UNIVERSITY OF WYOMING

AIAA

NSU3D Results for the First AIAA High Lift Prediction Workshop

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Presentation Outline

- NSU3D Flow Solver Overview
- Solution Convergence
- Grid Systems
- Case 1 - Grid Convergence
- Case 2 - Alpha Sweep - Config 1
- Case 2 – Effects of Flap Angle - Config 8
- Flow Details
- Conclusion

NSU3D Flow Solver

Unstructured Reynolds Averaged Navier-Stokes solver

- Vertex-based discretization
- Mixed elements (prisms in boundary layer)
- Edge data structure
- Matrix artificial dissipation
  - Option for Roe upwind scheme with gradient reconstruction
- No cross derivative viscous terms
  - Thin layer in all 3 directions
  - Option for full Navier-Stokes terms
- Turbulence Models
  - Spalart-Allmaras (original published form)
  - Shear Stress Transport
  - k-ω two equation model

NSU3D Flow Solver

- Jacobi/Line Preconditioning
  - Line solves in boundary layer regions
  - Relieves aspect ratio stiffness
- Agglomeration Multigrid
  - Fast grid independent convergence rates
- Parallel implementation
  - MPI/OpenMP hybrid model
    - HLPW runs all MPI only on:
    - NASA Pleiades (Quad core Intel Xeon)
    - UWYO Cluster (Dual core AMD Operon)

Typical Resource Requirements

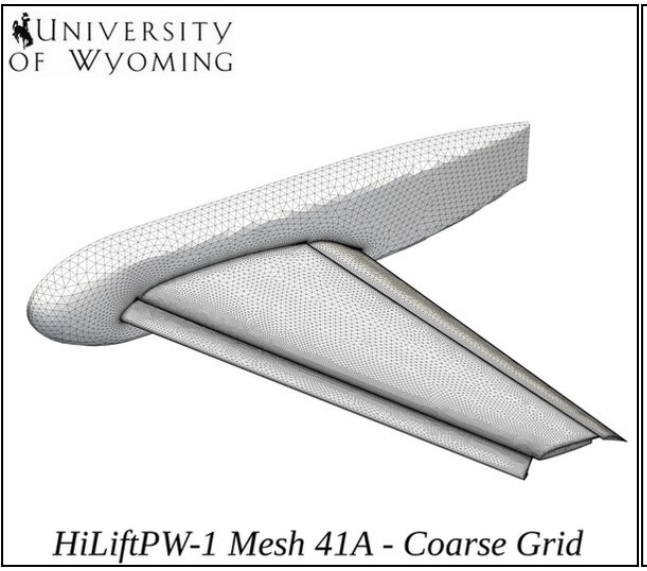
- Medium (10Mpts) grids used 64 cpus
  - 1000 multigrid cycles
- NASA Pleiades Supercomputer
  - SGI ICE with 51,200 Intel Harpertown Xeon Cores
  - ~1.5 hours for final solution
  - ~60GB memory allocated
- High alpha cases often require more iterations

Grid Systems

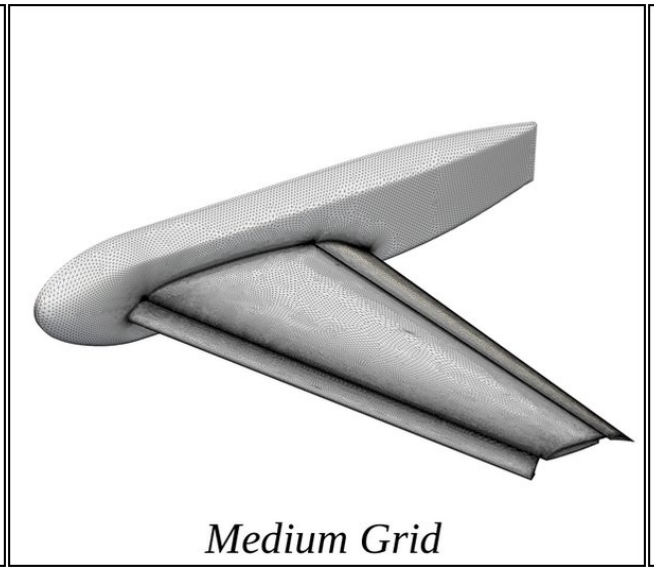
All cases used the UWYO contributed grids:

- Config 1 - Coarse
  - 3.64 Million Nodes
  - 1st BL Cell Height : 0.00019”
  - BL Growth Rate : 0.15
- Config 1 - Medium
  - 10.96 Million Nodes
  - 1st BL Cell Height : 0.00013”
  - BL Growth Rate : 0.15
- Config 1 - Fine
  - 32.30 Million Nodes
  - 1st BL Cell Height : 0.00009
  - BL Growth Rate : 0.15
- Config 8 - Medium
  - 11.52 Million Nodes
  - 1st BL Cell Height : 0.00013”
  - BL Growth Rate : 0.15

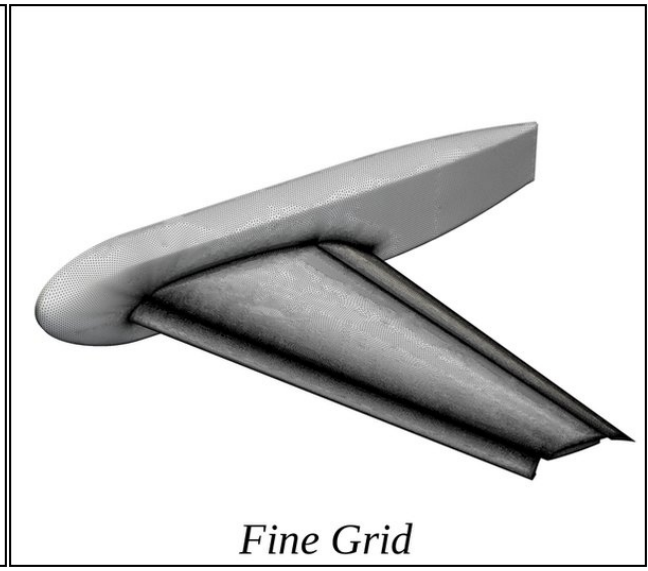
Grid Systems



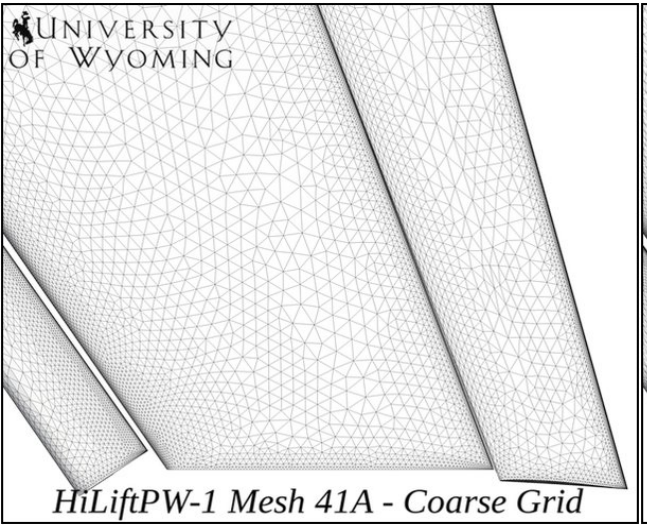
HiLiftPW-1 Mesh 41A - Coarse Grid



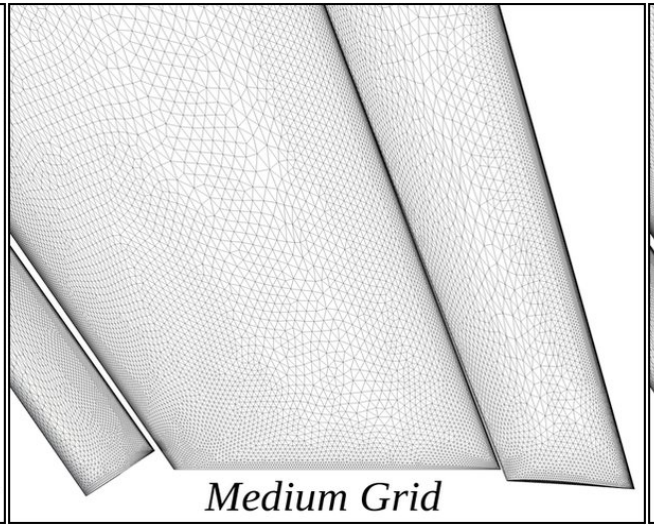
Medium Grid



Fine Grid



HiLiftPW-1 Mesh 41A - Coarse Grid



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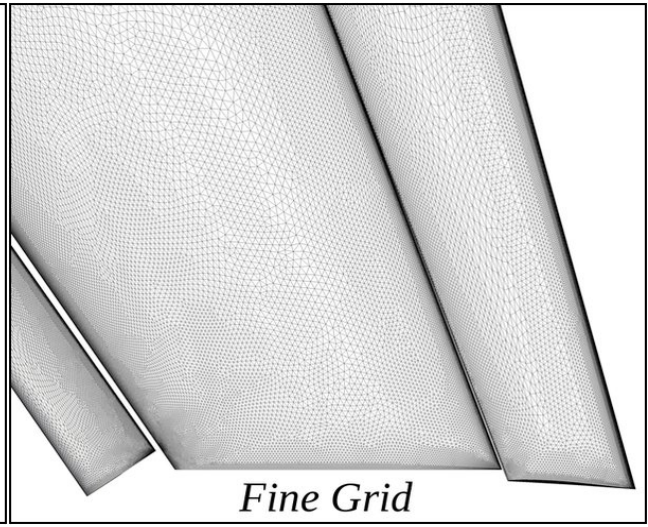
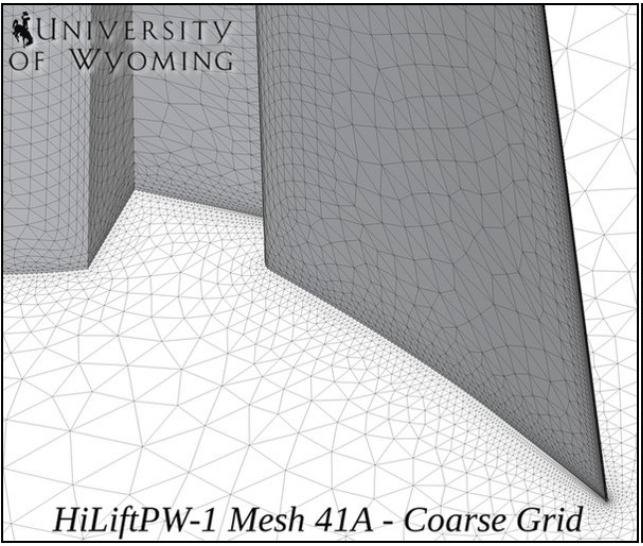
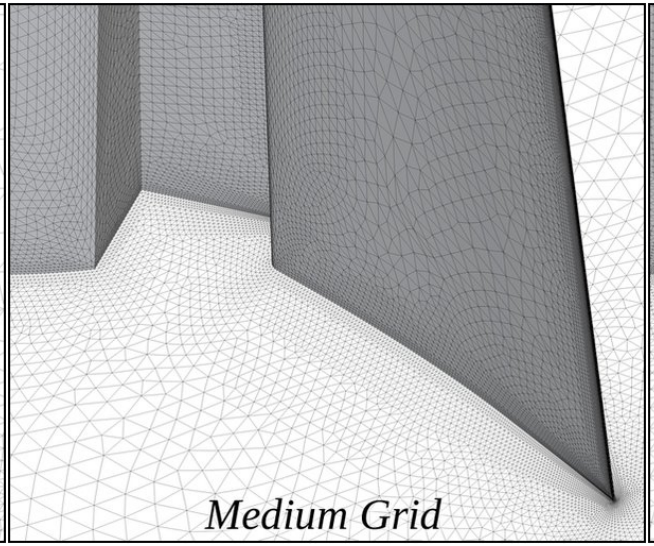
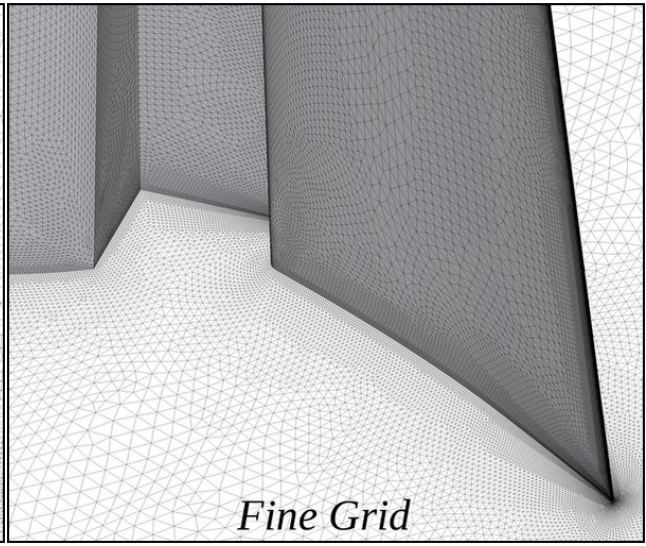


