FUN3D and CFL3D Calculations for the Fifth AIAA Drag Prediction Workshop

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Outline

- Case 1 grid refinement study
- Case 2 buffet study
- Drag adaptation
  - Case 3 NACA 0012
  - Case 1 flow conditions

CFL3D

- Cell-centered structured multiblock grids
- Blended upwind (Roe) and central difference, kappa=1/3
- Full Navier-Stokes terms
- Spalart-Allmaras turbulence model

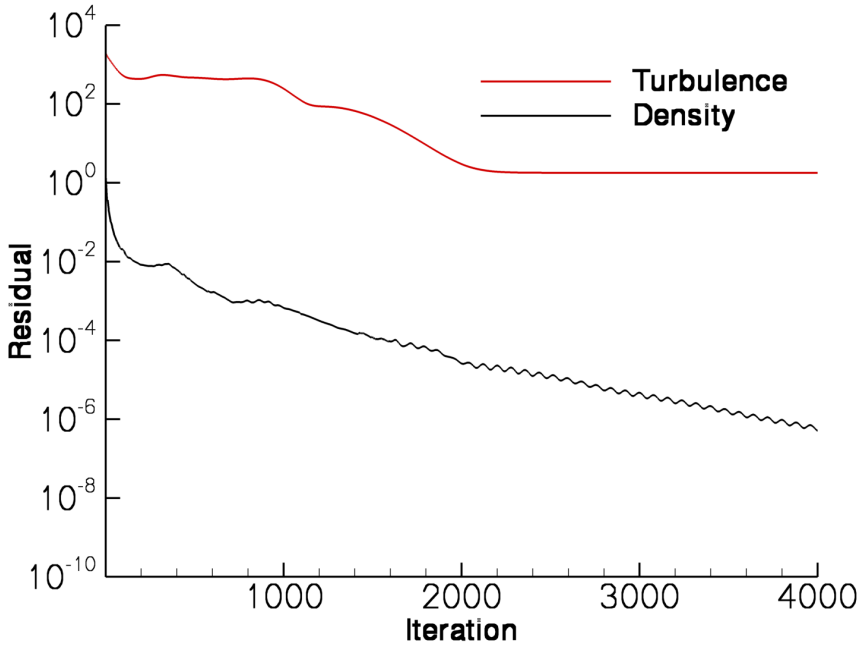
FUN3D

- Node-based mixed element grids
- Blended upwind (Roe) and central difference UMUSCL kappa=0.5 with Venkatakrishnan limiter (scaled to MAC)
- Full Navier-Stokes terms
- Spalart-Allmaras turbulence module loosely coupled and modified for negative working variable robustness

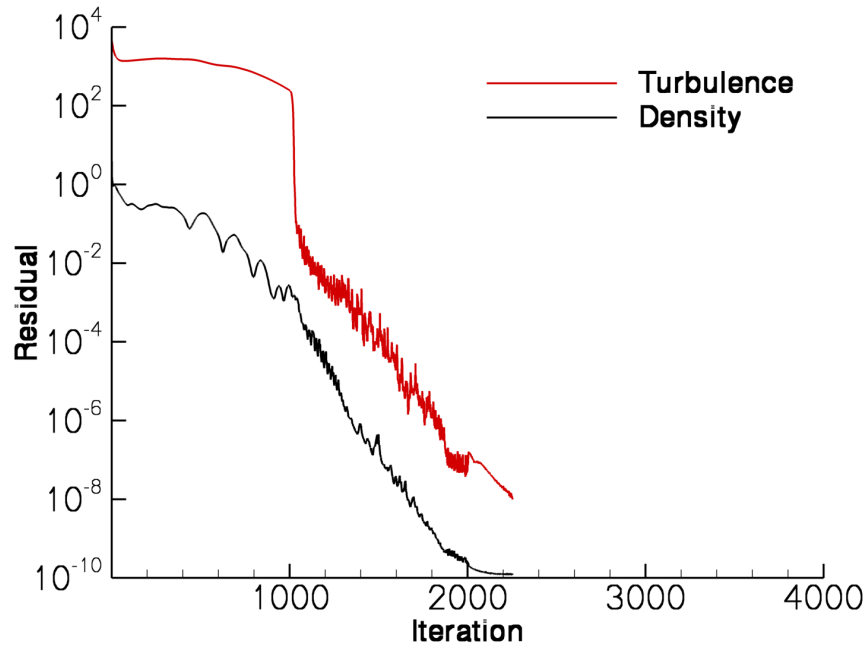
FUN3D Improvements

- SA model was modified to handle negative working variable transients (Thomas)
  - Moro, Nguyen, and Peraire AIAA-2011-3407
  - Oliver 2008 MIT PhD Thesis
  - Allmaras AIAA-1999-3336
- Generalized Conjugate Residual (CGR) wrapped exact first order preconditioner and Jacobian-free Newton (Thomas and Carpenter)
- Adaptive CFL (Thomas and Diskin)

