Results for the Sonic Boom Prediction Workshop Using LAVA

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Outline

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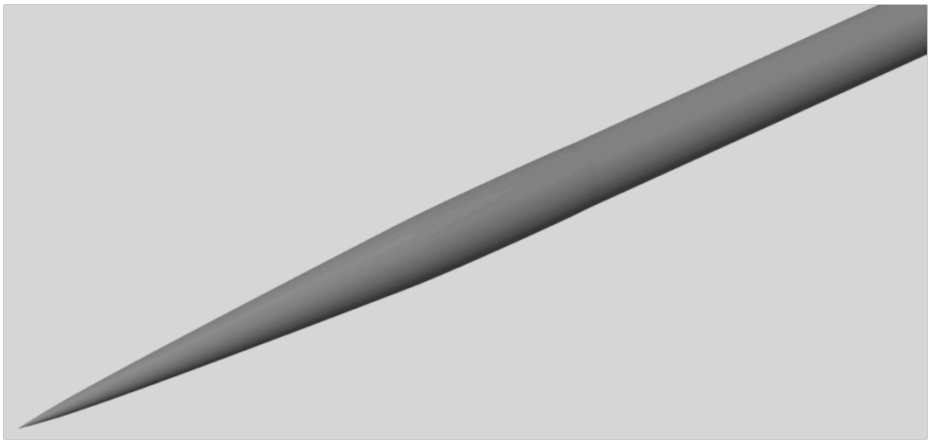
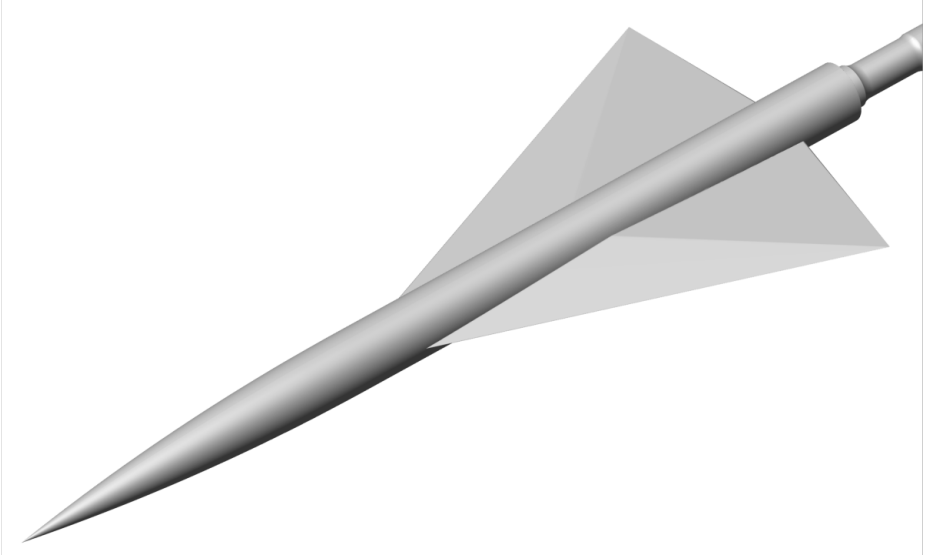
  - 69-Degree Delta Wing Body
- LAVA Solver
- Computing Requirements
- Computational Grids
- Solver Convergence
- Results
- Highlights
  - Grid Sensitivity
  - Viscous Effects
- Summary

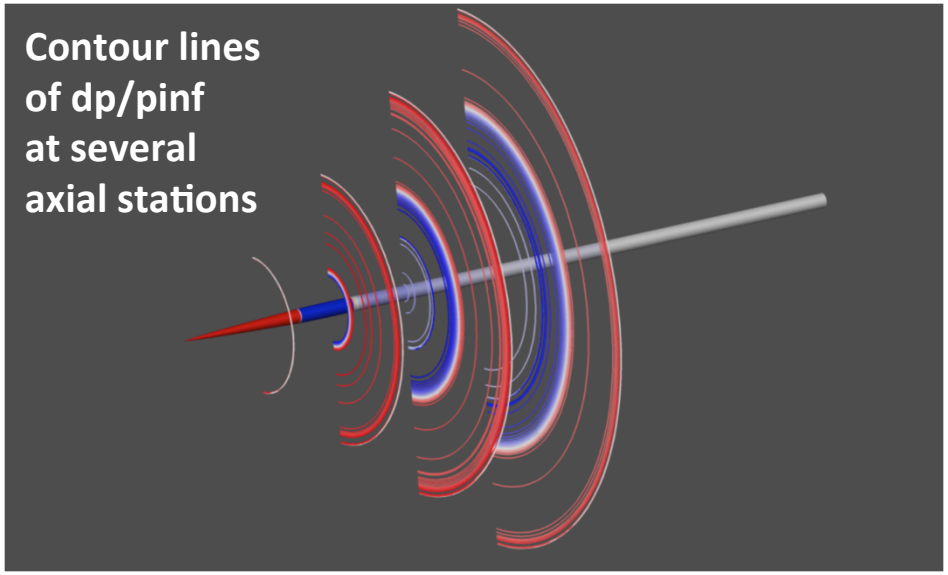


Seeb-ALR (Aft Lift Relaxation) Model

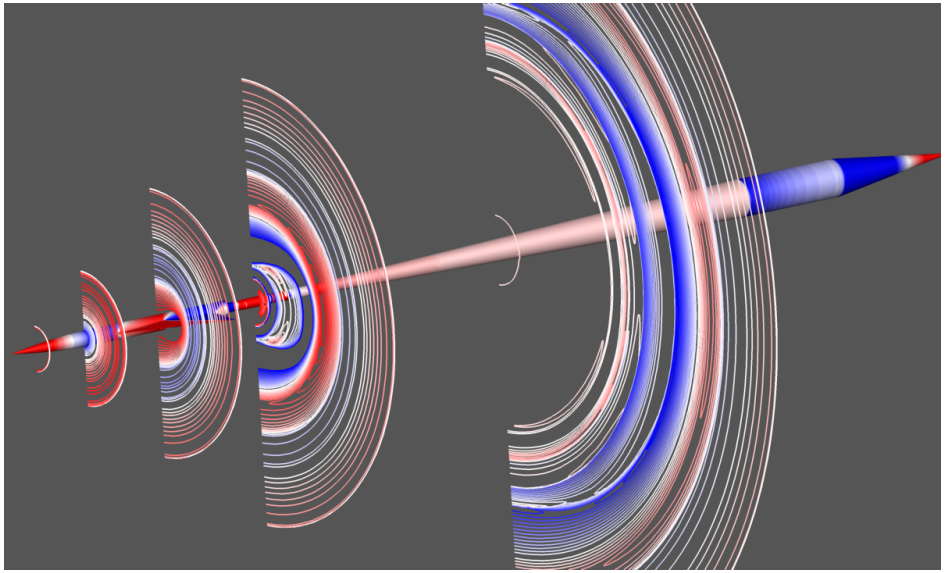


69-Degree Delta Wing Body

Summary of Cases

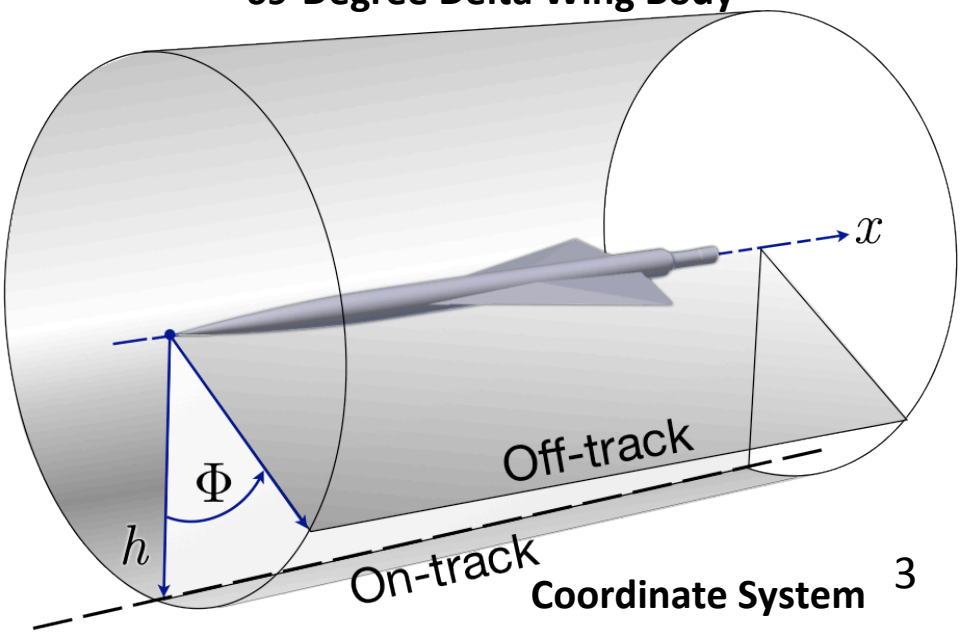


Seeb-ALR



69-Degree Delta Wing Body

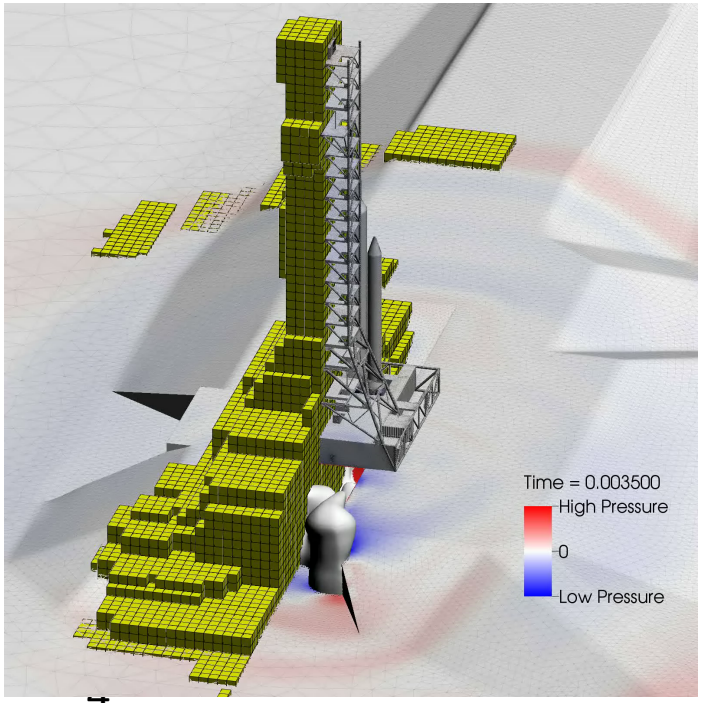
- Seeb-ALR (Euler and RANS)
  - Mach = 1.6
  - Re = 4.36×10^6 (per foot)
  - $\alpha = 0$ $\beta = 0$ degrees
- 69-Degree Delta Wing Body
  - Mach = 1.7
  - Re = 4.24×10^6 (per foot)
  - $\alpha = 0$ $\beta = 0$ degrees



