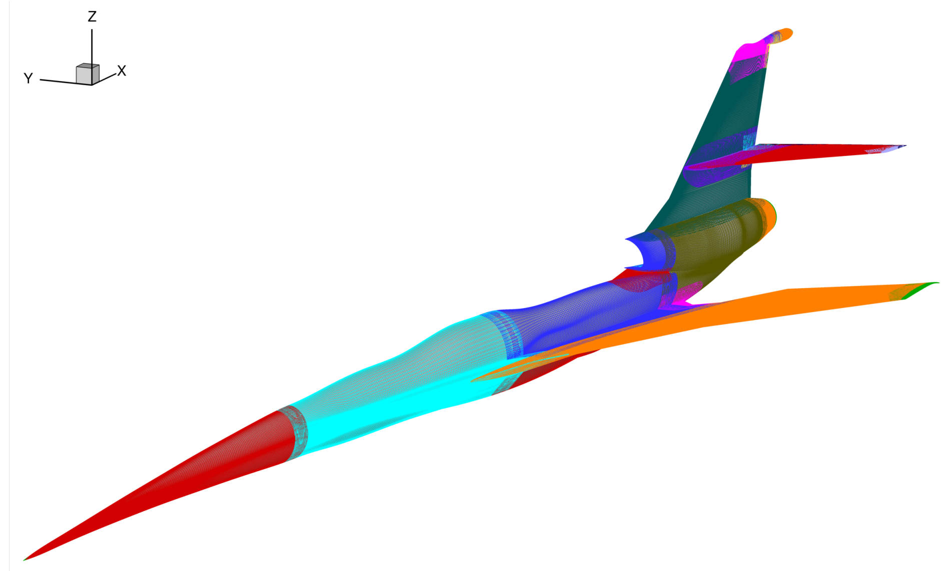


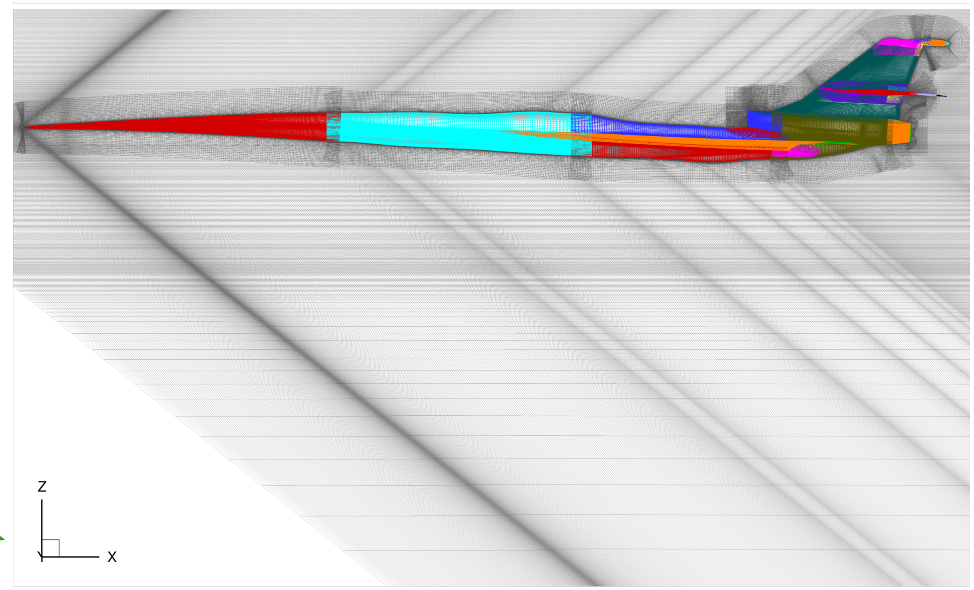


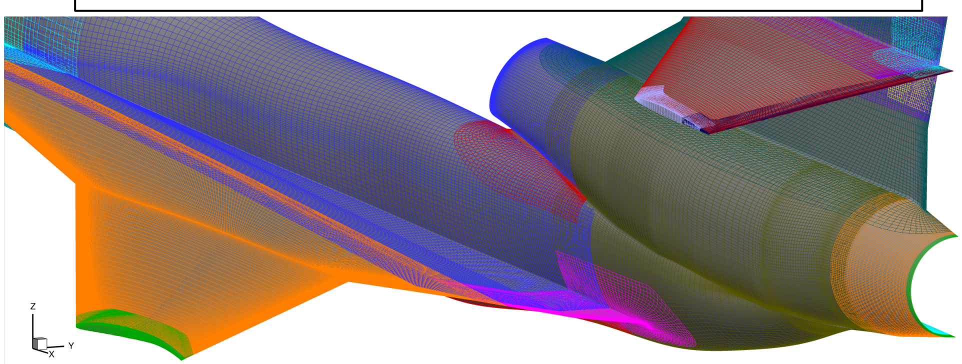
Computational Grids

Structured Grid Systems

- Axie
  - Coarse: 8.0 M
  - Medium: 25.0 M
- JAXA Wing Body
  - Coarse: 10.5 M
  - Medium: 18.0 M
  - Fine: 32.6 M
- C25d-Flowthru
  - Coarse: 25.4 M
  - Medium: 48.5 M