Iterative Convergence Improvement



Original Iterative Convergence

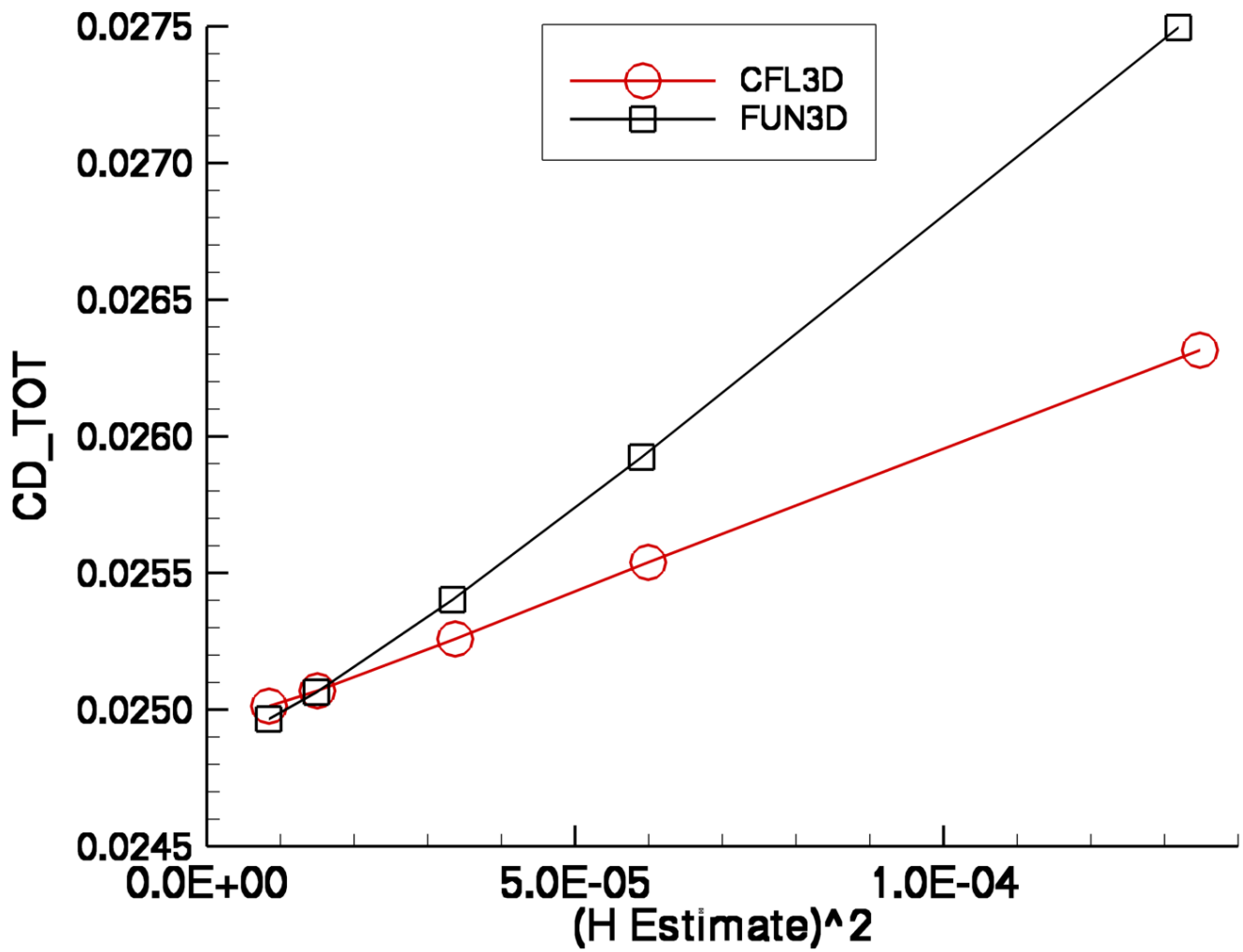


Improved Iterative Convergence

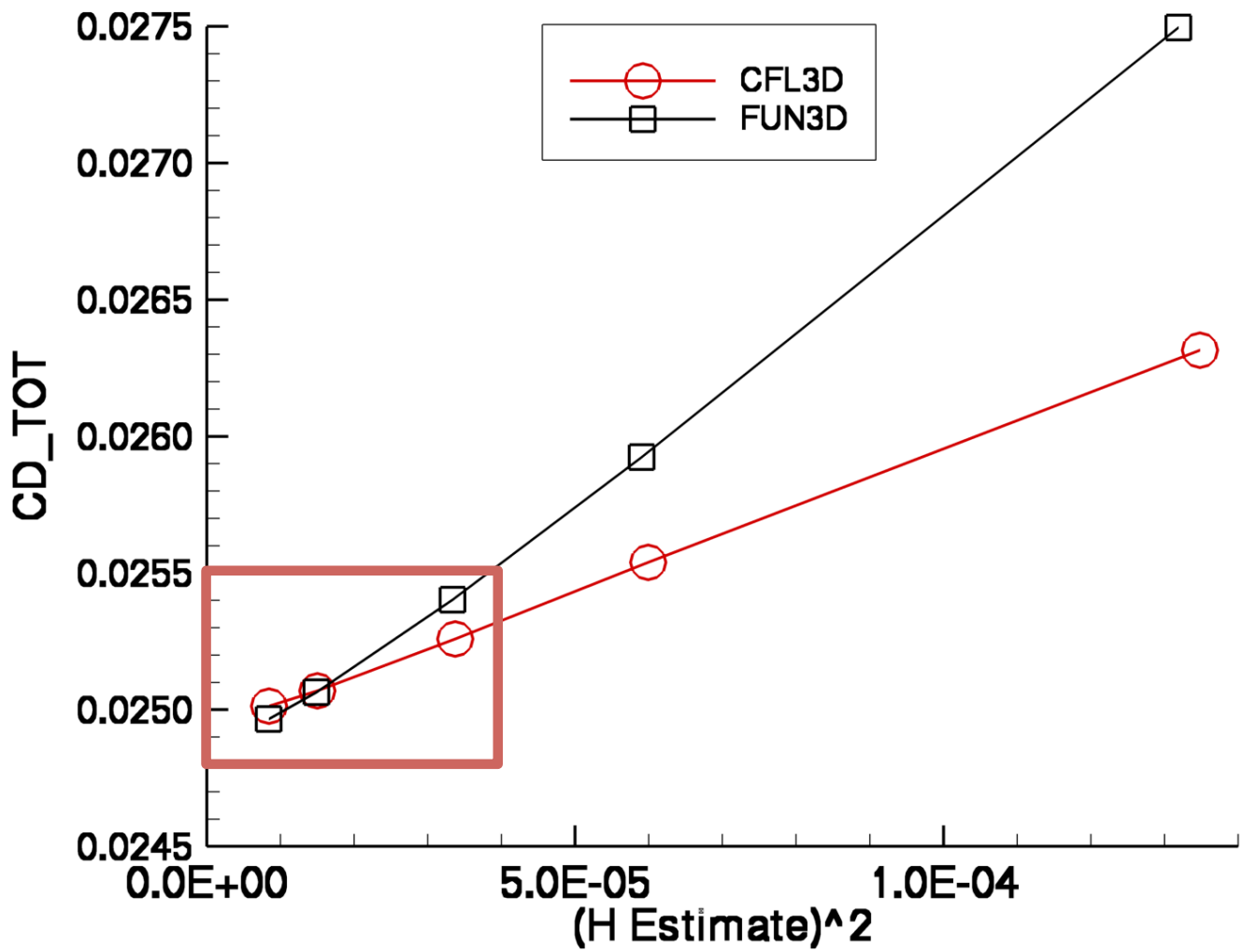
Case 1 Grid Convergence Study

- Mach = 0.85, Re = 5×10^6 per MAC, CL_TOT = 0.5
- CFL3D used the CommonMB and FUN3D used the CommonHybrid grid systems

