DPW-4 Results For NSU3D on LaRC Grids

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NSU3D Description

Unstructured Reynolds Averaged Navier-Stokes solver

- Vertex-based discretization
- 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
- Turbulence Models
  - Spalart-Allmaras (original published form)
  - k-omega
  - Interactive Boundary Layer (IBL)

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 all MPI only on:
      - UWYO Cluster (Dual Core Opteron)
      - NASA Columbia (Itanium 2)
      - NASA Pleiades (Quad Core Xeon)

Grid Generation

- All Runs based on NASA Langley supplied VGRIDns unstructured grids

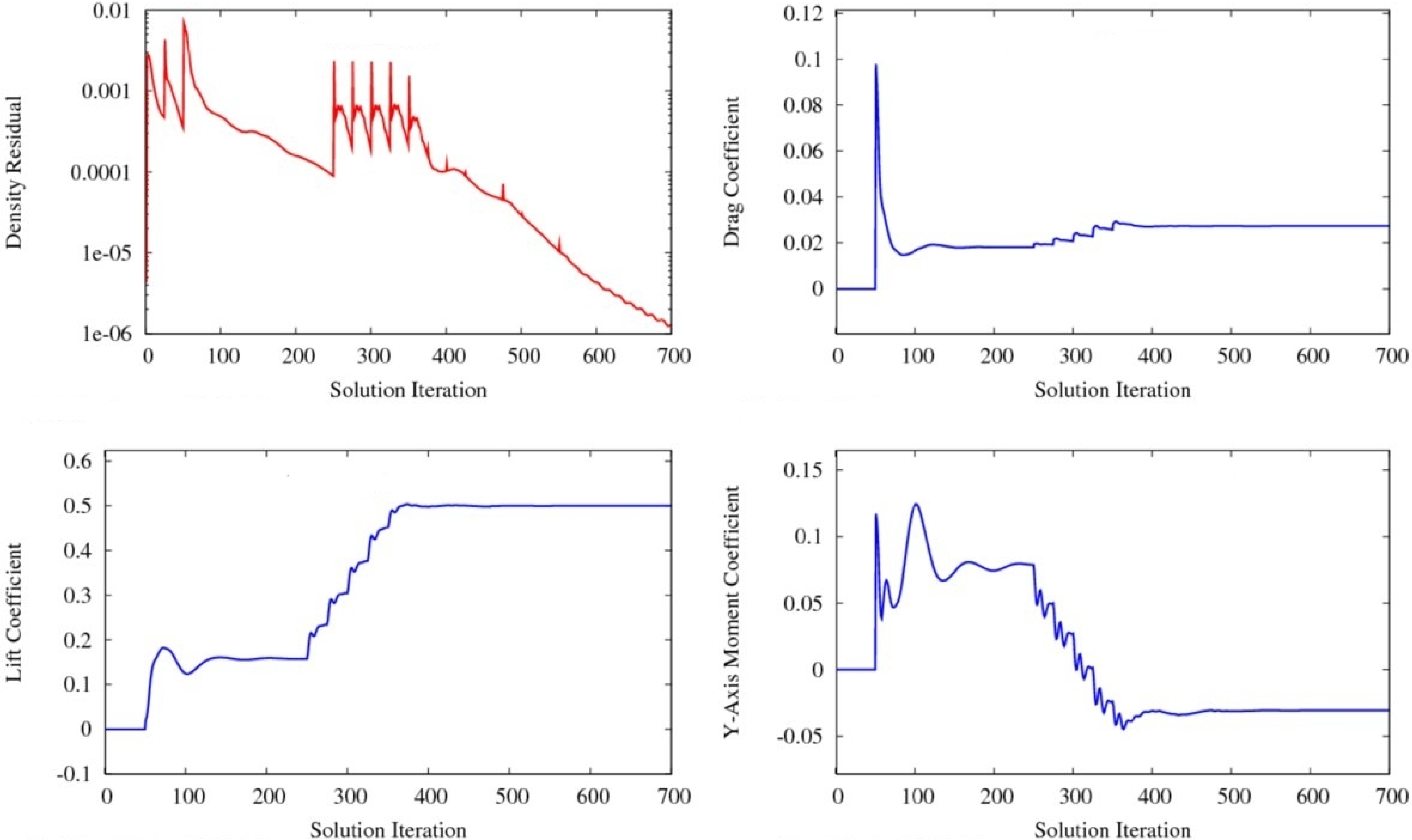
- Tetrahedra cells in the boundary layer merged into prismatic elements

- Grid sizes up to 36M pts, 122M elements after merging

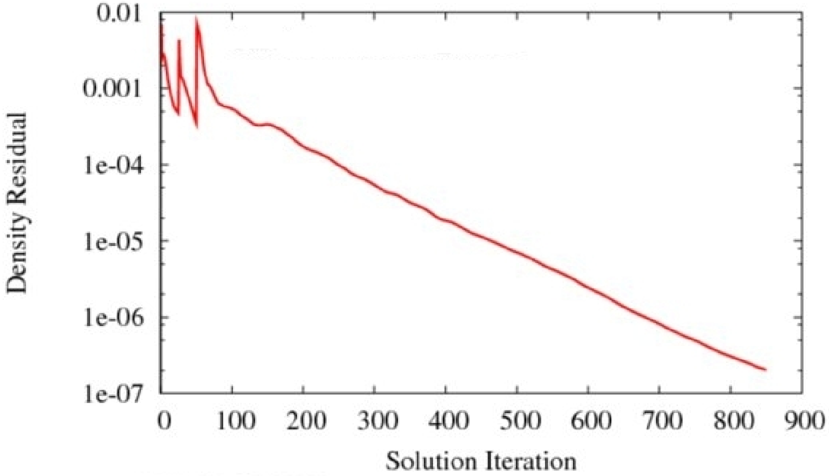
Typical Resource Requirements

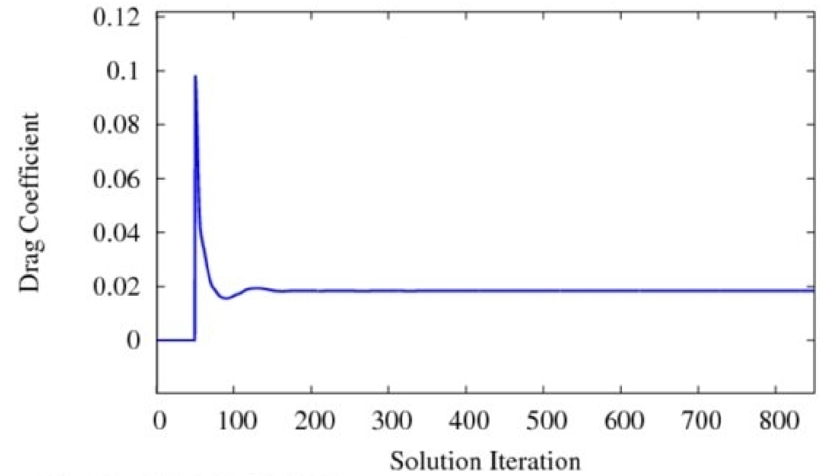
- NASA Pleiades Supercomputer
  - SGI ICE with 51,200 Intel Harpertown Xeon Cores
- Medium (10Mpts) grids used 64 cpus
  - 800 multigrid cycles (most cases converged <500)
  - ~1.7 hours for final solution
  - ~60GB memory allocated
- Fine Grid (36M pts) used 128 cpus
  - 800 multigrid cycles (CL driver converged <700)
  - ~3.7 hours for final solution
  - ~160GB memory allocated

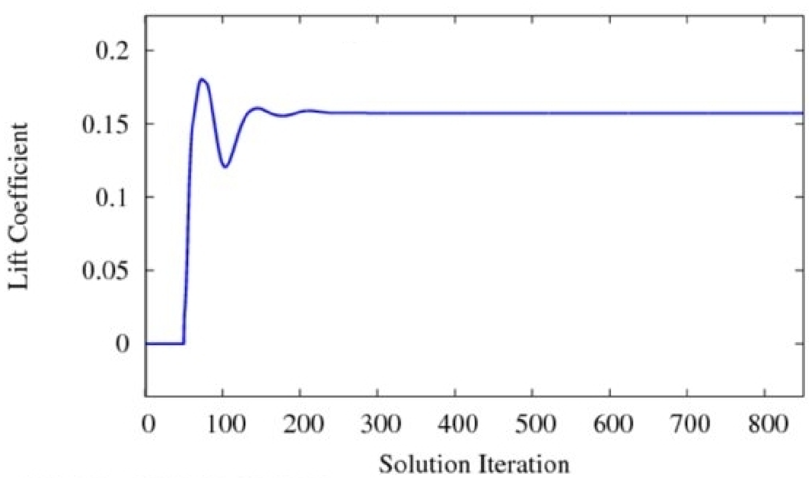
Typical Residual and Force History (Case 1 - Medium Grid, CL Driver)

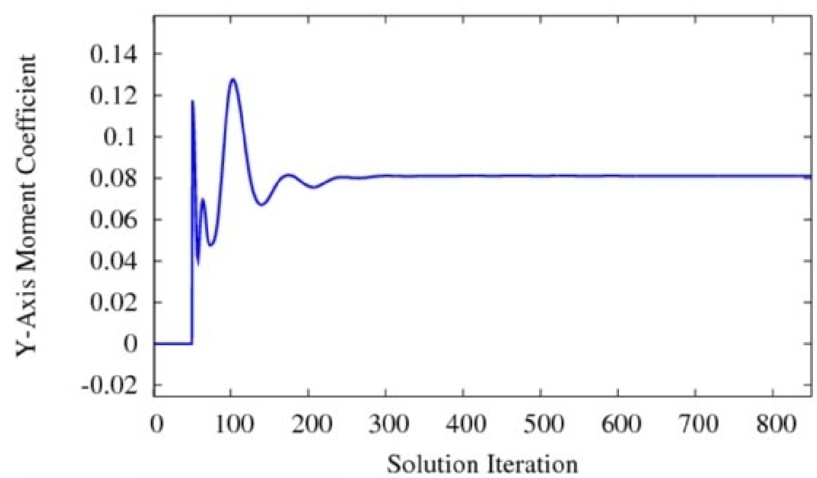


Typical Residual and Force History
(Case 2 Medium Grid)

