FUN3D Analysis of DPW-IV Common Research Model

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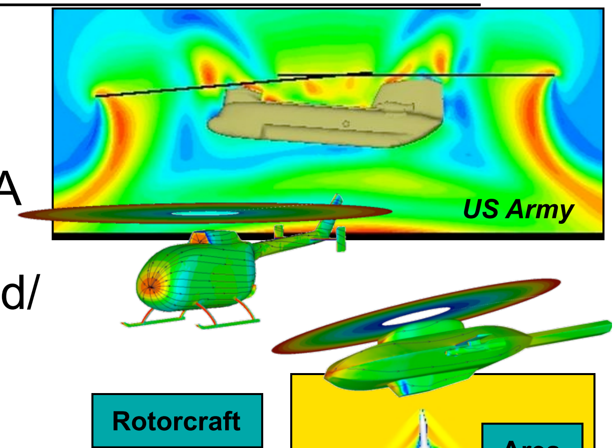
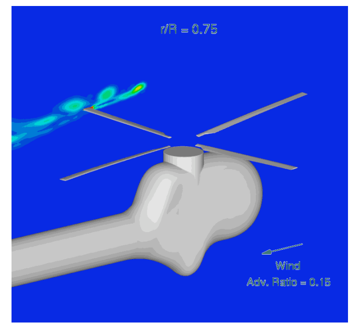
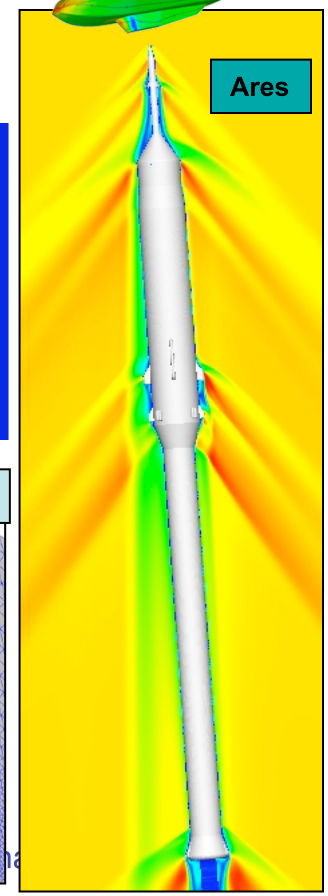
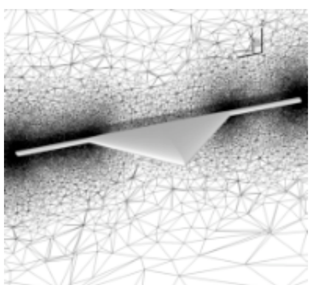
FUN3D Core Capabilities

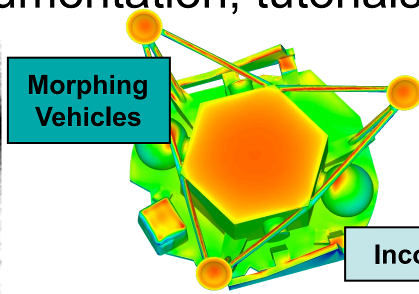
- Solves 2D/3D steady and unsteady Euler and RANS equations on node-based mixed element grids for compressible and incompressible flows
- Used for numerous projects internal and external to NASA across the speed range
- General dynamic mesh capability: any combination of rigid/ overset/morphing grids, including 6-DOF effects
- Aeroelastic modeling w/ mode shapes, full FEM, CC, etc
- Adjoint-based design optimization and mesh adaptation
- Linear scaling through 1000's of cores
- Capabilities fully integrated, large support team, online documentation, tutorials, etc