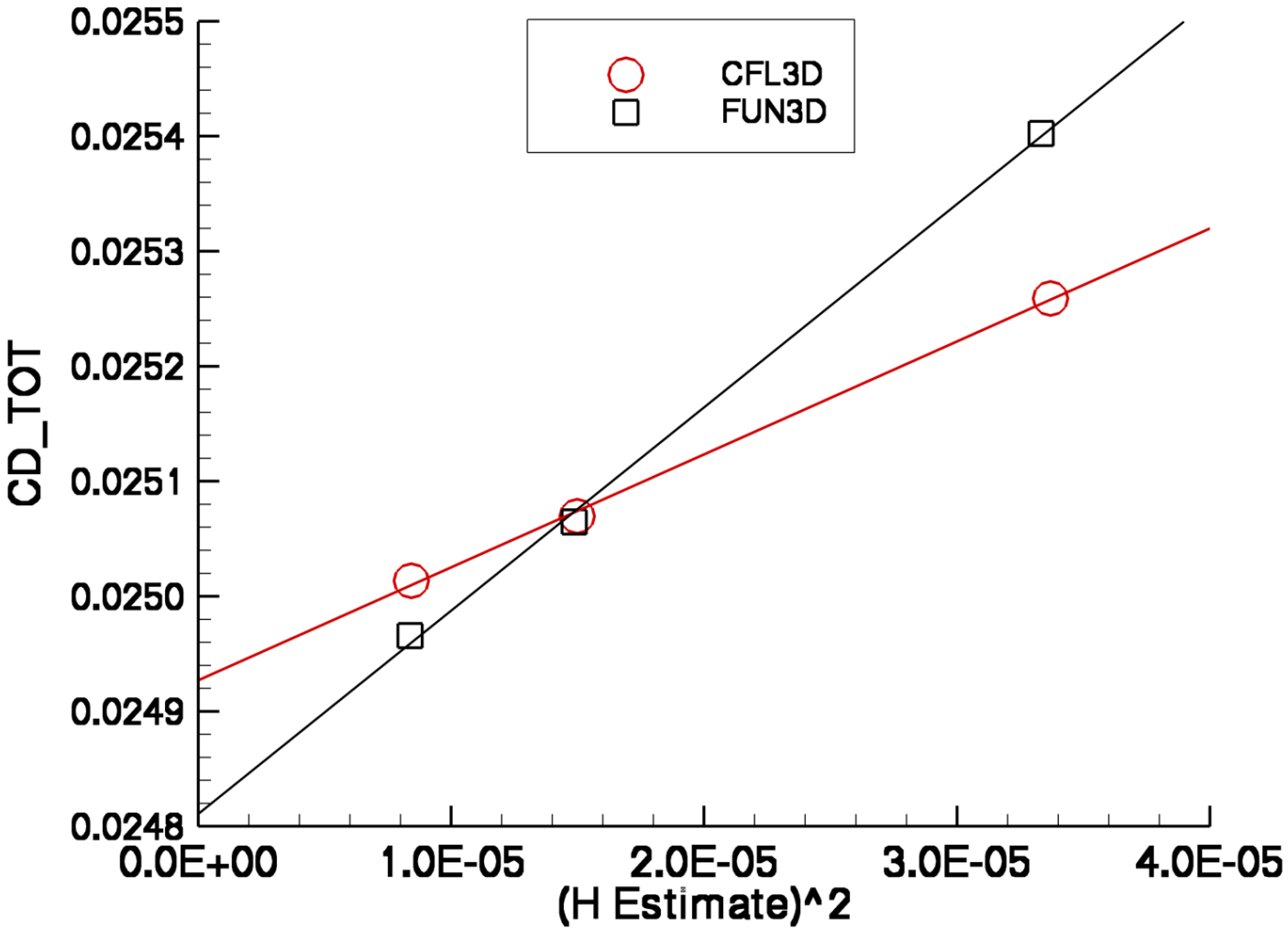
Common Grid Refinement



Common Grid Refinement



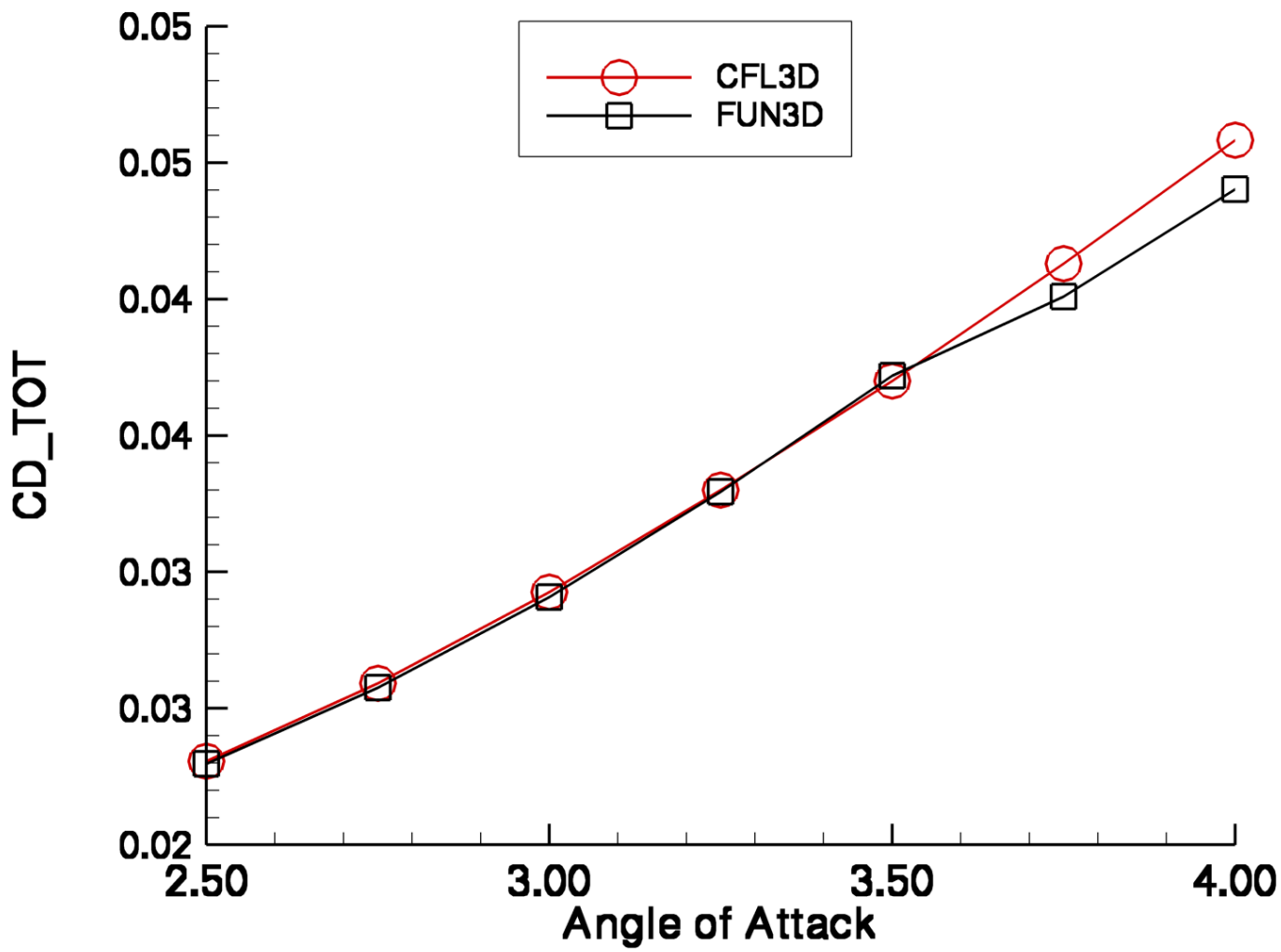
Common Grid Refinement



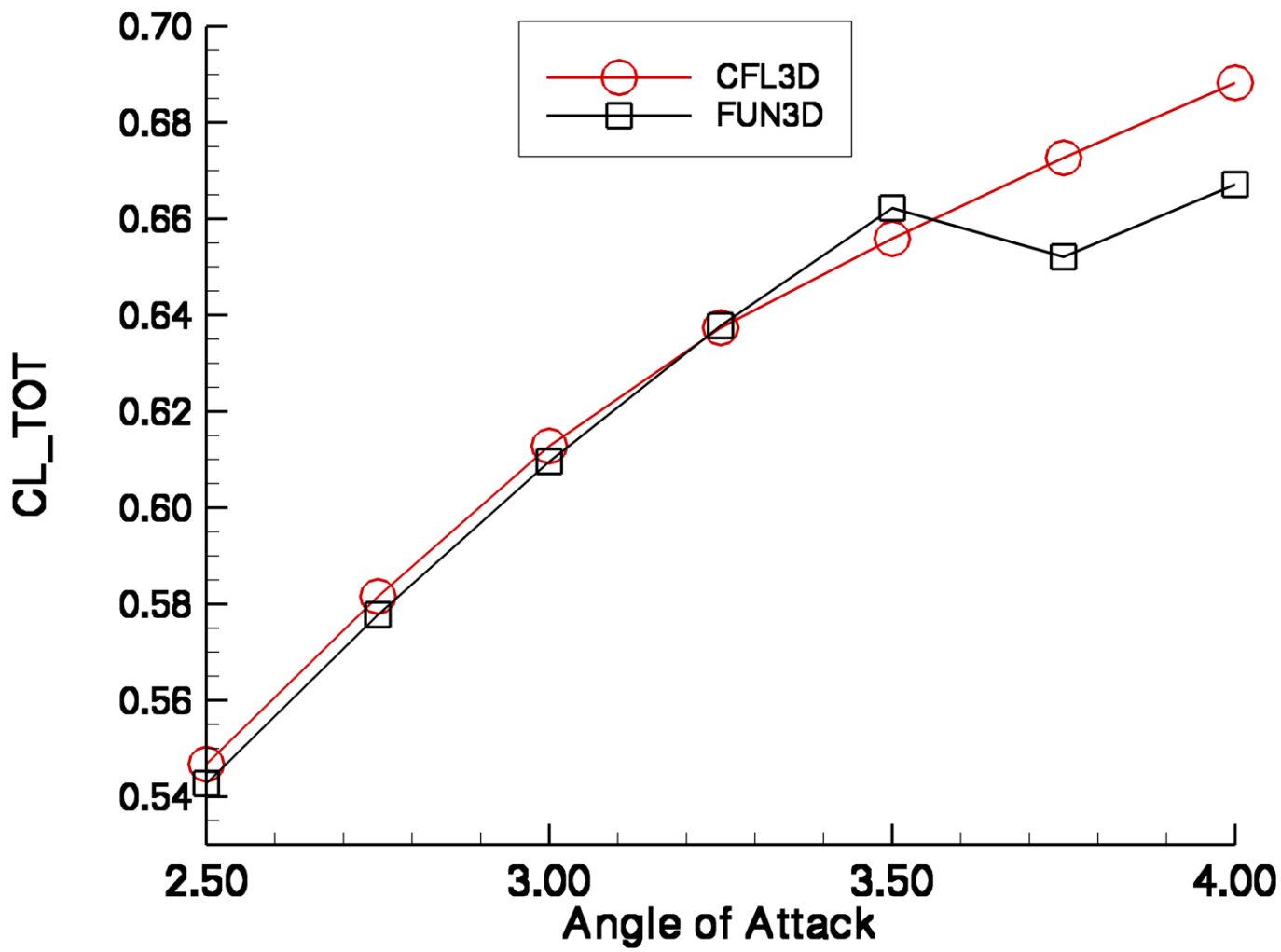
Case 2 Buffet Study

- Mach = 0.85, Re = 5×10^6 per MAC, Angles of Attack = 2.50, 2.75, 3.00, 3.25, 3.50, 3.75, 4.00
- Medium (L3) grid used from each grid system, CommonMB and CommonHybrid