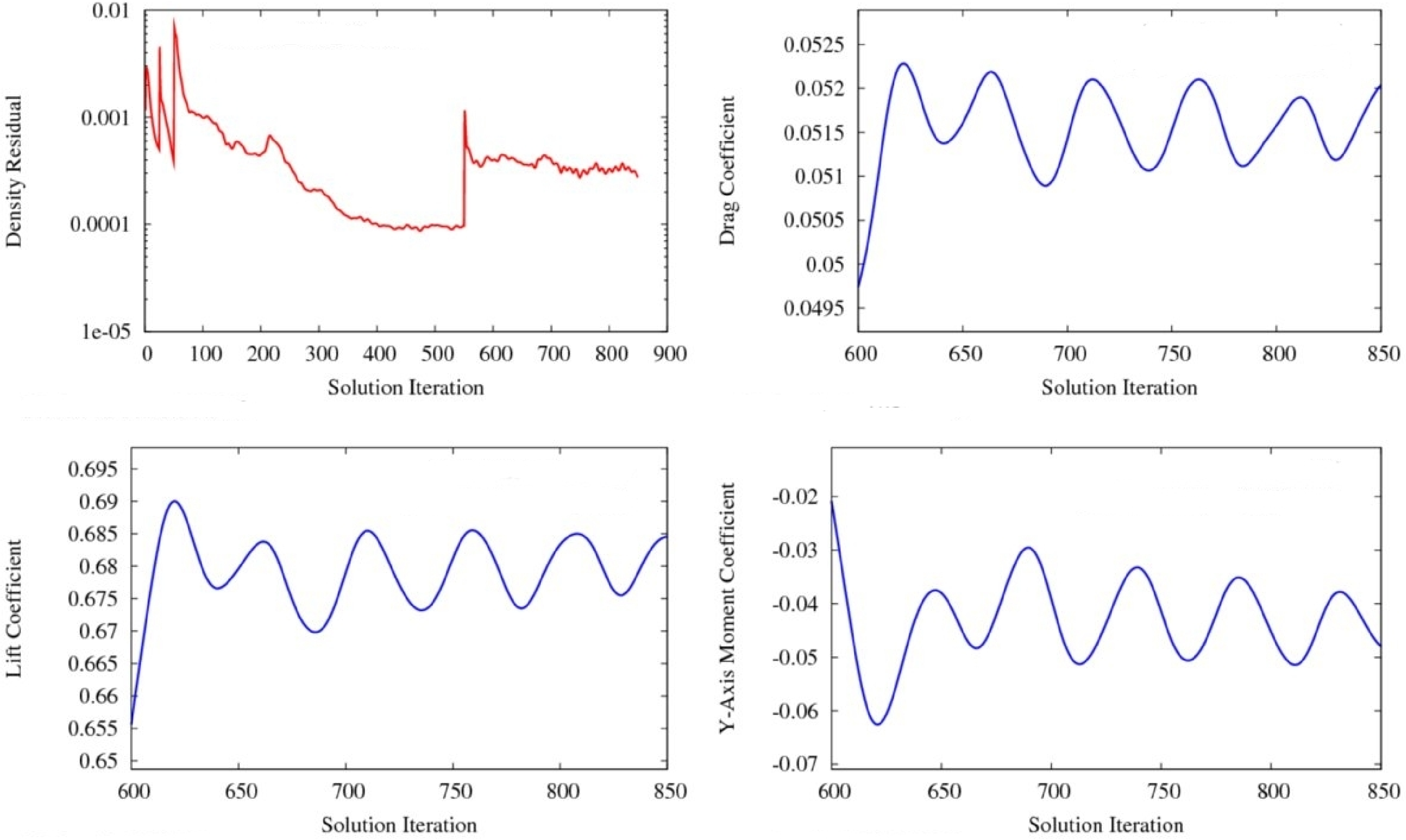








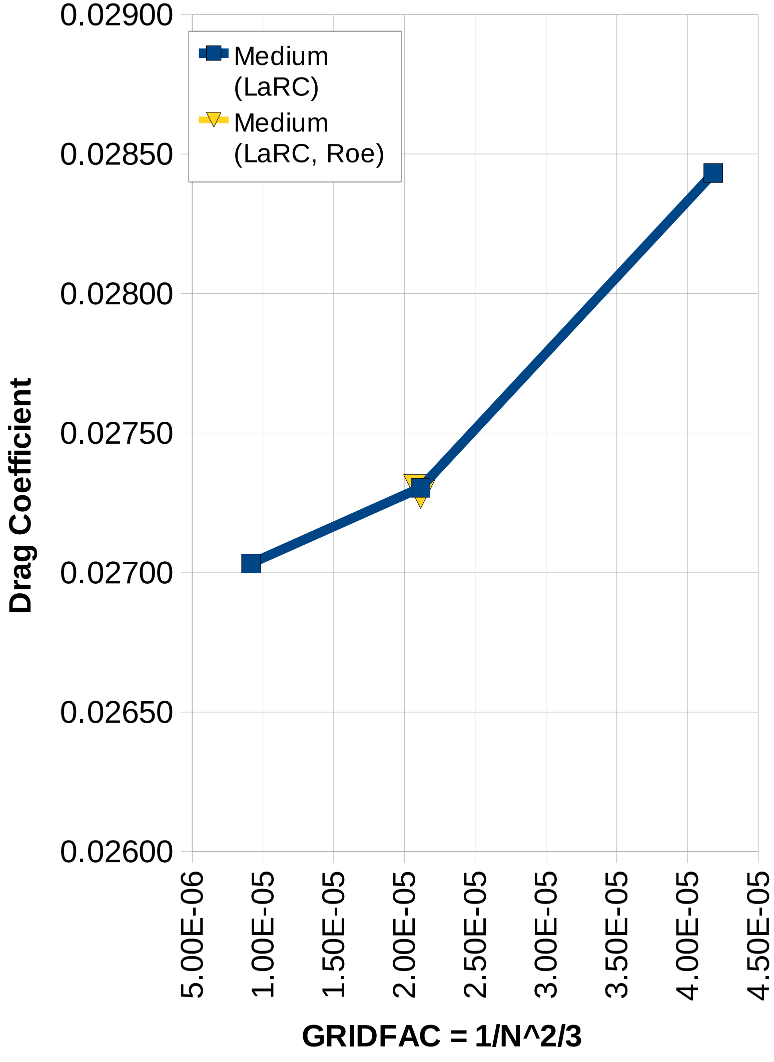
Typical Case with Unsteady Flow (AOA = 4°, Mach ≥ 0.85)

