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UNS3D Simulations for the 3rd AIAA Sonic Boom Prediction Workshop

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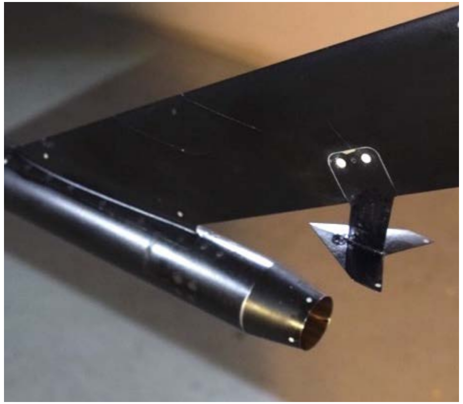
January 4, 2020
Orlando, FL

Presentation Outline

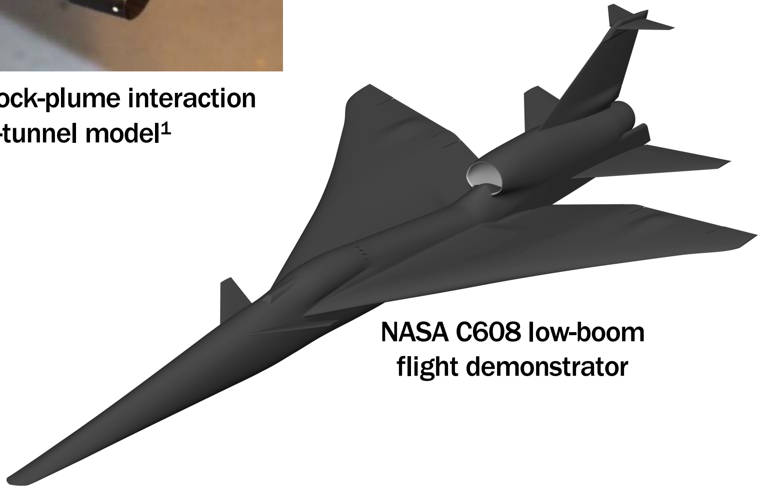
- Case summary
- Flow solver
- Simulation details
- Results
  - Biconvex wind-tunnel model
  - NASA C608 low-boom demonstrator
- Summary

Case Summary

- Both workshop cases were considered in this work
  - Biconvex 9x7 shock-plume interaction wind-tunnel model
  - NASA C608 low-boom flight demonstrator
- Cases were run to committee specifications
- Nearfield signatures extracted using provided Tecplot macro



Biconvex shock-plume interaction wind-tunnel model[1]



NASA C608 low-boom flight demonstrator

Flow Solver: UNS3D

- In-house Reynolds averaged Navier—Stokes solver[2]
  - Edge-based finite volume method
  - Roe's upwind convective flux algorithm with Harten entropy correction
  - Second-order spatial and temporal accuracy
  - Gradient reconstruction by least-square with QR decomposition
  - Time integration by four-stage Runge-Kutta
  - Menter's κ—ω SST turbulence model
- UNS3D has been successfully used to predict nearfield flow for low-boom configurations considered in previous workshop[3–5]

Flow Solver: UNS3D (Cont.)

- Piecewise linear reconstruction used to achieve second-order spatial accuracy
  - Requires use of solution limiters to prevent un-physical flow features
- Multiple limiters were exercised for comparison purposes
  - Venkatakrishnan[6]
  - Modified Venkatakrishnan[7]
  - Dervieux[7]

Computing Platforms

- High-performance parallel, distributed memory computing resources from Texas A&M University and NASA were used in this work
  - Ivy Bridge HECC Nodes were 1.5 times faster than TAMU nodes

	NASA HECC Nodes		Texas A&M		Average Fine
Case	Broadwell	Ivy Bridge	Intel Xeon	Cores: min/max	Mesh Run Time
Biconvex		X	X	84/336	1 Day
C608	X	X		336/1680	8 Days

Computational Grids

- Workshop provided grids were used in this work
  - Mixed-element grids only

Biconvex wind-tunnel grids used

Name	Scale	#Nodes	#Elements
Mixed-157	1.57	846,227	3,480,369
Mixed-128	1.28	1,576,352	6,984,508
Mixed-100	1.00	3,286,221	16,027,527

NASA C608 grids used

Name	Scale	#Nodes	#Elements
Mixed-128	1.28	11,782,783	29,824,790
Mixed-100	1.00	20,701,451	50,028,335
Mixed-080	0.80	34,879,443	82,274,480
Mixed-064	0.64	50,215,130	122,651,312

Flow Solver Convergence

Biconvex Wind Tunnel Test Case

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- Convergence criterion
  - **Primary:** 5 order drop in flow residual magnitude
  - **Secondary:** stabilization of body forces
- Each case setup to run 100,000 iterations
- Flow residuals achieved roughly 4 order drop in magnitude before convergence stalled
- Deemed converged based on body force histories