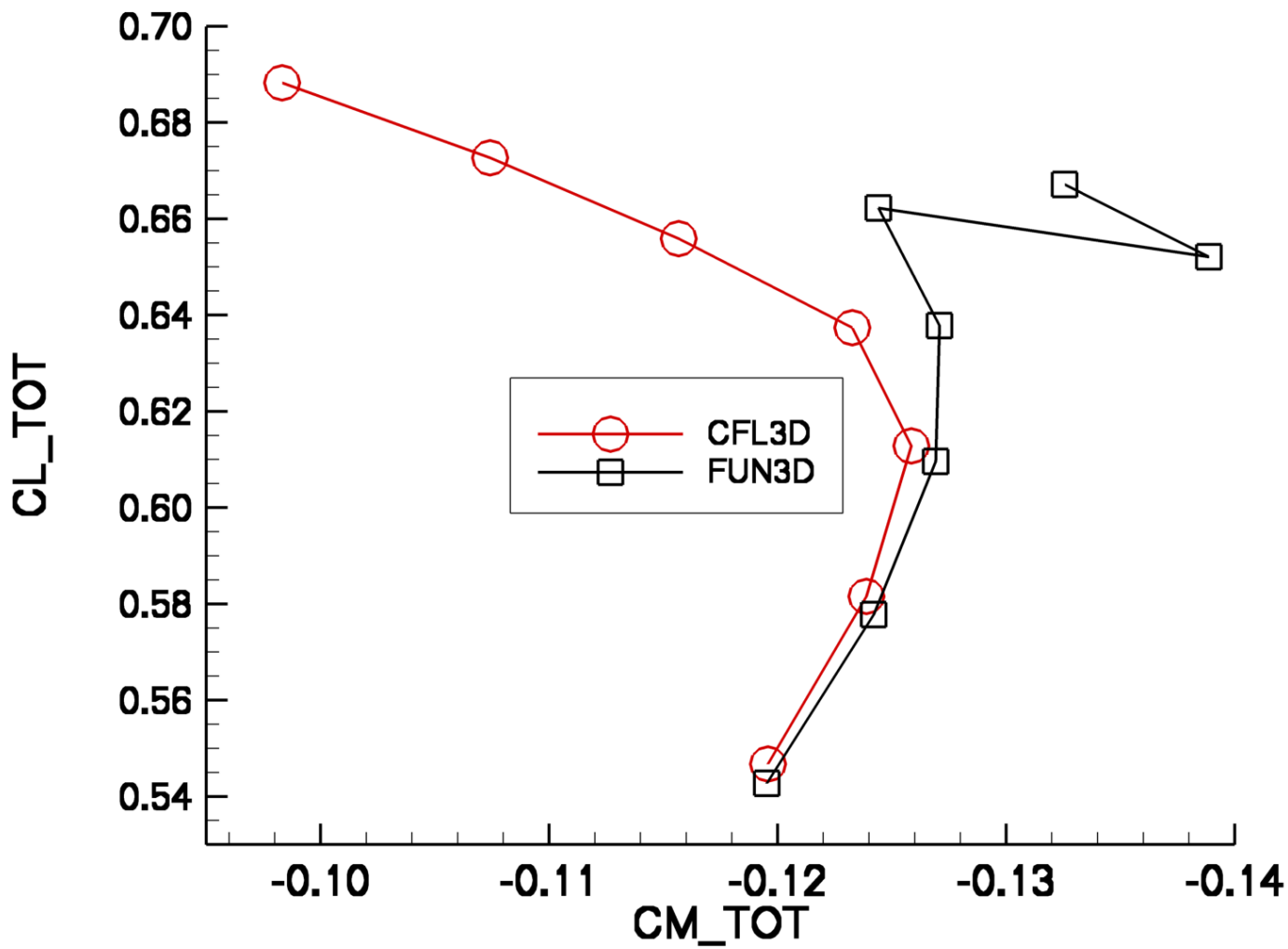
Buffet Study Drag



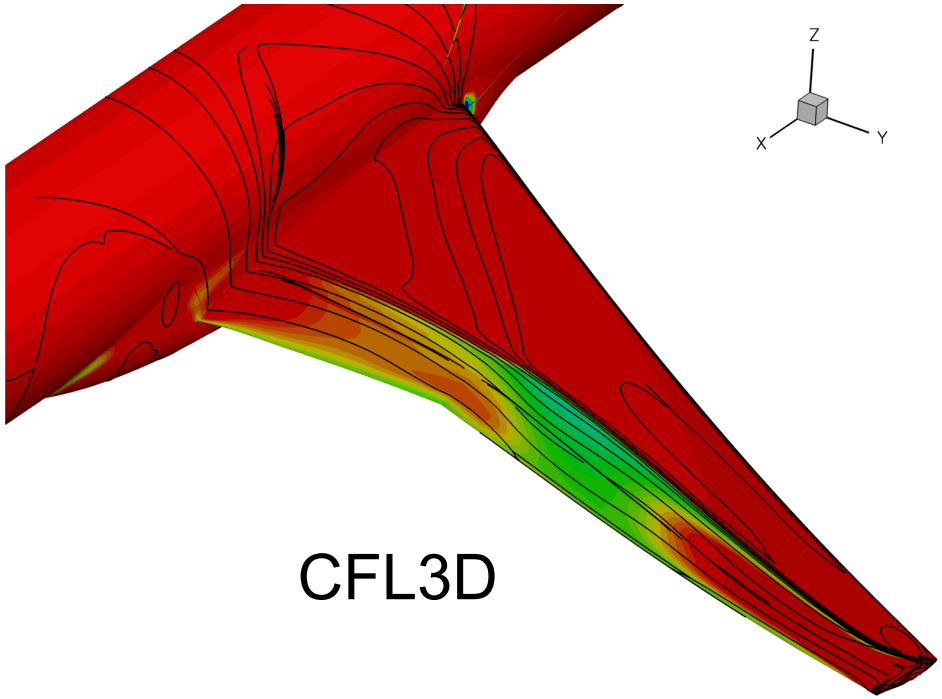
Buffet Study Lift



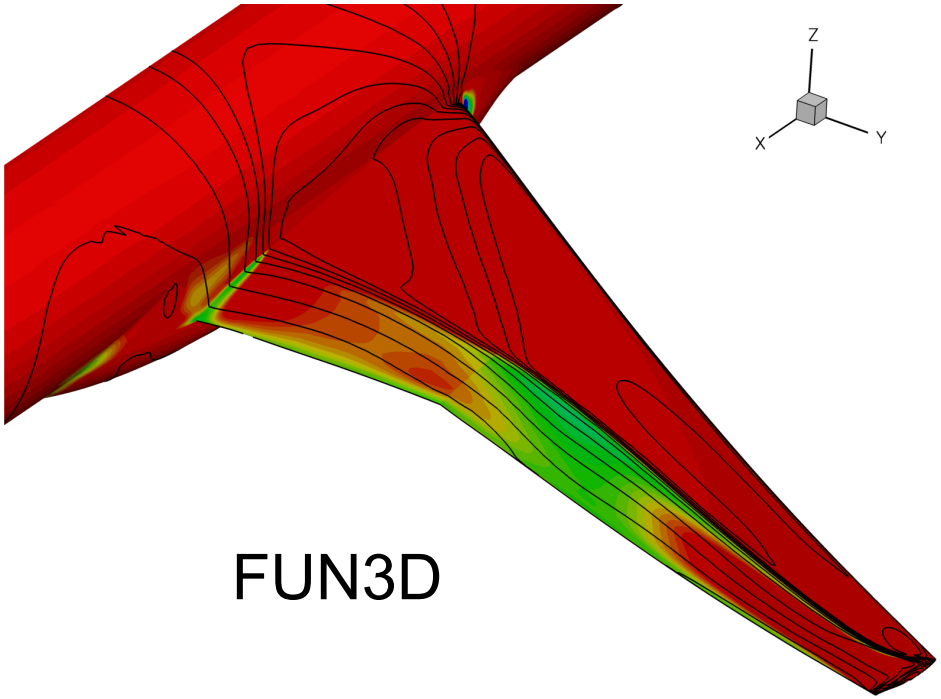
Buffet Study Pitching Moment



3.25 deg Angle of Attack



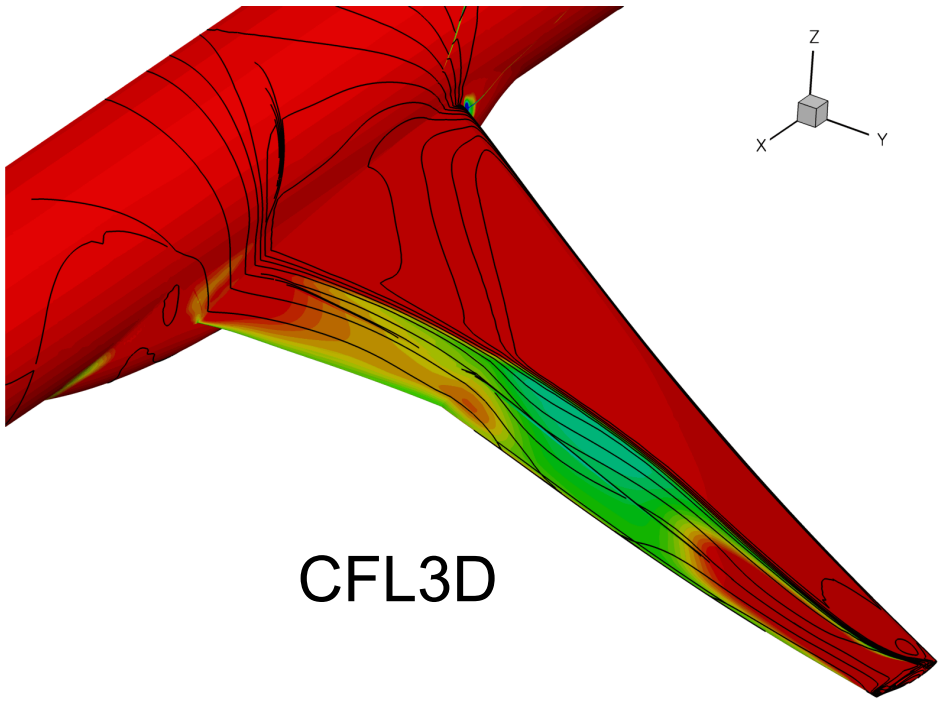
CFL3D



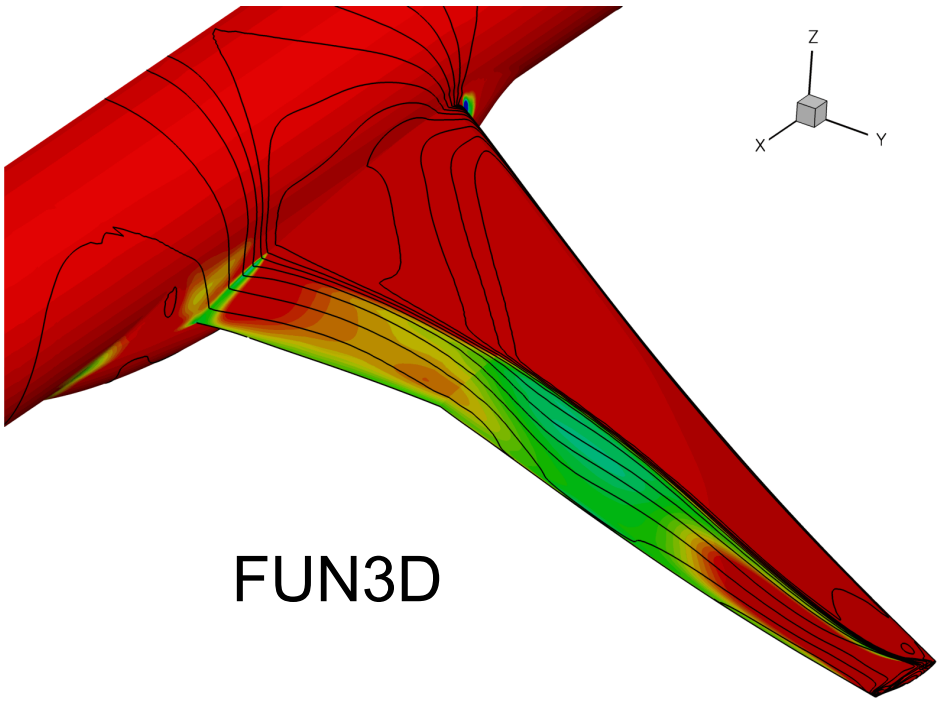
FUN3D

Color Contours - X Skin Friction Component
Black Lines - Cp in 0.1 intervals

3.50 deg Angle of Attack



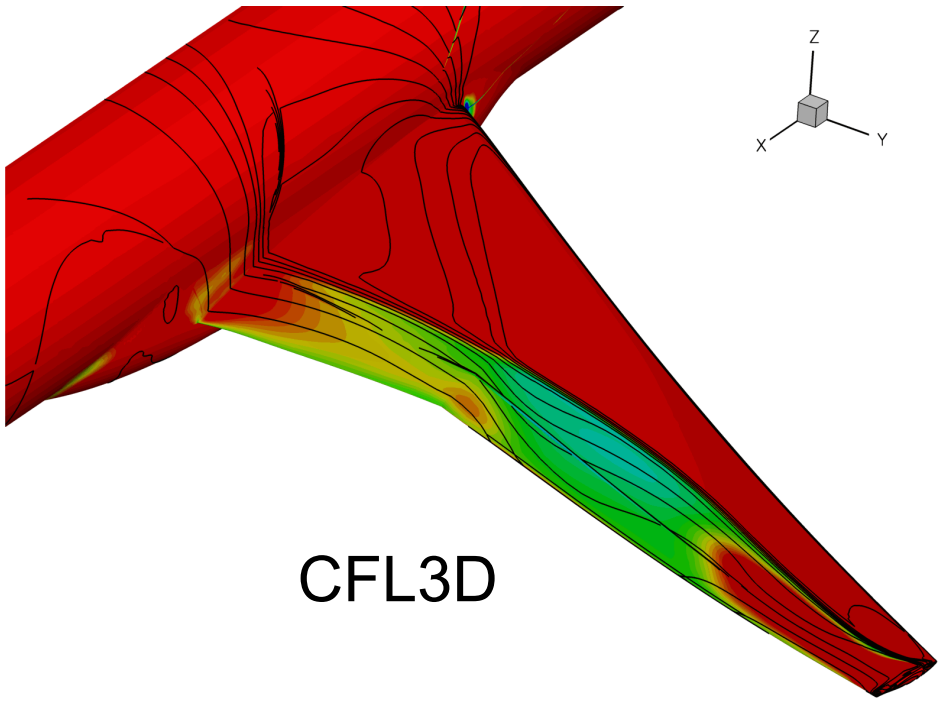