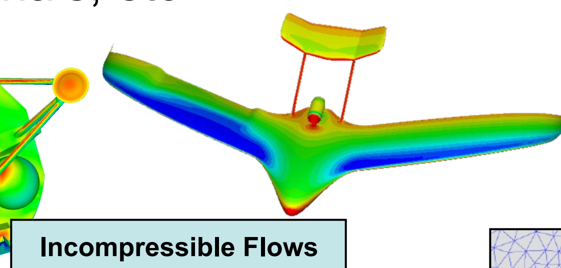


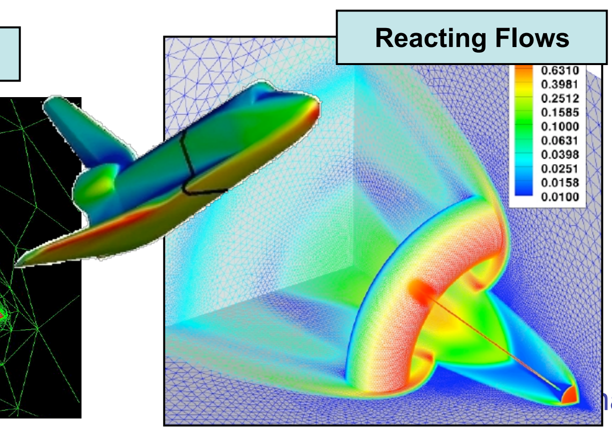


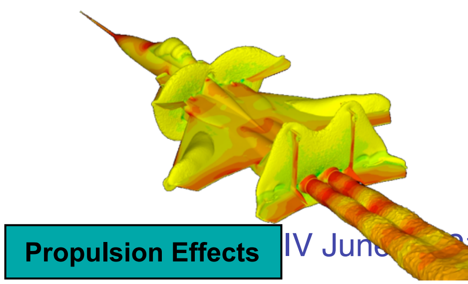


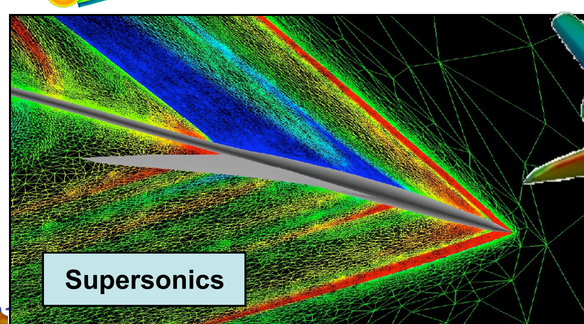










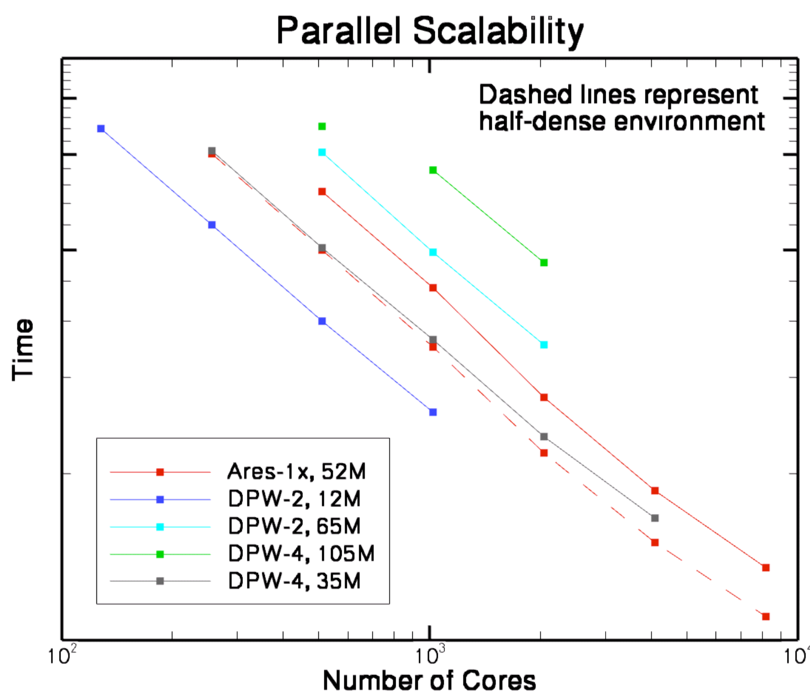


FUN3D Unstructured Grid Code

- Full Navier-Stokes equations-node centered
- Parallel 3D compressible finite-volume RANS for mixed-element meshes
- Implicit time-stepping using multi-color point Gauss-Seidel relaxation for linear system
- UMUSCL 0.5 scheme (CD + Roe) for inviscid fluxes with Venkatakrishnan limiter
- Combined Green-Gauss and edge-based gradients for viscous fluxes
- Spalart-Allmaras turbulence model (loosely coupled)

FUN3D Unstructured Grid Code

- Parallel version - MPI
  - Old paradigm (multiple steps)
    - * Sequential pre-processor using MeTiS domain decomposition or parallel pre-processor using ParMetis
    - * Parallel flow solver (reads partition files)
    - * Sequential post-processing for visualization
  - New paradigm (one step)
    - * Solver loads grid file directly in parallel and performs domain decomposition using ParMetis
    - * Global grid image not in-core at any time
    - * Parallel co-processing for animation, slicing, etc
    - * LaRC internal version



Summary of FUN3D Results

- **Case 1 :**
  - **Grid Convergence study** at Mach = 0.85, CL = 0.500 $\pm$0.001
    - Tail Incidence angle, $i_H = 0^o$
    - Coarse, Medium, Fine, and Extra-Fine Grids
    - Chord Reynolds Number Re_c=5x10^6, fully turbulent
  - **Downwash Study** at Mach = 0.85
    - Drag Polars for alpha = 0.0^o, 1.0^o, 1.5^o, 2.0^o, 2.5^o, 3.0^o, and 4.0^o
    - Tail Incidence angles $i_H = -2^o, 0^o, +2^o$, and Tail off
    - Medium grid
    - Chord Reynolds Number Re_c=5x10^6, fully turbulent
    - Trimmed Drag Polar (CG at reference center) derived from polars at $i_H = -2^o, 0^o, +2^o$
    - Delta Drag Polar of tail off vs. tail on (i.e. WB vs. WBH trimmed)

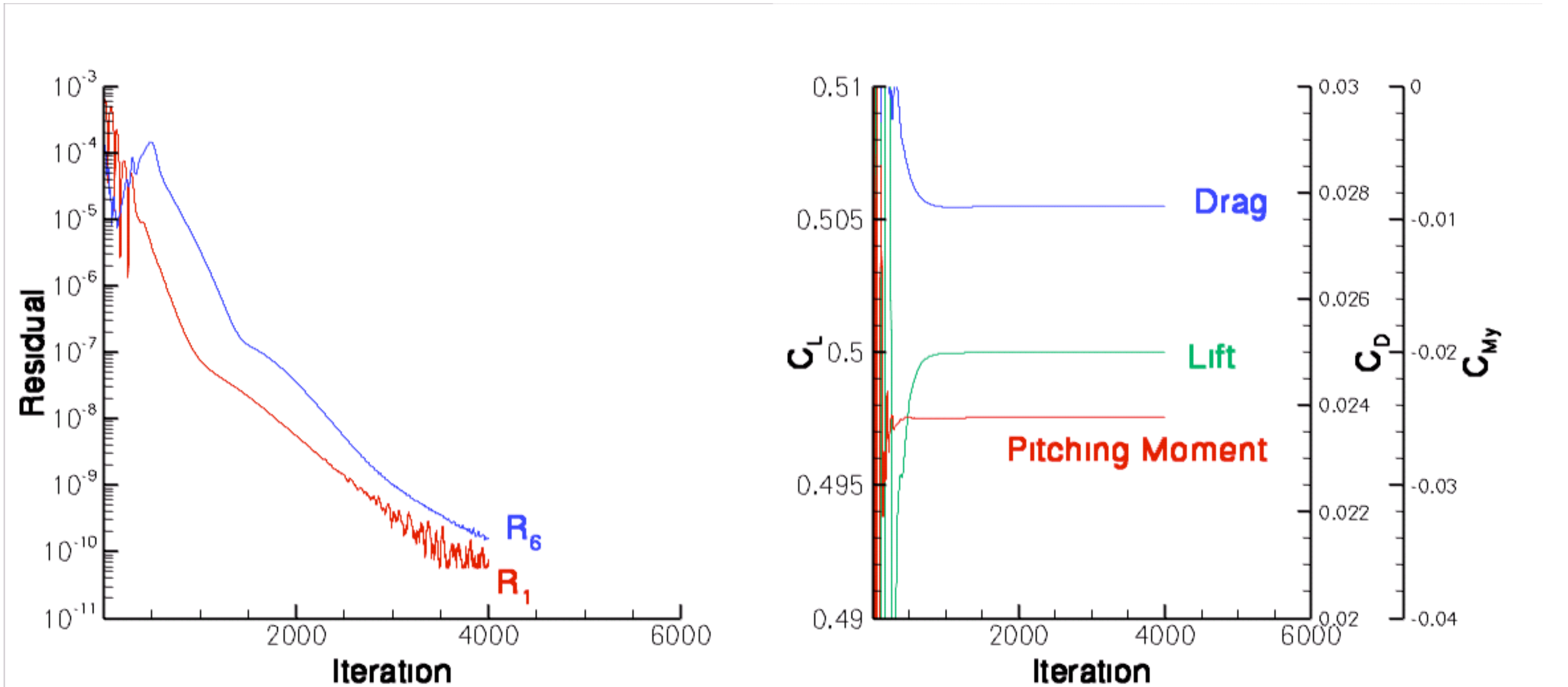
Computational Grids - CRM

- Mixed-element versions of the workshop unstructured node-based LaRC grids
- Advancing layer tetrahedra are merged into prisms/pyramids

	Original Grid		Merged Grid			
	Nodes	Cells Tet.	Nodes	Cells Tet.	Cells Prism	Cells Total
Coarse	3.7M	21.6M	3.7M	3.8M	5.9M	9.8M
Medium	10.2M	60.3M	10.3M	14.8M	15.2M	30.1M
Fine	36.0M	212.2M	36.0M	76.5M	45.2M	121.9M
Extra-Fine	105.6M	623M	105.7M	289.6M	111.1M	401.0M

