3rd Sonic Boom Prediction Workshop Near-field Propagation

Isik Ozcer, Ph.D.
Lead Software Developer
Fluids Aerospace Solver Technology
ANSYS Inc.

Introduction

- First time ANSYS participating
- Results from two solvers submitted
- Workshop-provided and ANSYS-created grids
- Calculations carried out on ANSYS clusters
  - 120 – 280 cores used (depending on availability)
- Outline
  - Flow solver details
  - Summary of cases
  - Results
    - Axie
    - Biconvex
    - C608
  - Concluding remarks

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Introduction

- The team

Isik Ozcer
Lead Software Developer
Fluids Aerospace Technology

Krishna Zore
Software Developer II
Applications Development Team

Luke Munholand
Lead Engineer
ANSYS ACE Team

John Stokes
Director of Software Development
Fluids Aerospace Technology

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Flow solver details

- HALO3D (High Altitude Low Orbit 3D)
  - Density-based solver
  - Coupled momentum/energy
  - Node-centered/edge-based Galerkin FEM
  - Newton-Krylov with ILU preconditioner
  - Roe and AUSM+up with MUSCL
  - Minmod, van Albada flux limiters
  - CFL-based local time stepping
  - Spalart-Allmaras turb. model
  - Not yet commercially available
    - ➢ R&D collaboration with McGill University
    - ➢ Technology incubator

- Fluent
  - Density-based solver option
  - Coupled momentum/energy
  - Cell-centered finite volume
  - Newton with AMG preconditioner
  - Roe and AUSM+ MUSCL
  - Standard and minmod gradient limiters
  - CFL-based local time stepping
  - Gradient-based mesh adaptation
  - Spalart-Allmaras and kw-SST turb. models
  - Part of standard ANSYS Fluent release

J. Seguin, S. Gao, W. G. Habashi, D. Isola, and G. Baruzzi, "A Finite Element Solver for Hypersonic Flows in Thermo-Chemical Non-Equilibrium, Part I", Invited Paper to Special Issue of the International Journal of Numerical Methods in Heat and Fluid Flow, DOI: 10.1108/HFF-09-2018-0498, December 2018

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Summary of cases

	Axie	Biconvex	C608
HALO3D	Inviscid-mixed-256 Coarse (0.6M nodes)	Visc-mixed-157 Coarse (0.8M nodes)	Visc-mixed-128 Coarse (12M nodes)
	Inviscid-mixed-200 Medium (1.6M nodes)	Visc-mixed-128 Medium (1.6M nodes)	Visc-mixed-100 Medium (21M nodes)
	Inviscid-mixed-160 Fine (5M nodes)	Visc-mixed-100 Fine (3.3M nodes)	Visc-mixed-080 Fine (35M nodes)
Fluent	Adapted inviscid mixed Coarse (49M cells)	Polyhedra, viscous No refinement (9.2M cells)	Visc-mixed-128 Coarse (30M cells)
	Adapted inviscid mixed Medium (101M cells)	Polyhedra, viscous, BOI refinement (44M cells)	Visc-mixed-080 Fine (83M cells)
	Adapted inviscid mixed Fine (198M cells)	Polyhedra, viscous Mesh adaptation (15-28M cells)	
	Axisymmetric, refined to mesh independence (50M)		

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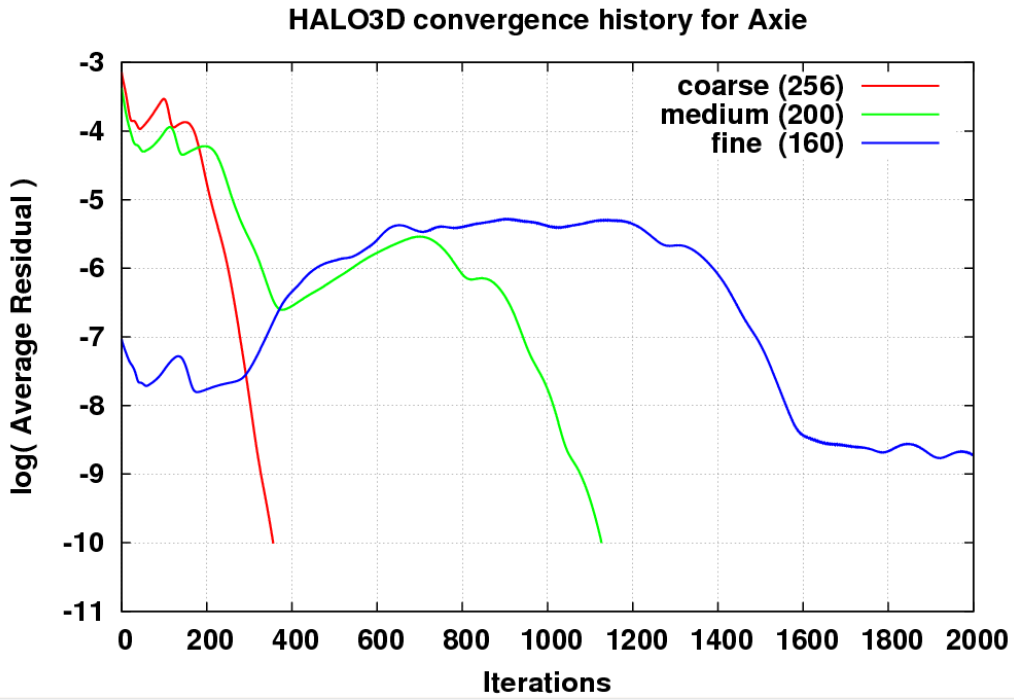
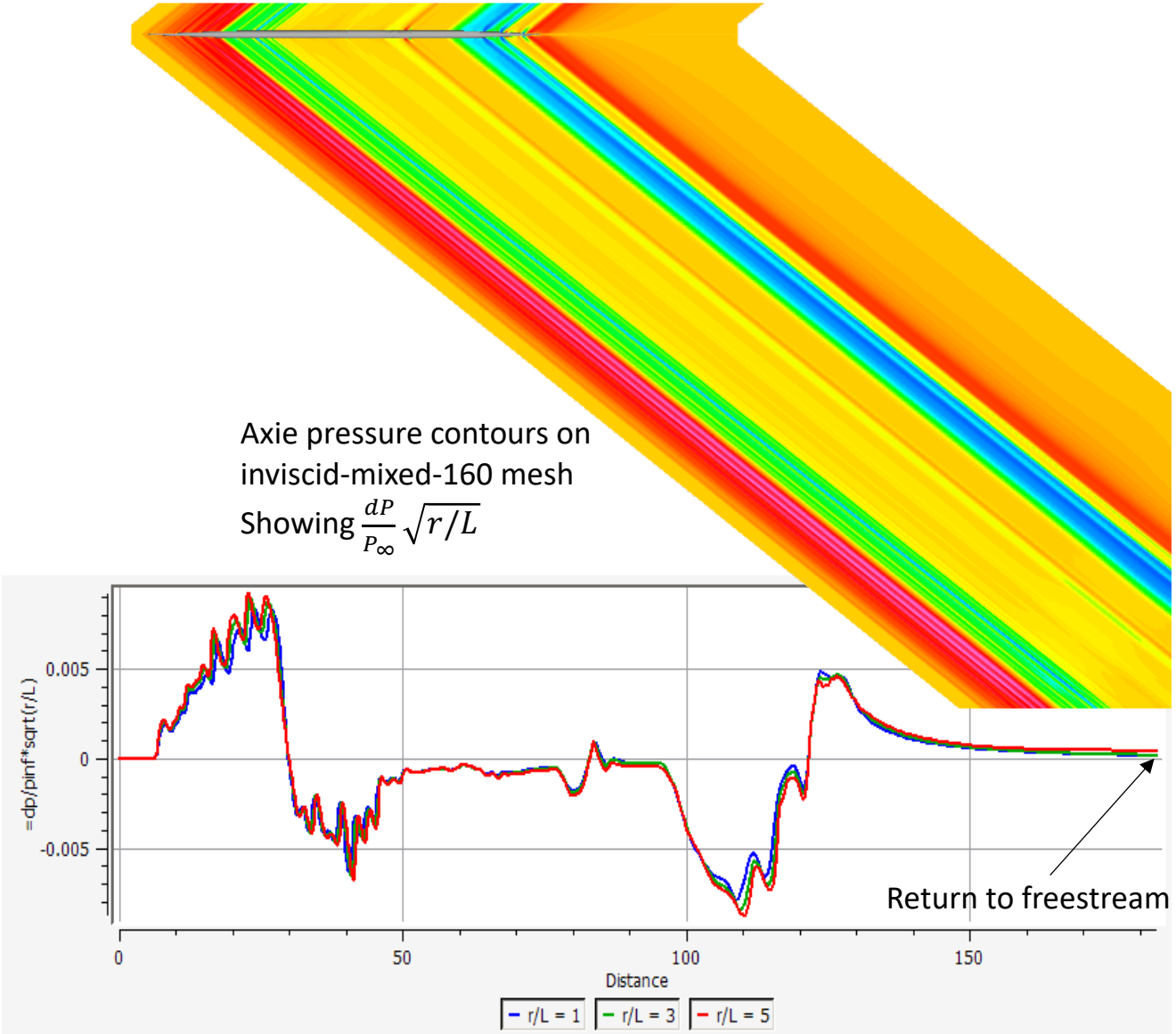
Results – Axie @ Mach 1.6