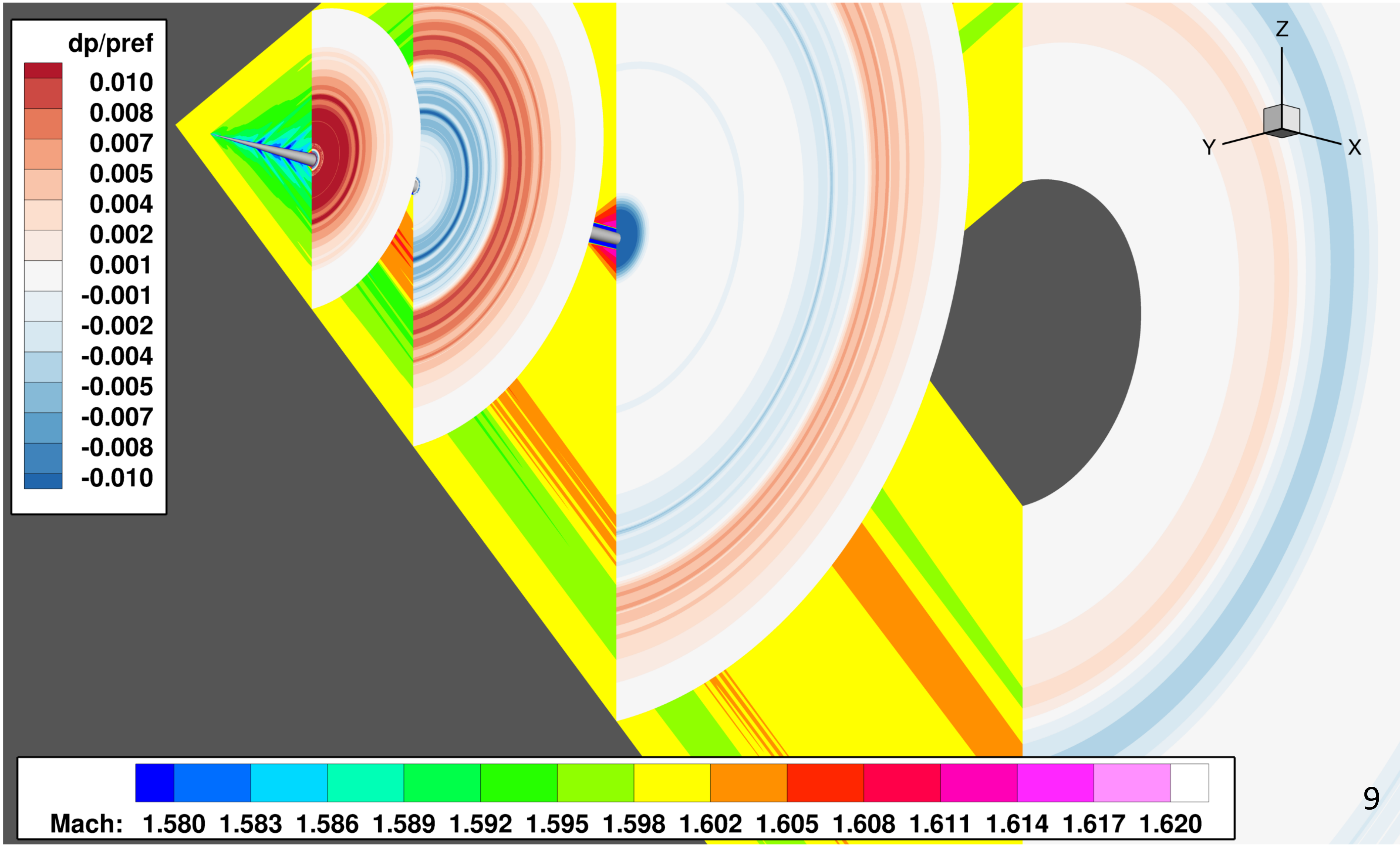




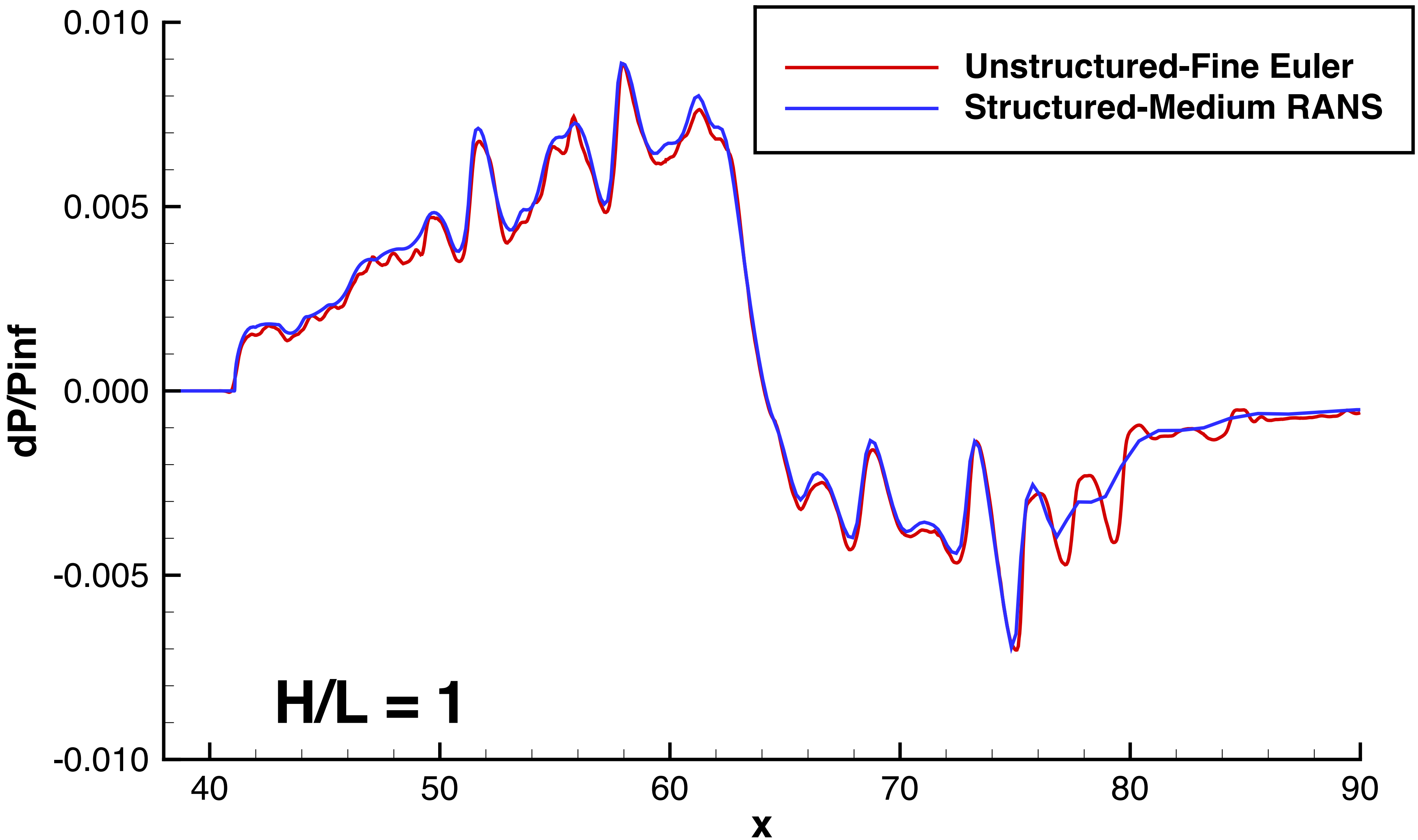


Results: Axie

Mach contour on symmetry plane with streamwise slices of pressure

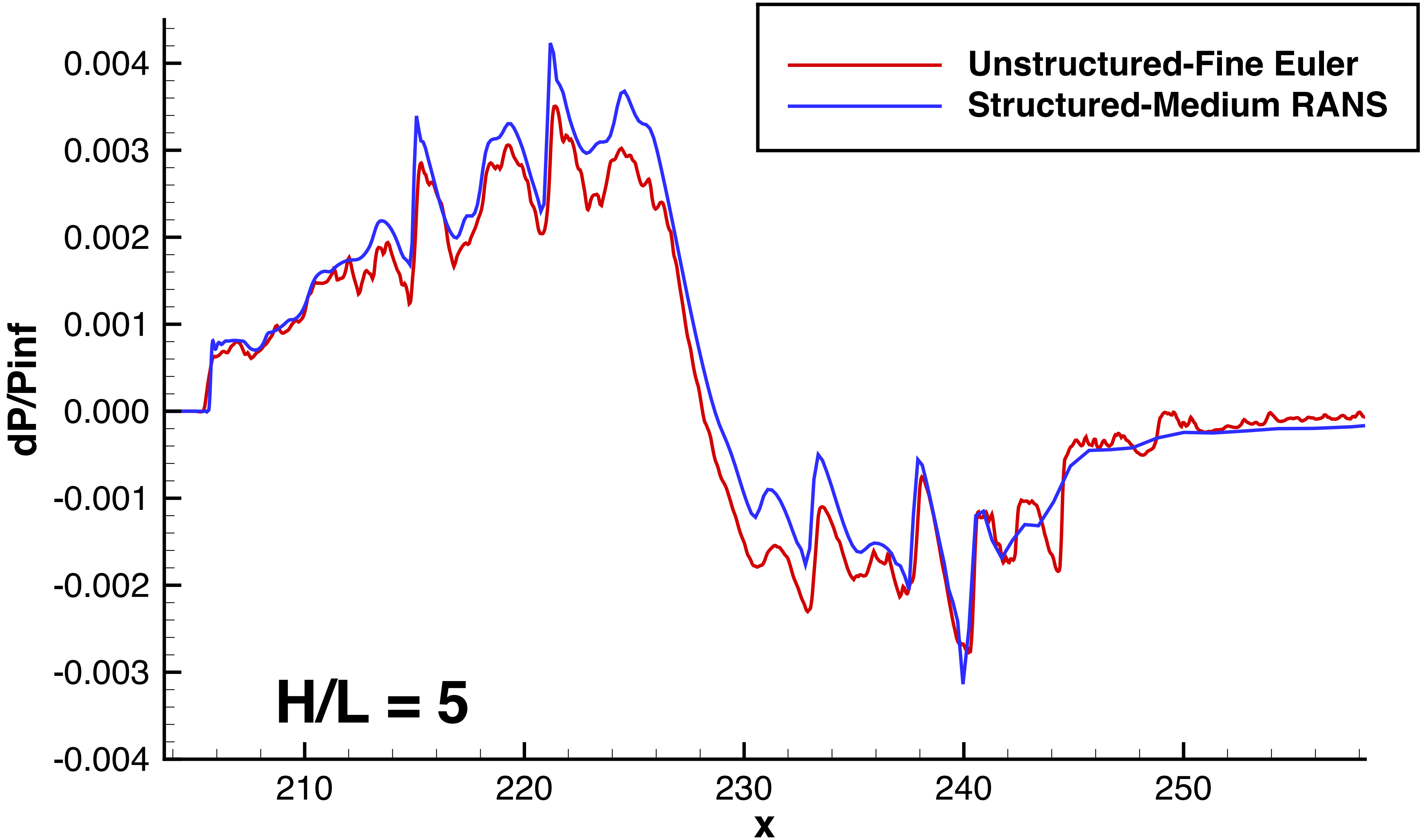


Results: Axie