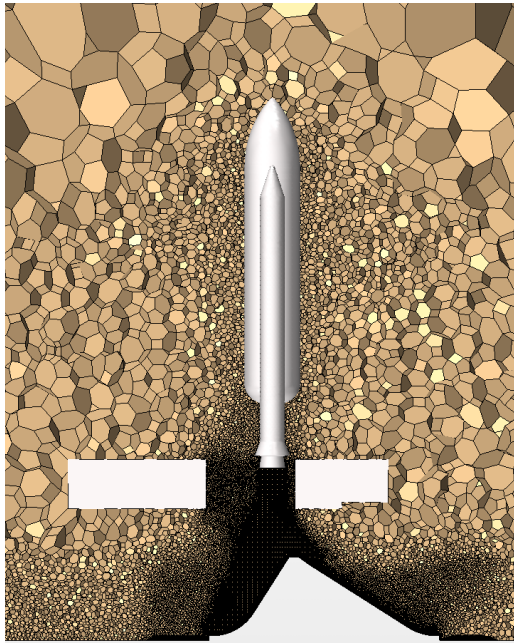
Coordinate System

Launch Ascent & Vehicle Aerodynamics (LAVA) Solver

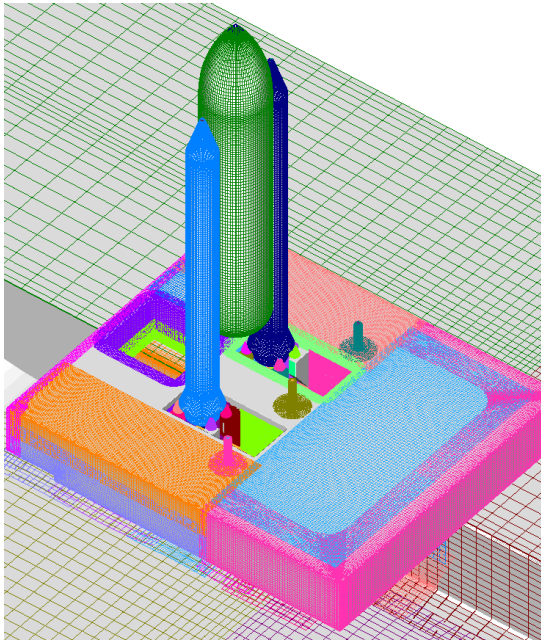
- Highly flexible with respect to computational mesh (grid-agnostic)
  - Block-structured Cartesian meshes with Adaptive Mesh Refinement (AMR) and Immersed-Boundary (IB)
  - Unstructured arbitrary polyhedral meshes
  - Structured curvilinear overset meshes
- Overset coupling of different mesh types



Cartesian AMR



Unstructured Arbitrary Polyhedral



Overset Structured Curvilinear

LAVA Capabilities

☑ Existing ■ Future

Capability	Cartesian	Unstructured	Curvilinear
Adaptive Mesh Refinement	☑	■	■
Immersed Boundary	☑		
Body-Fitted		☑	☑
Overset Grids			☑
Coupling with Cartesian Solver	-	☑	■
Coupling with Far-Field Acoustics	☑	☑	☑
Conjugate Heat Transfer		☑	■
Higher-Order Space/Time	☑	■	■
GMRES Linear Solver		☑	
Implicit Line Relaxation	☑		☑
Implicit Time-Stepping	☑	☑	☑
Preconditioning for low speed flows	☑	☑	☑
Multi-Species	☑	☑	☑
RANS & DES SA/SST Turbulence Models	☑	☑	☑
Parallel with MPI	☑	☑	☑

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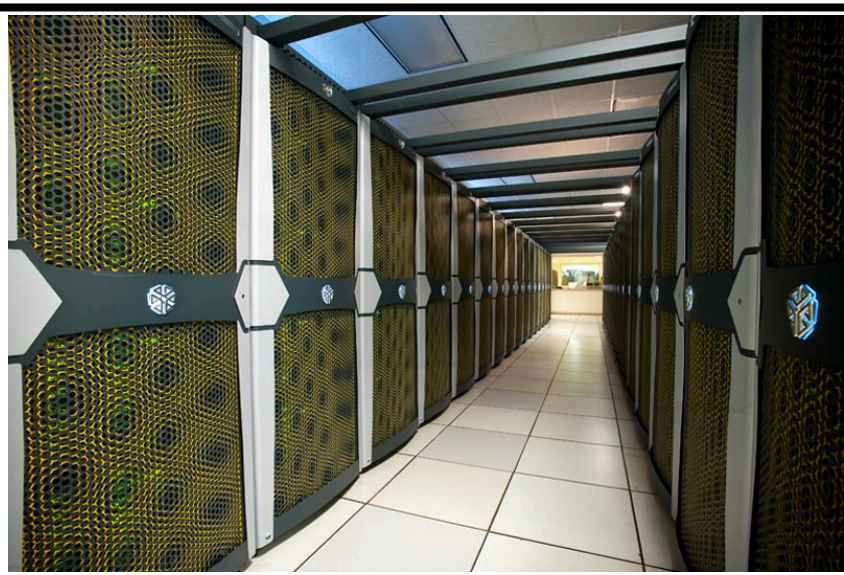
Computing Resources

Pleiades Supercomputer (NAS)



- Manufacturer: SGI
- 166 racks (11,136 nodes)
- 2.88 Pflops/s peak cluster
- 1.54 Pflops/s LINPACK (Nov. 2013)
- Total cores: 162,496

Resources for LBPW

- Timings based on 1000 iterations
- Seeb-ALR

Grid	Flux	Proc	CPU	Time
Structured	Central	Westmere	48	1 hr. 18 min.
Structured	Roe	Westmere	48	1 hr. 55 min.

- 69-Degree Delta Wing Body

Grid	Flux	Proc	CPU	Time
Structured	Central	Westmere	48	1 hr. 35 min.
Structured	Roe	Westmere	48	1 hr. 49 min.
Unstructured	AUSMPW+	Westmere	96	1 hr. 39 min.

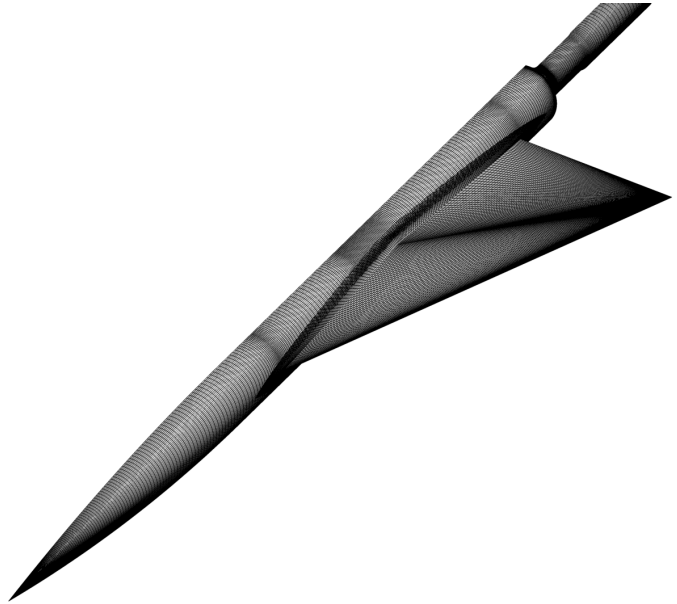
Computational Grids

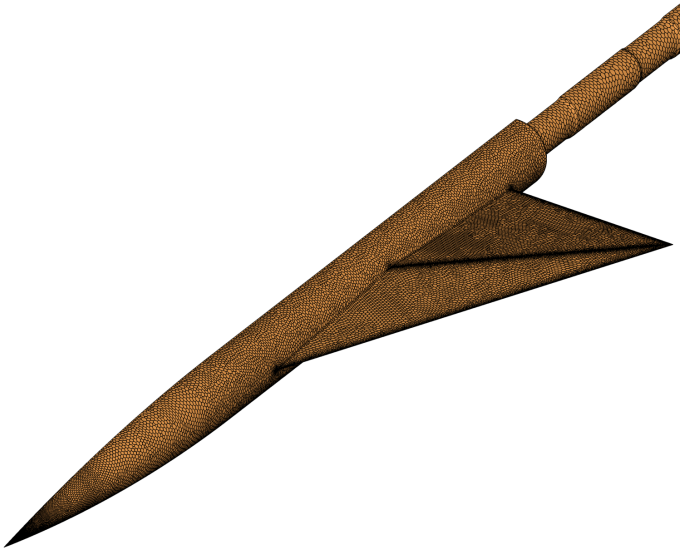
Structured Grid System

- Seeb-ALR
  - 4 overlapping grid zones
  - 21.7 M grid points
- 69-degree Delta Wing Body
  - 8 overlapping grid zones
  - 21.3 M grid points ($y^+<1$)

Unstructured Grid System

- Seeb-ALR
  - Axisymmetric zone from structured grid
  - 331 K cells
- 69-degree Delta Wing Body
  - 12.1 M polyhedral cells ($y^+<1$)

