Improved Unstructured Grids for Sonic Boom Prediction

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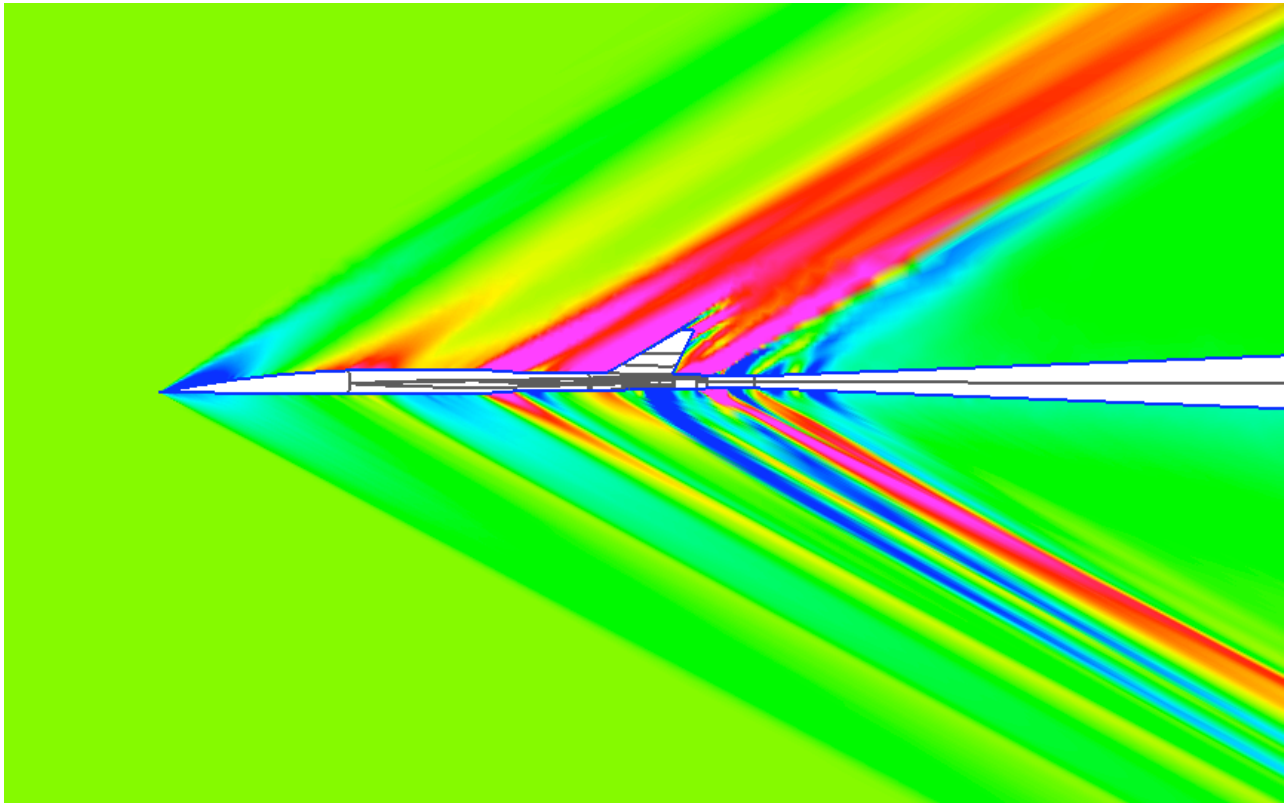

Team Members

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- Karen A. Deere
- Gregory E. Duckett
- Richard L. Campbell

Presentation Outline

- Background
- Methods
- Results
- Concluding remarks

Background

- Significant recent interest in supersonic overland flight
- Key aerodynamic challenges:
  - low boom for supersonic flight over land
  - low drag for reduced fuel-burn and emissions
- Accurate CFD analysis and design methods are needed to help address these challenges
  - drag prediction capability fairly well established
  - sonic boom prediction less mature, especially with unstructured grids
- Current practice for boom prediction:
  - use CFD to compute signature in mid-field (~3-10 body lengths)
  - extrapolate signature to ground using propagation code
- Key requirements for accurate CFD mid-field signature
  - sufficient grid density to resolve shock
  - aligning the field grid with shocks & expansions
  - stretching field grid along Mach lines to reduce dissipation

Some Current CFD Gridding Approaches for Sonic Boom Prediction

- Structured grid:
  + good control of mid-field grid alignment & spacing (A&S)
  - multiple blocks needed in near-field for complex configurations

- Unstructured grid:
  + simpler grid generation for complex configurations
  - weak control over mid-field grid A&S, can lead to excessive dissipation in flow solution

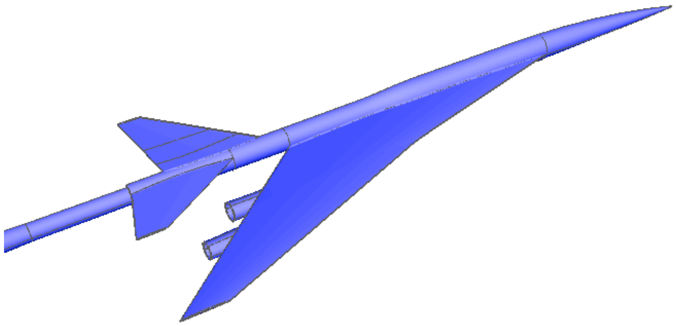
- Hybrid (unstructured near-field, structured mid-field):
  + easy near-field grid generation & good mid-field grid A&S
  - requires multiple grids and flow solvers + interpolation

- Unstructured grid with run-time adaptation:
  + easy near-field grid generation & good mid-field grid A&S
  - requires multiple runs of analysis and refinement codes (and adjoint solver), grids can get large if refinement is used

