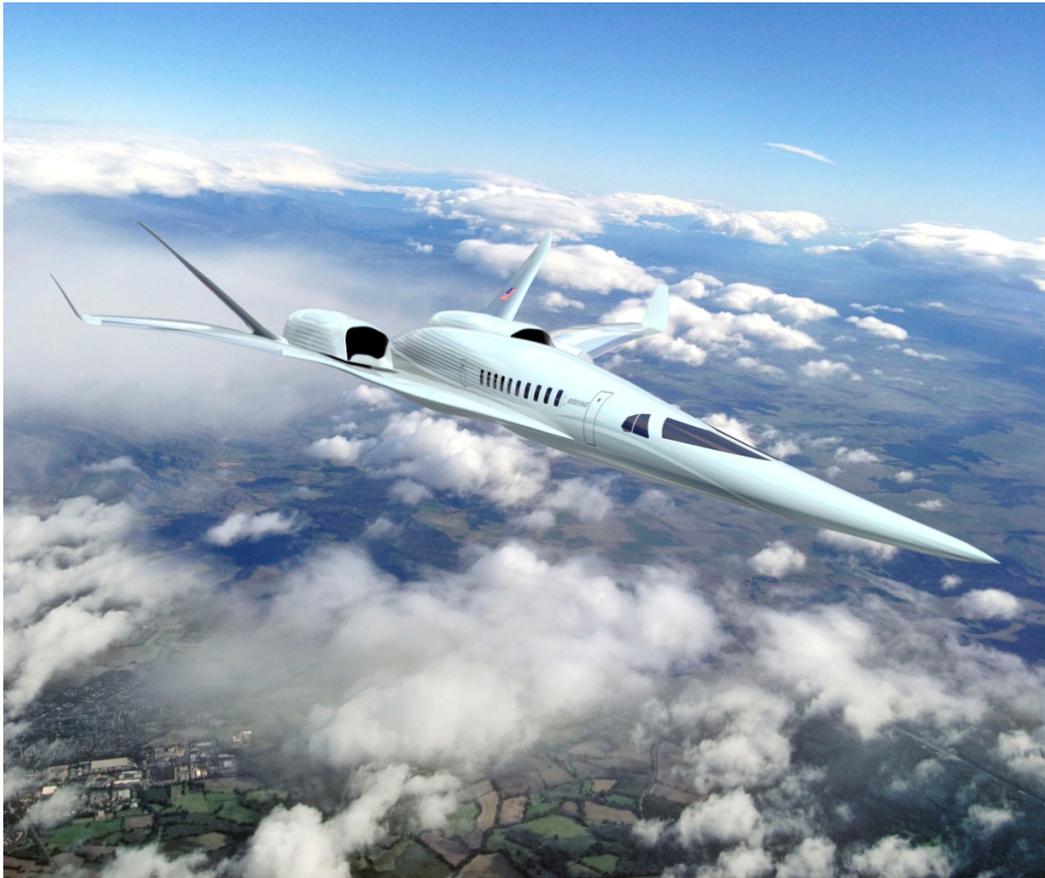




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Sonic Boom Prediction Workshop 2014

January 11, 2014

*Todd Magee, Spencer Fugal, David
Lazzara, Matt Sexton, Eric Unger*

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Agenda

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- **Introduction**
- **Cases Analyzed**
 - Grid Generation
 - Flow Solver
 - Solver Type
 - Compute Platform
 - Residual
 - Pressure Contours
- **Near-field Results & Comparisons**
- **Summary**

Cases Analyzed

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- **Two geometries analyzed with two different flow solvers**
 - SEEB-ALR
 - Cart3D
 - OVERFLOW
 - NASA 69-degree Delta Wing
 - Cart3D
 - CFD++
- **Four Boeing engineers provided solutions**
 - SEEB-ALR – Cart3D: Eric Unger
 - SEEB-ALR – OVERFLOW: Spencer Fugal
 - NASA 69-degree Delta Wing – Cart3D: David Lazzara
 - NASA 69-degree Delta Wing – CFD++: Matt Sexton

SEEB-ALR Using Cart3D

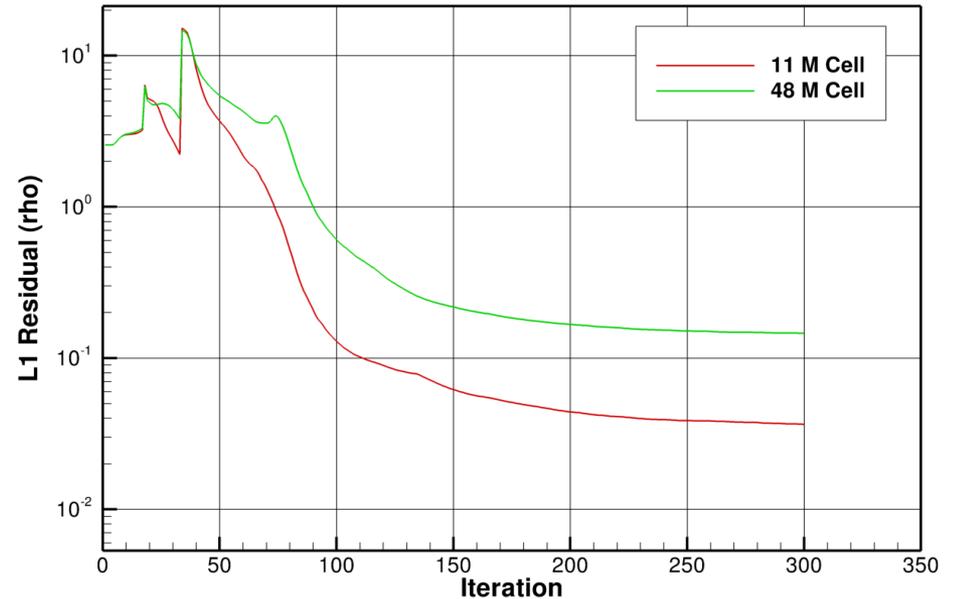
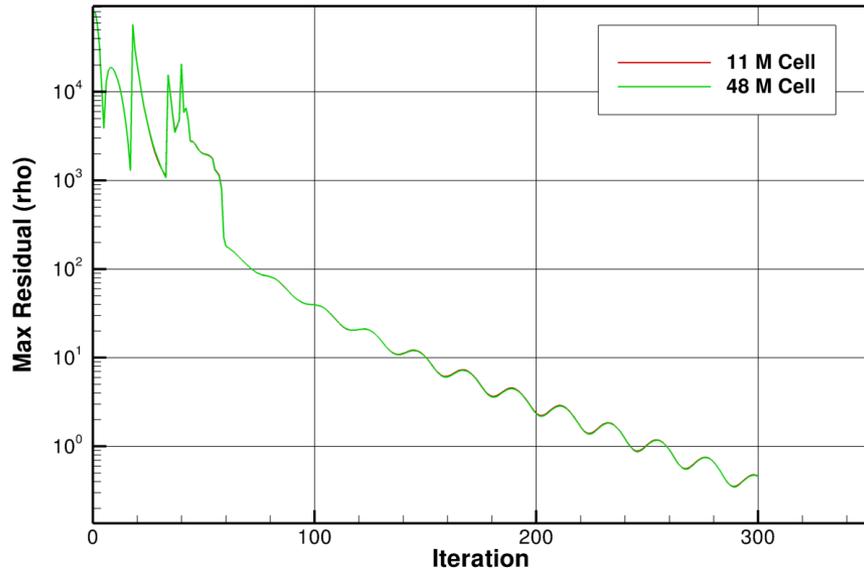
SEEB-ALR Using Cart3D

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- **SEEB-ALR case run at Mach=1.6 Angle-of-Attack=0.0 deg**
- **Cart3D**
 - Euler with Van-Leer flux & limiter
 - Used single 16 core node (shared memory)
- **Grid**
 - 11 million & 48 million cells (additional off-track cells)
 - X spacing at about 0.04”
 - Cartesian grid (generated by Cart3D) with 2:1 stretching in Y & Z directions
 - Grid rotated by Mach angle to closely capture signature
 - Surface grid generated in-house (MADCAP)
- **Solutions run for 300 iterations**
 - 24 minute run for 11M cells (16 cores)
 - 110 minute run for 48M cells (16 cores)

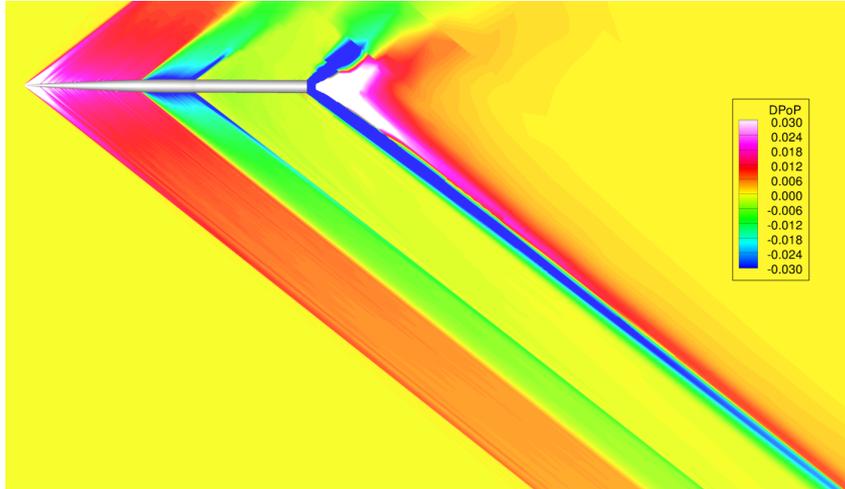
SEEB-ALR Cart3D Convergence History

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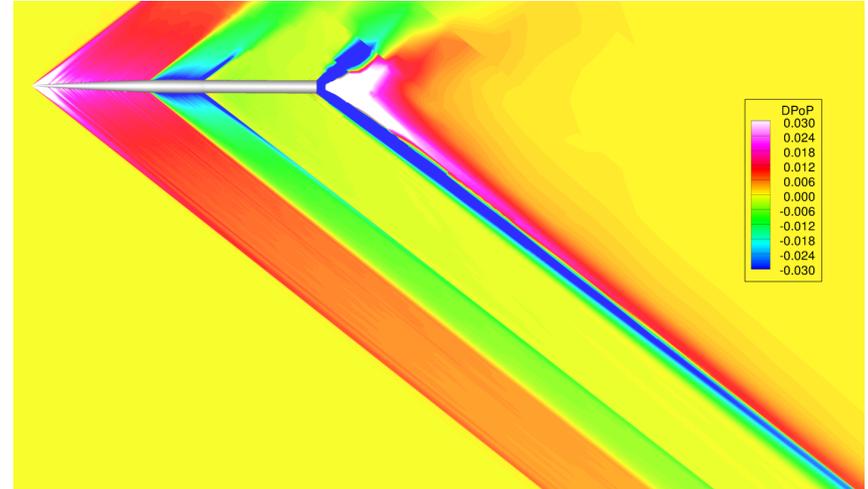