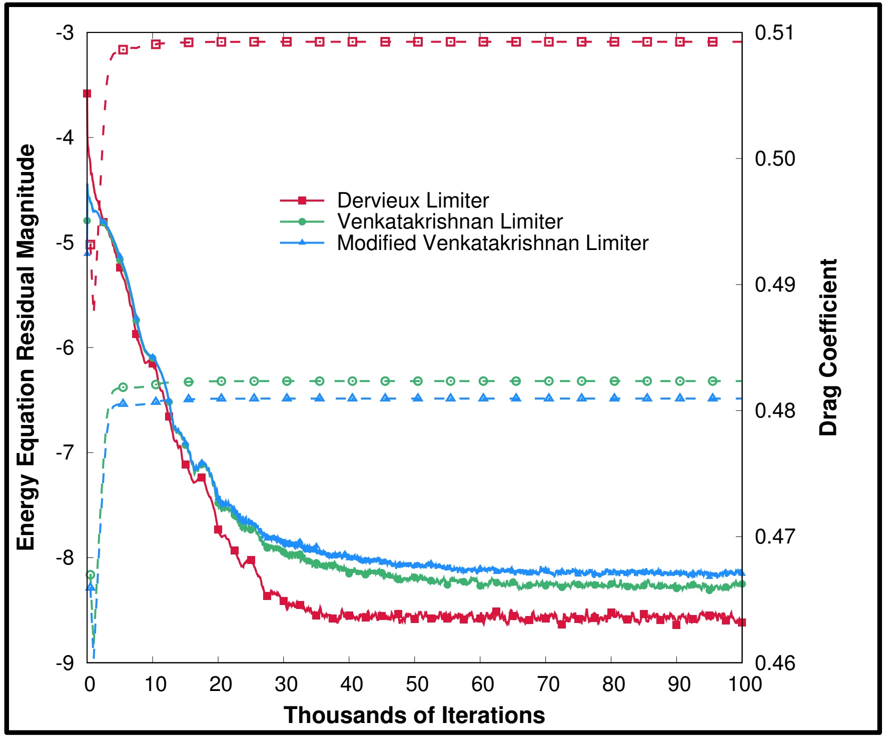
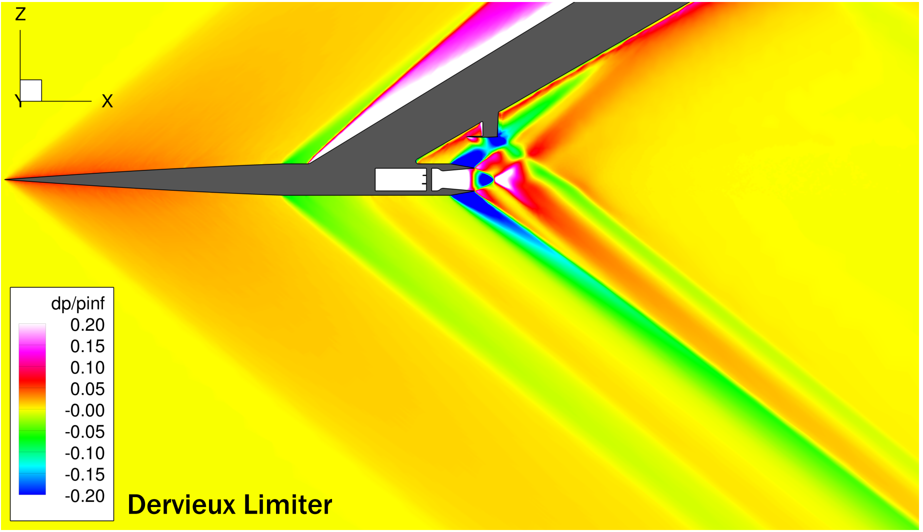


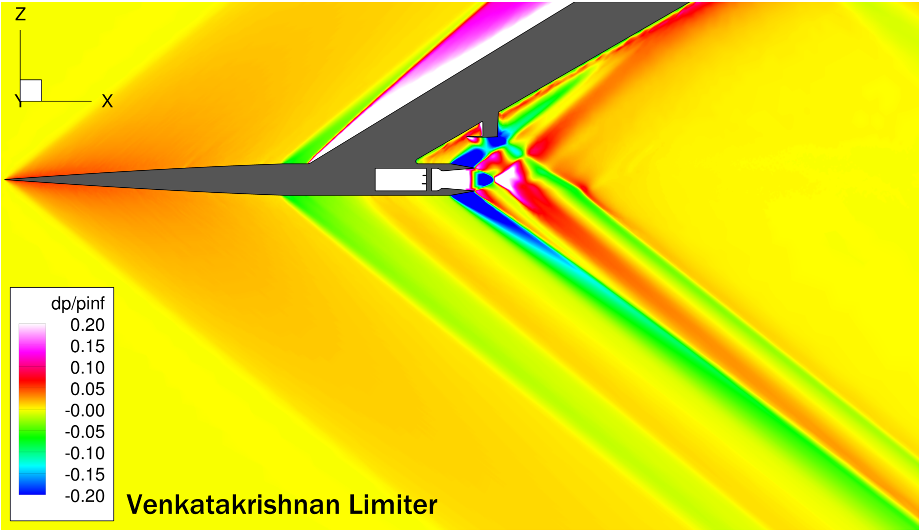
Figure: Typical flow and drag convergence, taken from fine mesh