Comparison of Unstructured Euler to Structured RANS: Near

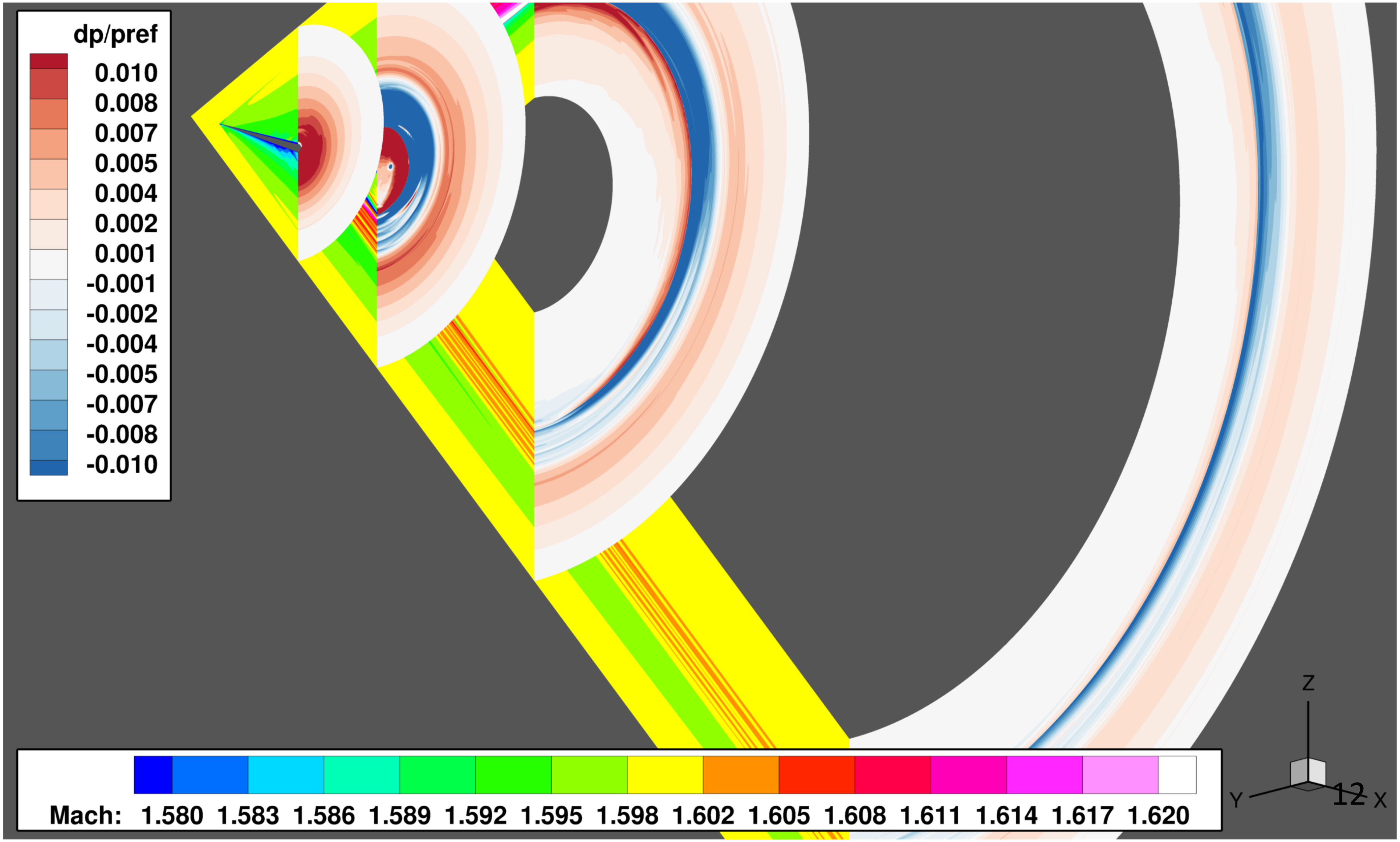
Results: Axie



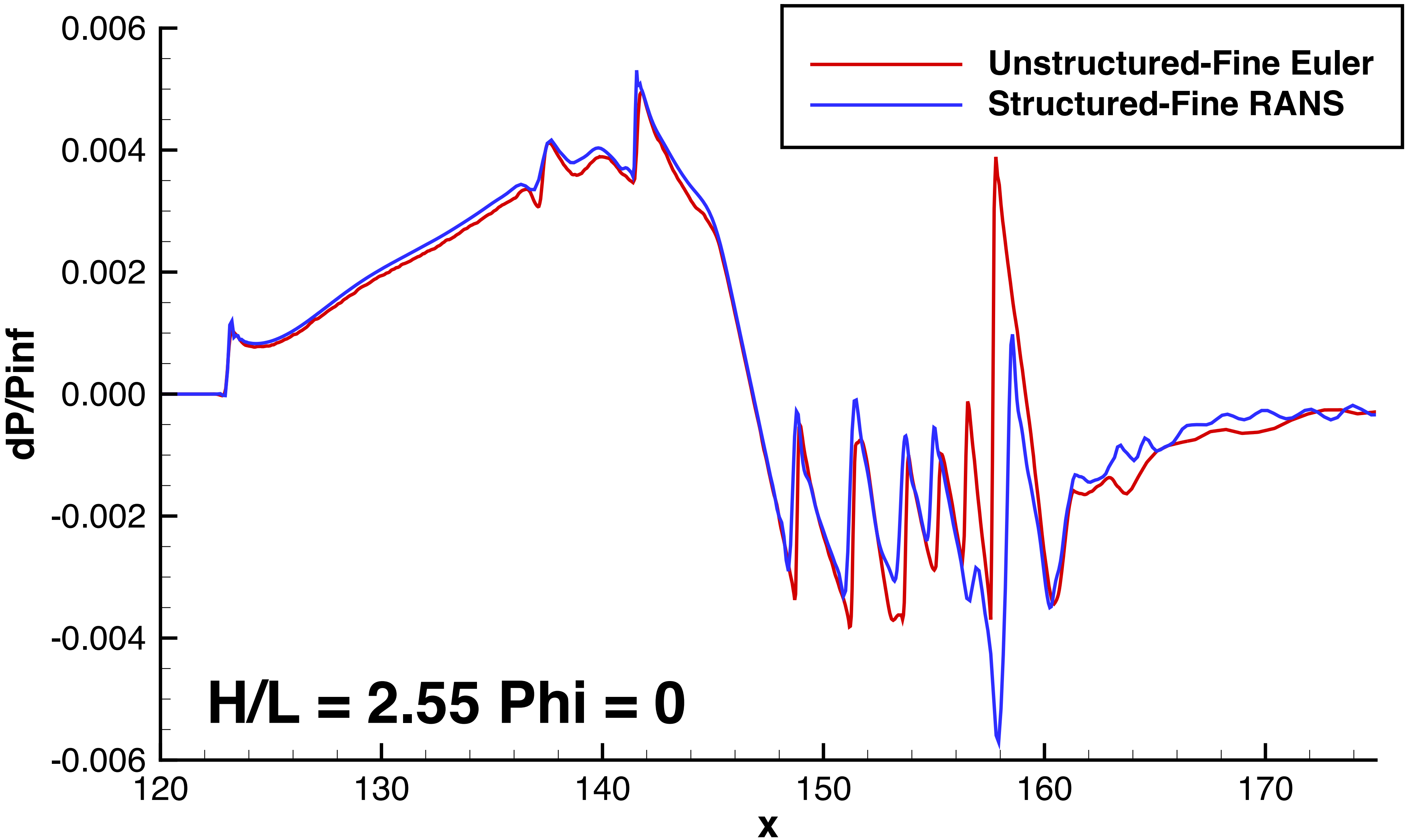
Comparison of Unstructured Euler to Structured RANS: Far