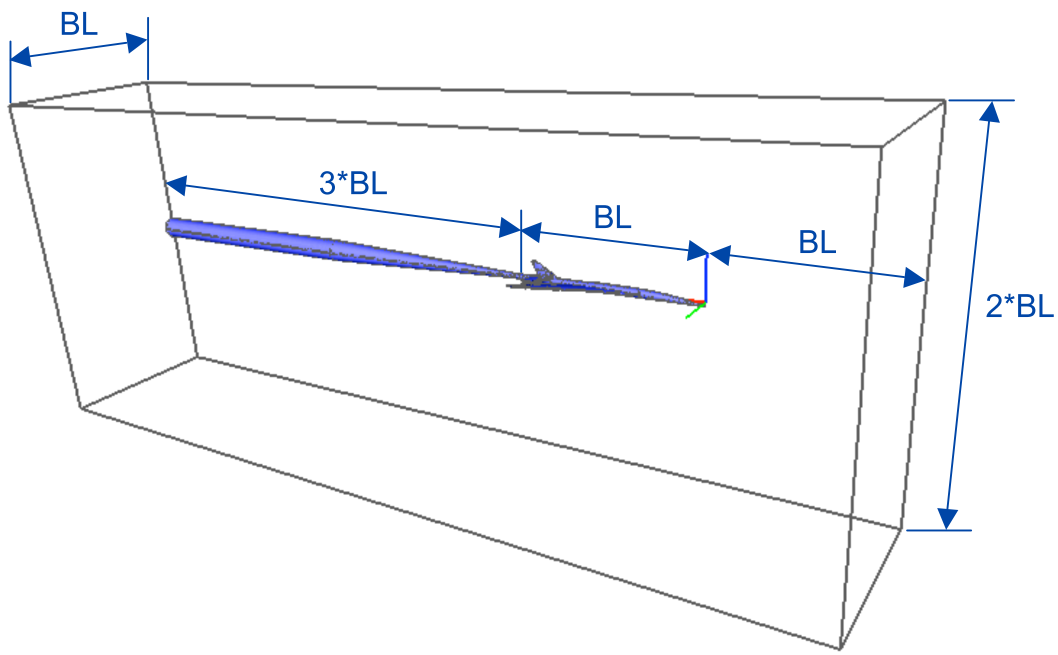
Methods

- TetrUSS unstructured grid software system used
- Geometry Setup - GRIDTOOL
  - develop surface patching from IGES or other geometry definition
  - define outer boundary patches
- Grid Sourcing - AUTOSRC
  - automatically locates and set sizes for sources that control surface and field grid spacing
- Grid Generation - VGRID
  - generates body-fitted tetrahedral mesh using advancing layers and advancing front methods
  - new volume source capability used to control field grid spacing below configuration (see AIAA-2008-7178)
- Grid Modification - SSGRID
  - shears and stretches grid for improved sonic boom prediction
- Flow Solver - USM3D
  - cell-centered RANS flow solver, Roe flux-difference scheme
  - all cases run in inviscid mode
  - limiters available for solution stability

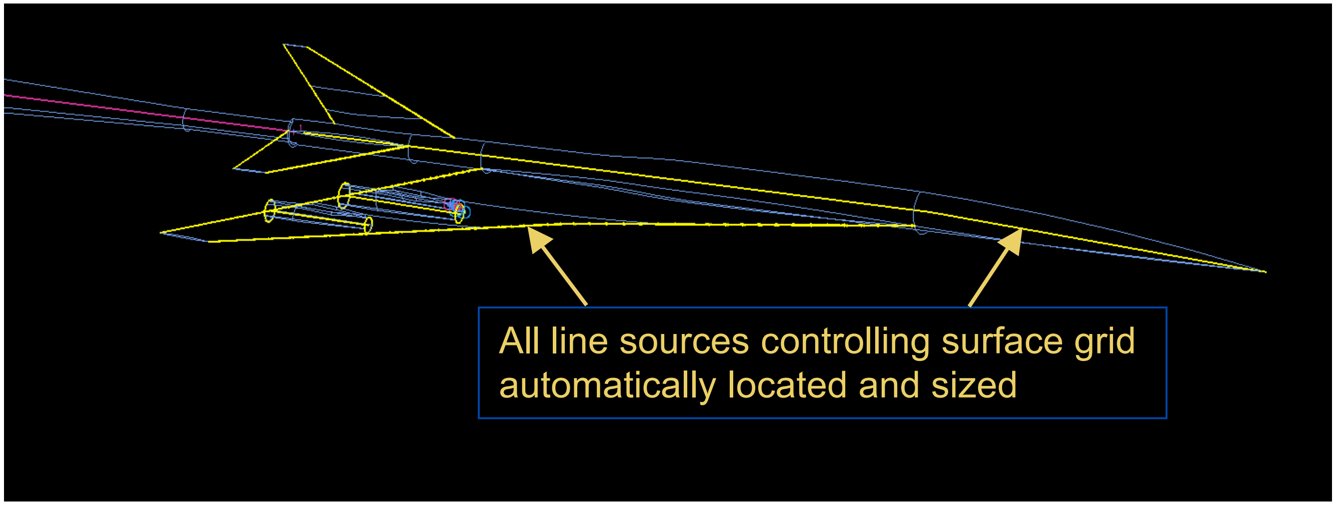
Geometry Setup - GRIDTOOL

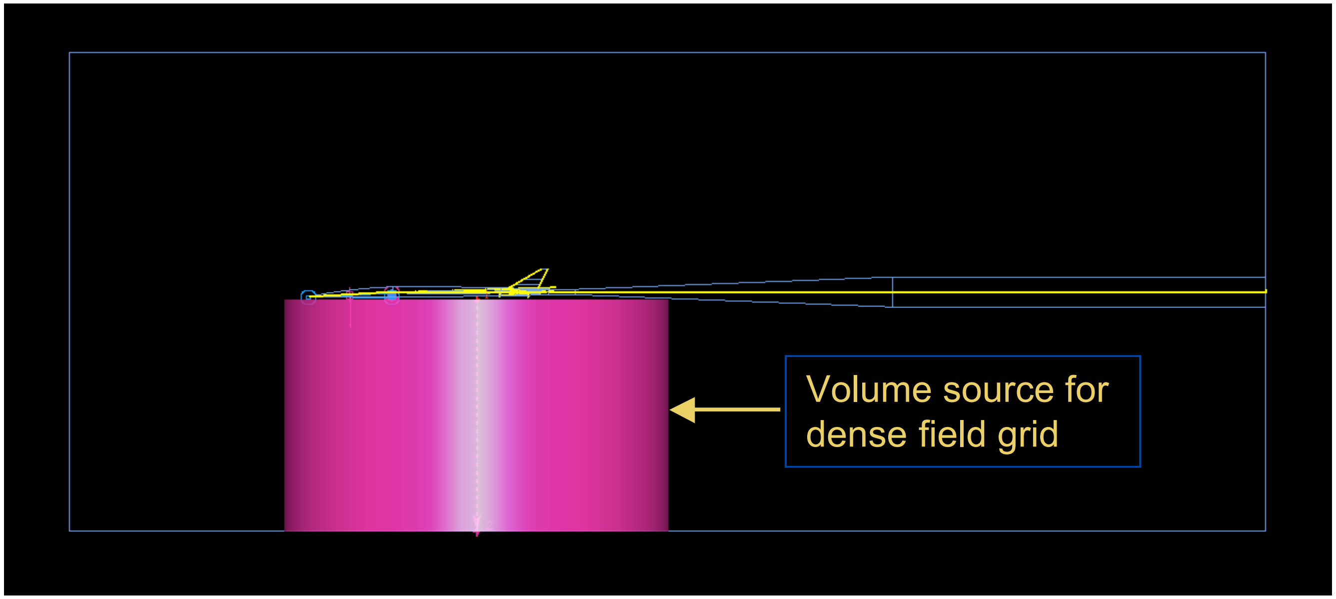


- Develop water-tight surface patches from IGES definition of geometry, including sting
- Add compact outer boundary box