- HALO3D, Galerkin FEM
  - Workshop provided grids: 160 / 200 / 256
  - Inviscid
  - Initialized with free stream
  - AUSM+up with MUSCL
  - CFL = 100, ramped from 1 in first 100 steps
  - Non-reflective in/outflow (1D Riemann)





Axie pressure contours on inviscid-mixed-160 mesh

Showing $\frac{dP}{P_\infty}\sqrt{r/L}$

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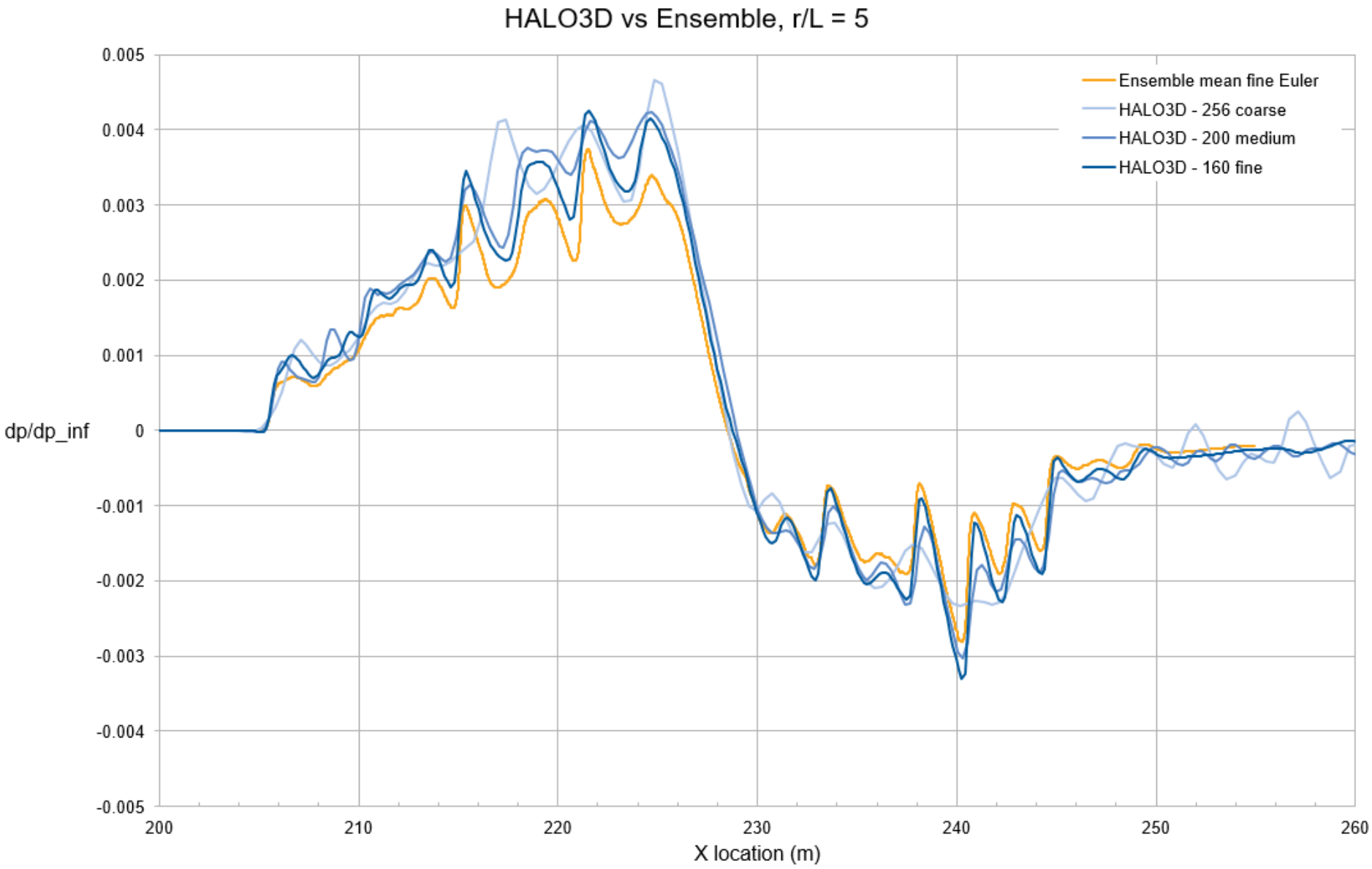
Results – Axie @ Mach 1.6



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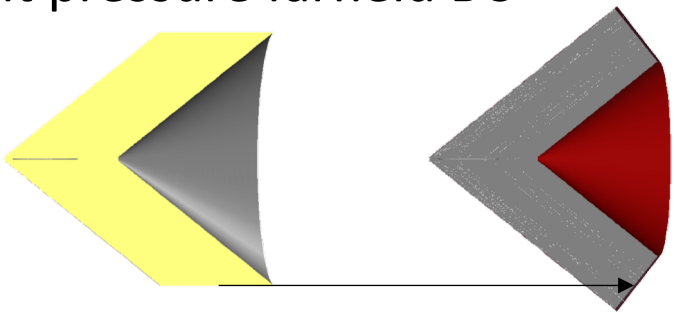
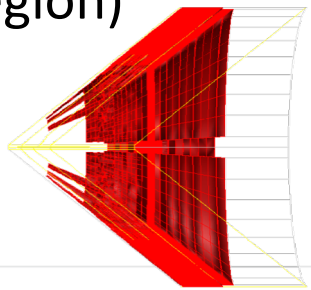
Results – Axie @ Mach 1.6

- Modifications to grid for use with current Fluent release:
  - Flow aligned farfield reoriented to better suit pressure farfield BC