SEEB-ALR Cart3D Symmetry Plane Pressure Distribution

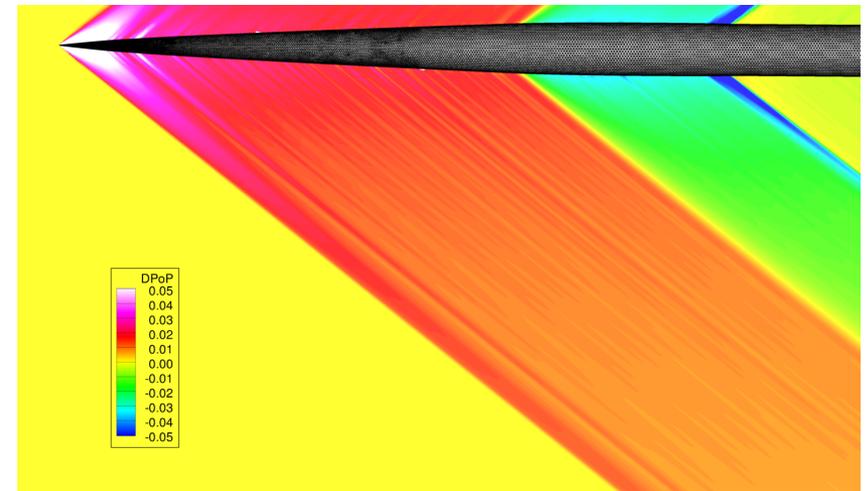
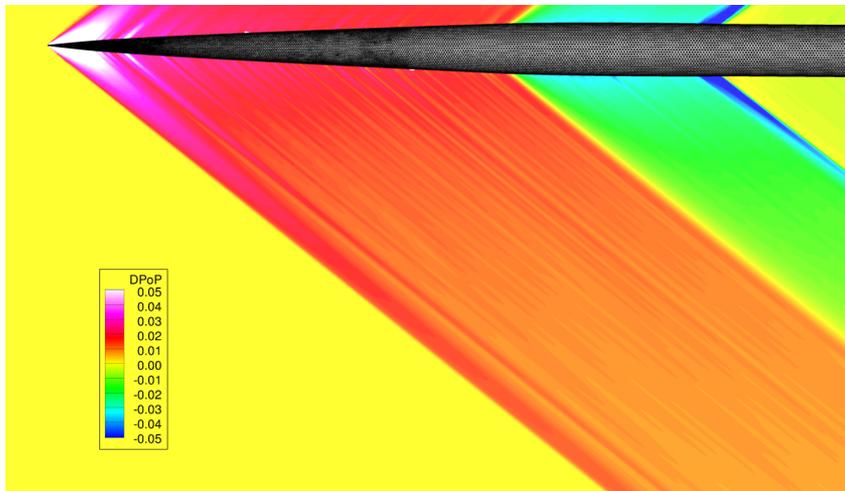
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11M Cells

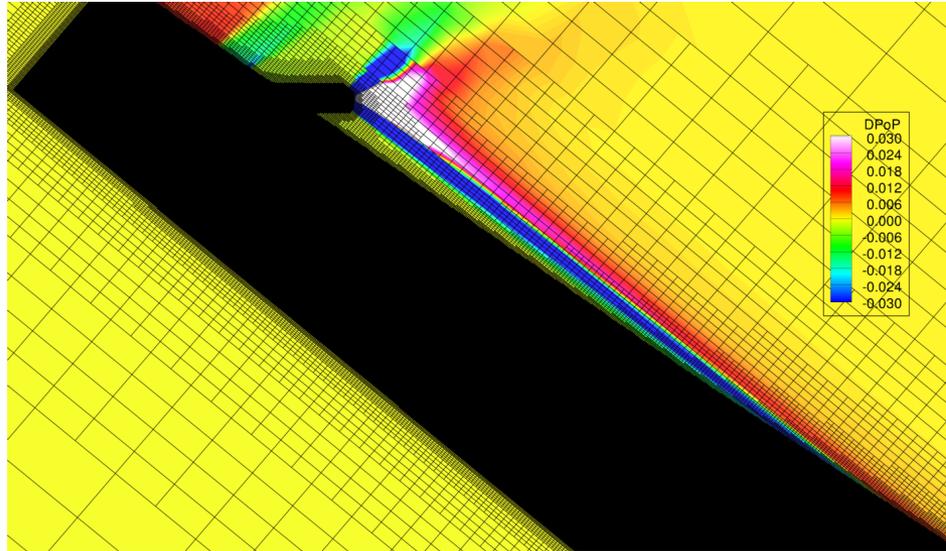


48M Cells

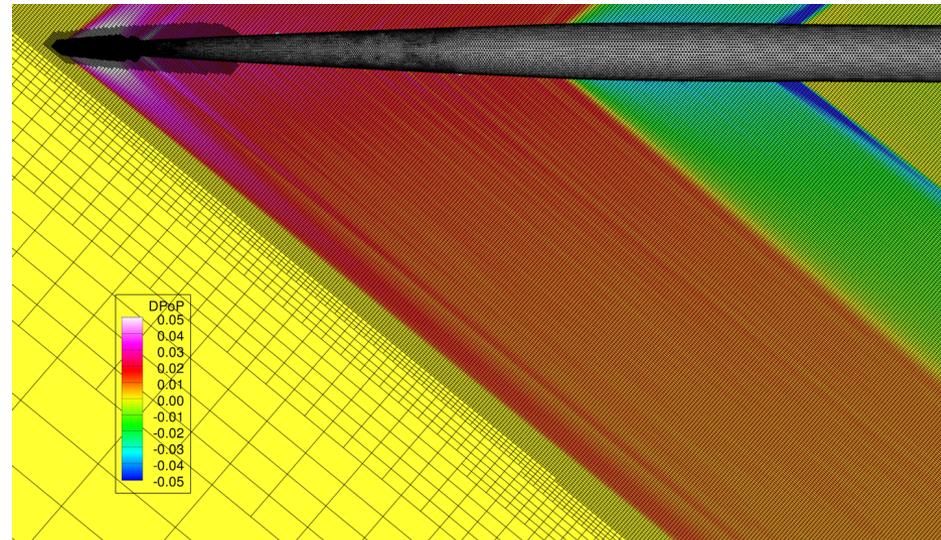


SEEB-ALR Cart3D Symmetry Plane Grid

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- 48 Million Cells
- Grid rotated to align with Mach lines

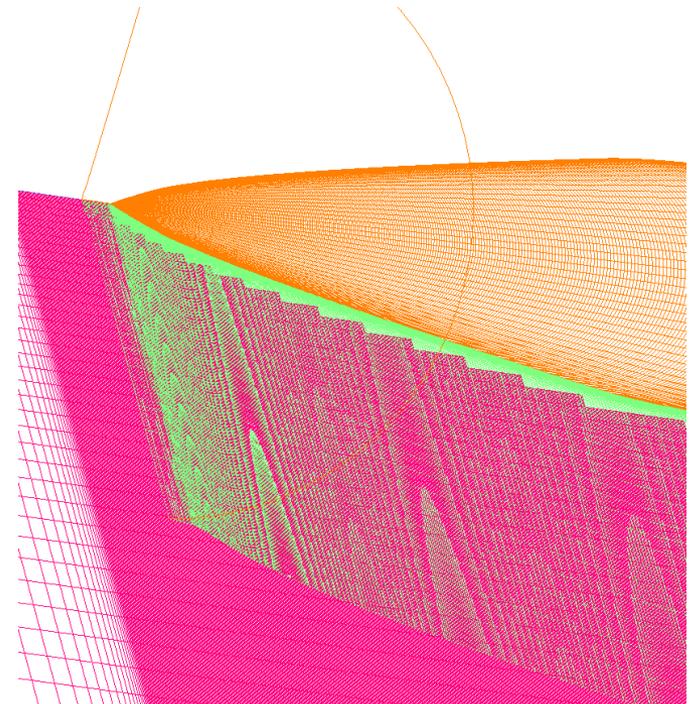
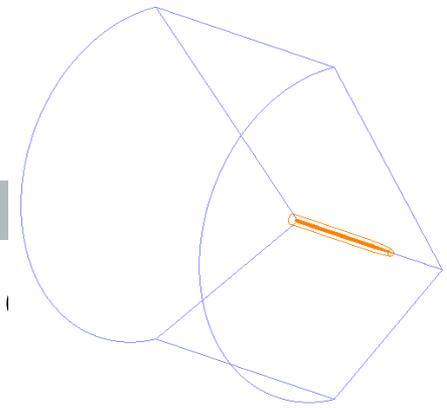