Grid Sourcing - AUTOSRC

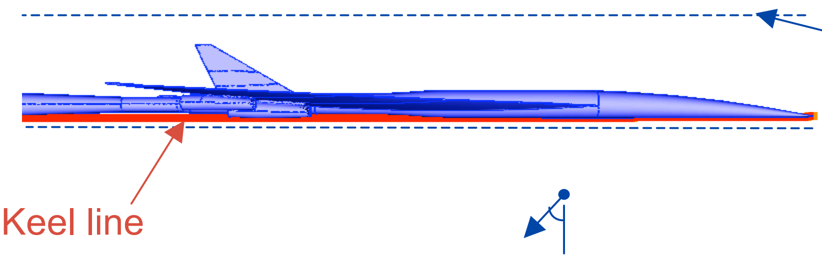


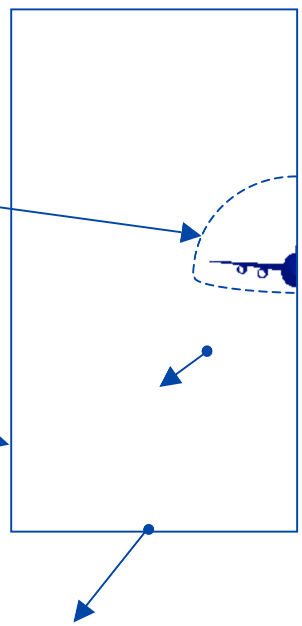


Grid Modification - SSGRID

- Grid alignment approximated by *a priori* axial shearing of grid based on free-stream Mach number and configuration angle of attack
- Grid stretching reduces grid size and signature dissipation to reach mid-field
- Inner cylinder region with no grid modifications prevents sheared & stretched grid from intersecting configuration
- Variable inner cylinder radius based on keel line allows grid modification to begin close to body
- Grids for different Mach number/angle-of-attack combinations can be quickly (~ 1 minute) developed from baseline grid

- Radial stretching based on distance between inner cylinder and outer boundary
- Stretching increased as $r^{0.25}$ for smooth cell size transition away from inner cylinder