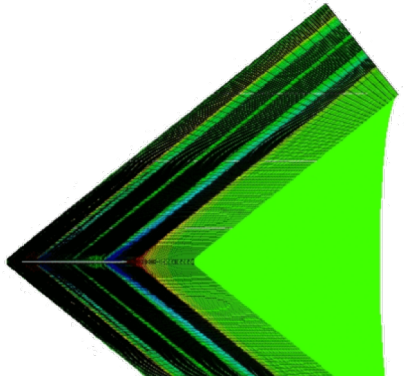


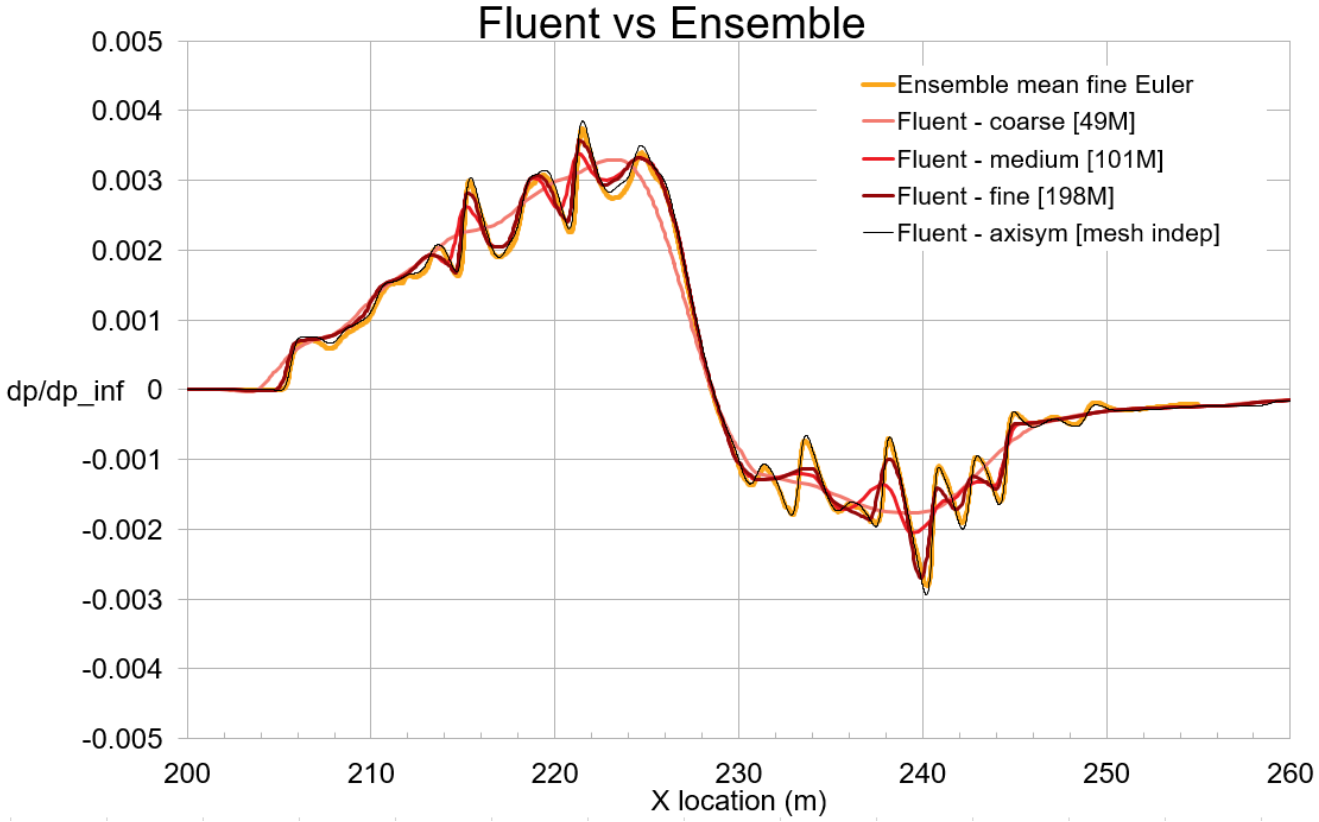
  - Far field prisms replaced with hexas to reduce skewness (pyramids used to connect to tetra region)

Elements marked with skewness > 0.97



  - Mesh adapted based on density gradient





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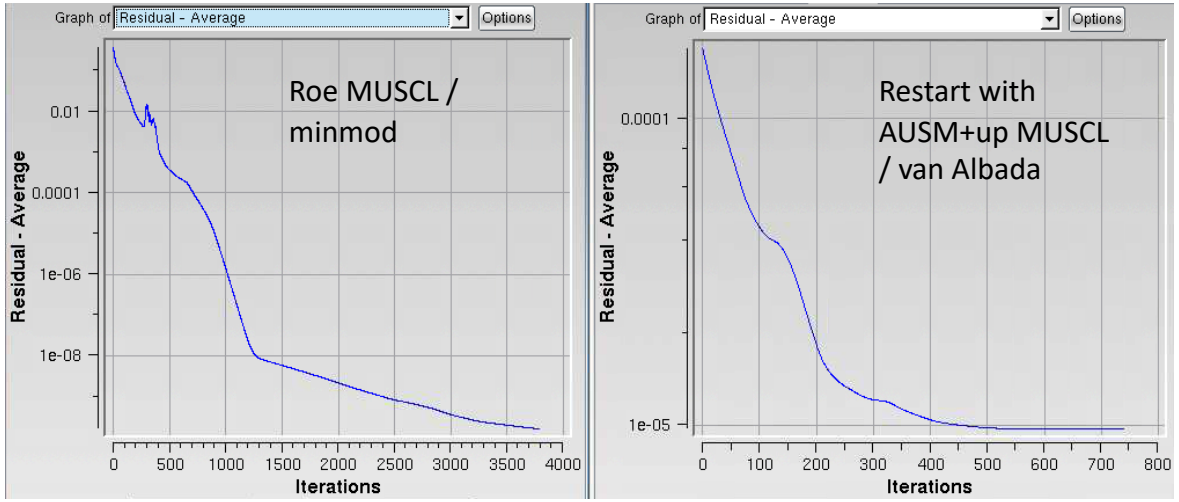
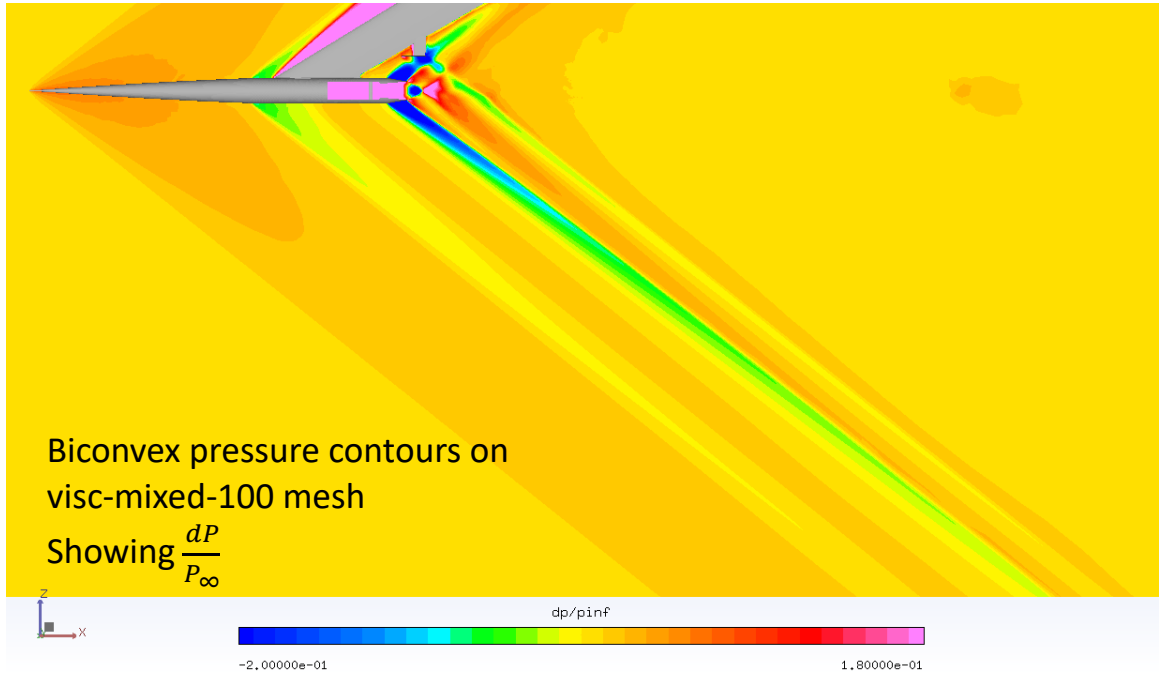
Results – Biconvex @ Mach 1.6

- HALO3D, Galerkin FEM
  - Workshop provided grids: 100 / 128 / 157
  - Viscous - SA
  - Initialized with Mach 0.35: Easier startup for the plenum
  - Progressive solution strategy:
    - ➢ Roe MUSCL, minmod limiter, CFL 0.1 → 20 in 300 iterations, converge
    - ➢ AUSM+up MUSCL, van Albada limiter, CFL 0.1 → 20 in 300 iterations, iterate as needed
  - Non-reflective in/outflow (1D Riemann)