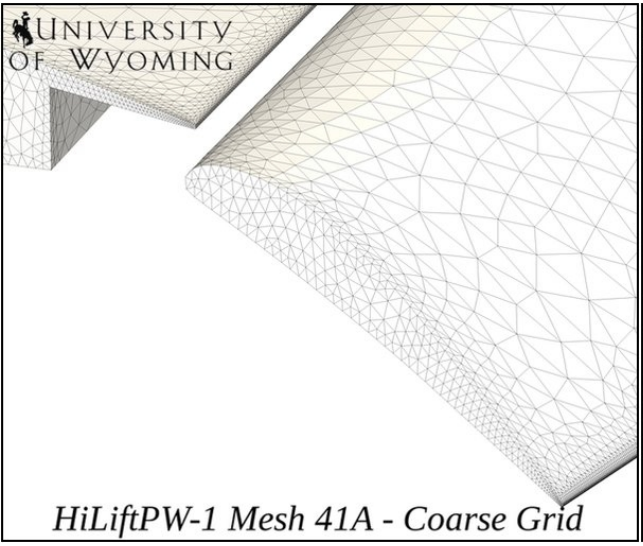
Fine Grid

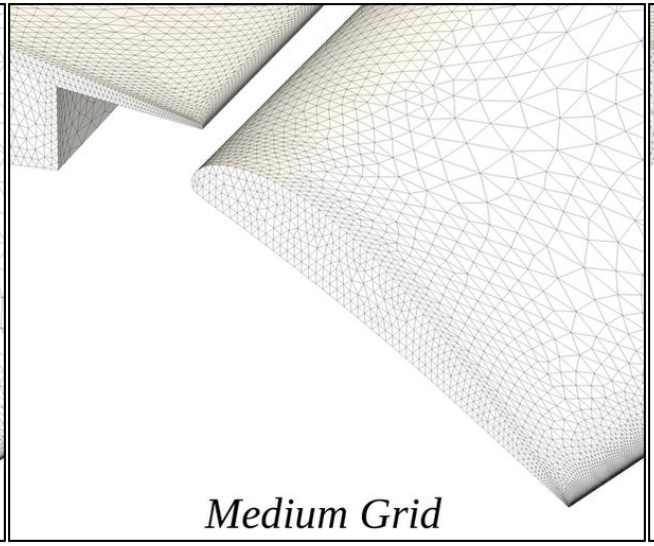
Grid Systems

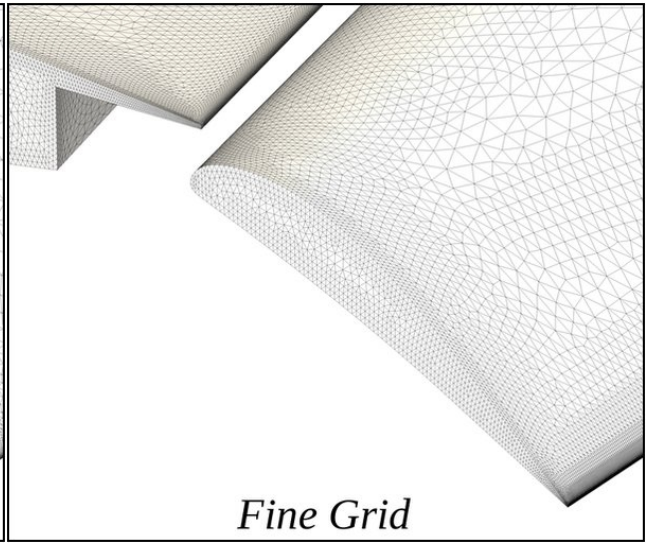




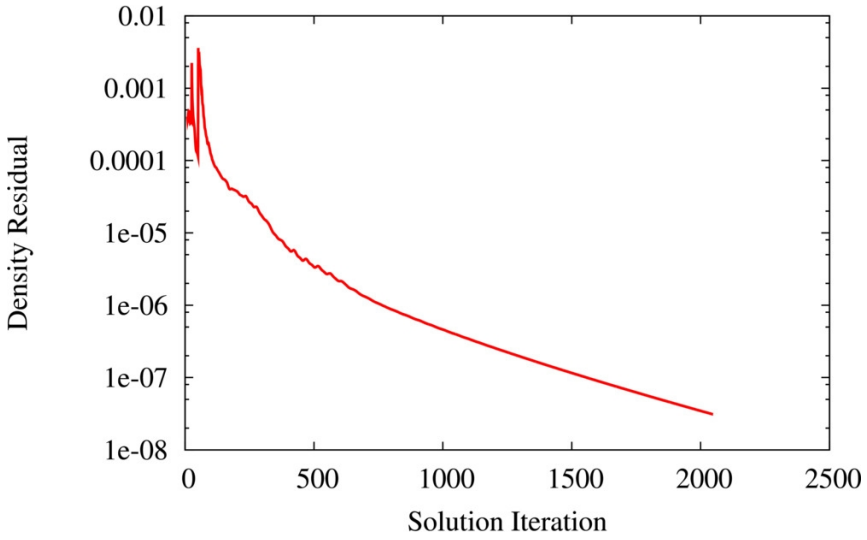


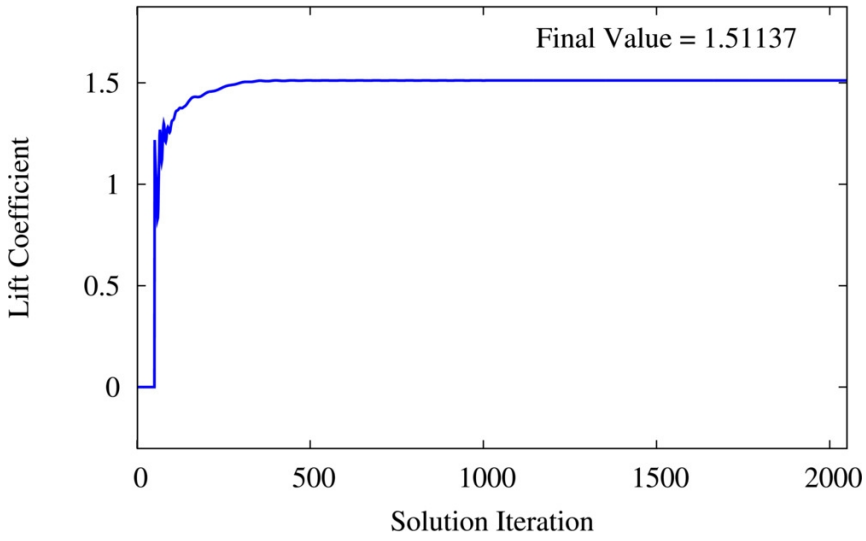






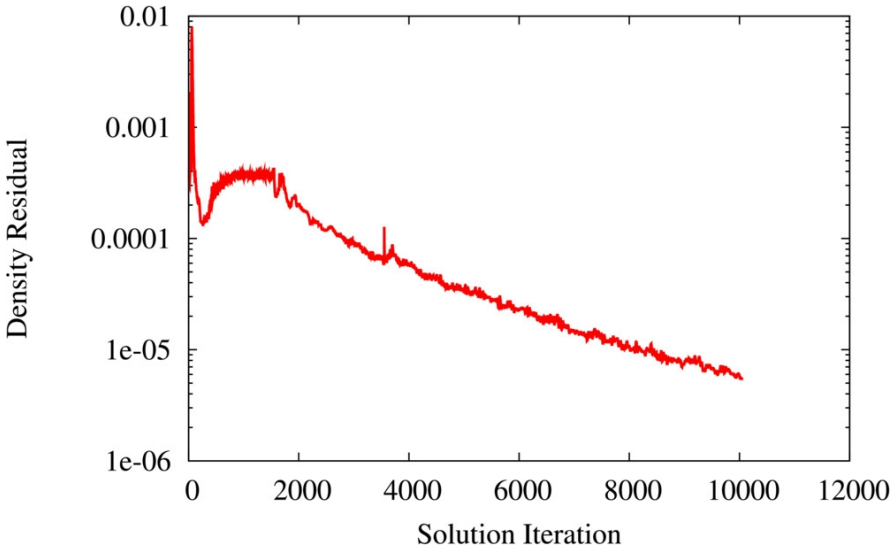
Solution Convergence

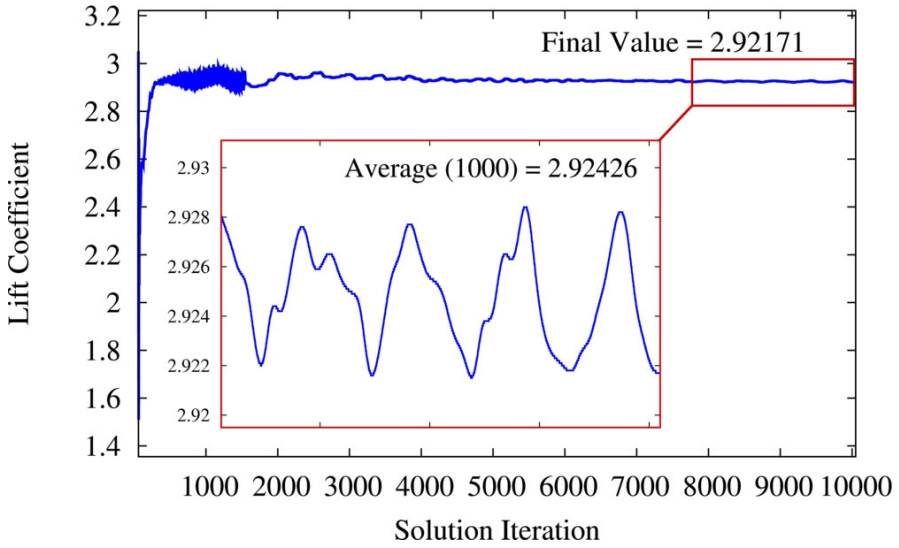




- Effective multigrid convergence for linear CL-alpha range cases (4 level W-cycle)

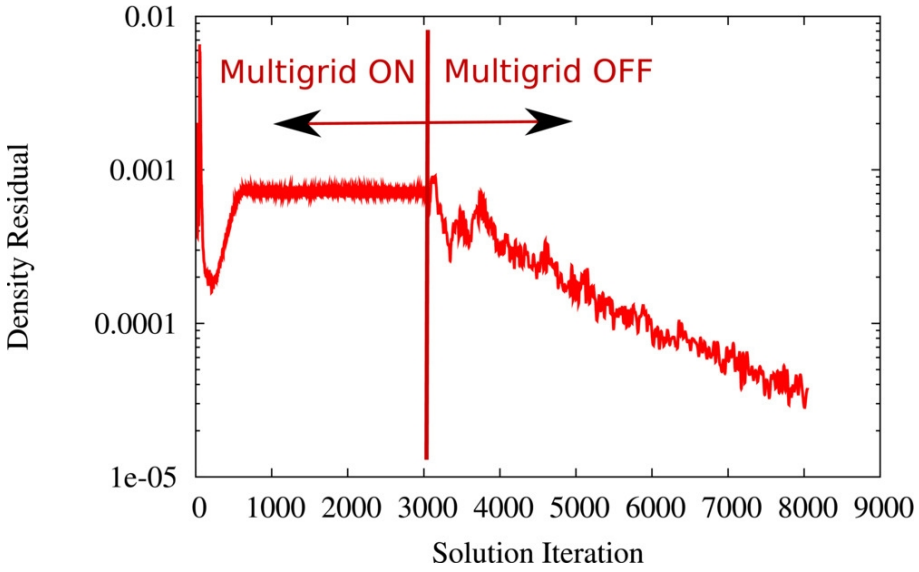
Solution Convergence (cont.)

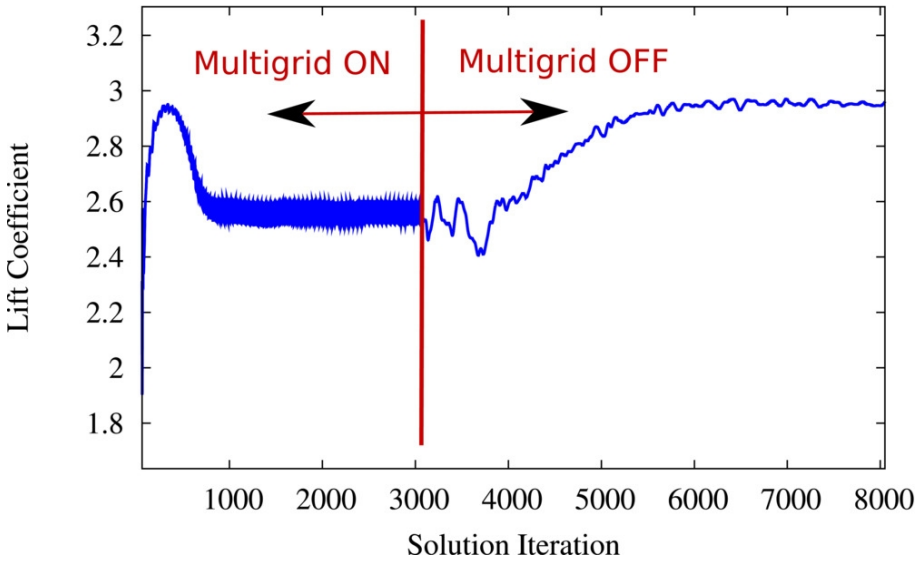




- Residuals stall for higher alpha cases
- Residual convergence resumes switching to single grid
  - Forces converge with small oscillations