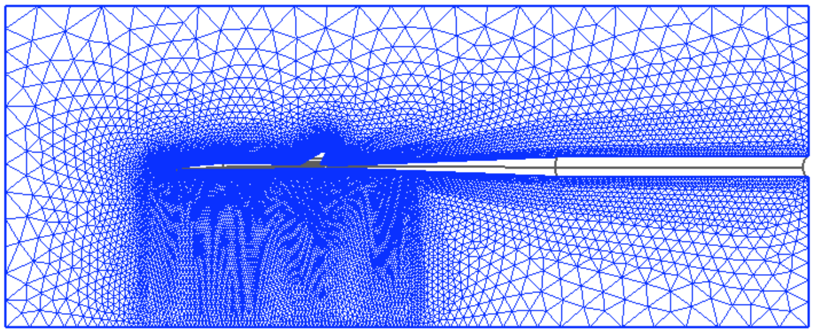




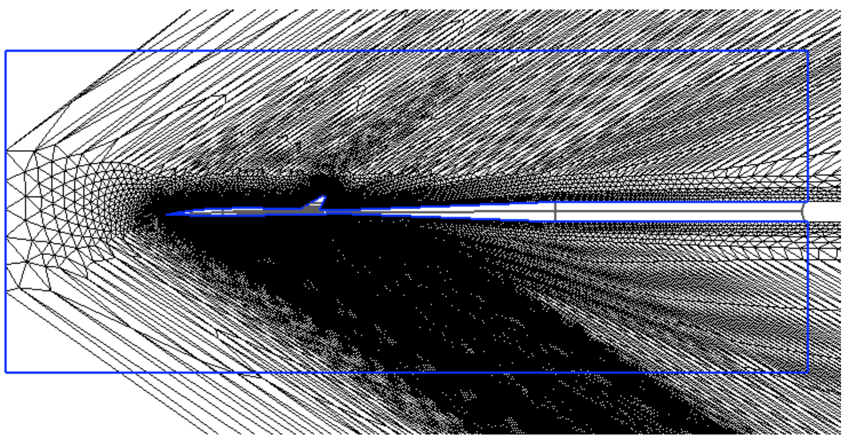
Axial shearing based on Mach angle

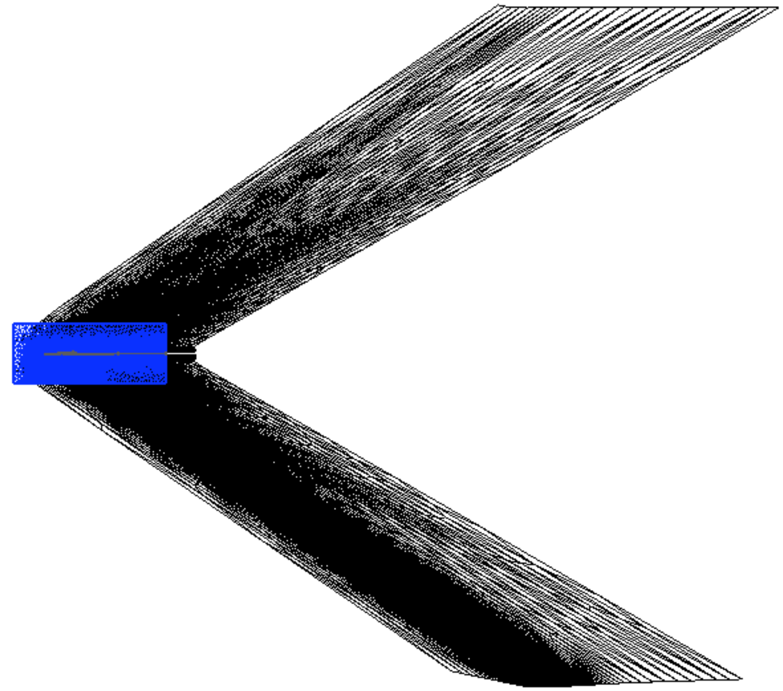
Grid Modification - SSGRID

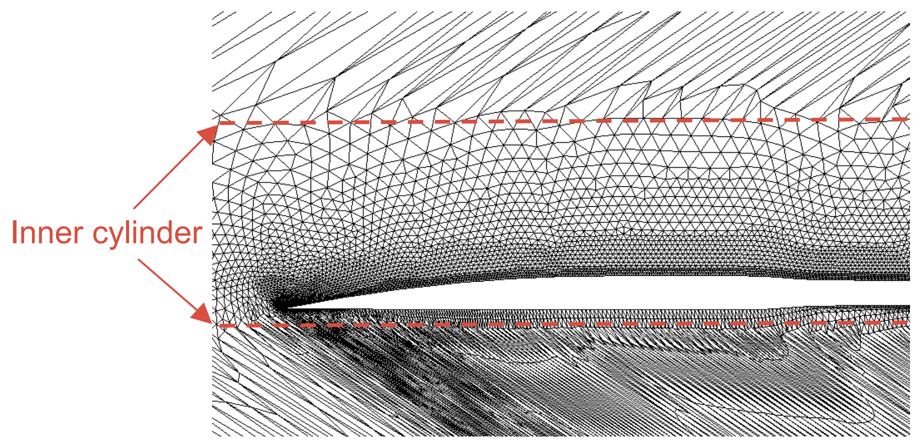
Baseline



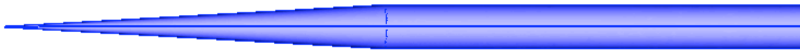
Sheared & Stretched



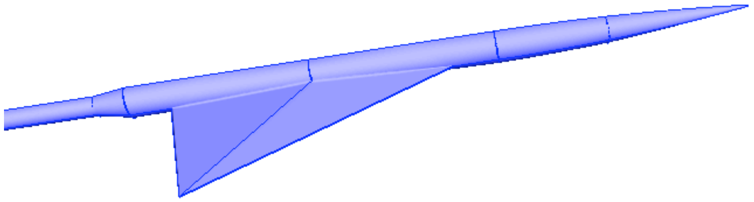




Configurations for Validation

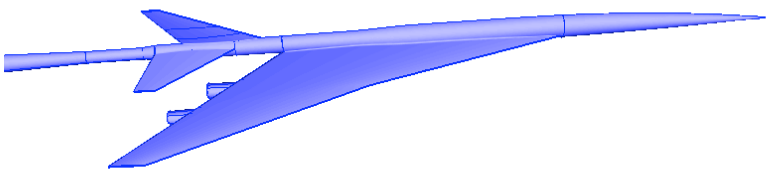


6.48º Cone-Cylinder (NASA TM X-2219)

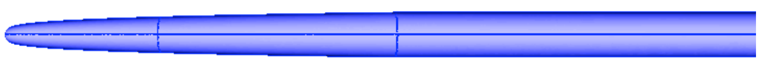


69º Swept Delta-Wing-Body
(NASA TN D-7160)

Parabolic Body of Revolution
(NASA TN D-3106, Model 4)



Ames Low Boom Wing Tail with Nacelles
(NASA CP-1999-209699, LBWT)

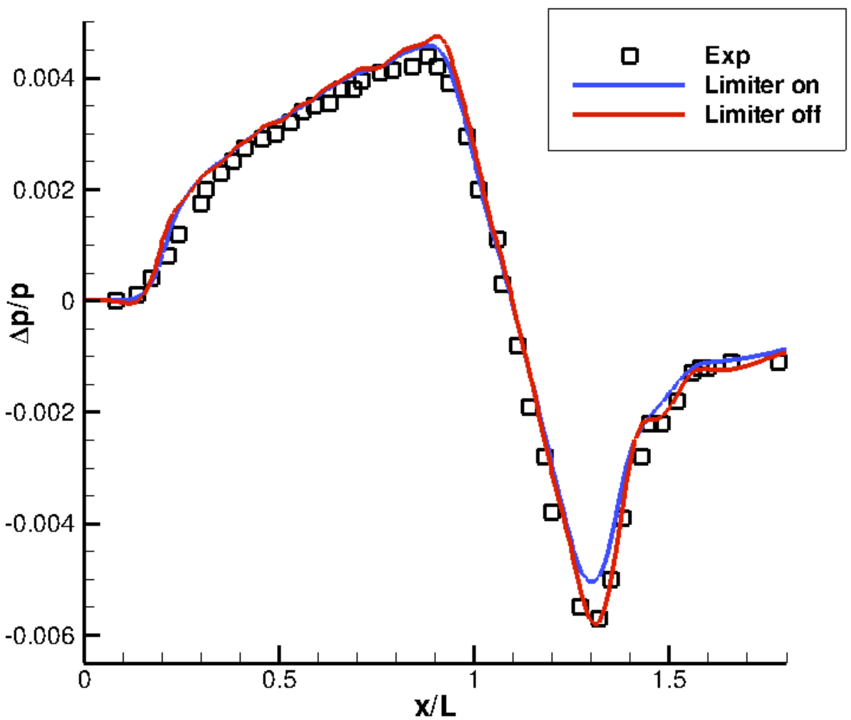


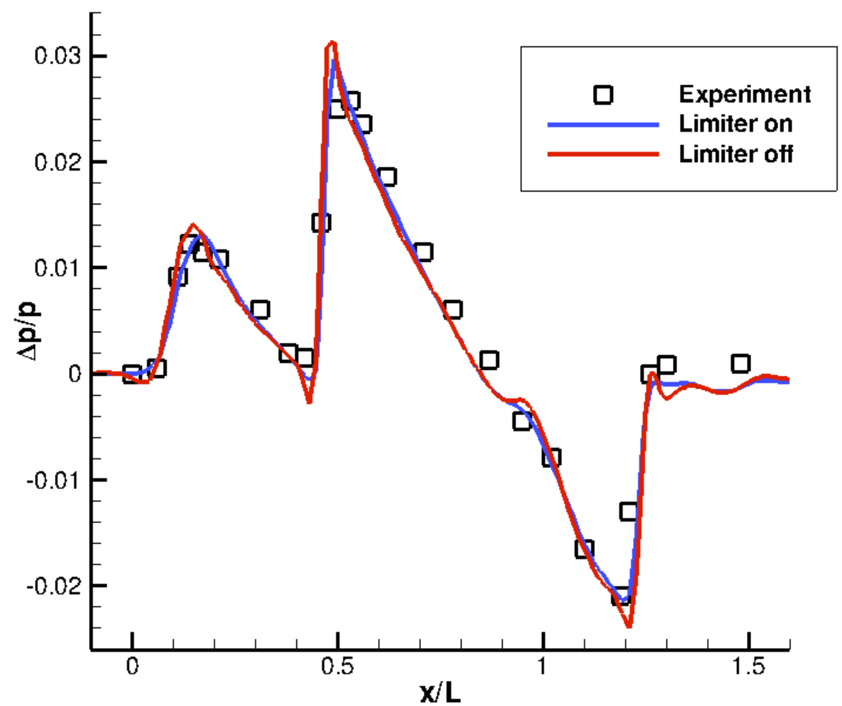
Quartic Body of Revolution
(NASA TN D-3106, Model 5)