Fine Mesh Predicted Pressure Field

Biconvex Wind Tunnel Test Case

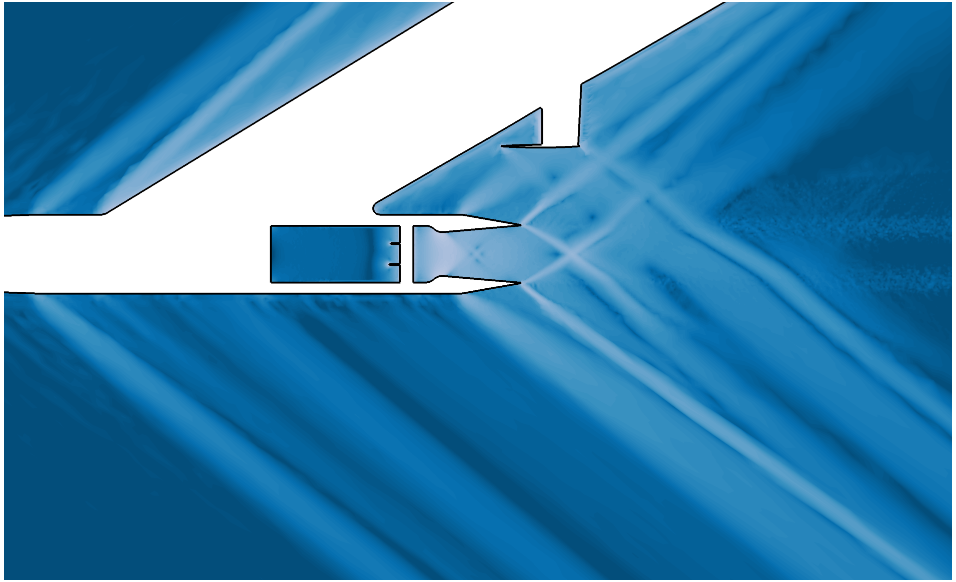
- Both limiters produce a qualitatively similar result
  - Venkatakrishnan result show more pronounced flow features
- Modified Venkatakrishnan solution nearly identical to standard limiter solution