SEEB-ALR Using OVERFLOW

SEEB-ALR Using OVERFLOW

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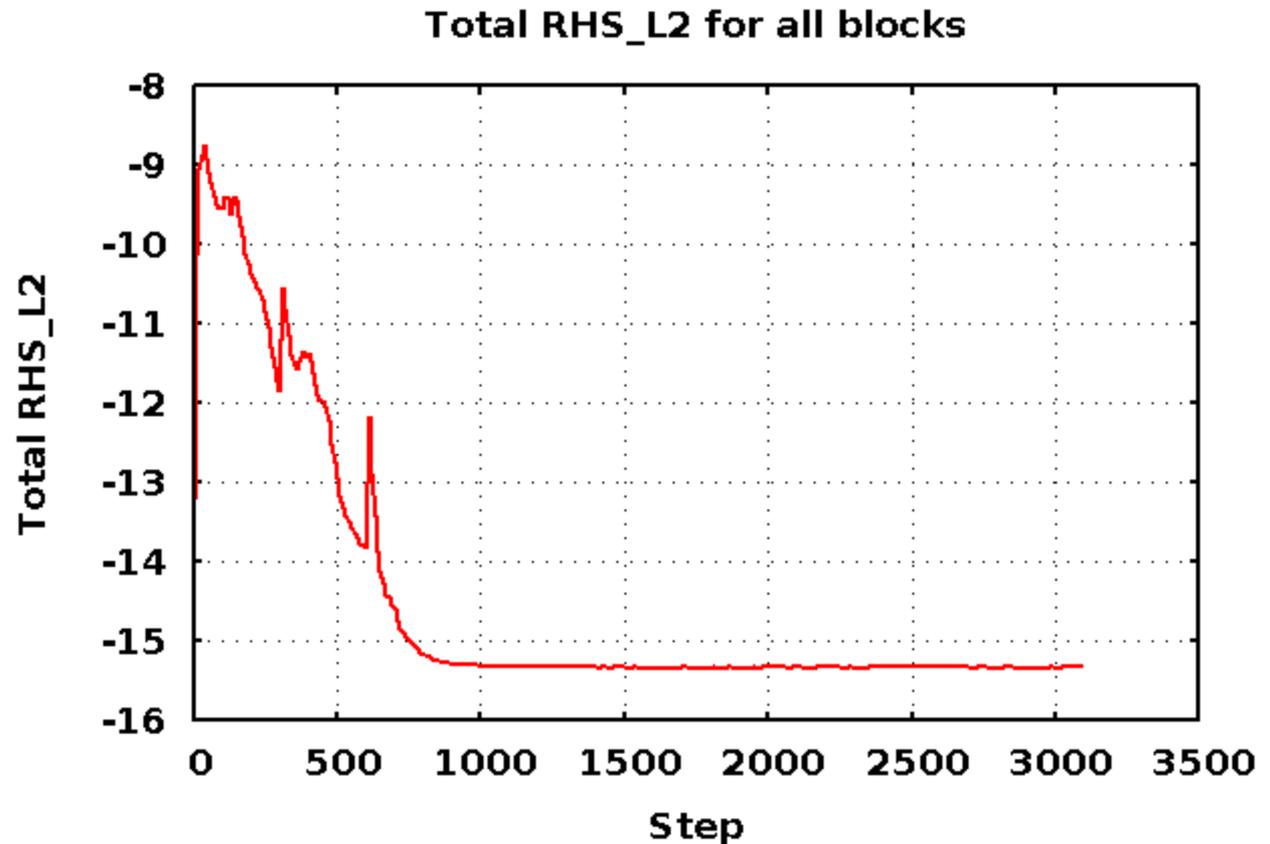
- **SEEB-ALR case run at Mach=1.6 Angle-of-Attack=0.0**
- **Overflow version 2.1x**
 - 2nd order central difference
 - ARC3D diagonalized Beam-Warming scalar pentadiagonal scheme
- **Grid**
 - Structured overset grid consisting of a near body block and an outer conical block
 - Body block 605x41x51
 - Tip streamwise spacing 0.01”
 - End of body spacing 0.08”
 - Wall spacing 0.001”
 - Cone 1505x129x129
 - Outer boundary at 75” radius
 - Total of 26.3 million cells
 - Grid lines swept at the Mach angle
- **Used 24 distributed memory processors**



SEEB-ALR OVERFLOW Solver Convergence

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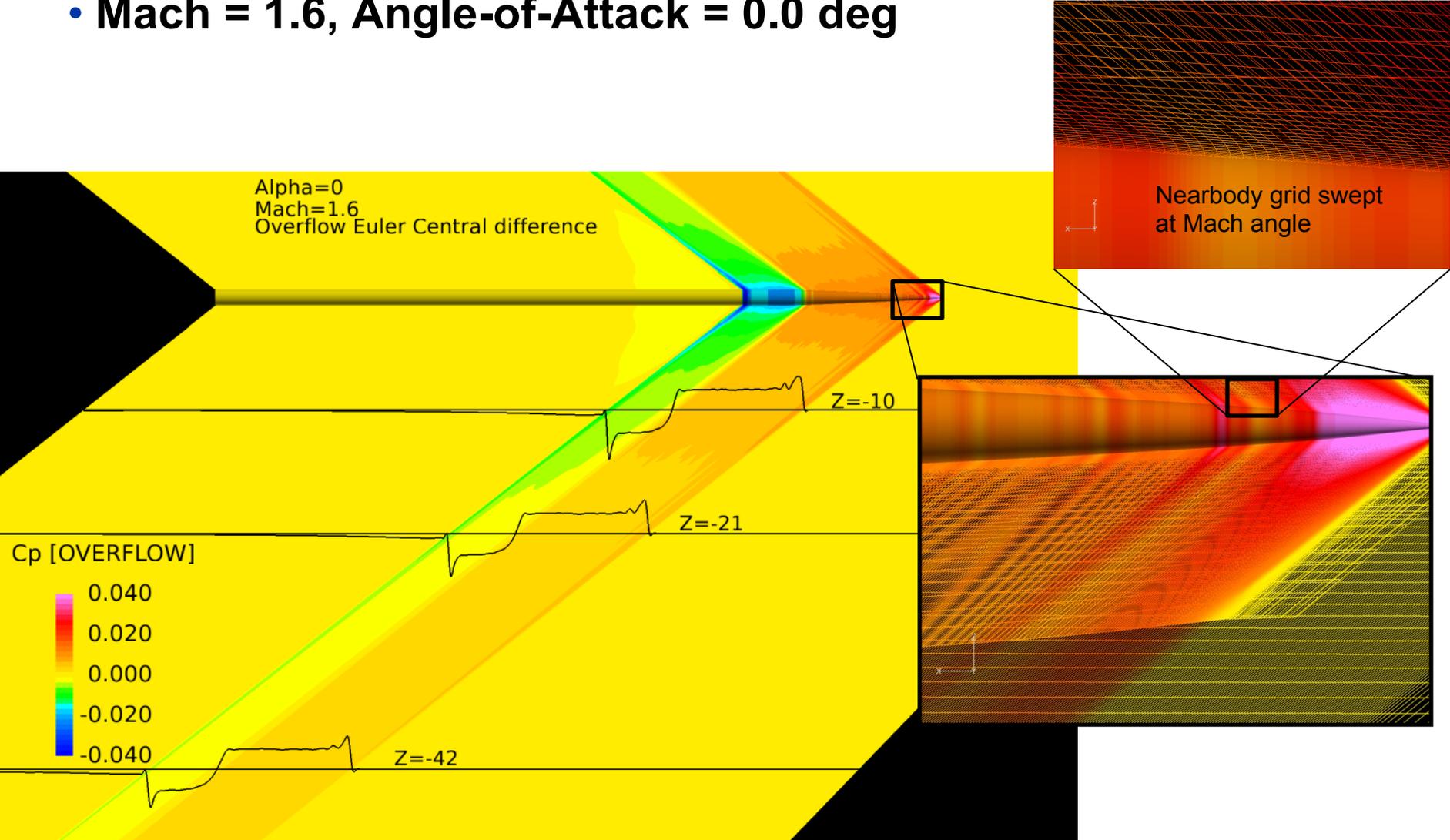
- **Ran a total of 3100 steps**
 - 300 coarse grid
 - 300 medium grid
 - 2500 fine grid



SEEB-ALR OVERFLOW Pressure Distribution

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- Mach = 1.6, Angle-of-Attack = 0.0 deg



69 Degree Delta Wing Using Cart3D

69-Degree Delta Wing Using Cart3D

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- **Grid**

- Unstructured surface meshes provided by the workshop
- Automated cartesian volume grid
 - Used fixed refinement regions and adaptation (maximum 50M cells)”
- Euler grid, rotated for shock alignment
- Geometry rotated for off-track cases on a full volume grid
- Geometry resolved to ~ 0.0001 [m] for each case

- **Flow solver**

- Cart3D CFD suite
- Finite-volume method
- Euler equations
- 4 levels of W-cycle multi-grid
- 5-stage Runge-Kutta, Van Leer flux function and limiter
- Flow solver stopped after residual drops 8 orders of magnitude or 300 iterations reached. Adjoint solver stopped after 350 iterations.

69-Degree Delta Wing Using Cart3D (Cont.)

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- **CFD Cases Run**

- Mach=1.7, Angle-of-attack = 0 deg, Fixed & Adapted Grids
 - H = 0.0127 [m], 0.53848 [m], 0.62992 [m], 0.80772 [m] @ Phi = 0.0 degrees
 - H = 0.62992 [m], Phi = 30.0, 60.0, and 90 degrees
 - H = 0.80772 [m], Phi = 30.0, 60.0, and 90 degrees

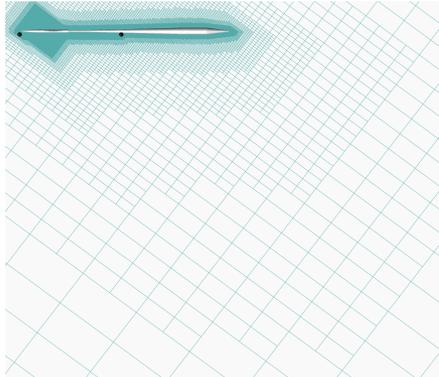
- **Computing Platform**

- Threaded parallel, single-node shared memory
- 16 processors

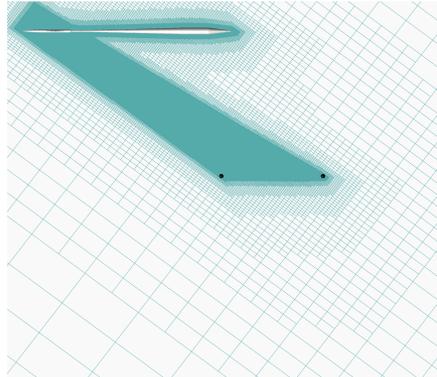
Symmetry Plane Grid (Phi = 0 degrees)

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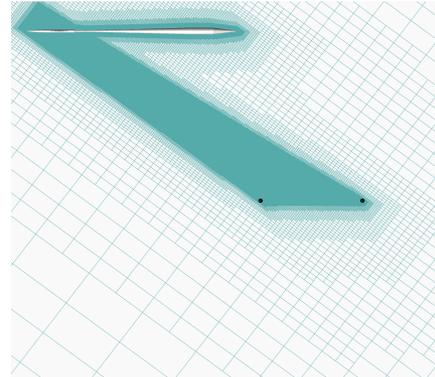
Fixed Grids