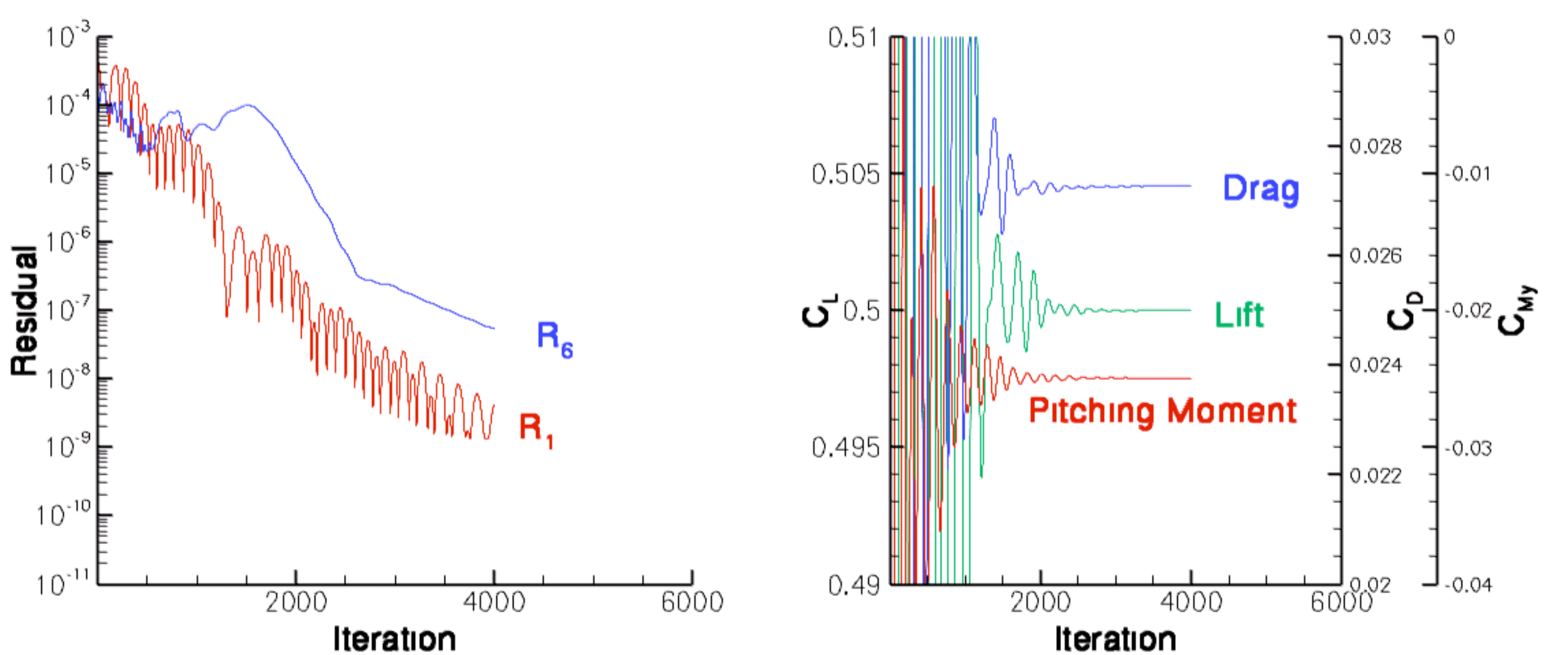
Residual Convergence Medium Grid for C_L=0.5

- During the convergence history, relaxation in alpha based on error in total lift (method from CFL3D as coded by Steve Allmaras)



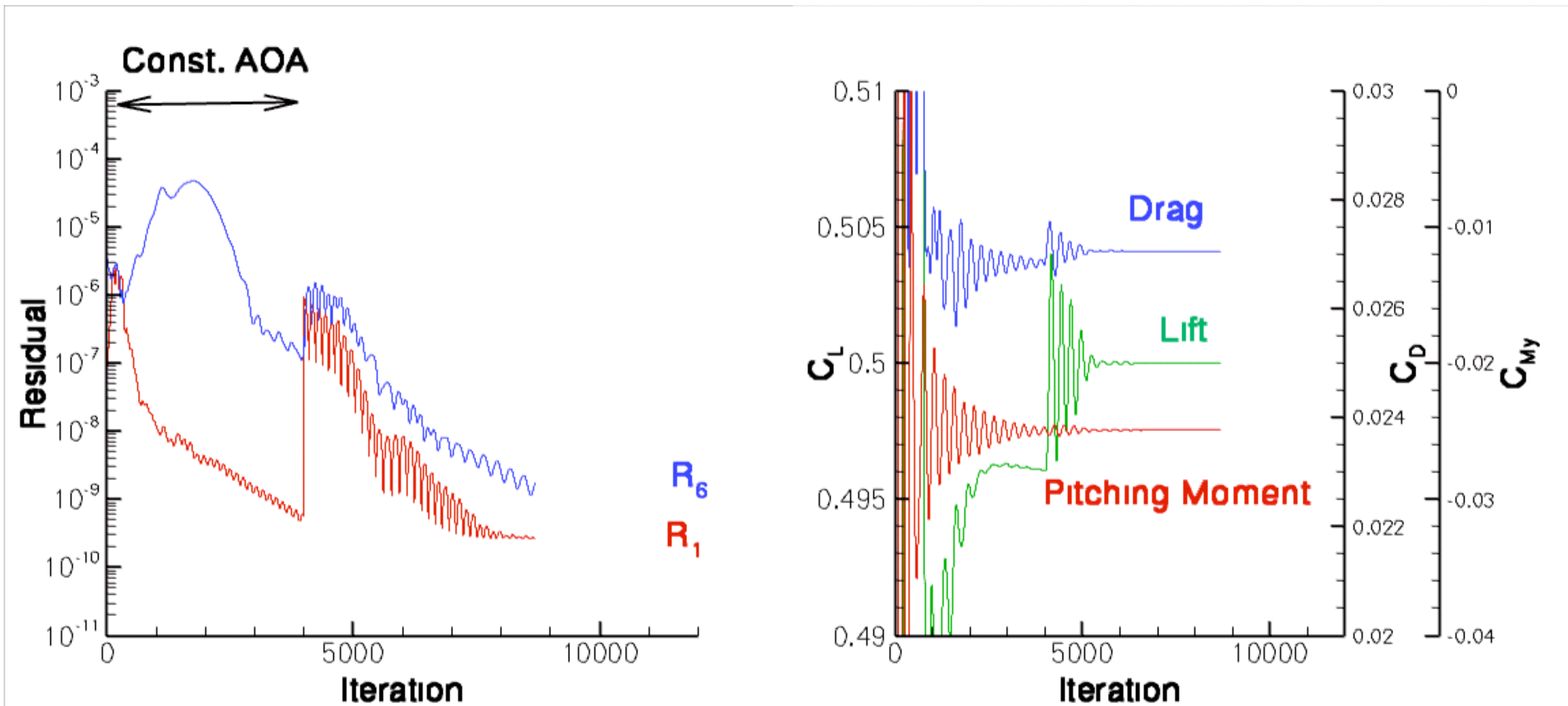
Residual Convergence Fine Grid for C_L=0.5