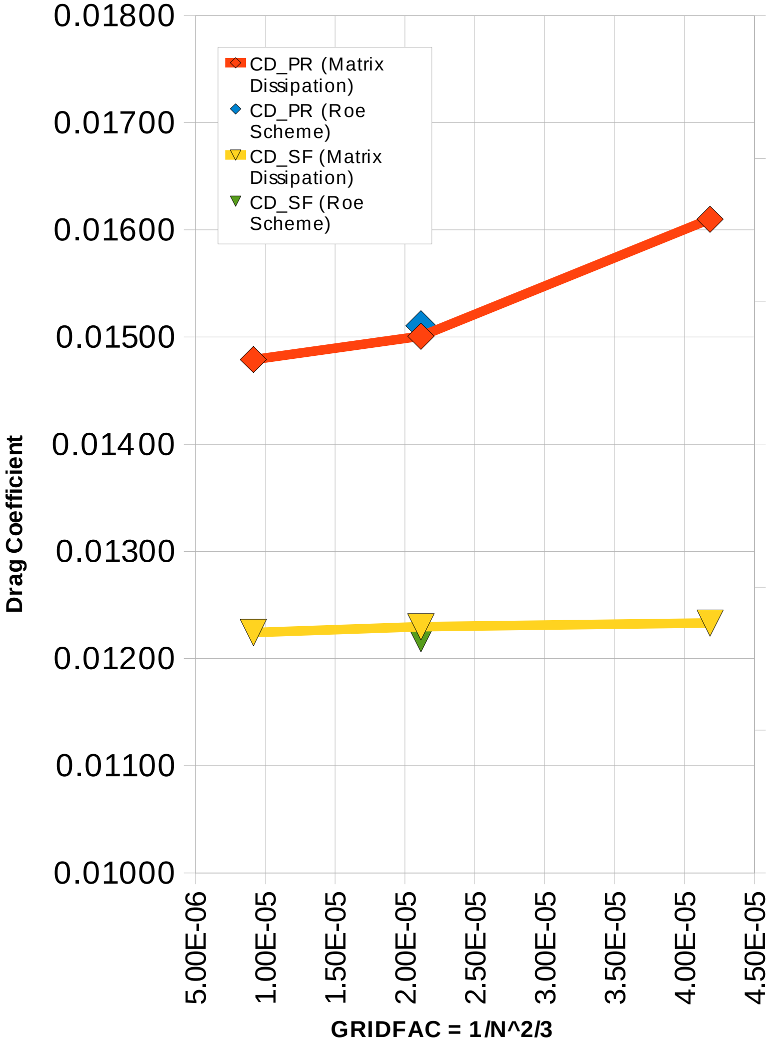


Case 1a: Grid Convergence Study

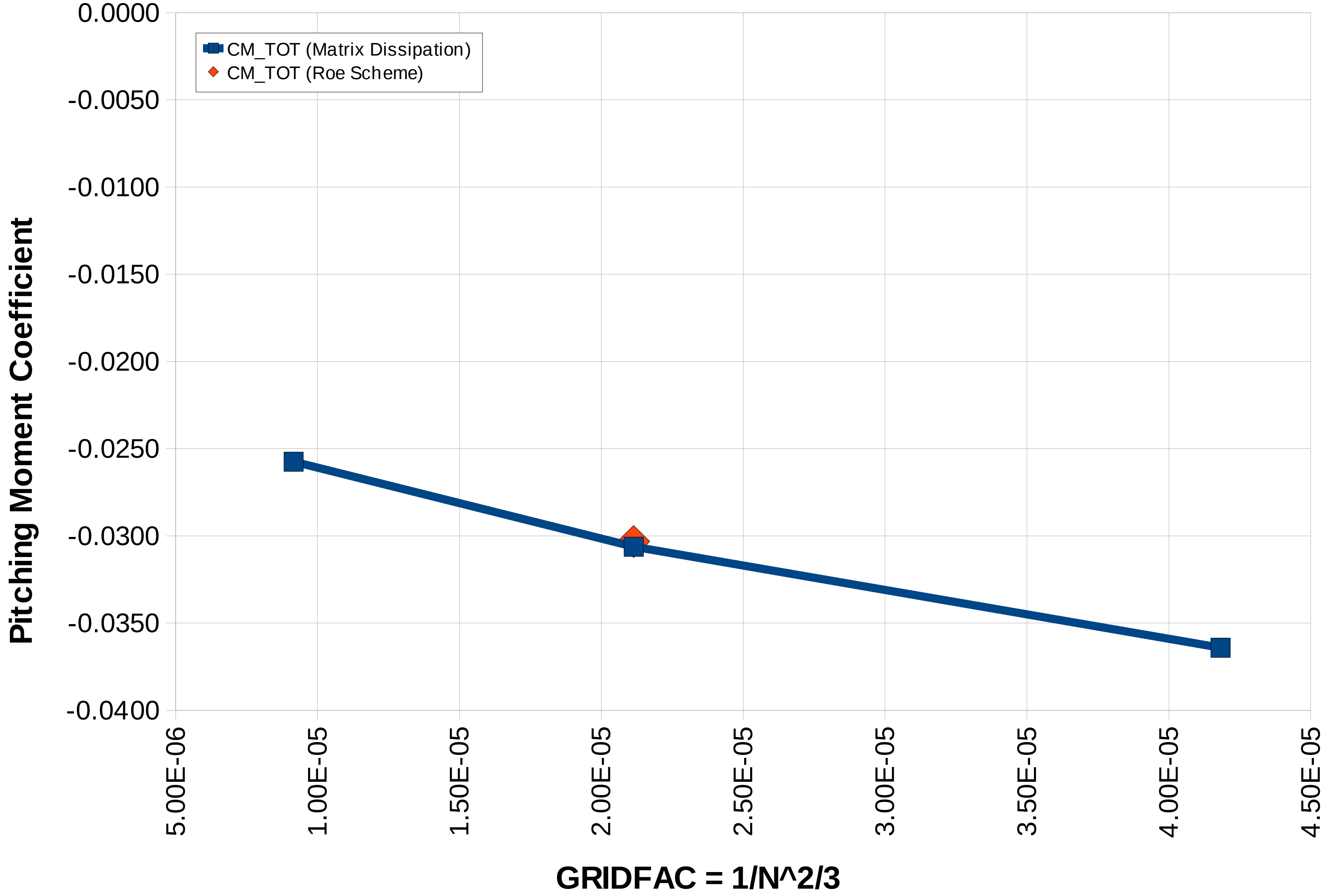
- Mach = 0.85, CL = 0.500 (±0.001)
- Tail Incidence angle= 0°
- Coarse, Medium, Fine, Extra-Fine Grids
  (Extra-Fine grid not completed)
- Chord Reynolds Number: Re = 5e+6

Sensitivity of Drag Coefficient to Grid Size
C_L = 0.5, Mach = 0.85, Tail 0°



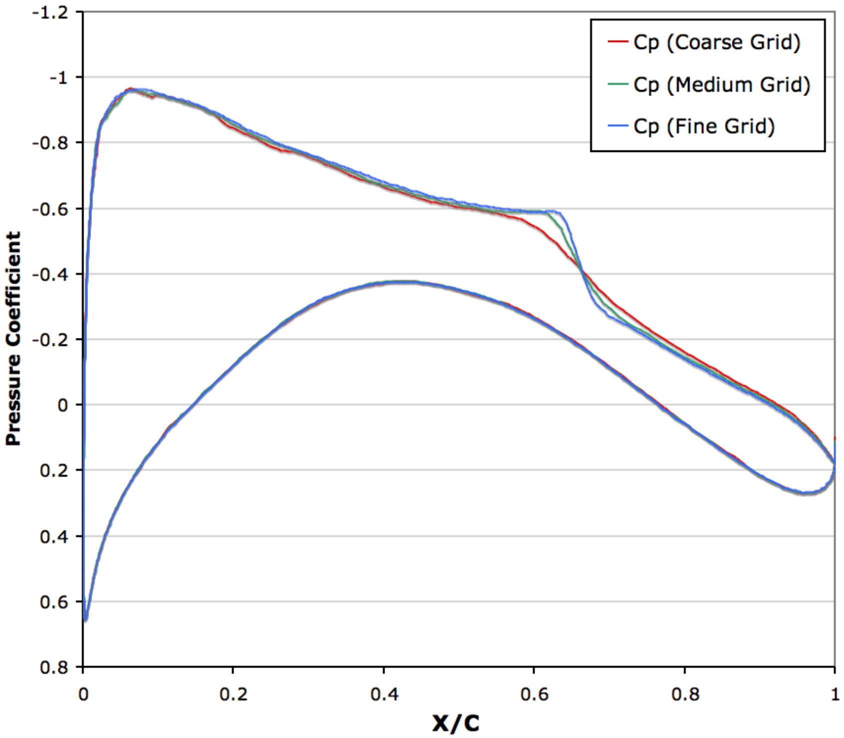


Sensitivity of Pitching Moment Coefficient to Grid Size
C_L = 0.5, Mach = 0.85, Tail 0°

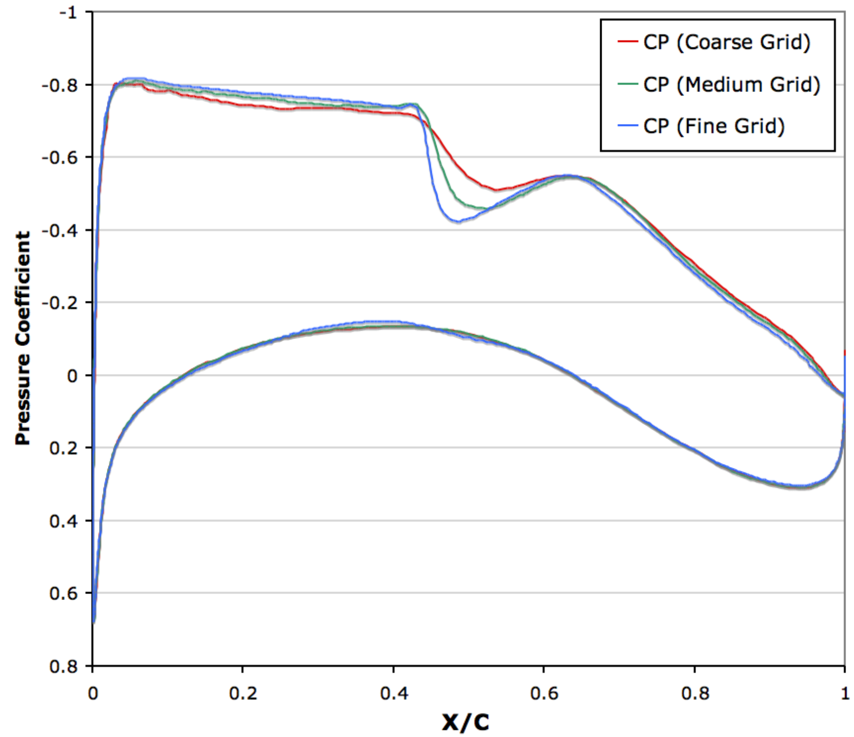


Wing Surface Pressure Grid Convergence

C_L = 0.5, Mach = 0.85, Tail 0°



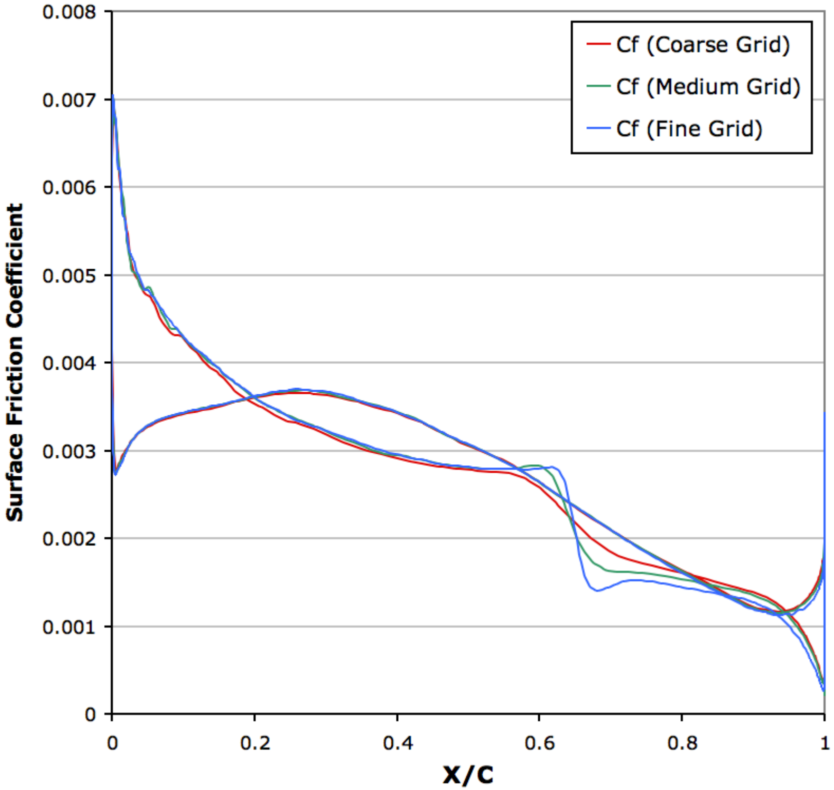
Inboard Section (Y=232.444)



