University of Wyoming Contribution to HiLiftPW-1

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1st AIAA CFD High Lift Prediction Workshop
Chicago, Illinois
26-27 June 2010

Presentation Outline

- NSU3D Flow Solver Overview
- Grid Systems
- Solution Convergence
- Case 1 - Grid Convergence
- Case 2 - Alpha Sweep - Config 1
- Case 2 - Alpha Sweep - 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

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 Nehalem-EP)

Typical Resource Requirements

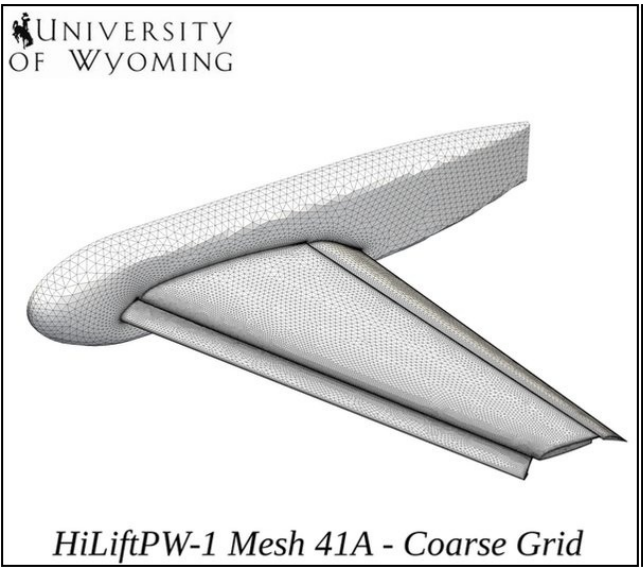
- NASA Pleiades Supercomputer
  - SGI ICE with 51,200 Intel Harpertown Xeon Cores
- Medium (10Mpts) grids used 64 cpus
  - 1000 multigrid cycles
  - ~1.5 hours for final solution
  - ~60GB memory allocated
- High alpha cases often require more iterations

Grid Systems

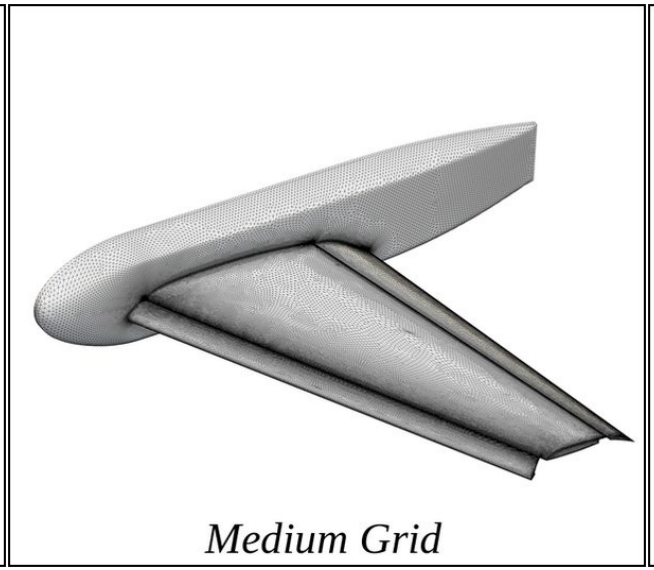
All cases used the UWYO contributed grids:

- 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

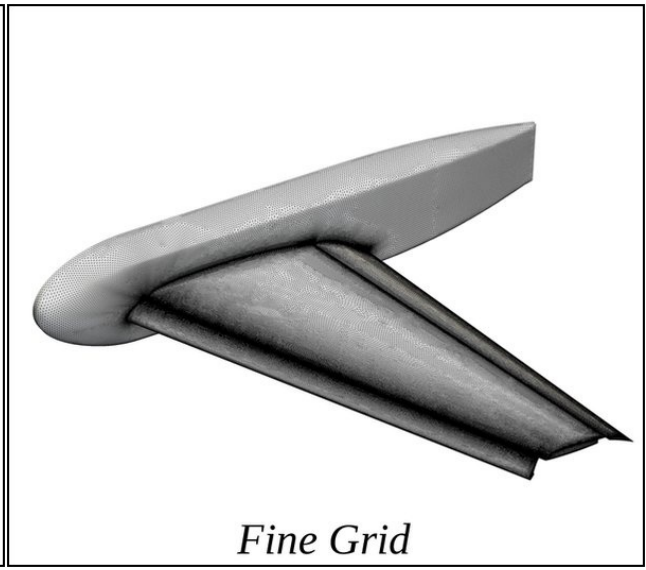
Grid Systems



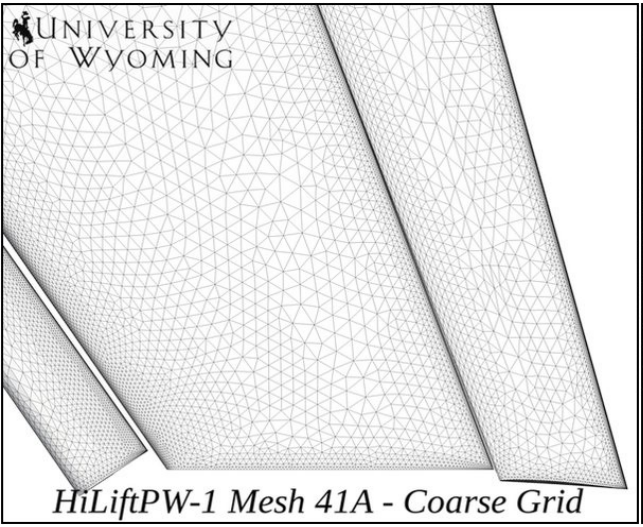
HiLiftPW-1 Mesh 41A - Coarse Grid



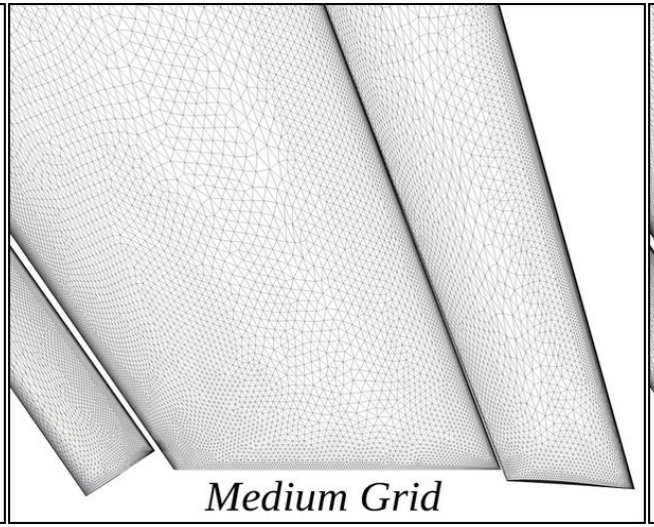
Medium Grid



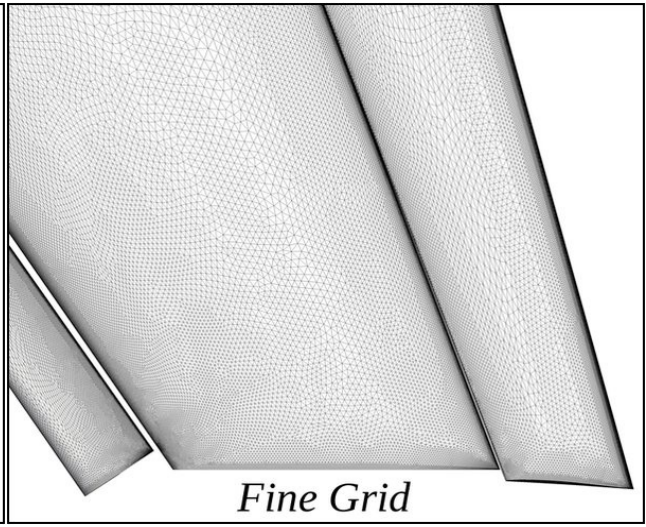
Fine Grid



HiLiftPW-1 Mesh 41A - Coarse Grid

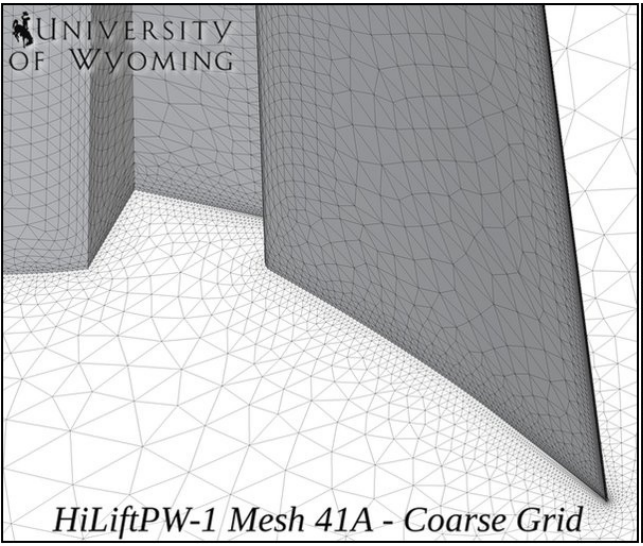


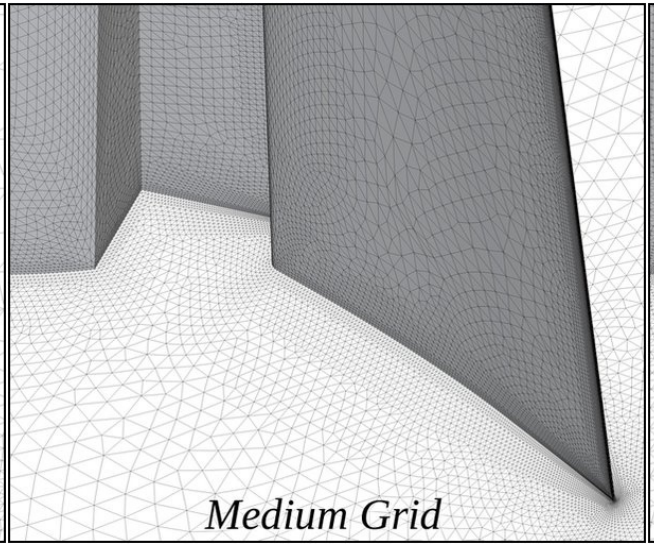
Medium Grid

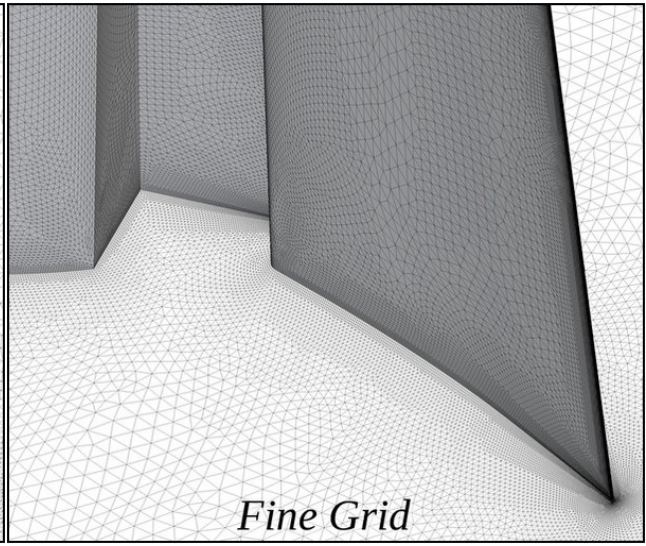


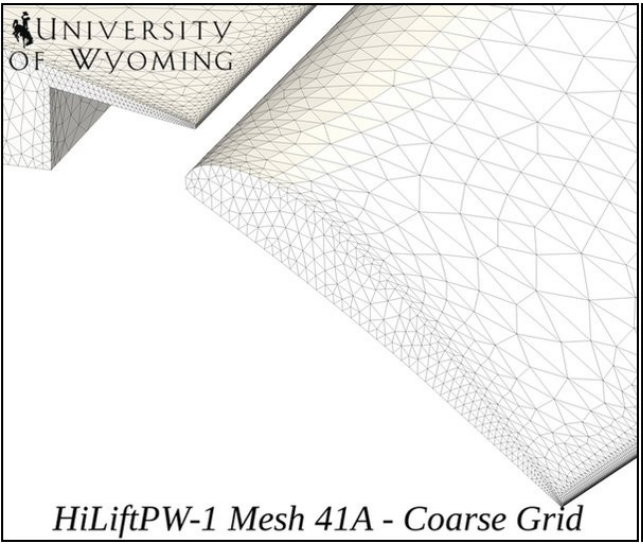
Fine Grid

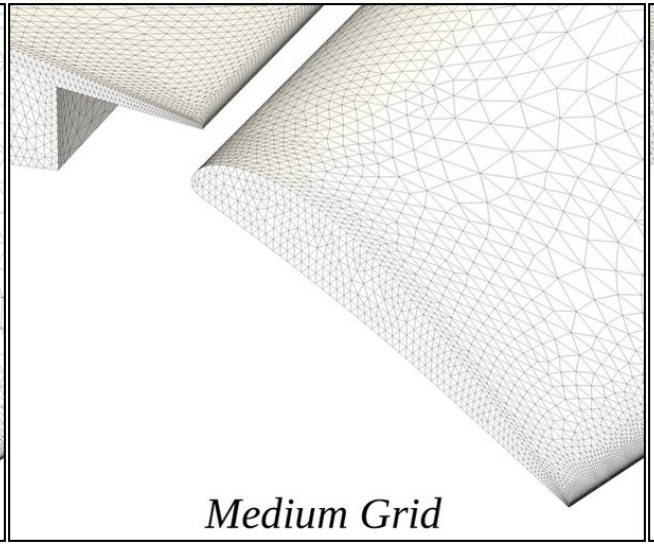
Grid Systems

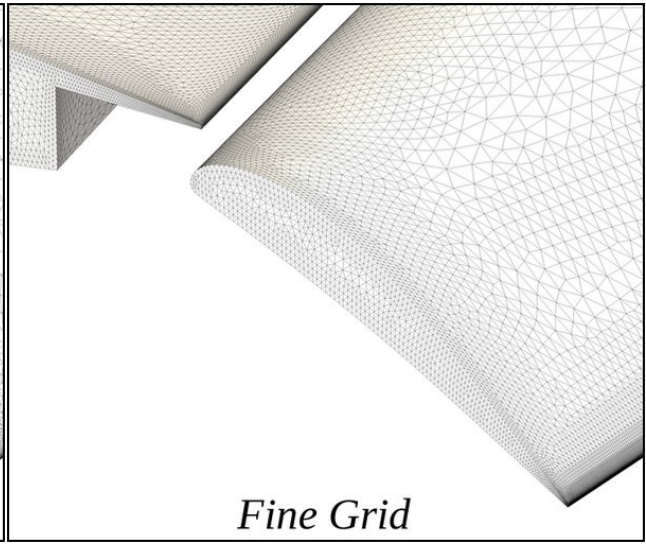








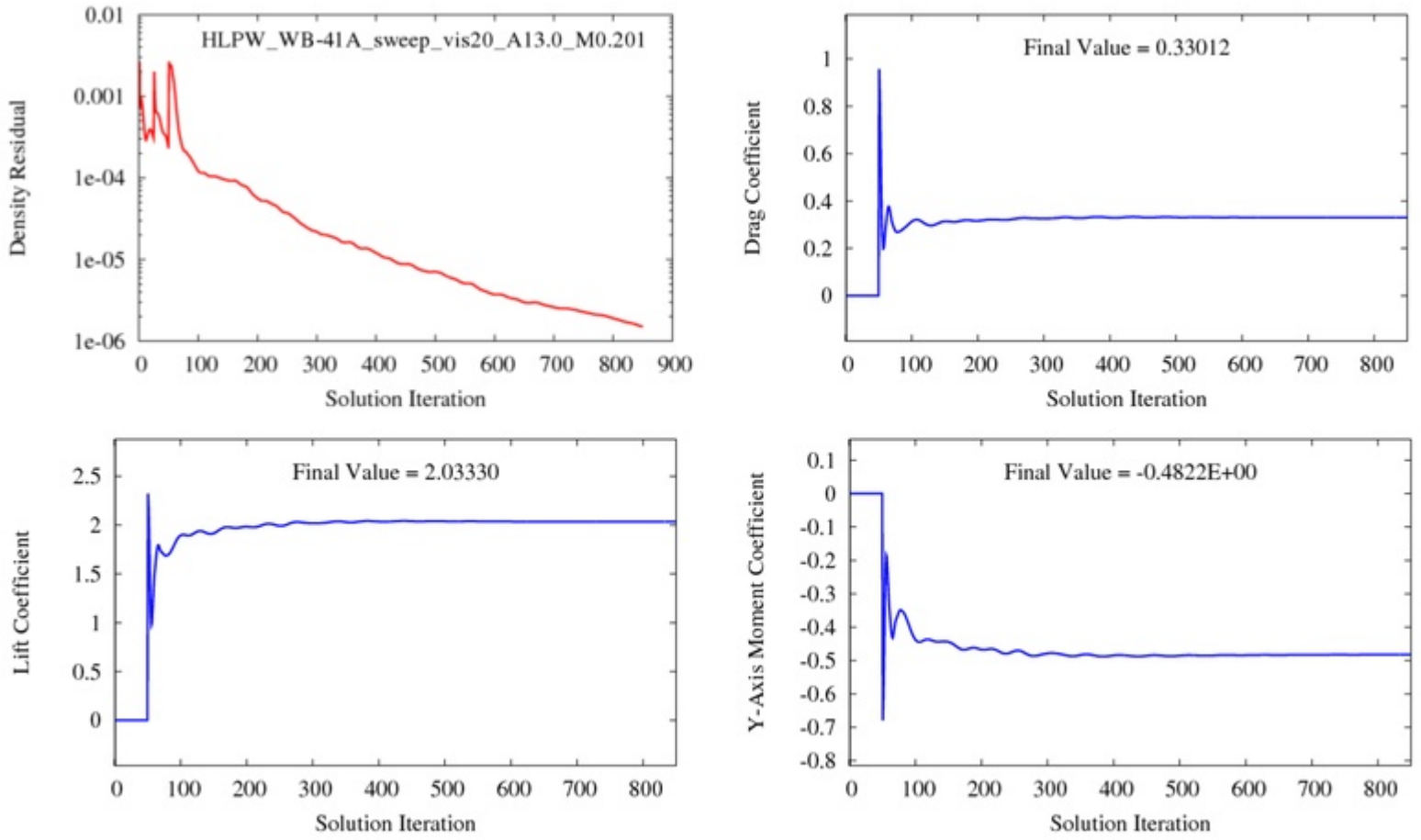




Test Case Summary

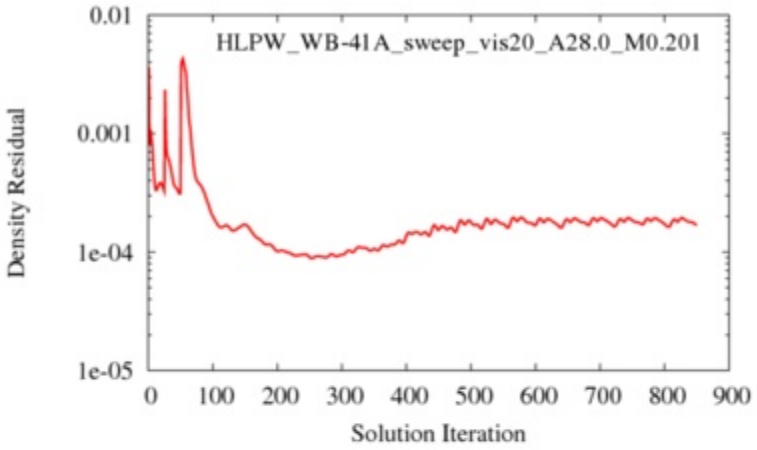
- **Test Case 1 – Grid Convergence Study**
  - Trap Wing “Config 1” (Slat 30, Flap 25)
  - Mach = 0.2, α = 13°, 28°
  - Re = 4.3M (based on MAC)
  - Tinf = 520°R
  - Coarse, Medium, Fine grids
- **Test Case 2 – Alpha Sweep, Flap Increments**
  - Trap Wing “Config 1” (Slat 30, Flap 25)
  - Trap Wing “Config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

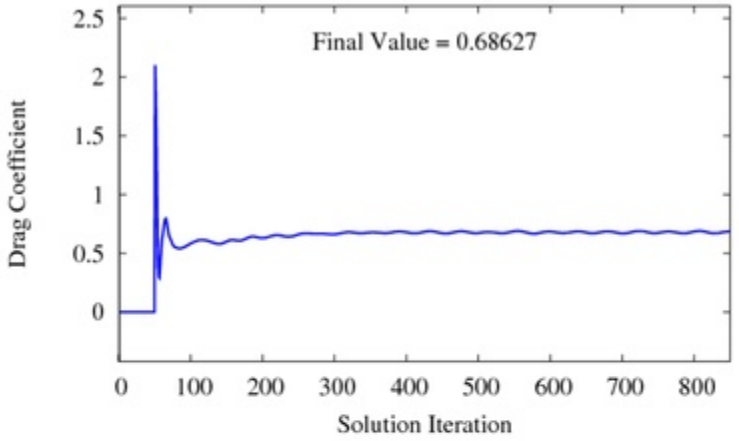
Multigrid Convergence (medium grid: 13°)

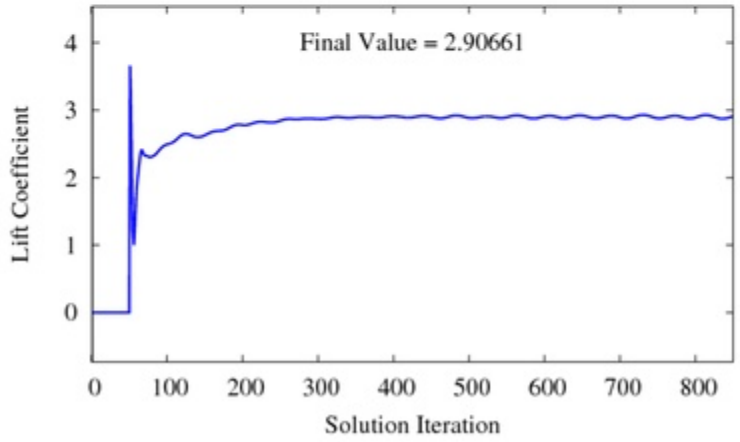


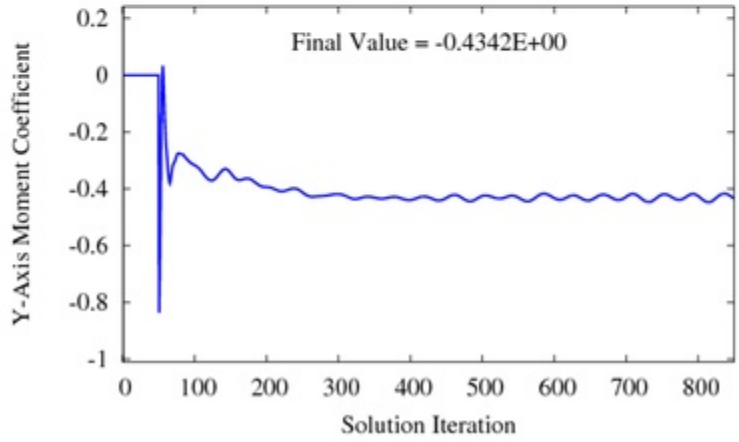
- Effective multigrid convergence for linear CL-alpha range cases (4 level W-cycle)

Multigrid Convergence (medium grid 28 ^{0})



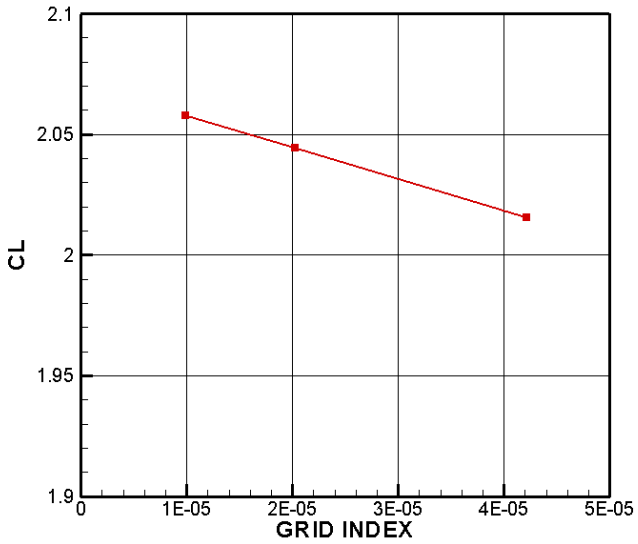


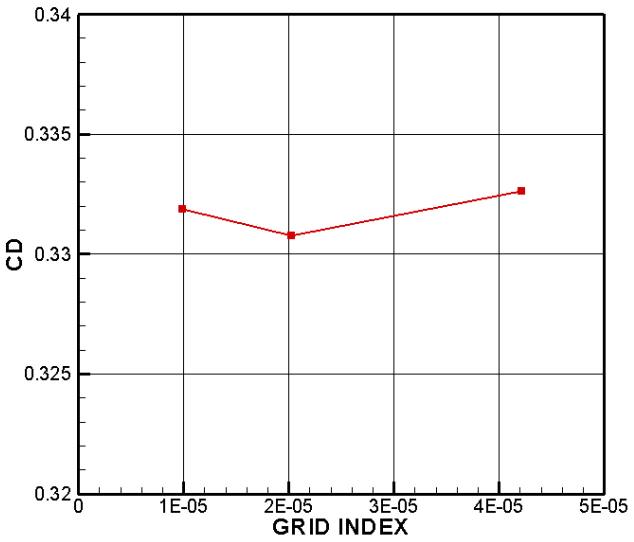


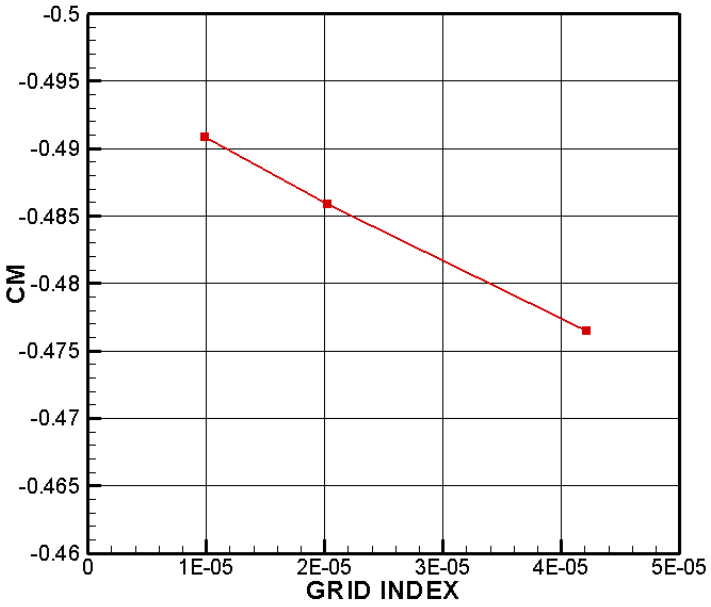


- Residuals stall for higher alpha cases
  - Forces converge (small oscillations)
- Residual convergence resumes switching to single grid

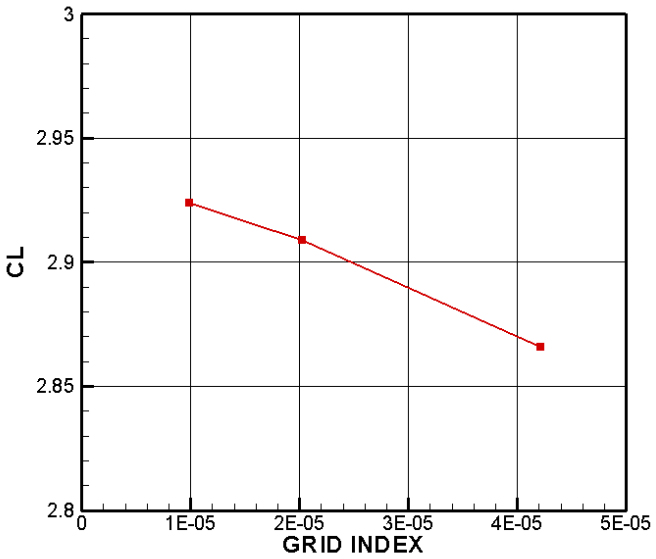
Grid Convergence (Config 1 @13°)

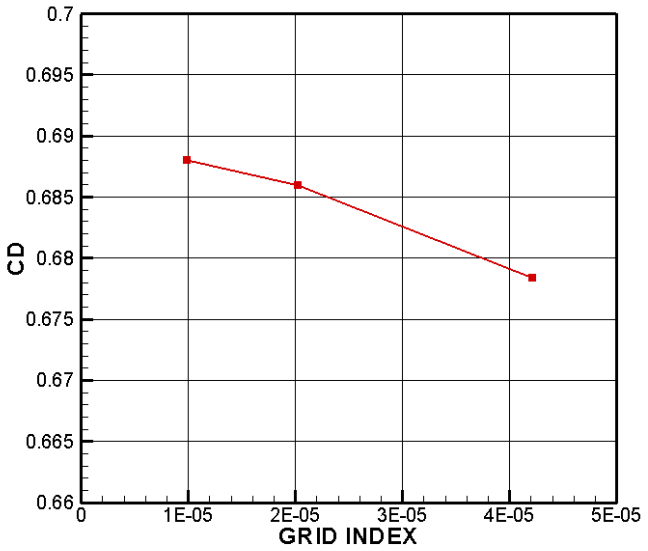


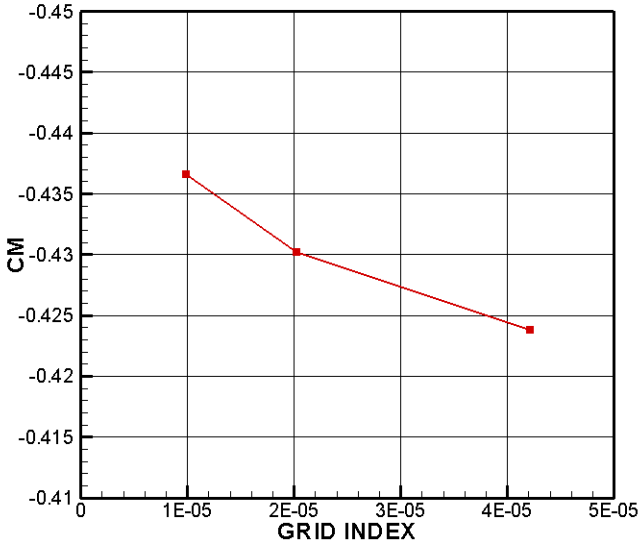




Grid Convergence (Config 1 @28^{o})