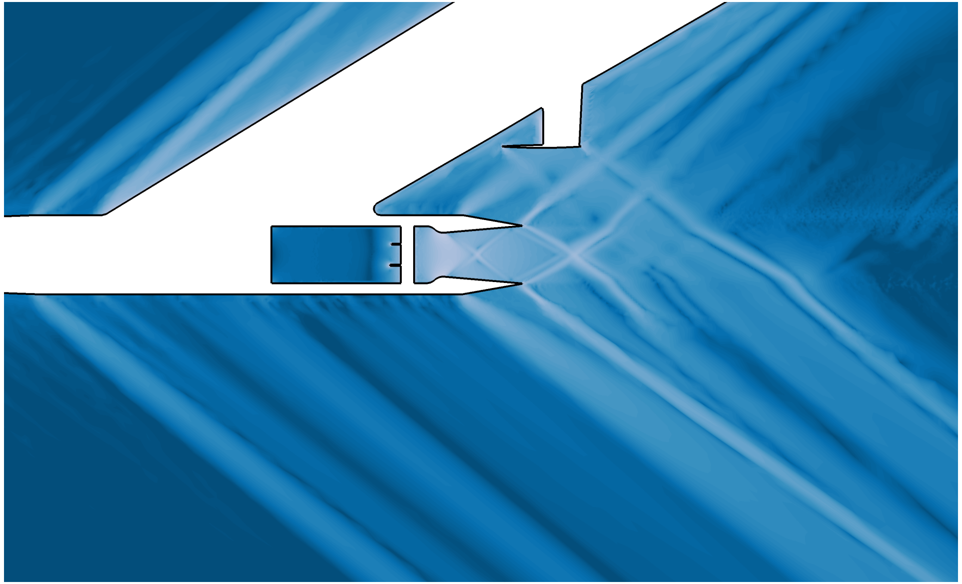


Fine Mesh Pressure Gradient Magnitude

Biconvex Wind Tunnel Test Case



Dervieux Limiter

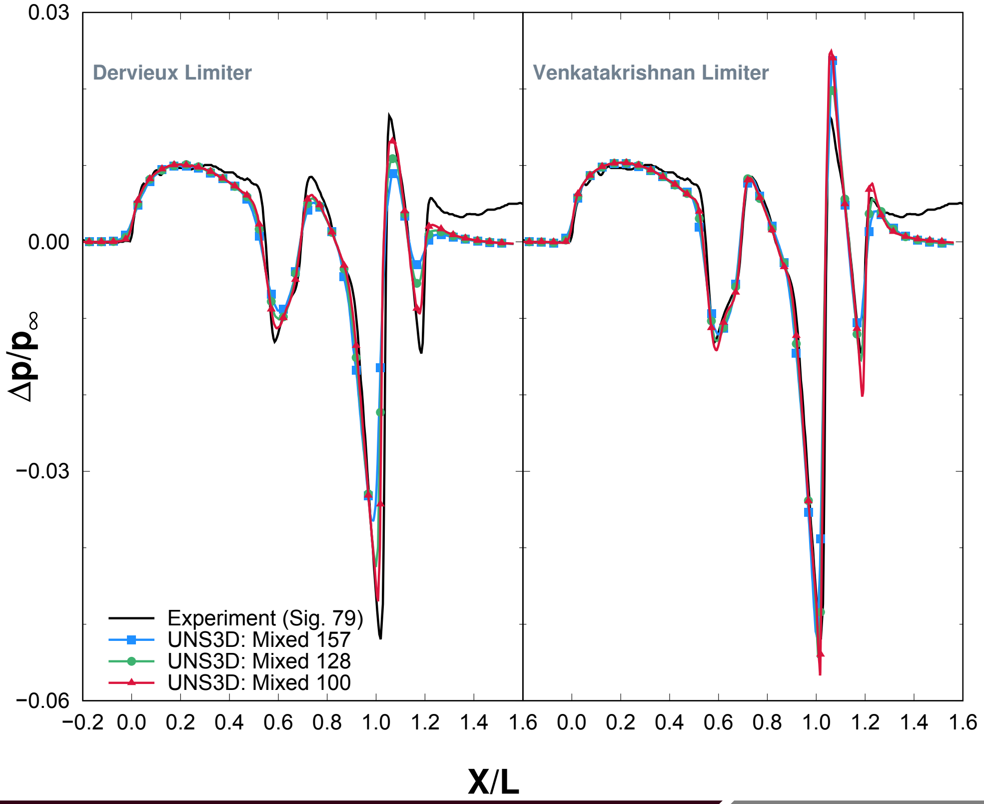


Venkatakrishnan Limiter

Undertrack Nearfield Signature Grid Convergence

Biconvex Wind Tunnel Test Case

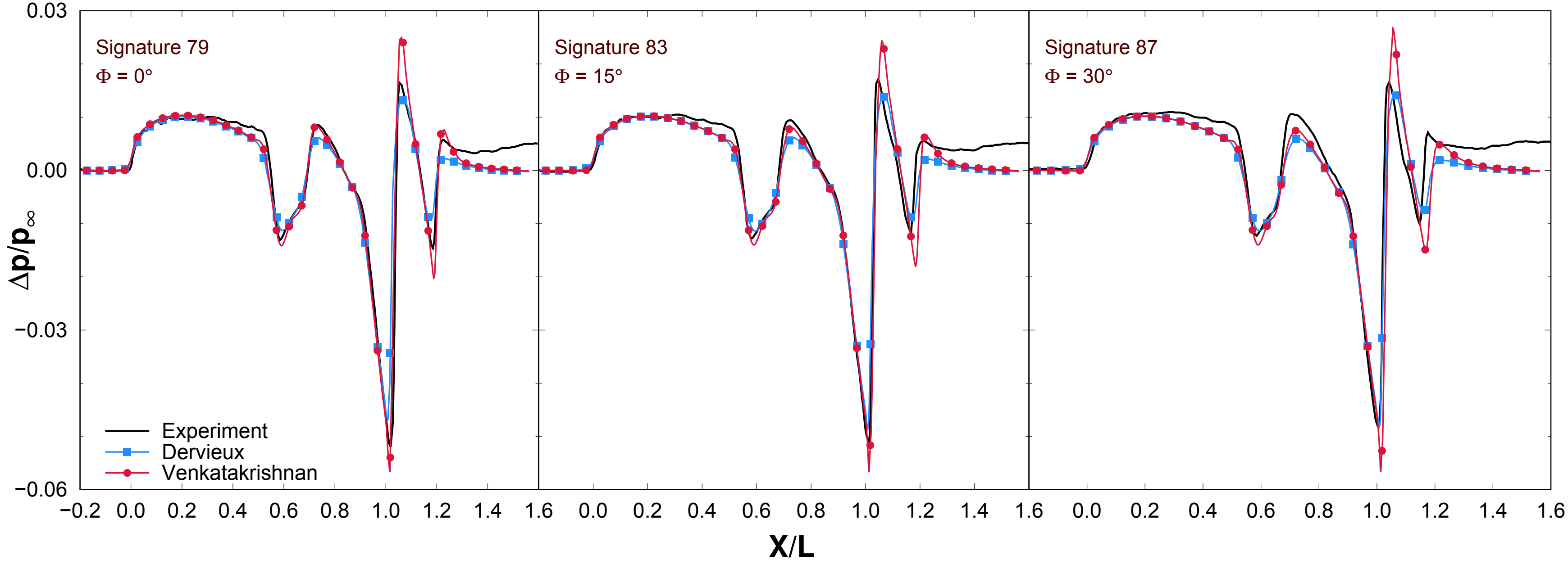
- Dervieux solutions exhibited most sensitivity to grid size
  - Most evident at local signature extrema
- Venkatakrishnan solutions overshot average experiment values at local extrema
  - Modified limiter produced nearly identical nearfield signatures as standard limiter
- Current solutions are qualitatively similar to published CFD predictions[1]



Nearfield Signature Azimuth Angle Comparison

Biconvex Wind Tunnel Test Case

- Predicted nearfield pressure showed good agreement with experiment data at all three measured azimuth angles



Flow Solver Convergence
NASA C608 Low-Boom Demonstrator

- Convergence criterion
  - **Primary:** 5 order drop in flow residual magnitude
  - **Secondary:** stabilization of body forces
- Dervieux limiter solutions achieved convergence on all but finest grid tried
- Venkatakrishnan limiter solution exhibited unsteady flow properties
  - Only able to obtain solution on coarsest mesh