Solution Convergence



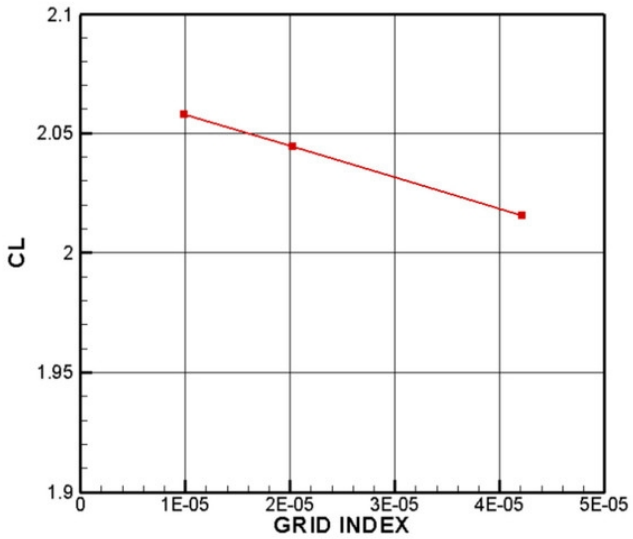


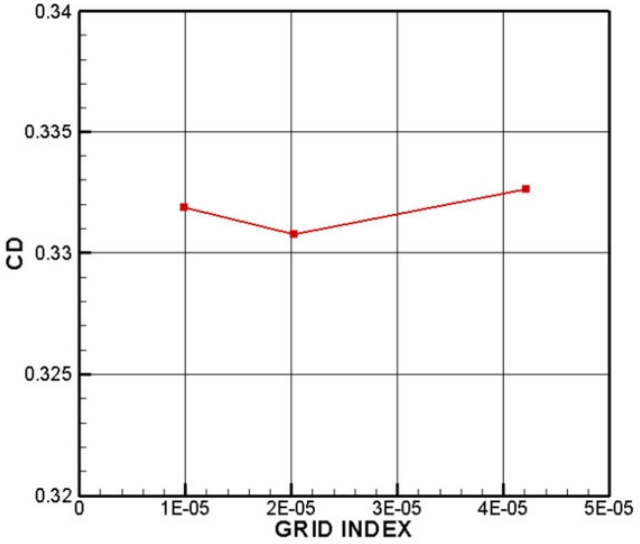
- Configuration 8, 28° and above
- Different result with and without multigrid
  - Similar behavior seen by other workshop participants

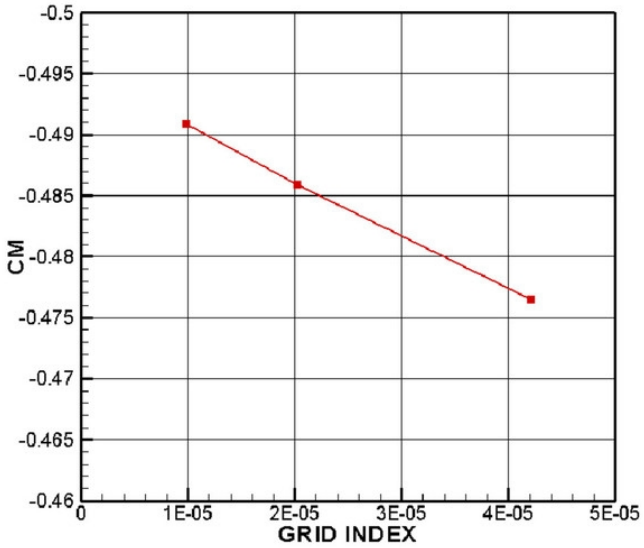
Test Case Summary

- **Test Case 1 – Grid Convergence Study**
  - Trap Wing “Config 1” (Slat 30, Flap 25)
  - Mach = 0.2, α = 13°, 28°
  - Re = 4.3M (based on MAC)
  - Tinf = 520°R
  - Coarse, Medium, Fine grids
- **Test Case 2 – Alpha Sweep, Flap Increments**
  - Trap Wing “Config 1” (Slat 30, Flap 25)
  - Trap Wing “Config 8” (Slat 30, Flap 20)
  - Mach = 0.2, α = 6°, 13°, 21°, 28°, 32°, 34°, 37°
  - Medium Grid
- **Optional Cases Not Completed**
  - Extra-Fine Grid
  - Slat/Flap Support Brackets

Grid Convergence

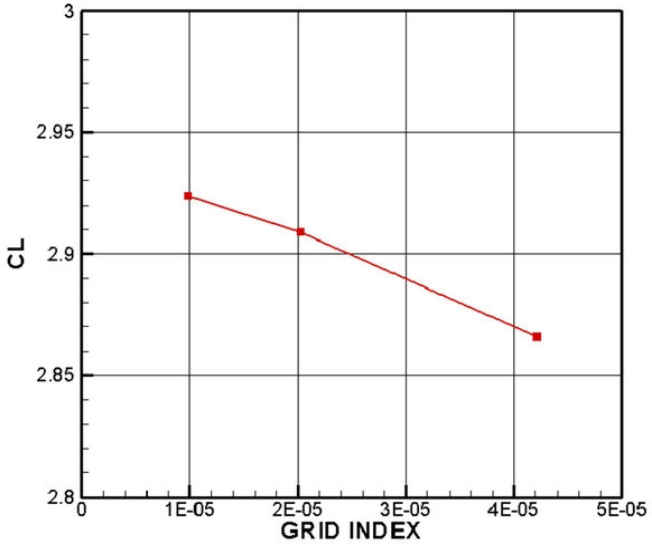


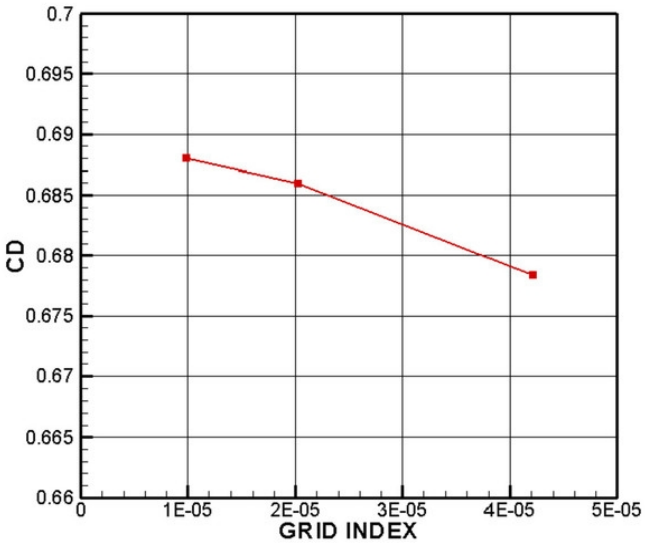


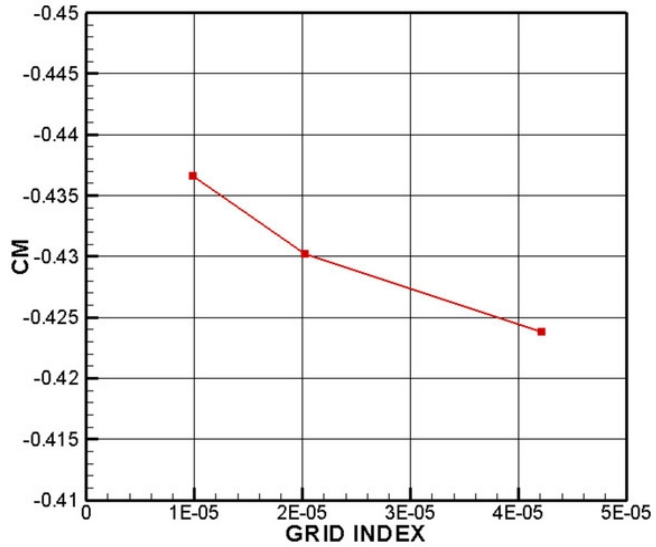


- Configuration 1, 13°
- Linear convergence seen for lift and moment
- Lift variation ~ 2.1%
- Drag variation ~ 0.5%
- Moment variation ~ 3.0%

Grid Convergence





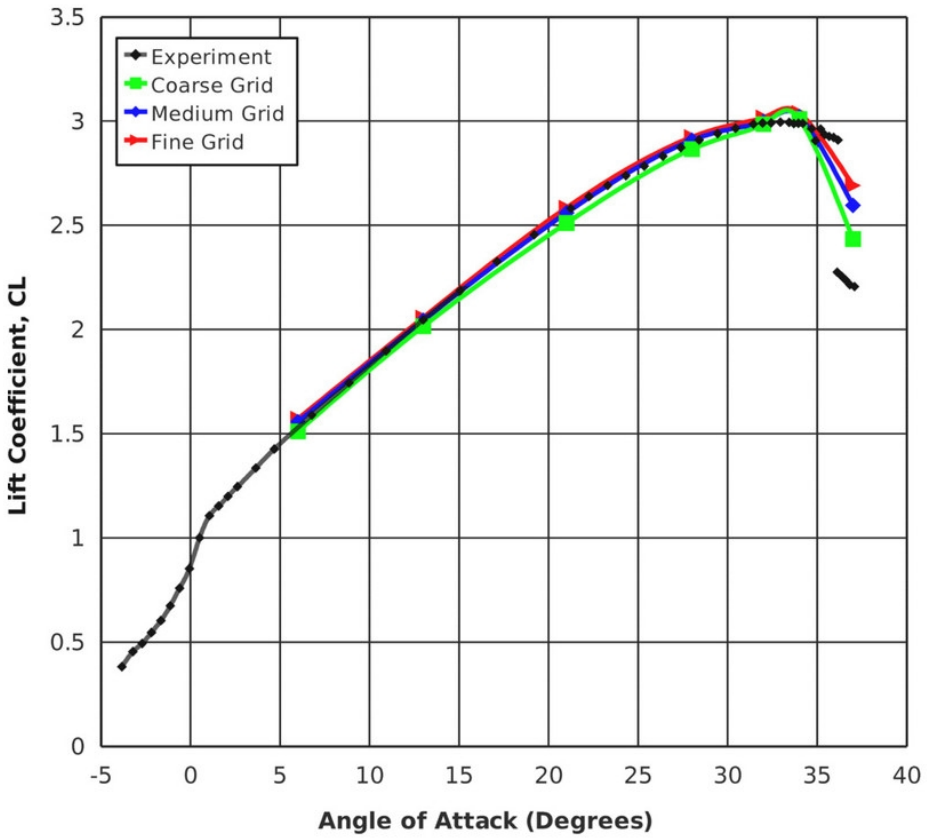


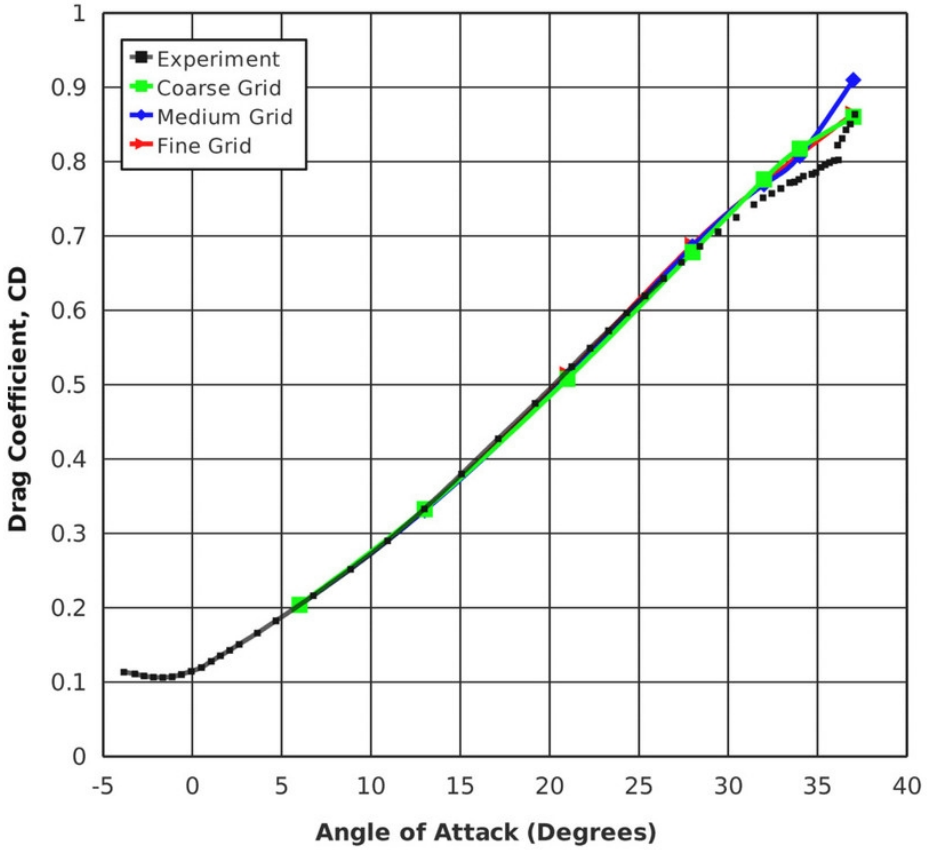
- Configuration 1, 28°
- Less linear behavior than 13° case – finer grid needed
- Lift variation ~ 2.0%
- Drag variation ~ 1.4%
- Moment variation ~ 3.0%

