W1 and W2 Results using NSU3D

Dimitri Mavriplis

University of Wyoming

NSU3D Description

- Unstructured Reynolds Averaged Navier-Stokes solver
  - Vertex-based discertization
  - Mixed elements (prisms in boundary layer)
  - Edge data structure
  - Matrix artificial dissipation
    - Option for upwind scheme with gradient reconstruction
  - No cross derivative viscous terms
    - Thin layer in all 3 directions
    - Option for full Navier-Stokes terms

Solver Description (cont'd)

- Spalart-Allmaras turbulence model
  - (original published form)
  - Optional k-omega model

Solution Strategy

- 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
    - DPW runs: MPI on local cluster and on NASA Columbia Supercomputer

Grid Generation

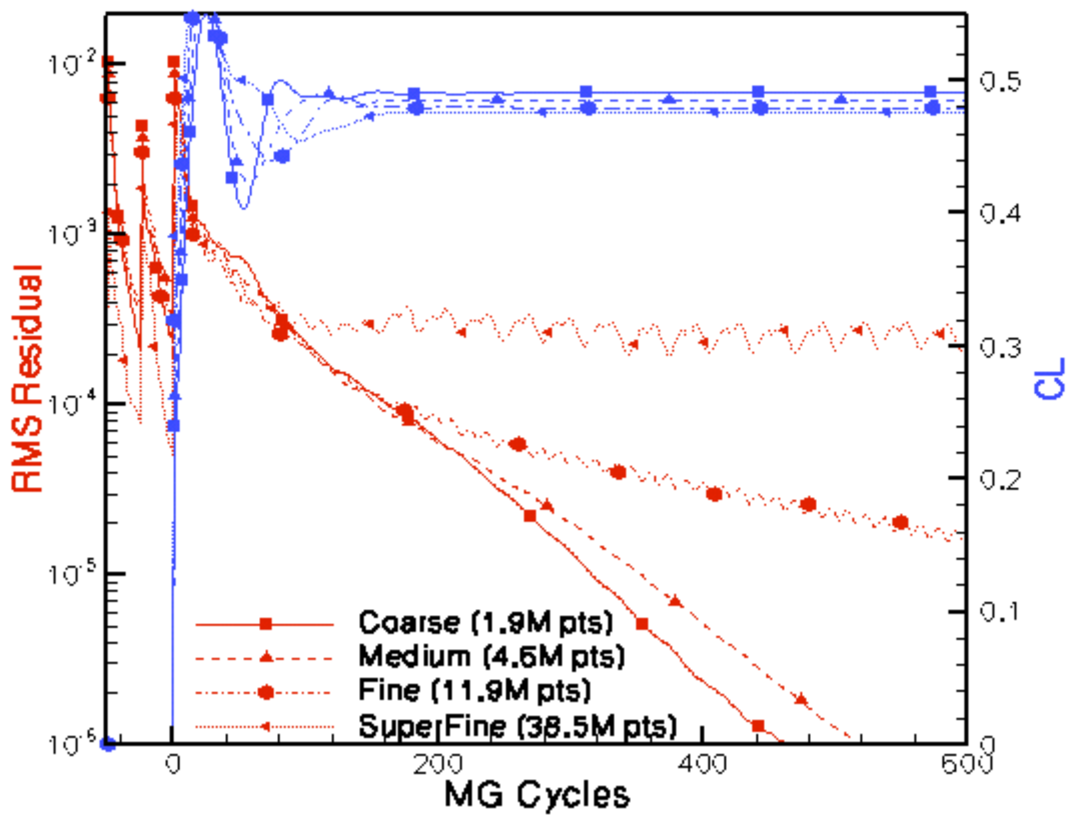
- Runs based on NASA Langley supplied VGRIDns unstructured grids
- Tetrahedra in Boundary Layer merged into prismatic elements

- Grid sizes up to 39M pts, 220M elements
  - Coarse ~1.8M pts
  - Medium ~4.5M pts
  - Fine ~14M pts
  - SuperFine ~39M pts

Sample Run Times

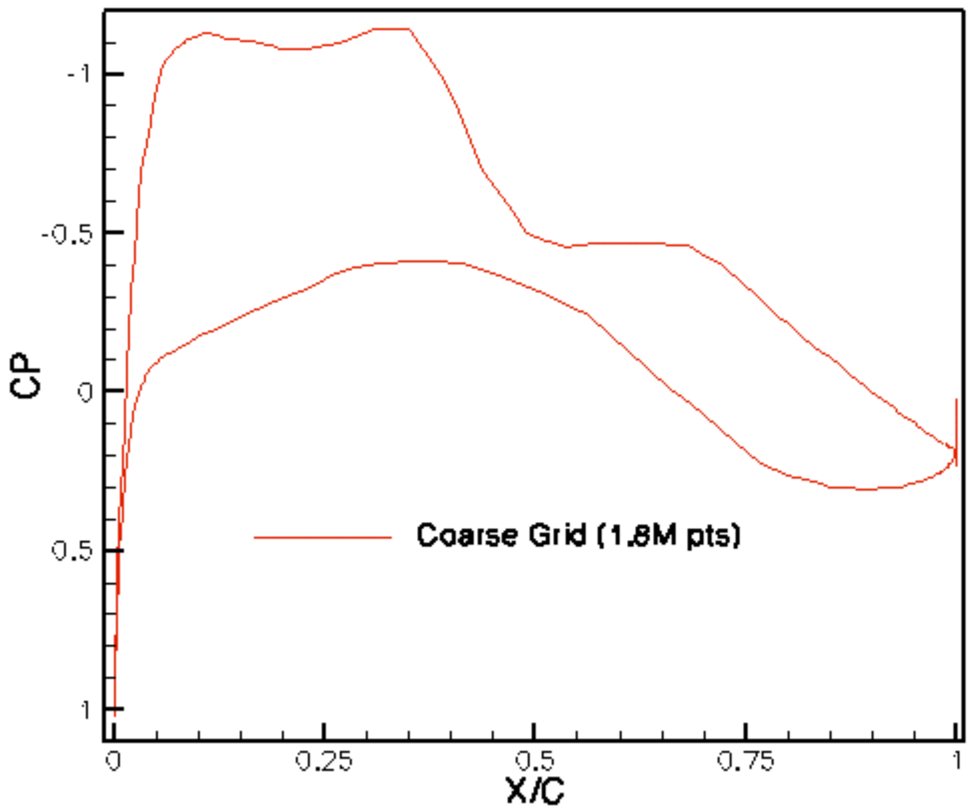
- All runs performed on NASA Columbia Supercomputer
  - SGI Altix 512cpu machines
  - Coarse/Medium (~15Mpts) grids used 96 cpus
    - Using 500 to 800 multigrid cycles
      - 30 minutes for coarse grid
      - 1.5 hrs for medium grid
  - Fine Grids (~40M pts) used 248 cpus
    - Using 500 to 800 multigrid cycles
      - 1.5 to 2 hrs for fine grid

W1 Convergence (fixed alpha=0.5)



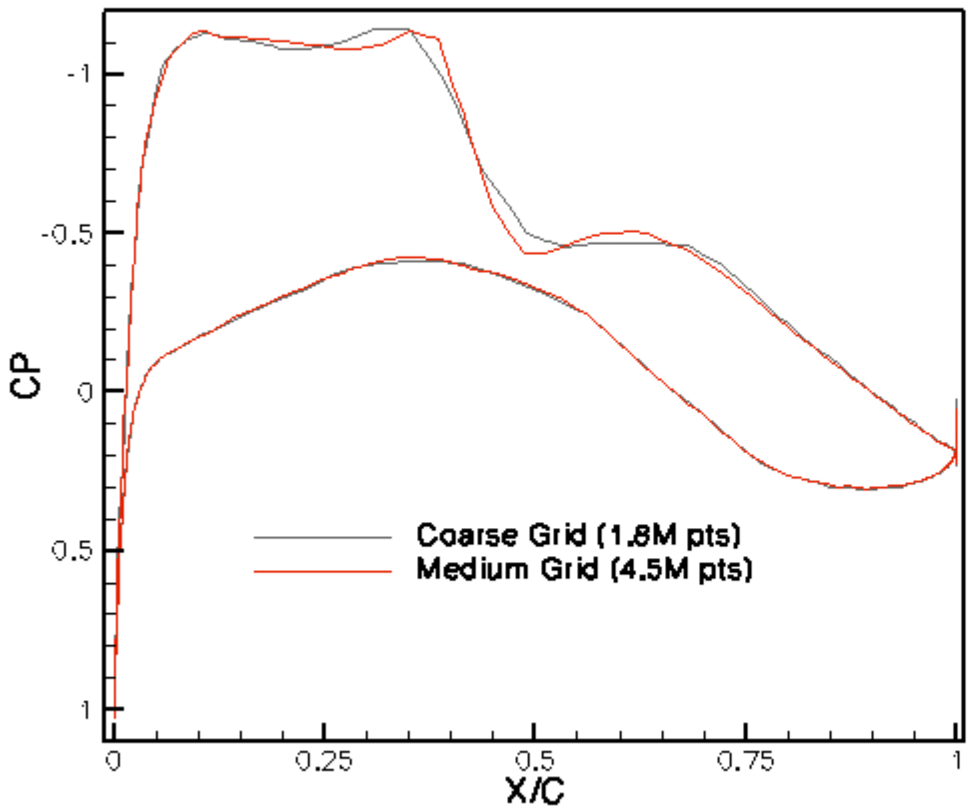
- "Similar" convergence for coarse/med grids
- Apparent unsteadiness in residual for finest grid
- Force coefficients well converged < 500 MG cycles for all grids

W1 Grid Convergence Study



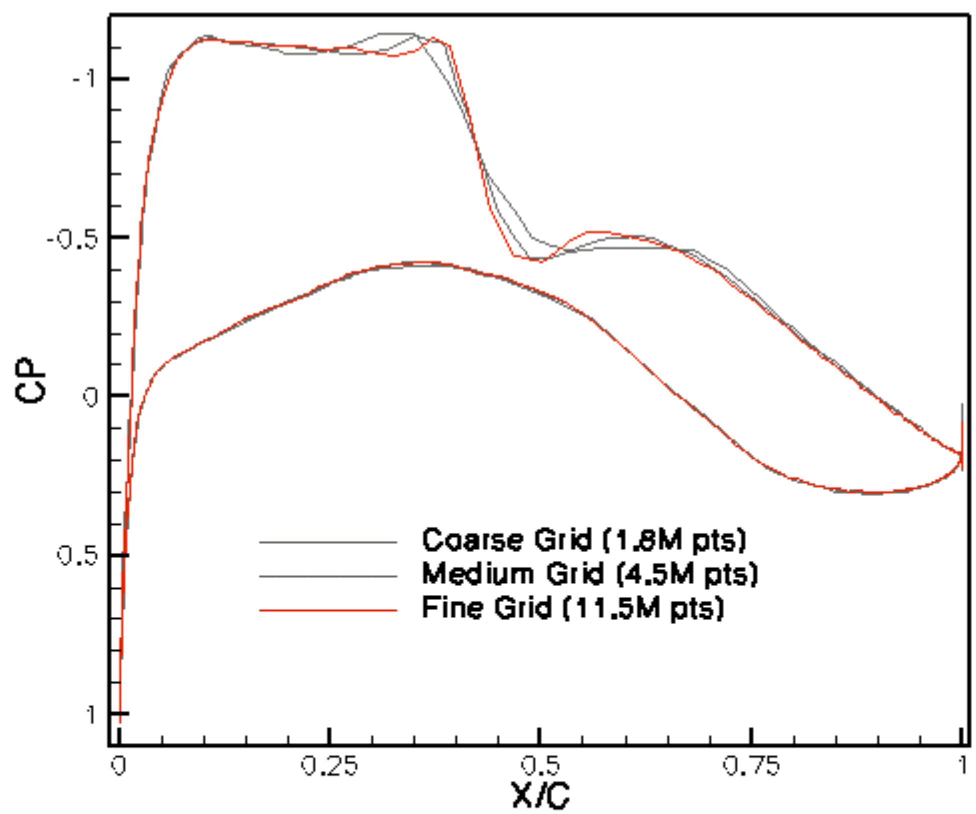
- CP at station 5:

W1 Grid Convergence Study



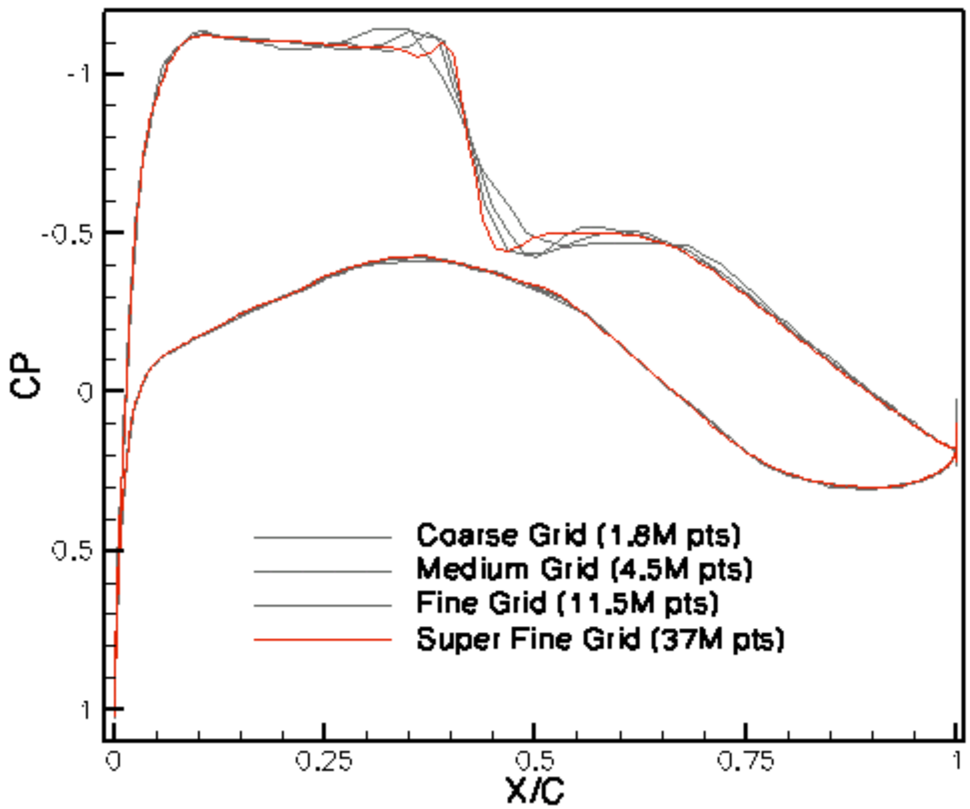
- CP at station 5:

W1 Grid Convergence Study



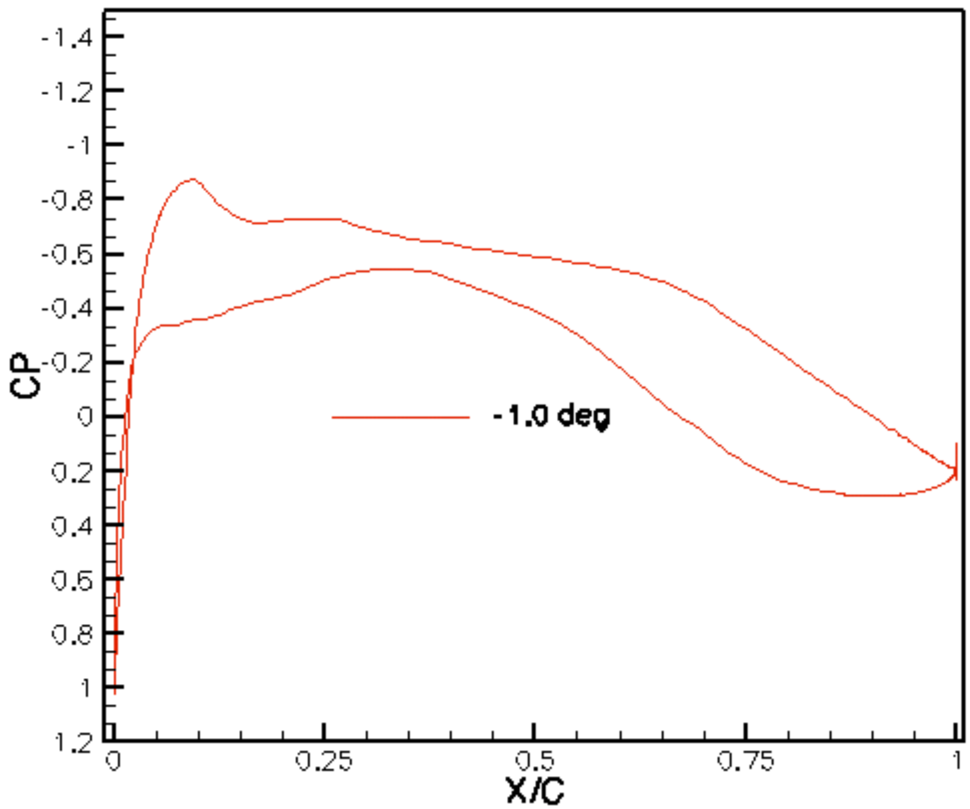
- CP at station 5:

W1 Grid Convergence Study



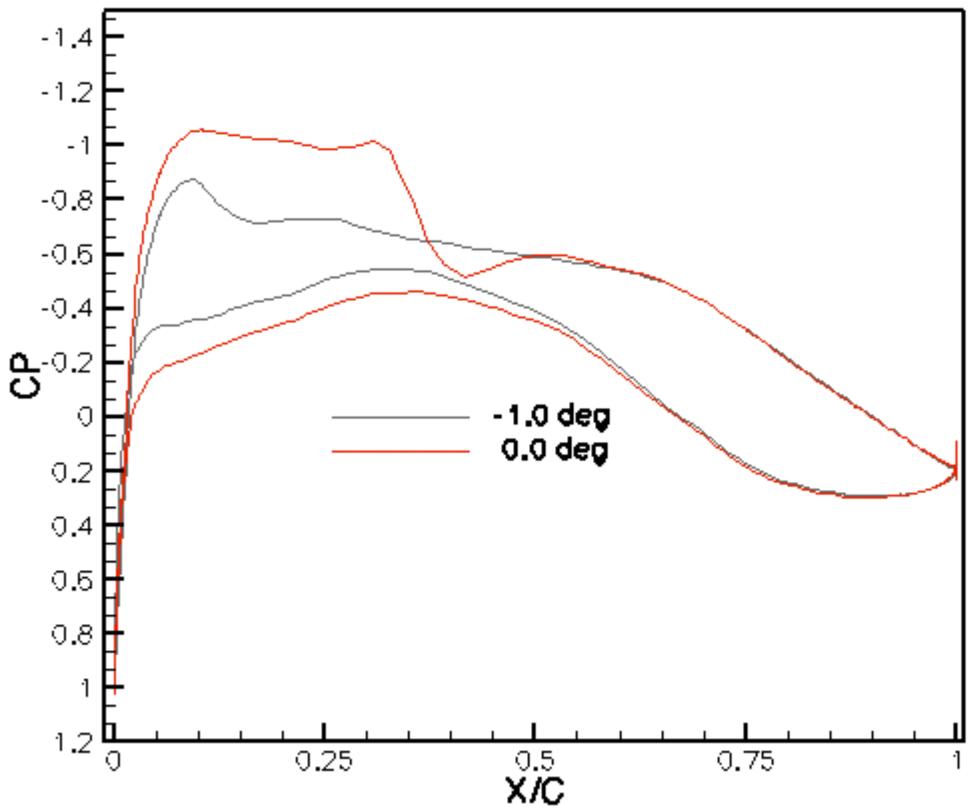
- CP at station 5:

W1 Grid Polar Sweep (Fine Grid)



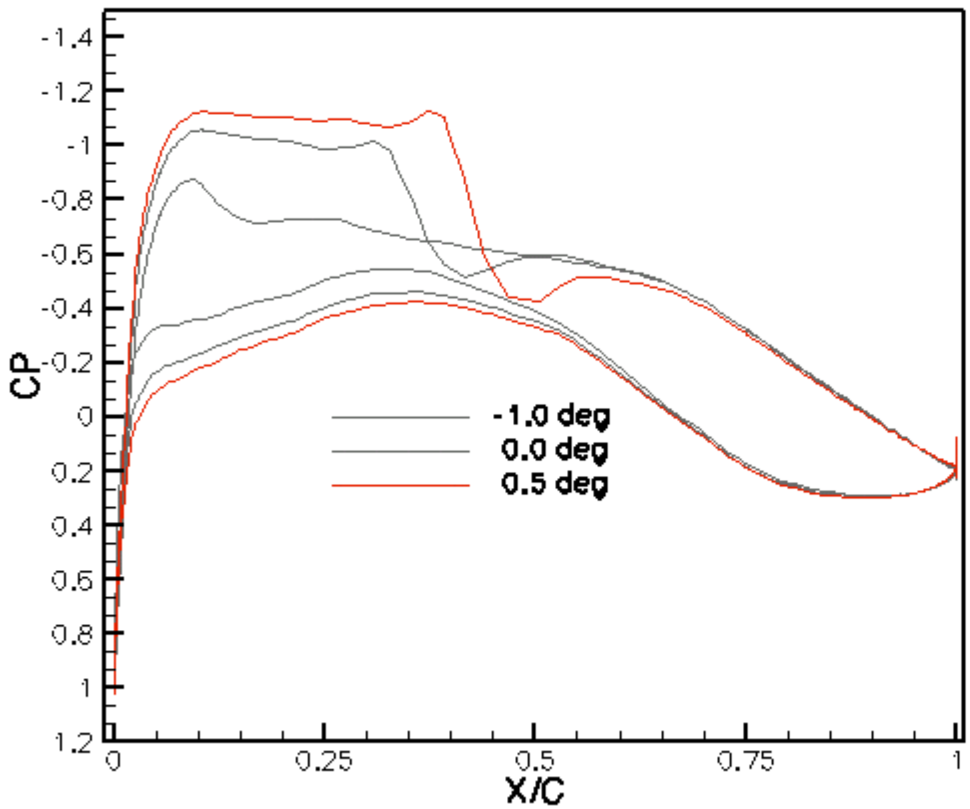
- CP at station 5

W1 Grid Polar Sweep (Fine Grid)



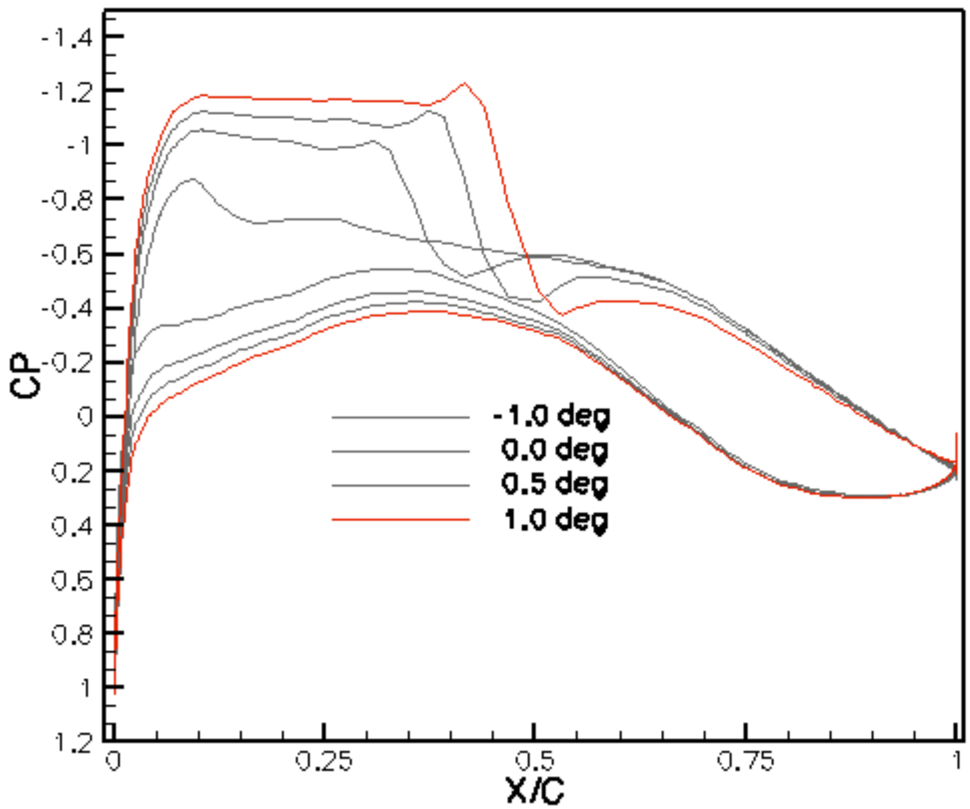
- CP at station 5

W1 Grid Polar Sweep (Fine Grid)



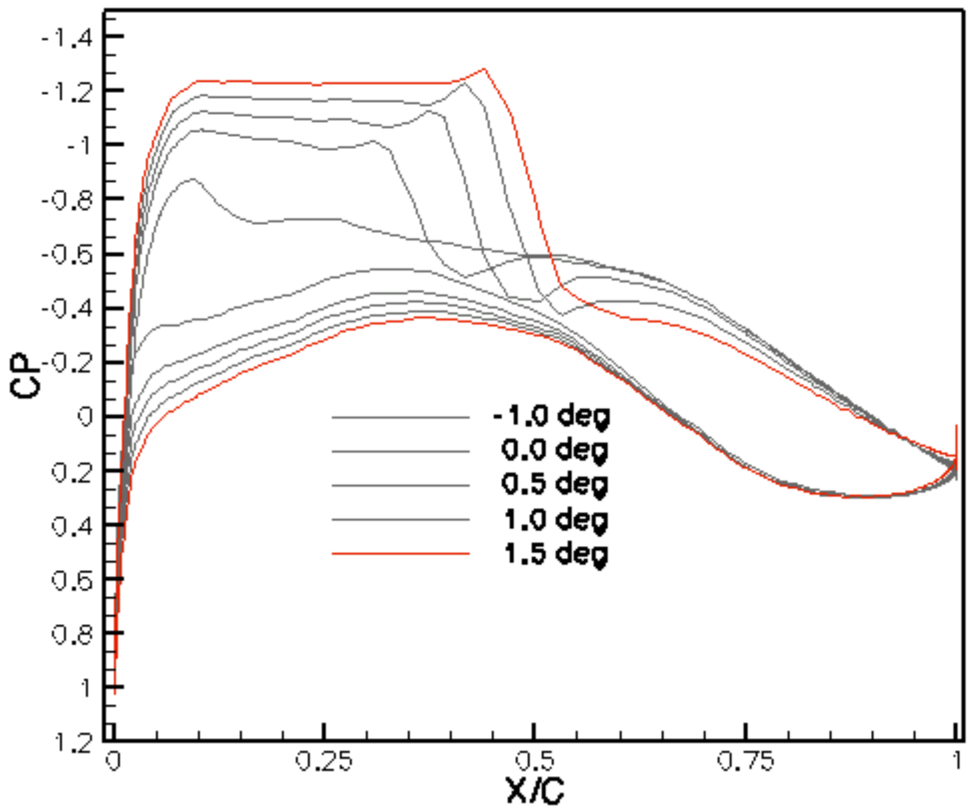
- CP at station 5

W1 Grid Polar Sweep (Fine Grid)



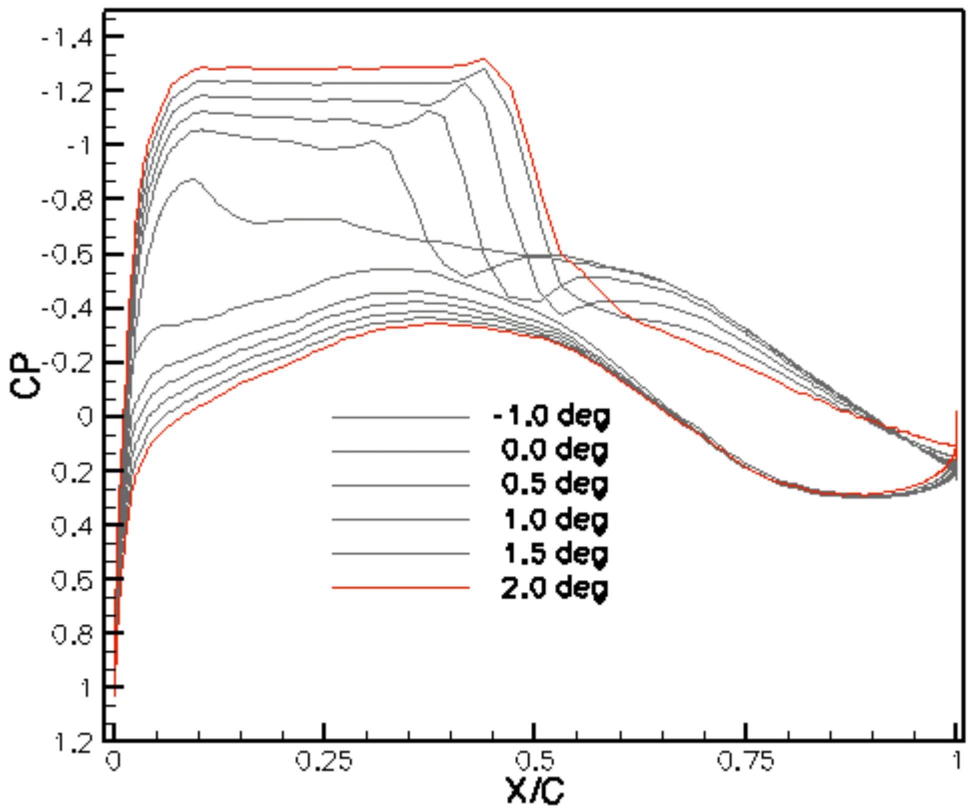
- CP at station 5

W1 Grid Polar Sweep (Fine Grid)