Results: JAXA Wing Body

Mach contour on symmetry plane with streamwise slices of pressure

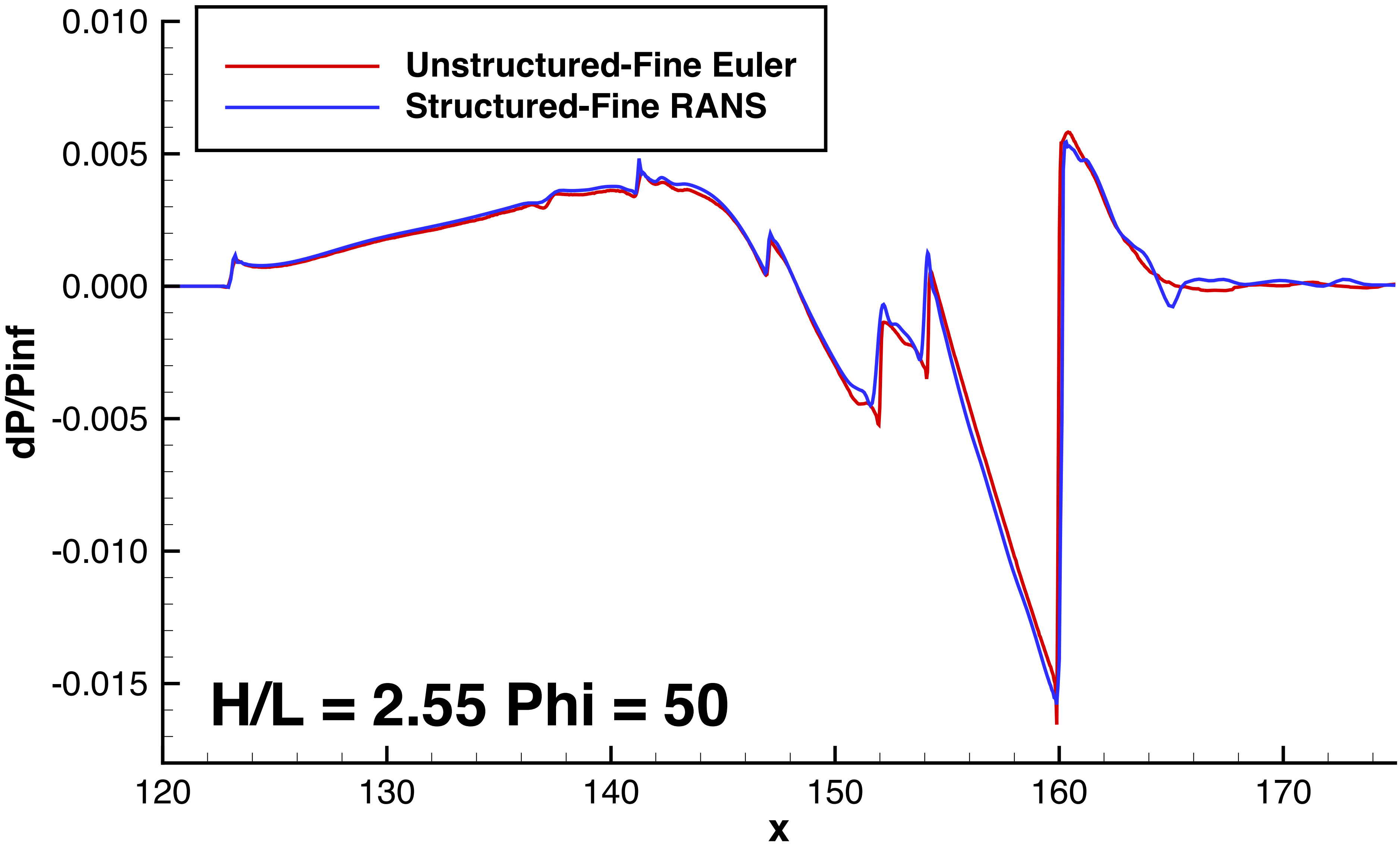


Results: JAXA Wing Body



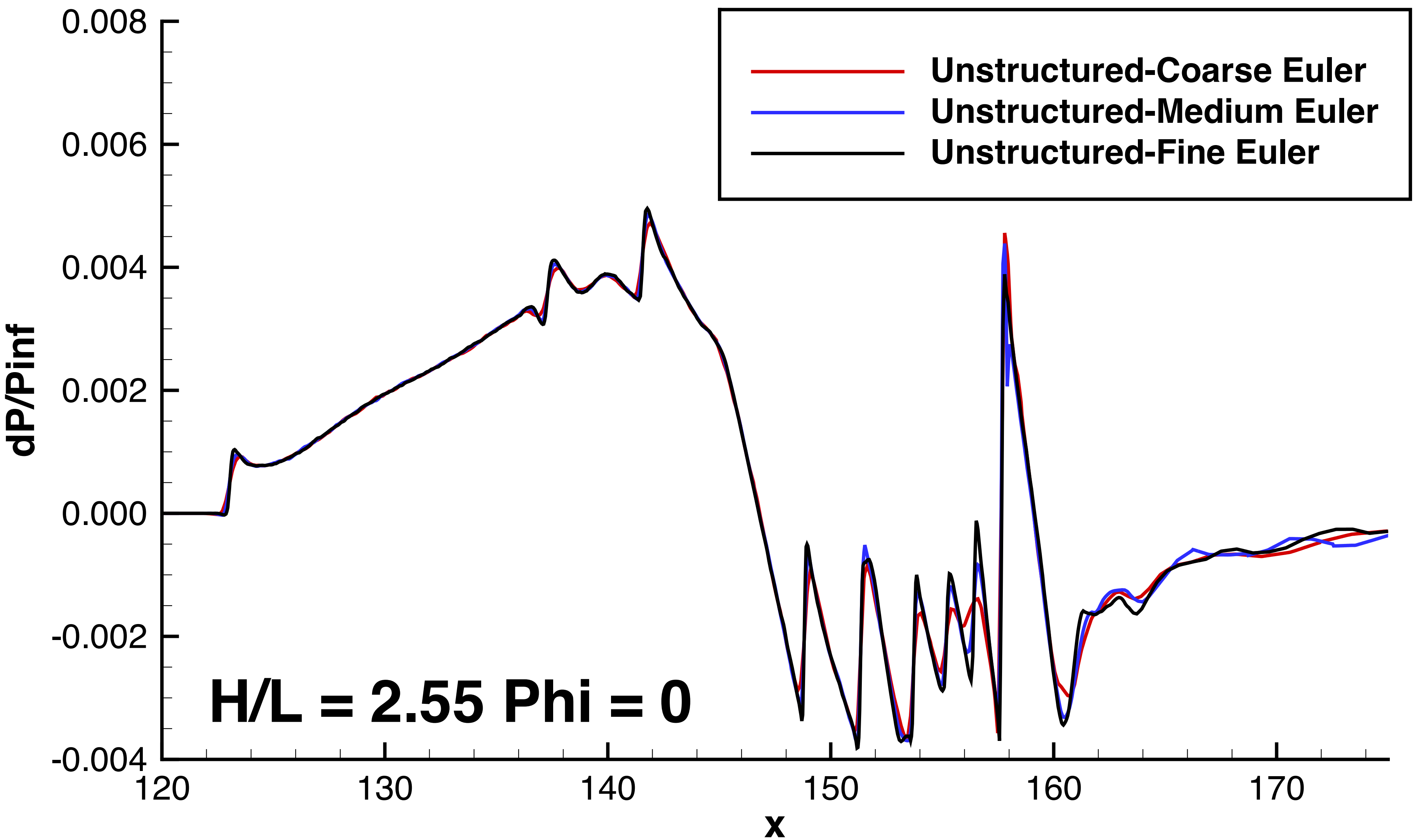
Comparison of Unstructured Euler to Structured RANS: On-track