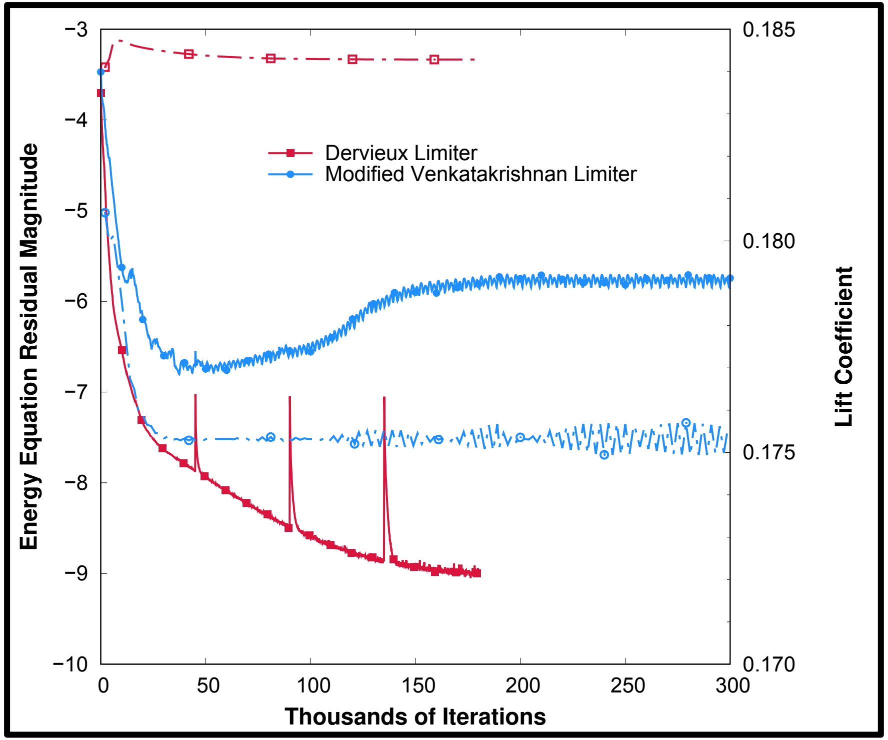
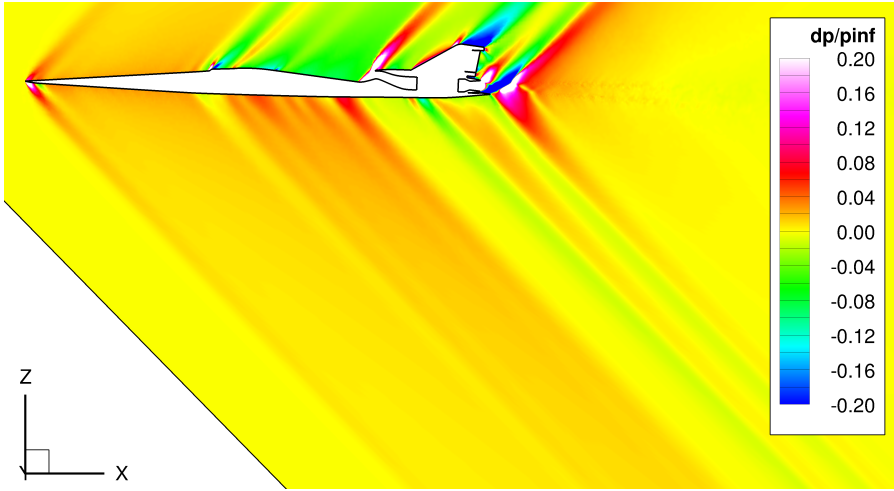


Figure: Flow and lift coefficient convergence from coarse mesh simulations.

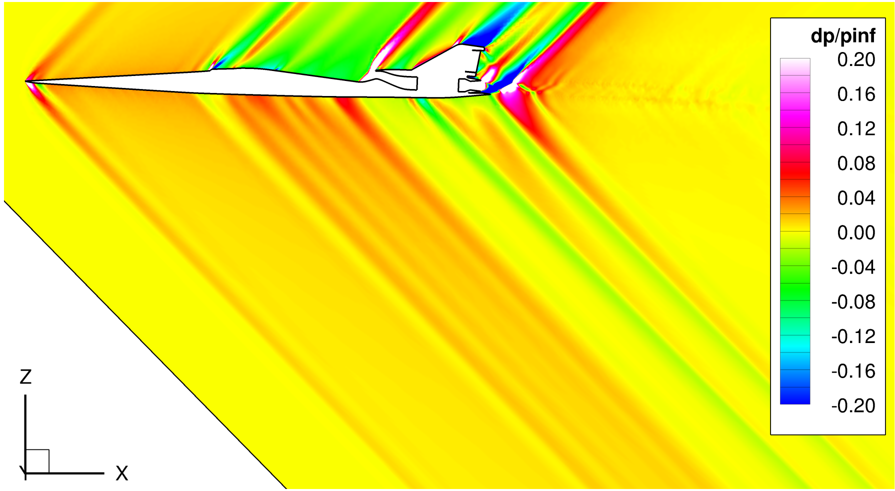
Coarse Mesh Predicted Pressure Field

NASA C608 Low-Boom Demonstrator

- Venkatakrishnan limiter results in sharper representation of shocks and salient flow features
  - Introduces less dissipation than Dervieux limiter