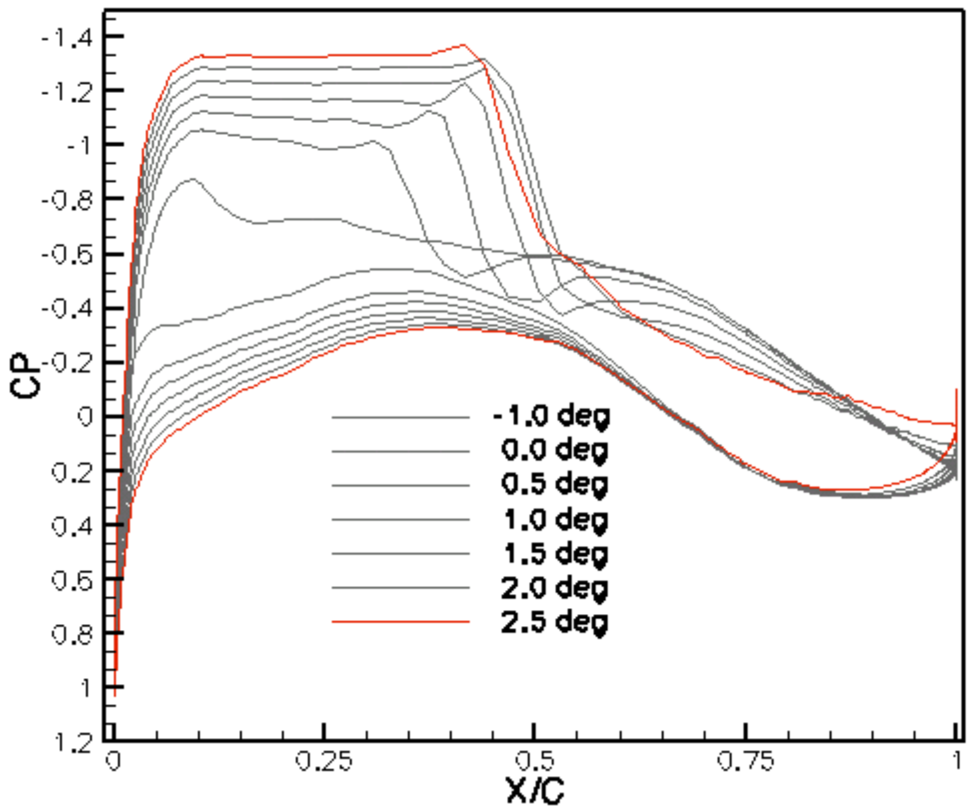
- CP at station 5

W1 Grid Polar Sweep (Fine Grid)



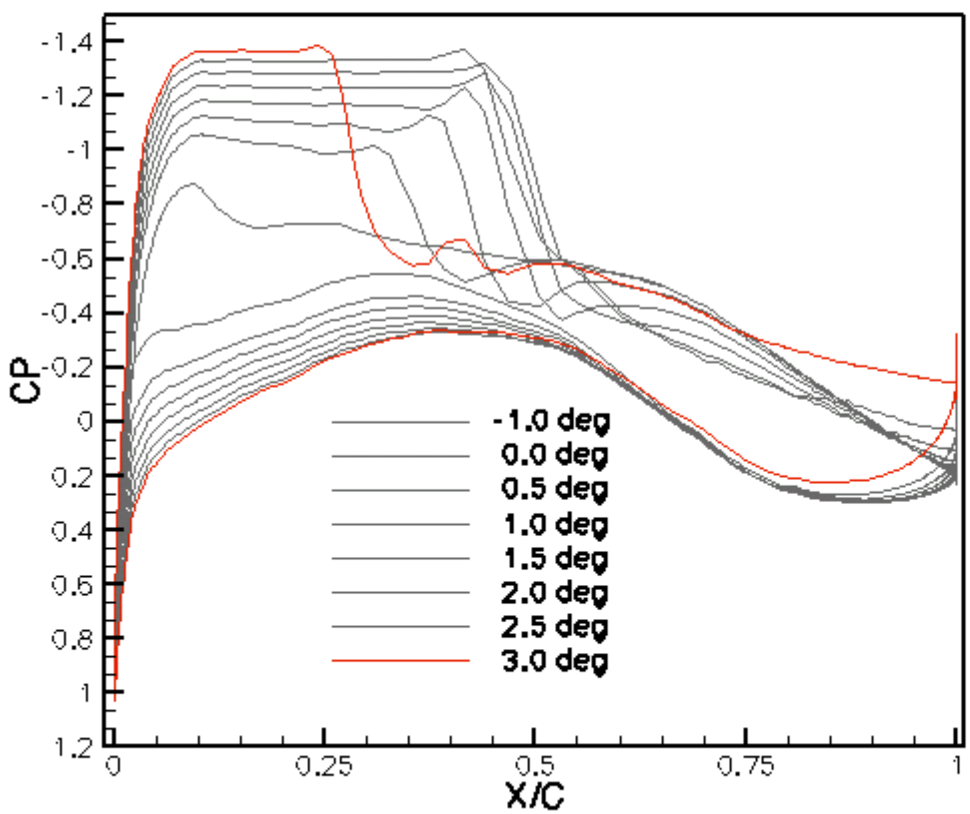
- CP at station 5

W1 Grid Polar Sweep (Fine Grid)



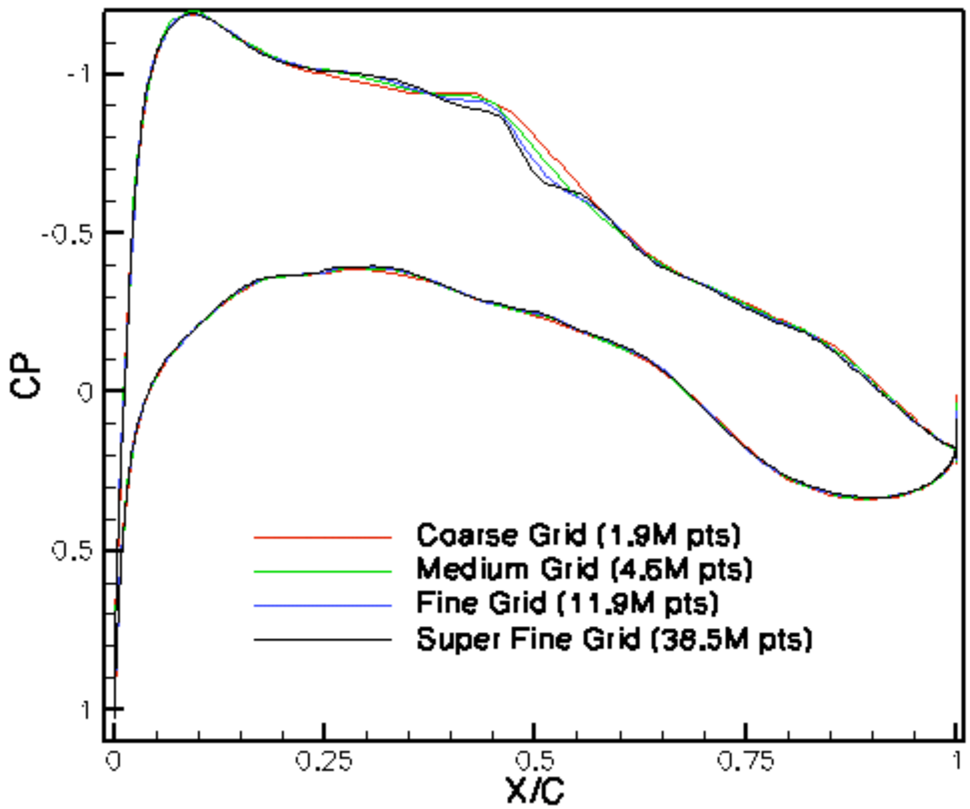
- CP at station 5

W1 Grid Polar Sweep (Fine Grid)



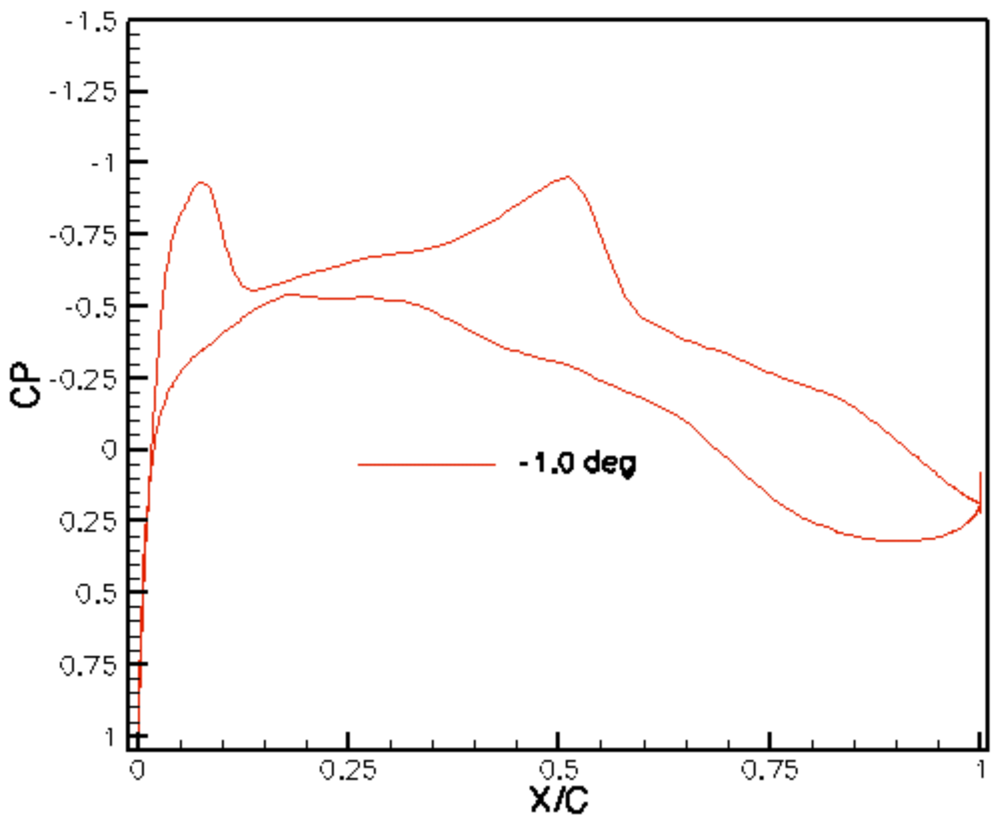
- CP at station 5

W2 Grid Convergence Study



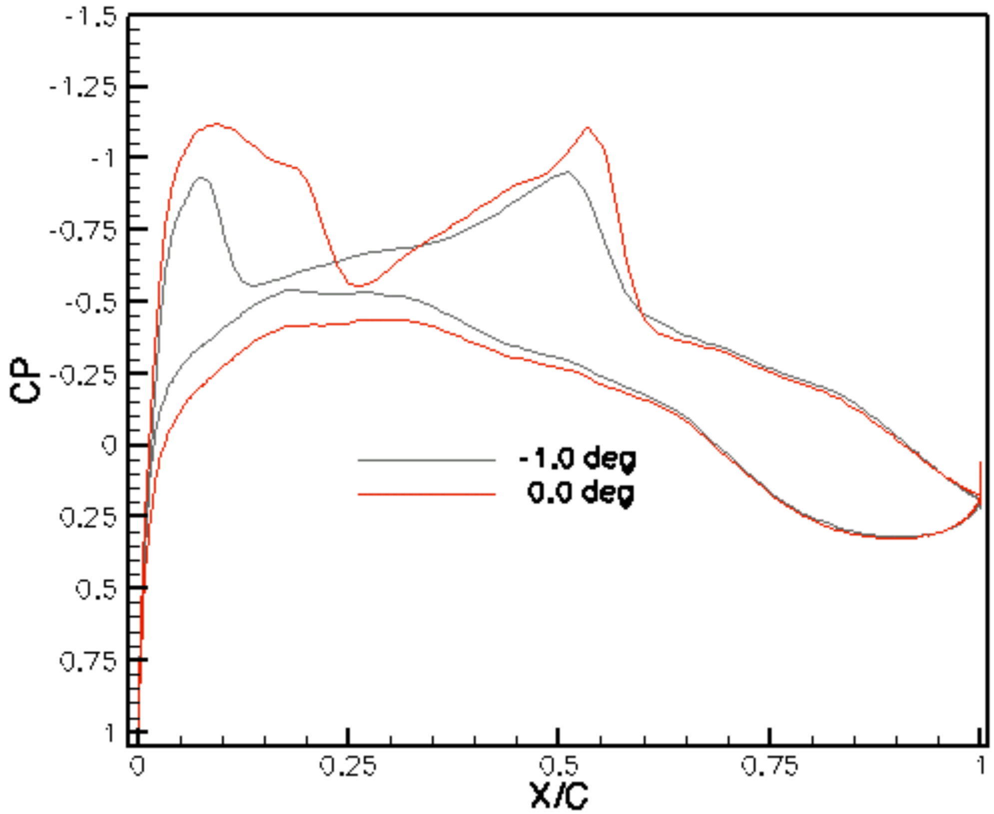
- CP at station 5

W2 Grid Polar Sweep (Fine Grid)