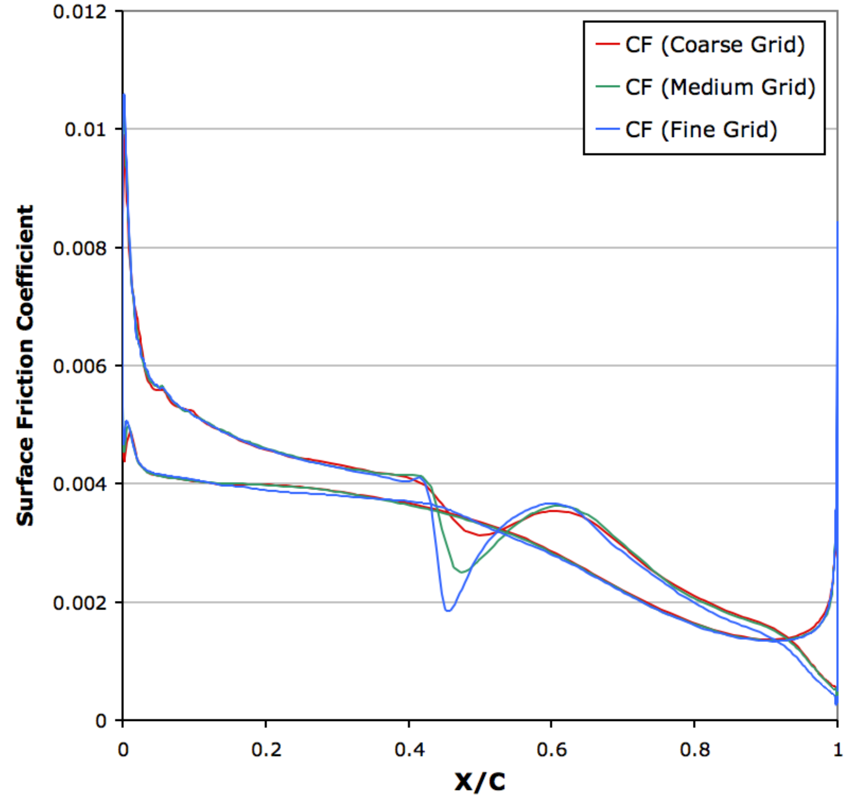
Outboard Section (Y=978.148)

Wing Surface Friction Grid Convergence

C_L = 0.5, Mach = 0.85, Tail 0°

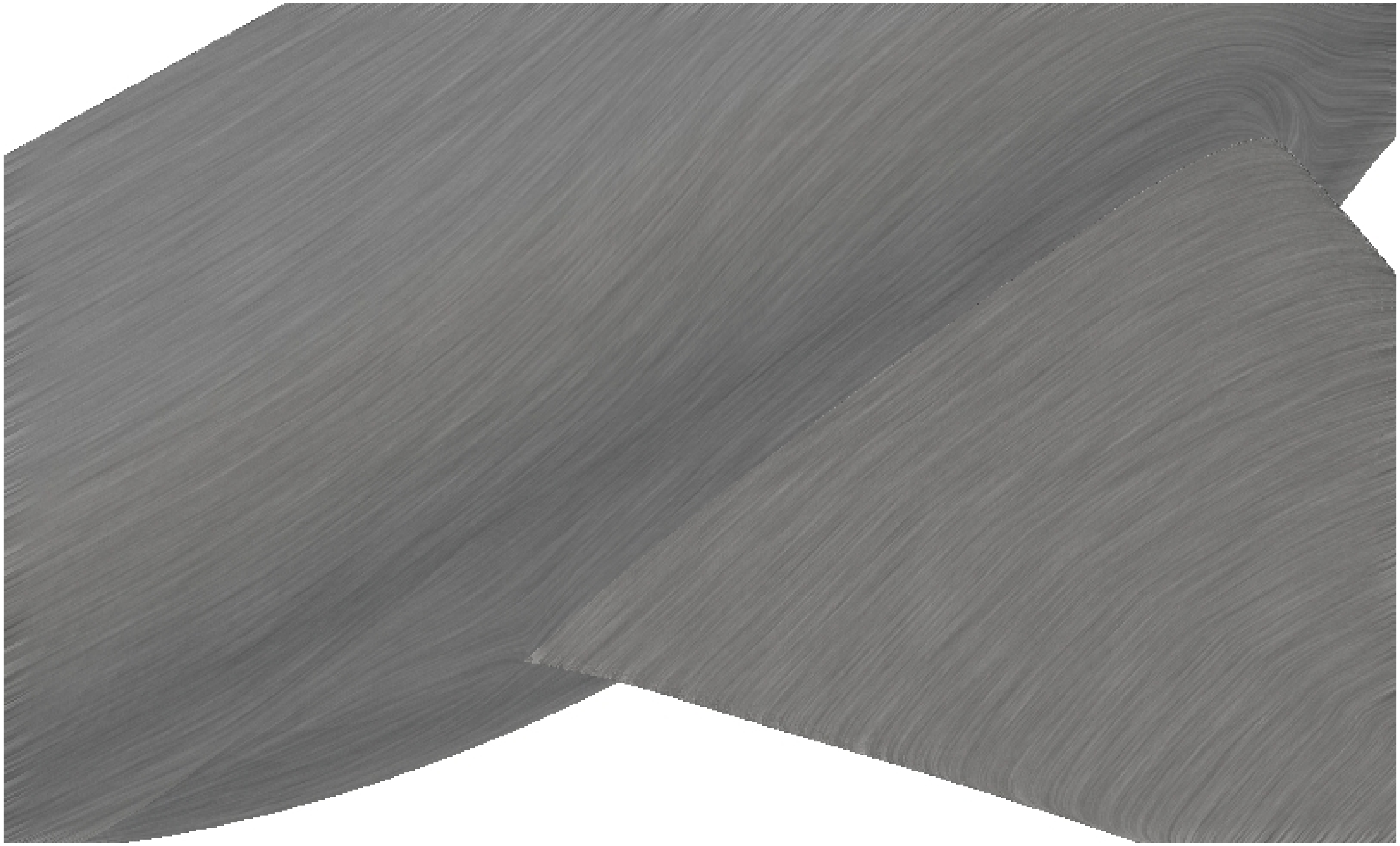


Inboard Section (Y=232.444)



Outboard Section (Y=978.148)