Results: JAXA Wing Body



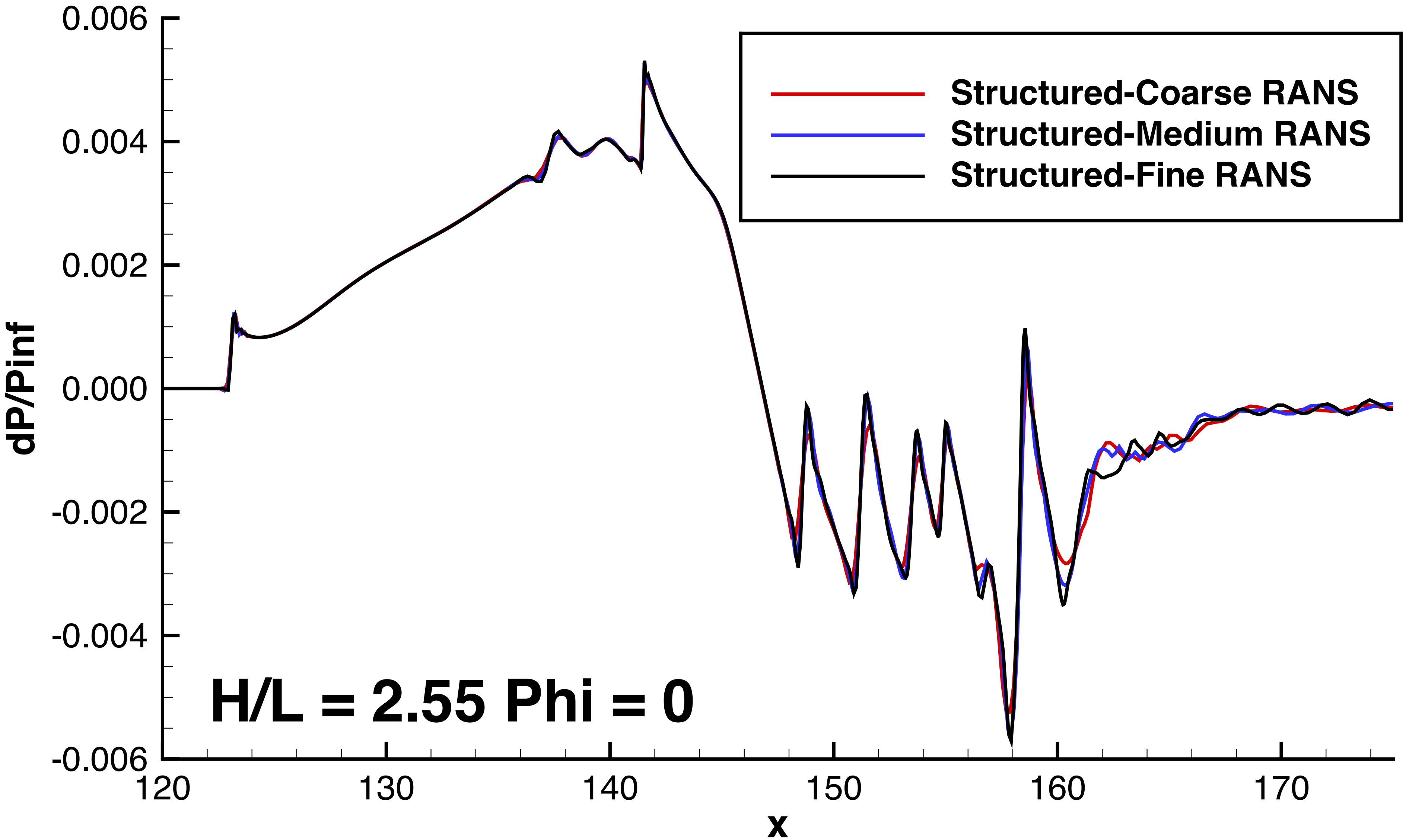
Comparison of Unstructured Euler to Structured RANS: Off-track