CFL3D



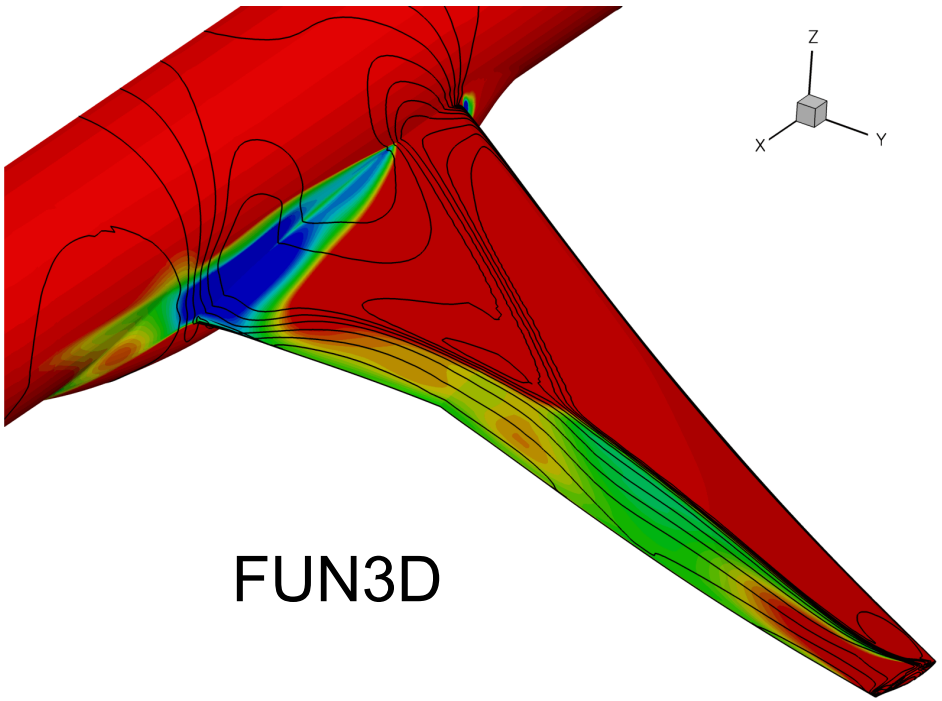
FUN3D

Color Contours - X Skin Friction Component
Black Lines - Cp in 0.1 intervals

3.75 deg Angle of Attack



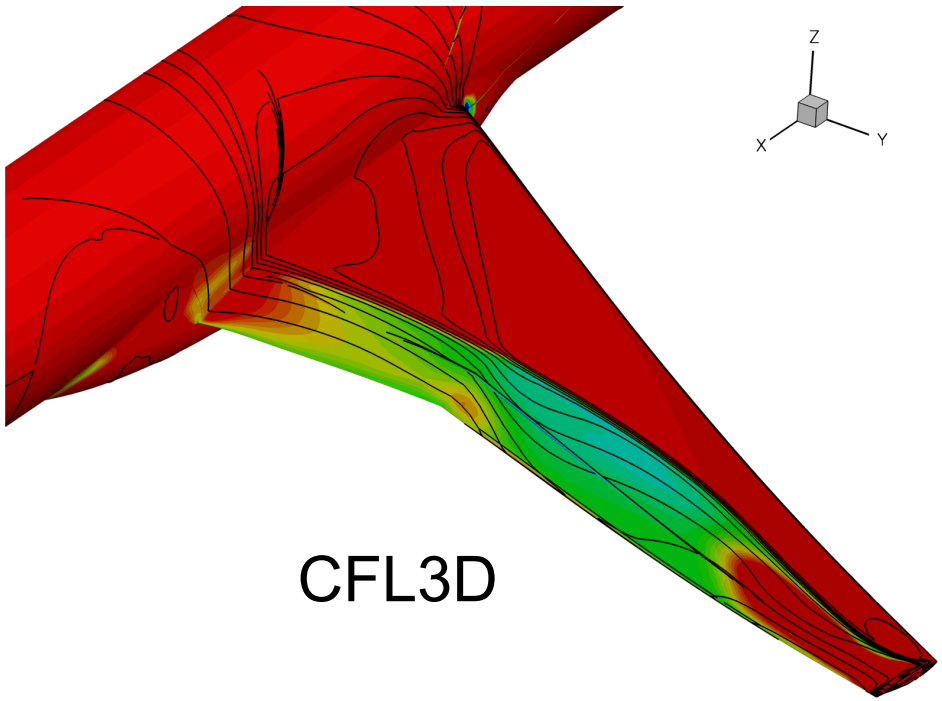
CFL3D



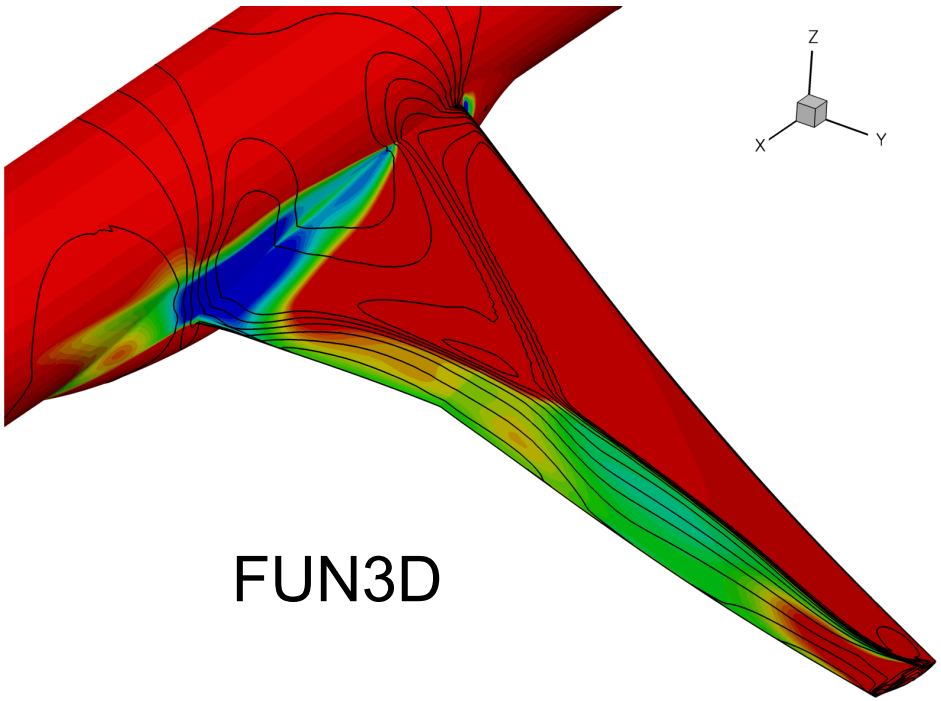
FUN3D

Color Contours - X Skin Friction Component
Black Lines - Cp in 0.1 intervals

4.00 deg Angle of Attack



CFL3D



FUN3D

Color Contours - X Skin Friction Component