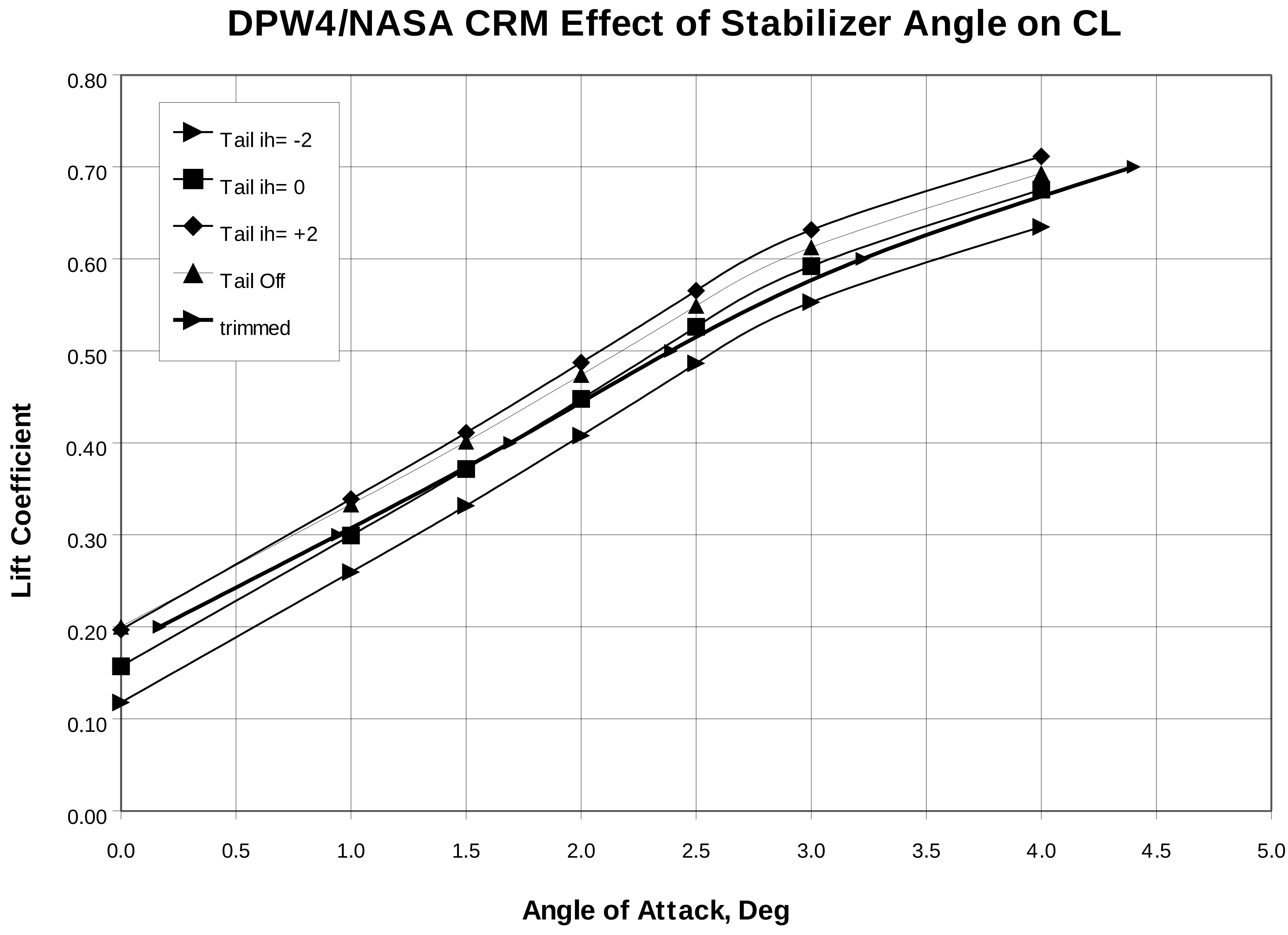
No Side of Body Separation Seen



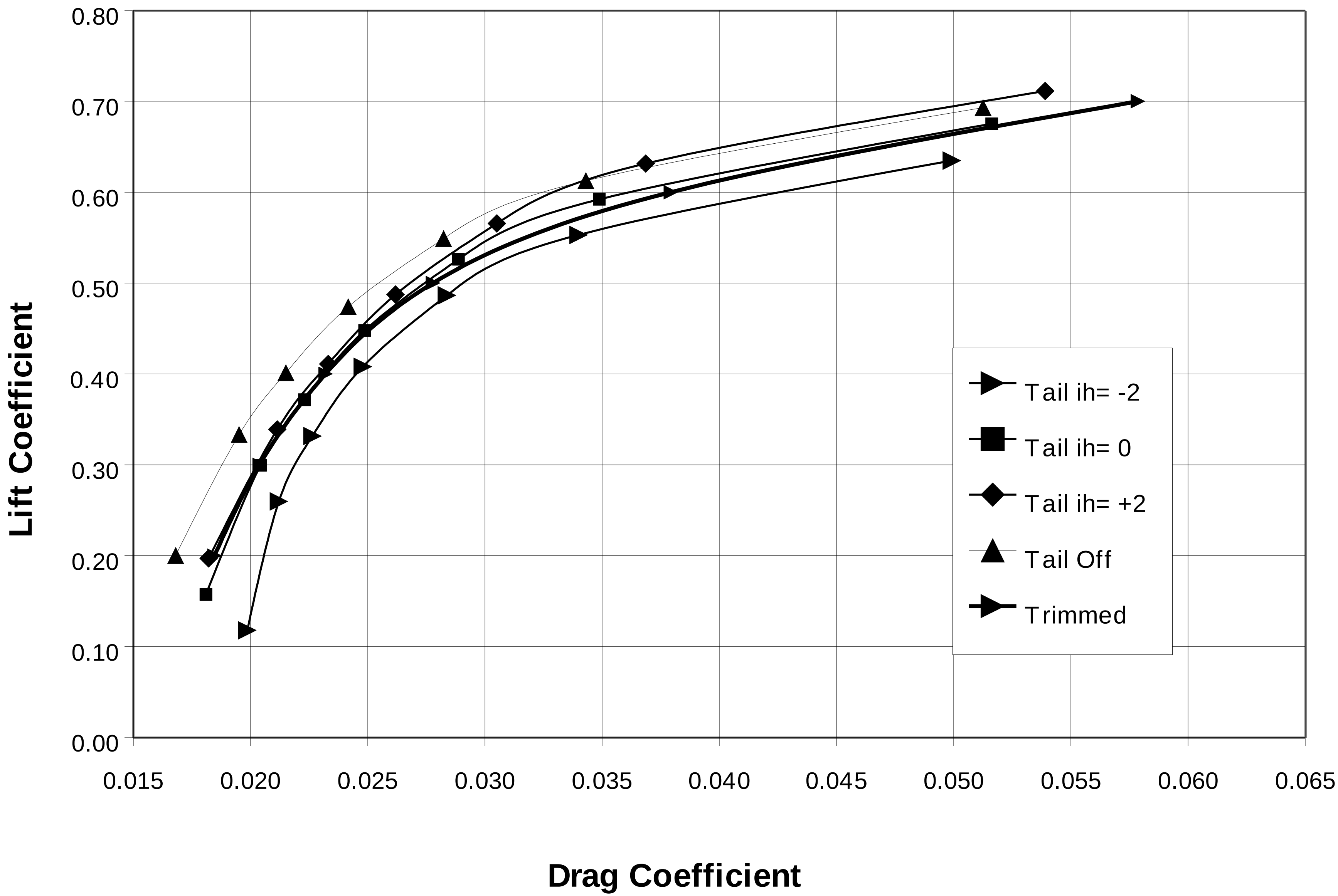
Surface streamlines via Line Integral Convolution (Paraview)
Case 1.1 (Medium Mesh, CL=0.5, M=0.85)