Dervieux Limiter

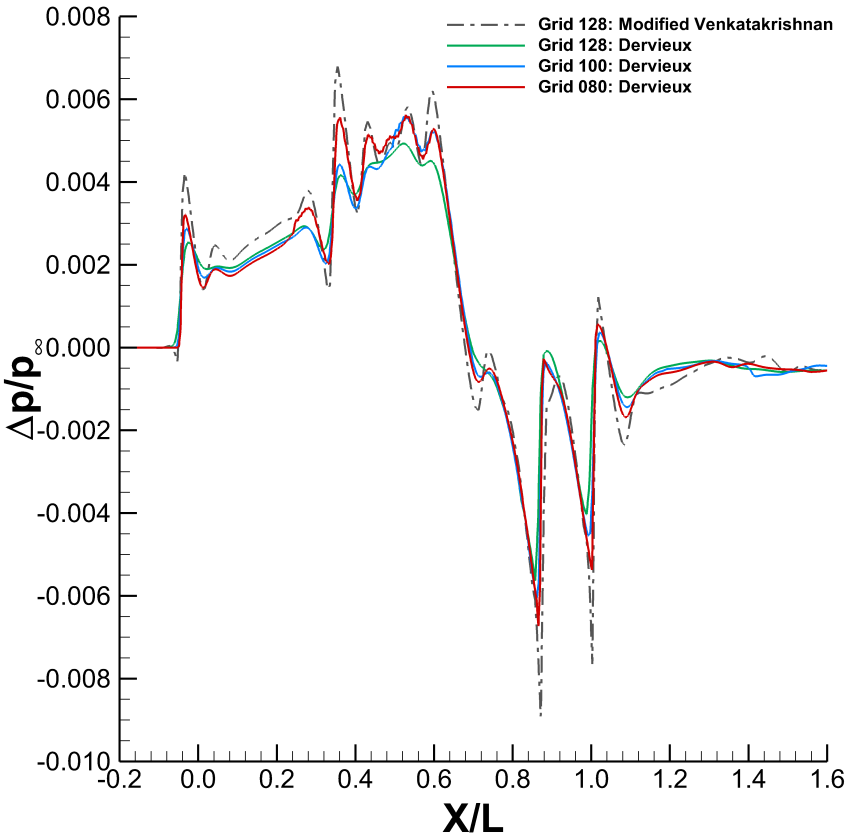


Modified Venkatakrishnan Limiter

Undertrack Nearfield Signature Grid Convergence

NASA C608 Low-Boom Demonstrator

- Coarse Venkatakrishnan solution shows a number of small amplitude features
- Dervieux solutions on coarser grids followed general trend of Venkatakrishnan solution
  - Flow features in forward portion of signature are attenuated
  - Salient flow features better captured as grid refined



Mixed-128 C608 Venkatakrishnan Energy Equation Residuals

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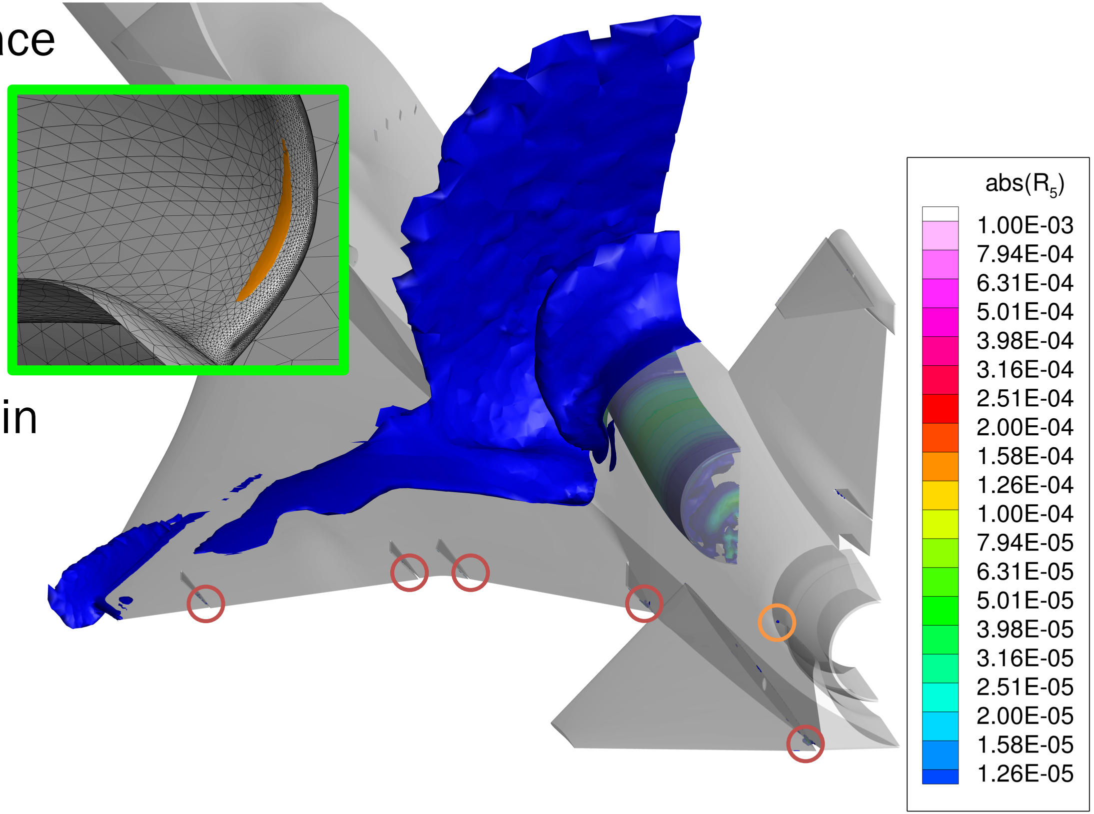
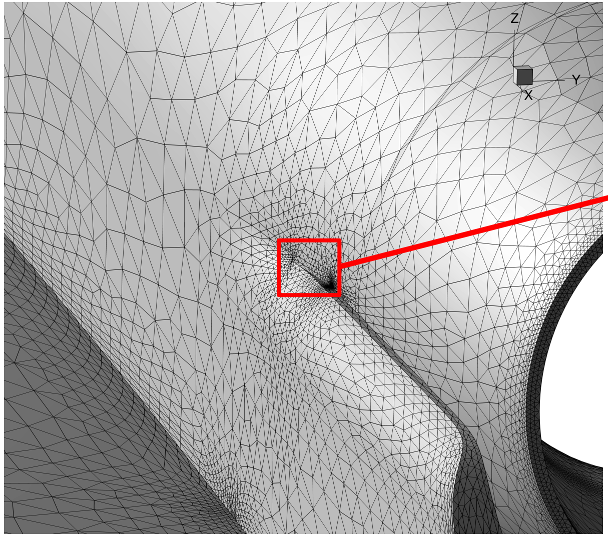
- Large residuals located surface adjacent to:
  - Control surface gaps
  - Engine inlet mouth
  - Discontinuous surface feature
- Location of max residual sat in vicinity of discontinuous surface feature
  - Occasionally jumped to elevator gap location