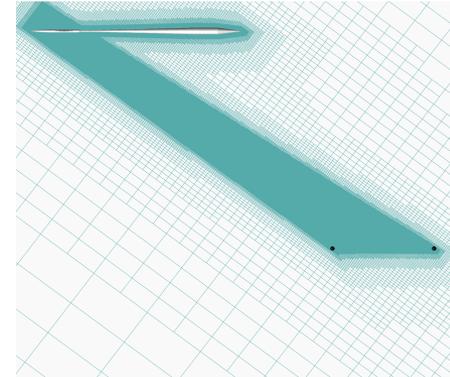
H=0.0127 m: 15,000,259 cells



H=0.53848 m: 56,925,628 cells

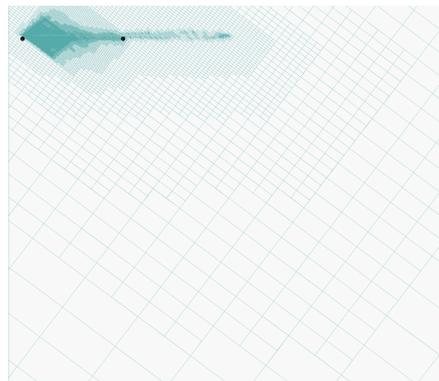


H=0.62992 m: 64,797,492 cells

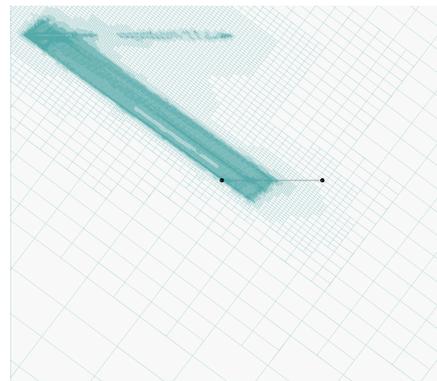


H=0.80772 m: 80,107,472 cells

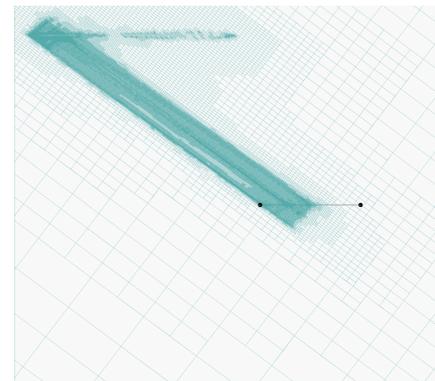
Adapted Grids (10 Adaption Cycles)



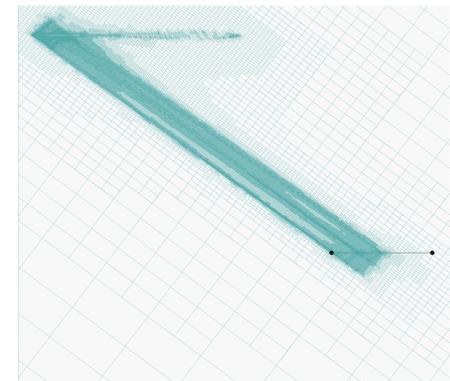
H=0.0127 m: 48,680,169 cells



H=0.53848 m: 48,957,219 cells



H=0.62992 m: 49,152,171 cells

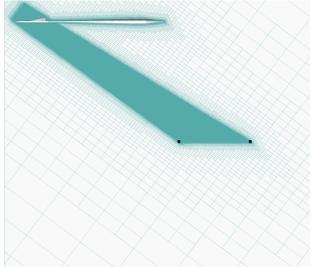


H=0.80772 m: 49,195,471 cells

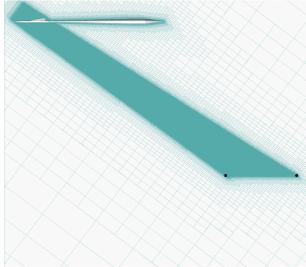
Symmetry Plane Grid (Phi = 30, 60, and 90 degrees)

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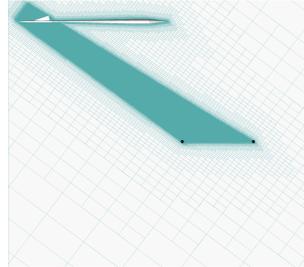
Fixed Grids



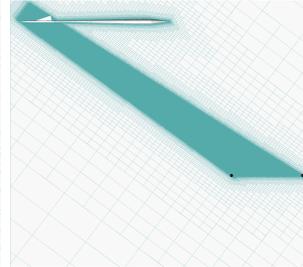
H = 0.62992 m
79,153,425 cells
Phi = 30 deg



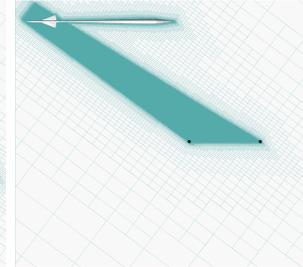
H = 0.80772 m
98,365,688 cells
Phi = 30 deg



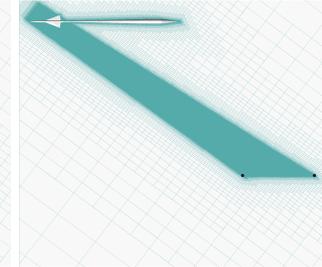
H = 0.62992 m
80,398,333 cells
Phi = 60 deg



H = 0.80772 m
99,612,689 cells
Phi = 60 deg

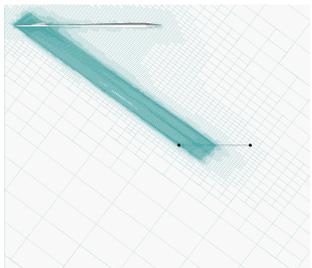


H = 0.62992 m
80,912,530 cells
Phi = 90 deg

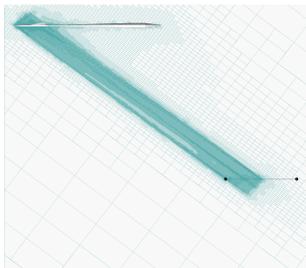


H = 0.80772 m
100,127,908 cells
Phi = 90 deg

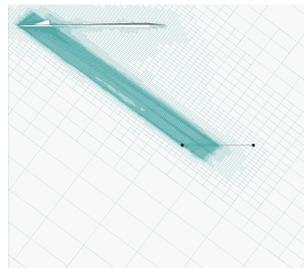
Adapted Grids (9 Adaption Cycles)



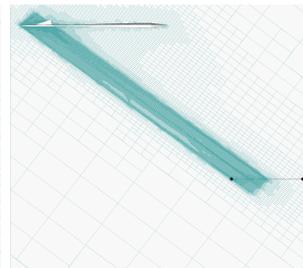
H = 0.62992 m
48,805,435 cells
Phi = 30 deg



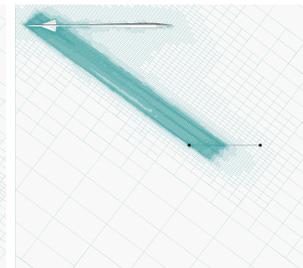
H = 0.80772 m
49,169,775 cells
Phi = 30 deg



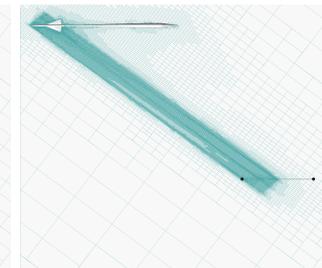
H = 0.62992 m
48,949,188 cells
Phi = 60 deg



H = 0.80772 m
48,931,605 cells
Phi = 60 deg



H = 0.62992 m
49,000,703 cells
Phi = 90 deg

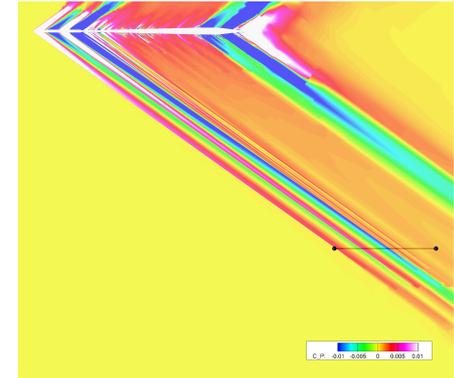
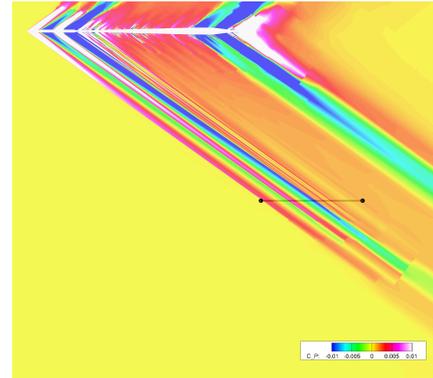
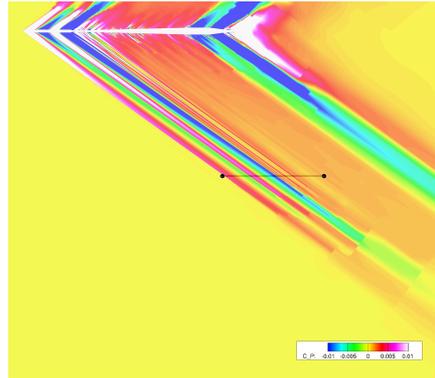
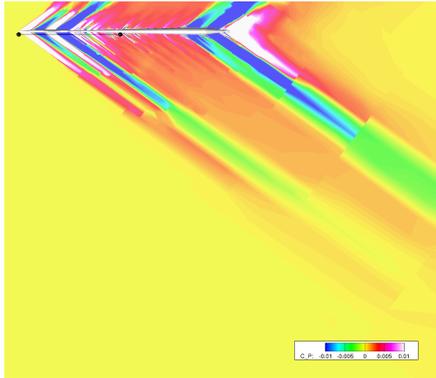


H = 0.80772 m
48,818,673 cells
Phi = 90 deg

Symmetry Plane Pressure Distribution (Phi = 0 degrees)