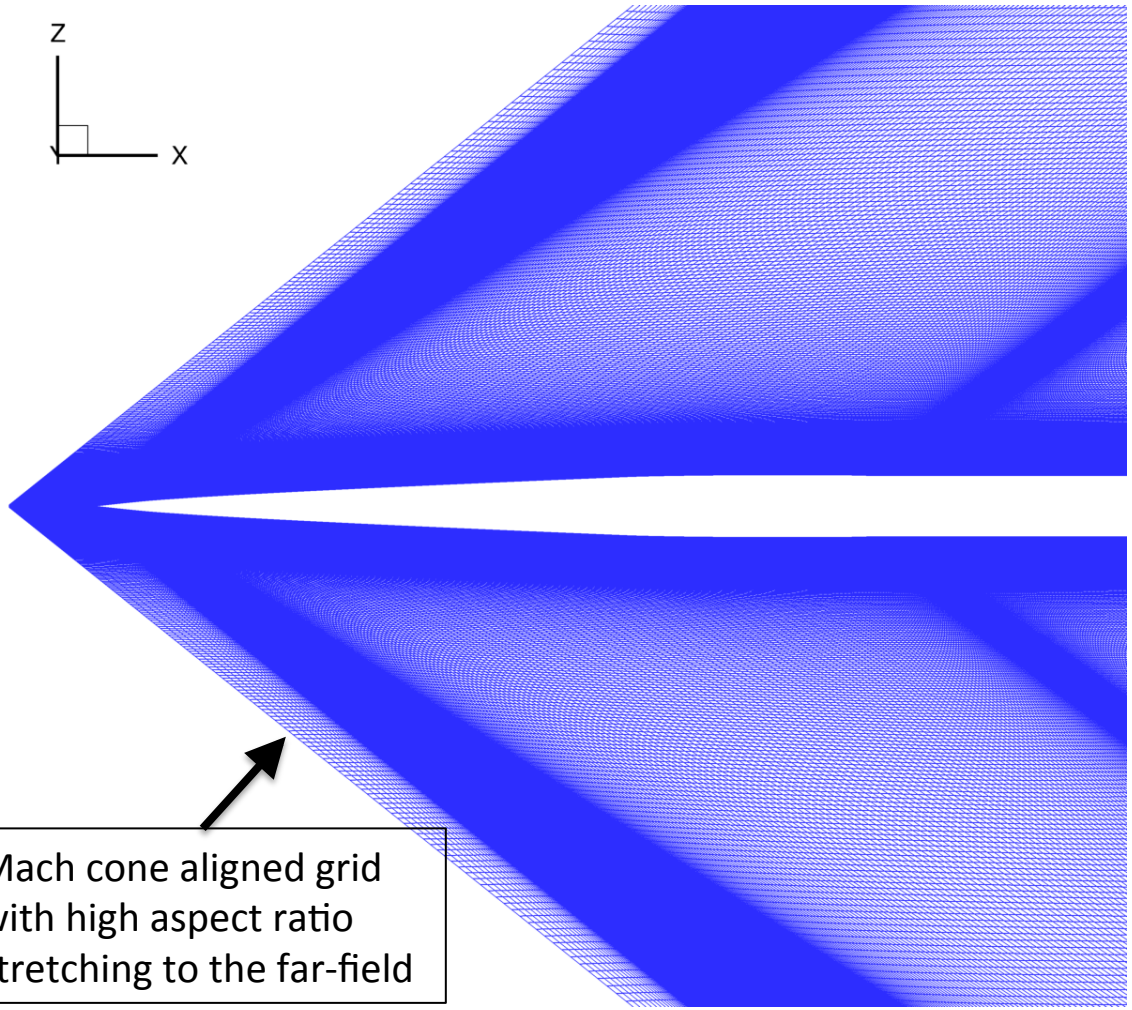




Computational Grids

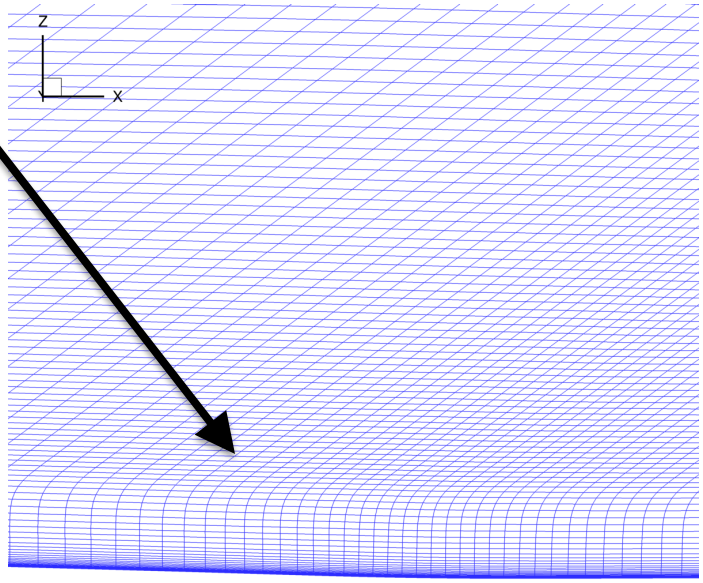
Seeb-ALR

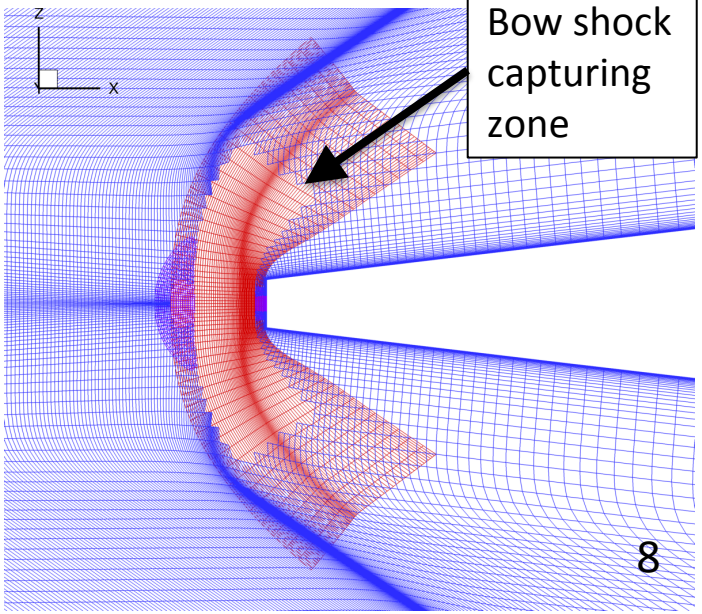
Overset Structured



Mach cone aligned grid with high aspect ratio stretching to the far-field

Hyperbolic Marching from wall, blended to Mach cone aligned grid





Bow shock capturing zone

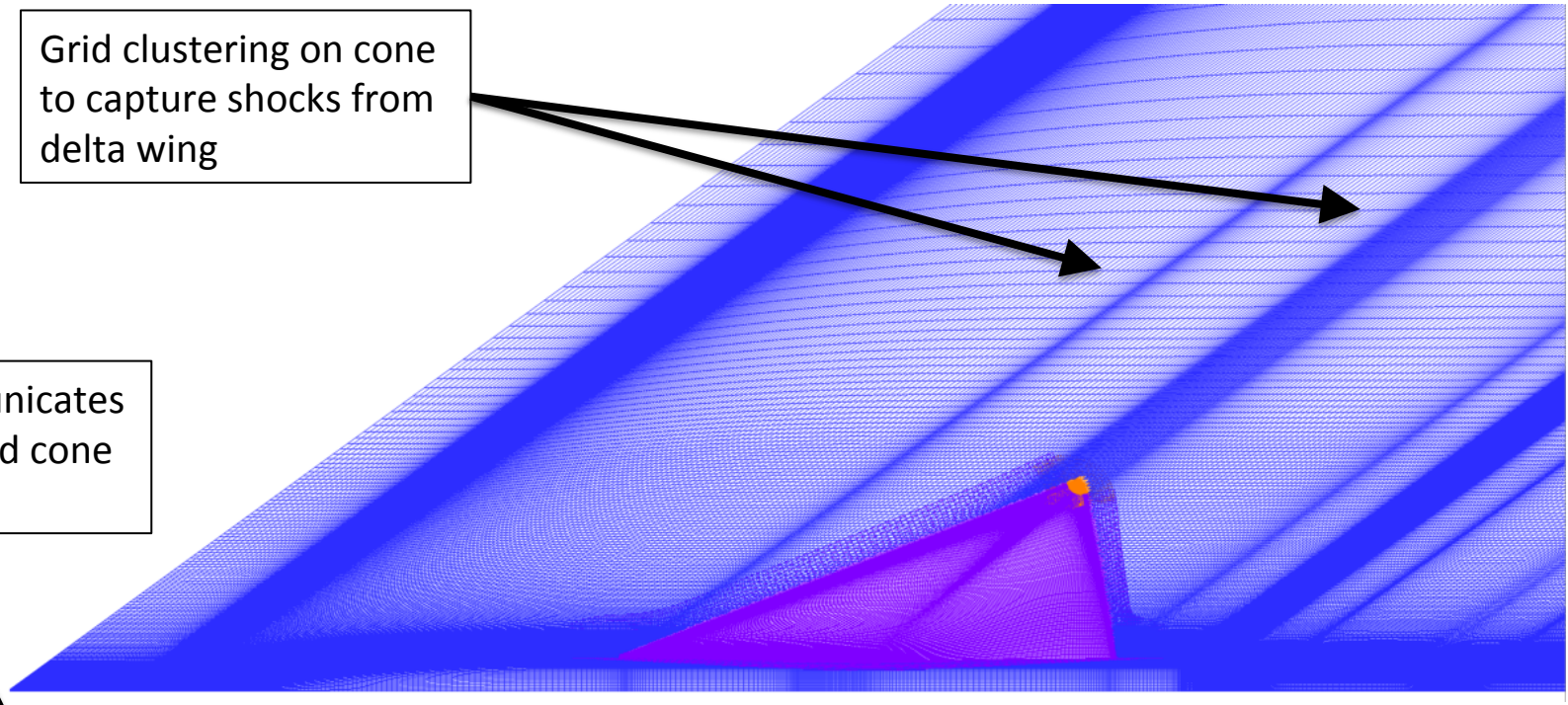
Computational Grids

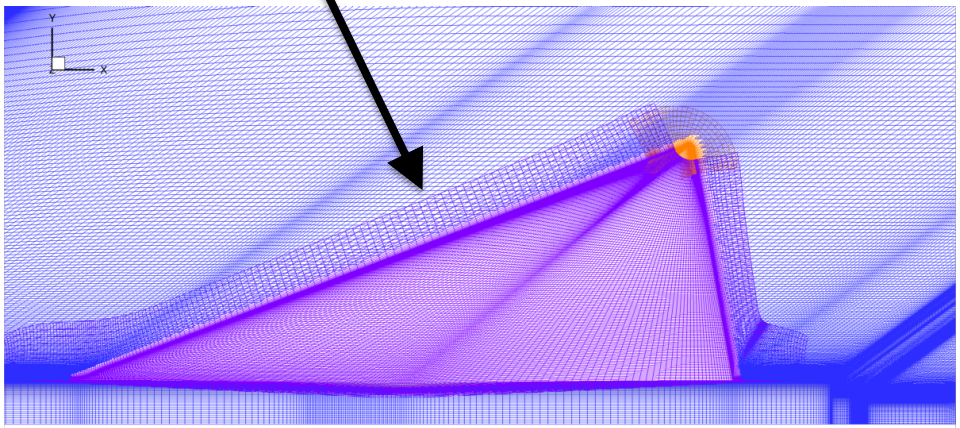
69-Degree Delta Wing Body

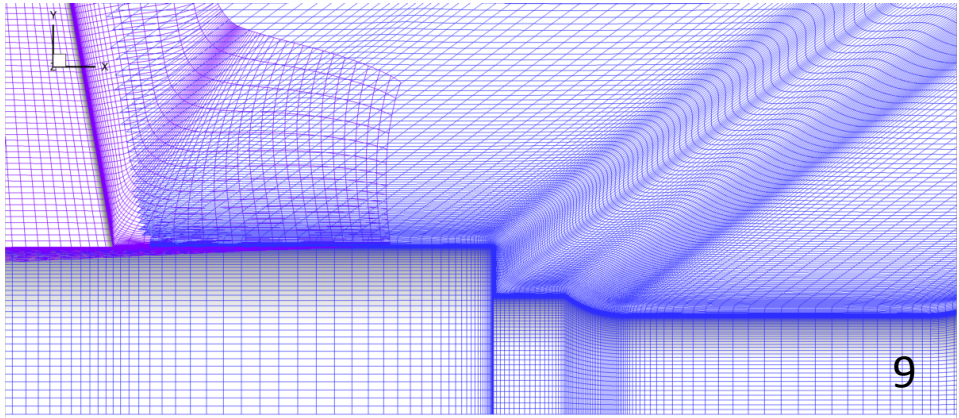
Overset Structured

Grid clustering on cone to capture shocks from delta wing

Wing grid communicates with shock-aligned cone grid