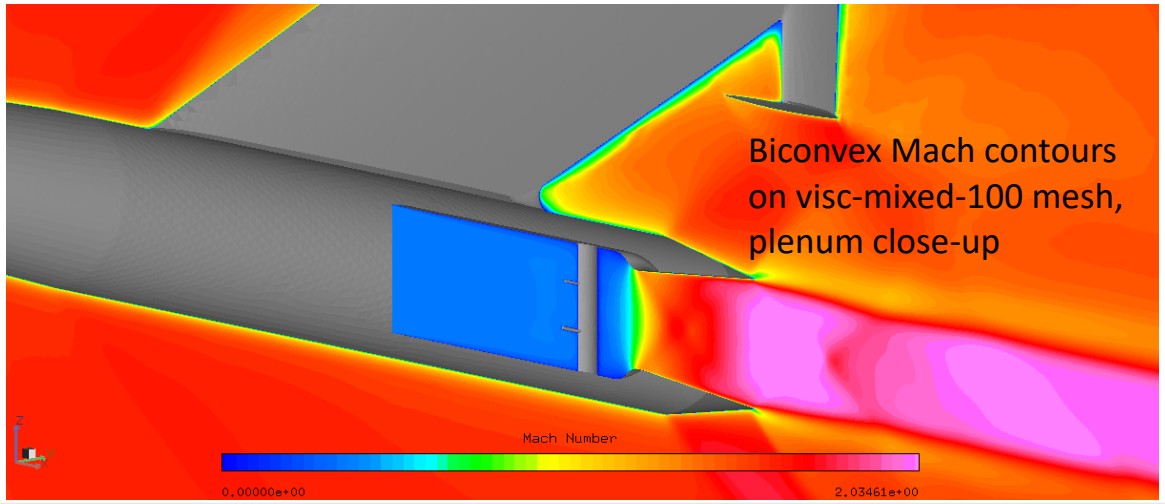


HALO3D convergence history for biconvex fine case, using the visc 100 grid



Biconvex pressure contours on visc-mixed-100 mesh

Showing $\frac{dP}{P_\infty}$



Biconvex Mach contours on visc-mixed-100 mesh, plenum close-up

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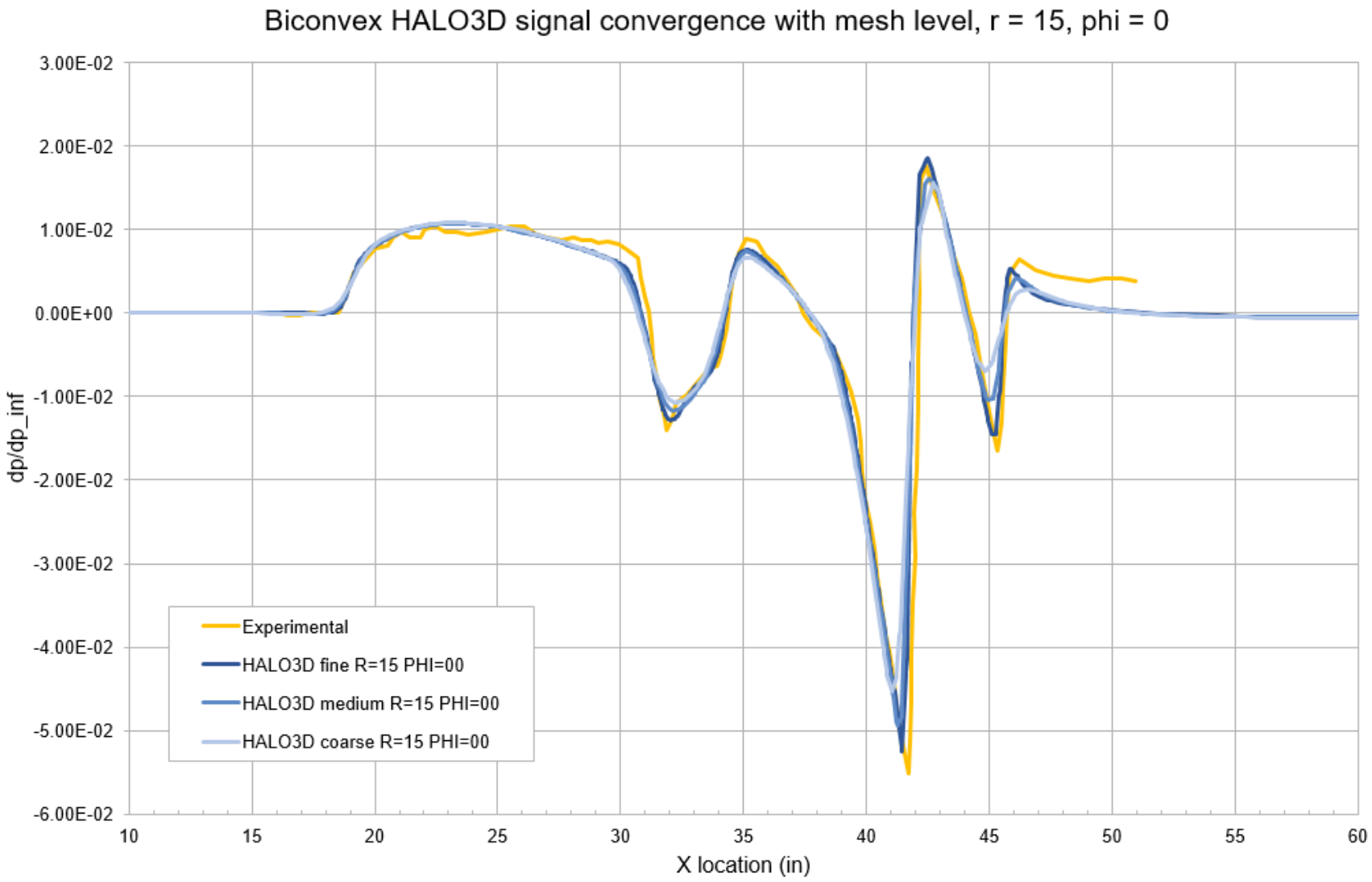
Results – Biconvex @ Mach 1.6



Calculation times between 1-7 hours on 120 cores, number of nodes 0.85M - 3.3M

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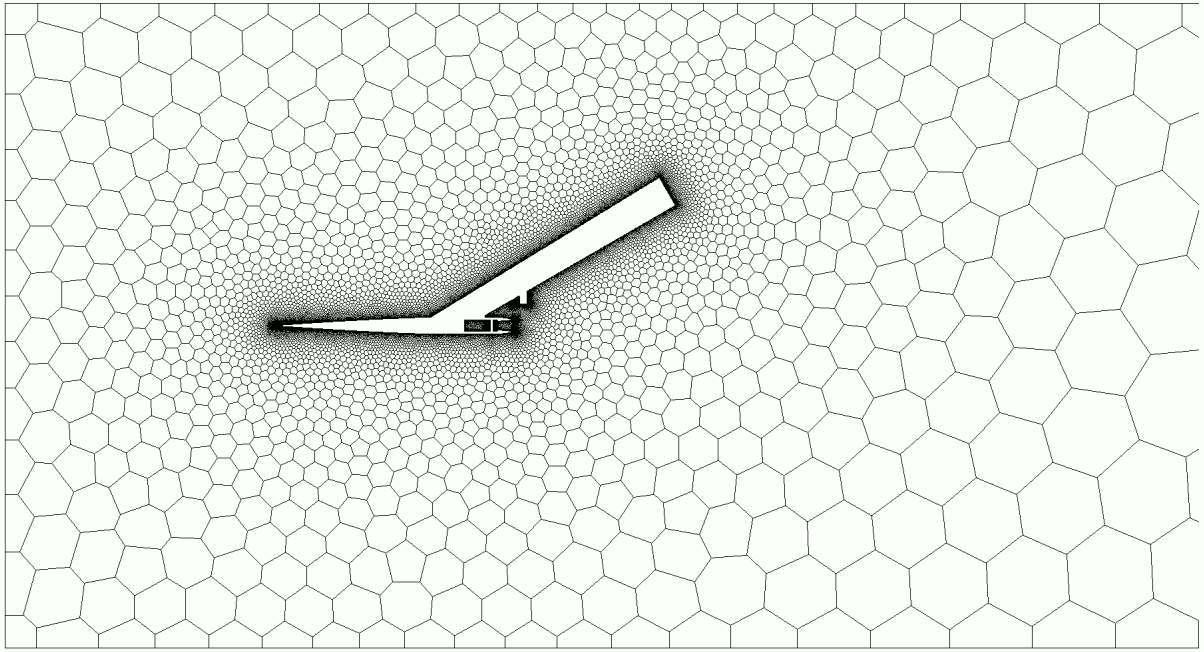
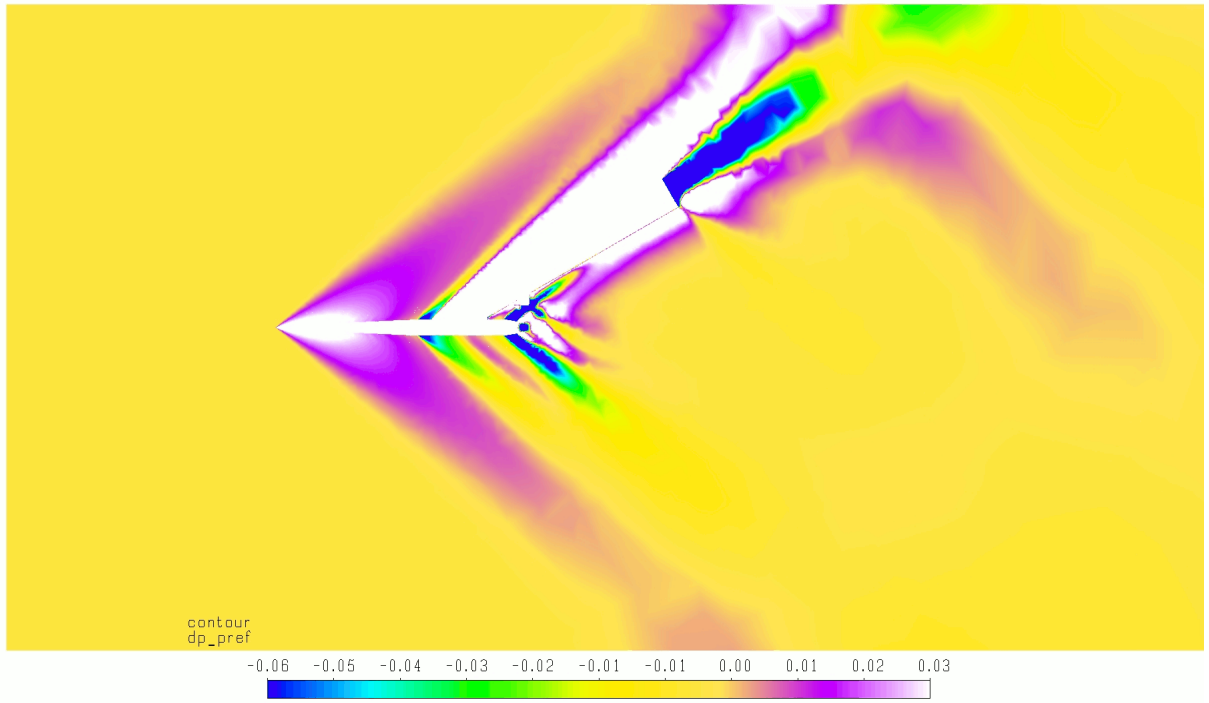
Results – Biconvex @ Mach 1.6