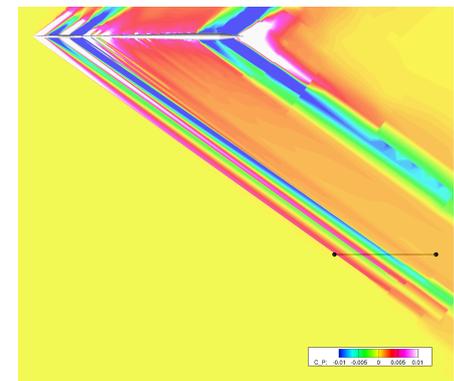
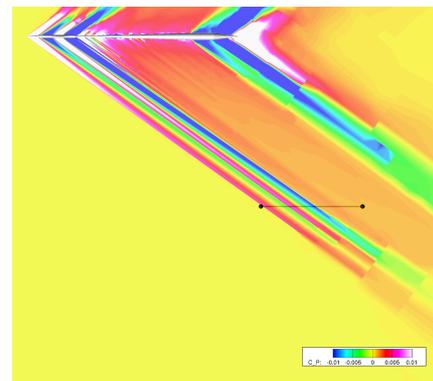
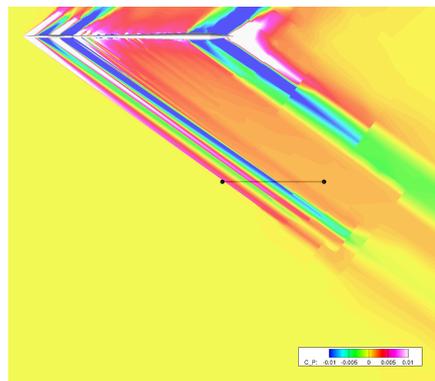
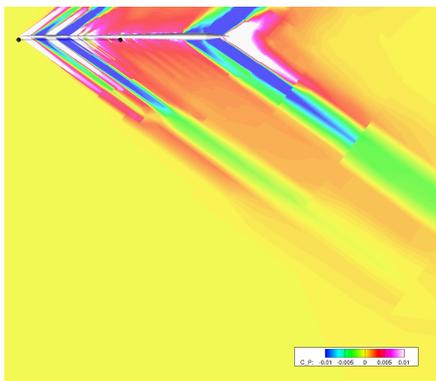
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Fixed Grids



H=0.0127 m: 15,000,259 cells H=0.53848 m: 56,925,628 cells H=0.62992 m: 64,797,492 cells H=0.80772 m: 80,107,472 cells

Adapted Grids (10 Adaption Cycles)

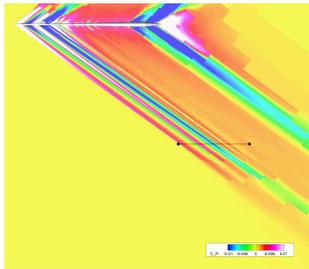


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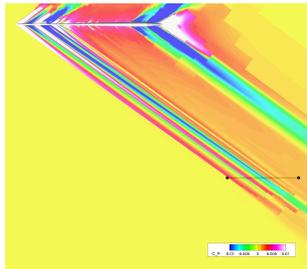
Symmetry Plane Pressure Distribution (Phi = 30, 60, 90 degrees)

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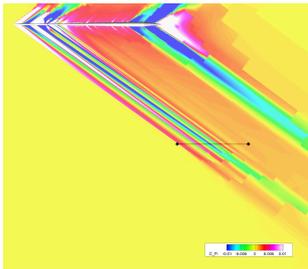
Fixed Grids



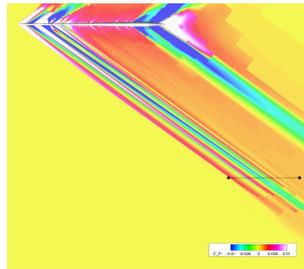
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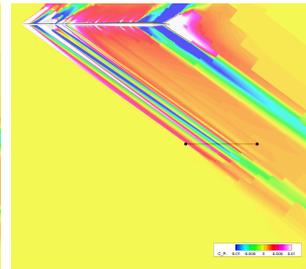
H = 0.80772 m
98,365,688 cells
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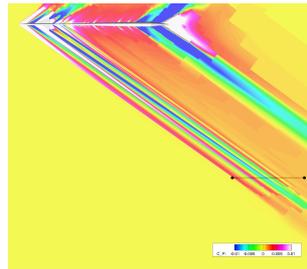
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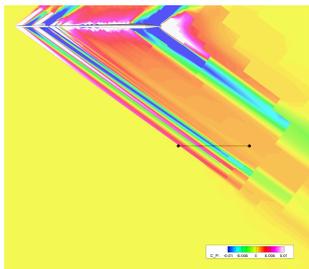


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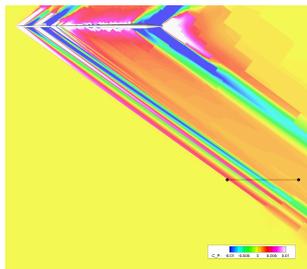


H = 0.80772 m
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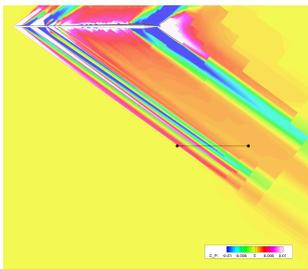
Adapted Grids (9 Adaption Cycles)



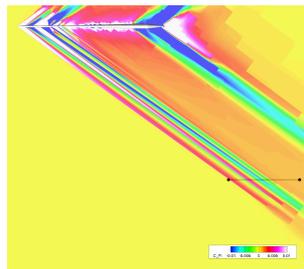
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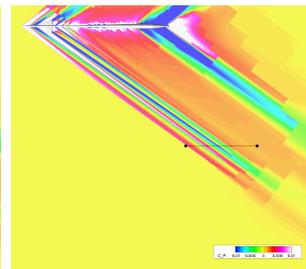
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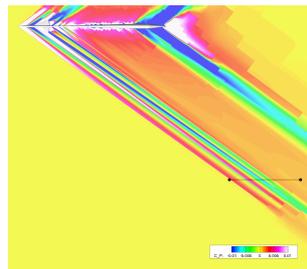
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69 Degree Delta Wing Using CFD++

69-Degree Delta Wing Using CFD++

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- **Flow solver**

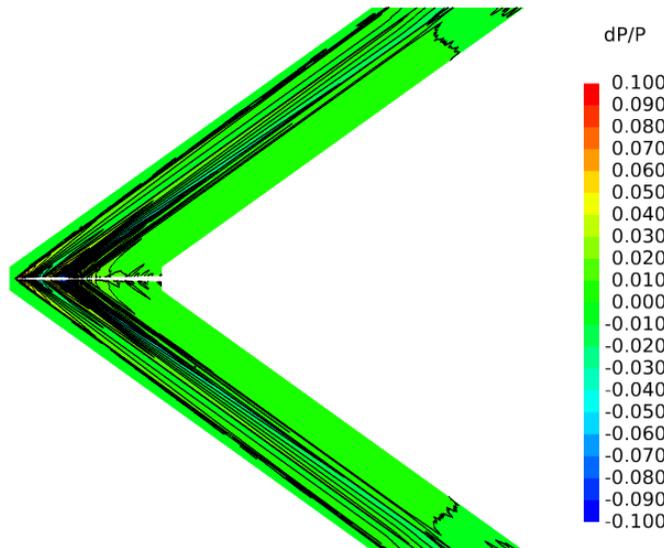
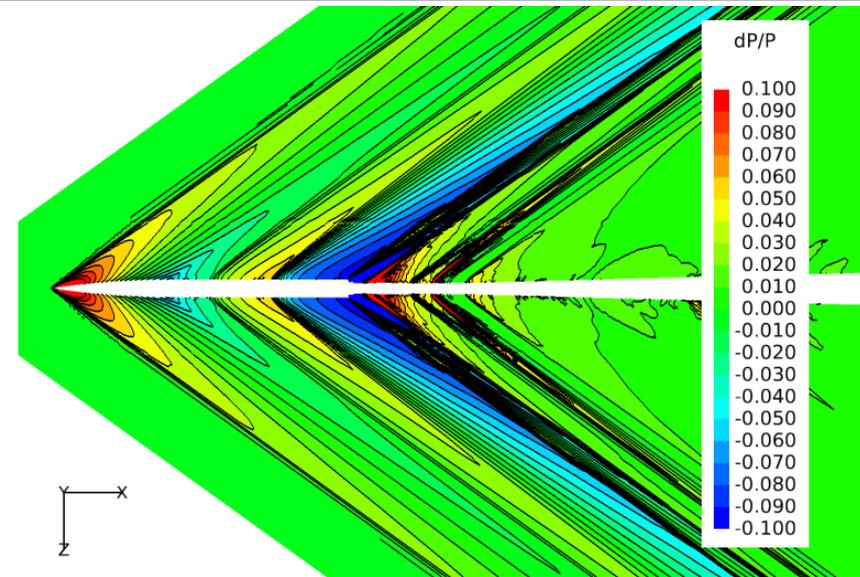
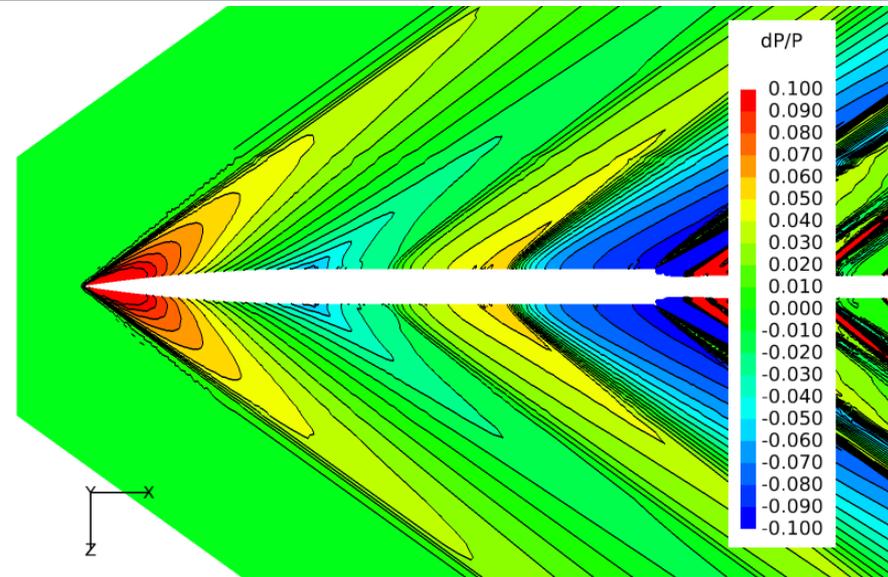
- CFD++
- Finite-volume method
- Euler equations
- Default settings for all