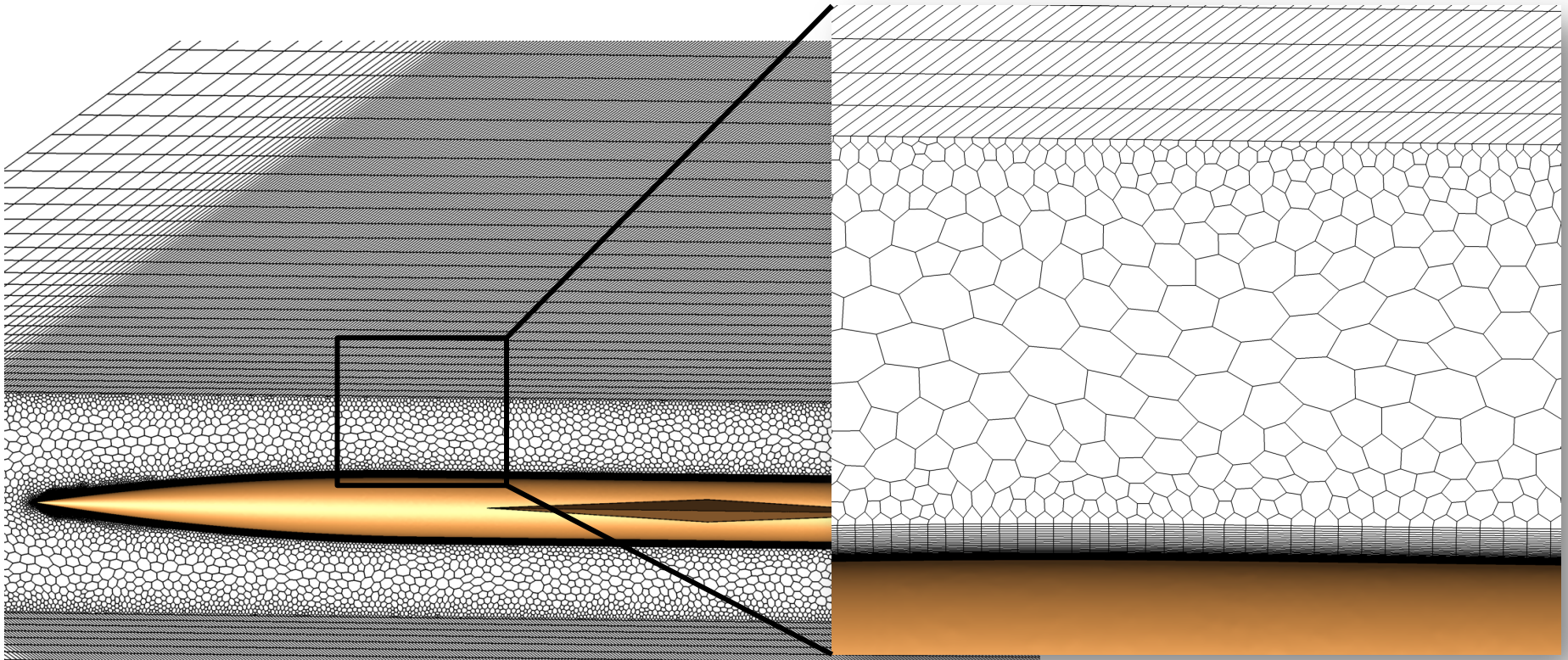




Computational Grids

69-Degree Delta Wing Body

Close-up

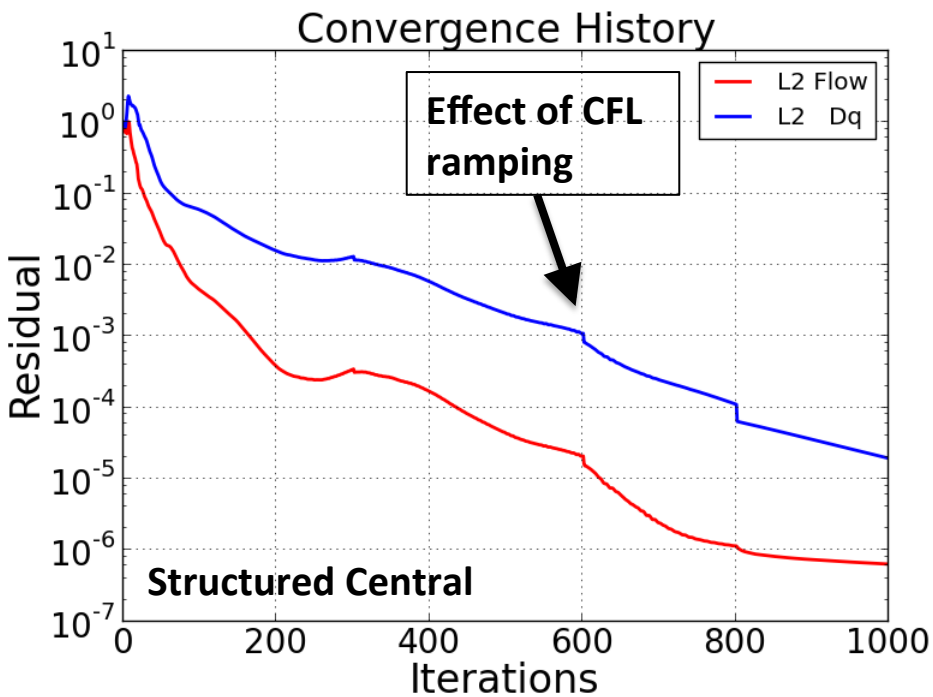


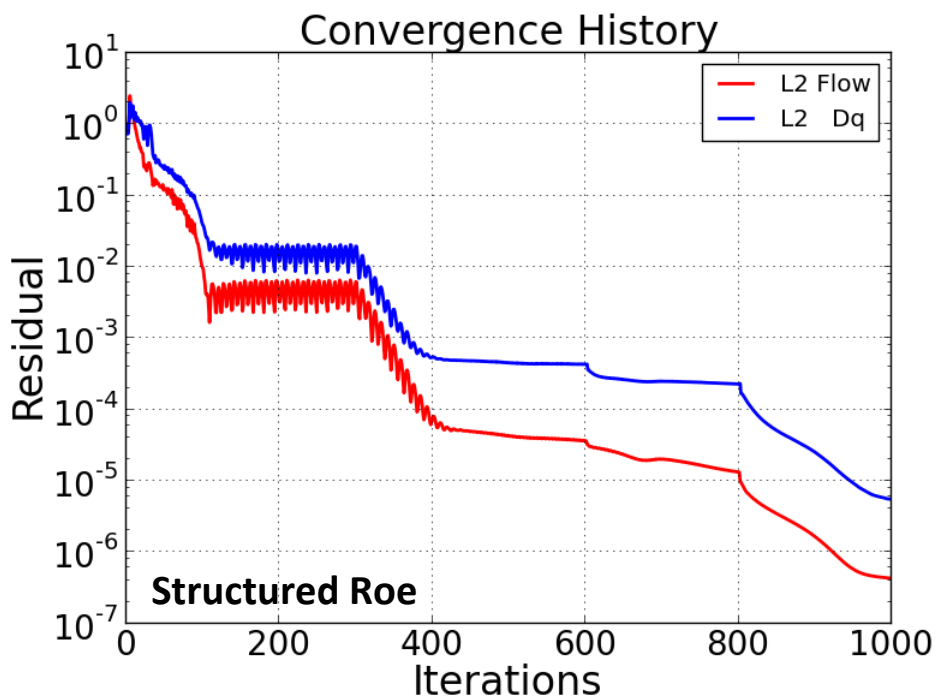
Mach cone aligned grid with stretching to the far-field

Isotropically meshed in axial and circumfertial directions

Solver Convergence

Seeb-ALR (Euler)

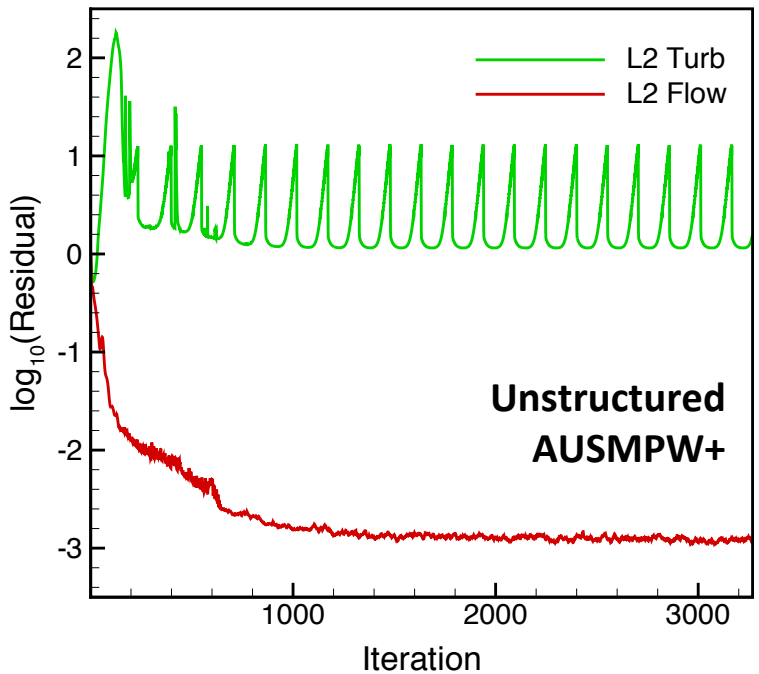


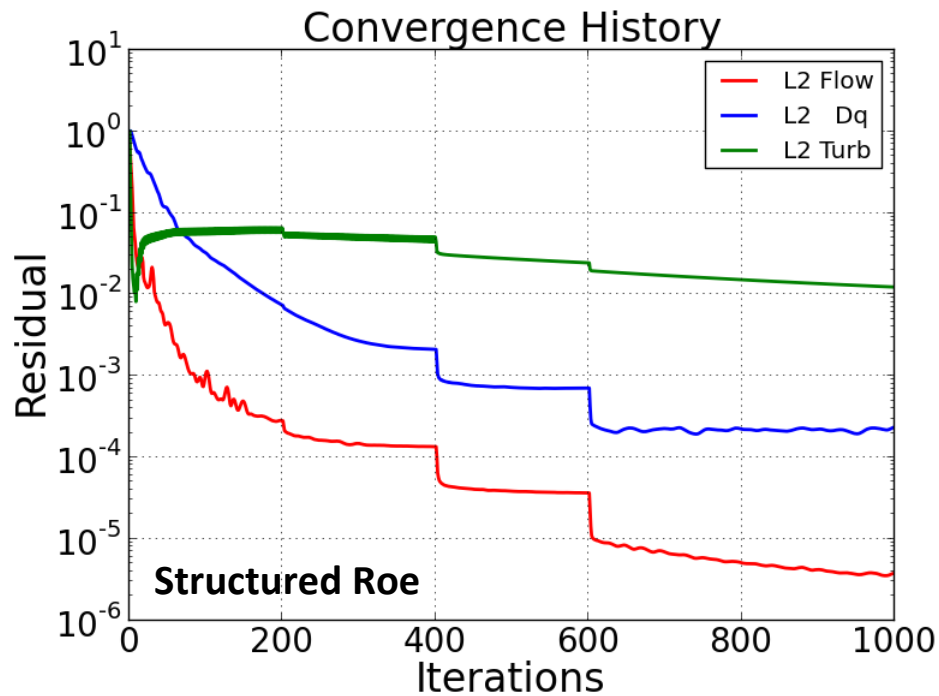


- 1000 iterations of alternating line Jacobi relaxation
- Local CFL time-stepping with CFL ramping used to accelerate convergence
- Far-field pressure signals were converged in approx. 100 iterations