Alpha Sweep

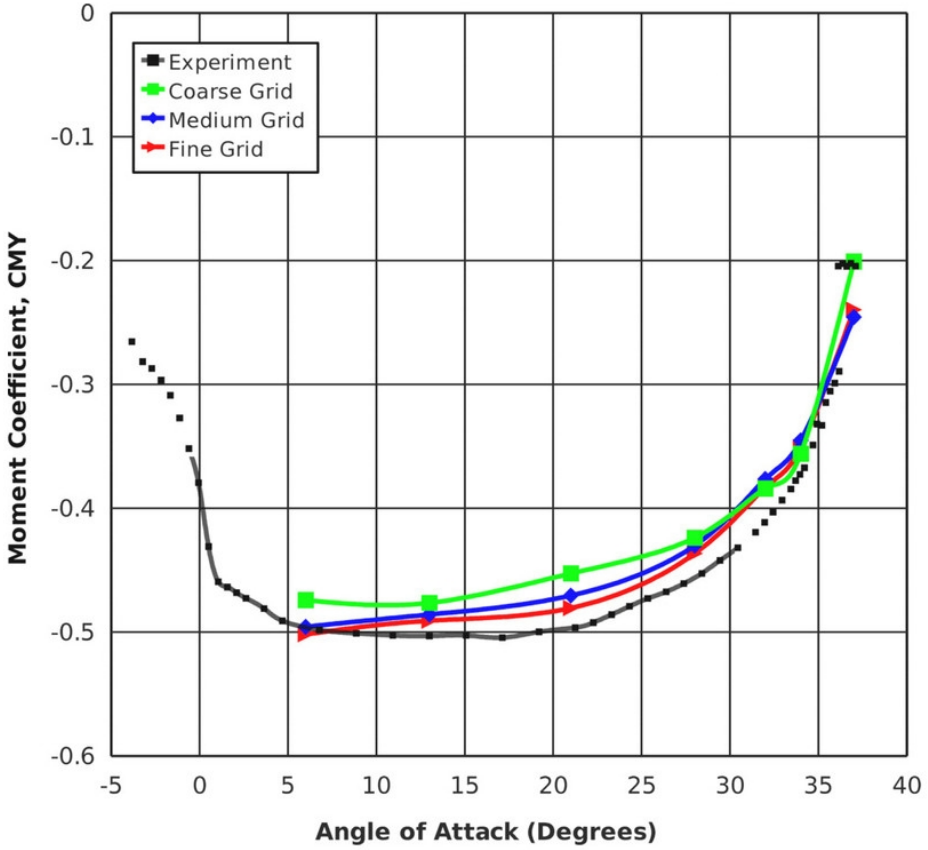
- Trap Wing “Config 1” (Slat 30, Flap 25)
- Trap Wing “Config 8” (Slat 30, Flap 20)
- Mach = 0.2, α = 6°, 13°, 21°, 28°, 32°, 34°, 37°
- Medium grid required
- Sweep completed on coarse and fine grids
- SA turbulence model on all grids