Results: JAXA Wing Body



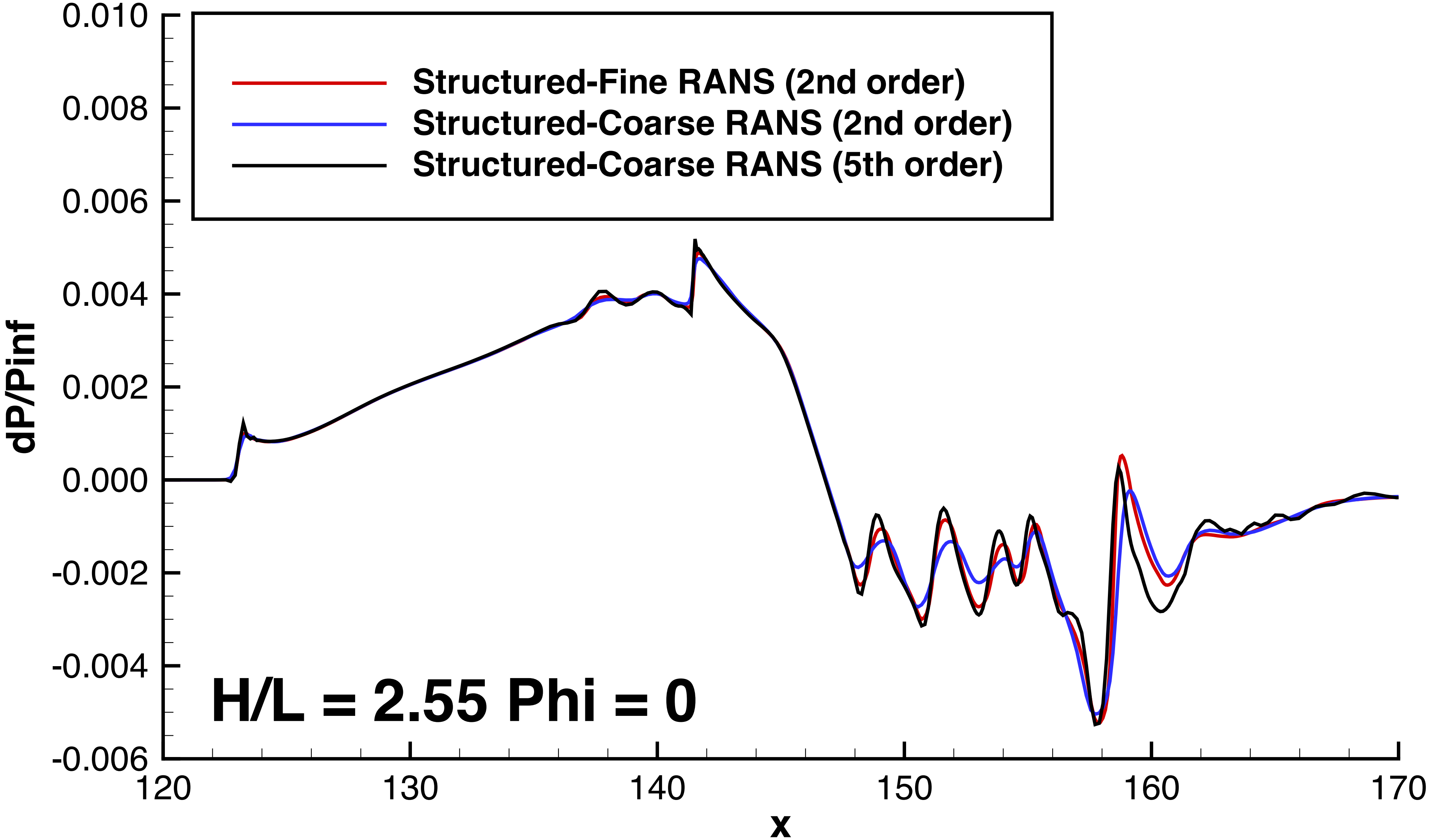
Grid Sensitivity of Unstructured Euler

Results: JAXA Wing Body



Grid Sensitivity of Structured RANS

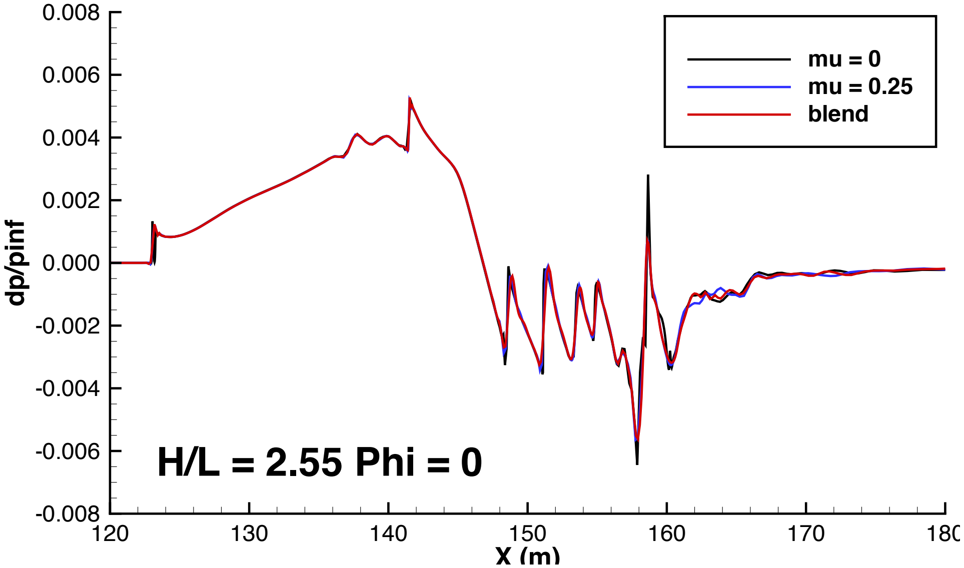
Results: JAXA Wing Body

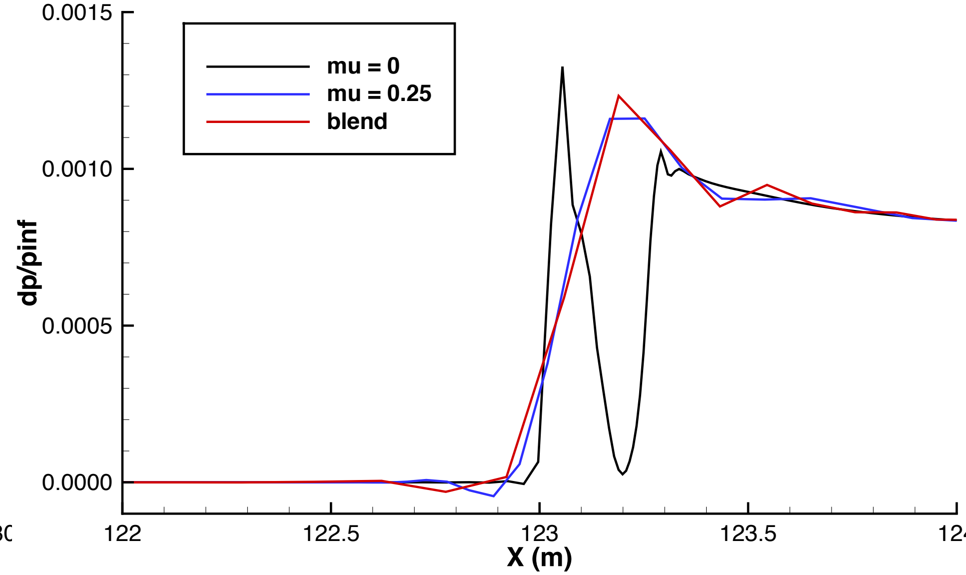


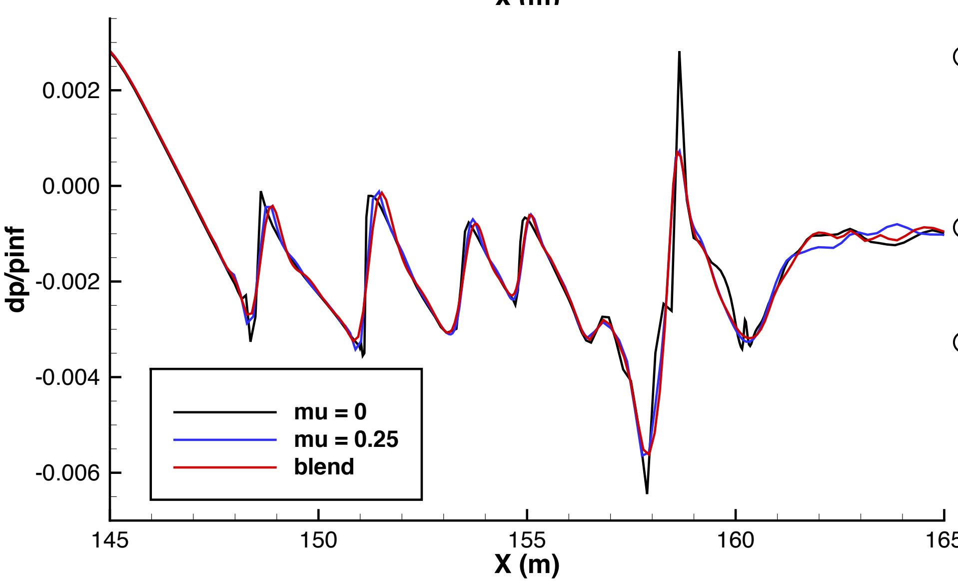
Sensitivity to Order of Accuracy for Structured RANS