Solver Convergence

69-Degree Delta Wing Body (RANS-SA)

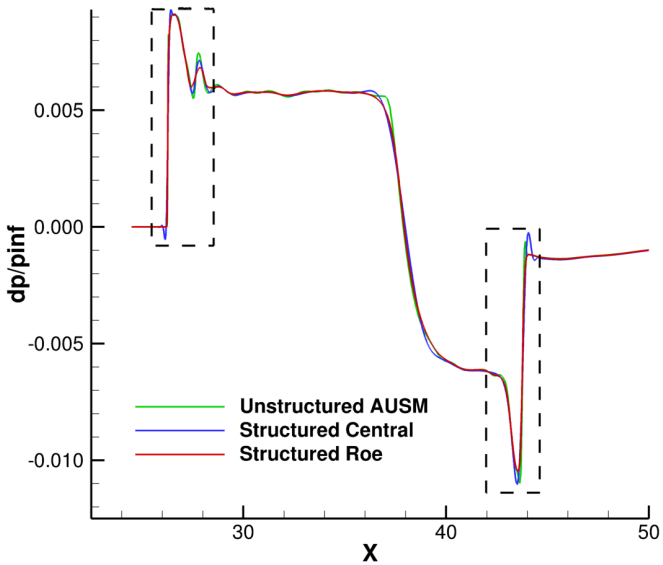


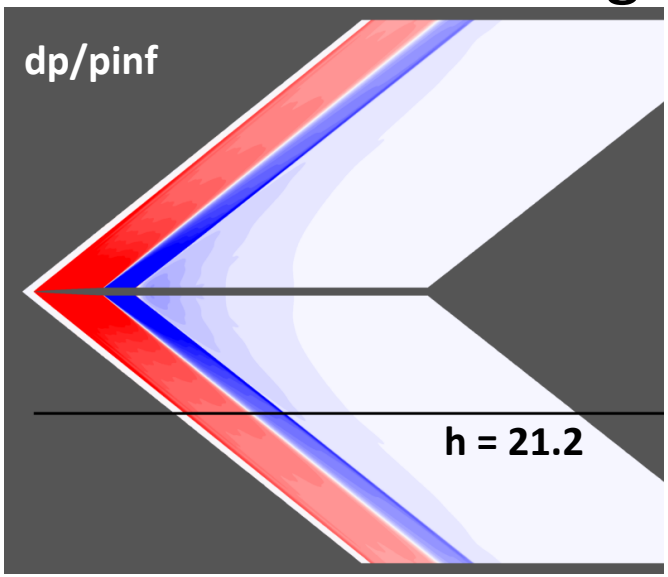


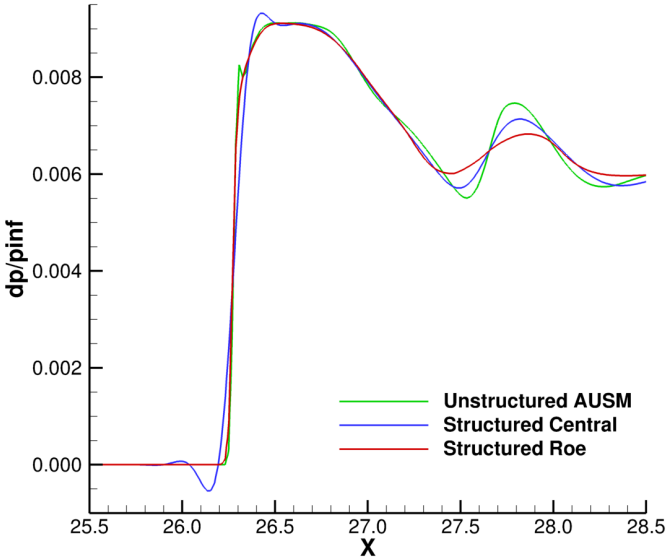
- Far-field pressure signatures appeared converged after approx. 200 iterations
- Poor convergence observed in turbulence model near base of sting

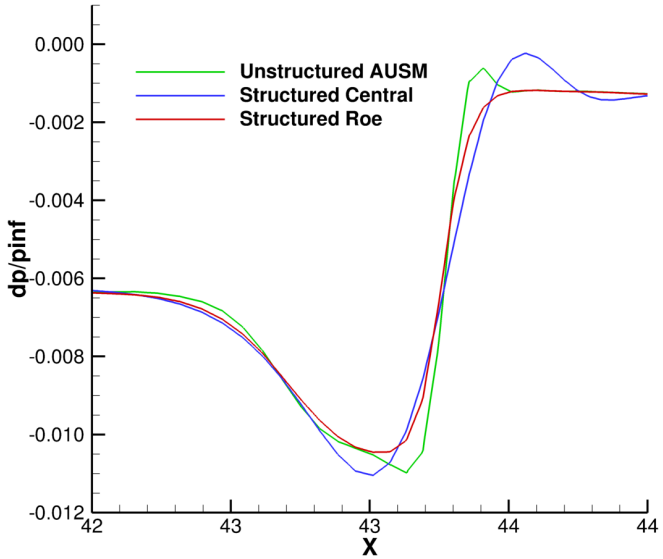
Results

Seeb-ALR (Euler): h = 21.2 inches Φ = 0 degrees





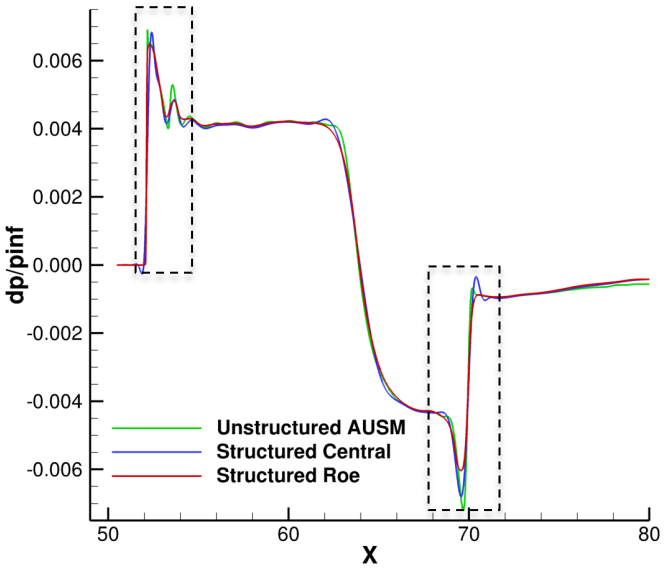


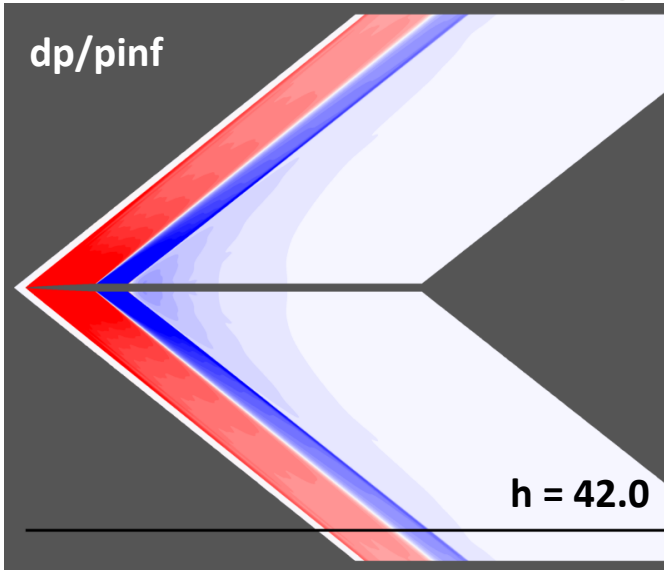


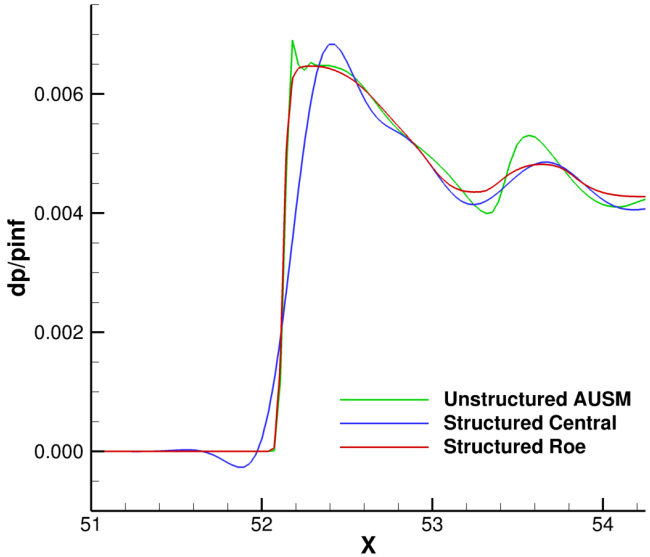
- Similar pressure signatures obtained with unstructured and structured approaches and various numerical flux functions
- Small sonic glitch on first shock using AUSMPW+ and central
- Roe scheme appears dissipative