- Fluent
  - Remeshed domain using polyhedral
  - Body of influence and solution-based mesh refinement employed
  - kw-SST turbulence model
  - 2nd order Roe
  - Green-Gauss node-based gradients
  - CFL 25





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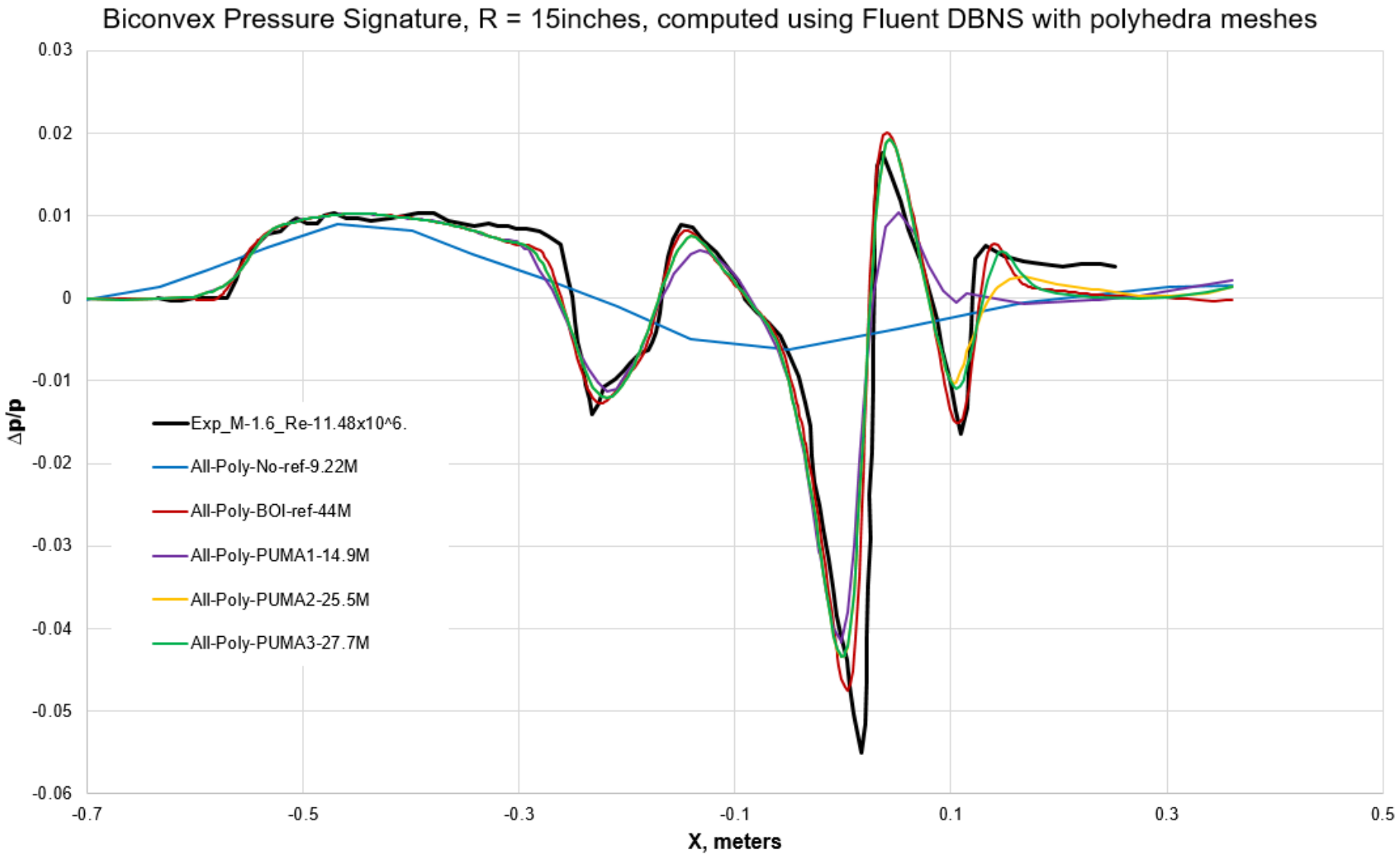
Results – Biconvex @ Mach 1.6