Black Lines - Cp in 0.1 intervals

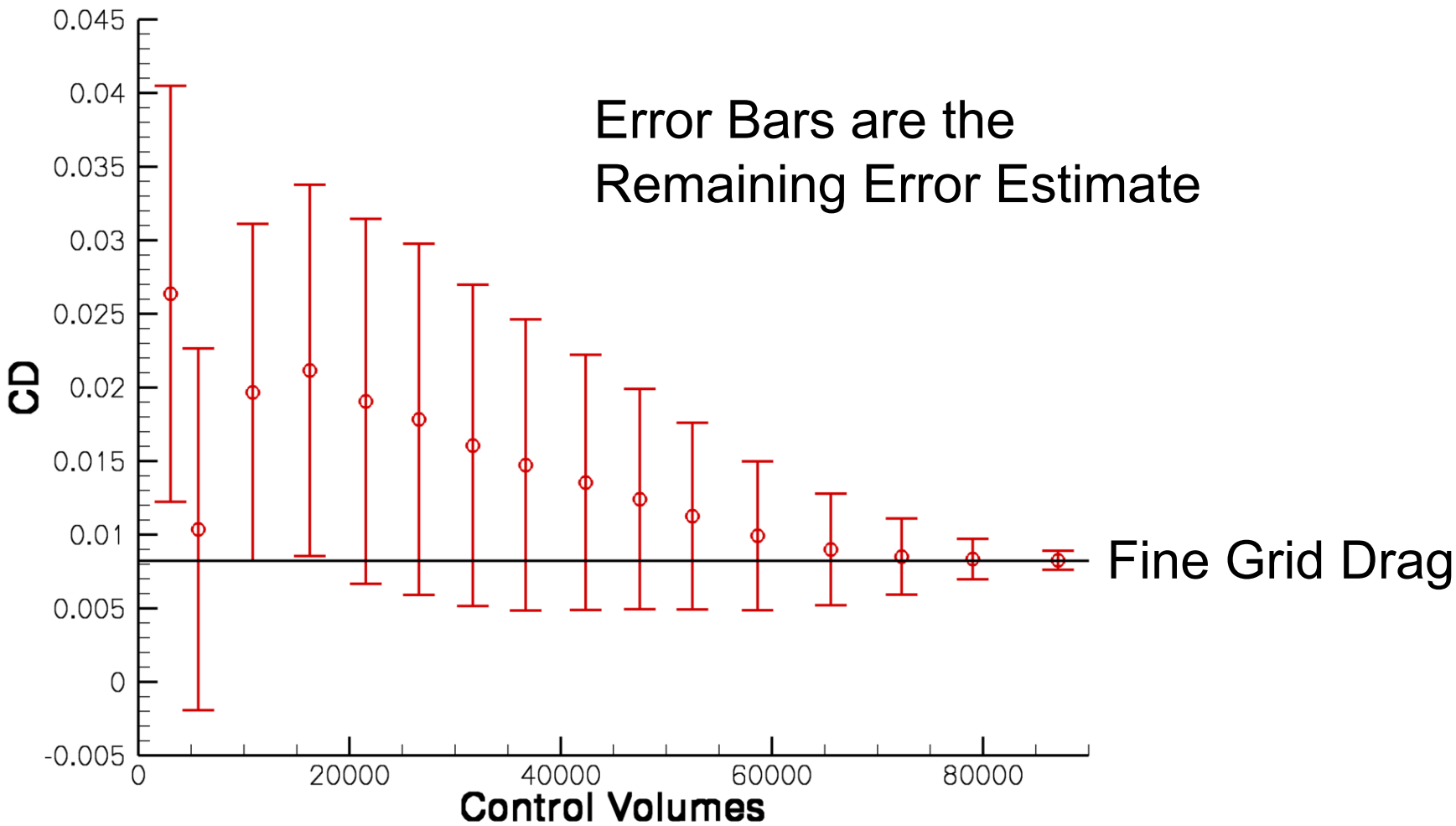
Grid Adaptation

- Venditti error estimation
  - Output error controls isotropic grid density via adjoint solution
  - Mach Hessian controls anisotropy
  - Remaining error estimate available
- Adaptive grid mechanics most challenging portion of the process
  - 2D: unstructured anisotropic triangles
  - 3D: unstructured anisotropic tetrahedra and prismatic boundary layer element subdivision