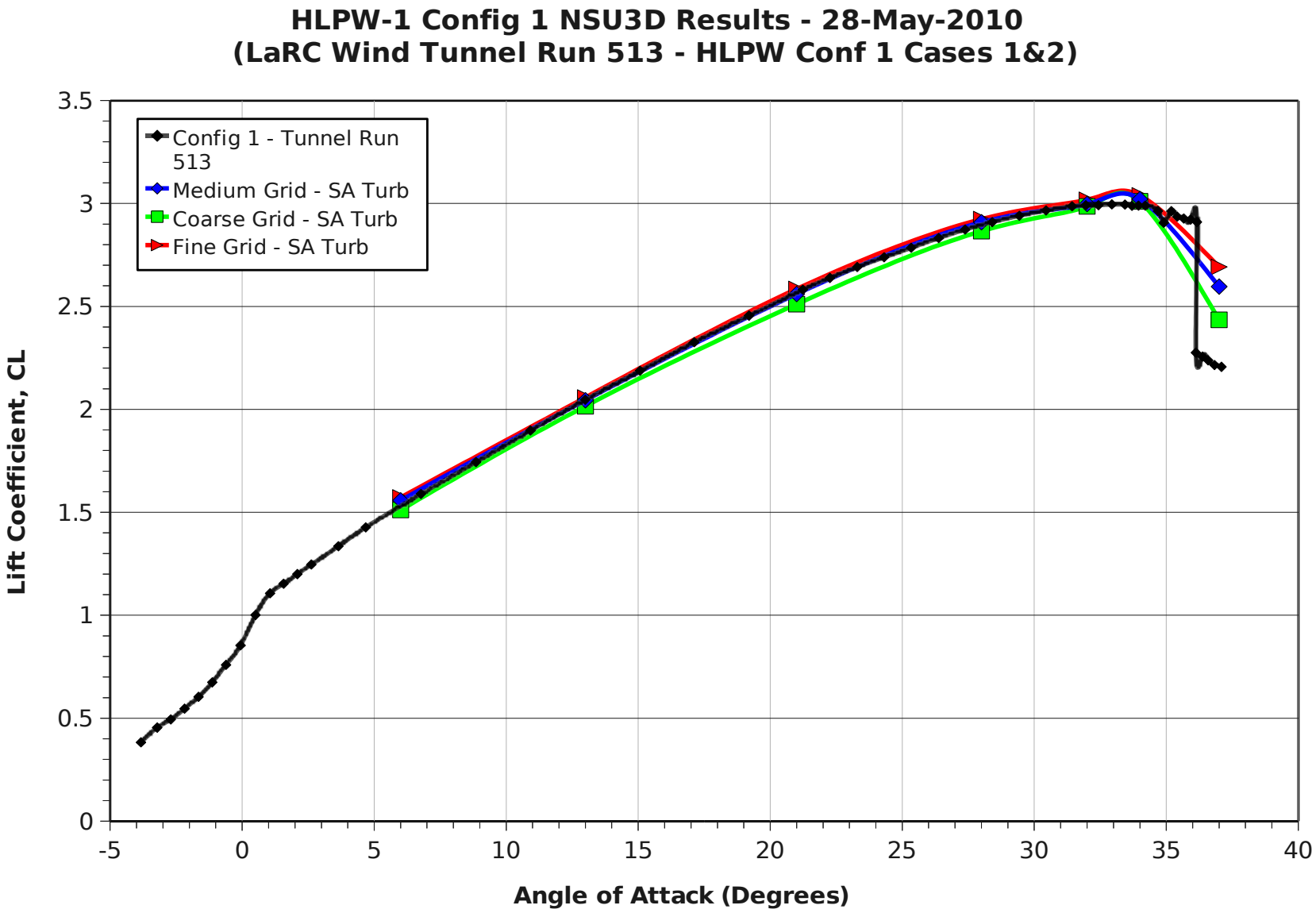




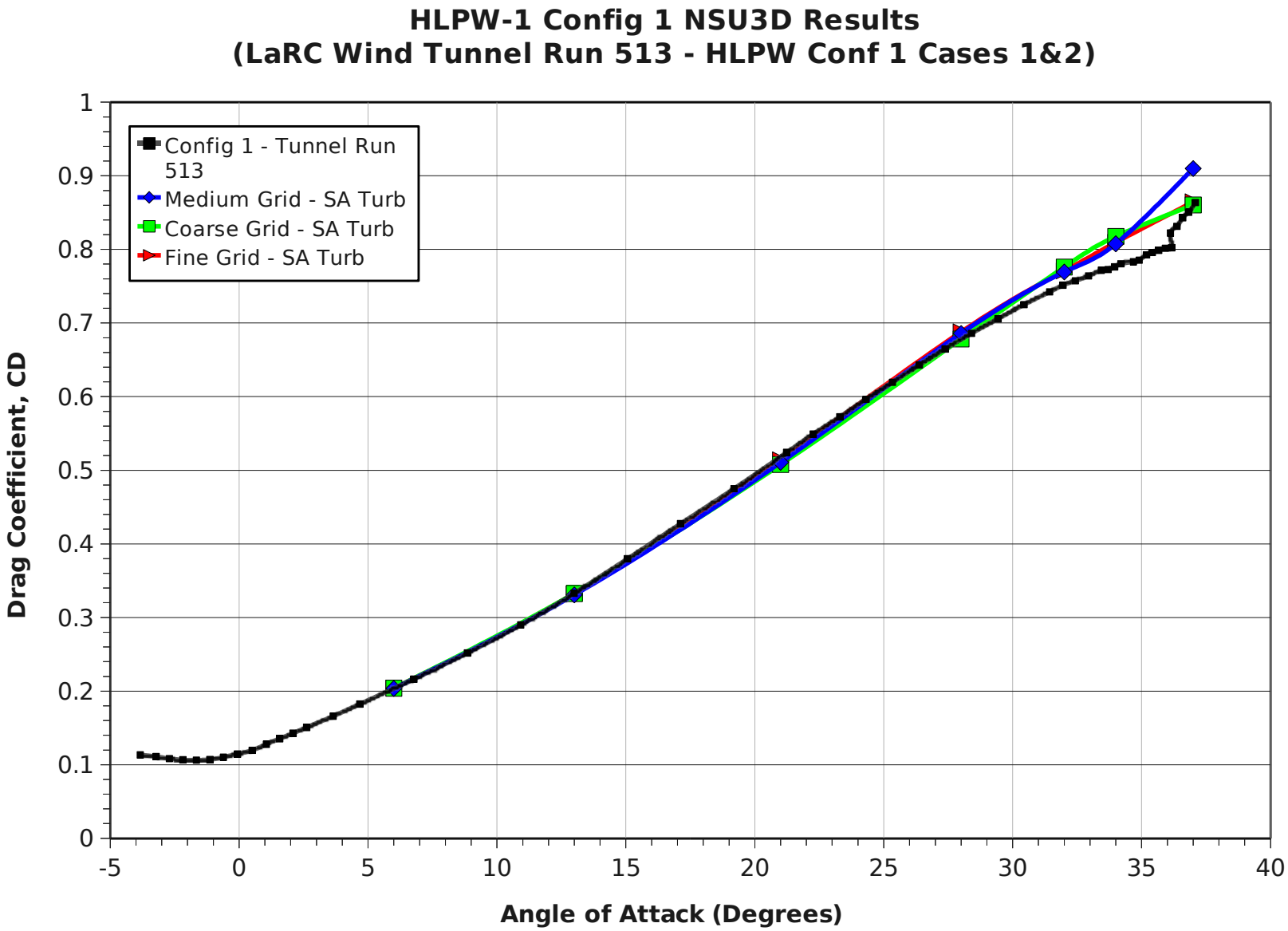
Case 2 – Alpha Sweep

- 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
- SST turbulence model on medium grid