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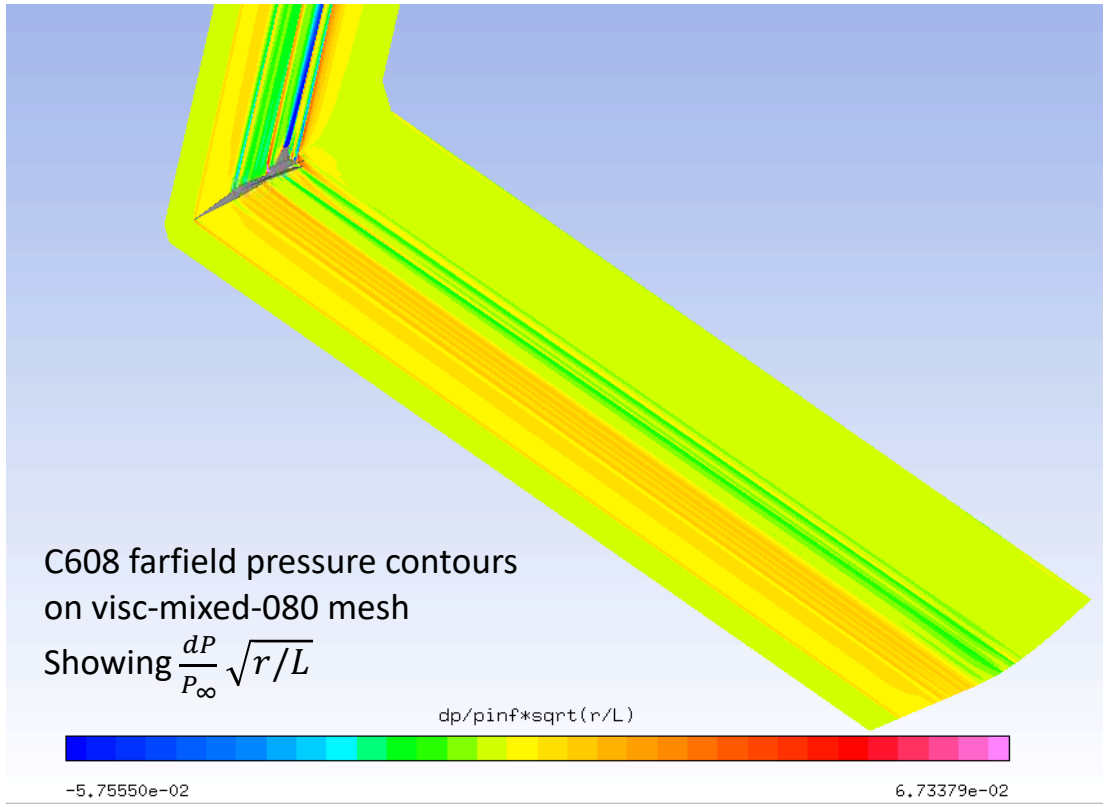
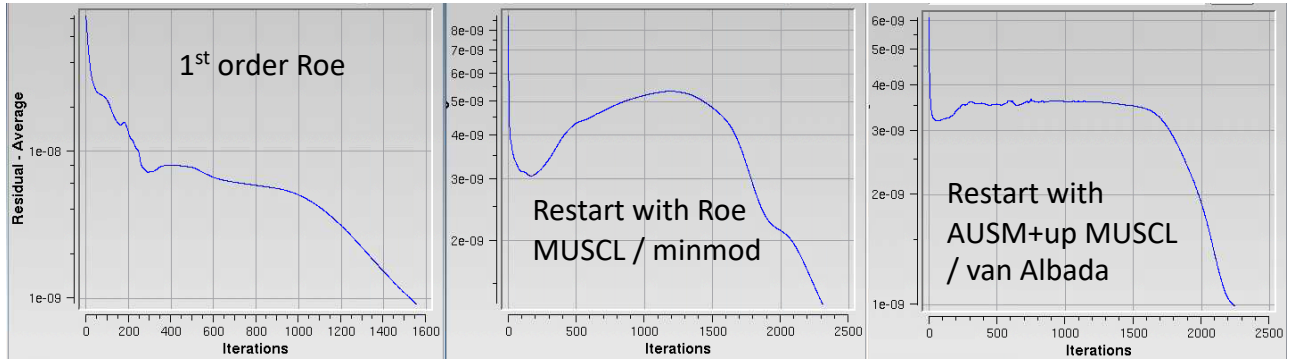
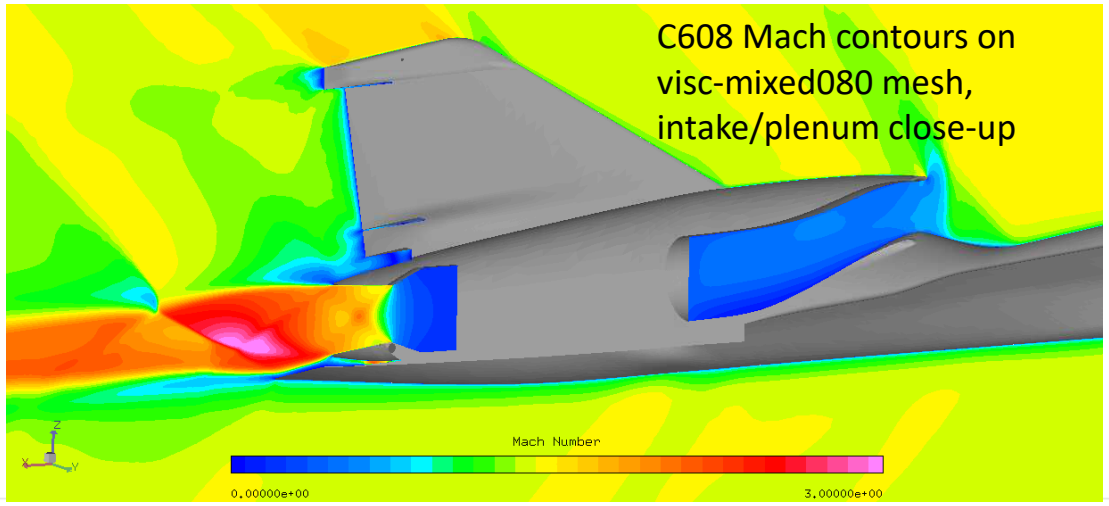
Results – C608 @ Mach 1.4

- HALO3D, Galerkin FEM
  - Workshop provided grids: 080 / 100 / 128
  - Viscous - SA
  - Initialized with free stream
  - Progressive solution strategy:
    - Roe 1st order, CFL 2
    - Roe MUSCL, minmod limiter, CFL 5
    - AUSM+up MUSCL, van Albada limiter, CFL 5
  - Non-reflective in/outflow (1D Riemann)





HALO3D convergence history for C608 medium case, using the visc 100 grid



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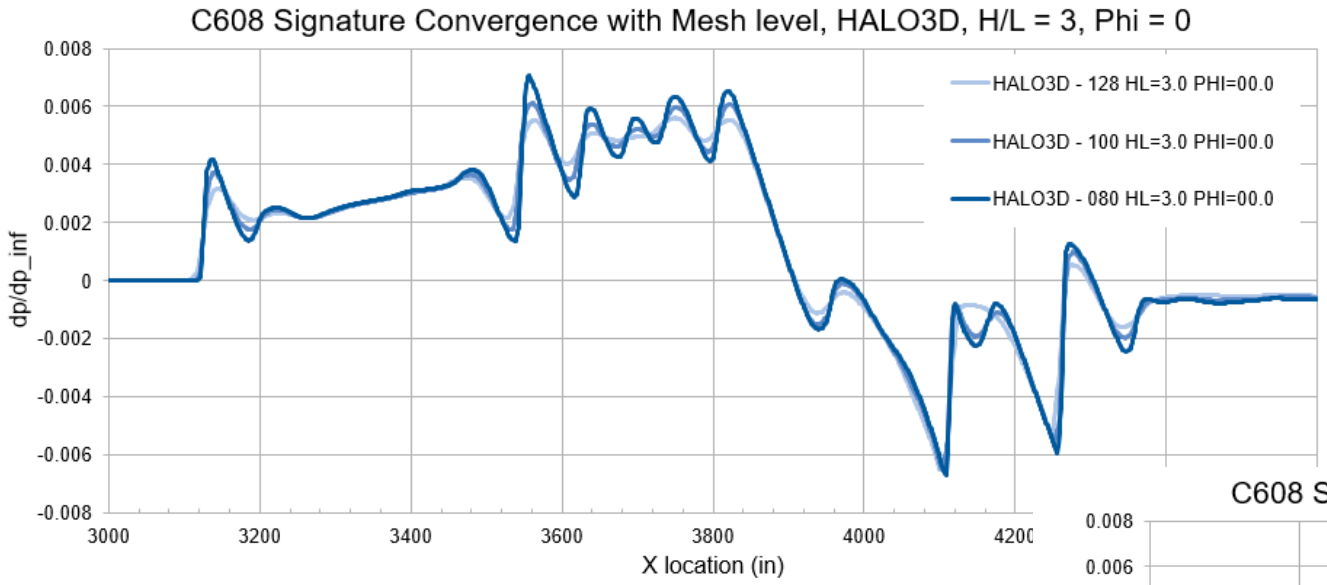
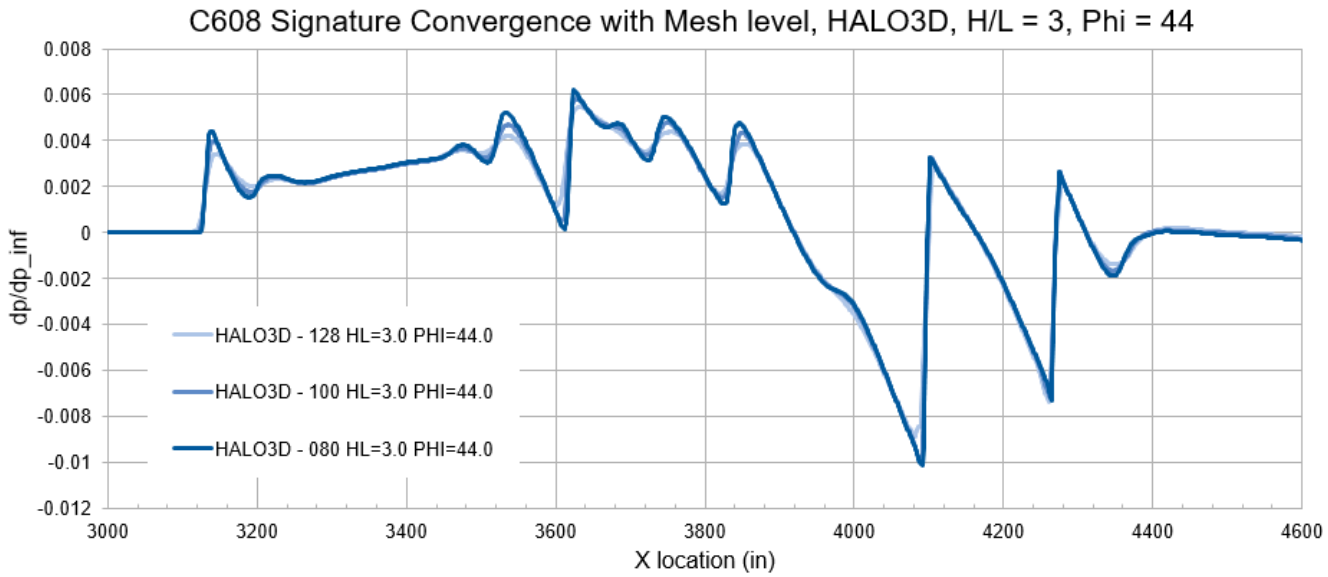
Results – C608 @ Mach 1.4