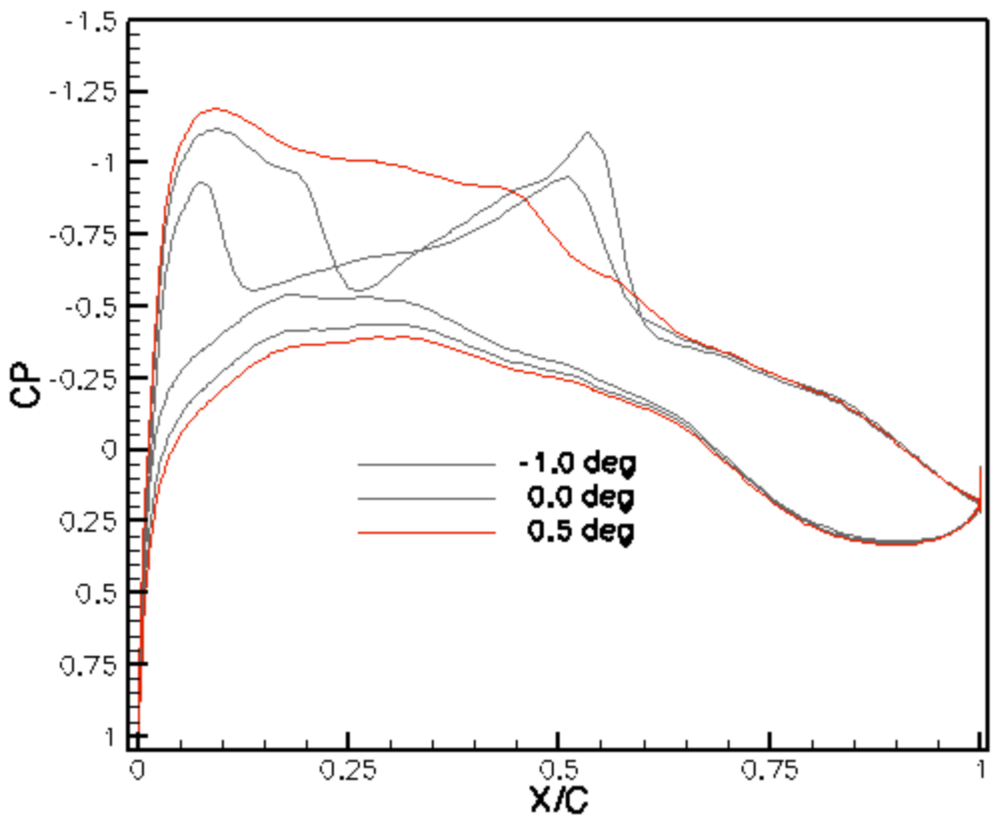
- CP at station 5

W2 Grid Polar Sweep (Fine Grid)



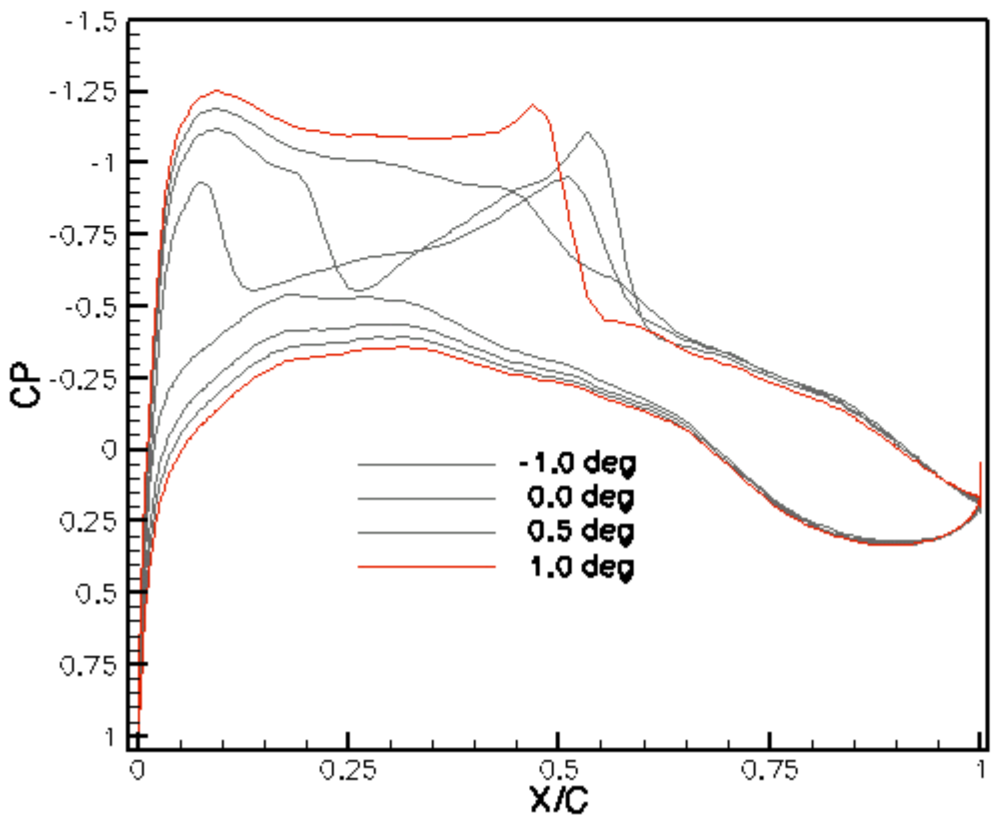
- CP at station 5

W2 Grid Polar Sweep (Fine Grid)



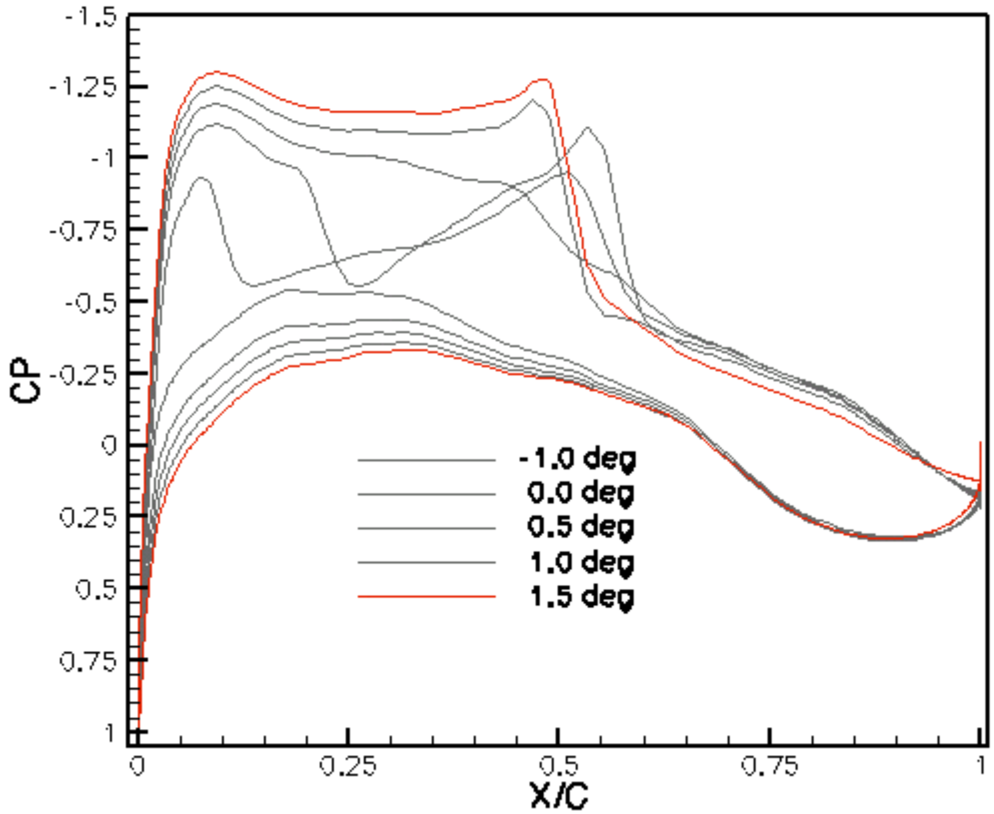
- CP at station 5

W2 Grid Polar Sweep (Fine Grid)



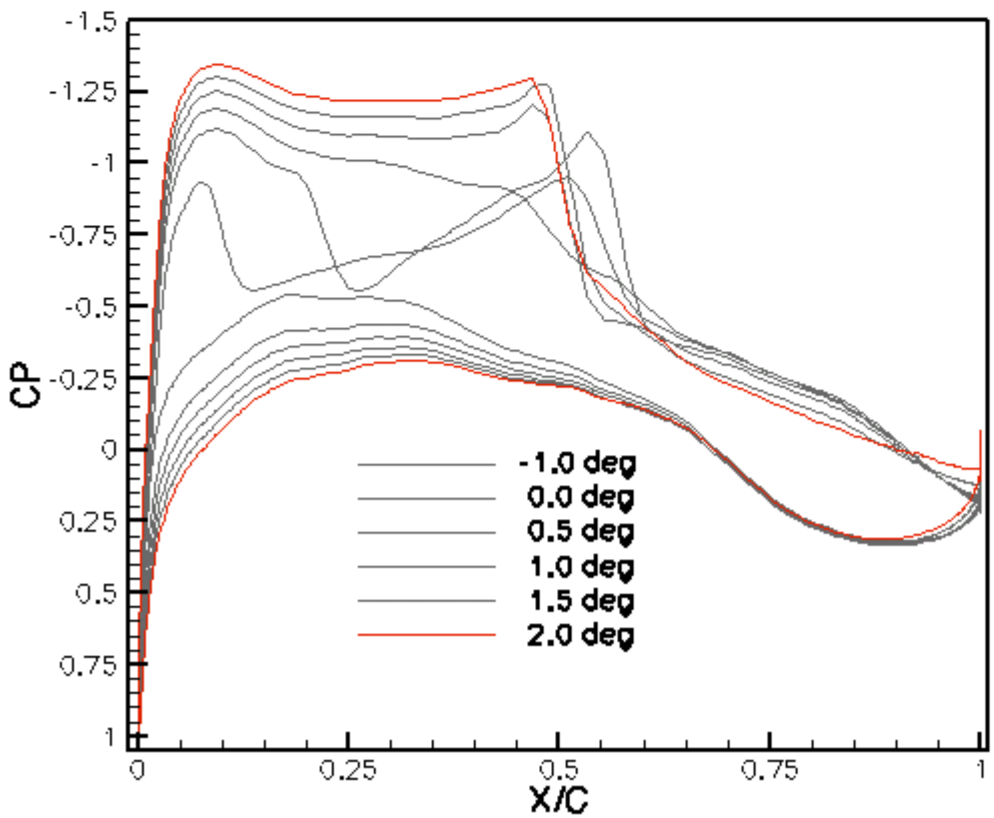
- CP at station 5

W2 Grid Polar Sweep (Fine Grid)



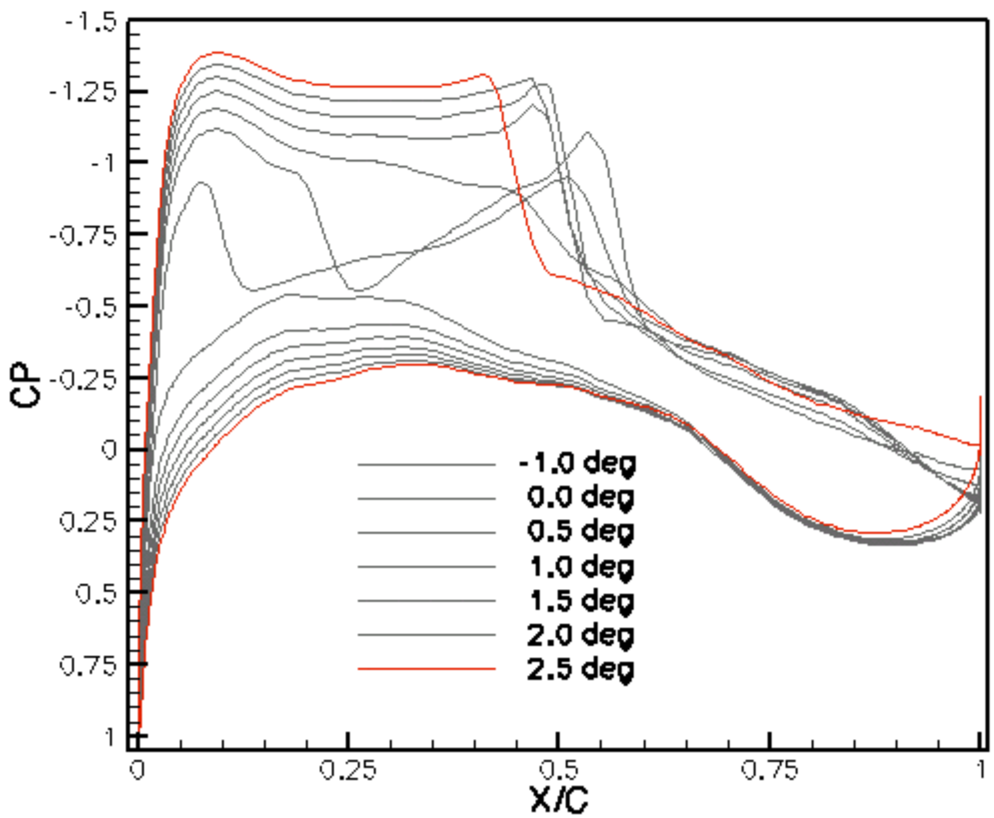
- CP at station 5

W2 Grid Polar Sweep (Fine Grid)