Results of Flow Solver Limiter Study

6.48º Cone-cylinder, fine grid
M_∞= 1.68 α = 0.0° h/L = 10

Delta wing-fuselage, coarse grid
M_∞= 1.68 α = 4.74° h/L = 3.6



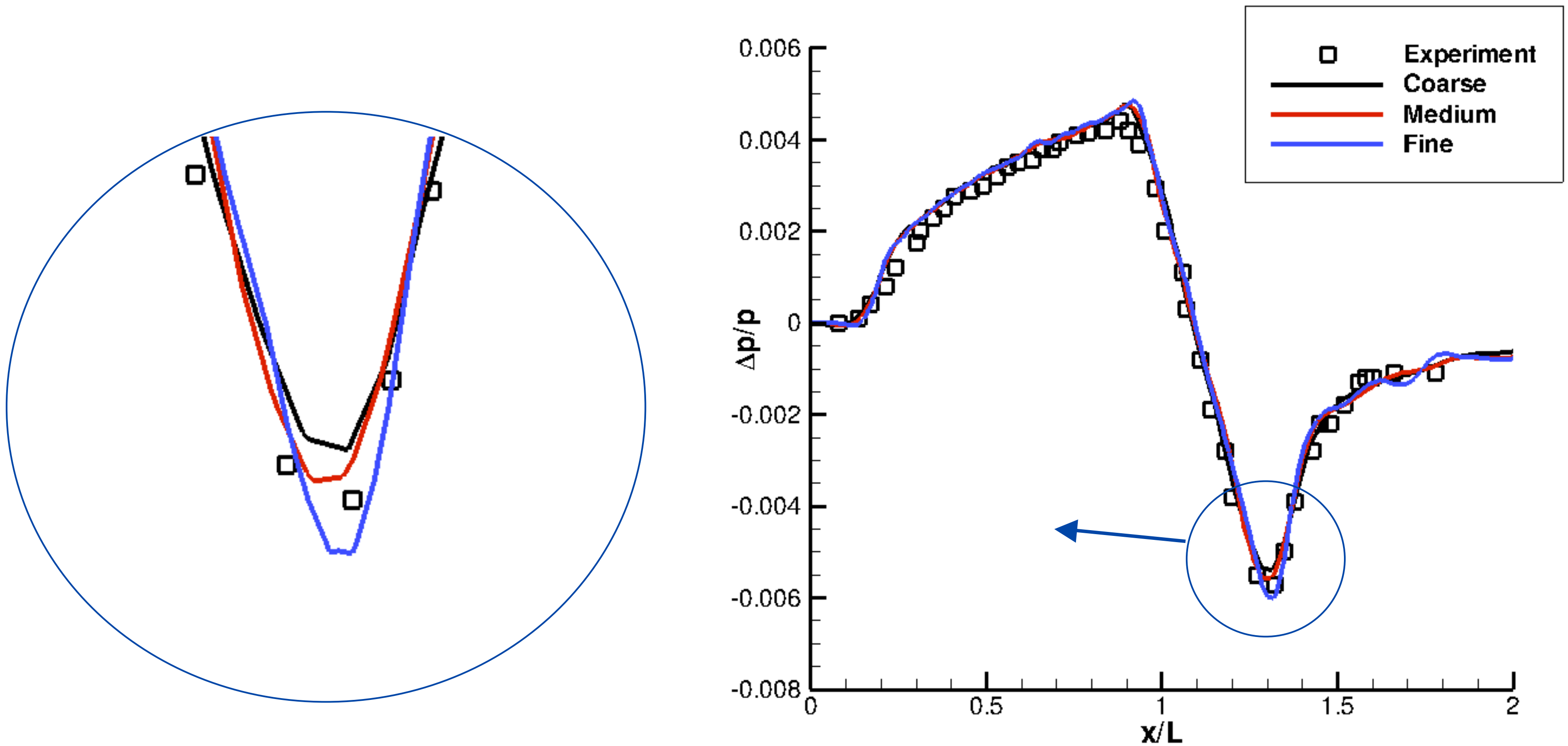


Use limiter only if needed for solution stability

SSGRID Results For 6.48° Cone-cylinder

Case	# Cells(M)	Timing (minutes)		
		Grid	Run	Total
Coarse	2.0	6	8	14
Medium	3.6	10	14	24
Fine	9.7	23	40	63

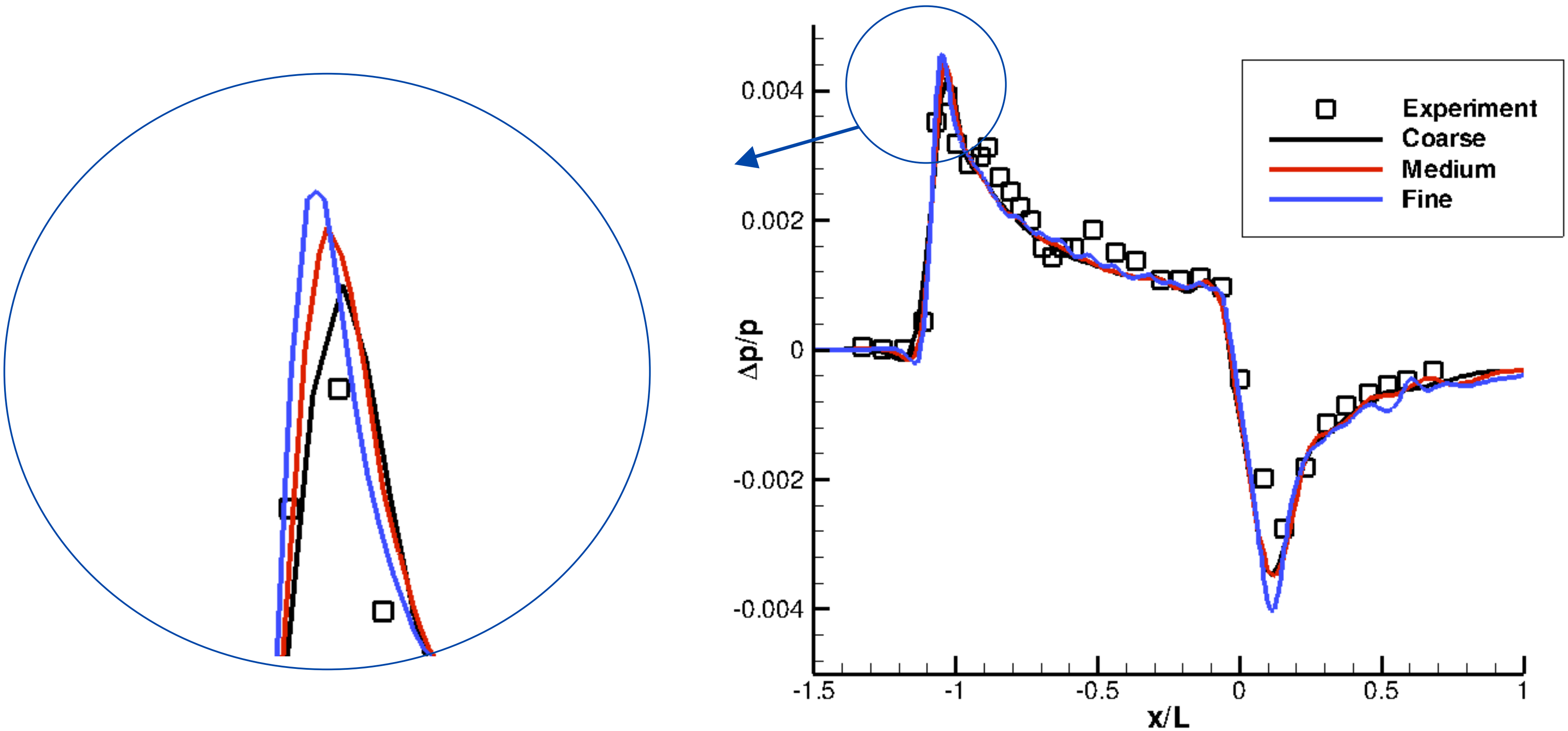
$M_\infty = 1.68$ $\alpha = 0.0°$ $h/L = 10$