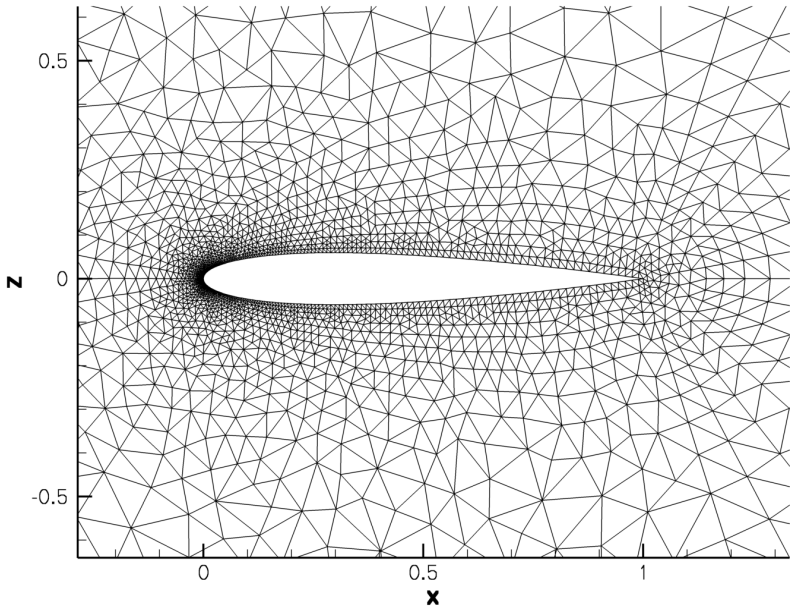
Case 3 Turb Model Validation

- Introduce adaptation with NACA0012 airfoil at 0 deg angle of attack
- Triangular grid extruded into a single layer of prisms
  - Exercise the 3D mixed element flow solver, adjoint solver, error estimation, and metric construction for the 2D example
- BAMG (Hecht) for 2D grid adaptation