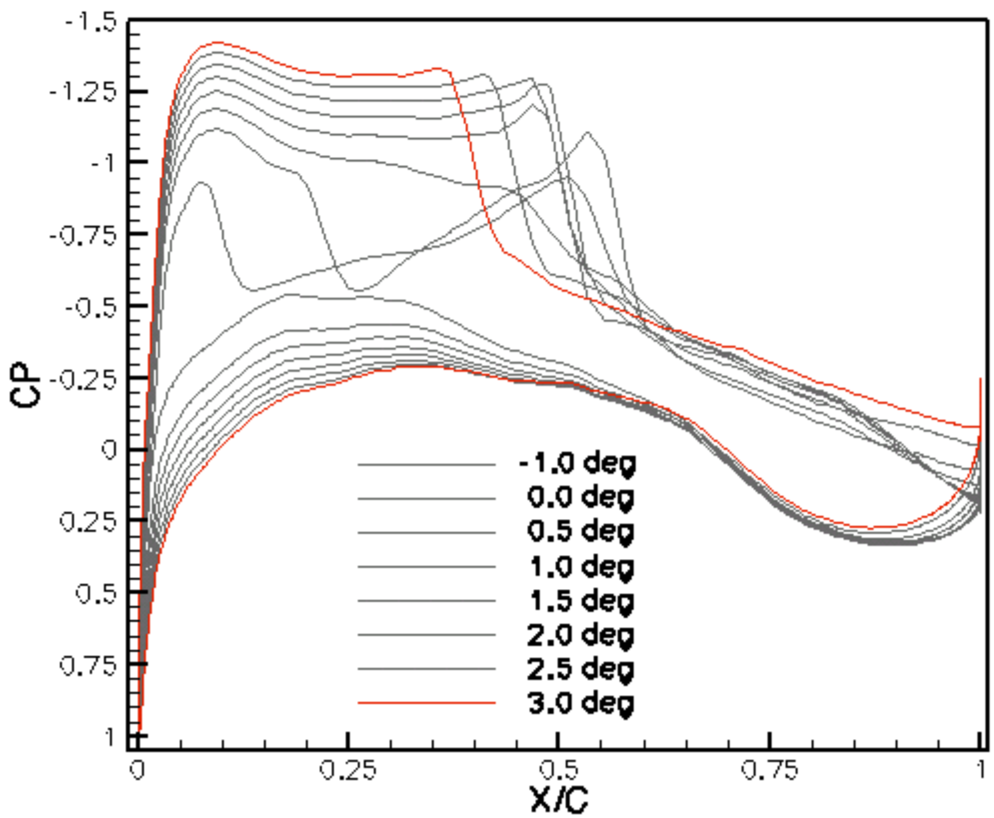
- CP at station 5

W2 Grid Polar Sweep (Fine Grid)



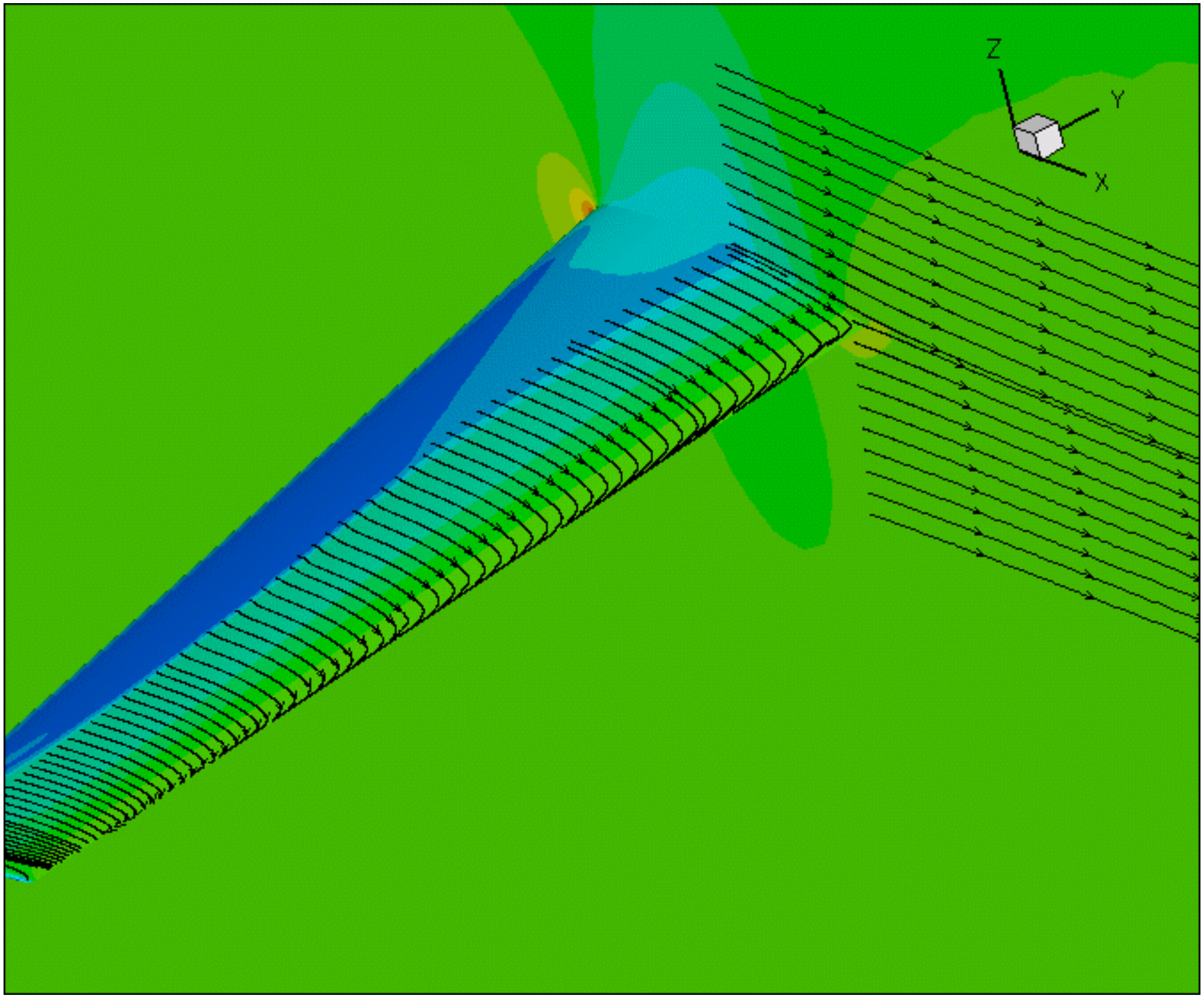
- CP at station 5

W2 Grid Polar Sweep (Fine Grid)

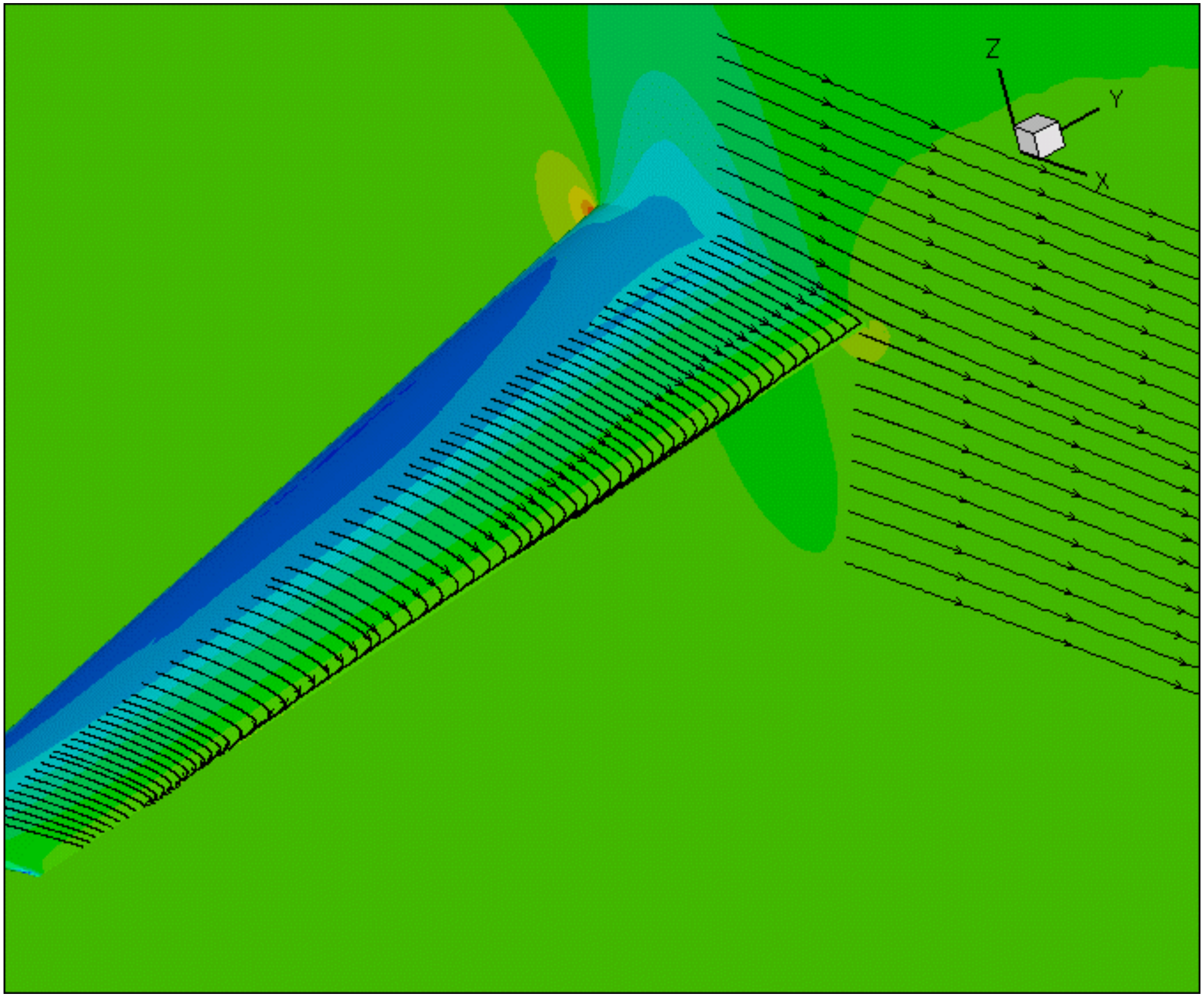


- CP at station 5

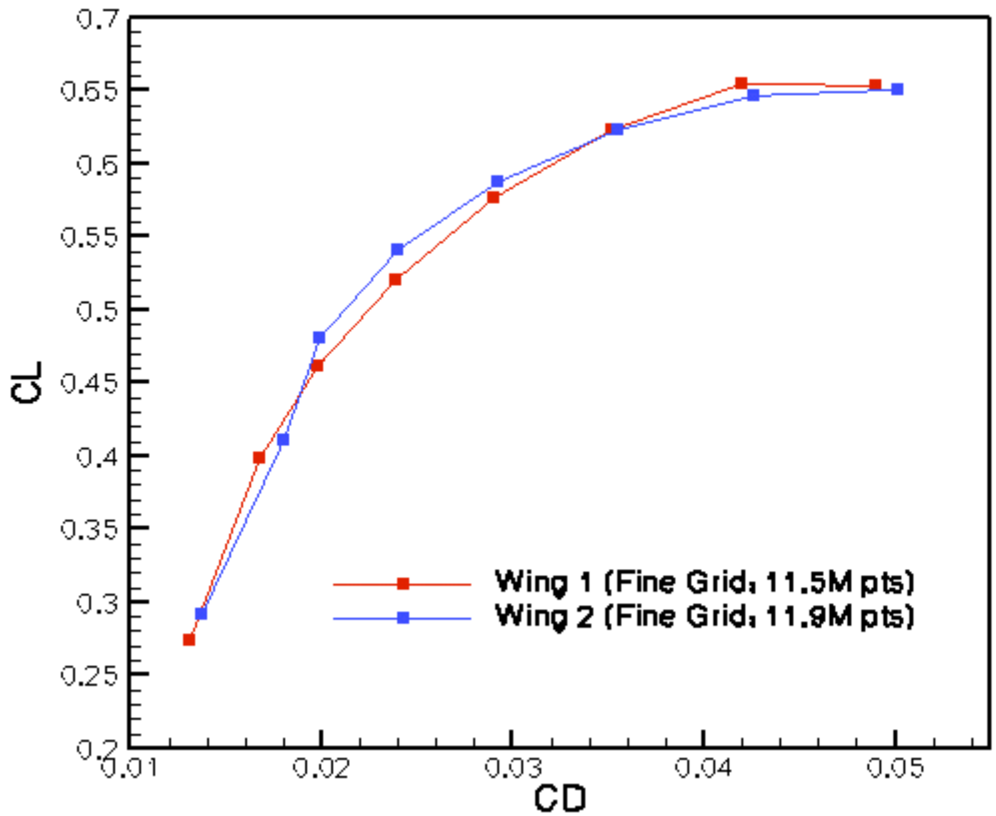
Streamlines at 0.5 degrees (W1)



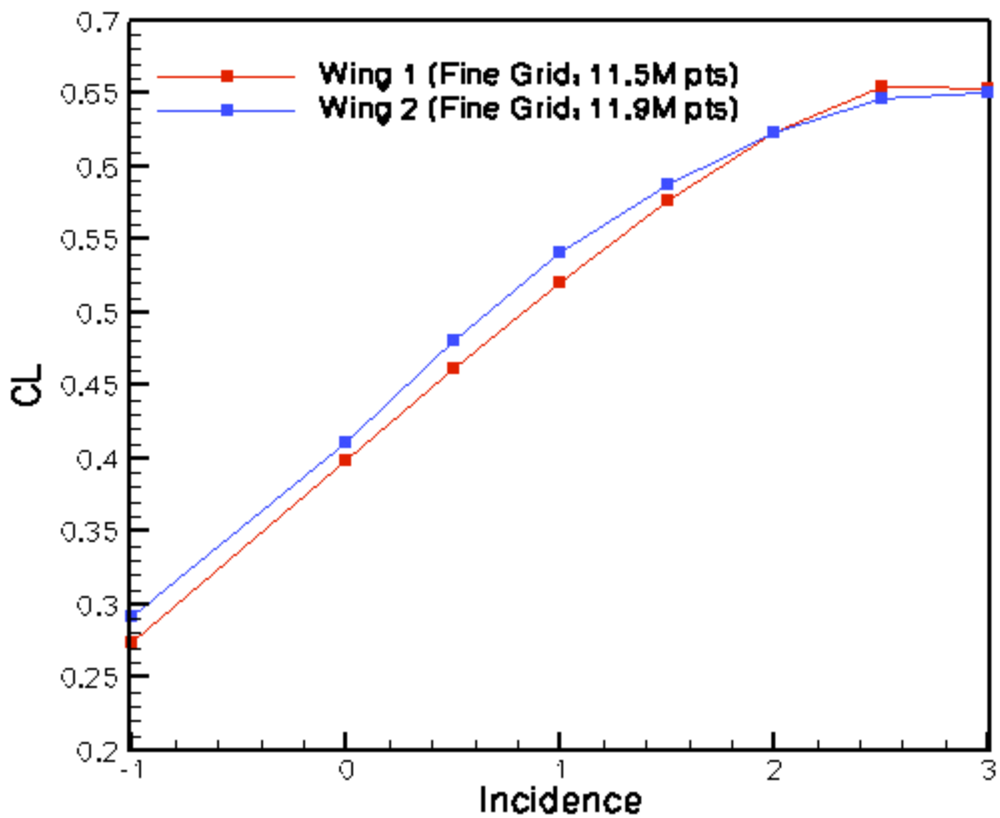
Streamlines at 0.5 degrees (W2)