SSGRID Results For Parabolic Body (Model 4)

Case	# Cells(M)	Timing (minutes)		
		Grid	Run	Total
Coarse	1.9	5	10	15
Medium	3.5	9	19	28
Fine	9.8	24	54	78

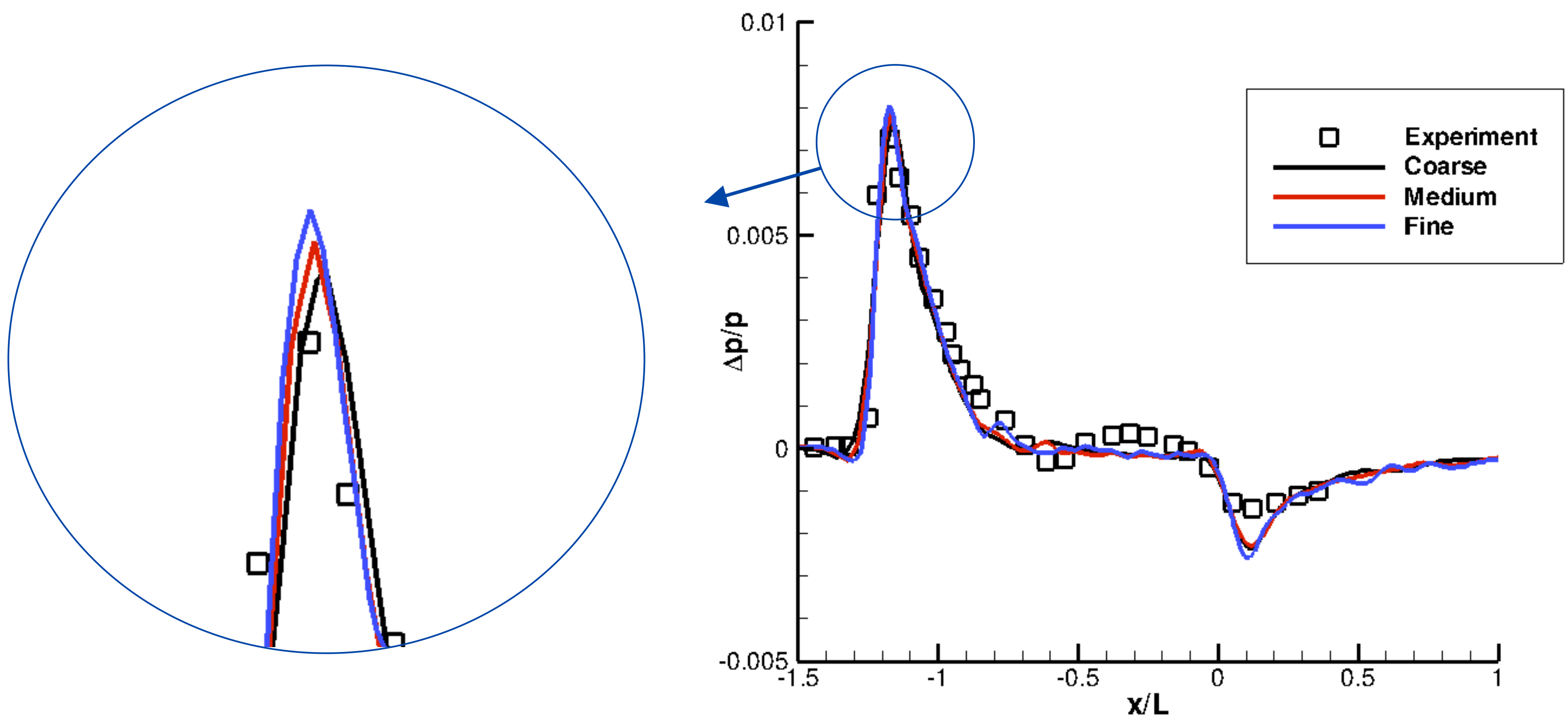
$M_\infty = 1.41$ $\alpha = 0.0°$ $h/L = 10$



SSGRID Results For Quartic Body (Model 5)

Case	# Cells(M)	Timing (minutes)		
		Grid	Run	Total
Coarse	1.8	5	10	15
Medium	3.4	9	18	27
Fine	9.5	24	53	77