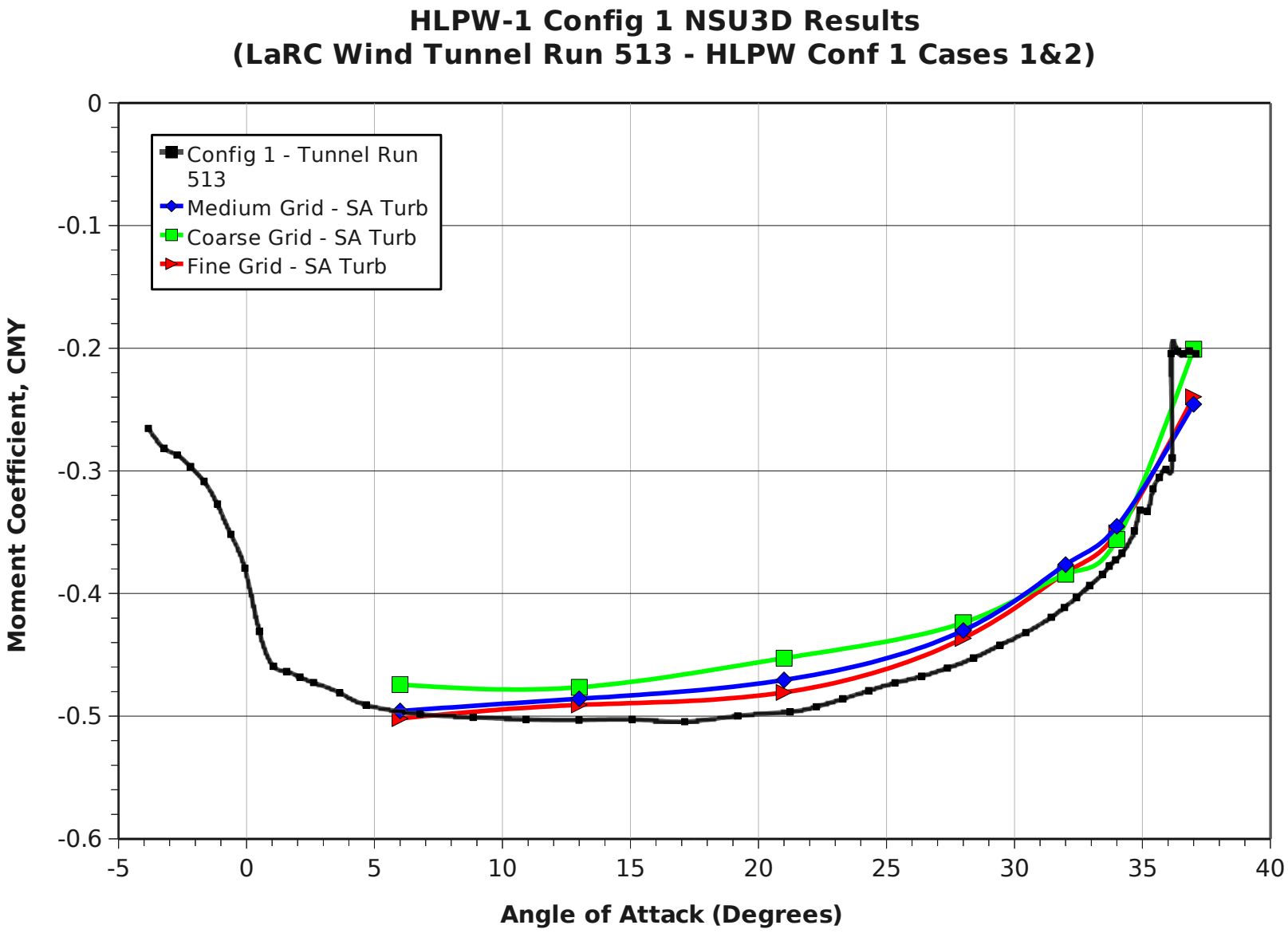
Case 2 – Alpha Sweep – Config 1



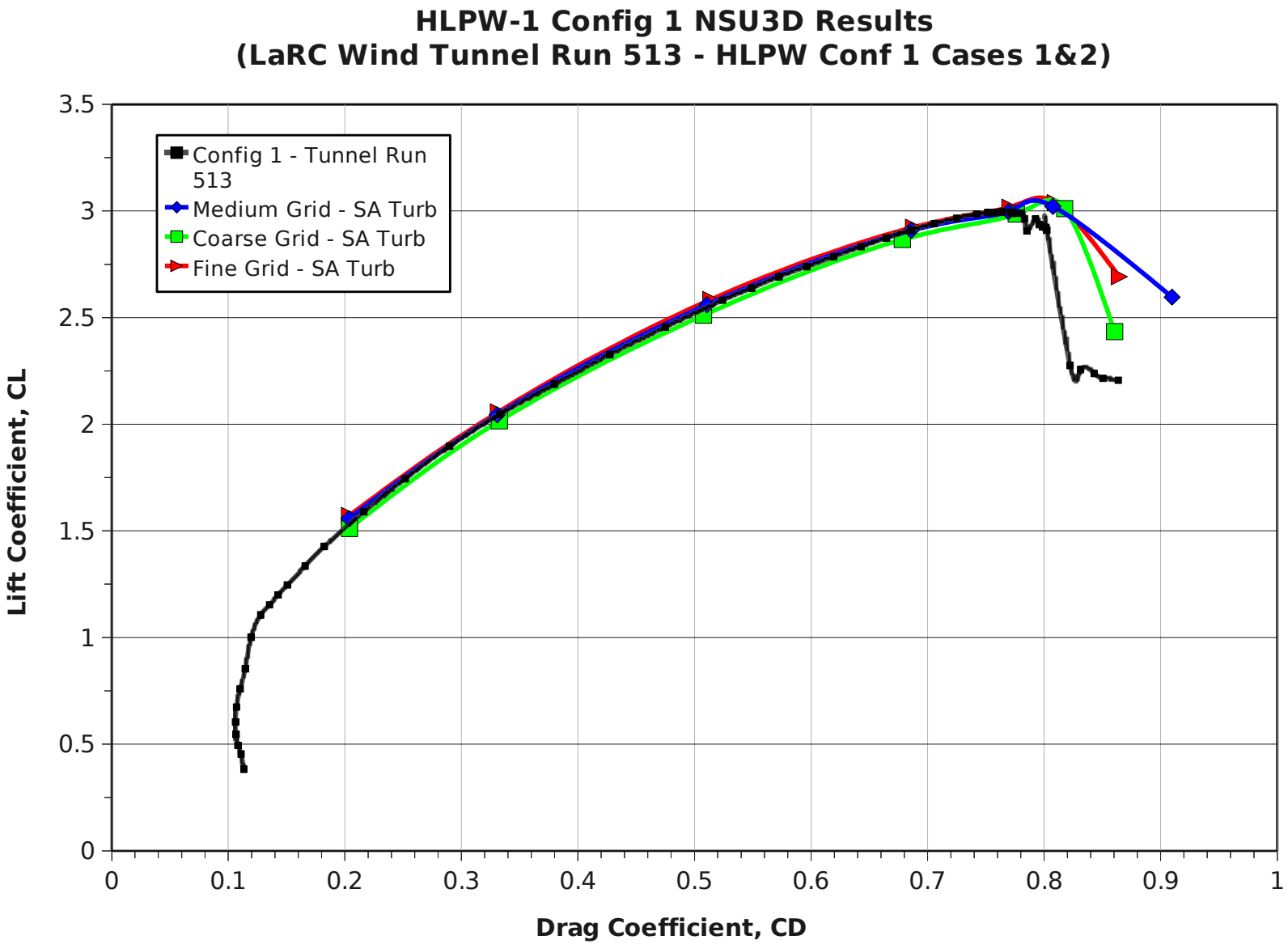
Case 2 – Alpha Sweep – Config 1



Case 2 – Alpha Sweep – Config 1



Case 2 – Alpha Sweep – Config 1



Case 2 – Alpha Sweep – Config 1

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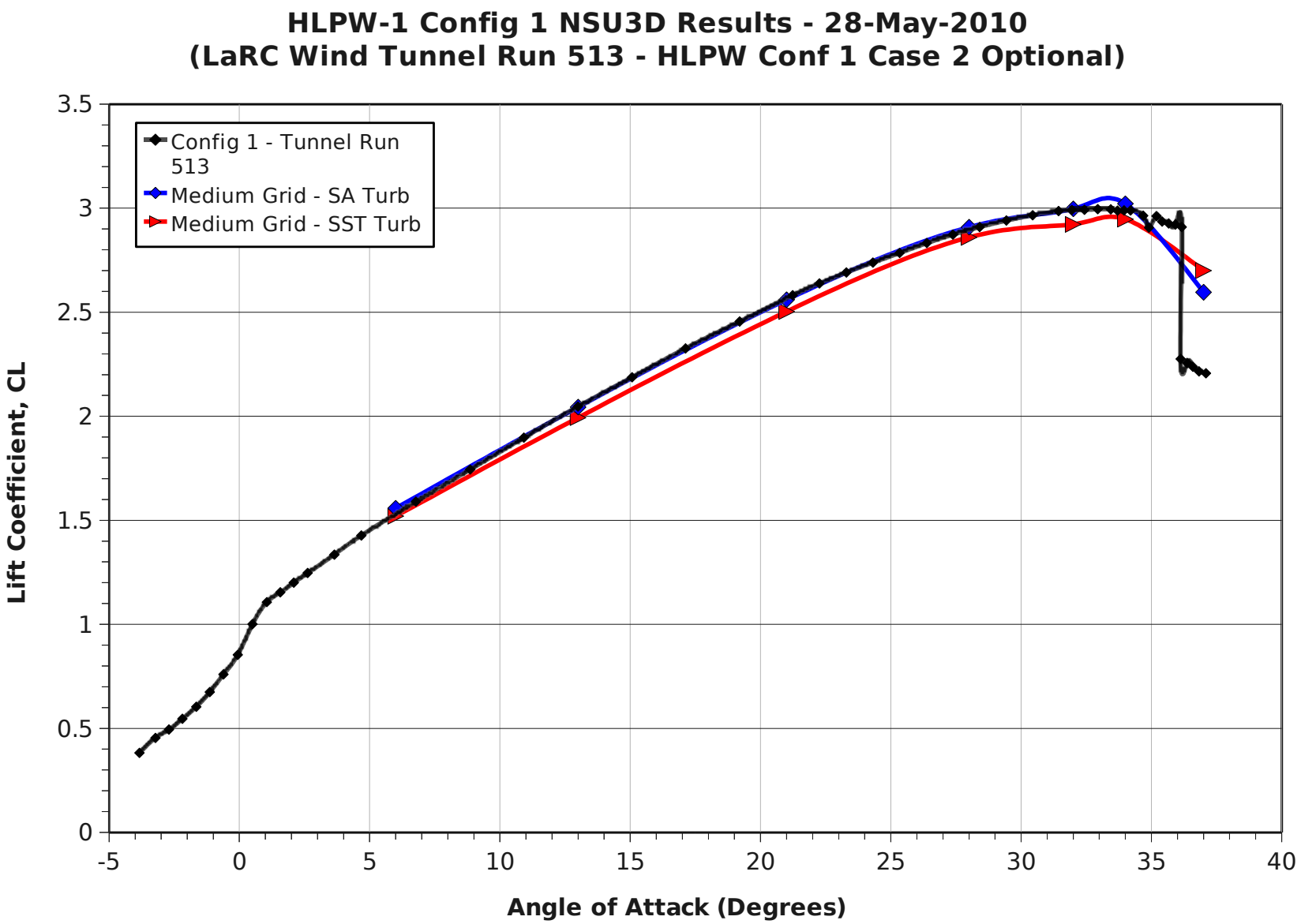
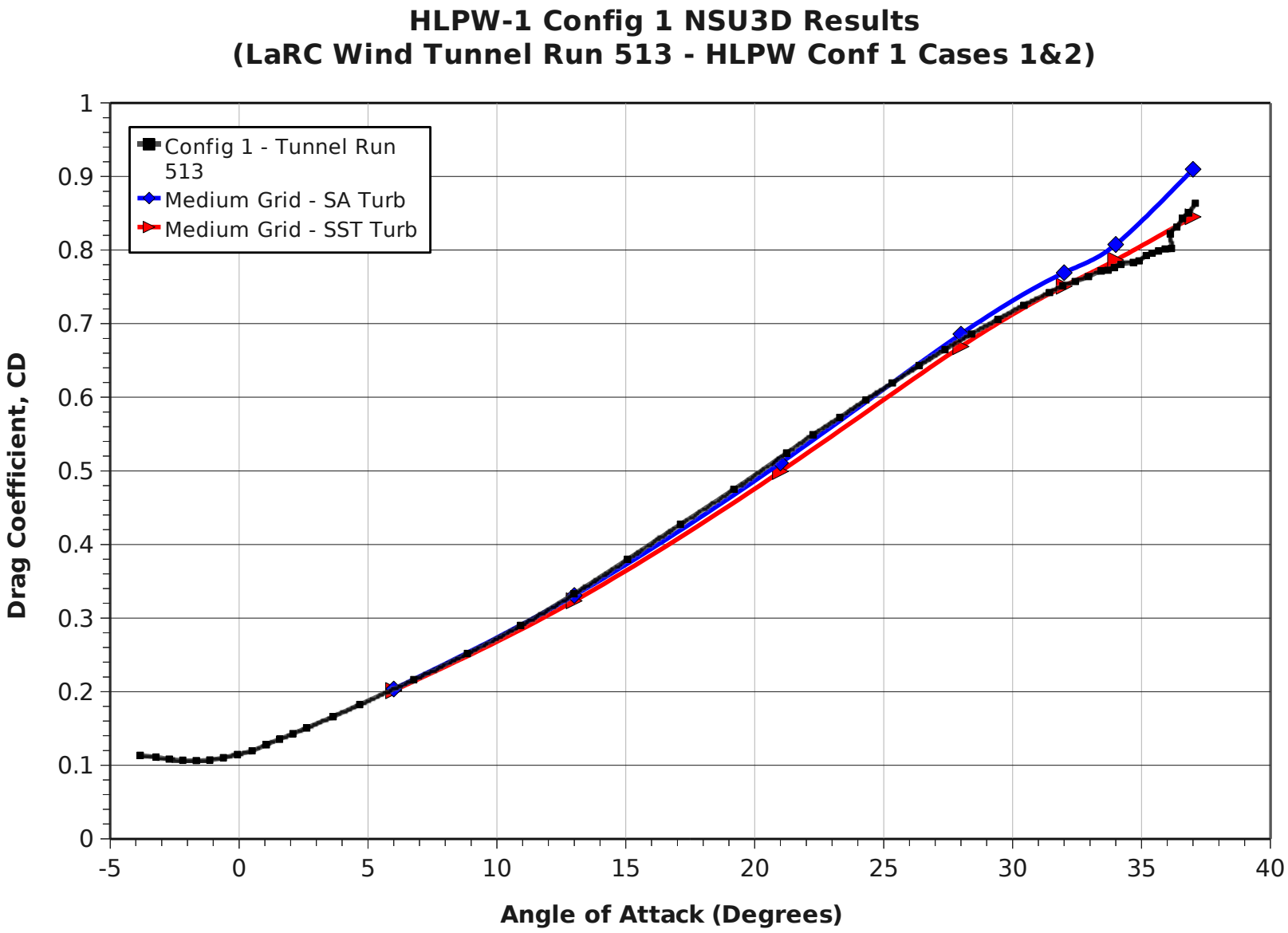
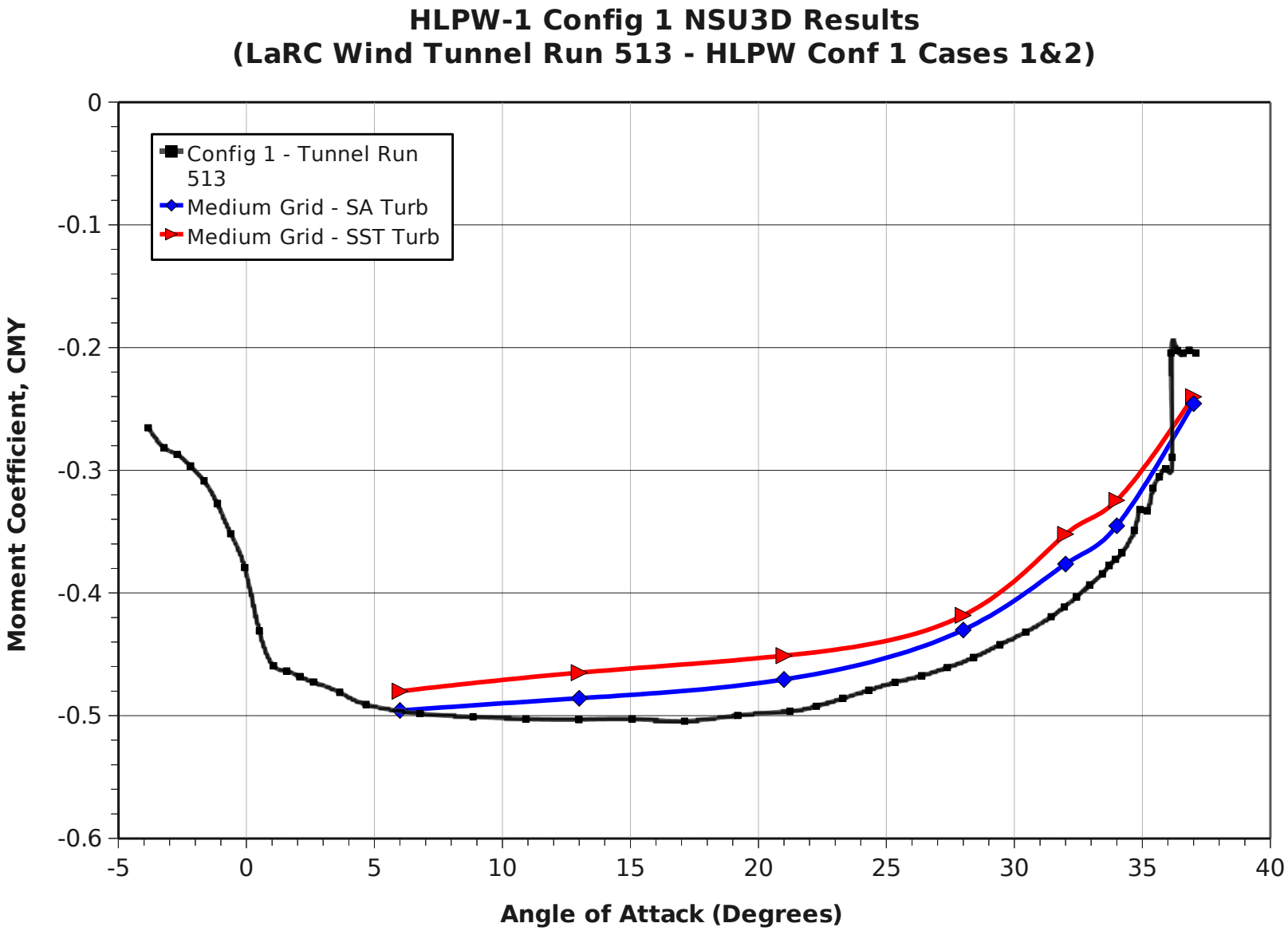