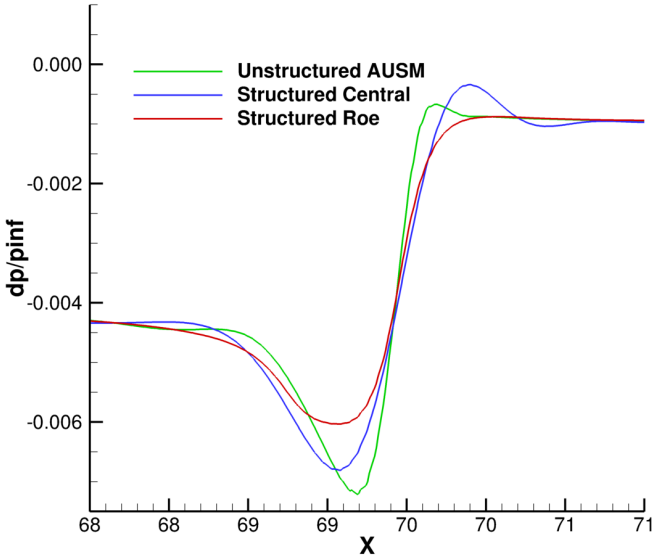
Results

Seeb-ALR (Euler): h = 42.0 inches Φ = 0 degrees





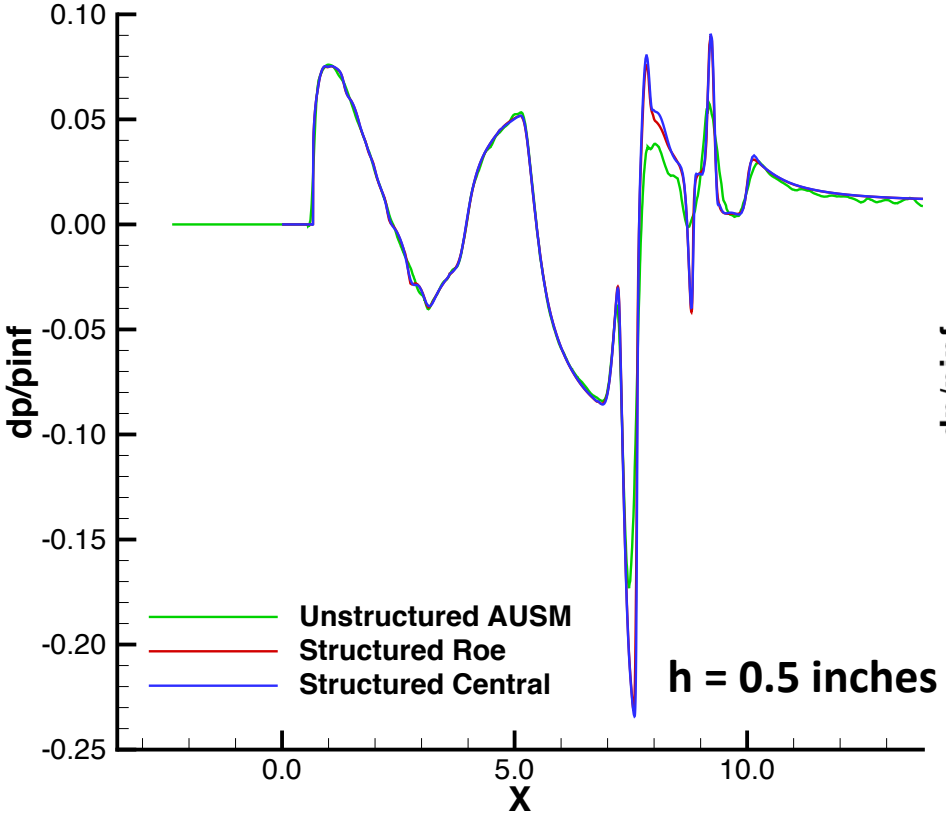


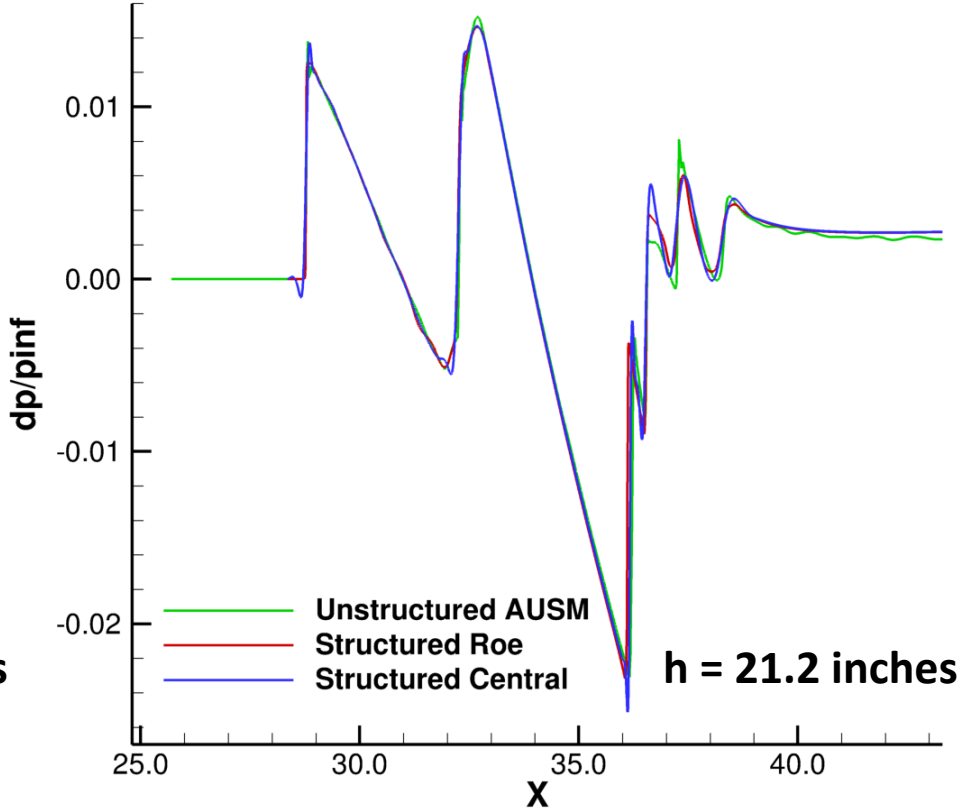


- Smoothing of lead shock observed with central
- Sonic glitch generated with AUSMPW+
- Excessive dissipation after lead shock persists with Roe flux

Results

69-Degree Delta-Wing Body (RANS): Φ = 0 degrees

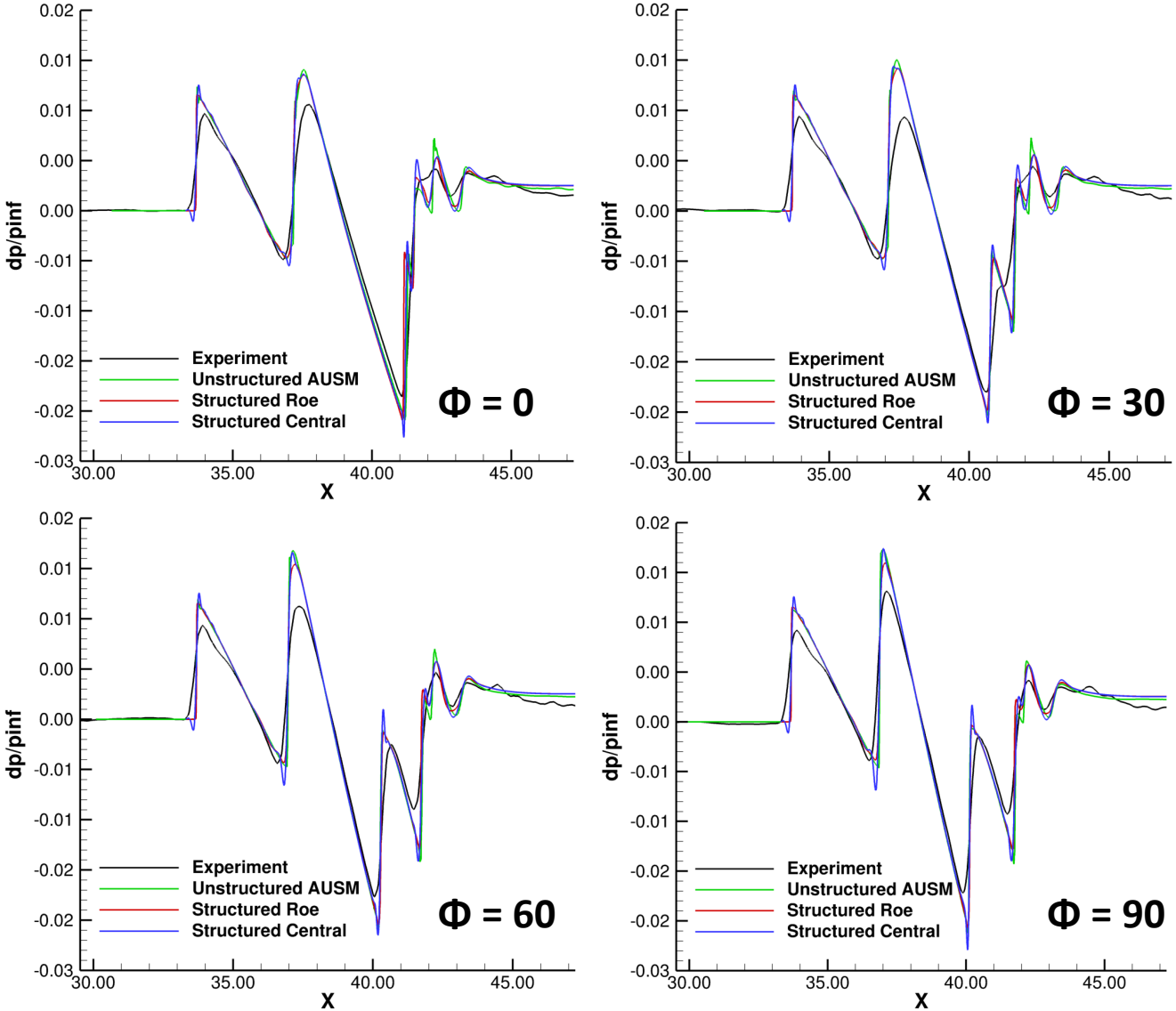




- Close agreement is observed in the front part of the model at h = 0.5
- Small differences observed at the rear of the model between the structured and unstructured grids
- These differences are reduced at h = 21.2 inches