Calculation times between 1-3 days on 120 cores, number of grid nodes 12M – 35M

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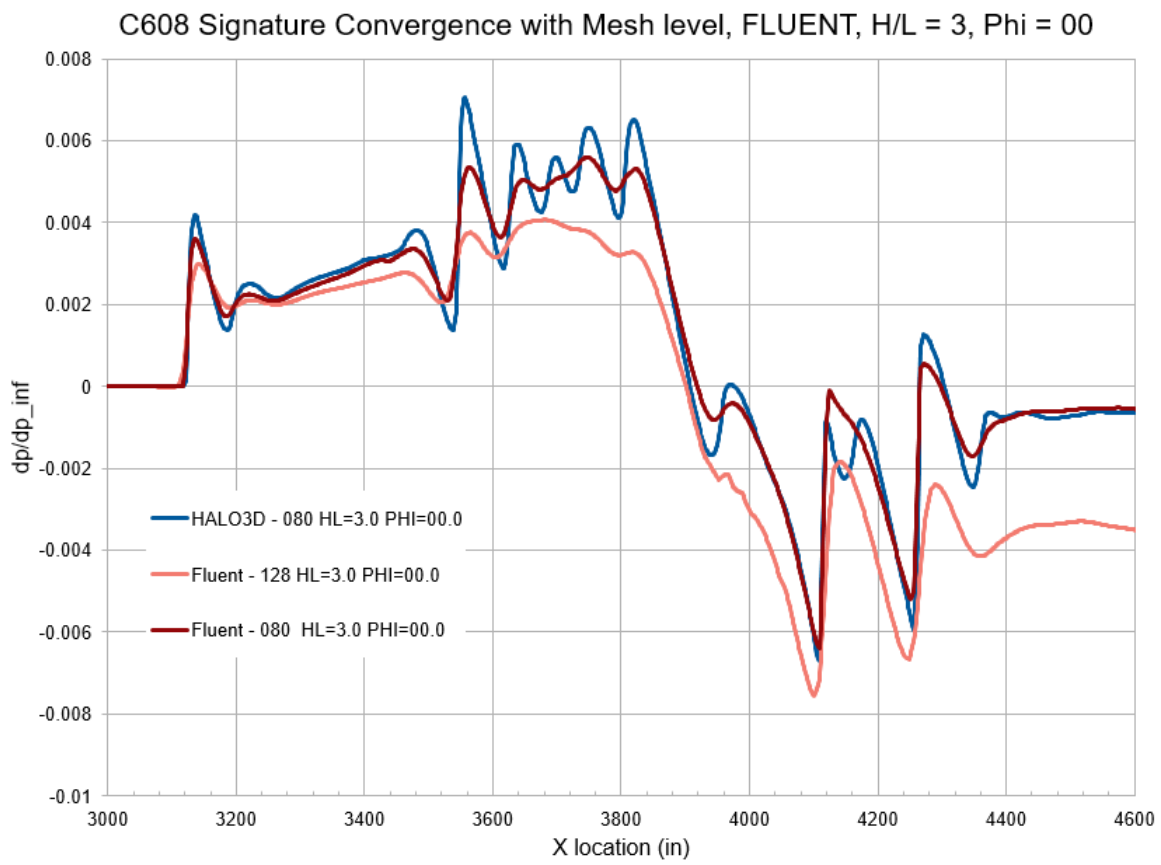
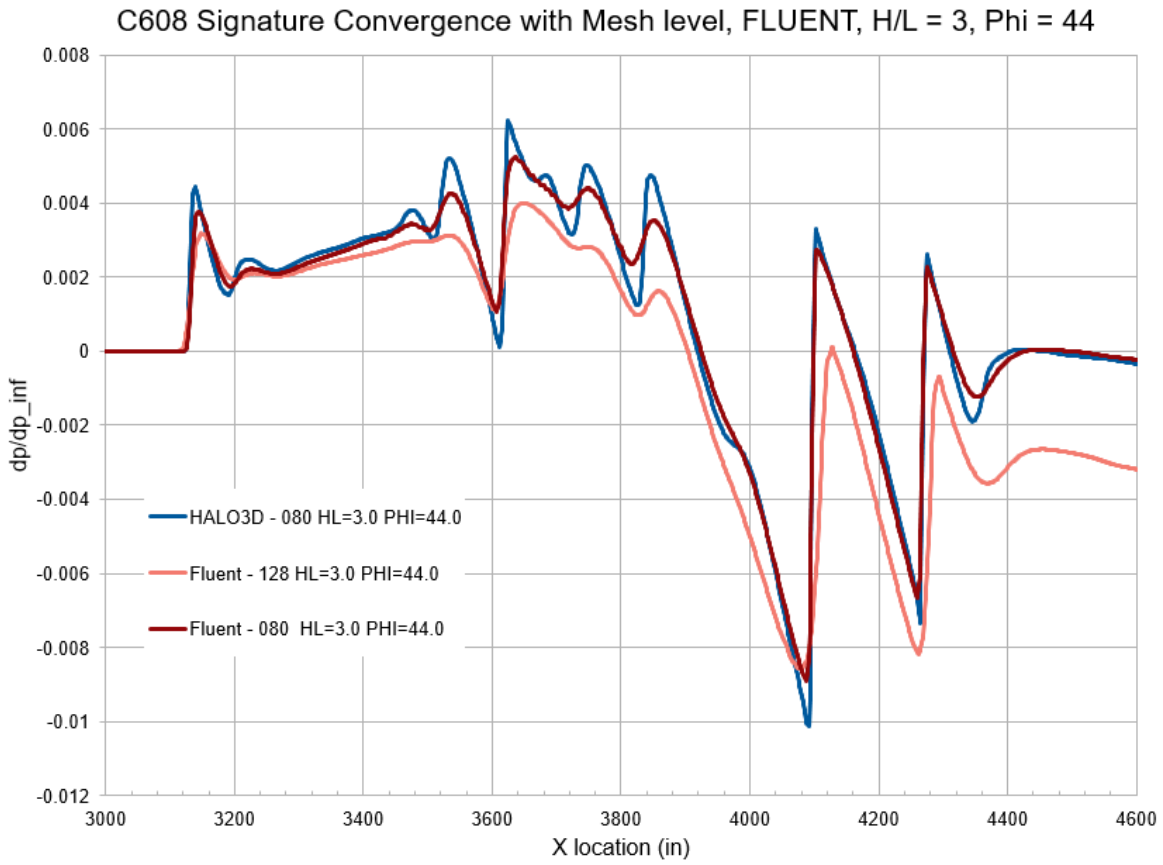
Results – C608 @ Mach 1.4