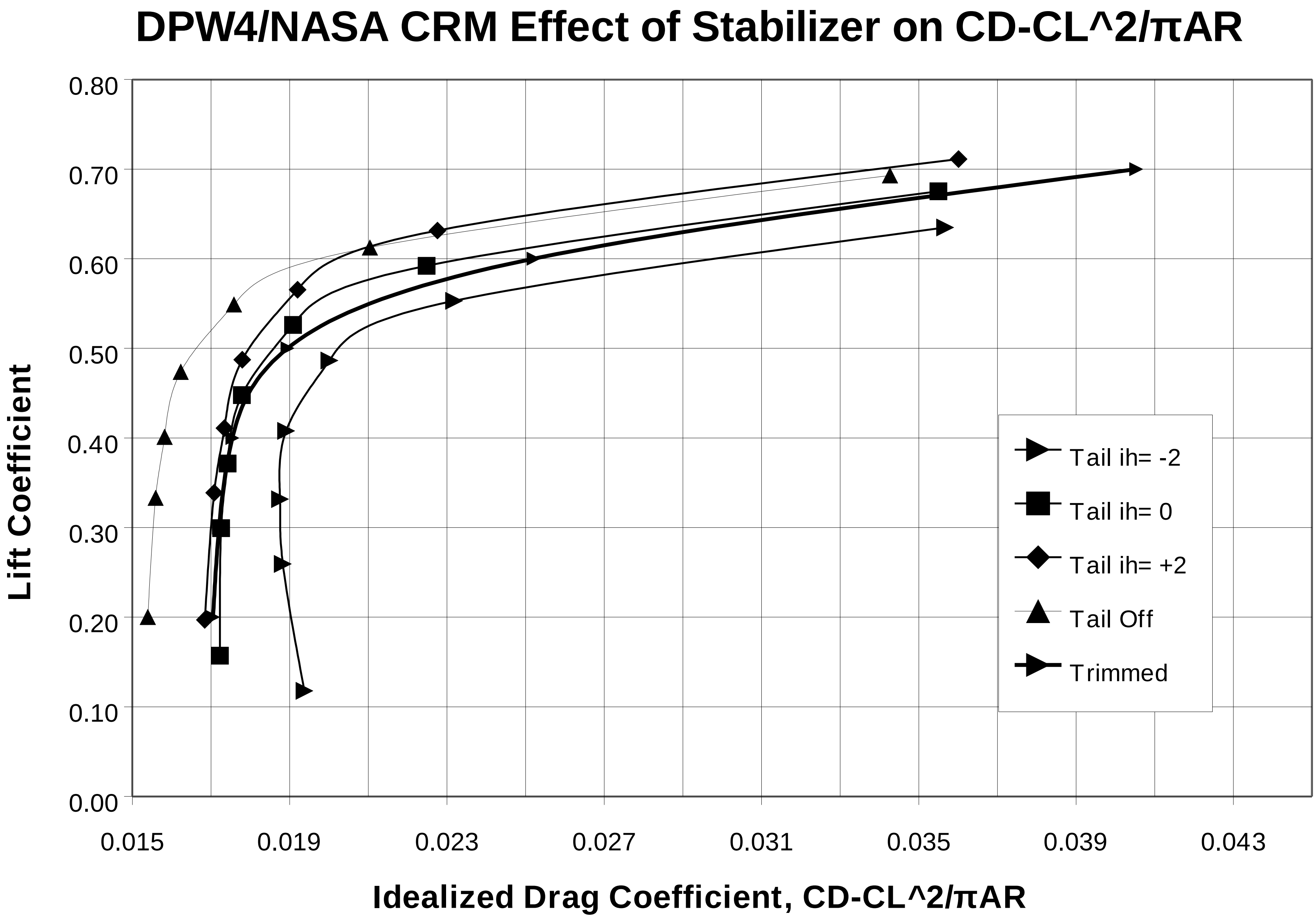
Case 1b: Downwash Study

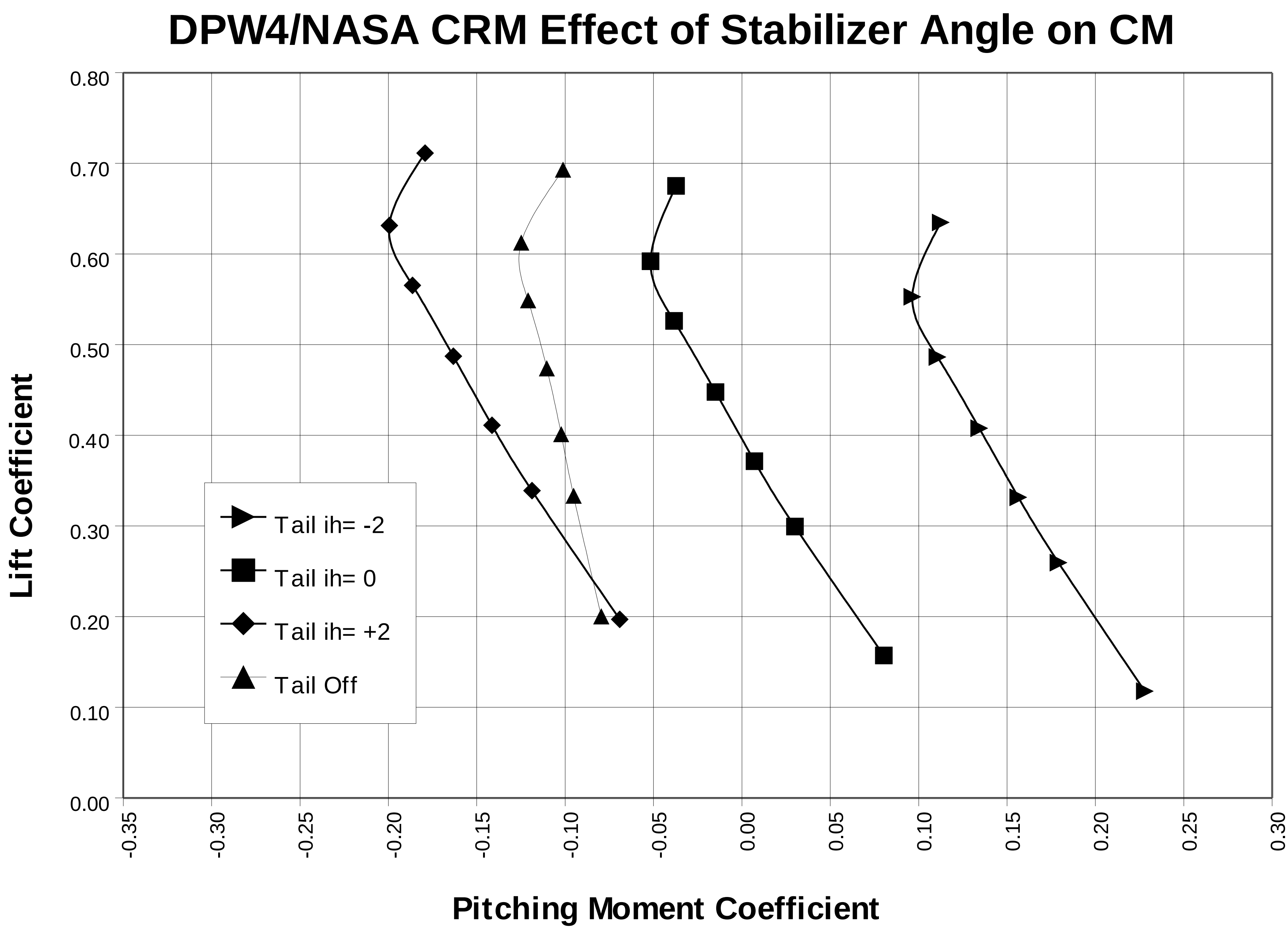
- Mach = 0.85–Drag Polars for alpha = 0.0°, 1.0°, 1.5°, 2.0°, 2.5°, 3.0°, 4.0°
- Tail Incidence angles iH = -2°, 0°, +2°, and Tail off Medium grid
- Chord Reynolds Number: Re=5M
- Trimmed Drag Polar (CG at reference center) derived from polars at iH= -2°, 0°, +2°
- Delta Drag Polar of tail off vs. tail on (i.e. WB vs. WBH trimmed)


DPW4/NASA CRM Effect of Stabilizer Angle on CL
Lift Coefficient
Angle of Attack, Deg
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Tail ih= -2
Tail ih= 0
Tail ih= +2
Tail Off
trimmed

DPW4/NASA CRM Effect of Stabilizer Angle on CD




DPW4/NASA CRM Effect of Stabilizer on CD-CL^2/πAR
Lift Coefficient
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.015
0.019
0.023
0.027
0.031
0.035
0.039
0.043
Idealized Drag Coefficient, CD-CL^2/πAR
Tail ih= -2
Tail ih= 0
Tail ih= +2
Tail Off
Trimmed


DPW4/NASA CRM Effect of Stabilizer Angle on CM
Lift Coefficient
Pitching Moment Coefficient
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
-0.35
-0.30
-0.25
-0.20
-0.15
-0.10
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
Tail ih= -2
Tail ih= 0
Tail ih= +2
Tail Off

Case 2 – Mach Sweep Study

Drag Polars at:

- Mach = 0.70, 0.75, 0.80, 0.83, 0.85, 0.86, 0.87

- Drag Rise curves at CL = 0.400, 0.450, 0.500 (±0.001)

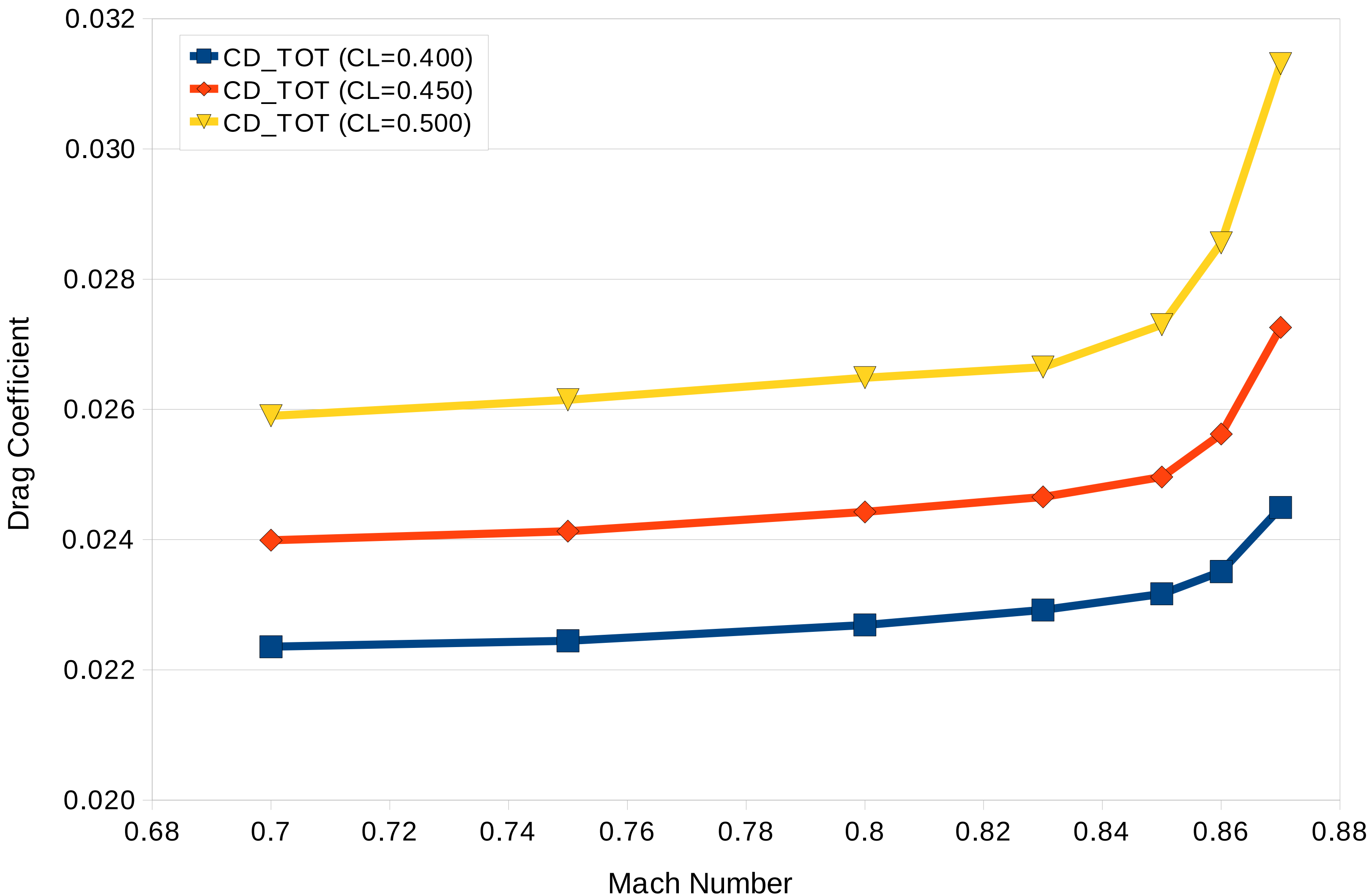
- Untrimmed, Tail Incidence angle, iH = 0°