Results

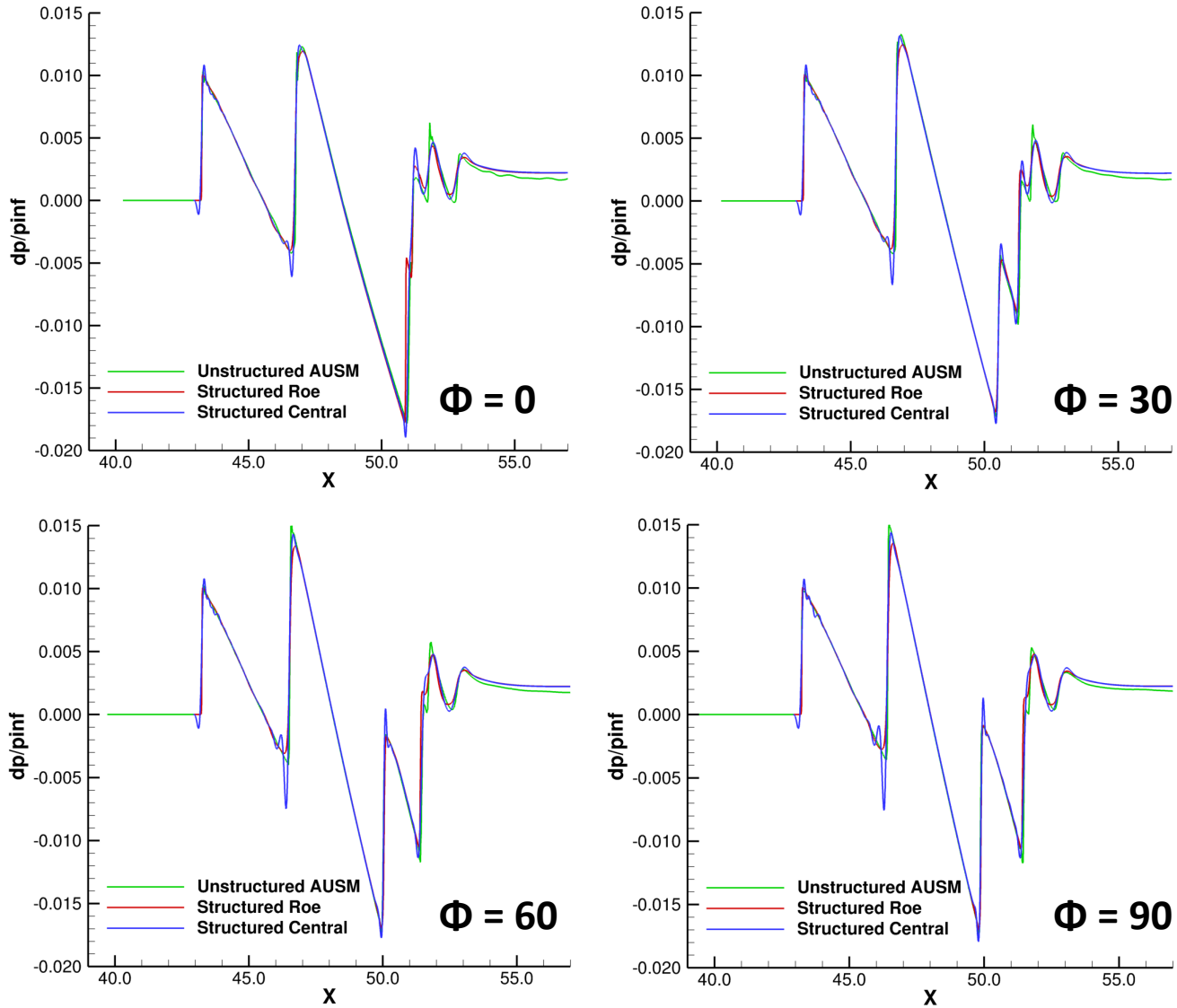
69-Degree Delta-Wing Body (RANS): 24.8 inches



- Experimental data close to these conditions obtained from S. Cliff (NASA)
- All numerical solutions predict similar signatures
- Strength of the shocks are much larger than experiment
- Trailing edge wing shock is also captured earlier in numerical solutions

Results

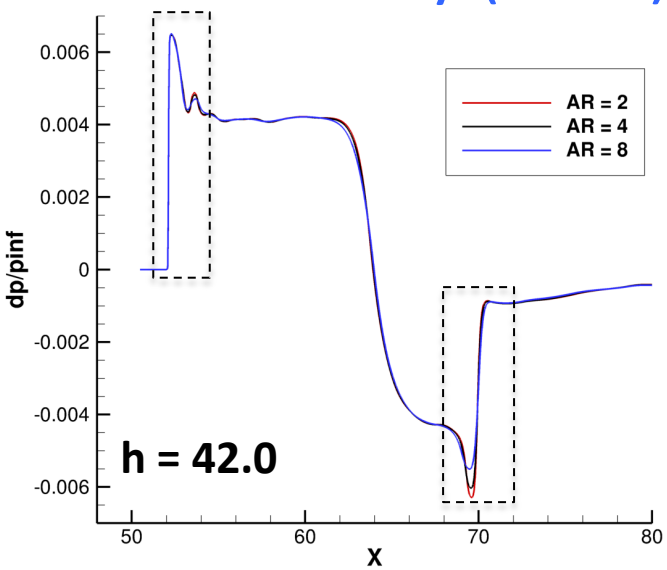
69-Degree Delta-Wing Body (RANS): 31.8 inches

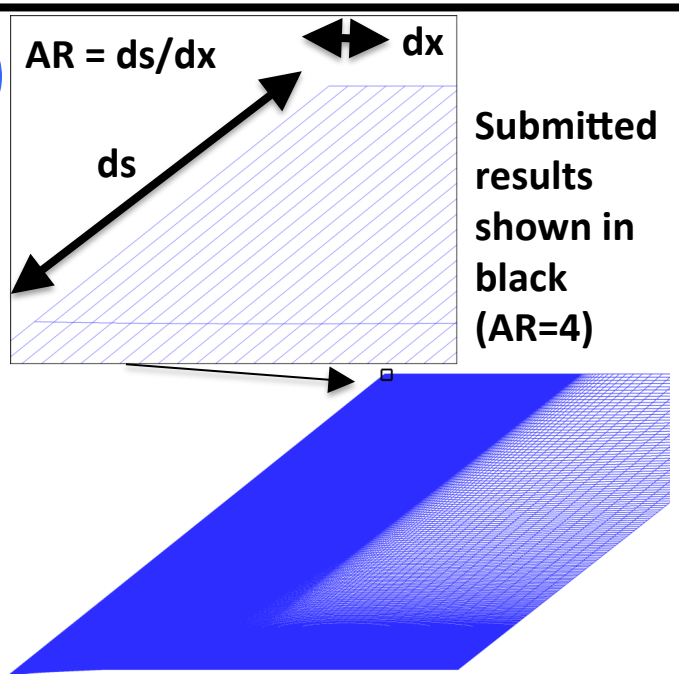


- Large undershoot is observed before the wing leading edge using the central scheme
- Solutions using Roe and AUSM fluxes appear nearly identical while using different grid methodologies

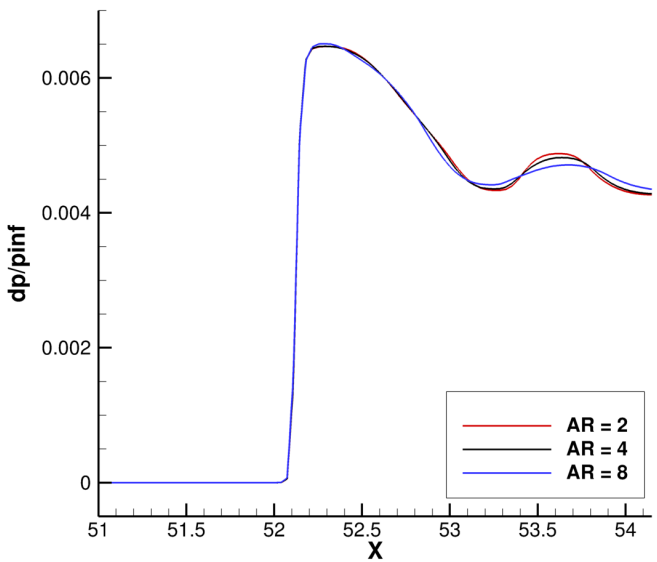
Highlights

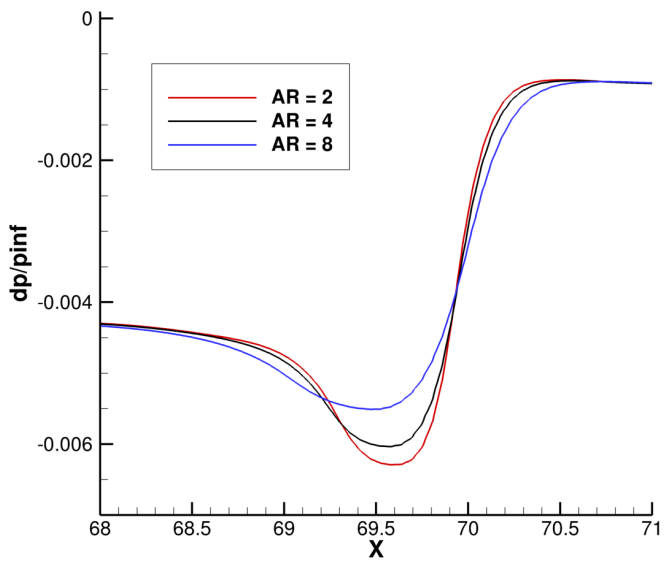
Grid Sensitivity (Seeb)





Submitted results shown in black (AR=4)