- **Grid**

- Unstructured volume meshes provided by the workshop
- Euler grid
- delta-split-tet-000a-170m-100s.b8.ugrid

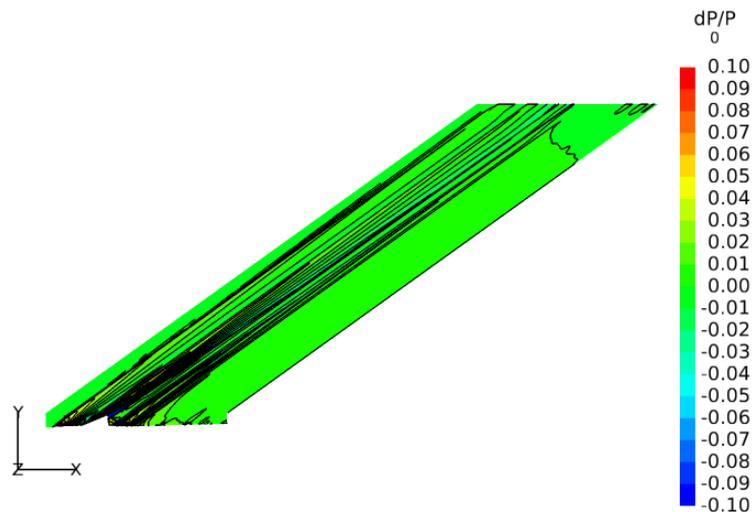
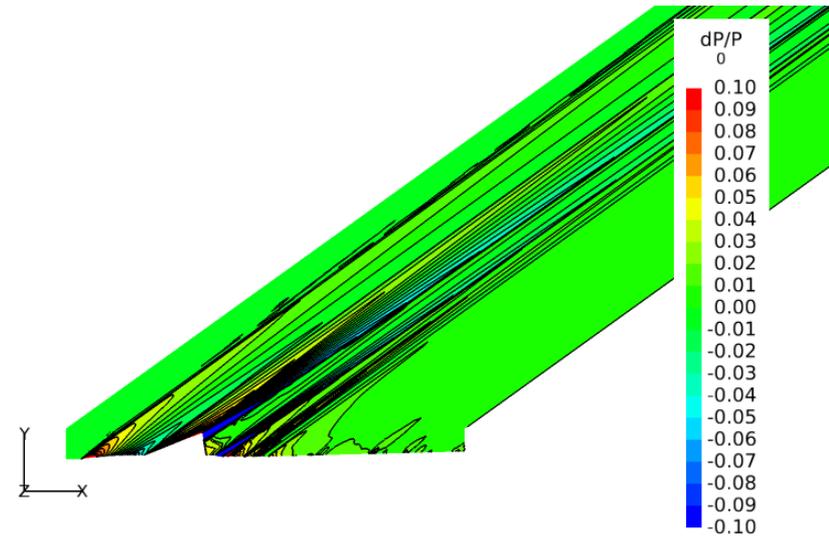
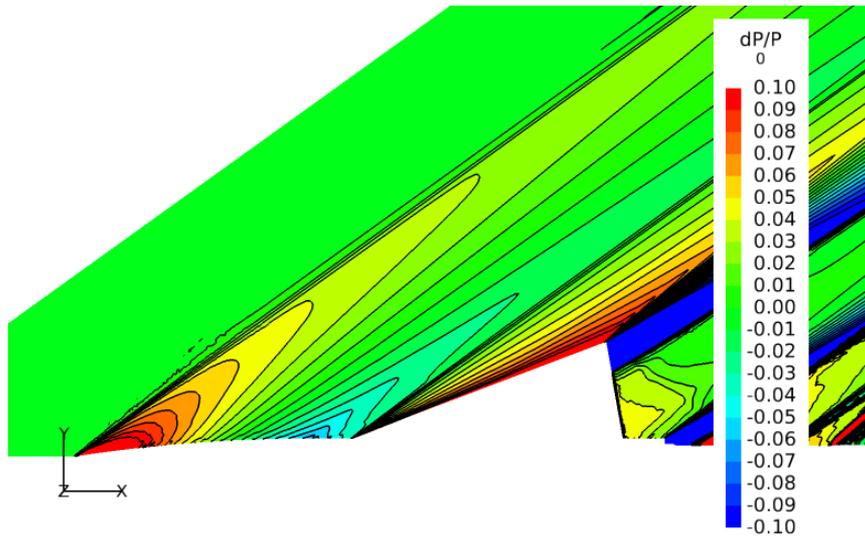
CFD++ Pressure Distribution - Side View

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CFD++ Pressure Distribution - Top View

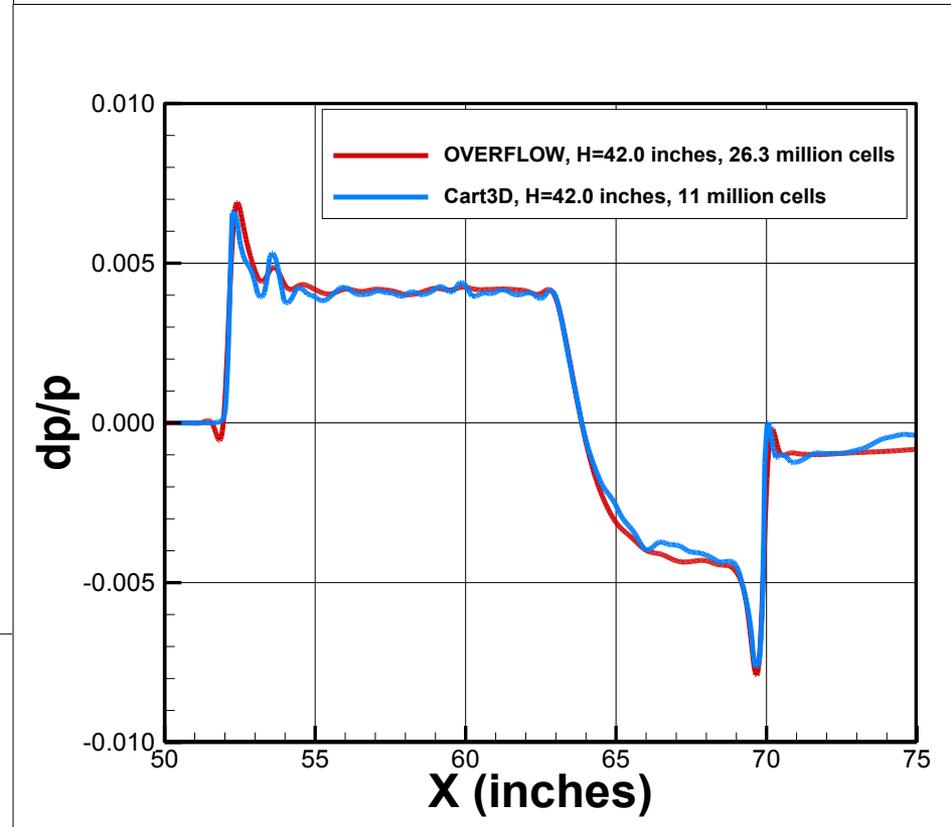
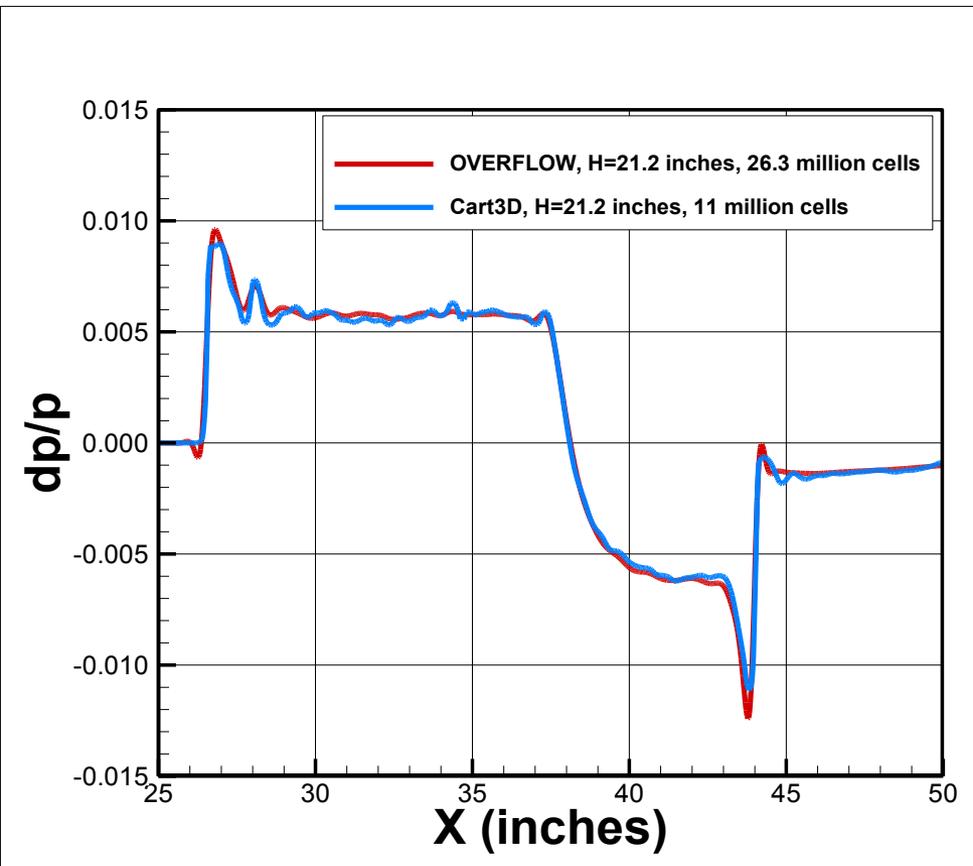
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Results & Comparisons