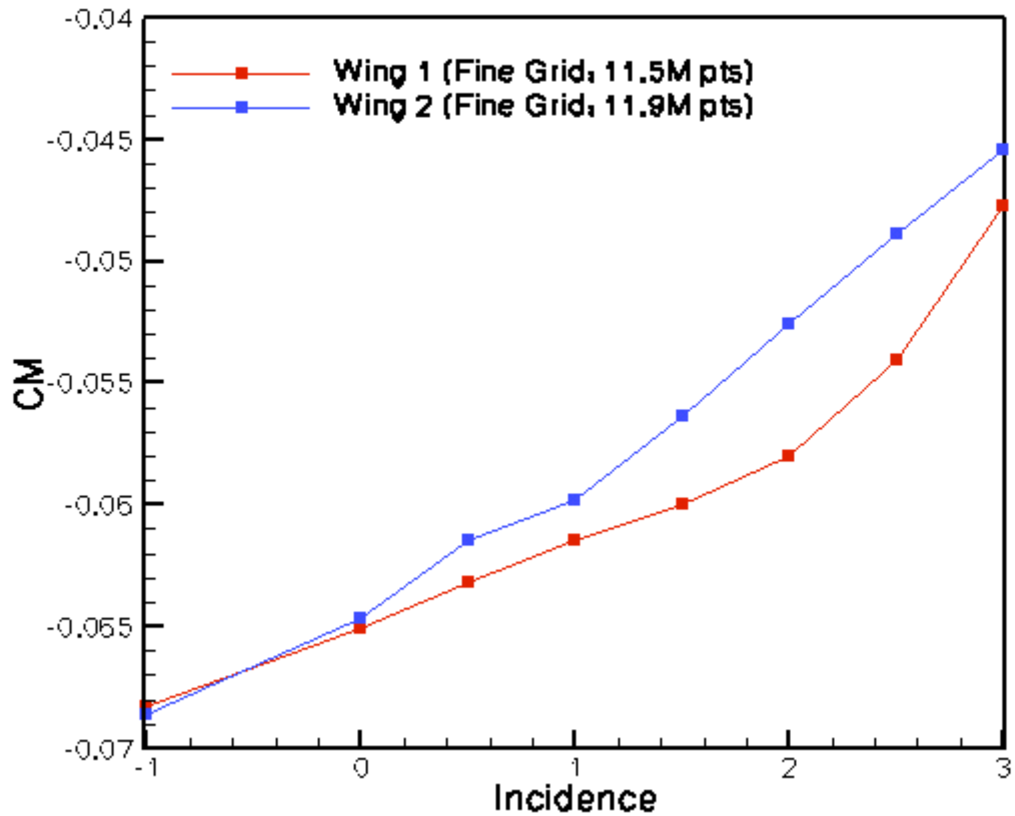
W1-W2 Grid Polar Comparison(Fine Grid)



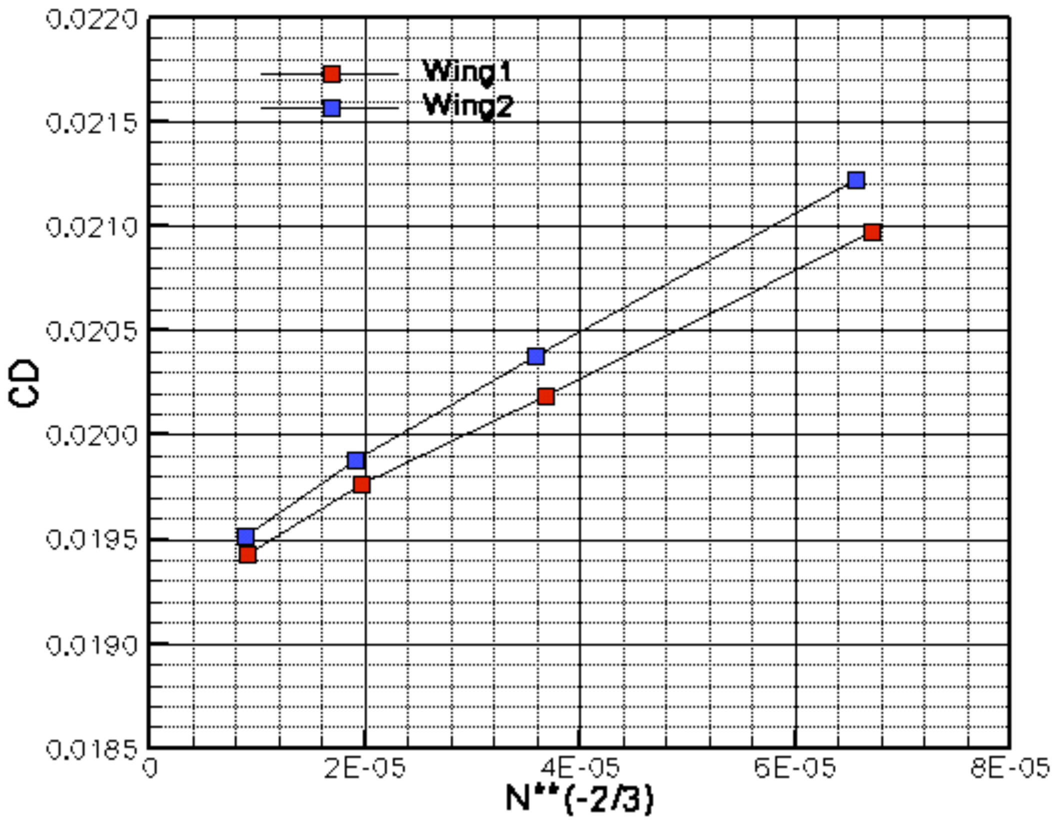
W1-W2 CL-Incidence Comparison(Fine Grid)



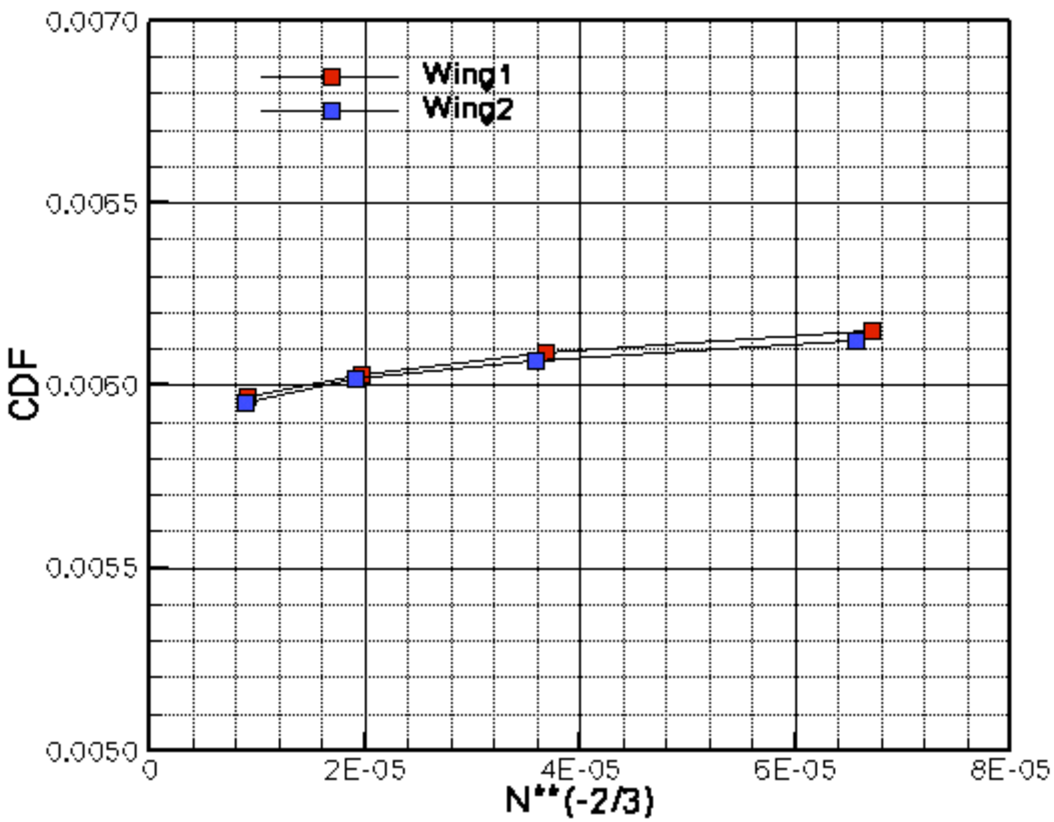
W1-W2 Moment Comparison (Fine Grid)