- During the convergence history, relaxation in alpha based on error in total lift (method from CFL3D as coded by Steve Allmaras)

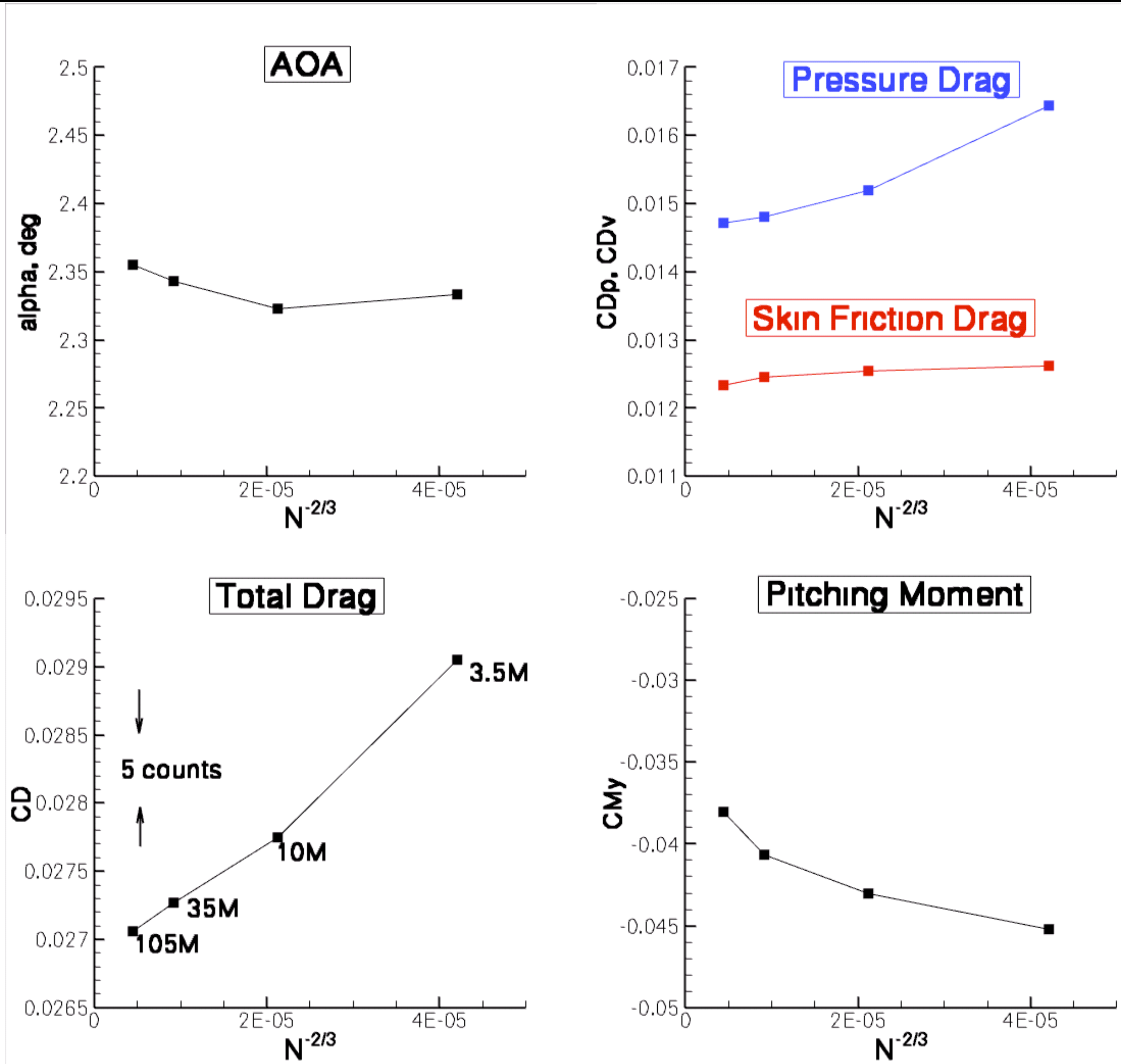


Residual Conv. Extra-Fine Grid for C_L=0.5

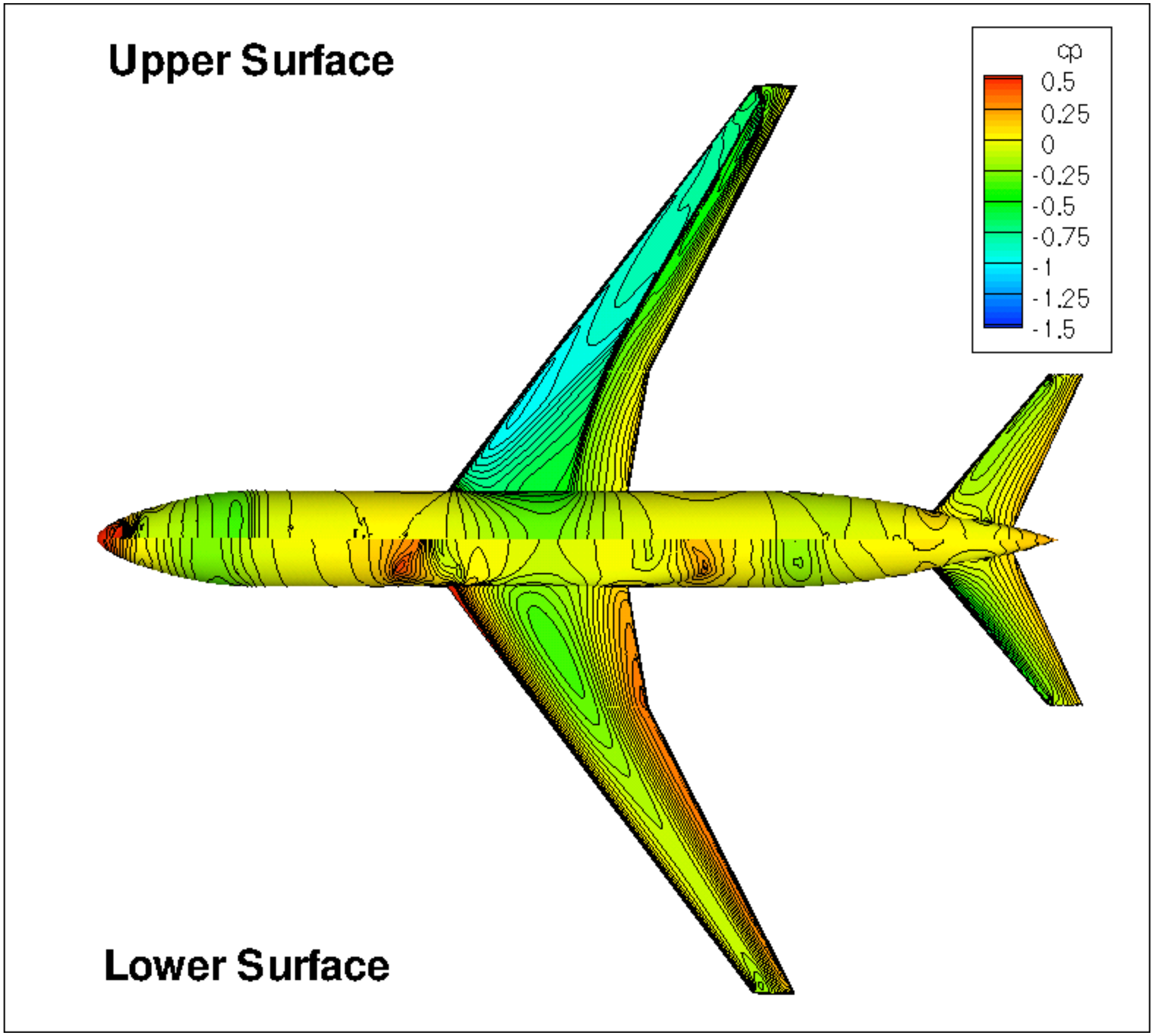
- From raw grid to solver iterations in ~20 minutes using fully parallel paradigm on 1024 distributed memory processors
- Output slices, surface flows, etc generated simultaneously
- Old paradigm: pre-processing grid would take 10-15 days and ~180GB on Columbia-class shared-memory machine