Results: JAXA Wing Body

Sensitivity to Mach-angle alignment for Structured RANS



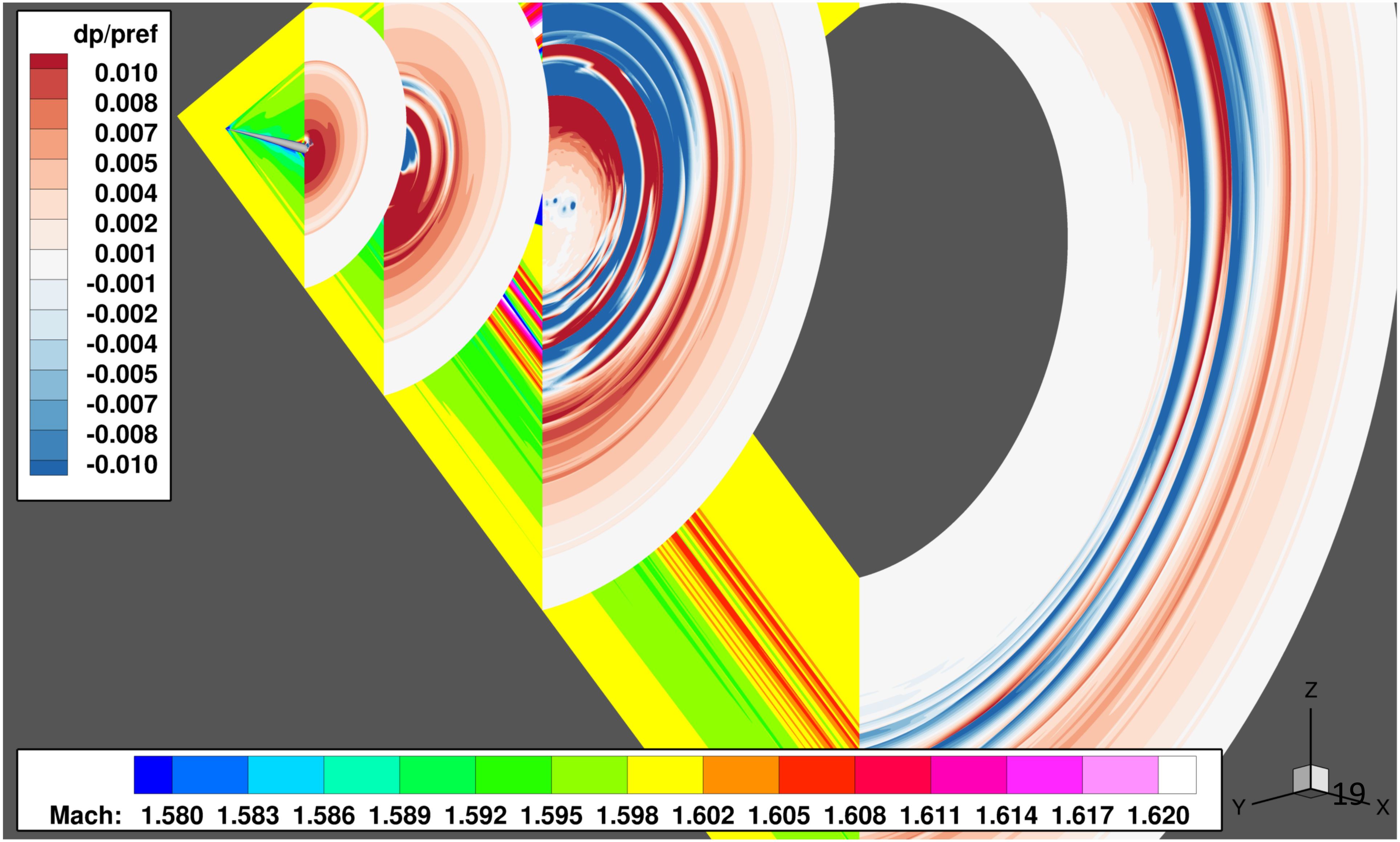




- Perfect Mach-angle alignment leads to spurious behavior of the high-order finite-difference scheme at shocks
- Off-setting the Mach-angle by a 1/4° corrects the behavior
- Adjusting the mesh spacing to become uniform in the streamwise direction effectively produces the slight mis-alignment, but causes additional diffusion