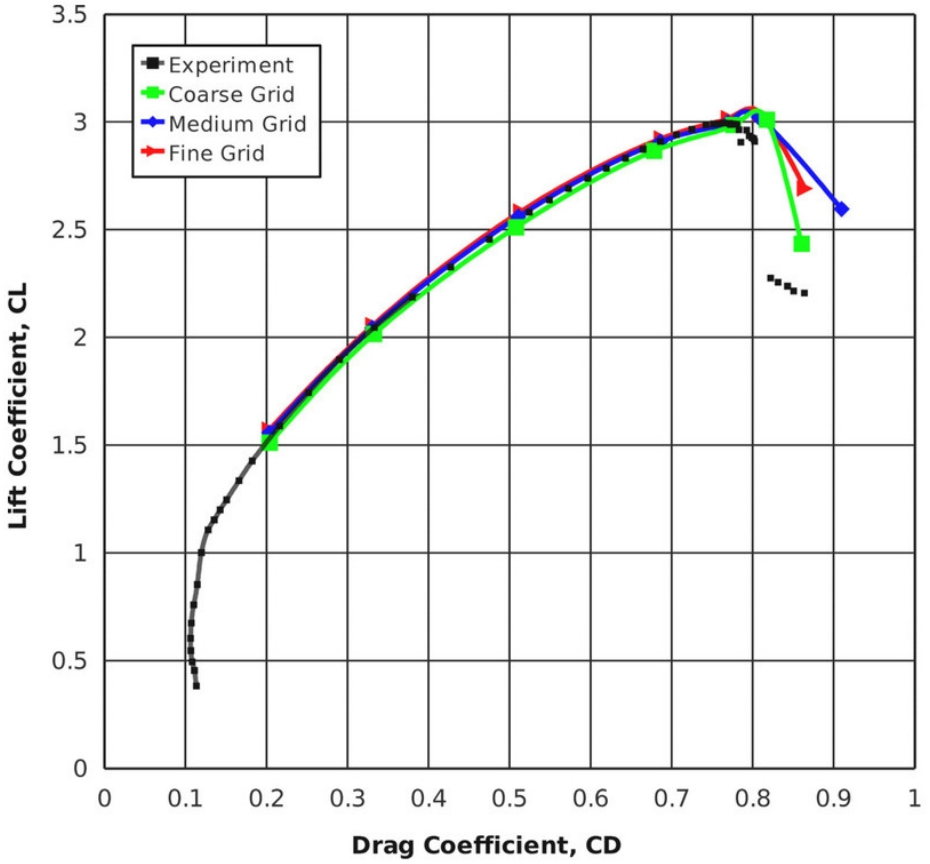
Alpha Sweep – Config 1



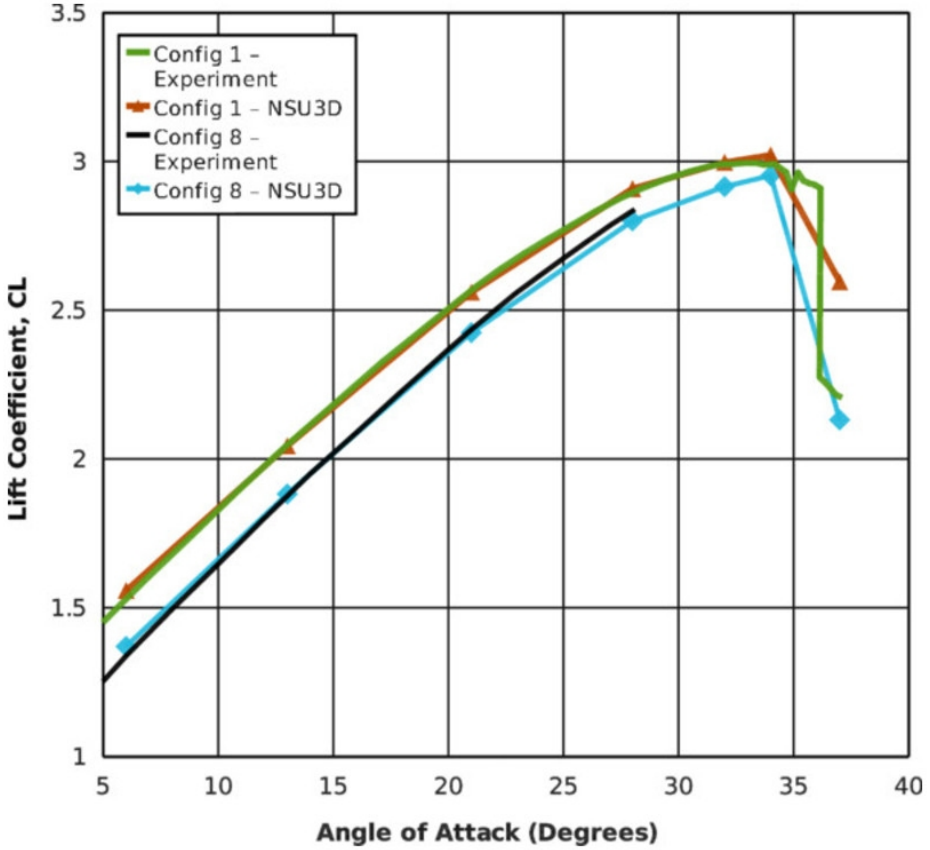


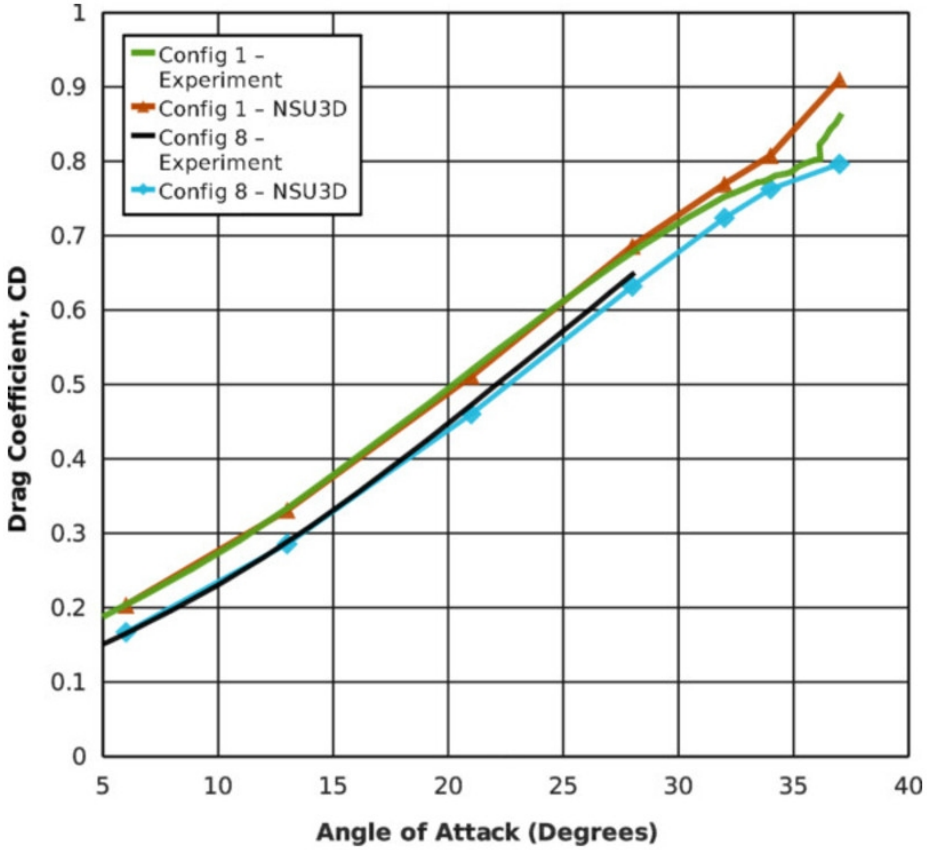
Alpha Sweep – Config 1



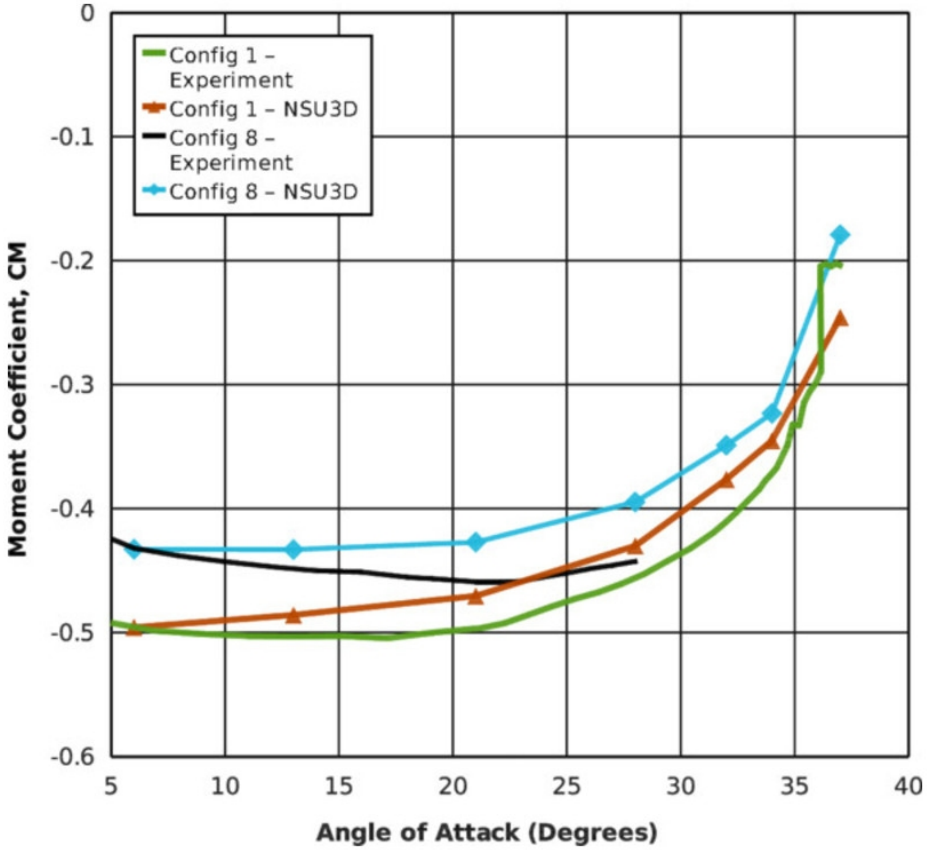


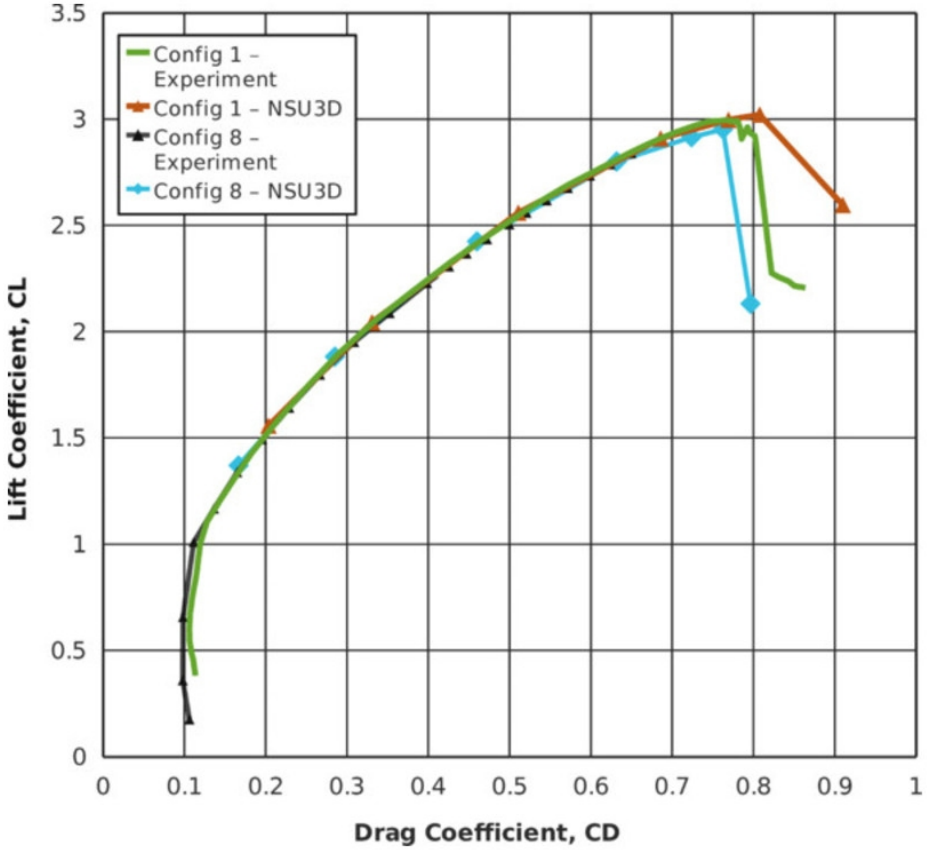
Effect of Flap Deflection



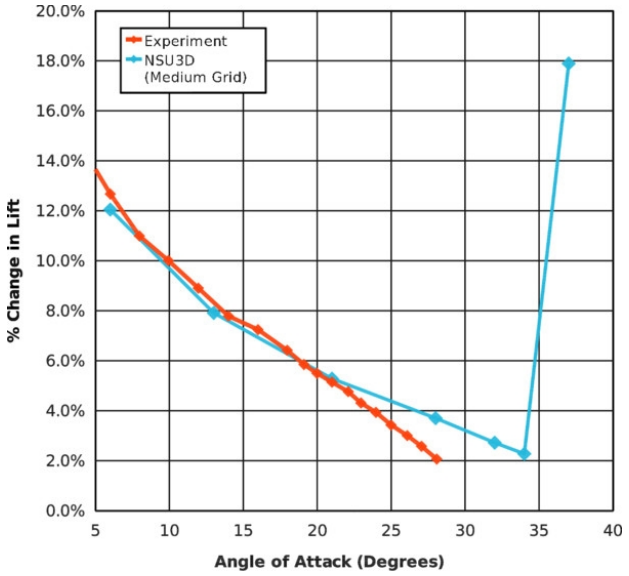


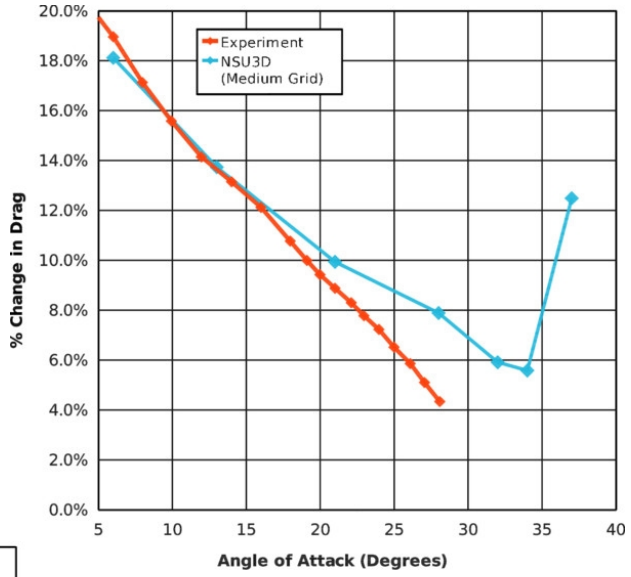
Effect of Flap Deflection

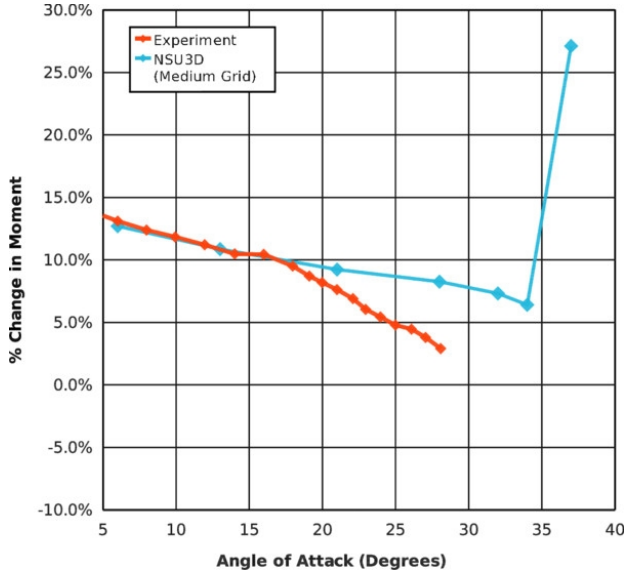




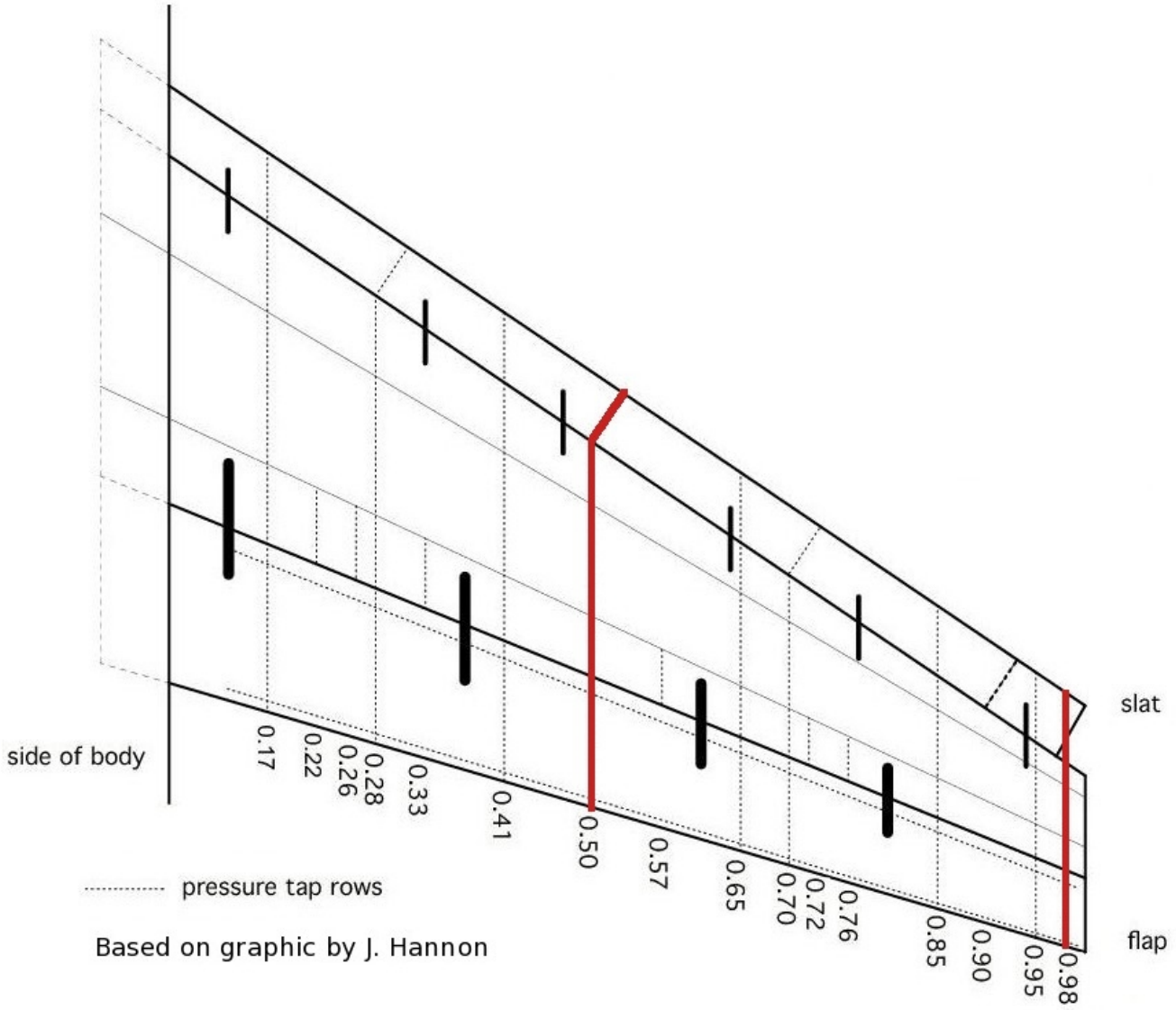
Effect of Flap Deflection





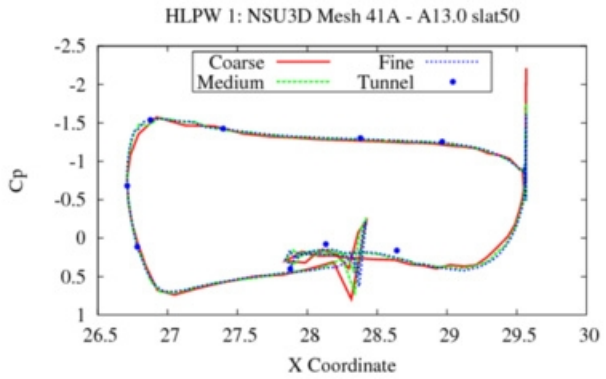


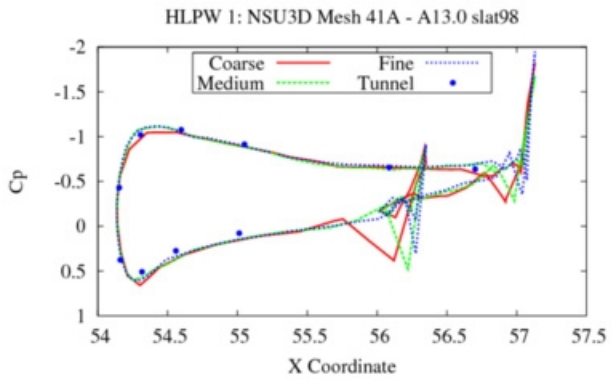
Surface Cp Comparisons



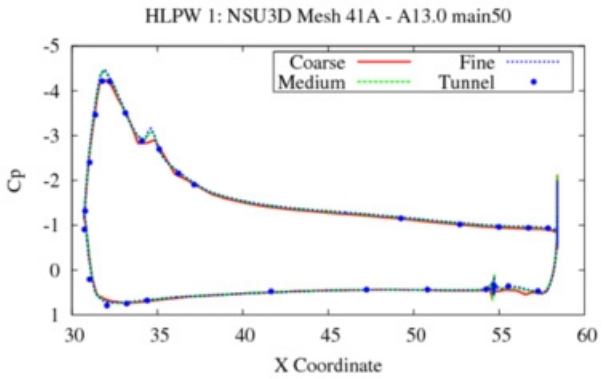
Surface Cp Comparisons

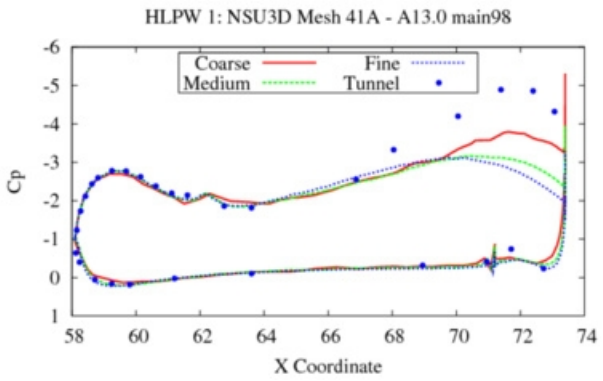
Slat



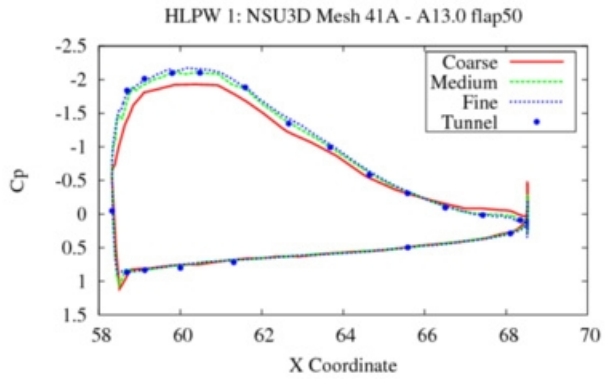


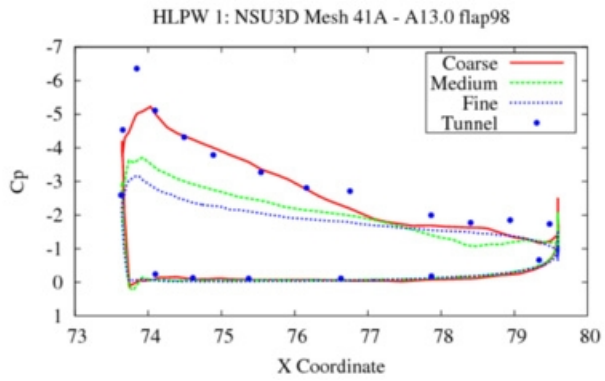
Main





Flap

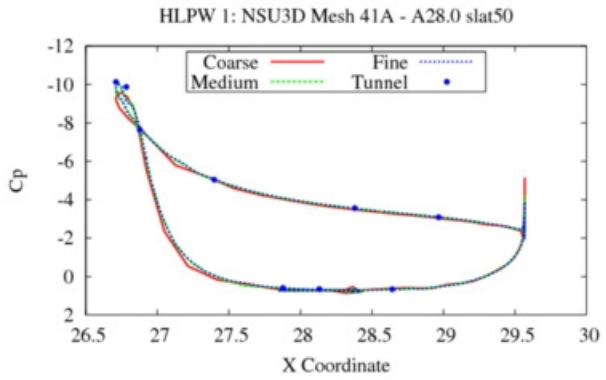


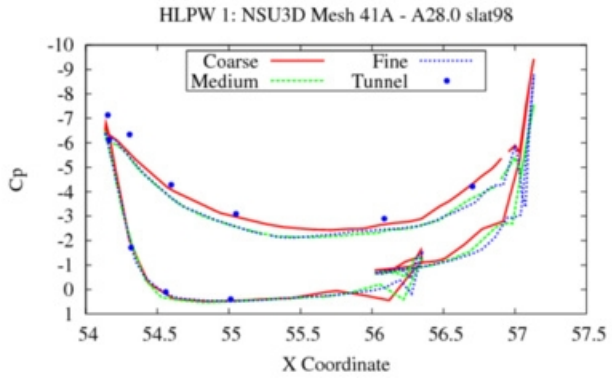