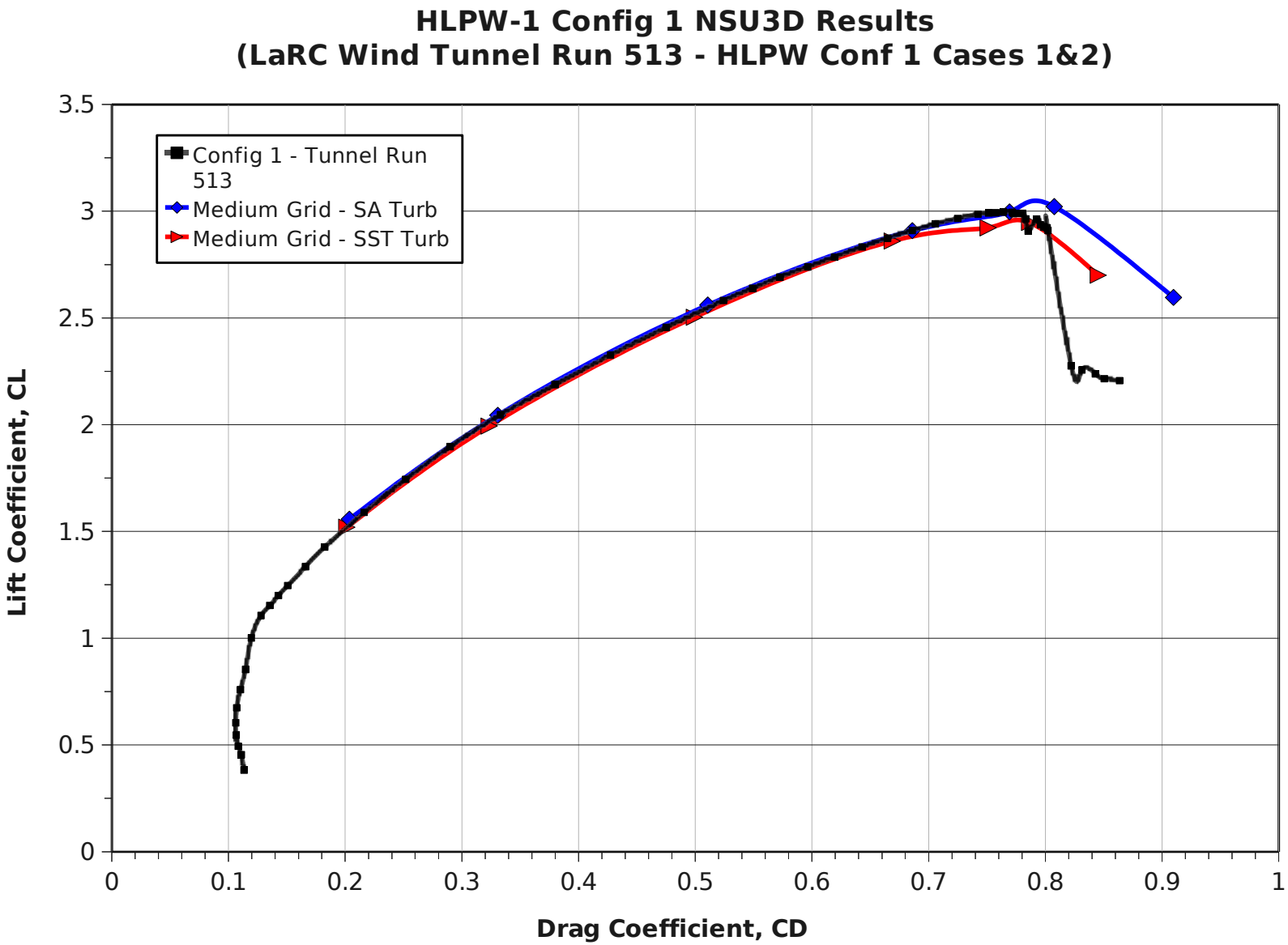
Case 2 – Alpha Sweep – Config 1



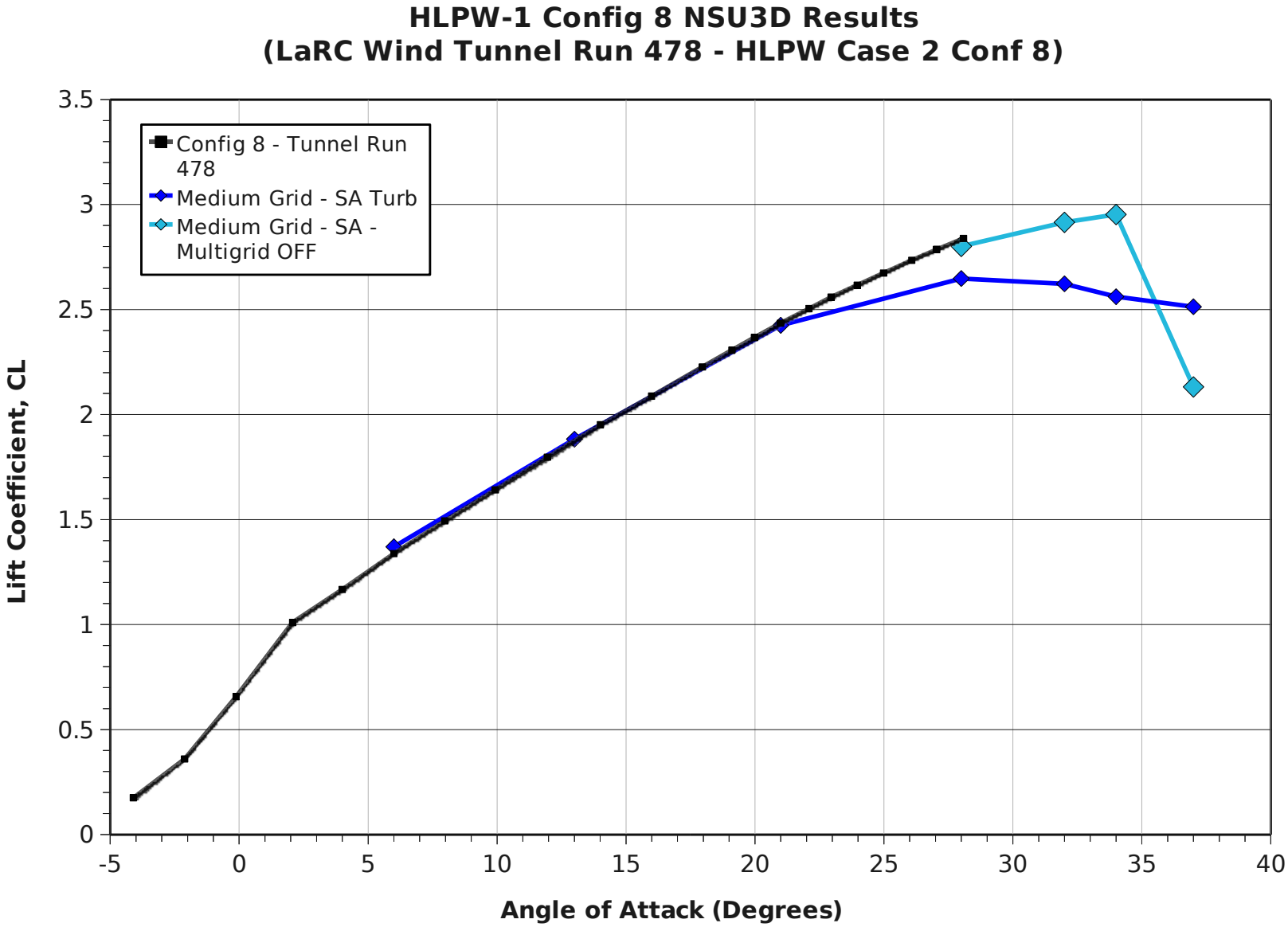
Case 2 – Alpha Sweep – Config 1



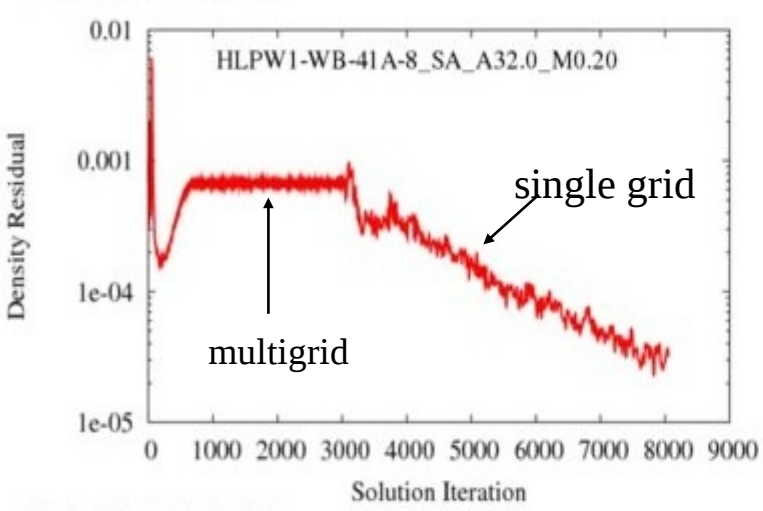
Case 2 – Alpha Sweep – Config 1

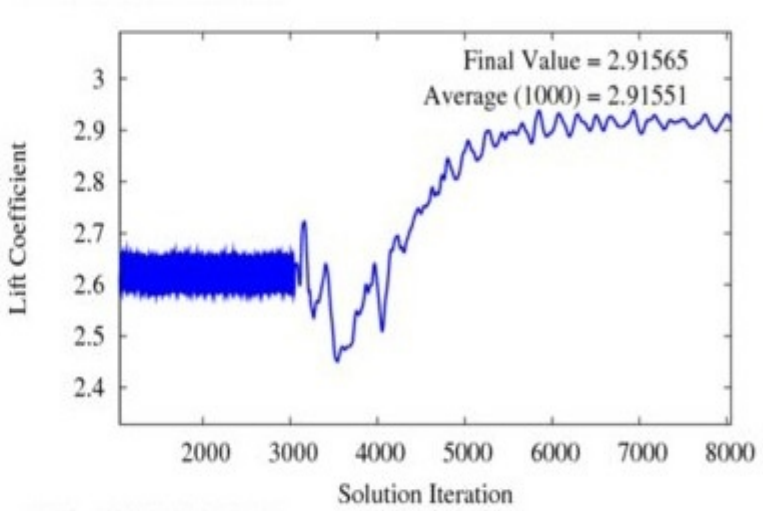


Case 2 – Alpha Sweep – Config 8



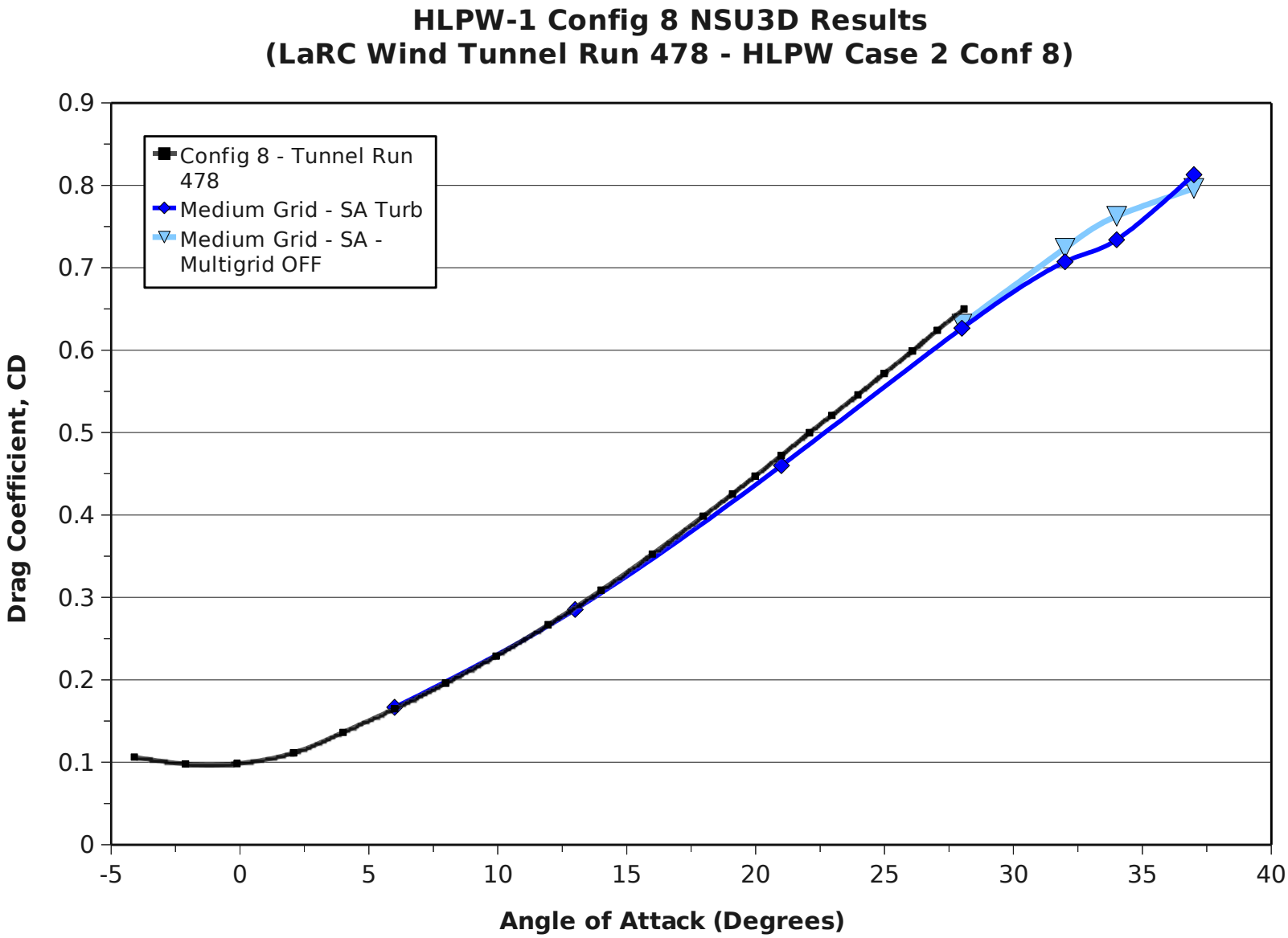
Config 8 Convergence at 32°



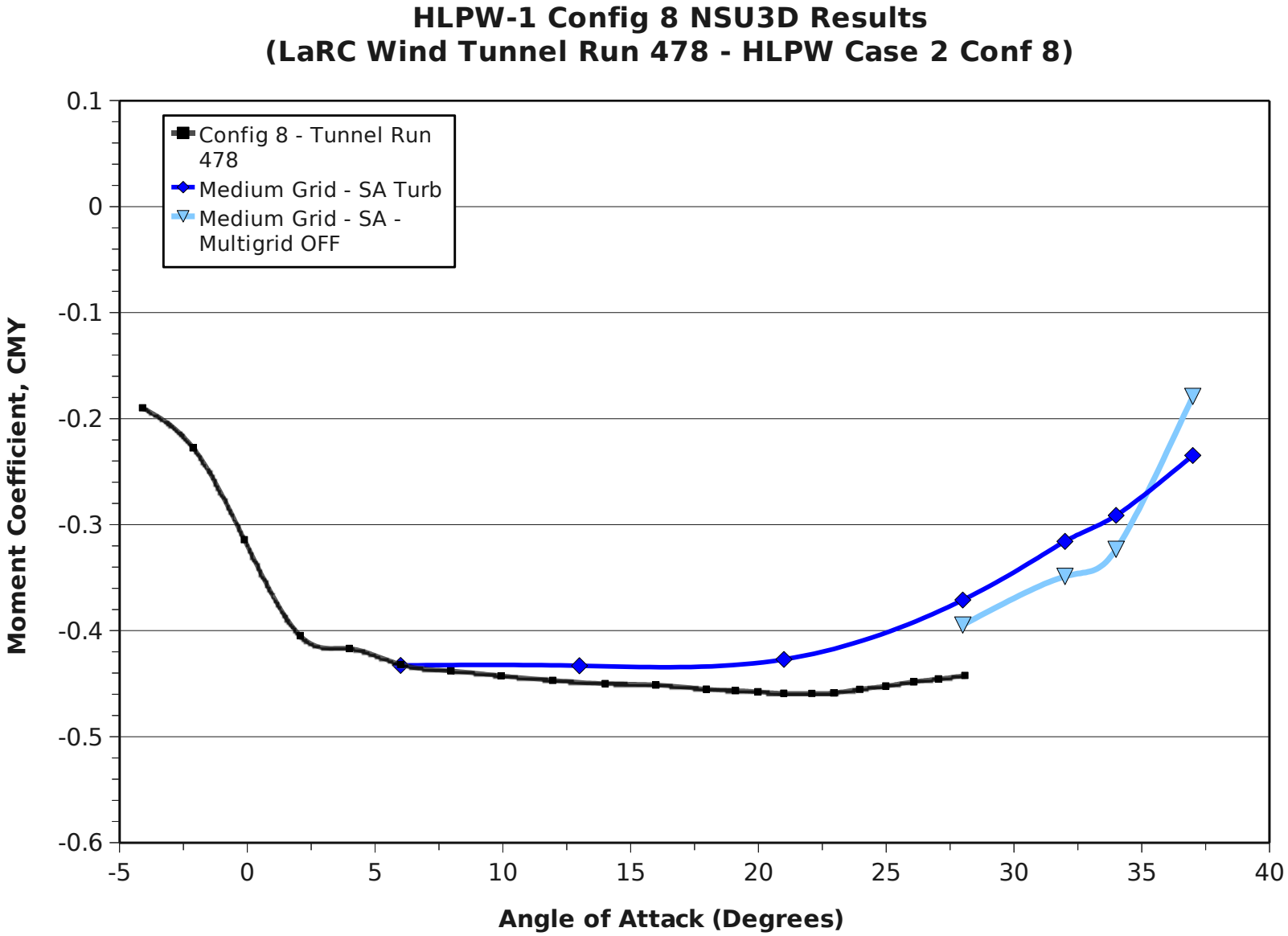


- Multigrid convergence stalls ~ 1000 cycles
- Convergence resumes with single grid solver
  - CL rises to higher value (and closer to experimental curve)