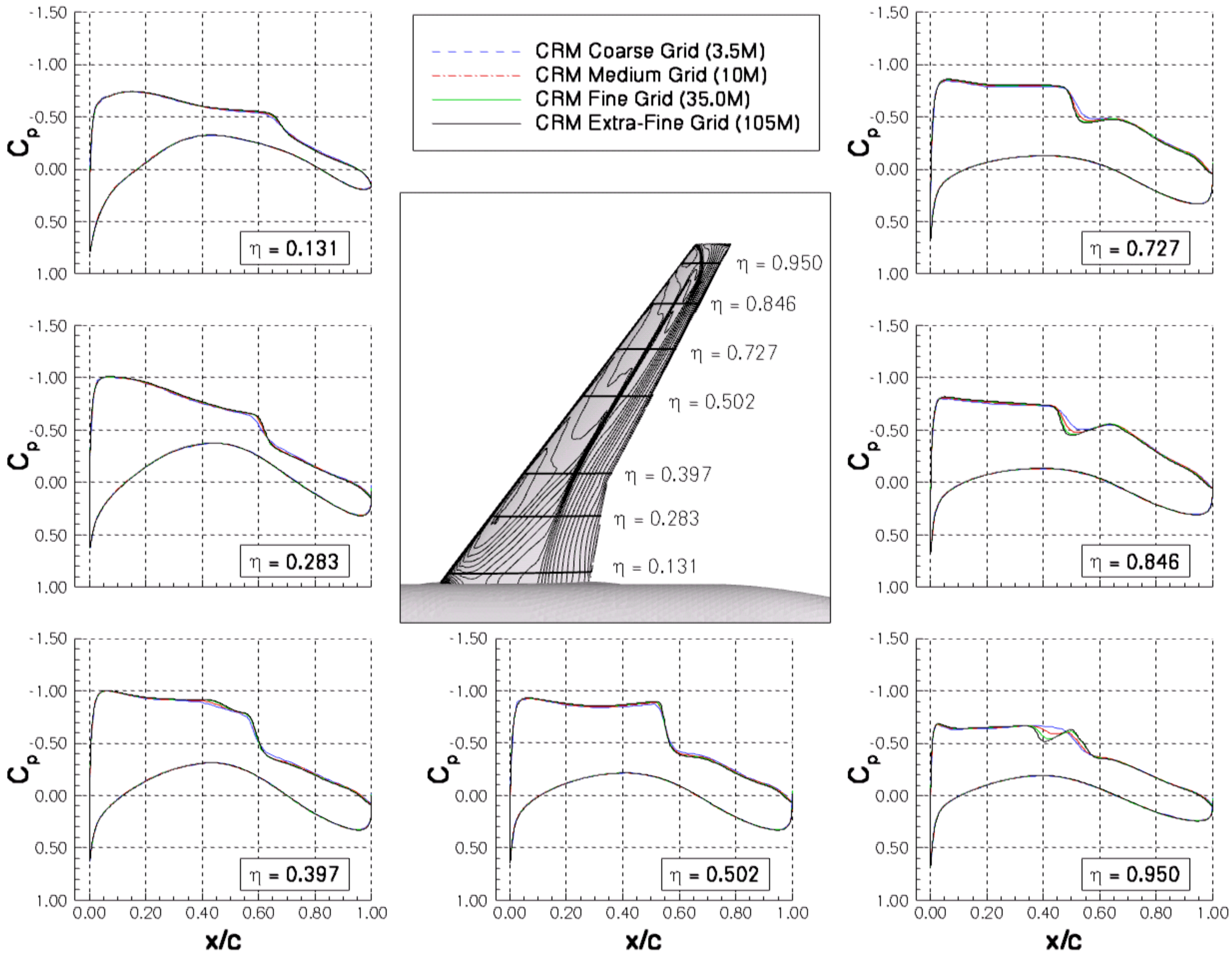
Grid Convergence of CRM Forces/Moment



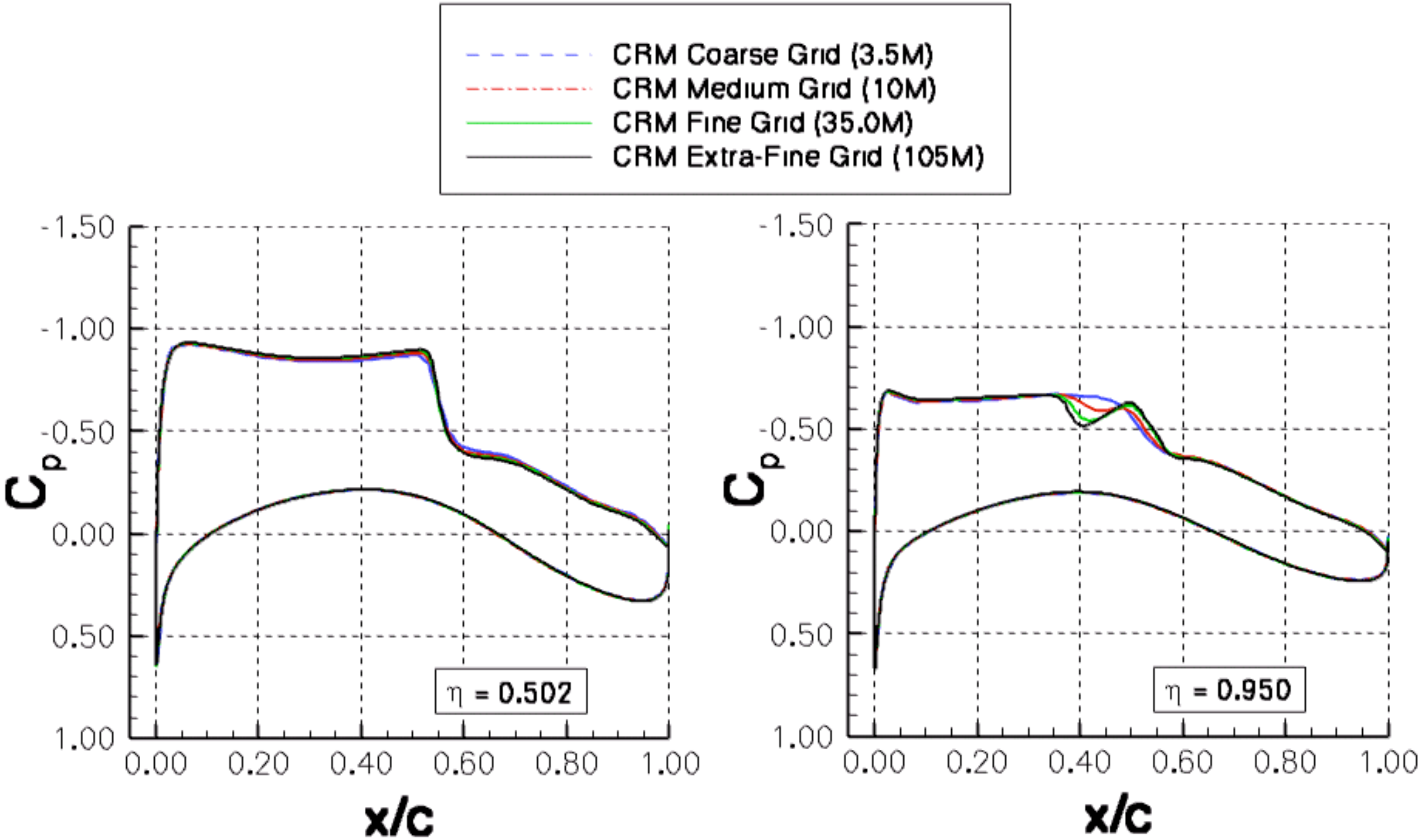
Fine Grid Pressure Contours



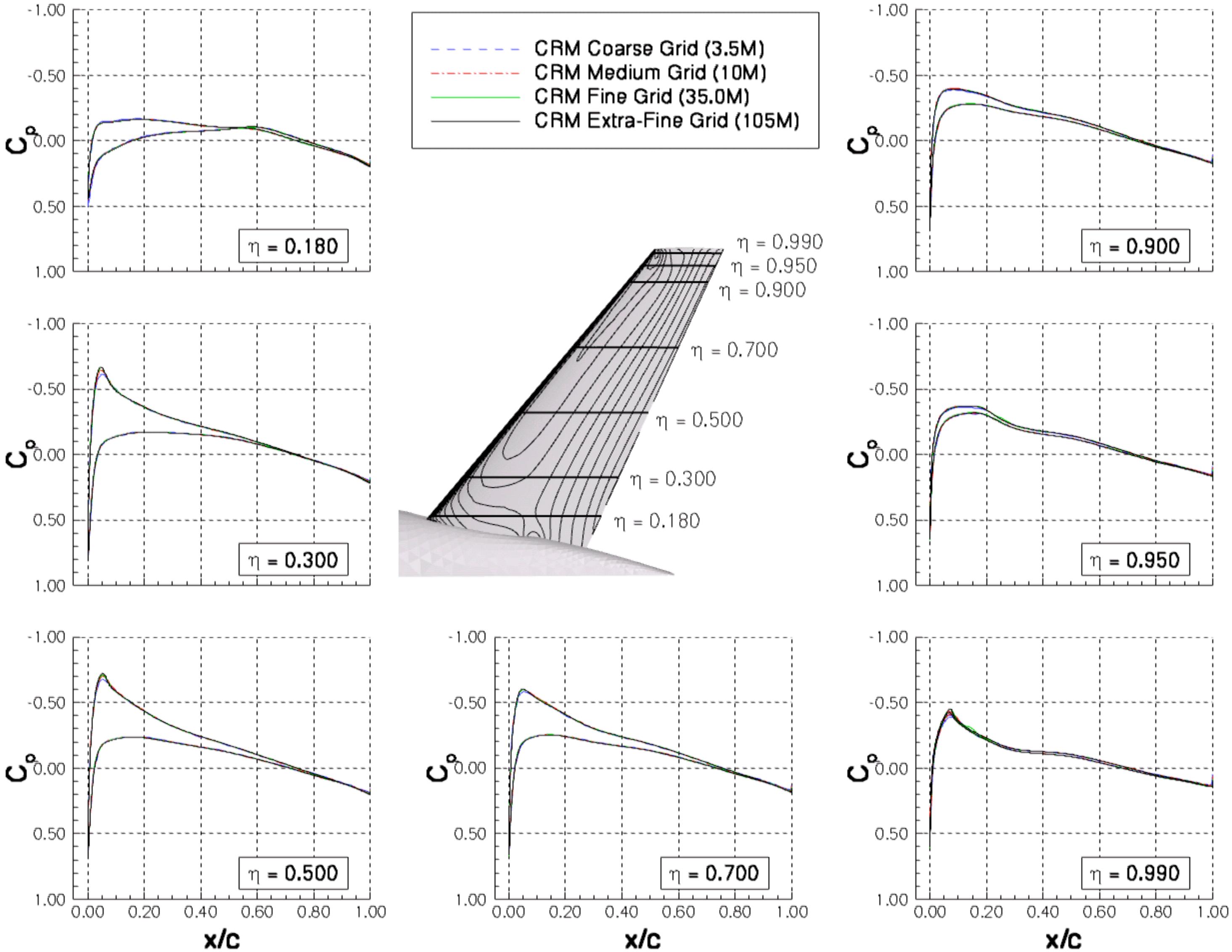