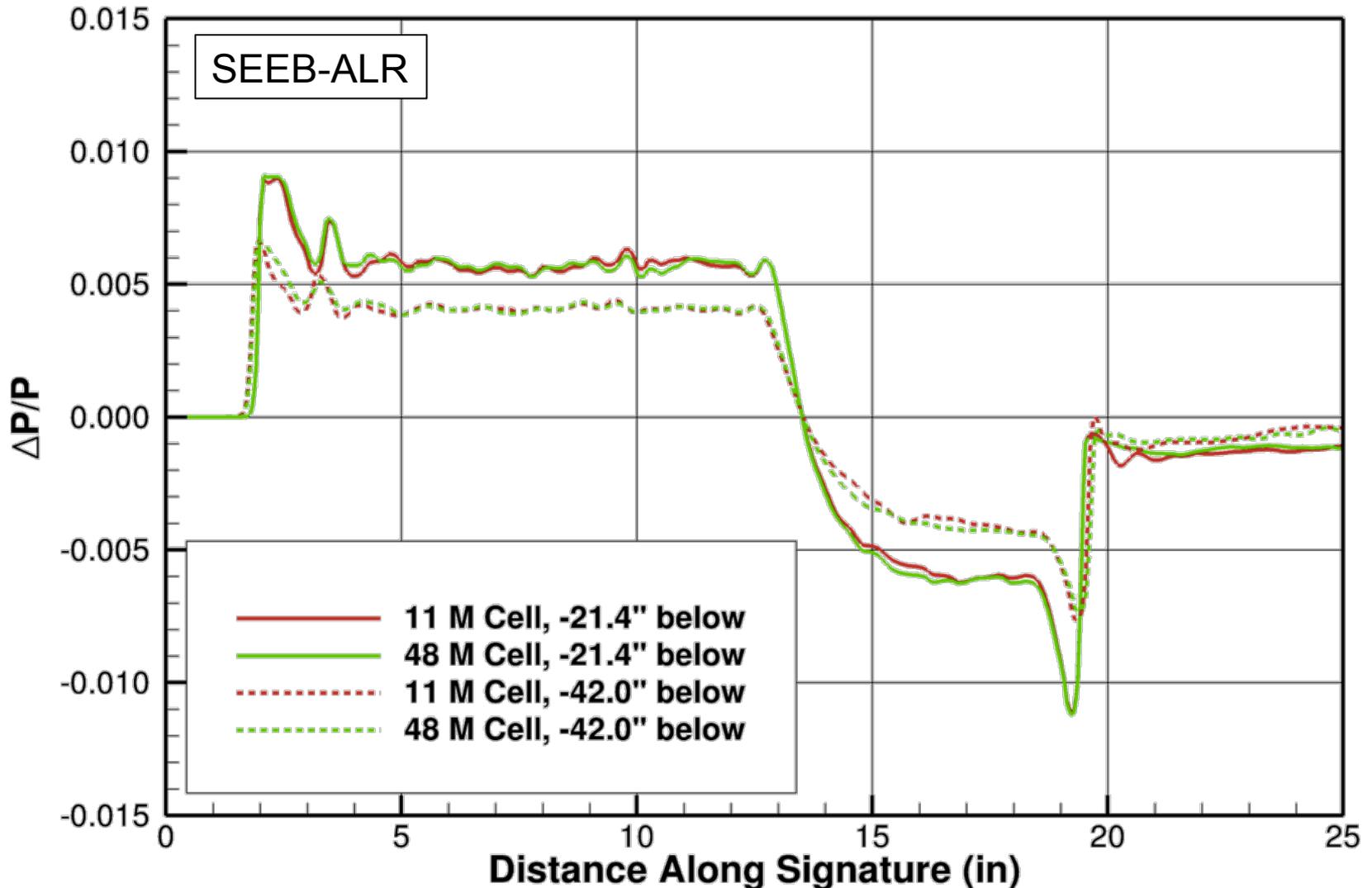
SEEB-ALR Results

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Cart3D Grid Refinement Shows Similar Results Between Small and Large Grids

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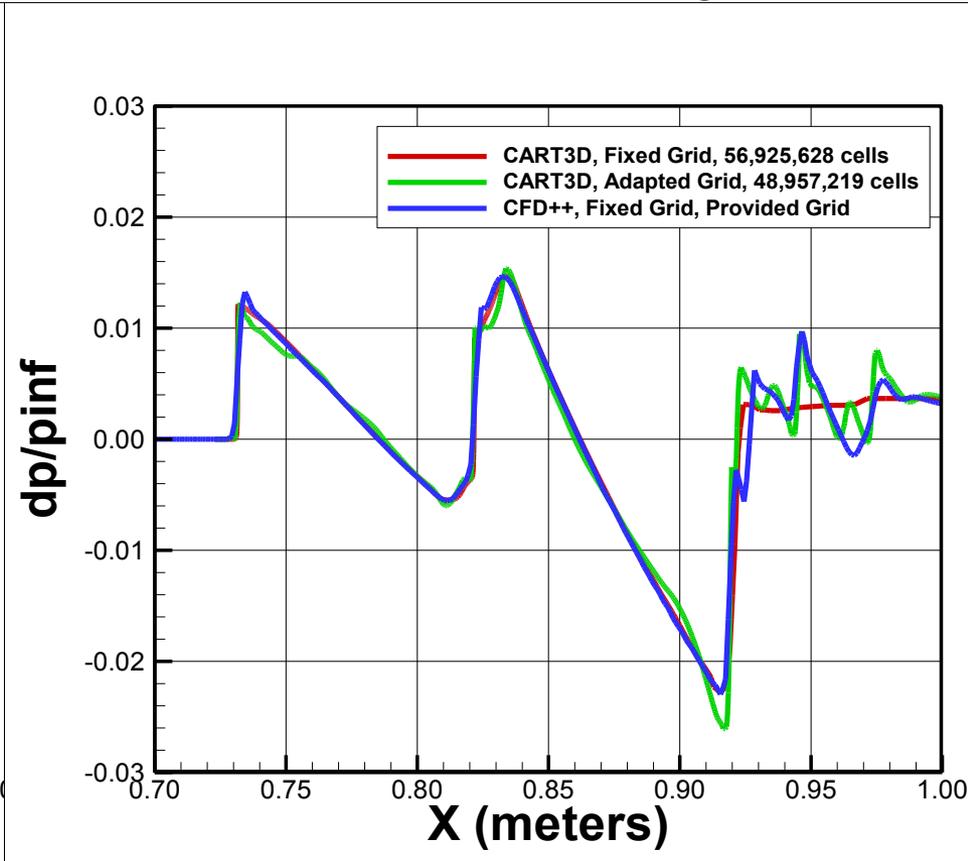
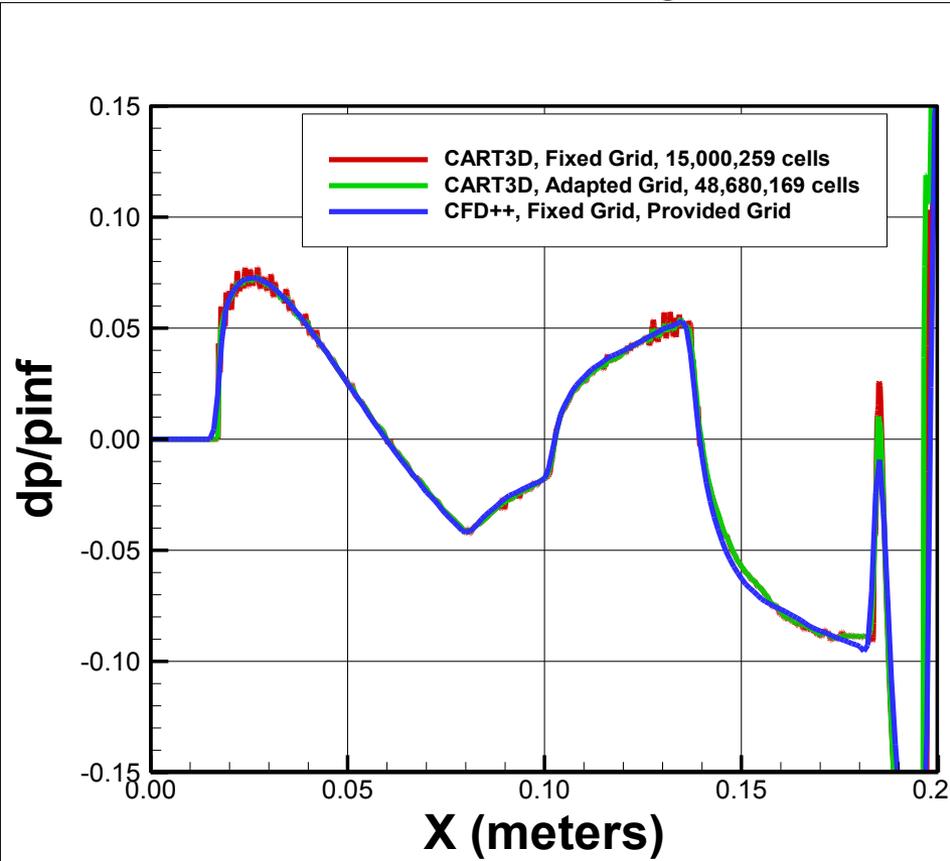