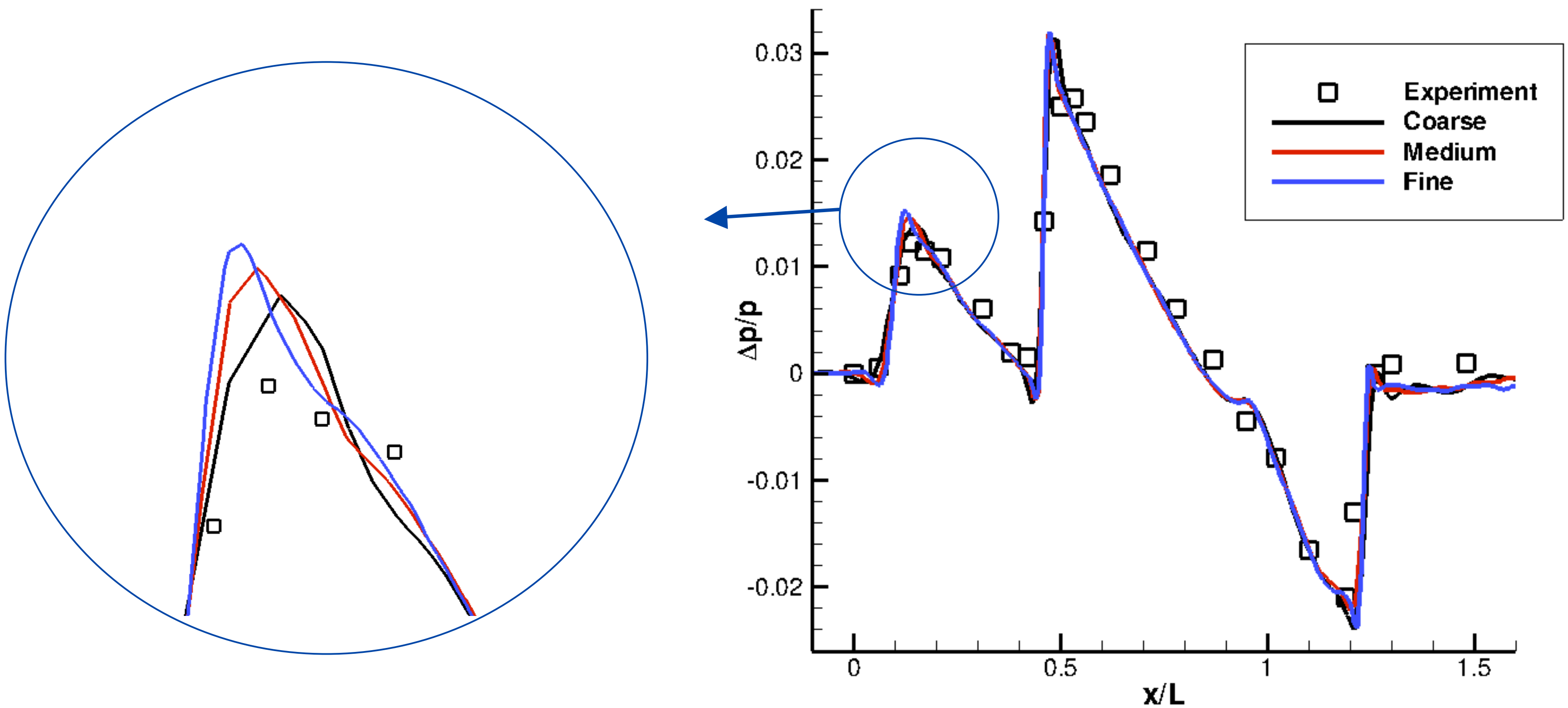
$M_\infty = 1.41 \quad \alpha = 0.0° \quad h/L = 10$



SSGRID Results For 69° Swept Delta-wing-body

Case	# Cells(M)	Timing (minutes)		
		Grid	Run	Total
Coarse	2.7	9	18	27
Medium	4.3	13	32	45
Fine	10.5	29	98	127

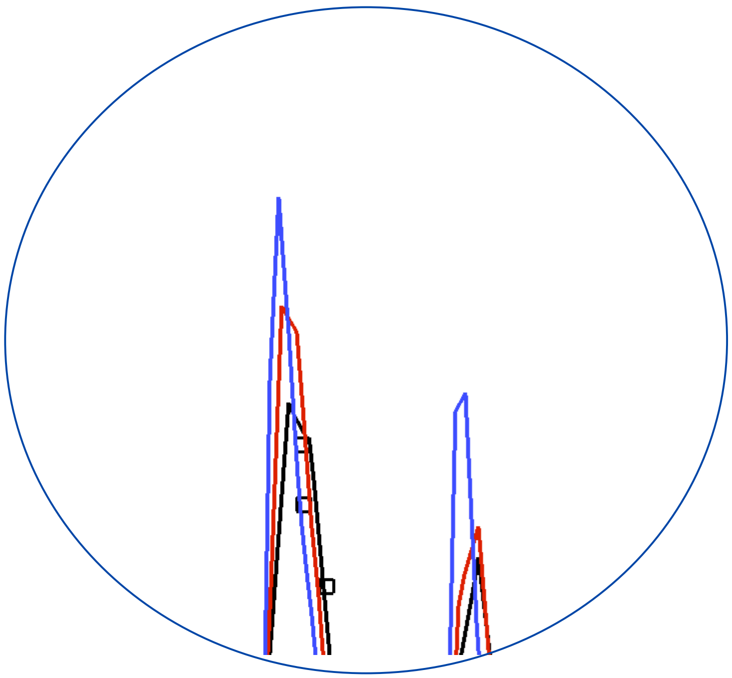
$M_\infty = 1.68$ $\alpha = 4.74°$ $h/L = 3.6$