Grid Convergence of CRM Wing Pressures



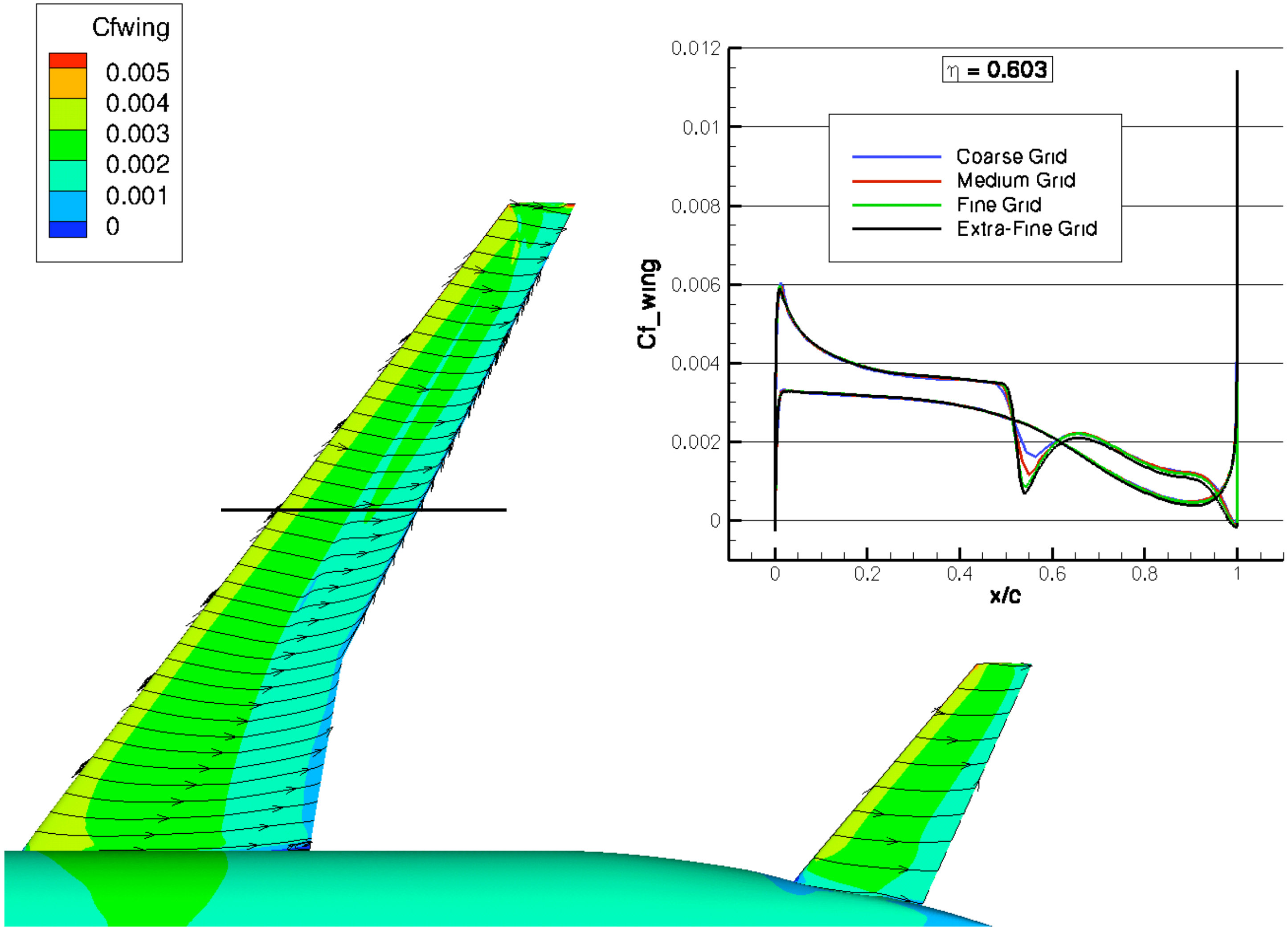
Grid Convergence of CRM Wing Pressures



Grid Convergence of CRM Tail Pressures