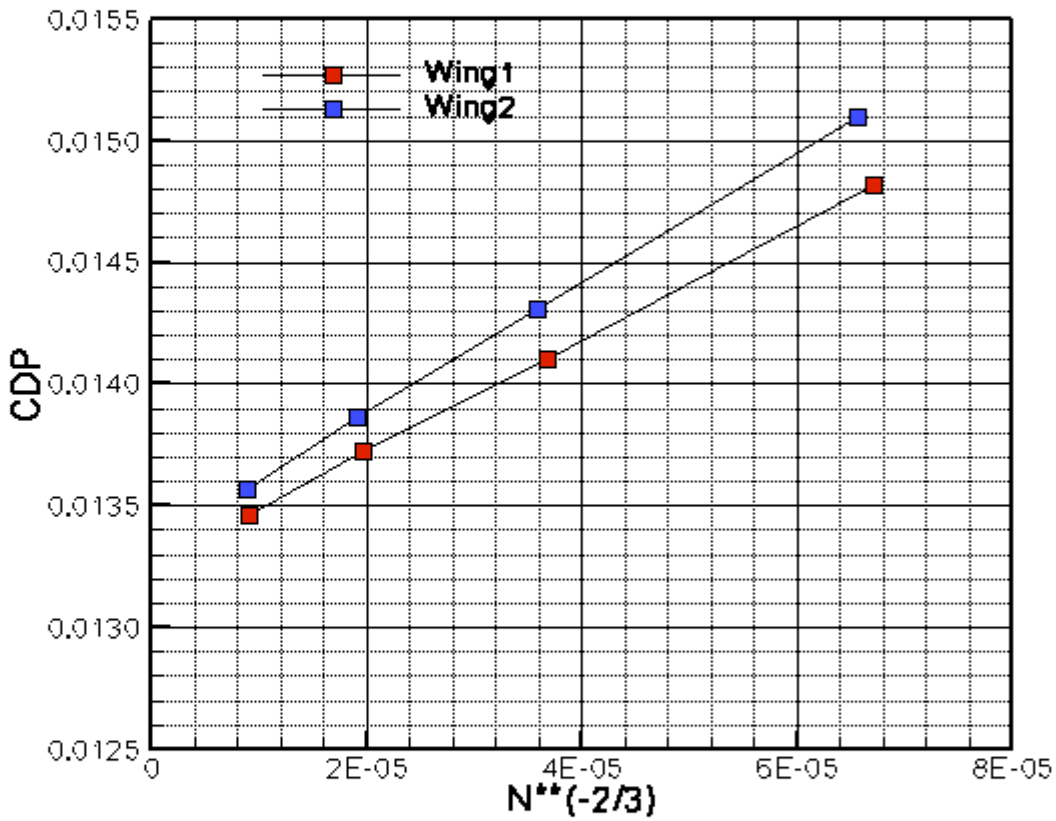
W1-W2 Grid Convergence Study



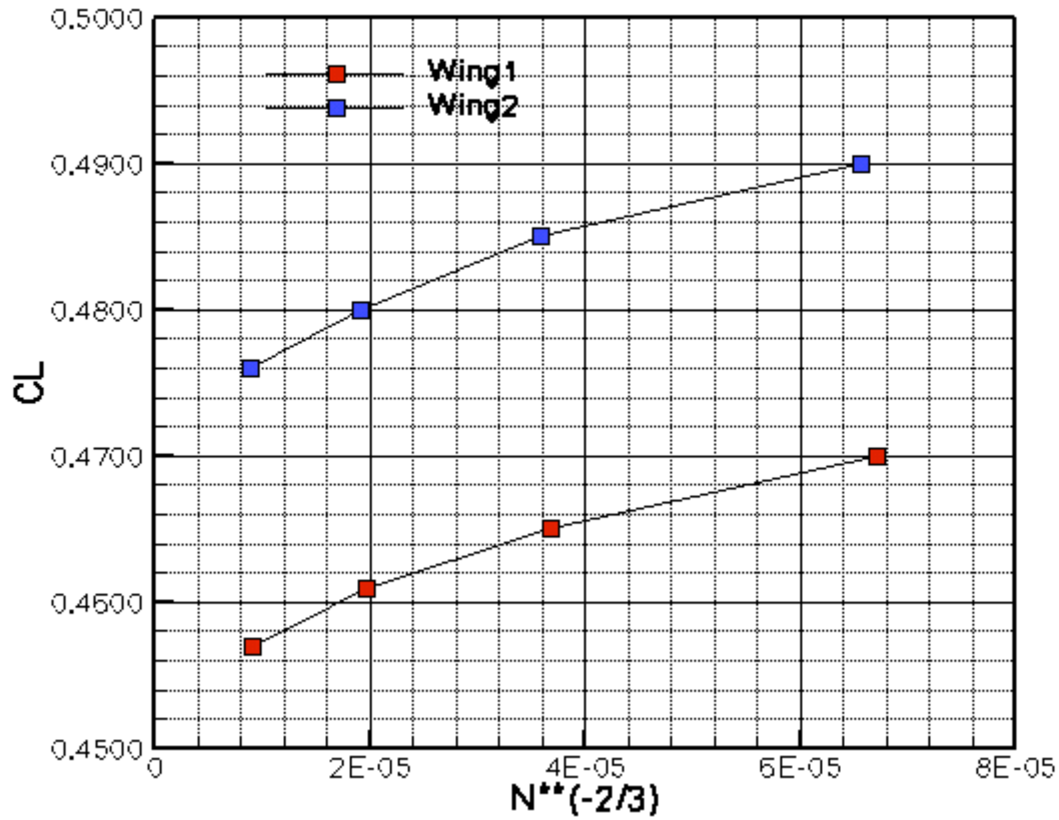
W1-W2 Grid Convergence Study



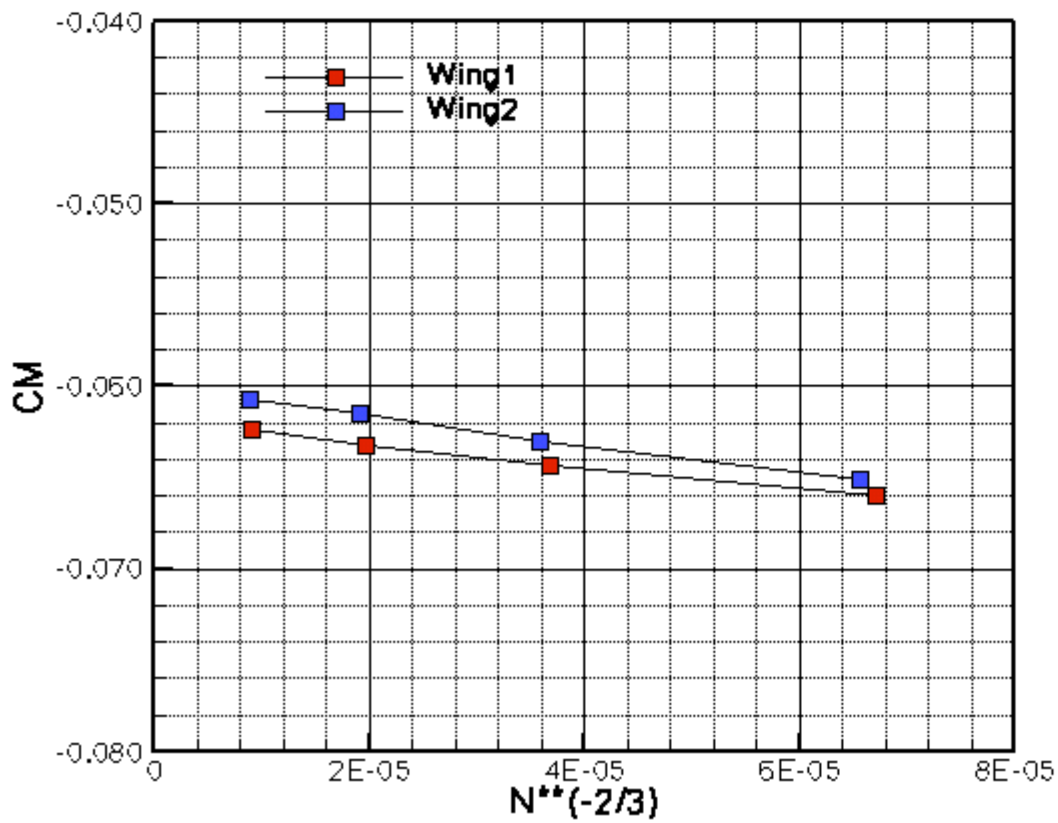
W1-W2 Grid Convergence Study



W1-W2 Grid Convergence Study



W1-W2 Grid Convergence Study



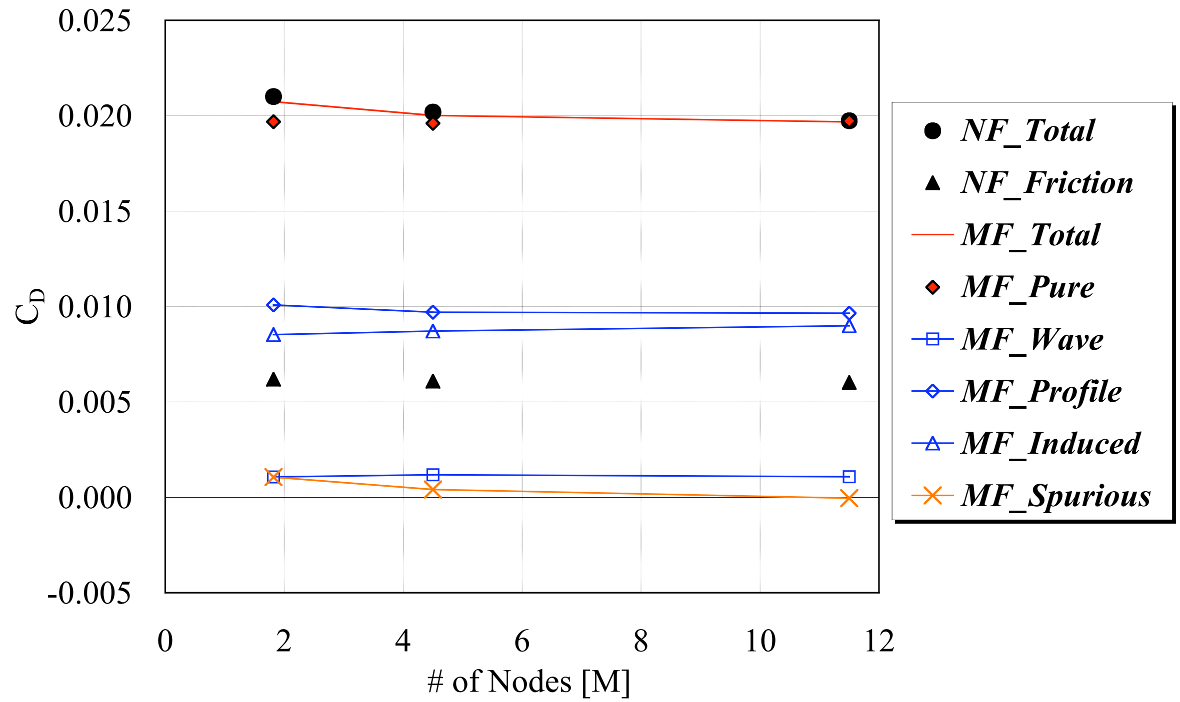
Drag Decomposition

- Performed by W. Yamazaki

  (Tohoku University, Japan)

- Decompose drag (through volume integral):
  - Induced Drag
  - Wave Drag
  - Profile Drag
  - Spurious Drag
    - Enables subtraction of spurious drag to get pure drag

DPW-W1

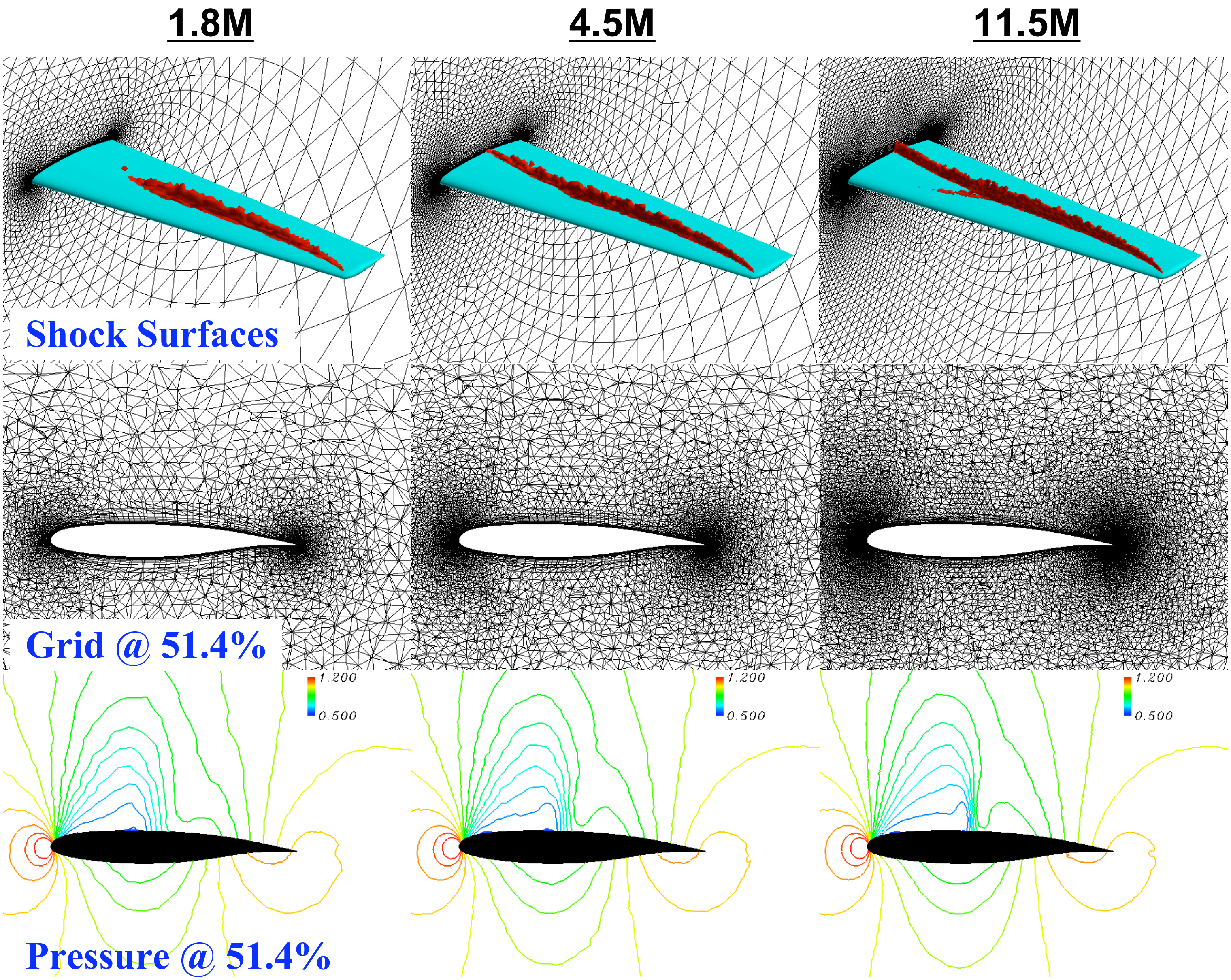


- ✓ The reduction of spurious drag to zero
- ✓ Almost constant of pure (wave+profile+induced) drag
- ✓ Good agreement between the total & pure drag at fine mesh
- ✓ Good agreement of the form factor (k) with following formula
  k = profile / friction ~ 97cts/61cts = 1.59

$$k = 1 + \frac{2C(t/c)\cos^2\Lambda}{\sqrt{1 - M_\infty^2\cos^2\Lambda}} + \frac{C^2\cos^2\Lambda(t/c)^2(1 + 5\cos^2\Lambda)}{2(1 - M_\infty^2\cos^2\Lambda)} \cong 1.53$$

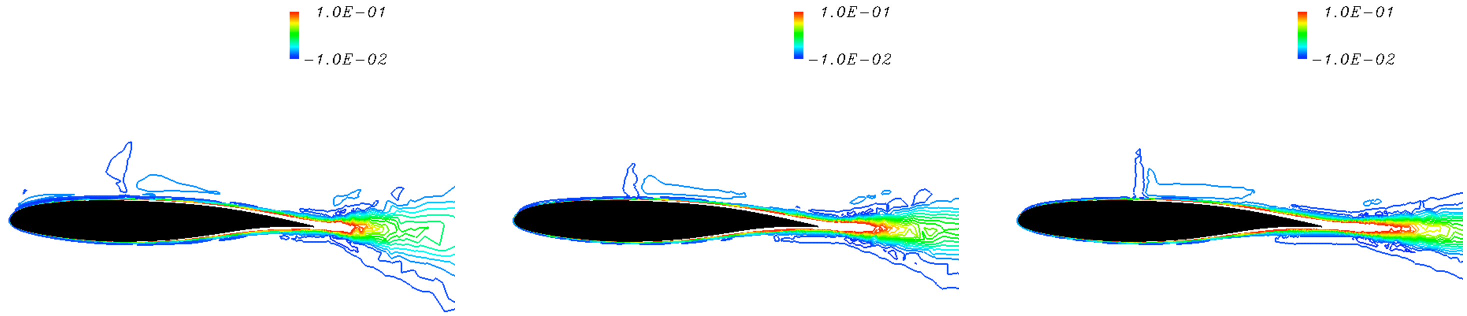
$$\left(\Lambda = 14.8^\circ, C = 1.1, (t/c) = 0.133, M_\infty = 0.76\right)$$