Case 2 – Alpha Sweep – Config 8



Case 2 – Alpha Sweep – Config 1



Surface Cp Comparisons

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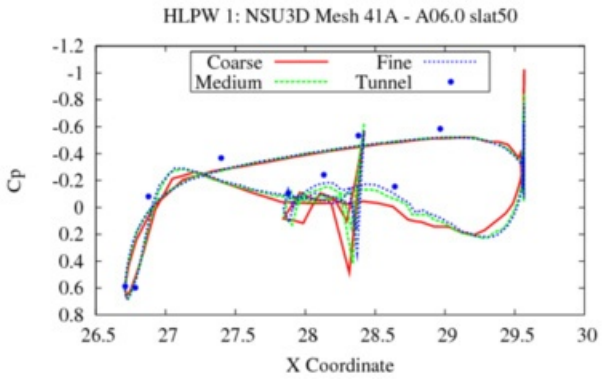
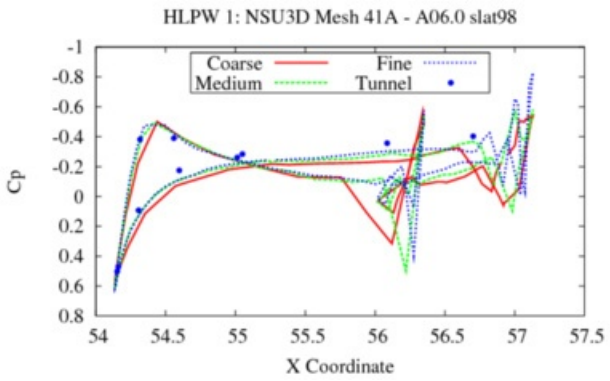
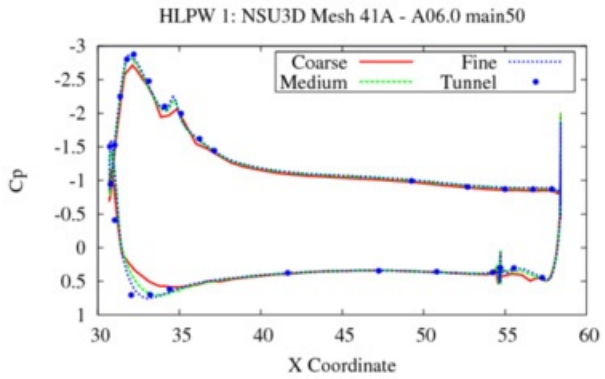
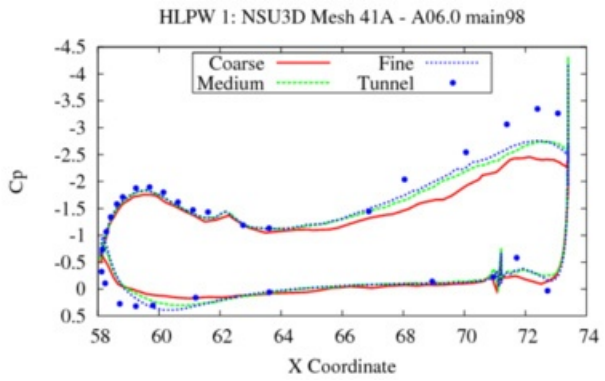
Slat



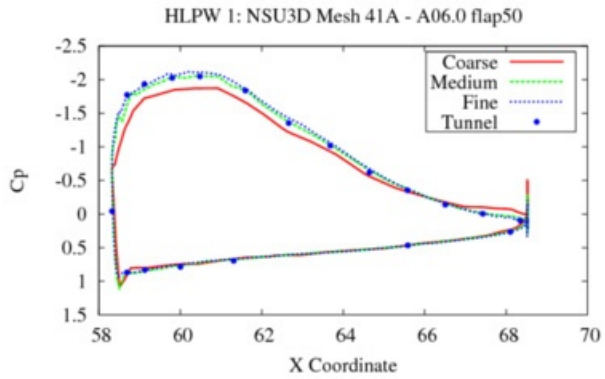


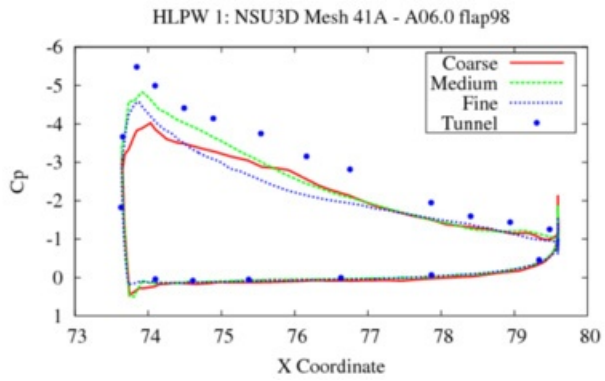
Main





Flap





Alpha = 6°

Surface Cp Comparisons

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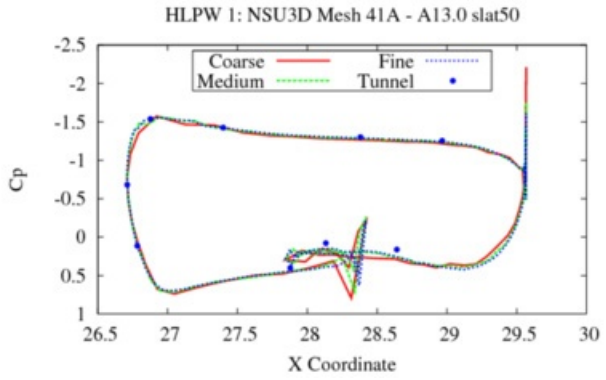
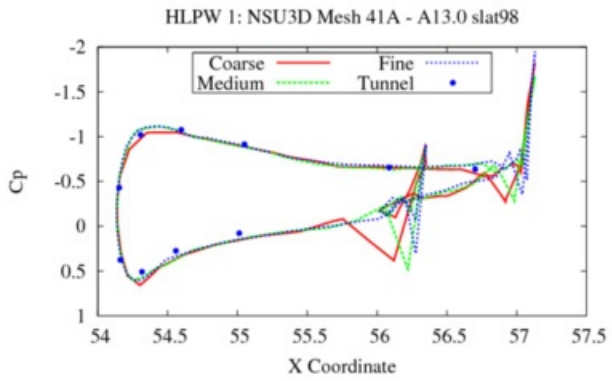
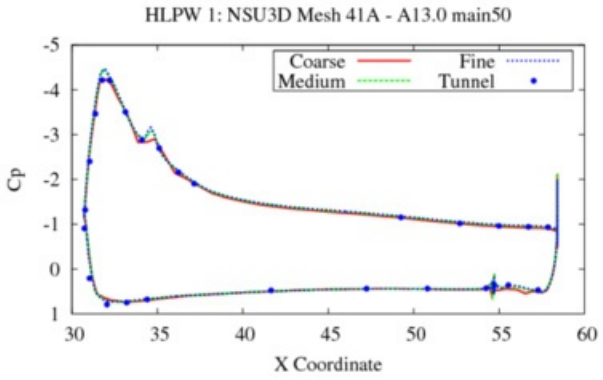
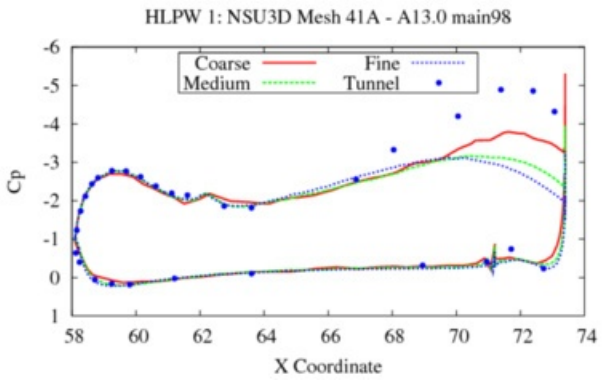
Slat



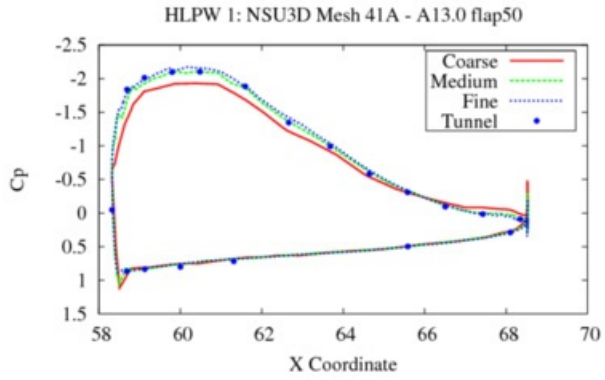


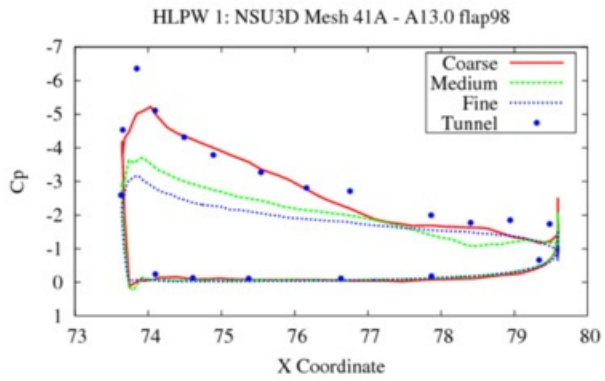
Main





Flap





Alpha = 13°

Surface Cp Comparisons

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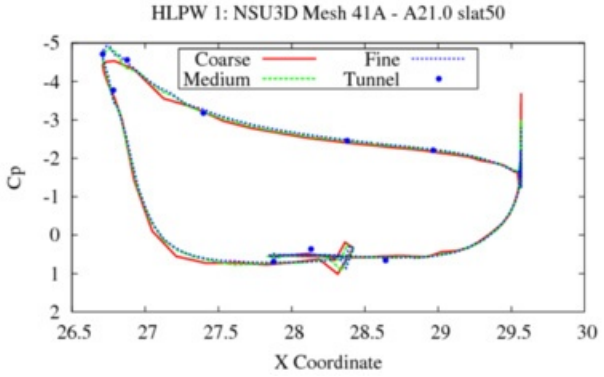
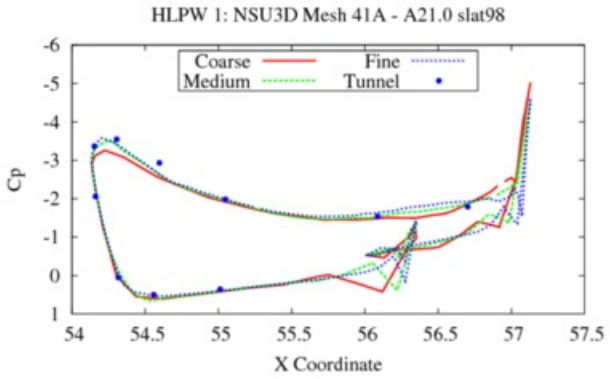
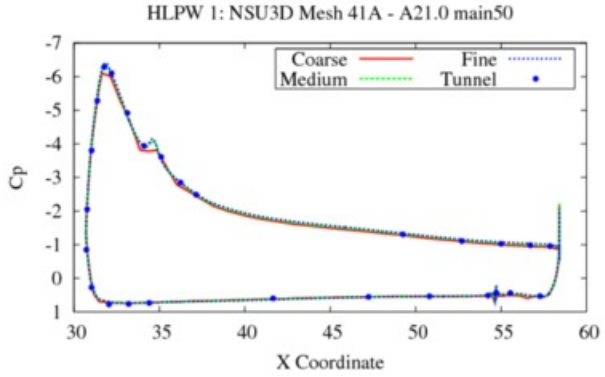
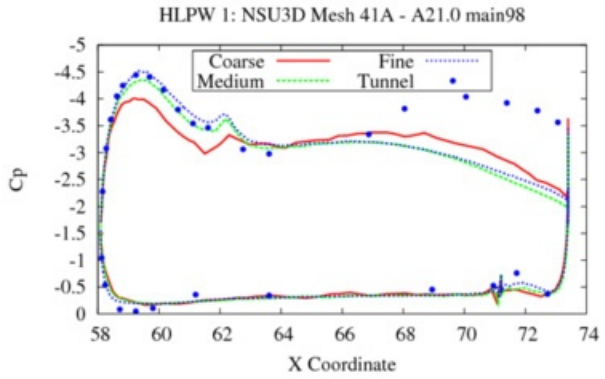
Slat