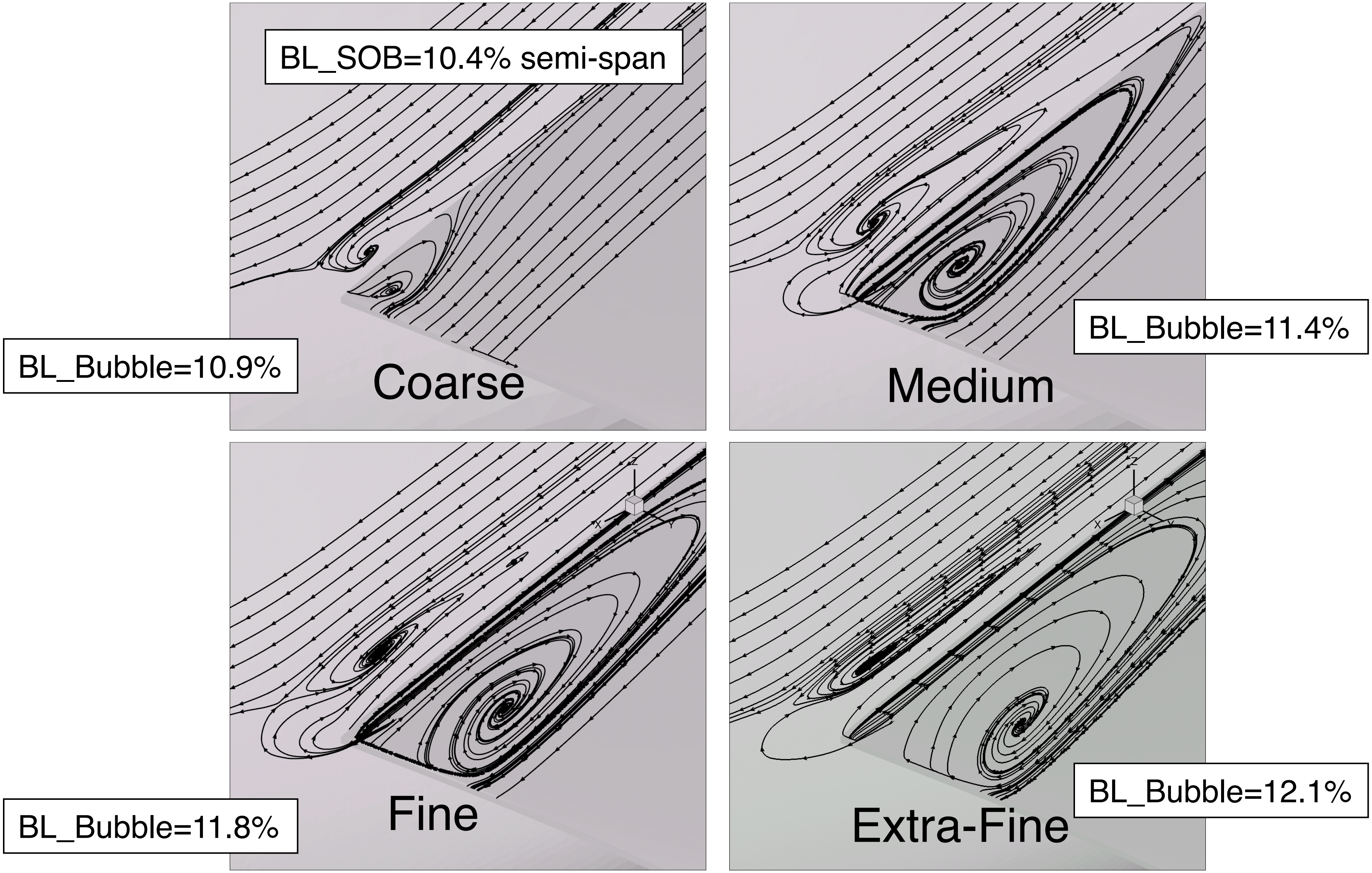


Fine Grid SOB & Trailing-Edge Separation



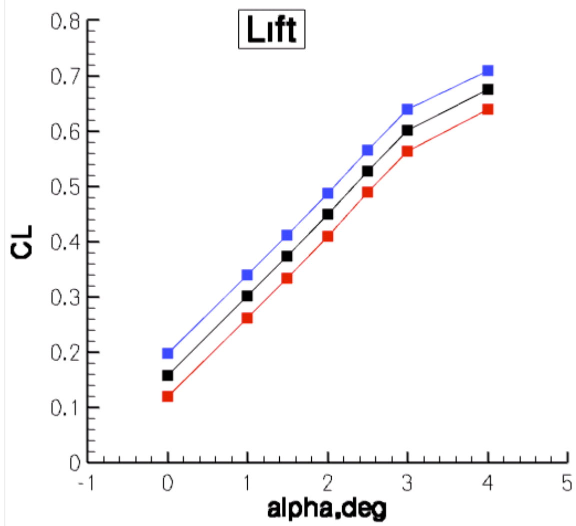
Cf wing = cfx*cos($\Lambda_{c/4}$) + cfy*sin($\Lambda_{c/4}$)