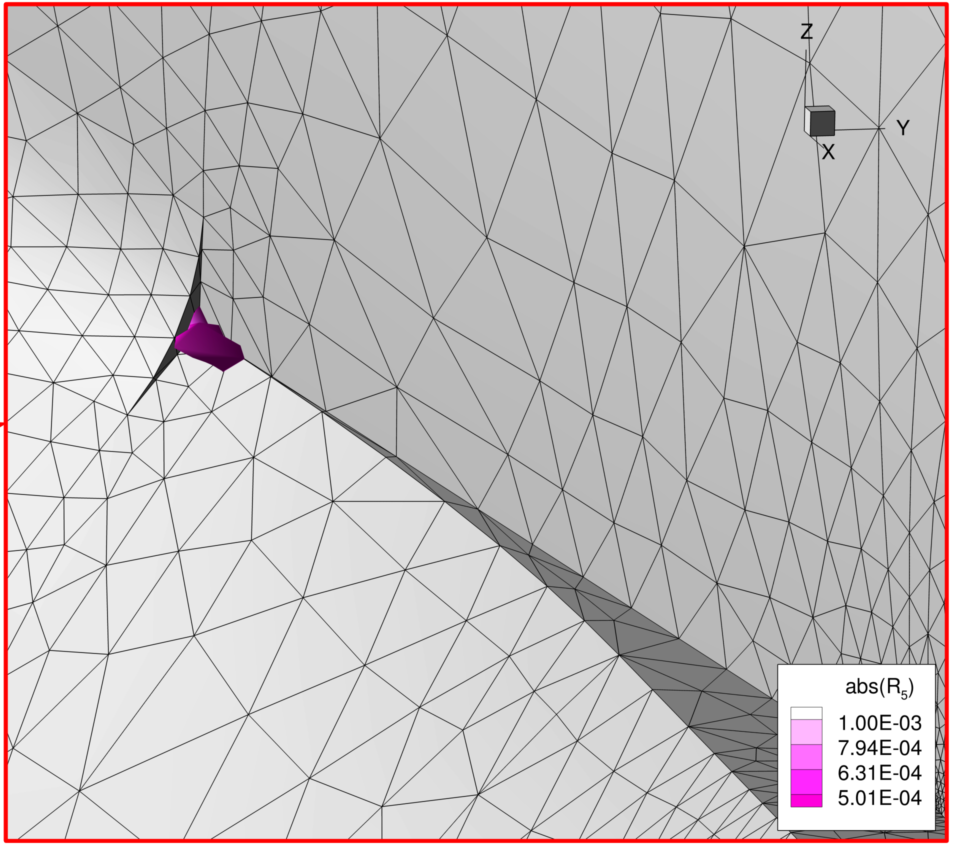


Mixed-128 C608 Venkatakrishnan Energy Equation Residuals (Cont.)