Results: C25d-Flowthru

Mach contour on symmetry plane with streamwise slices of pressure

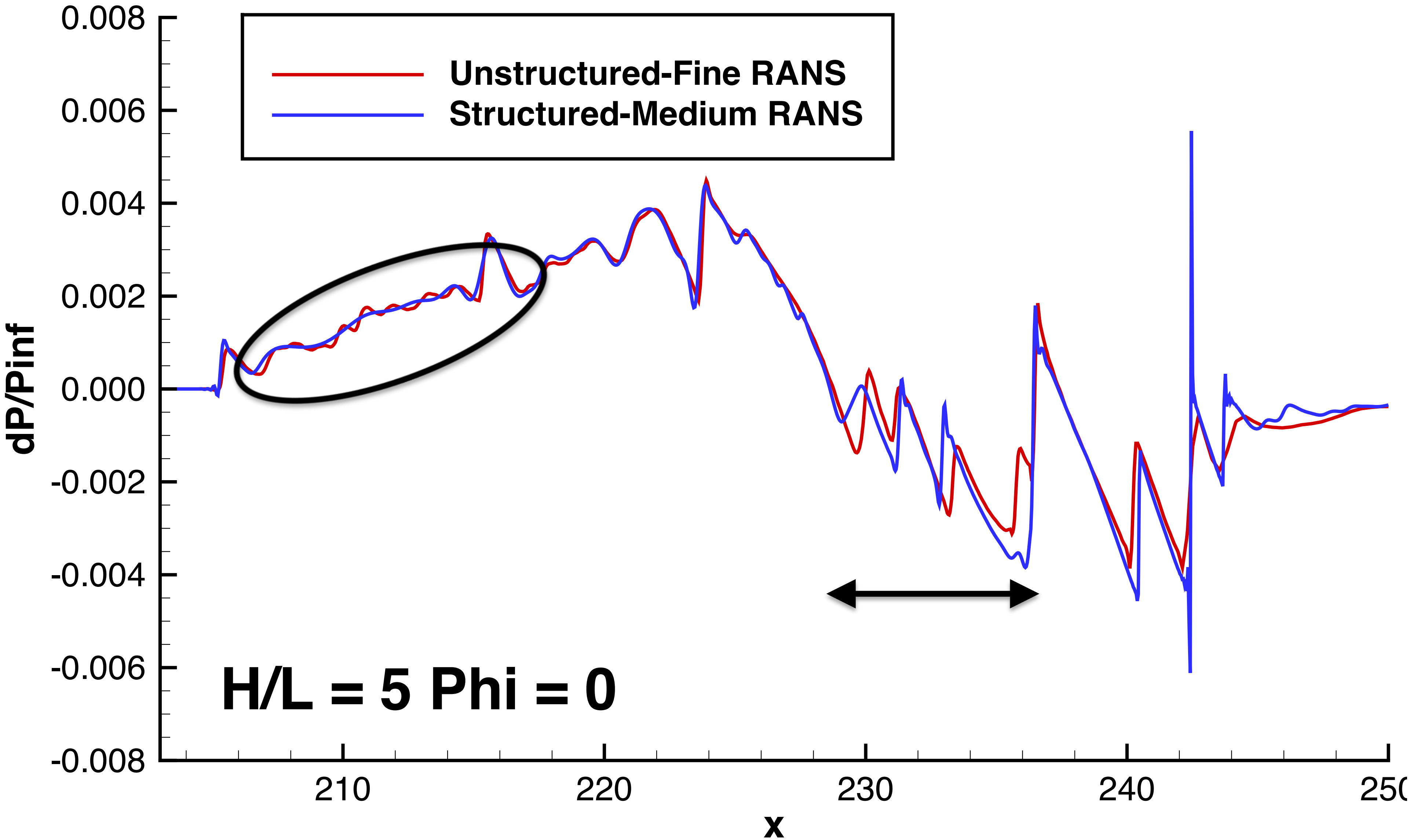


Results: C25d-Flowthru

Comparison of Loads and Residual Convergence

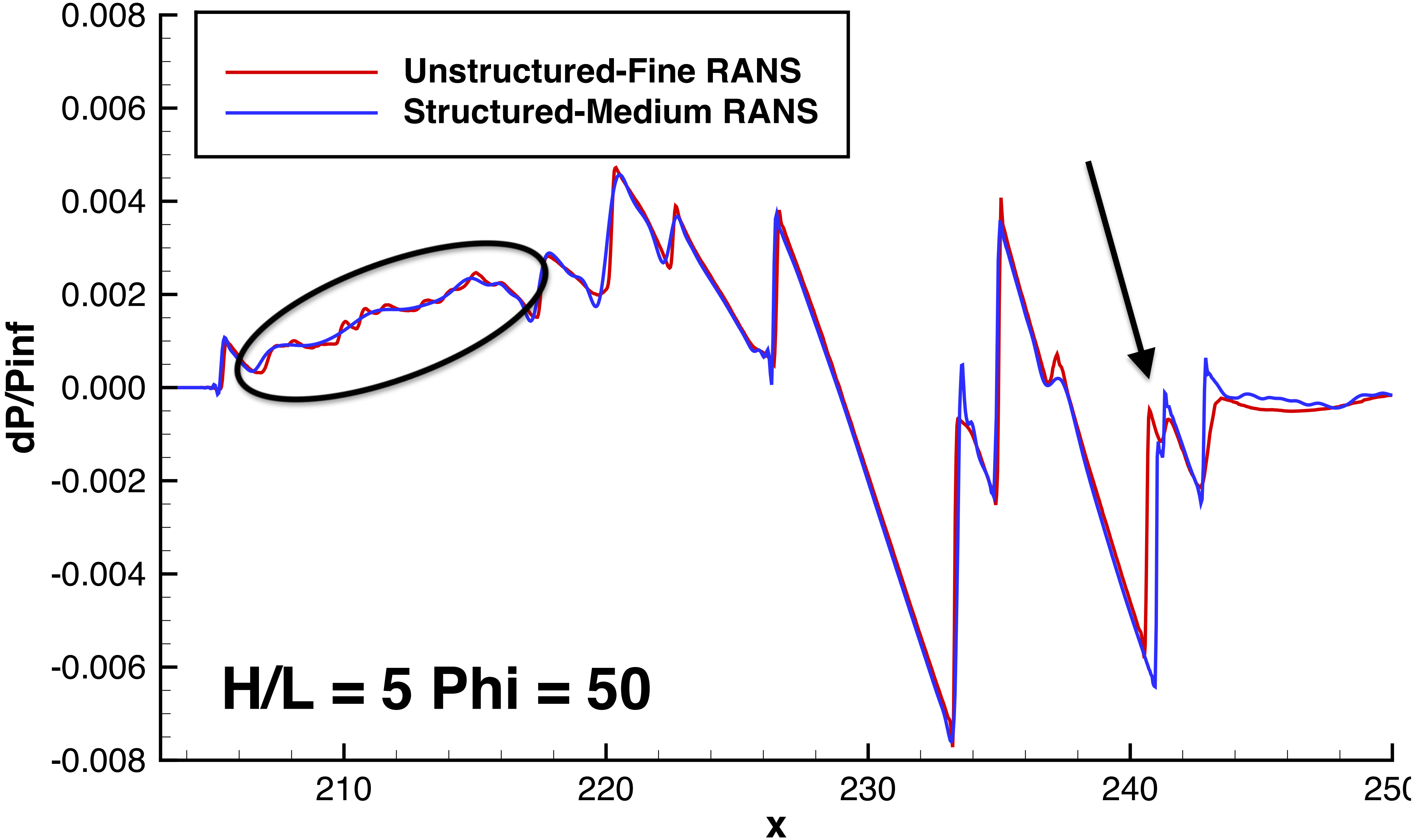
Grid	Flux	CL	CD	CM	Meanres	Turbres
U-Coarse	Roe	0.0665	0.0146	-0.050	4.7e-5	5.5e-2
U-Medium	Roe	0.0664	0.0145	-0.050	4.5e-5	4.2e-3
U-Fine	Roe	0.0661	0.0143	-0.050	5.0e-5	1.1e-1
S-Coarse	Roe	0.0658	0.0145	-0.050	3.4e-5	6.5e-6
S-Medium	Roe	0.0659	0.0144	-0.050	1.5e-5	5.1e-6
S-Coarse	HWCNS	0.0658	0.0144	-0.050	2.0e-2	6.7e-6
S-Medium	HWCNS	0.0659	0.0144	-0.050	1.3e-2	5.8e-6

Results: C25d-Flowthru



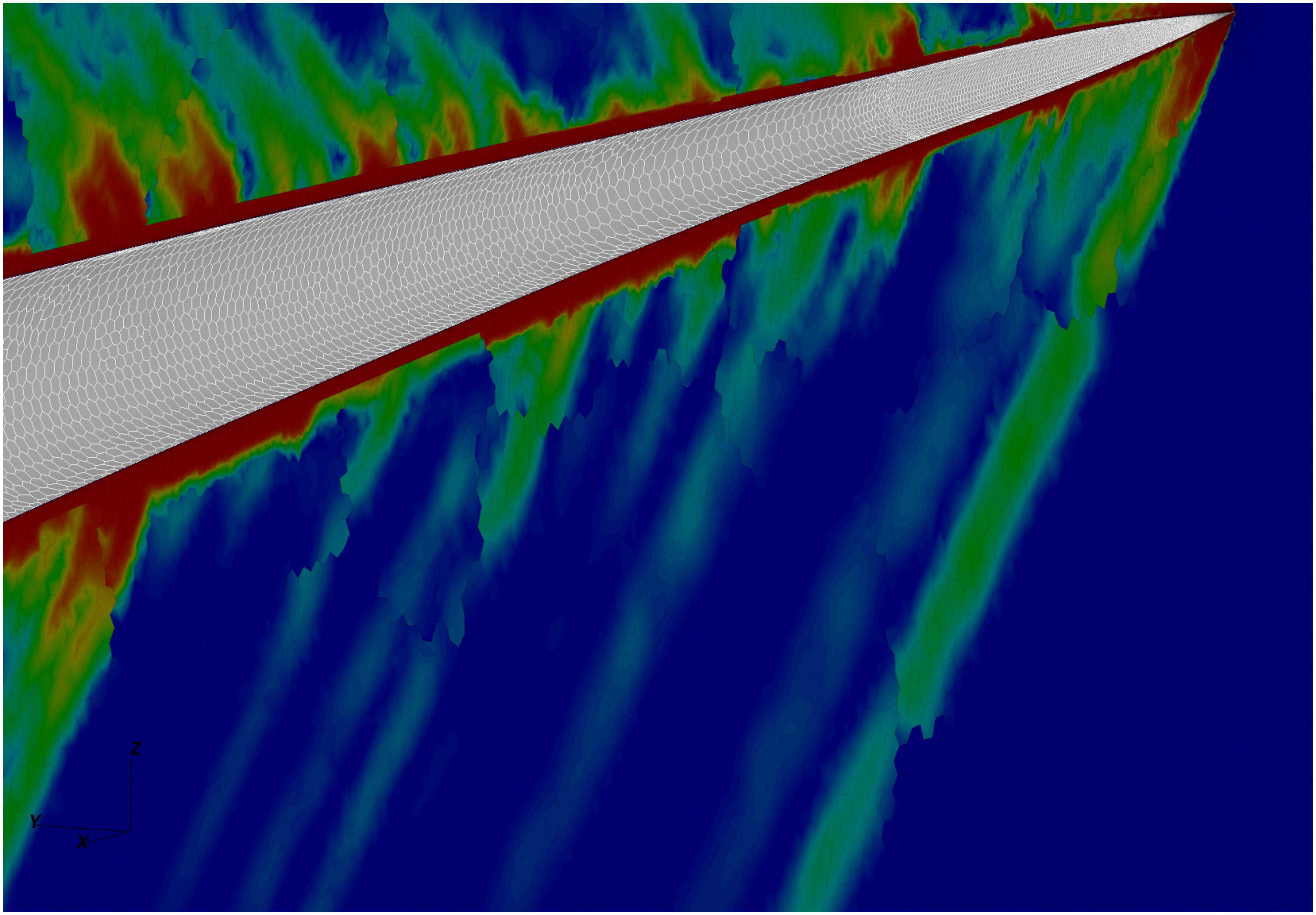
Comparison of Unstructured Euler to Structured RANS: On-track

Results: C25d-Flowthru



Comparison of Unstructured Euler to Structured RANS: Off-track

Results: C25d-Flowthru



High-Frequency Wave Number Content from Geometry Representation

Summary

- The LAVA framework using both unstructured polyhedral and structured overlapping grids has been applied to test cases for the 2nd AIAA Sonic Boom Prediction Workshop
- Both grid methodologies show consistent mesh convergence of off-body pressure signatures and similar prediction of loads
- Small differences between calculations using unstructured grids versus structured overlapping grids are observed:
  - Effective body thickening from boundary layer (Euler vs. RANS)
  - High-frequency wave content from geometry representation
- Higher-order accurate discretizations on coarse grids produce nearly equivalent off-body pressure signatures to 2nd-order accurate discretizations on fine grids
- Using Mach-angle aligned meshes with a small offset and without blending is the best practice for off-body structured overset grid generation when using the high-order accurate discretization

Acknowledgements

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- The authors would like to thank the 2nd AIAA Low Sonic Boom Prediction Workshop committee members for organizing the workshop and providing the CAD and problem specifications
- Computer time has been provided by the NASA Advanced Supercomputing (NAS) facility at NASA Ames Research Center

Go see James Jensen's talk on Monday 11:30-12:00 (Dallas 2)
AIAA-2017-0042