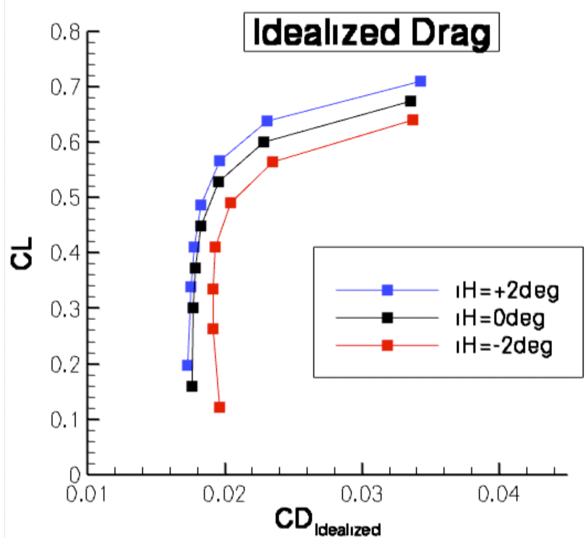
Grid Convergence of SOB Separation

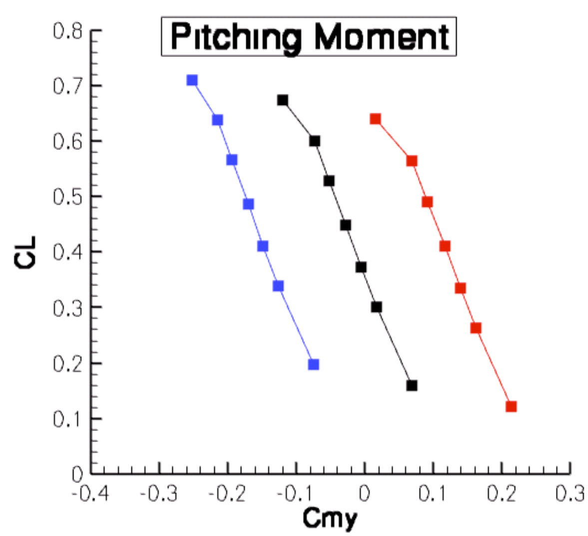


CRM Downwash Study

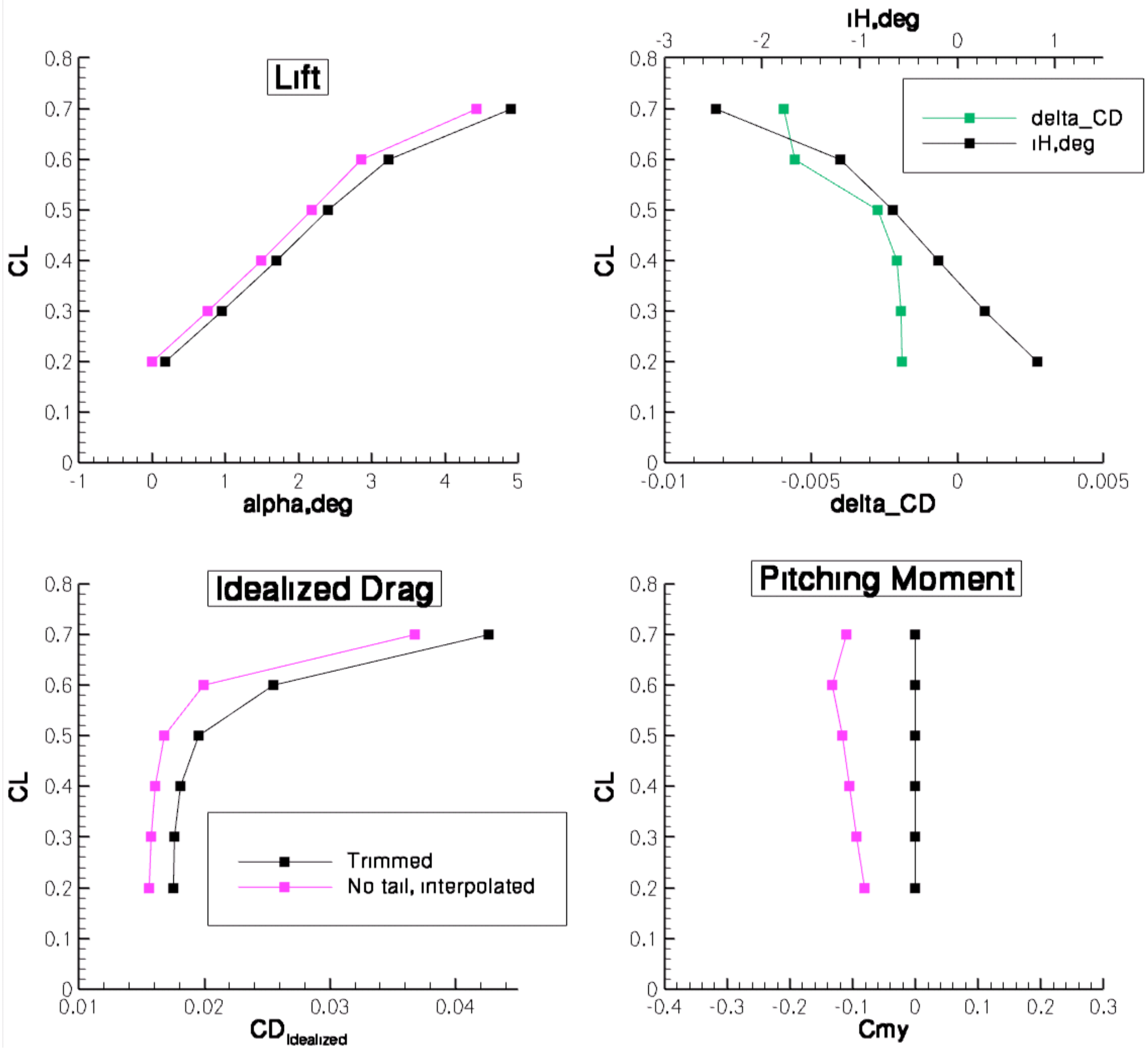
- Mach 0.85
- $Re_c = 5 \times 10^6$
- Spalart-Allmaras
- Fully Turbulent
- Medium Grids







CRM Downwash Study



Summary

- Grid convergence study
  - Good residual convergence on 4 grid (up to 105 million nodes) with CL driver active
  - Linear variation in total drag on finest 3 grids (delta CD = 6 counts)
  - Small variations in wing/tail Cp with grid refinement
  - 1-2% chord wing TE separation (mid-span)
  - Small wing SOB separation
  - No tail SOB/TE separation
- Downwash study(medium grid)
  - Delta drag 27 counts at $C_L = 0.5$

Acknowledgements

- Dr. Robert Biedron, NASA LaRC
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