Alpha = 13°

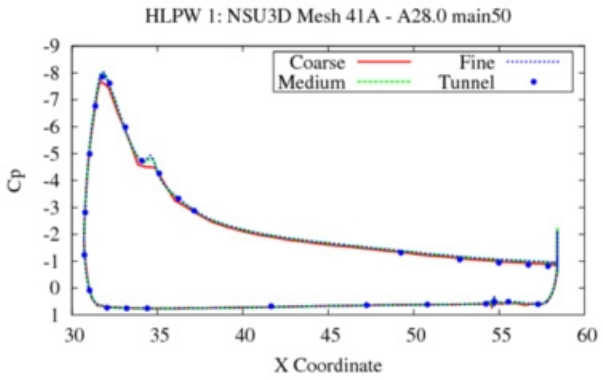
Surface Cp Comparisons

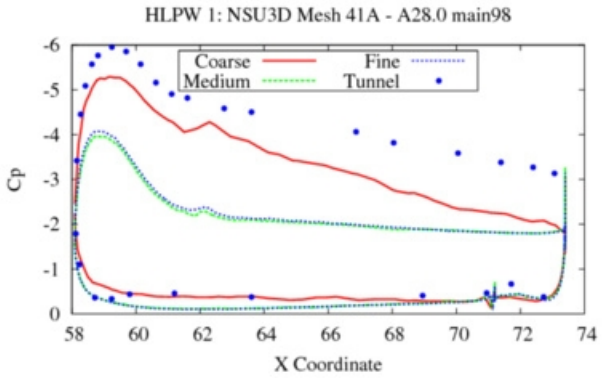
Slat



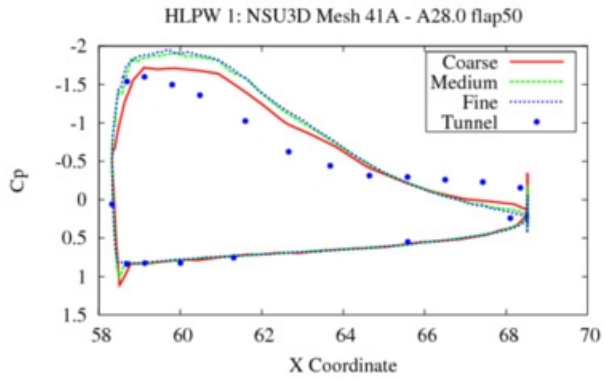


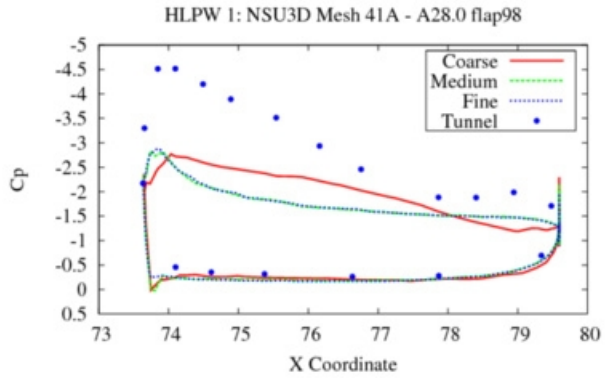
Main





Flap

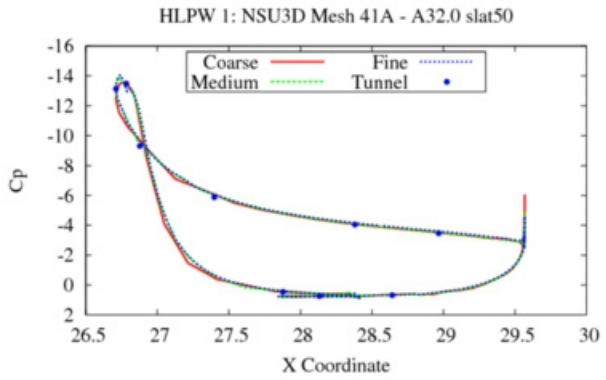


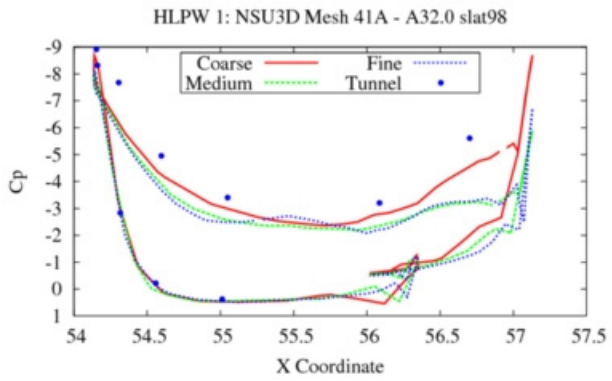


Alpha = 28°

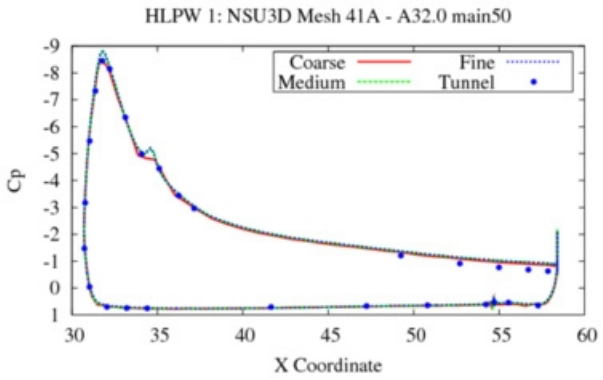
Surface Cp Comparisons

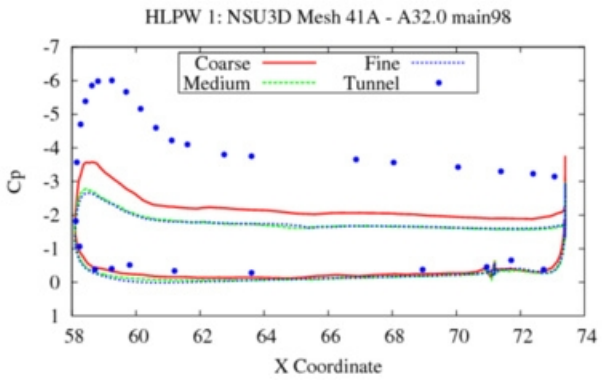
Slat



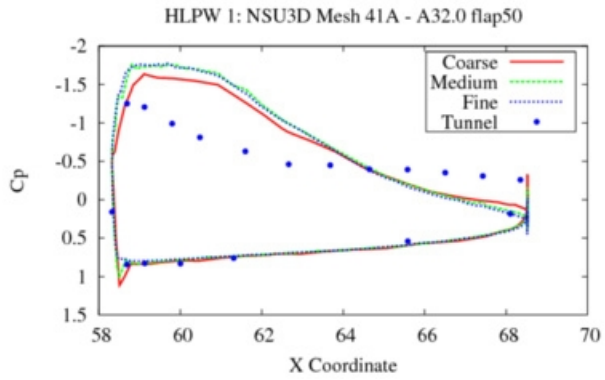


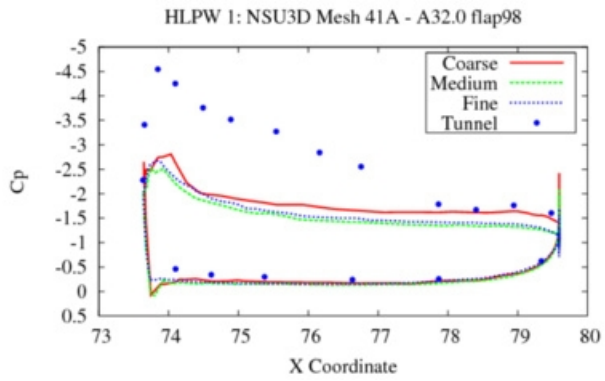
Main





Flap

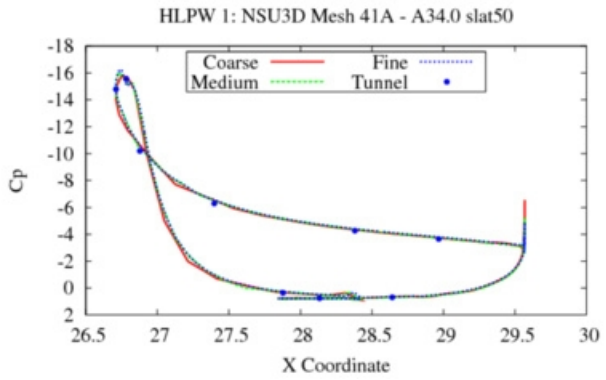


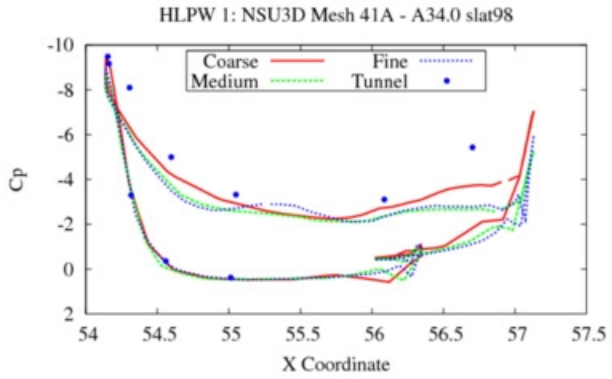


Alpha = 32°

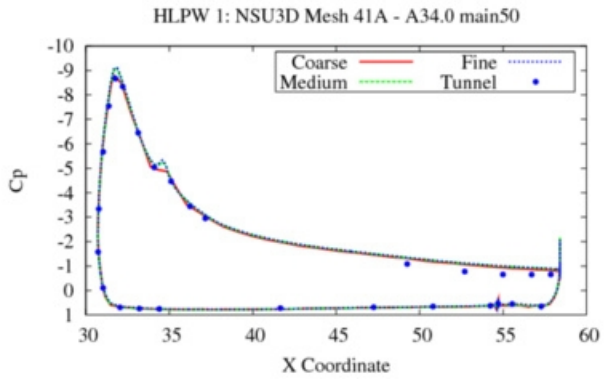
Surface Cp Comparisons

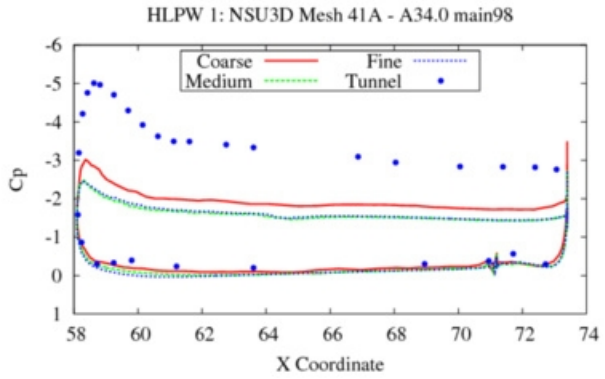
Slat



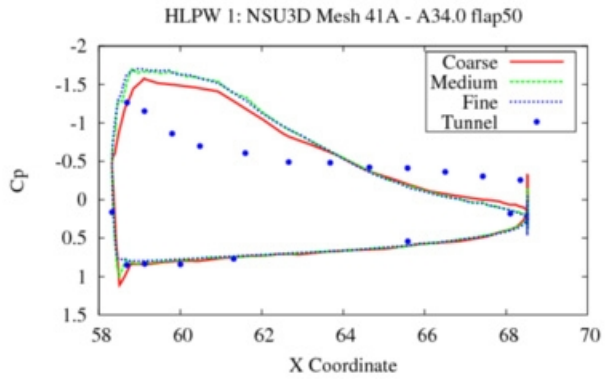


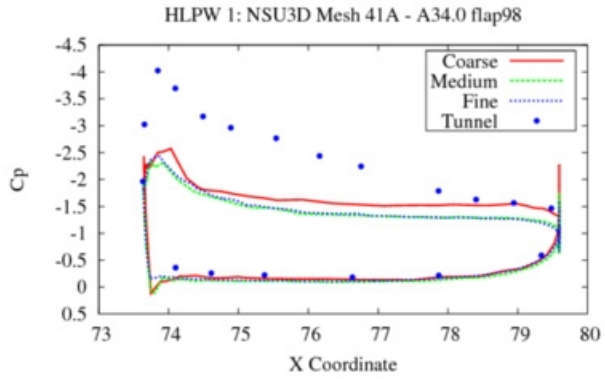
Main





Flap

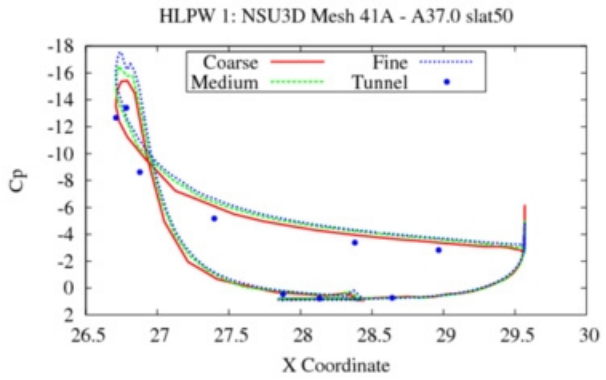