69-Degree Delta Wing Results

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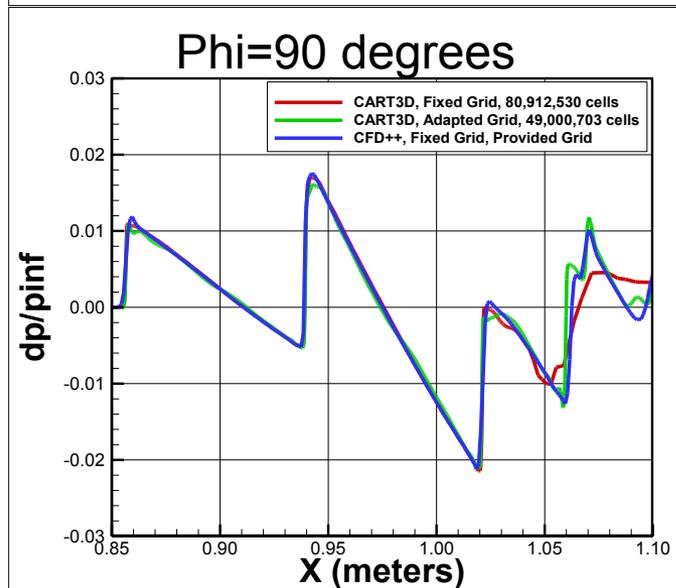
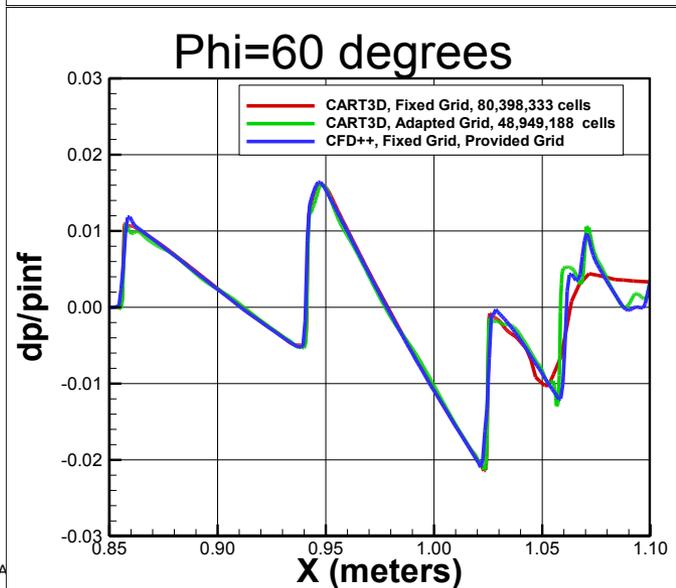
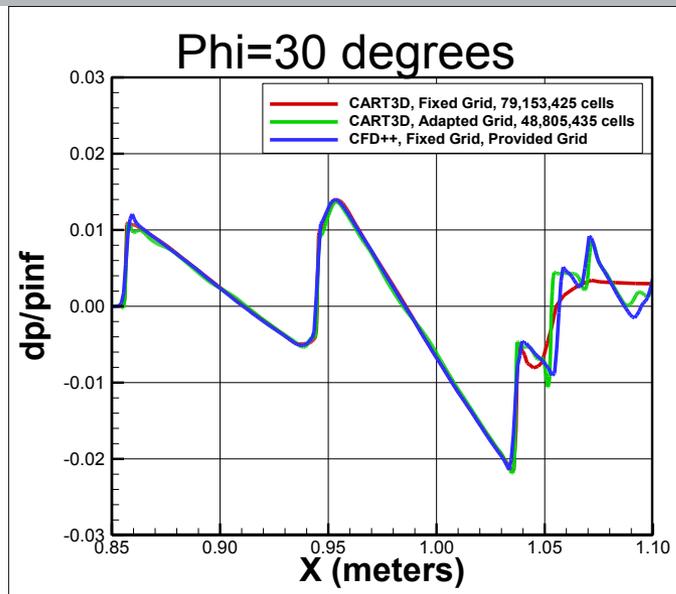
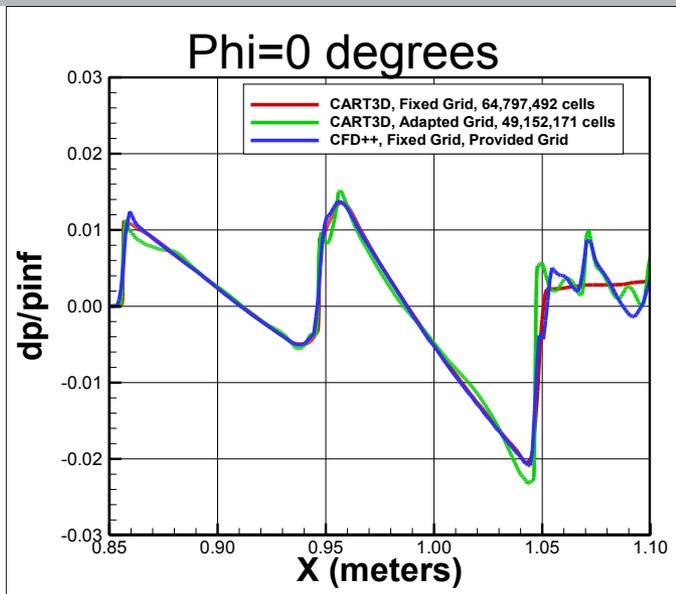
H=0.0127 m, Phi=0 degrees

H=0.53848 m, Phi=0 degrees



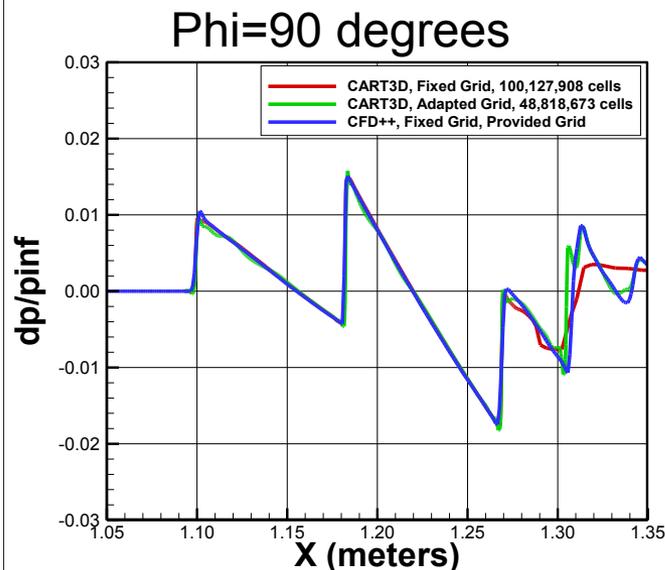
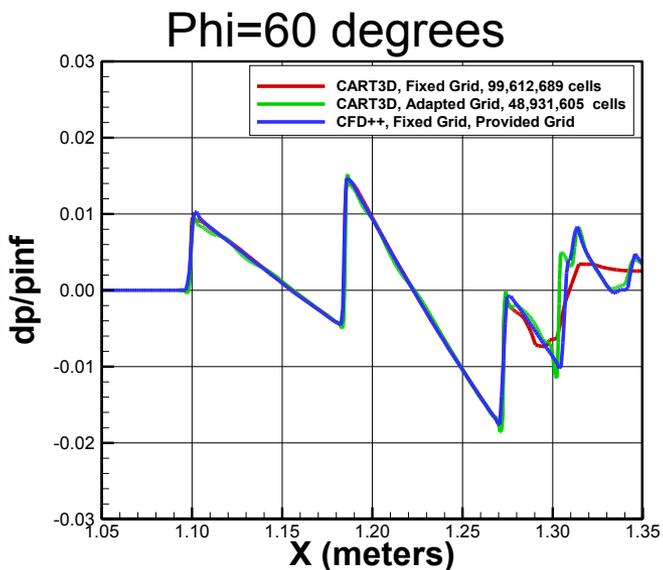
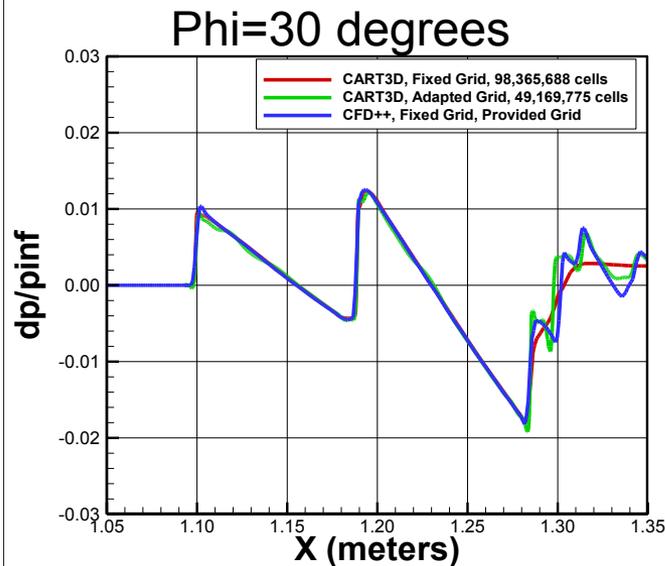
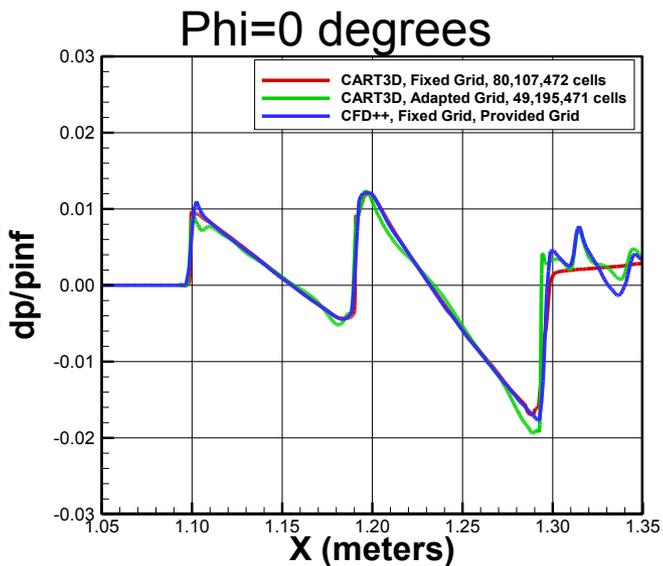
69-Degree Delta Wing Results (H=0.62992 m)

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69-Degree Delta Wing Results (H=0.80772 m)

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Summary / Conclusions

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- **All methods give very similar near-field results**
 - SEEB-ALR
 - OVERFLOW results agree well with Cart3D results
 - Neither grid was adapted or optimized
 - Cart3D gets similar results using either the 11 million or 48 million cell grids
 - OVERFLOW central difference scheme generates typical “Under/over shoot” behavior for shocks, but seems to provide superior shock propagation (less dissipative) compared to upwind scheme
 - OVERFLOW results have less variation in the flat portion of the SEEB-ALR signature
 - Could be a function of surface grid noise in the unstructured grid
 - 69-degree Delta Wing
 - Cart3D agrees well CFD++
 - Generally small differences in results between Cart3D fixed grids and adapted grids
 - Adapted grids are much smaller than fixed grids
 - Front part of adapted grid signature does not agree as well as the fixed grid does with the CFD++ solution.
 - Adapted grid could benefit from “tuning” which may result in a better match with the other results
- **Aligning grid with shock provides improved results**