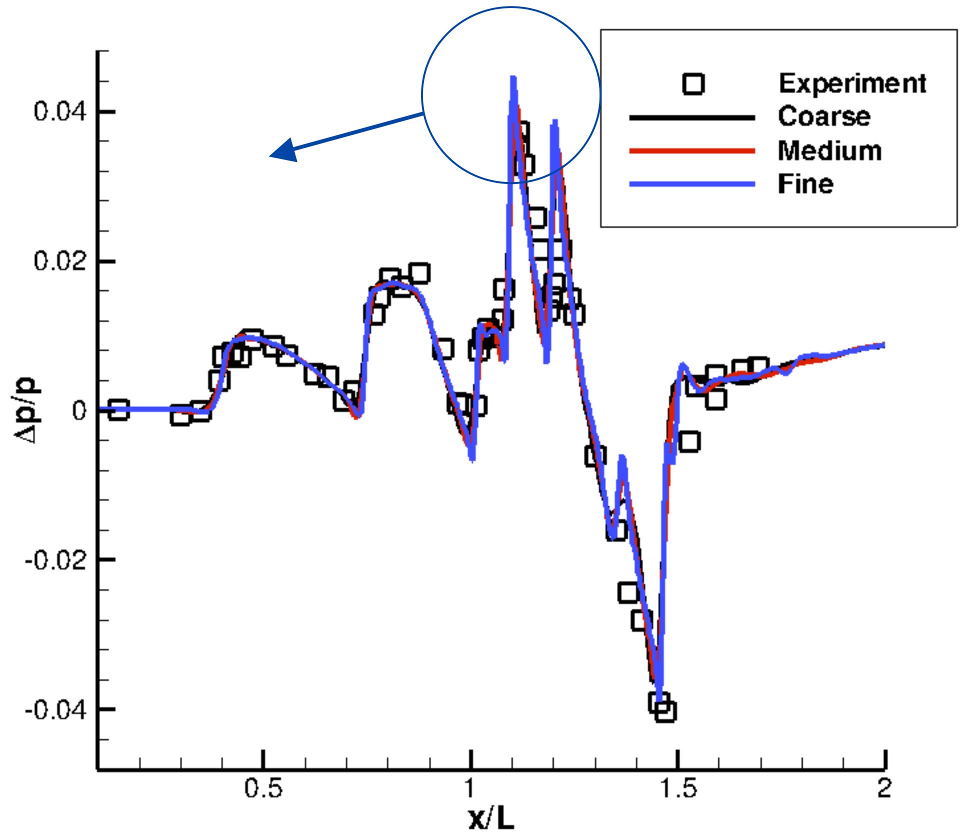


SSGRID Results For LBWT

Case	# Cells(M)	Timing (minutes)		
		Grid	Run	Total
Coarse	4.2	15	32	47
Medium	7.1	24	54	78
Fine	15.9	50	127	177

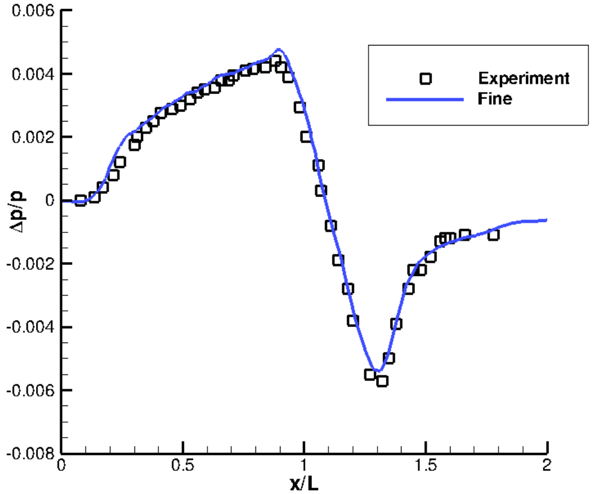
$M_\infty = 2.0$ $\alpha = 2.0°$ $h/L = 1.167$



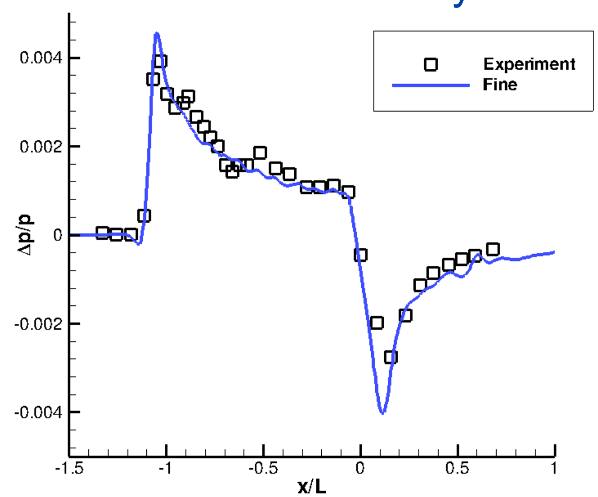


Final Comparison of CFD and Wind Tunnel Results

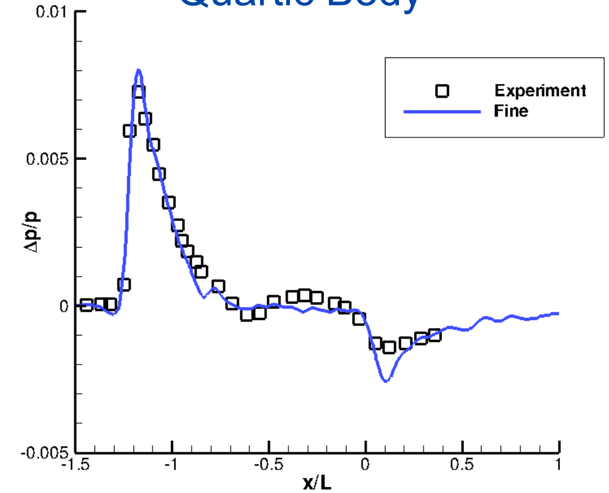
Cone-cylinder



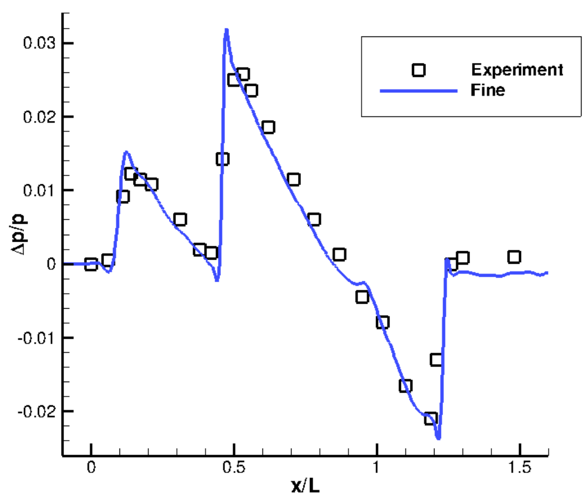
Parabolic Body



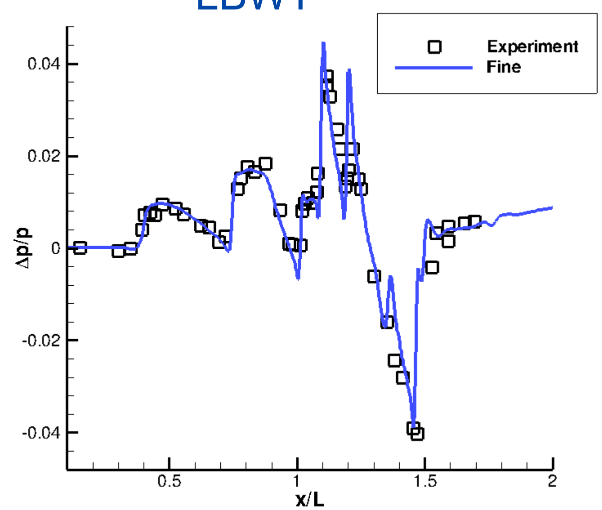
Quartic Body



Delta Wing-body



LBWT



Concluding Remarks

- Mid-field boom signatures obtained using the fine grid option in AUTOSRC correlate well with wind tunnel data
- Grid size studies indicate that coarser grids can give up to 5x reduction in case time with little loss of accuracy
- SSGRID can quickly (~1 minute) modify a baseline grid for analysis at other Mach numbers or angles of attack
- SSGRID provides an efficient method for developing unstructured grids for accurate prediction of sonic boom signature at mid-field distances