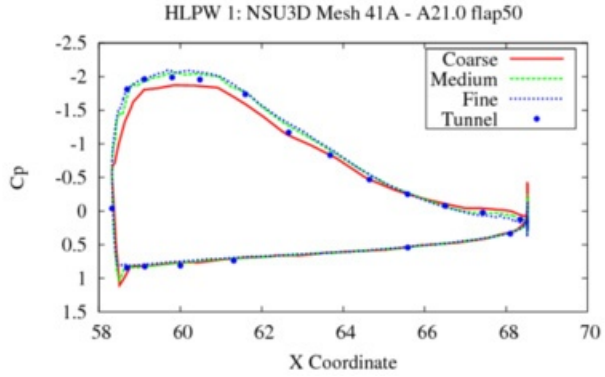


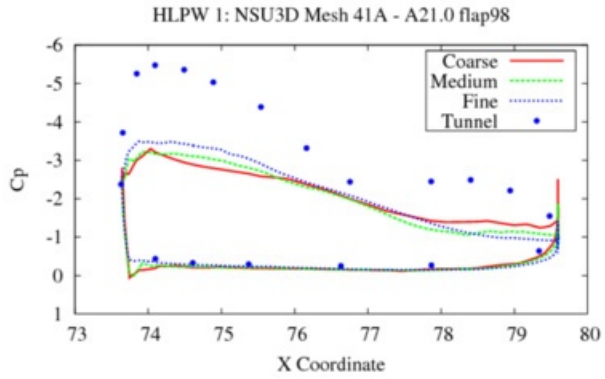
Main





Flap

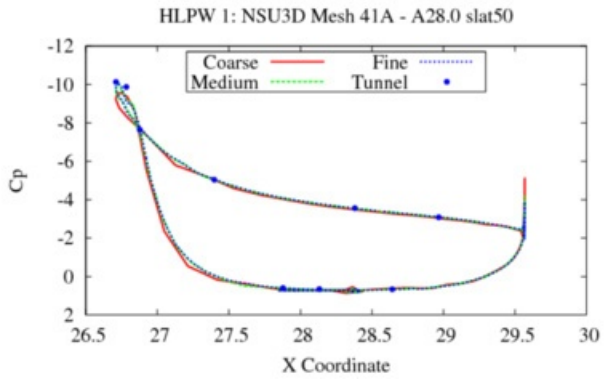


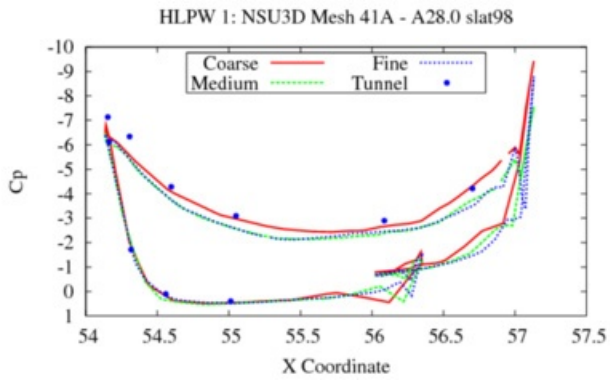


Alpha = 21°

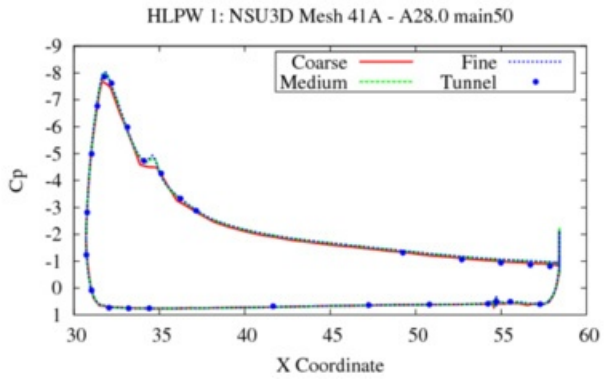
Surface Cp Comparisons

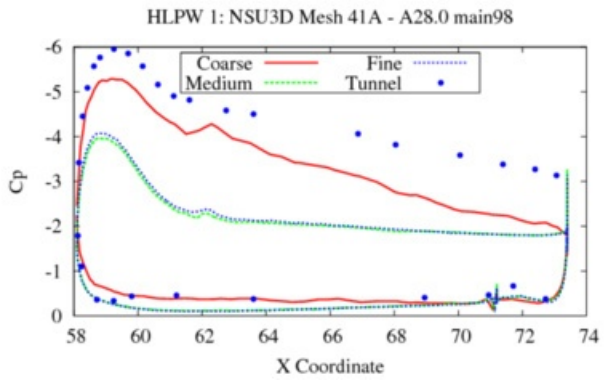
Slat



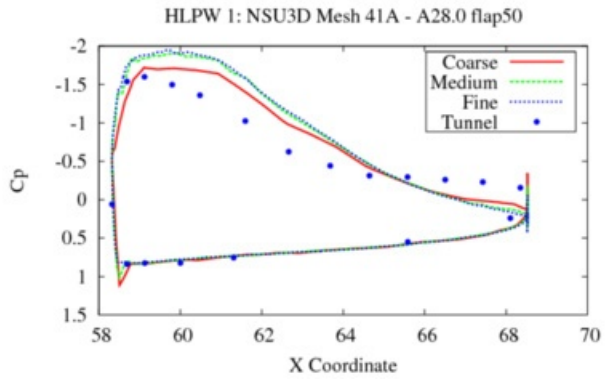


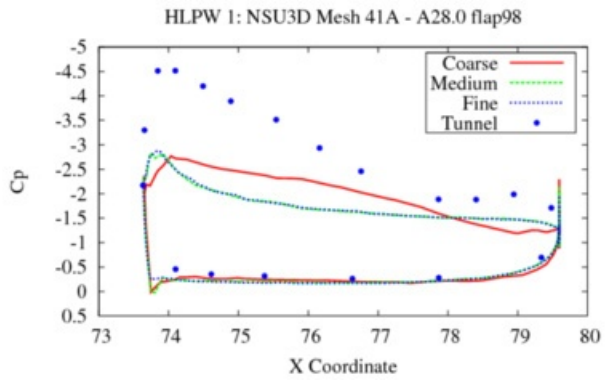
Main





Flap

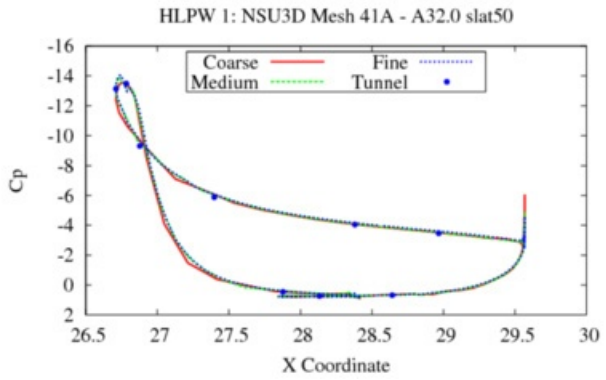


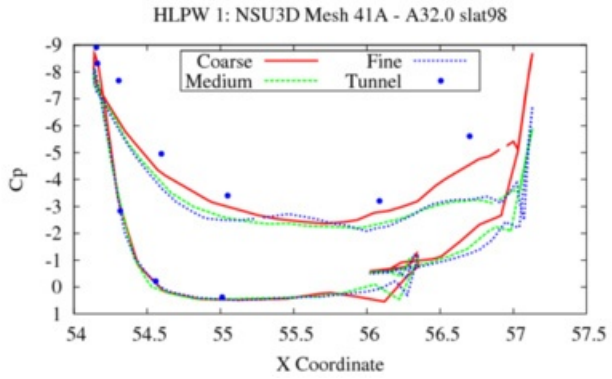


Alpha = 28°

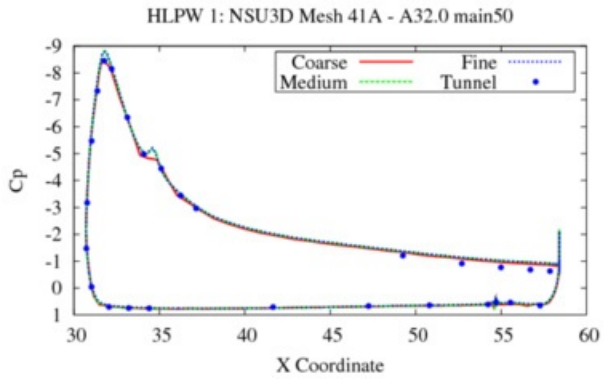
Surface Cp Comparisons

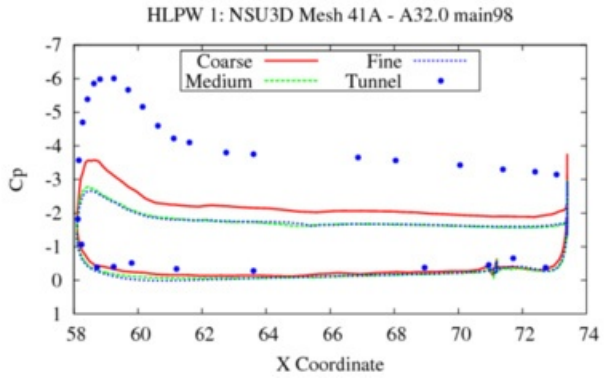
Slat



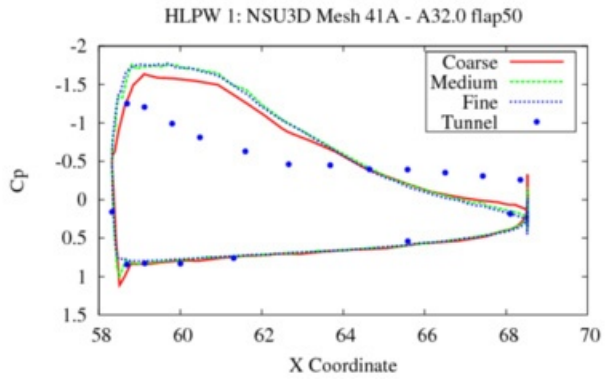


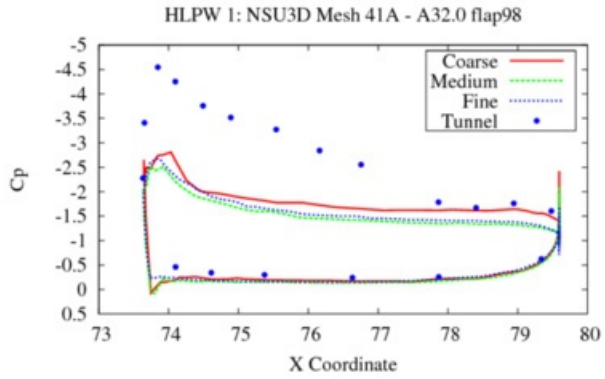
Main





Flap



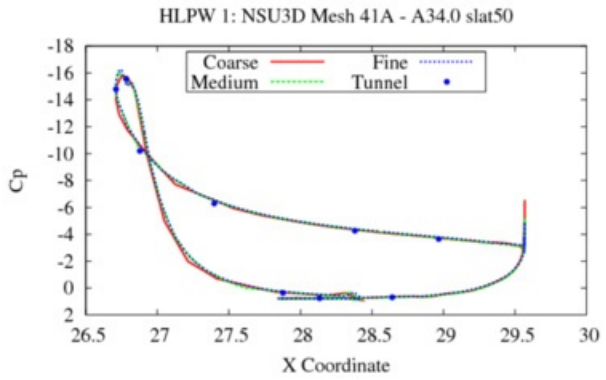


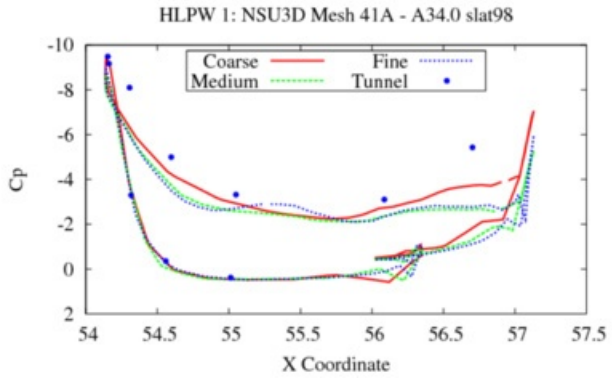
Alpha = 32°

Surface Cp Comparisons

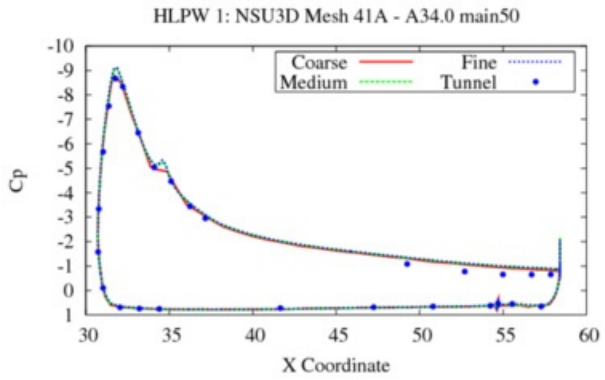
AIAA CFD High Lift Prediction Workshop

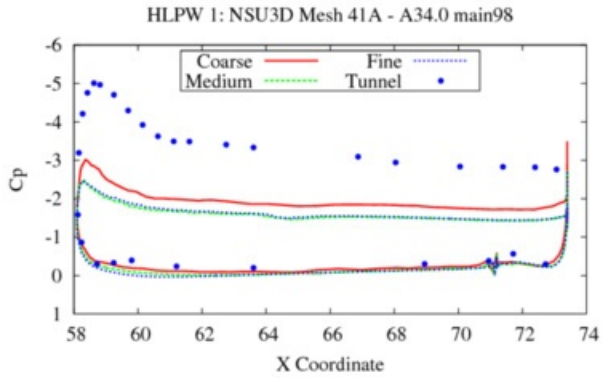
Slat



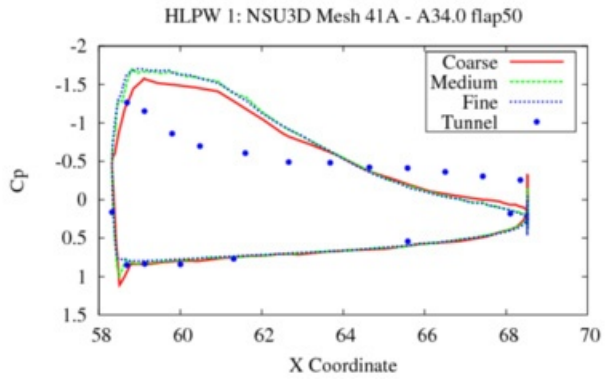


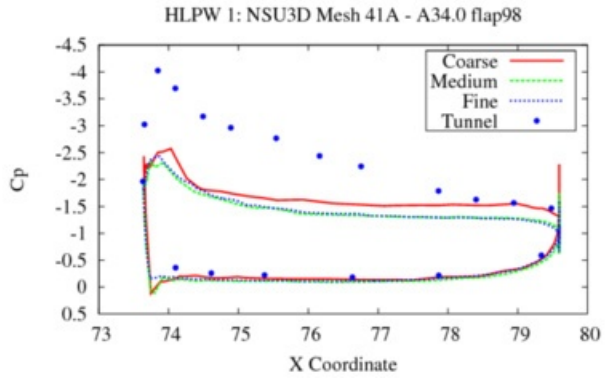