Primary Max Residual Location

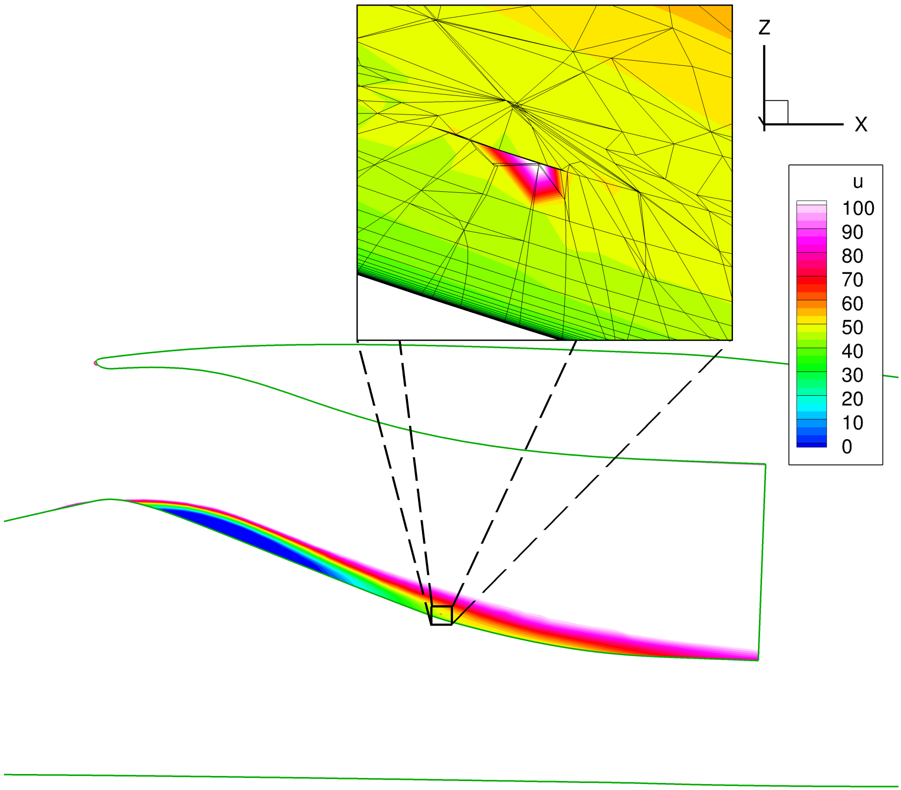
- Backwards facing step with a surface “singularity”





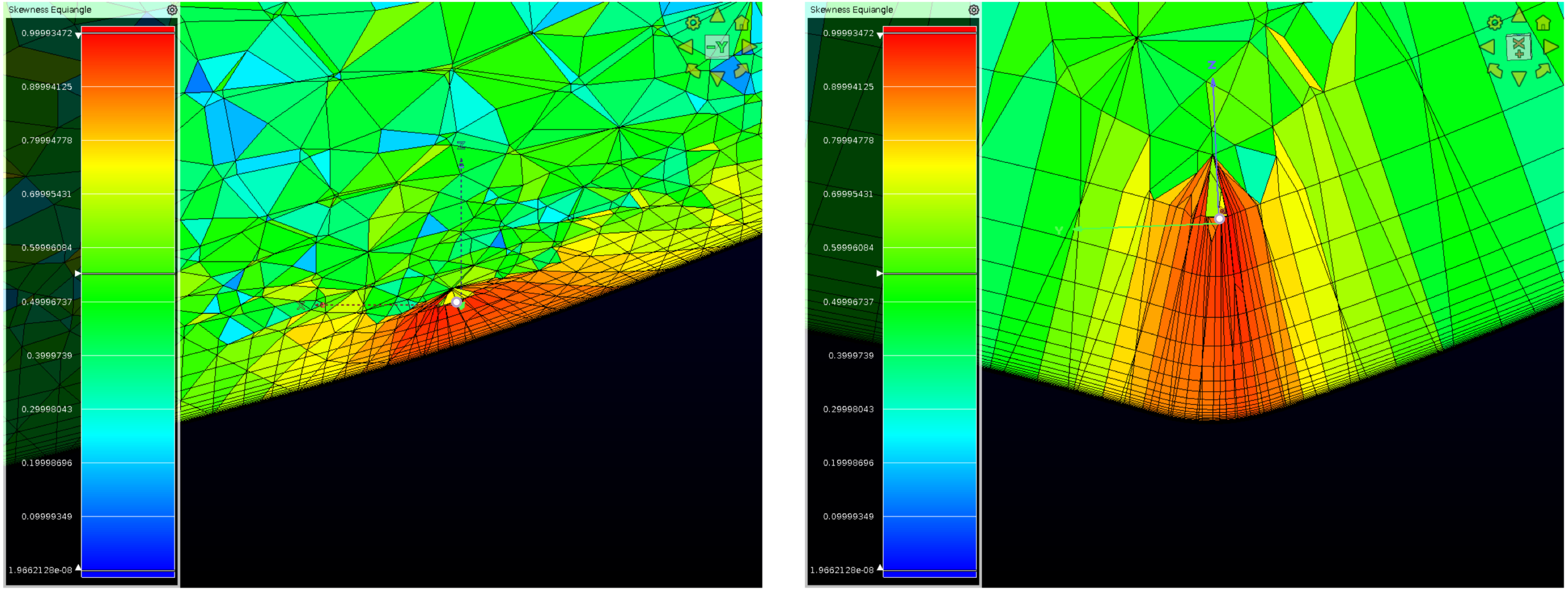
Mixed-064 Dervieux C608 Divergence

- Solution diverges in early stages of simulation on finest grid tried
- Location of divergence found inside engine inlet region
- Associated with set of highly-skewed cells in prism/tet transition zone



Mixed-064 Dervieux C608 Divergence (Cont.)

- Elements skewness equiangle $\gtrapprox 0.95$ in vicinity of divergence



Summary

- Nearfield pressures predicted for biconvex shock-plume interaction model found to be in good agreement with published experimental data
- Use of a dissipative limiter was required to achieve convergence on three coarsest NASA 608 grids
  - Geometry simplification and strategic surface grid clustering could improve convergence in viscous dominated regions of flow
- Solution limiter study showed all three limiters tested produced solutions with good qualitative agreement
  - Dervieux limiter required a finer mesh to capture the lower amplitude features found in the nearfield pressure signatures

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Questions?

Thank you for your attention!

References

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Extra Slides

Predicted Pressure Field

NASA C608 Low-Boom Demonstrator