Visualizations-1

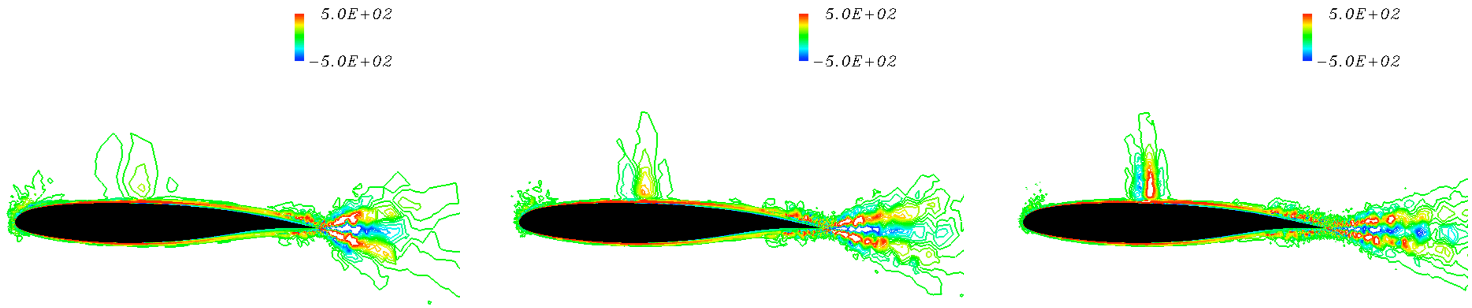


Visualizations-2

1.8M **4.5M** **11.5M**

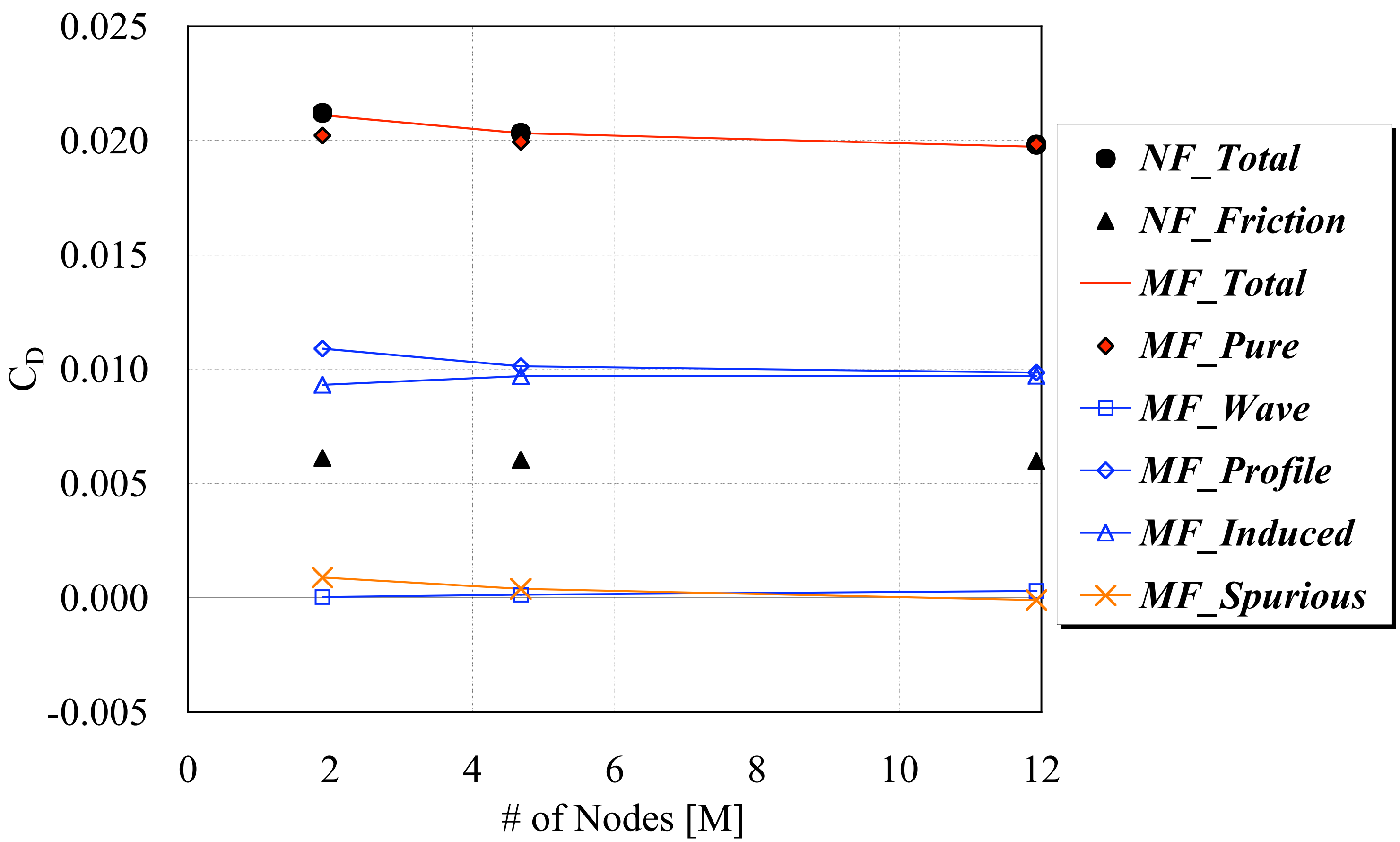


Entropy Variation @ 51.4%



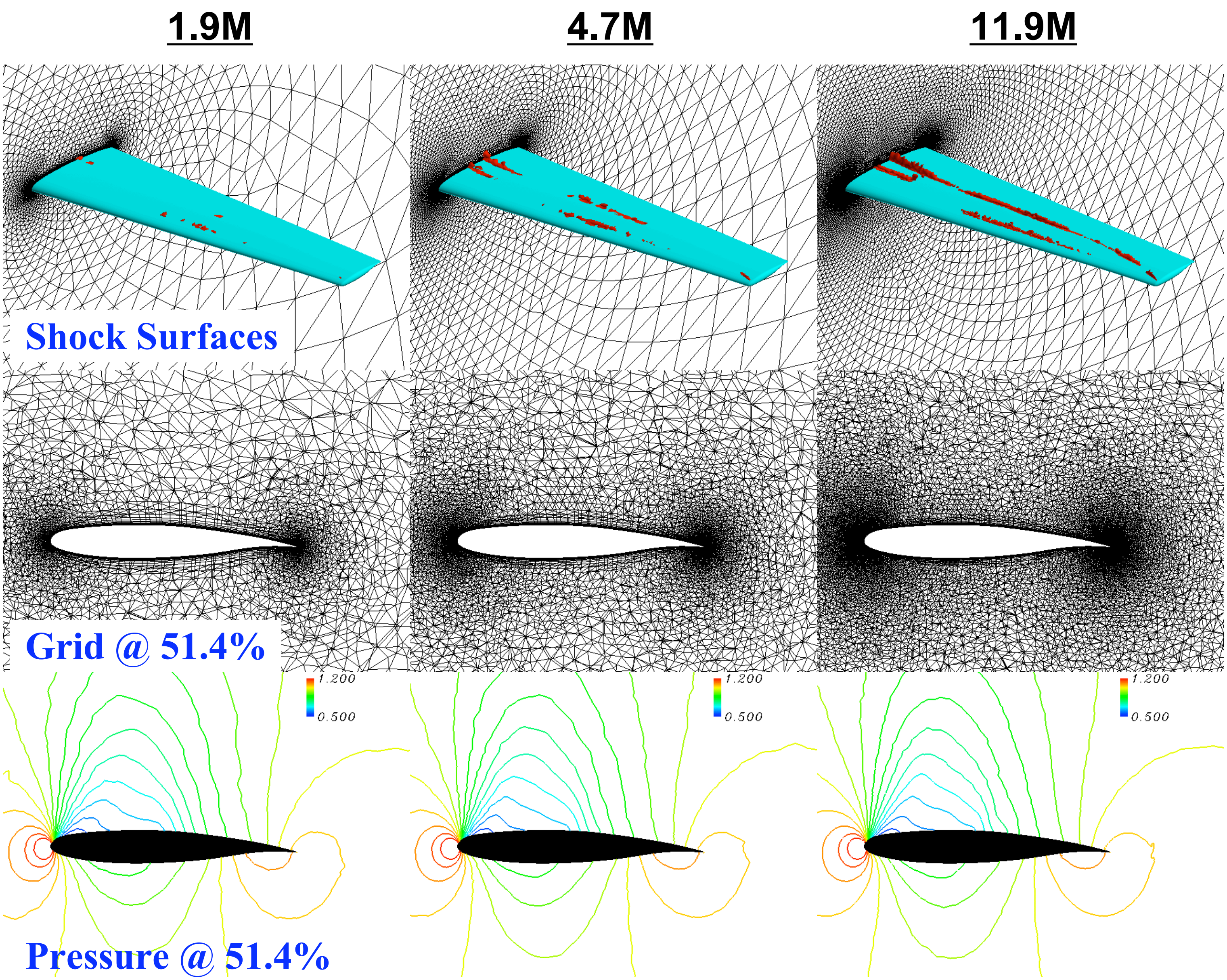
Entropy Drag @ 51.4%

DPW-W2



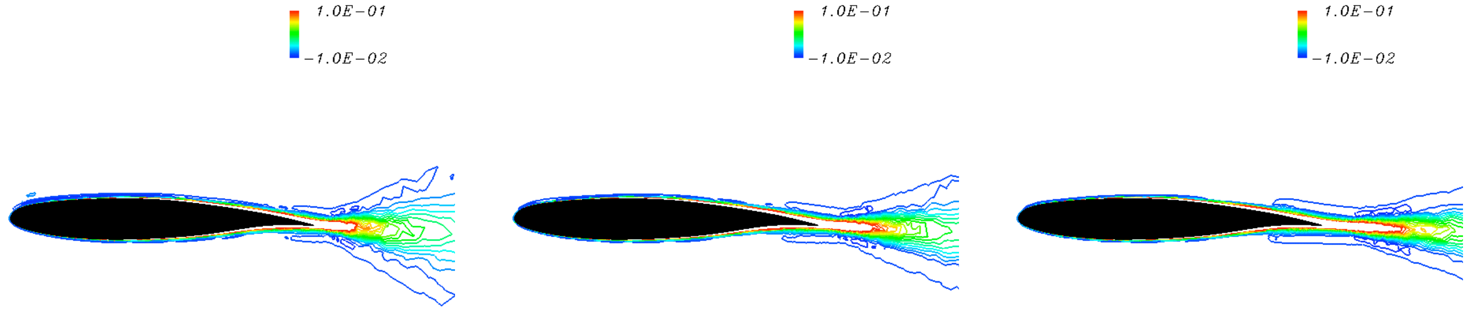
✓ Almost same tendency with the results of DPW-W1

Visualizations-1

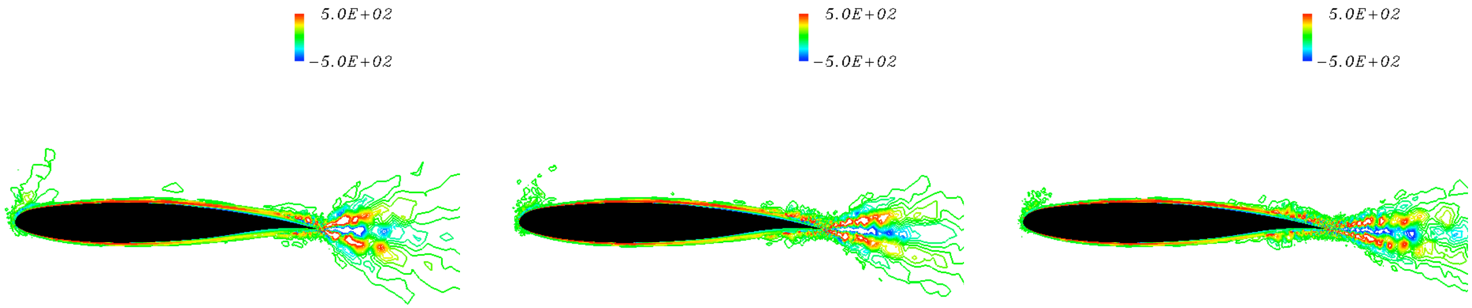


Visualizations-2

1.9M **4.7M** **11.9M**

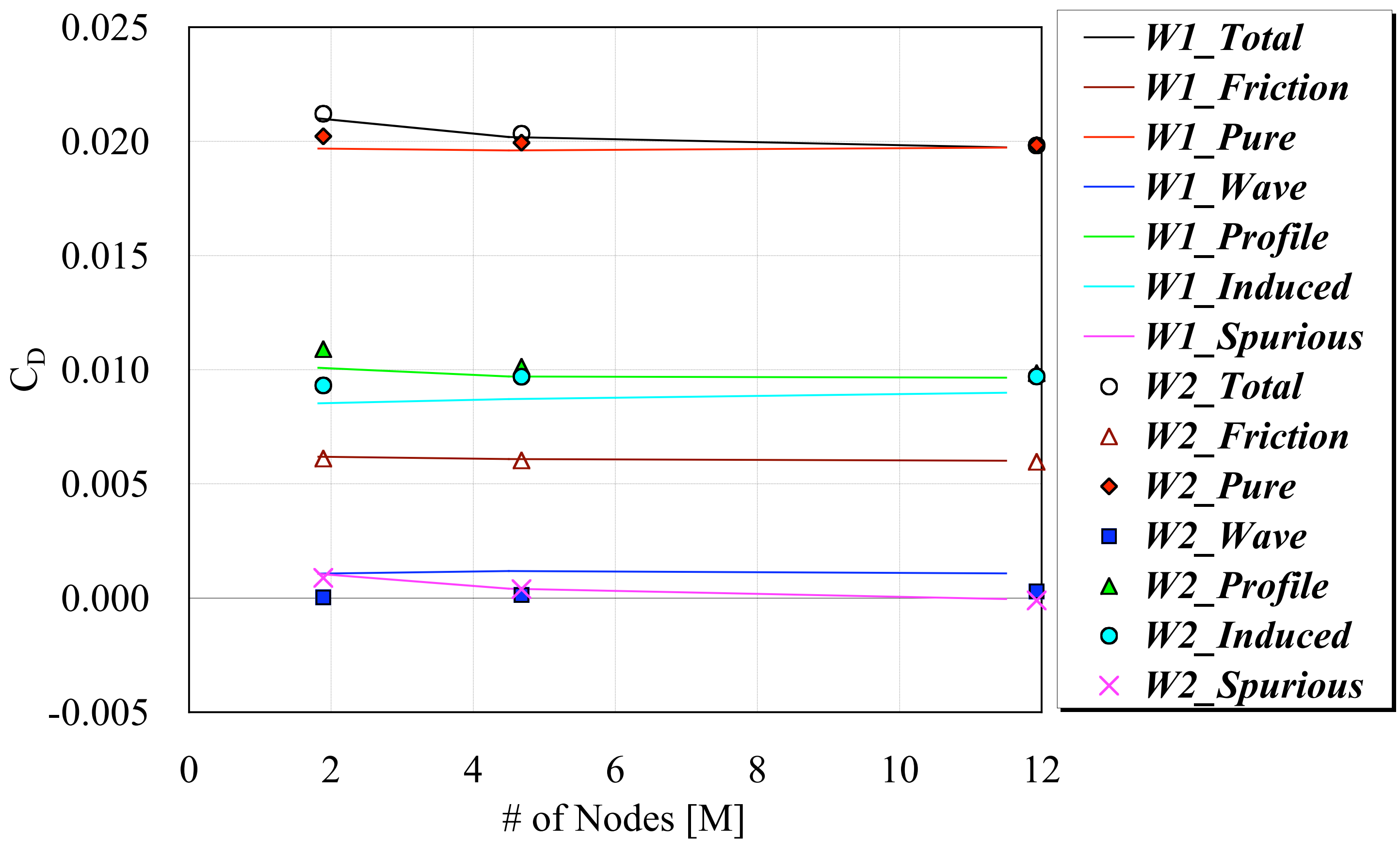


Entropy Variation @ 51.4%



Entropy Drag @ 51.4%

W1 vs. W2



- ✓ Wave drag reduction in case W2
- ✓ Almost same about profile drag
- ✓ Induced drag increase in case W2 because of higher C_L

Summary

- W1-W2 appear to be in asymptotic grid convergence range
  - Cd difference ~ 1 count at 0.5 degrees
- Grids are getting finer …..40M pts ~1 hr on NASA Columbia Supercomputer
- Drag decomposition useful in providing better drag estimates on coarser grids