- Medium grid

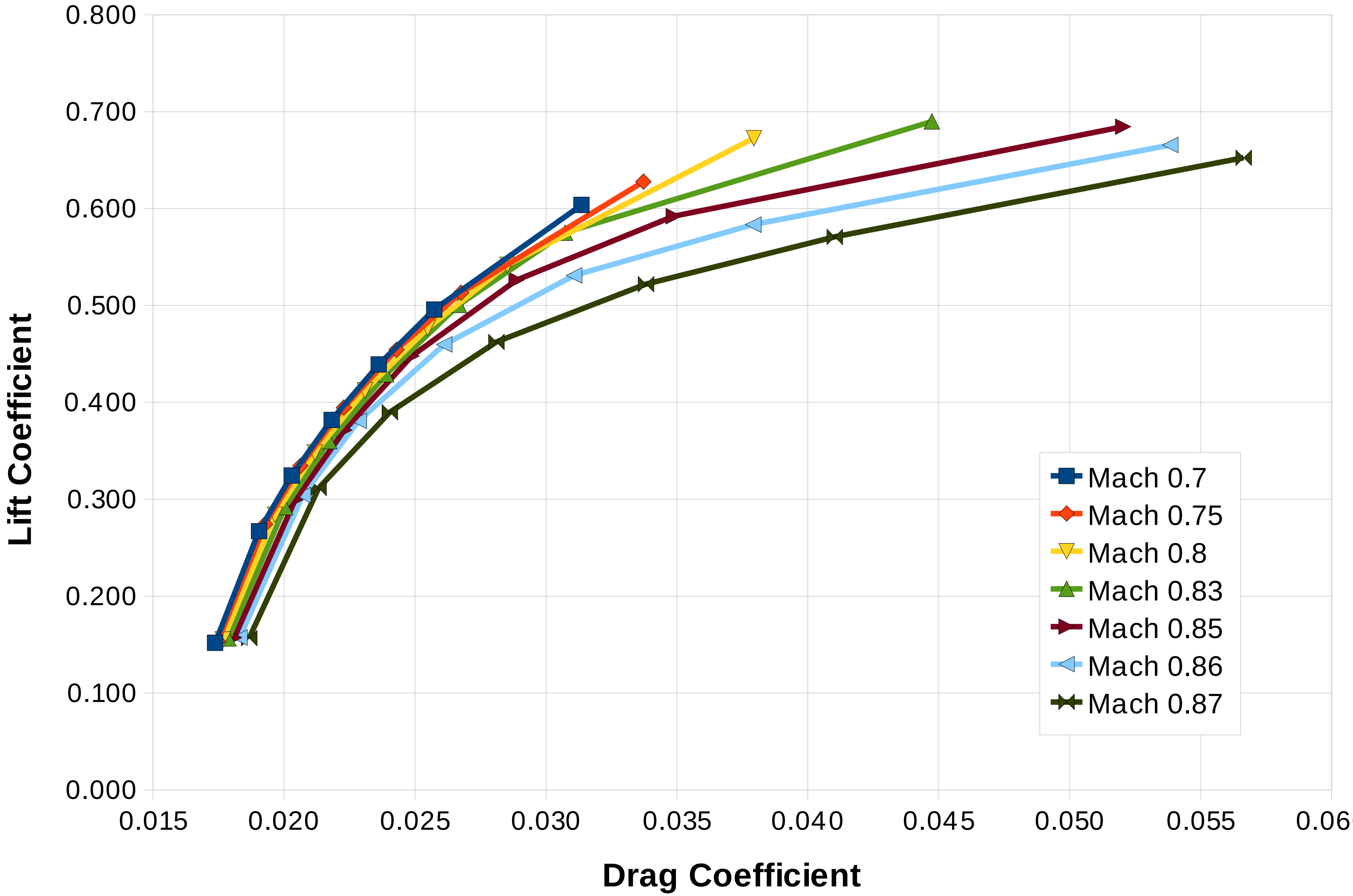
- Chord Reynolds Number 5x106 based on cREF = 275.80 in

- Reference Temperature = 100°F

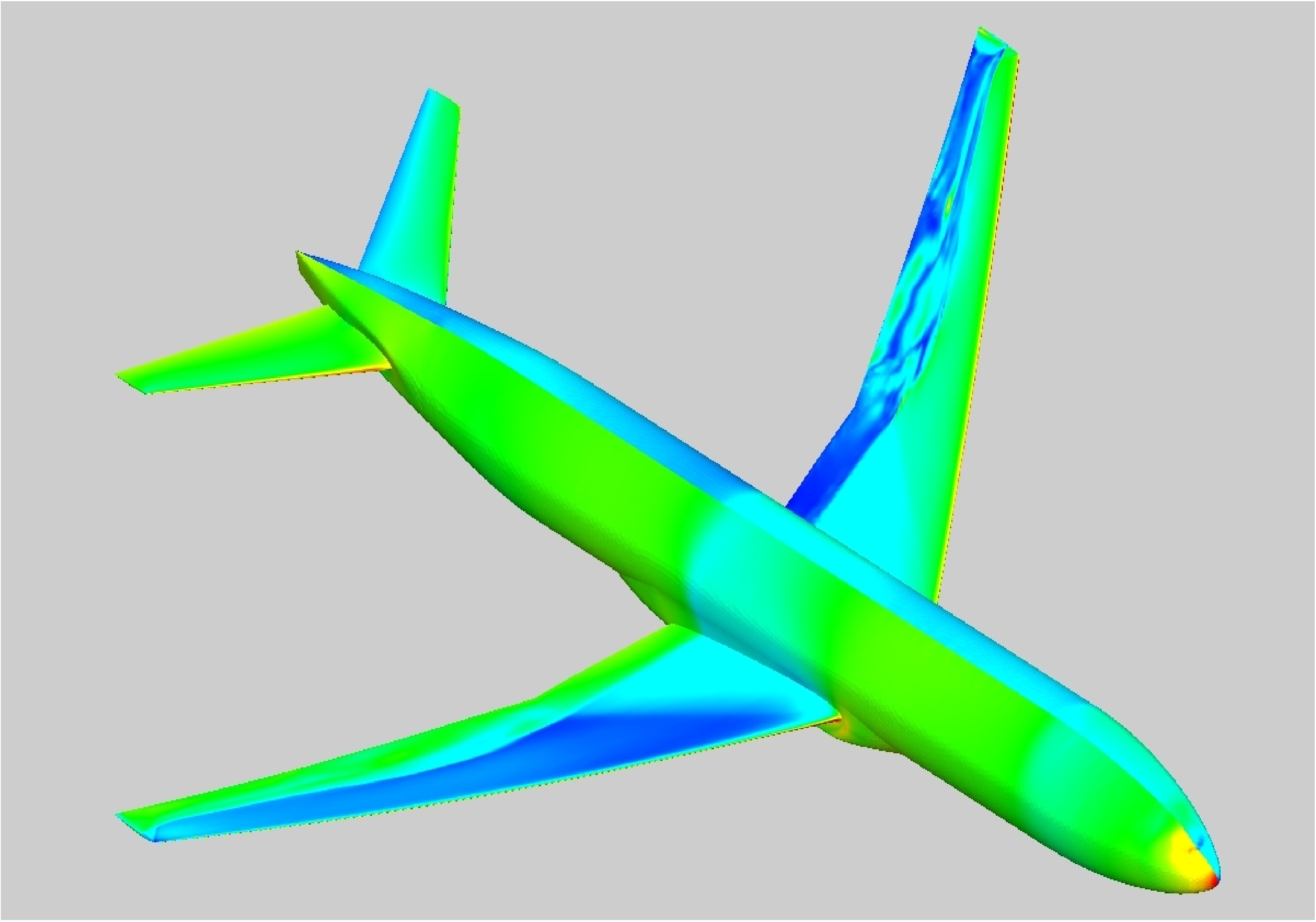
Case 2 - Drag Rise at Fixed CL
(LaRC Medium Grid Tail 0°)



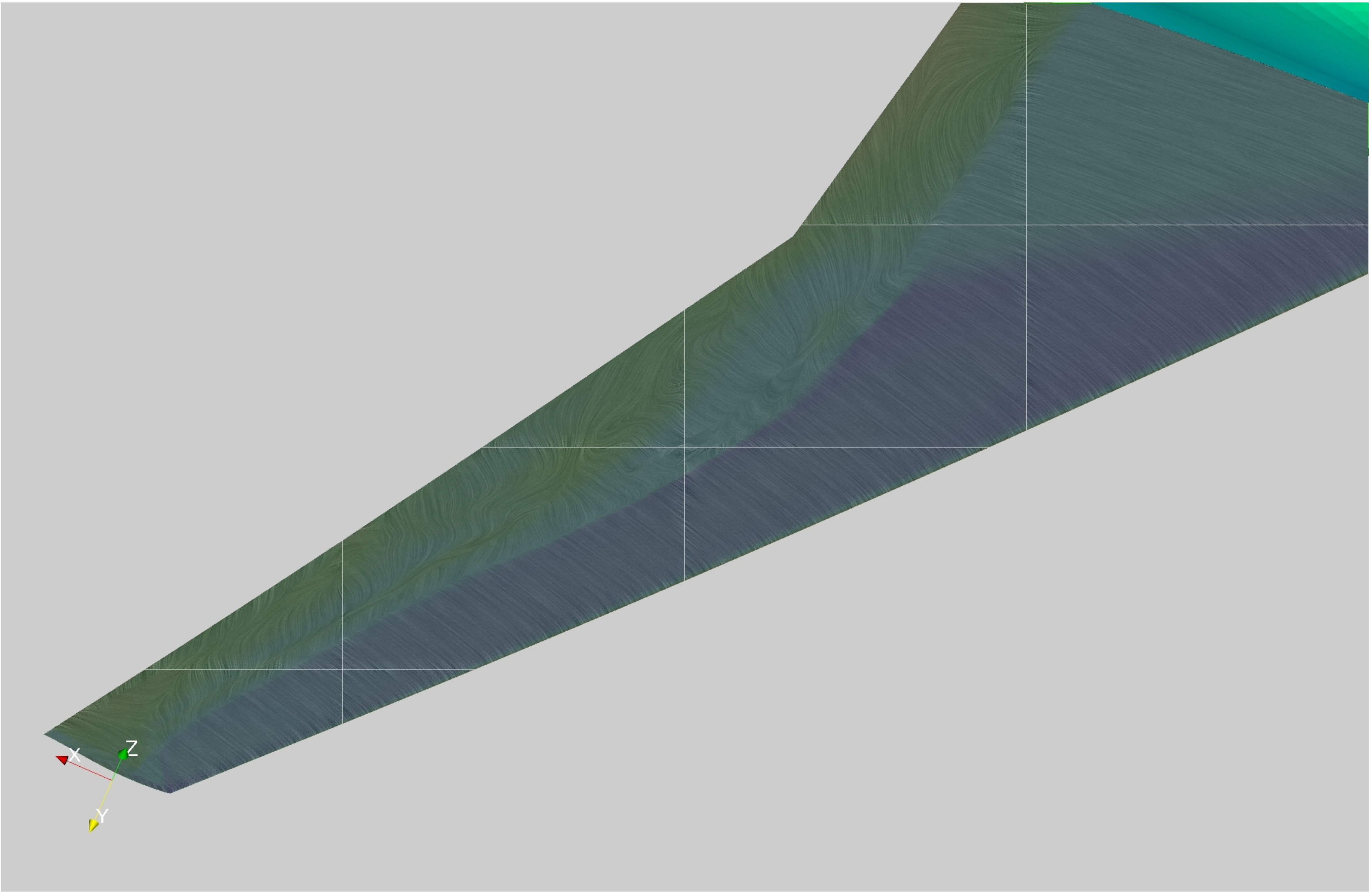
Case 2 - Drag Polars
(LaRC Medium Grid Tail 0°)