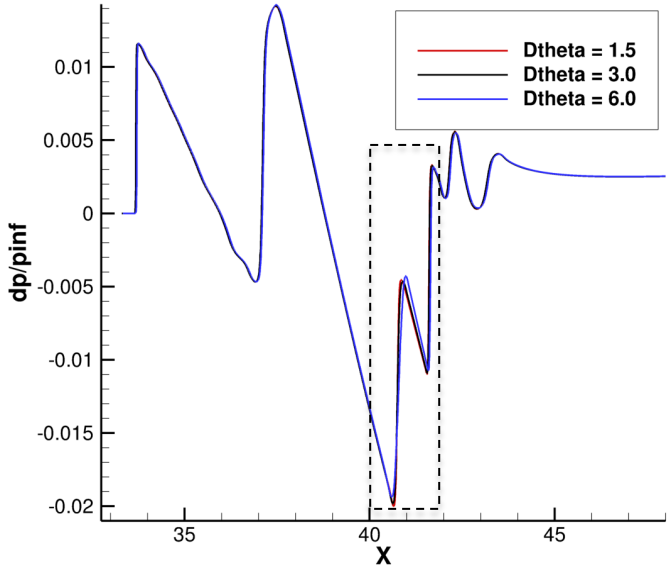


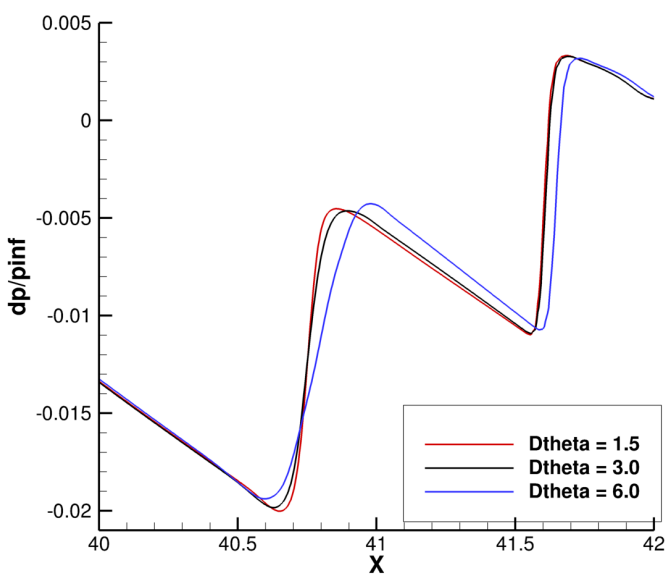


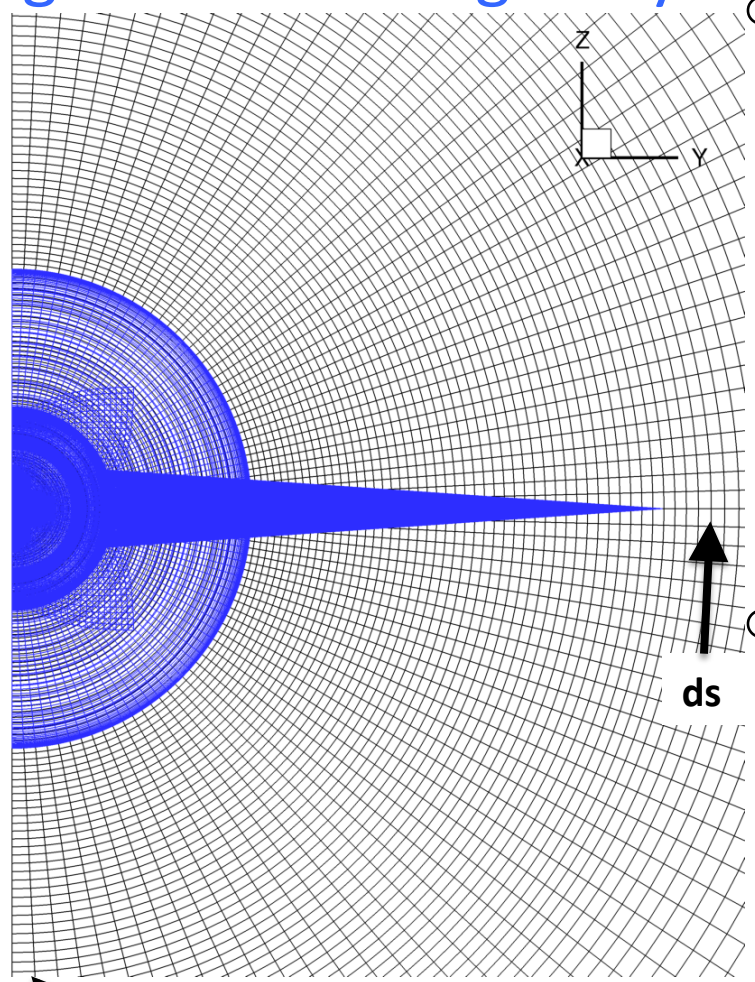
- Sensitivity to far-field grid Aspect Ratio (AR) was performed for **Seeb-ALR**
- Secondary peak and pre-recovery peak pressures show sensitivity to AR
- Change in peak decreases with decreasing AR
- AR = 8 appears too aggressive

Highlights

Grid Sensitivity: 69-Degree Delta Wing Body





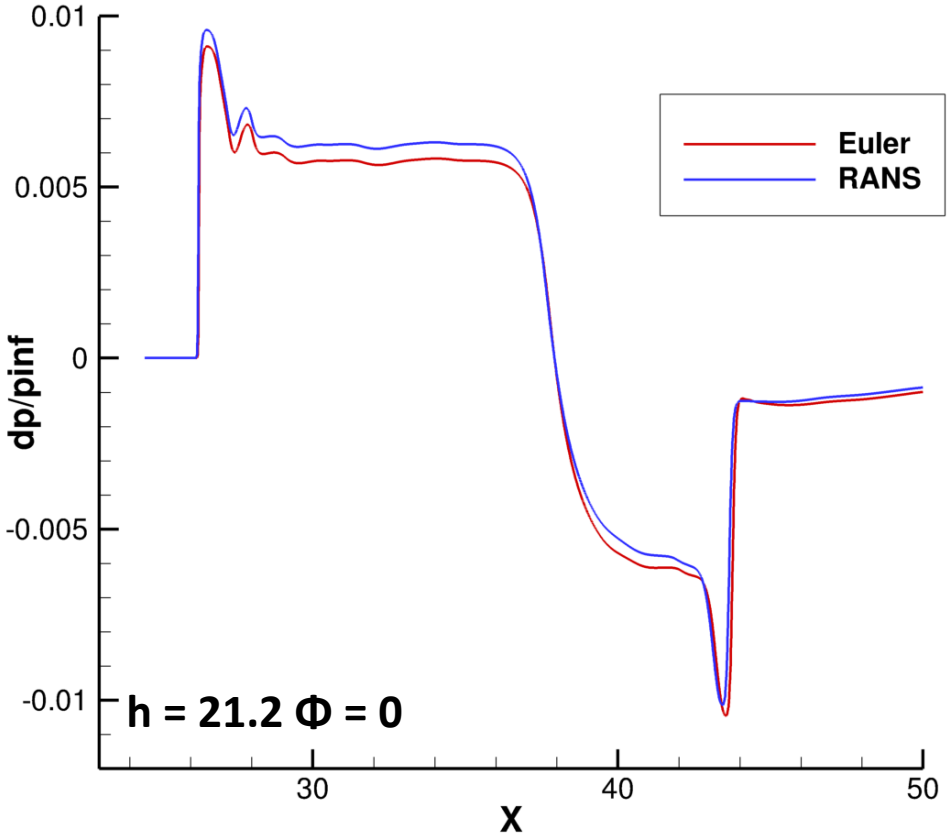


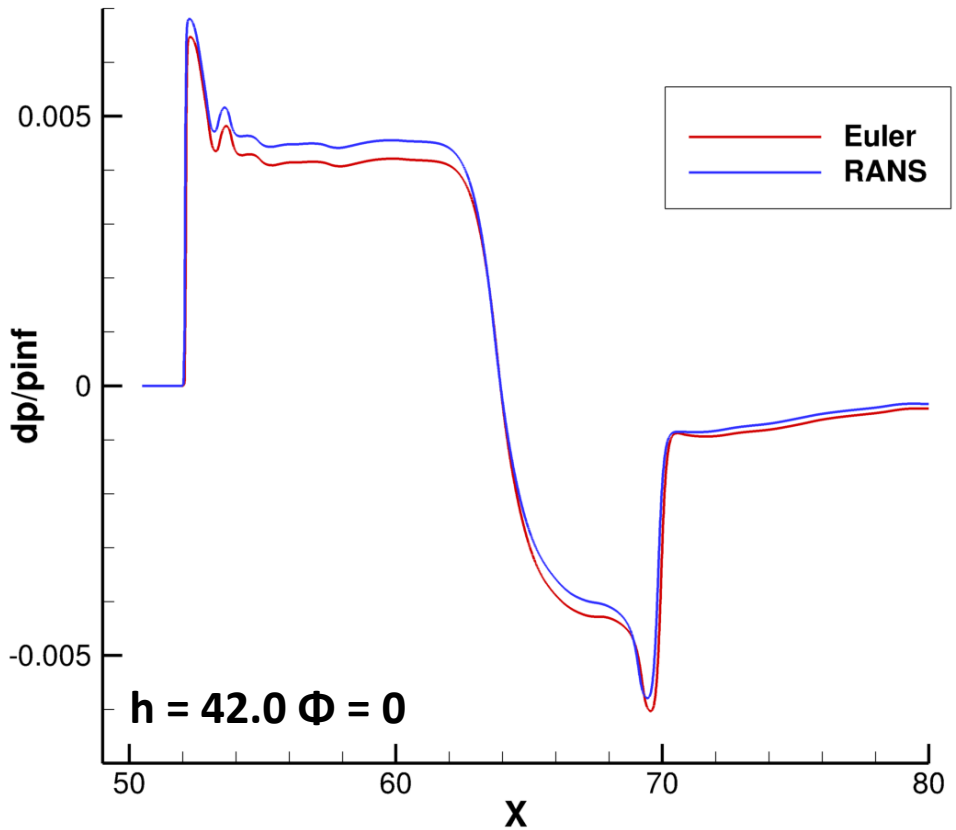
- Circumferential spacing is blended from Dtheta at symmetry plane to ds to match wing spacing near wing tip.
- As Dtheta is reduced, the shock from the mid and trailing edges of the wing sharpen.

Submitted results shown in black (Dtheta = 3)

Highlights

Viscous Effects (Seeb-ALR)



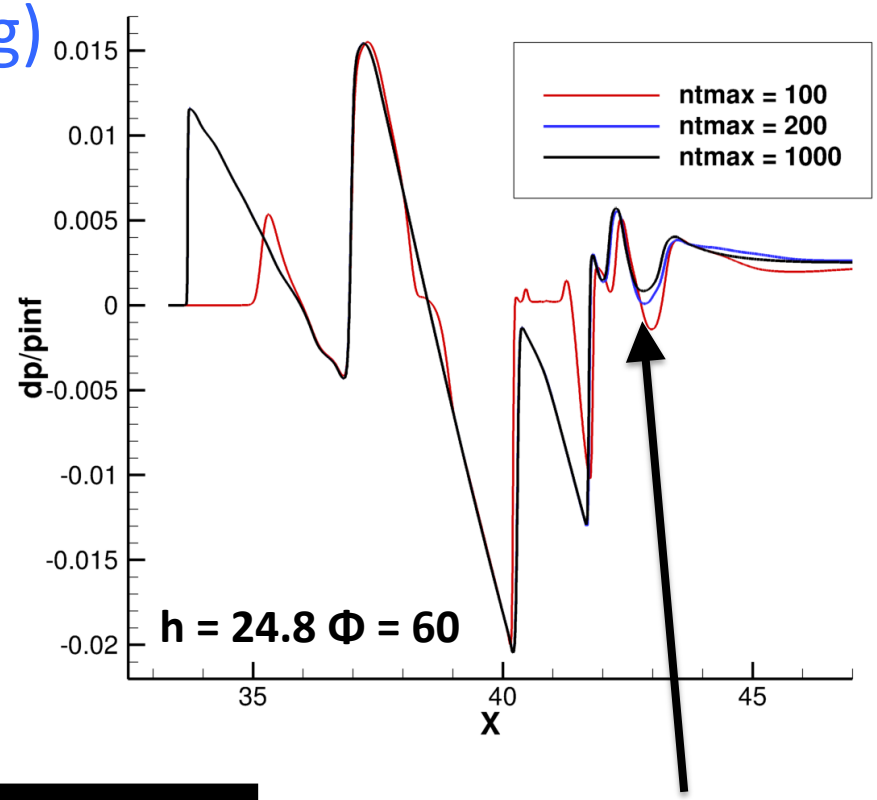


- A delta off-set in pressure signature is observed between the Euler and RANS results at both extraction locations
- Boundary layer appears to make the body effectively thicker
- The same offset was observed using both SA and SST models

Highlights

Number of Iterations (Delta-Wing)

- Main part of pressure signal is converged after 200 iterations
- Additional iterations are necessary for the aft part of signal to converge
- This most likely caused by the slower turbulence residual convergence at that base and sting of model



Small discrepency in aft part of signal

Grid	Flux	Proc	CPU	Iterations	Time
Structured	Roe	Westmere	48	100	11 min.
Structured	Roe	Westmere	48	200	21 min.
Structured	Roe	Westmere	48	1000	1 hr. 35 min.

Summary

- Structured Overlapping and Unstructured grid methods within the LAVA framework were applied to two of the Sonic Boom Prediction Workshop problems
- Similar results were obtained with both grid methodologies as well as several different convective flux functions
- Small oscillations before and after the shocks were observed using central differencing
- A sonic glitch was observed in the lead shock using the AUSMPW+ flux
- The Roe flux is void of glitches, but appears overly diffusive after lead shock
- Grid sensitivity analysis suggests that far-field pressure signatures are sensitive to grid aspect ratio in the far-field and circumferential spacing (AR = 4 and Dtheta = 3 were chosen for submission)
- Application of RANS turbulence model to the Seeb-ALR case showed a larger pressure profile suggesting an effectively thicker body