Main





Flap



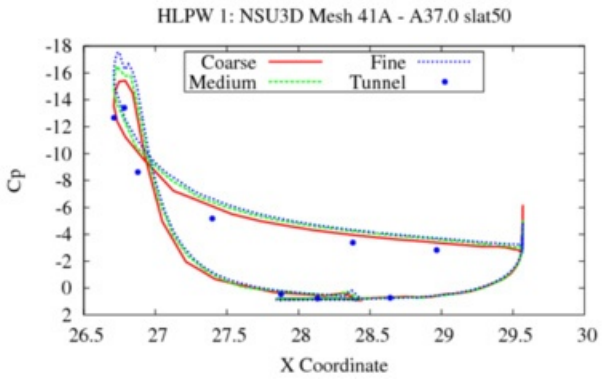


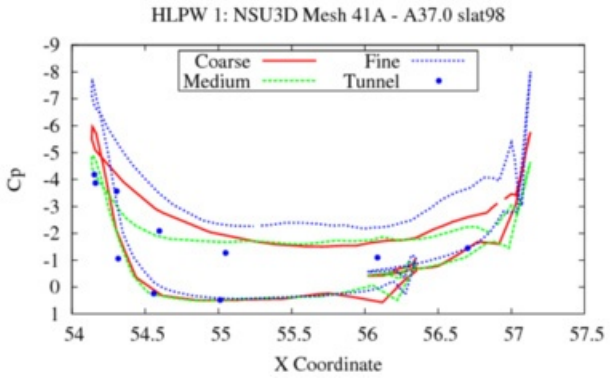
Alpha = 34°

Surface Cp Comparisons

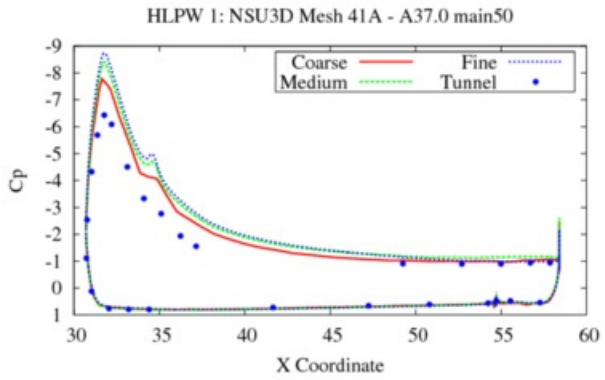
CFD High Lift Prediction Workshop

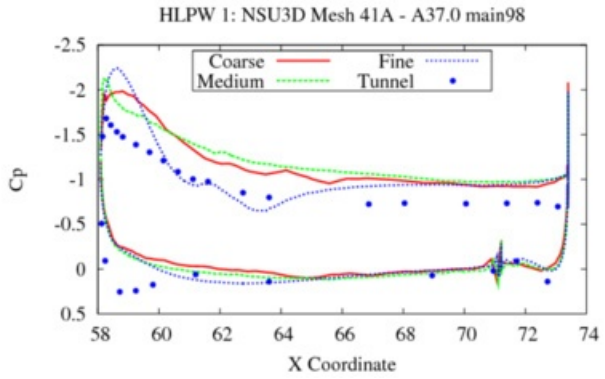
Slat



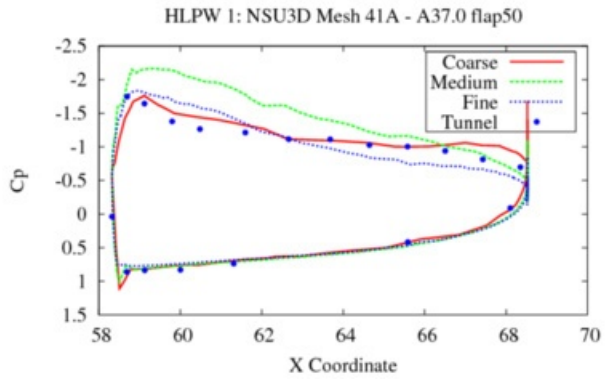


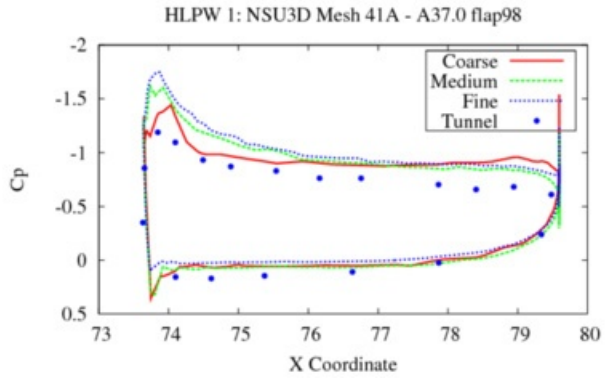
Main





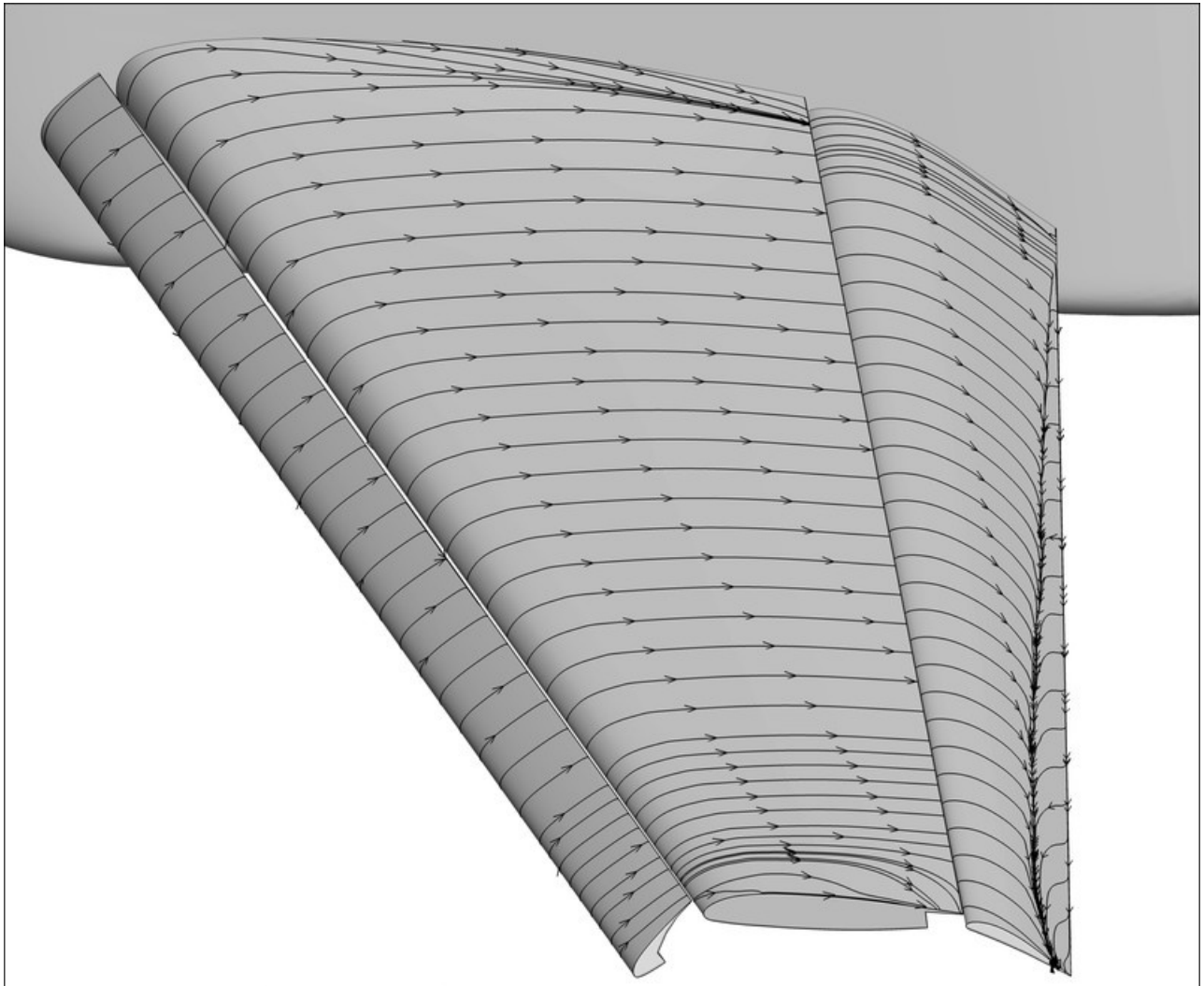
Flap





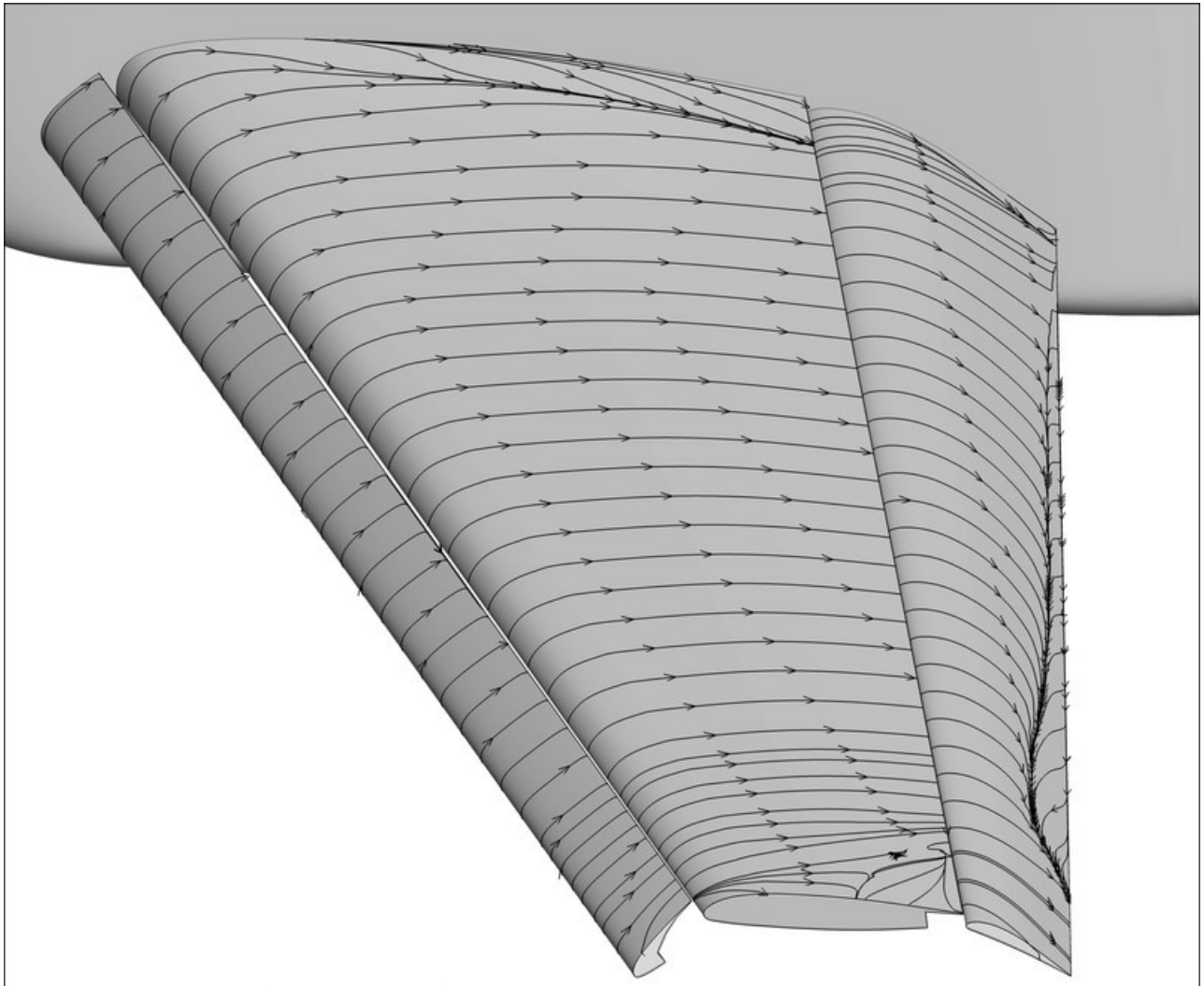
Alpha = 37°

Surface Oil Flows



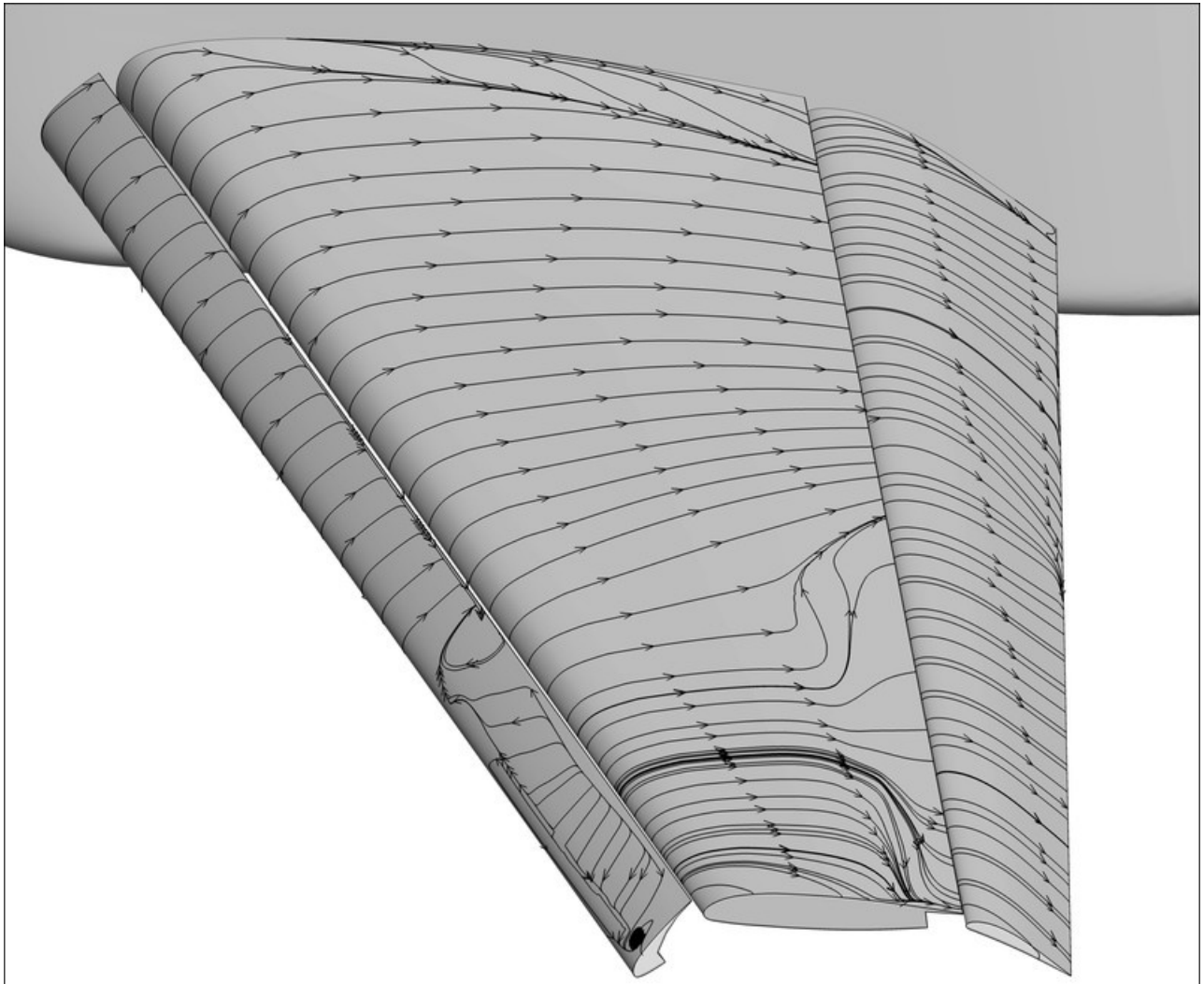
Config 1 SA -- 13 Degrees

Surface Oil Flows



Config 1 SA -- 28 Degrees

Surface Oil Flows



Config 1 SA -- 37 Degrees

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...
- **Compared SA and SST models on Configuration 1**
  - SST model consistently produces slightly lower lift and more separation
- **Convergence issues on Configuration 8**
  - Possible manifestation of hysteresis effect

Acknowledgments

HLPW Organizing Committee for making this happen!

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