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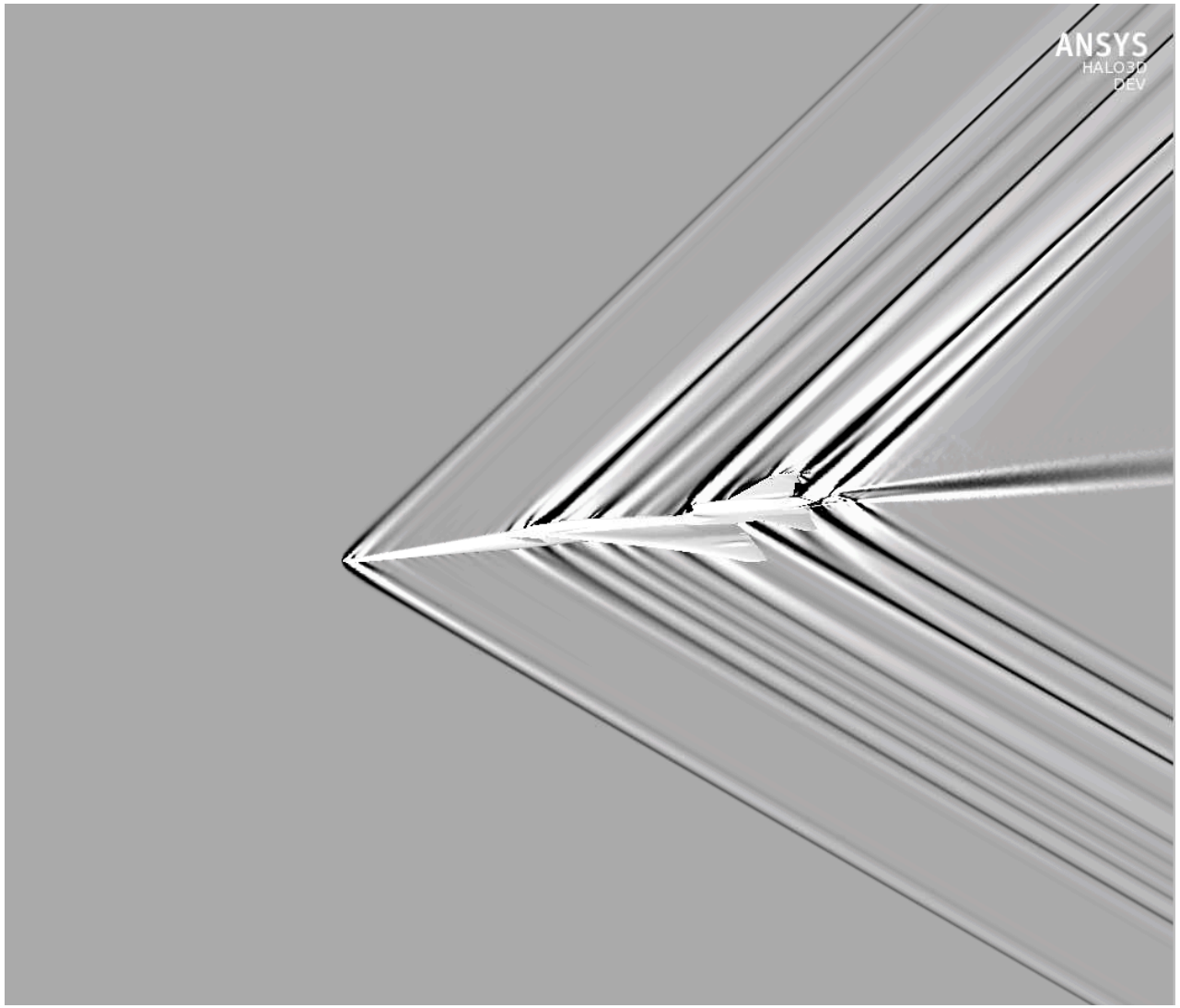
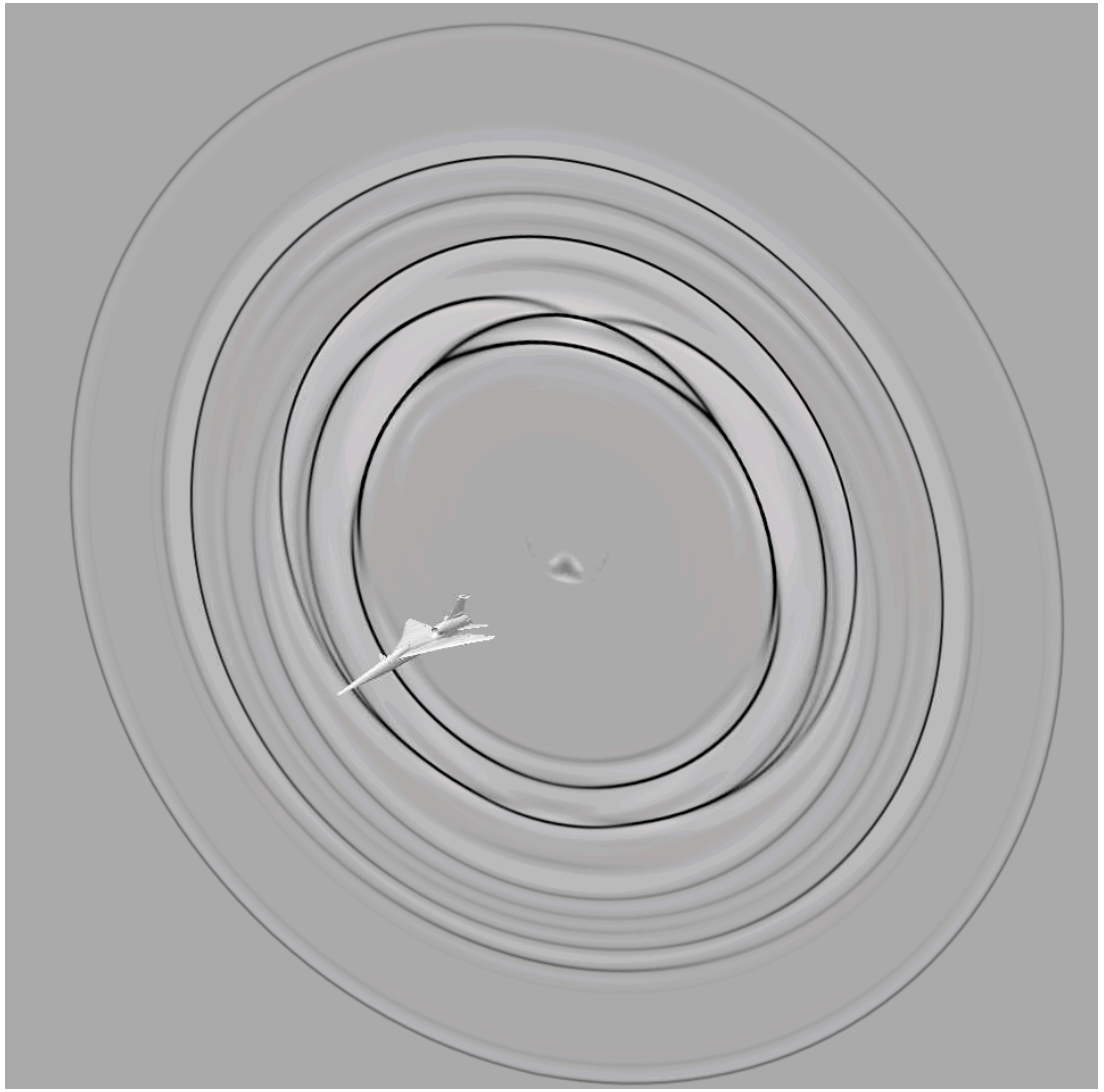
Results – C608 @ Mach 1.4 – simulated schlieren graphs





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Concluding Remarks

- Observations
  - New solver technology displays robustness and accuracy advantages
  - 2nd order Roe significantly more dissipative than AUSM+up
  - Minmod limiter “rings” less, but van Albada produces sharper shocks
  - Good initialization for efficient calculation with plenums and intakes is challenging
    - Use of freestream conditions requires small iterations through non-physical ‘start-up’ phase
  - Automatic mesh adaption shows promise as part of an efficient solution strategy
  - Workshop grids with Mach aligned prism blocks for mid-field work quite well
- Outlook
  - Further development of alternative flux schemes
  - C608 runs with inviscid grids to speed up turnaround time for signature predictions
  - Application of anisotropic adaption techniques
  - Far-field signal propagation through stratified atmosphere

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