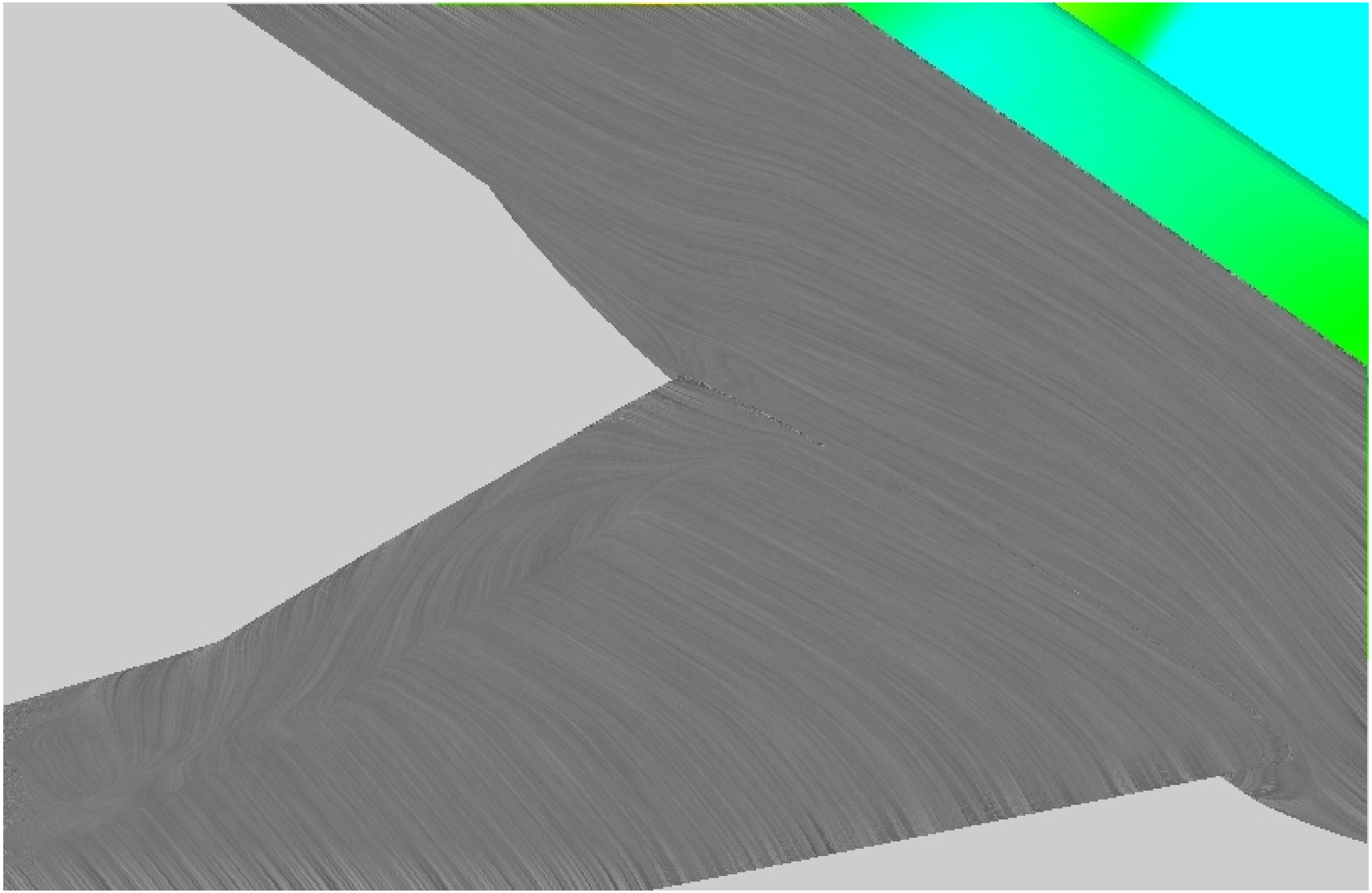
Surface Pressure and Friction Coefficients
(LaRC Medium Grid, M = 0.87, AOA = 4.0°)



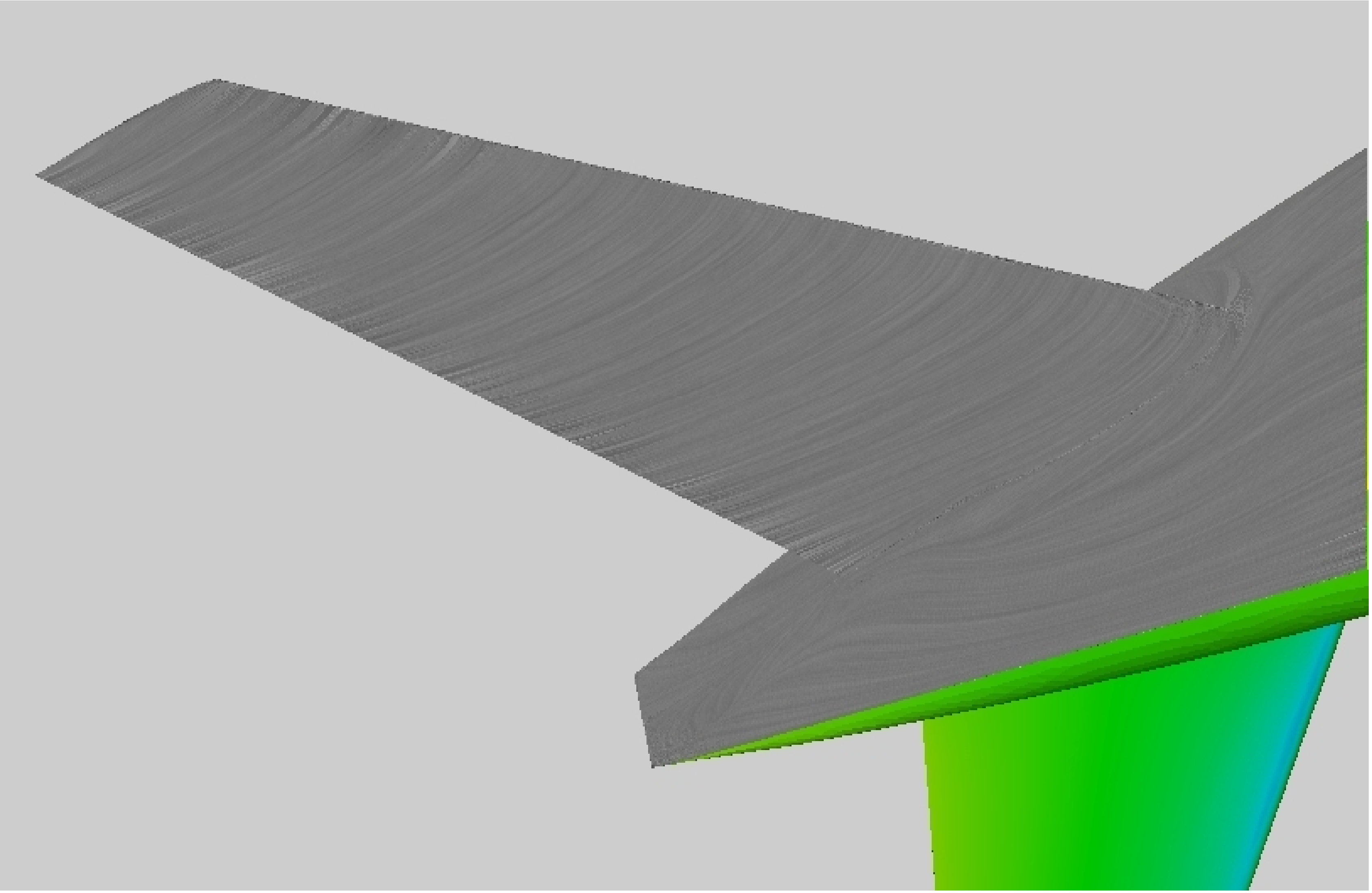
Surface Flow Patterns
(LaRC Medium Grid, M = 0.87, AOA = 4.0°)



Surface Flow Patterns
(LaRC Medium Grid, M = 0.87, AOA = 4.0°)



Surface Flow Patterns
(LaRC Medium Grid, M = 0.87, AOA = 4.0°)



Case 3 – Reynolds Number Effect

(LaRC Med Grid, CL=0.5, M=0.85, AOA=0, Tail=0°)

Reynolds Number	ALPHA	CL_TOT	CD_TOT	CD_PR	CD_SF	CM_TOT
5 Million	**2.330**	**0.4999**	**0.02730**	**0.01501**	**0.01230**	**-0.03061**
20 Million	**2.141**	**0.5000**	**0.02423**	**0.01384**	**0.01039**	**-0.03649**
Delta	**-0.18857**	**0.0001**	**0.00307**	**0.00117**	**0.00190**	**0.00588**
%	**-8.09%**	**0.01%**	**-11.25%**	**-7.79%**	**-15.48%**	**19.20%**

Conclusions

- All required cases converged with SA turbulence model and low dissipation
- Grid convergence is apparent for medium and fine grids
- Optional case 2 completed with good convergence except for extremes
- Optional extra-fine mesh presented some challenges
- Optional case 3 was run on the same mesh for both Reynolds Numbers
- Separation only seen at high AOA and high Mach