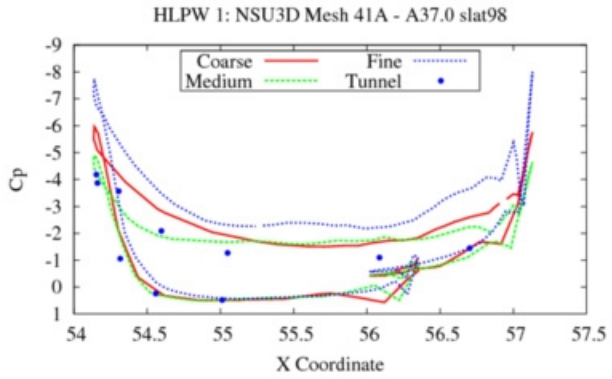


Alpha = 34°

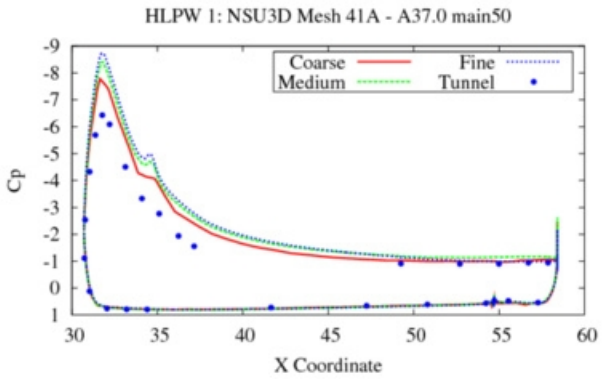
Surface Cp Comparisons

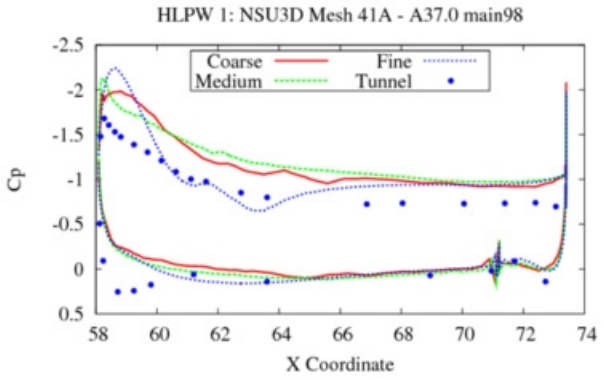
Slat



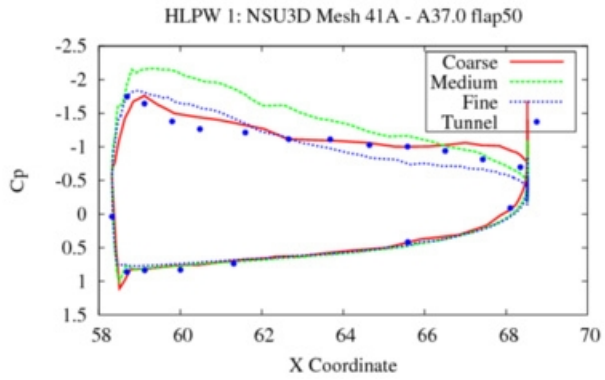


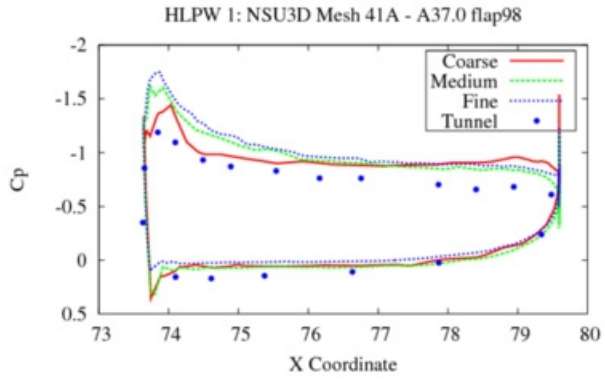
Main





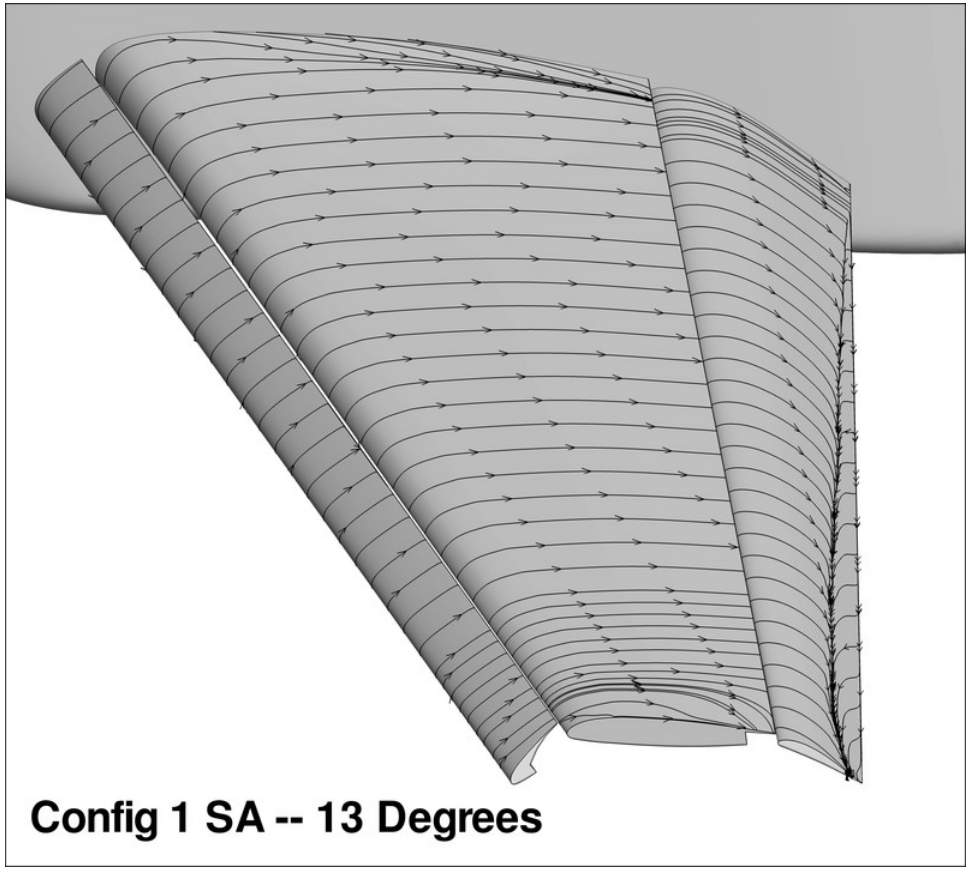
Flap

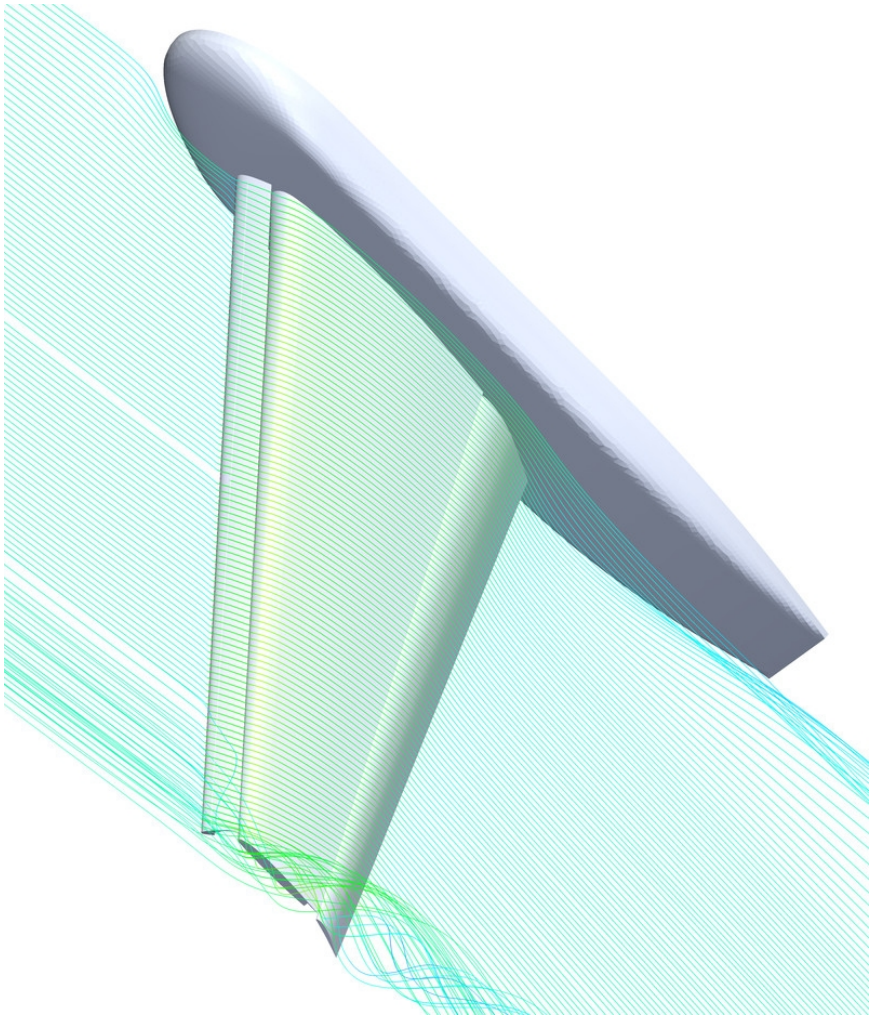




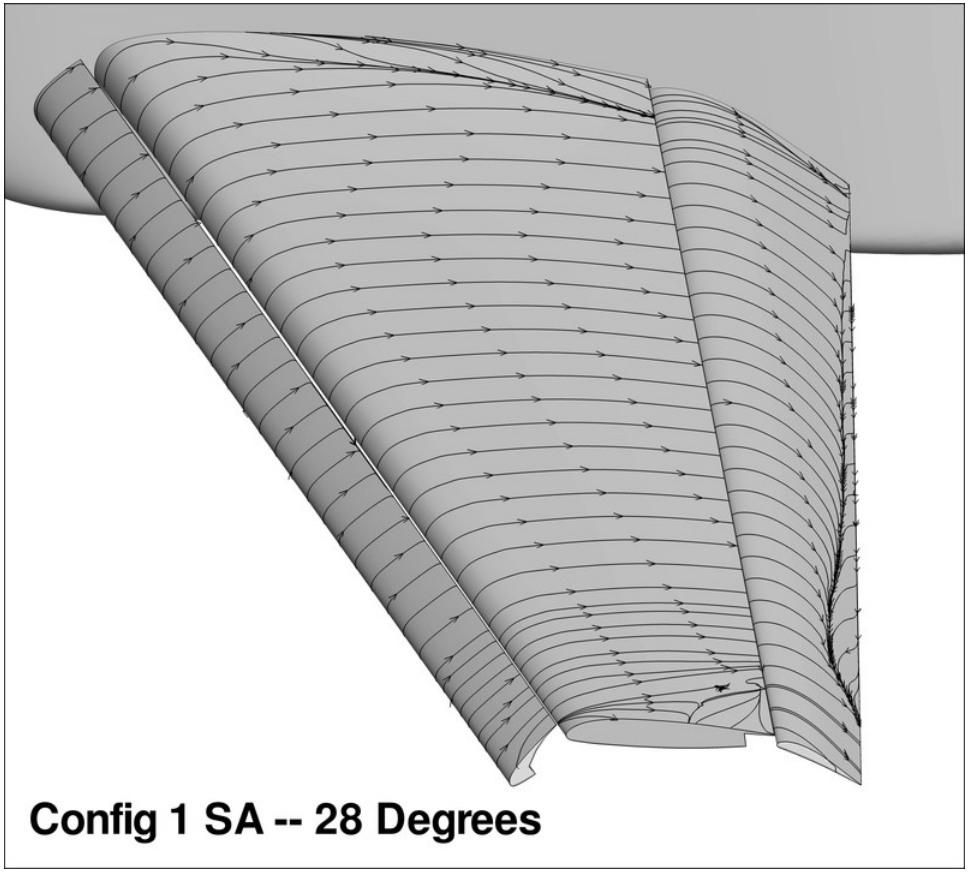
Alpha = 37°

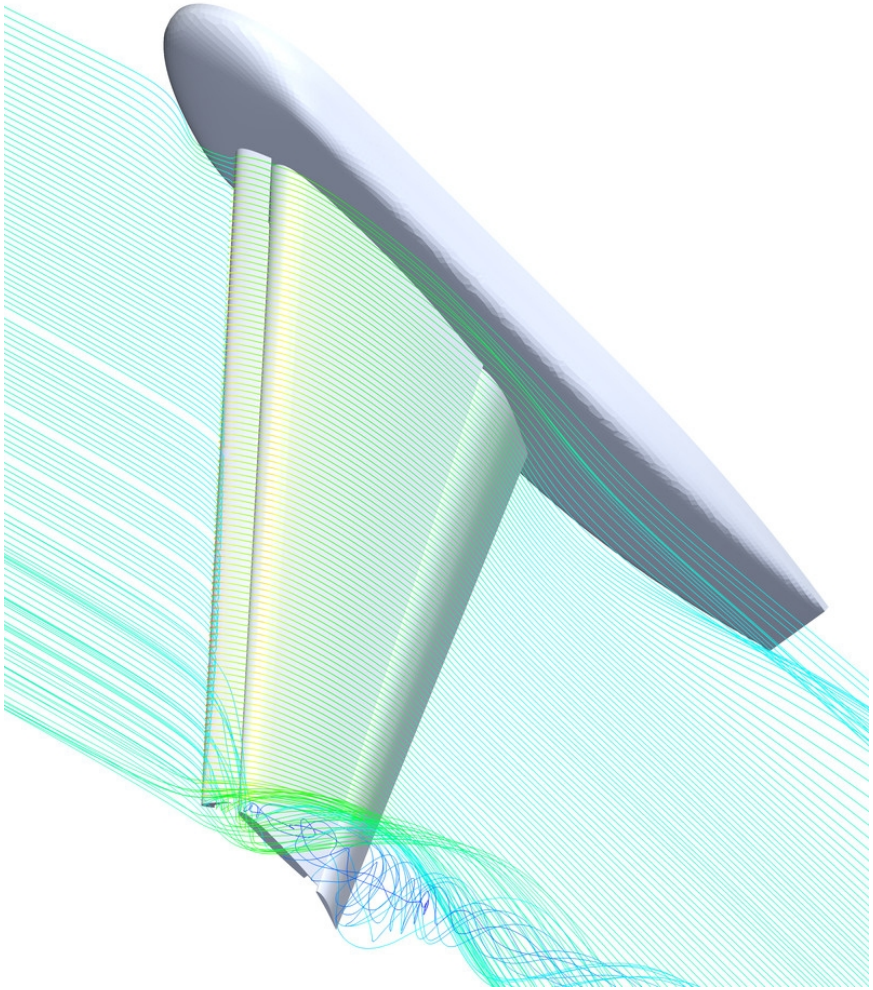
Solution Visualization



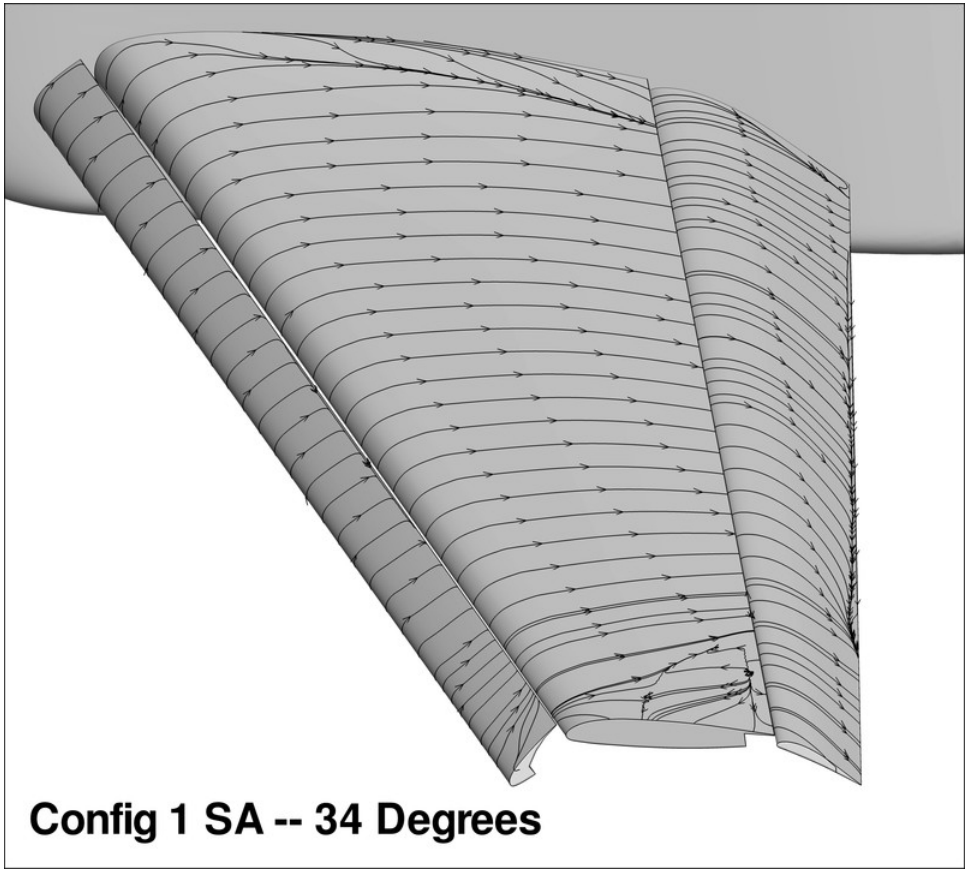


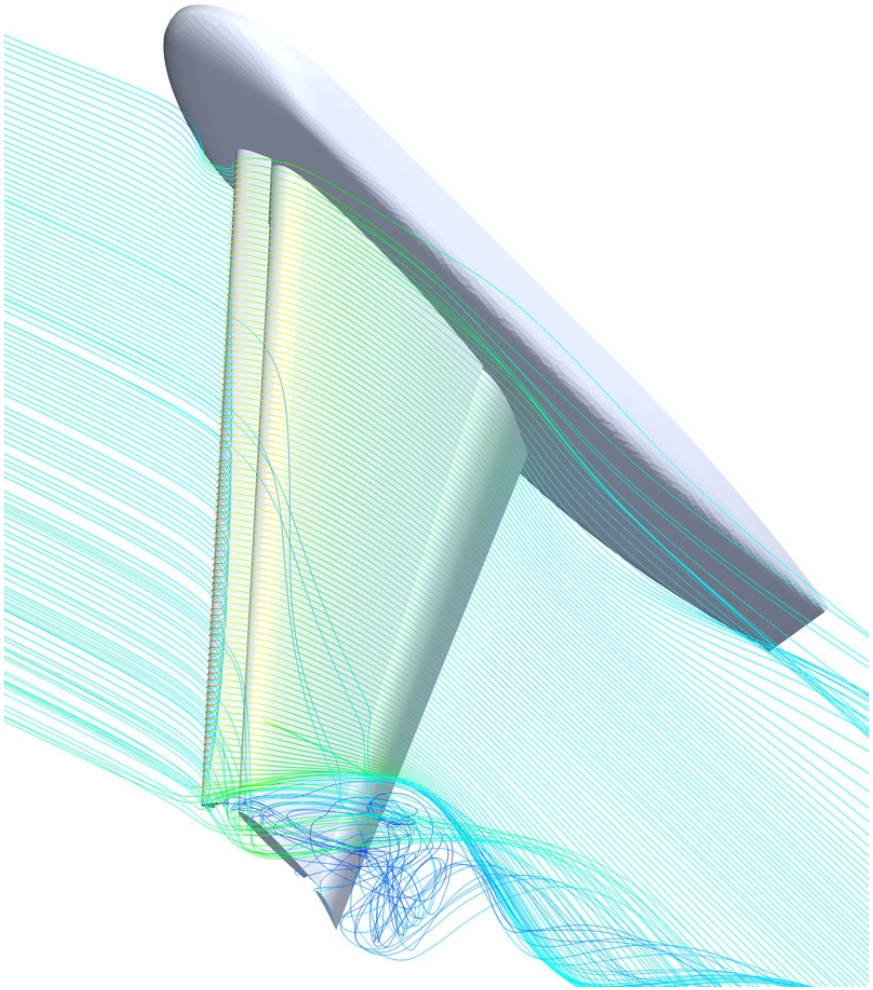
Solution Visualization



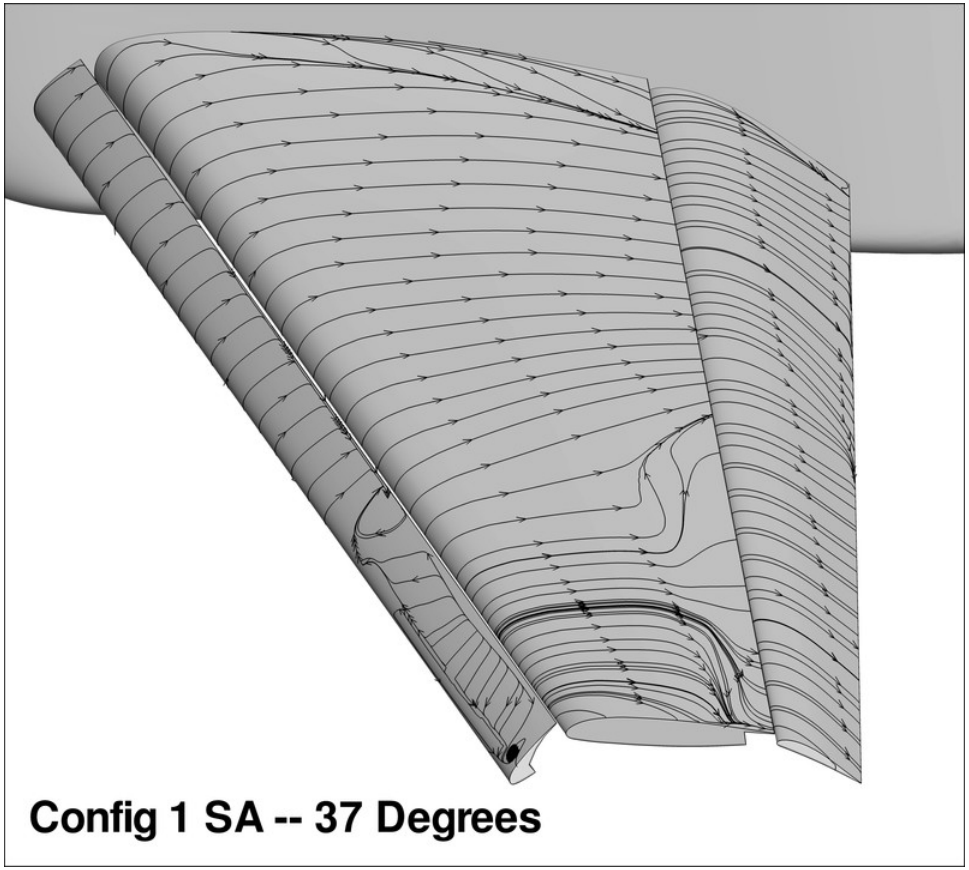


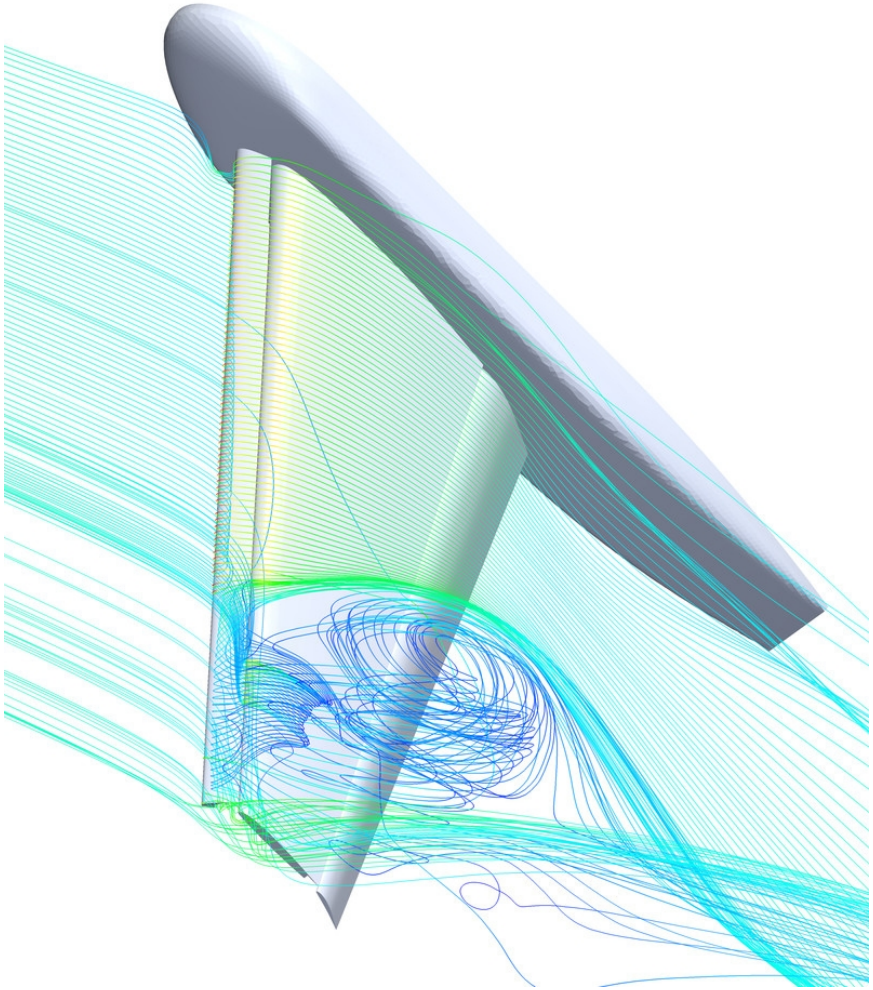
Solution Visualization





Solution Visualization





In Conclusion

- **Resonable agreement with experimental data**
  - All cases run from scratch
    - Line implicit, Full multigrid for startup
  - No brackets, transition, wall effects
- **Reasonable grid convergence observed on configuration 1 using three grids**
  - Effect of finer grids...
- **Effect of flap deflection modeled very well at lower alphas**
  - Reasonable agreement with experiment at higher alphas
- **Convergence issues on Configuration 8**
  - Possible manifestation of hysteresis effect
- **Most difficult area to model is the ouboard 5-10% span**

Moving Forward...

- Simulations including the cross-derivative terms (full Navier-Stokes)
- Simulations using other turbulence models available within NSU3D.
- Modeling the slat and flap brackets
- Modeling the tunnel walls and comparing to uncorrected experimental data
- Time accurate simulations to better resolve the maximum lift region and post stall behavior.

Acknowledgments

HLPW Organizing Committee for making this happen!

NASA Advanced Supercomputing Division for providing the CPU time to make the UWYO efforts possible!