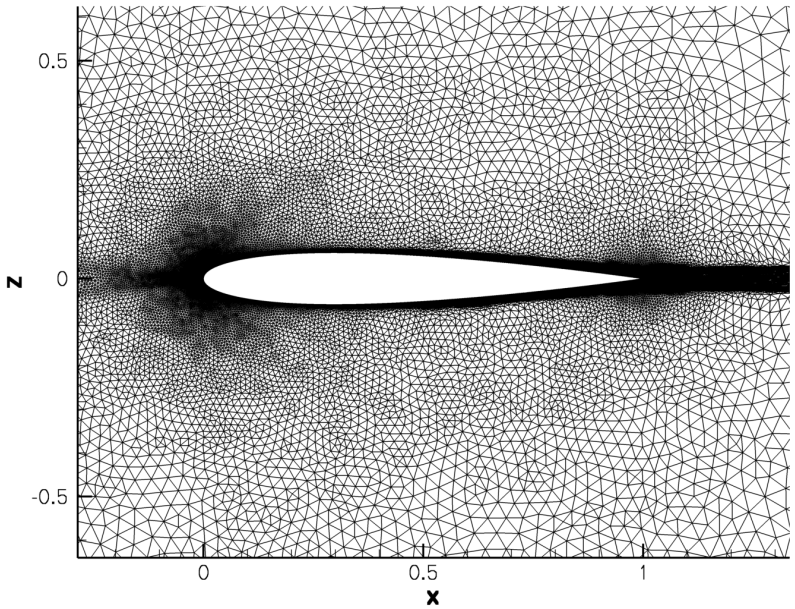
NACA0012 Drag Adaptation



NACA0012 Grid

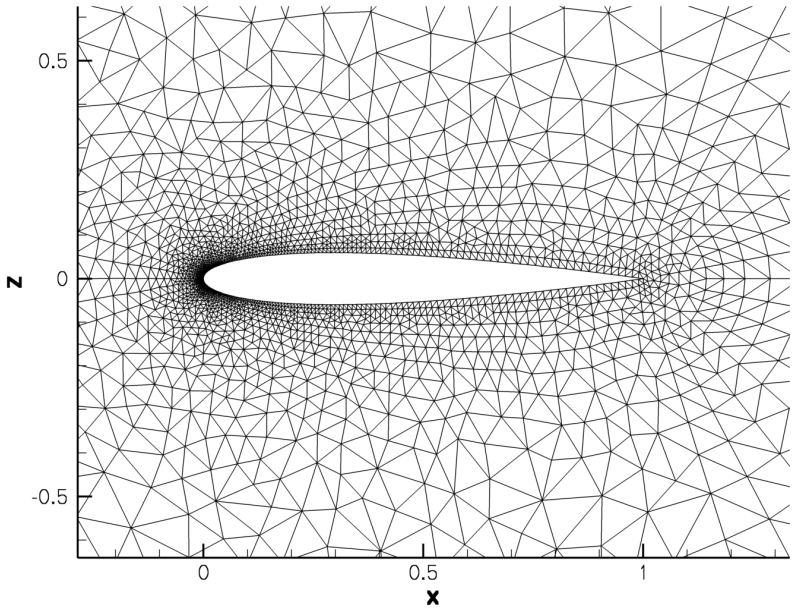


Original Grid

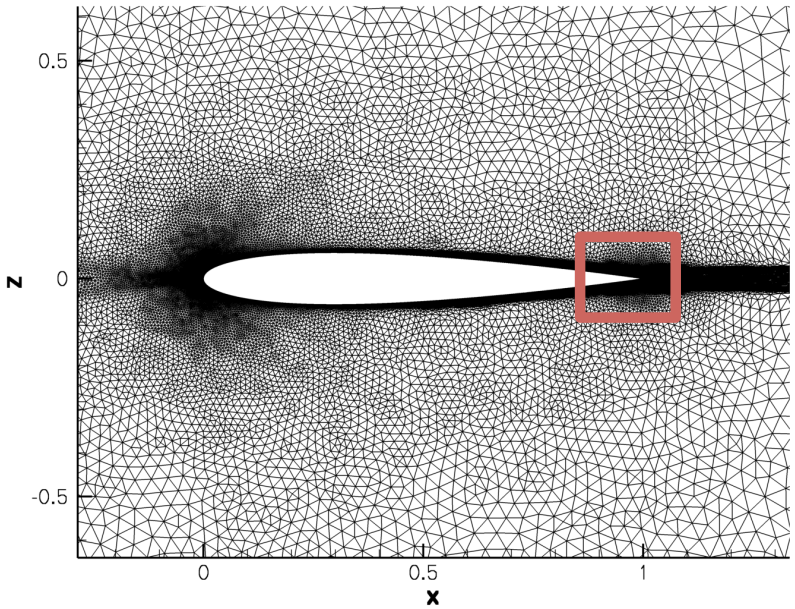


Final Drag Adapted Grid

NACA0012 Grid

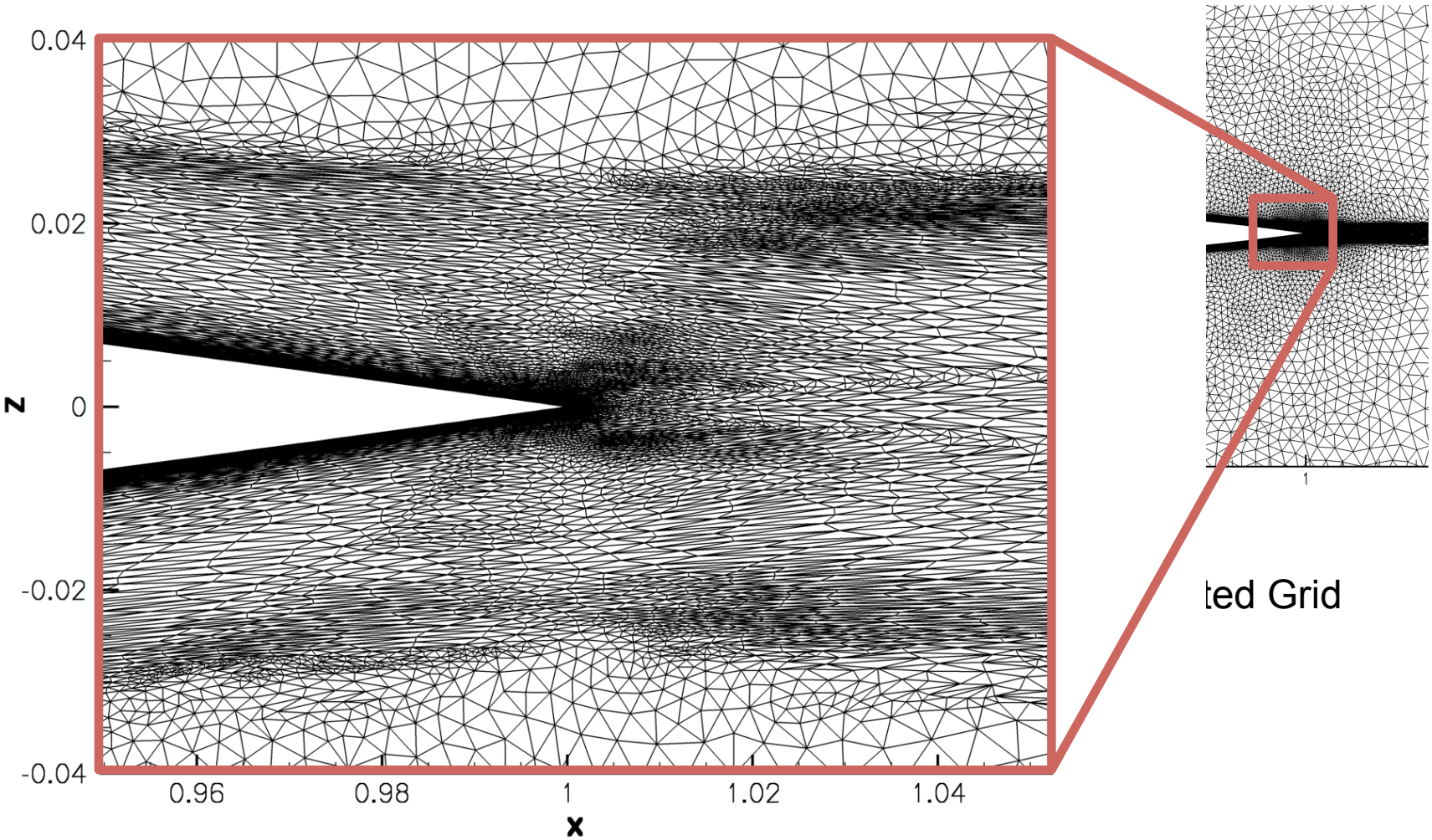


Original Grid

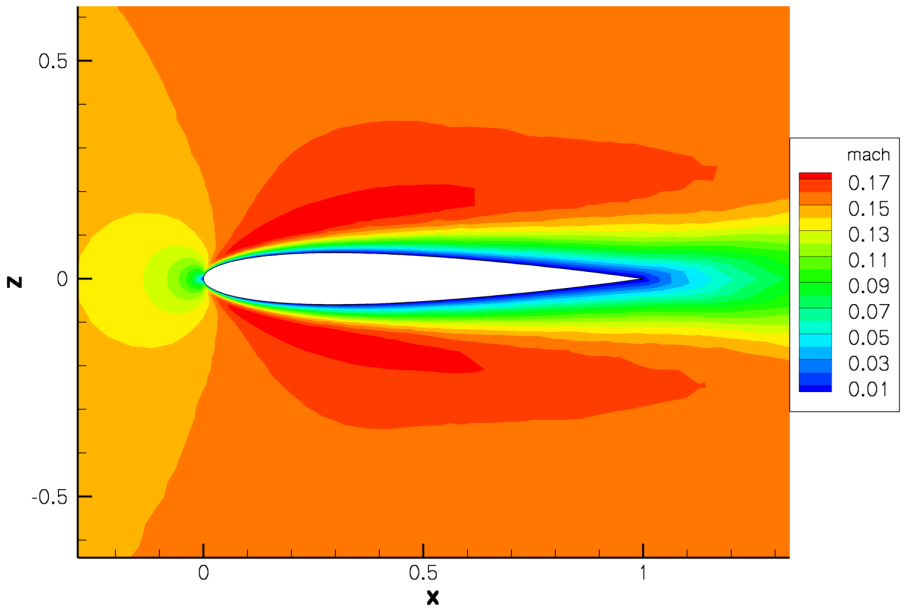


Final Drag Adapted Grid

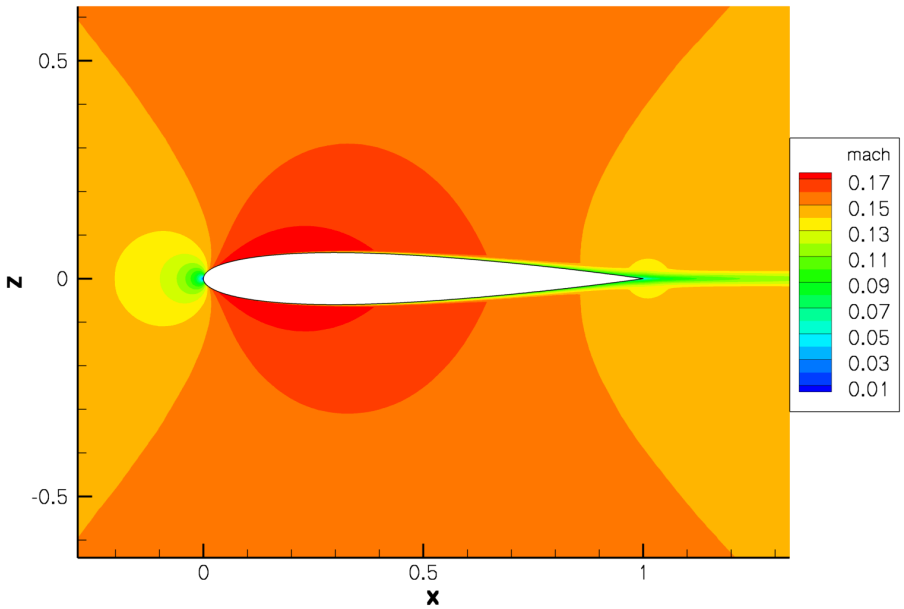
NACA0012 Grid



NACA0012 Mach

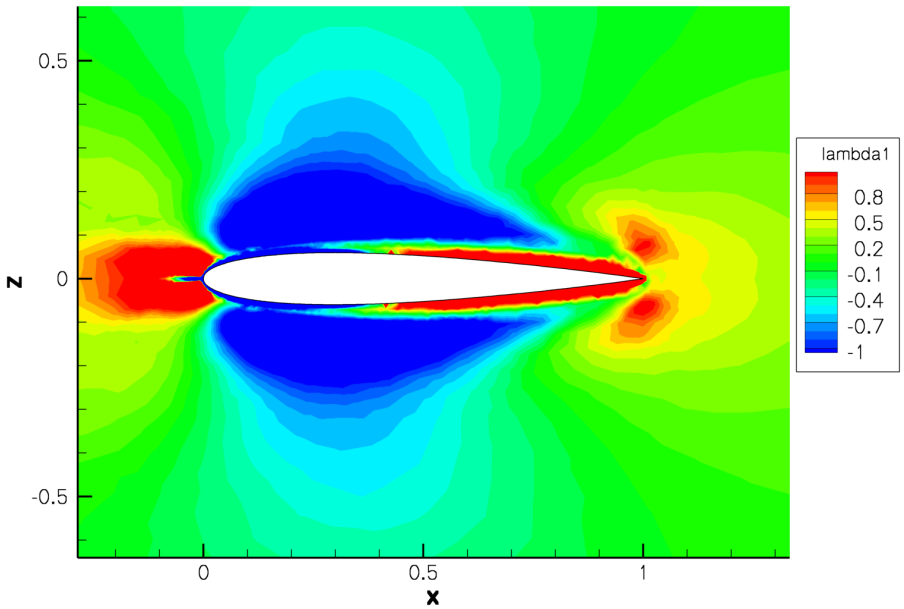


Original Grid

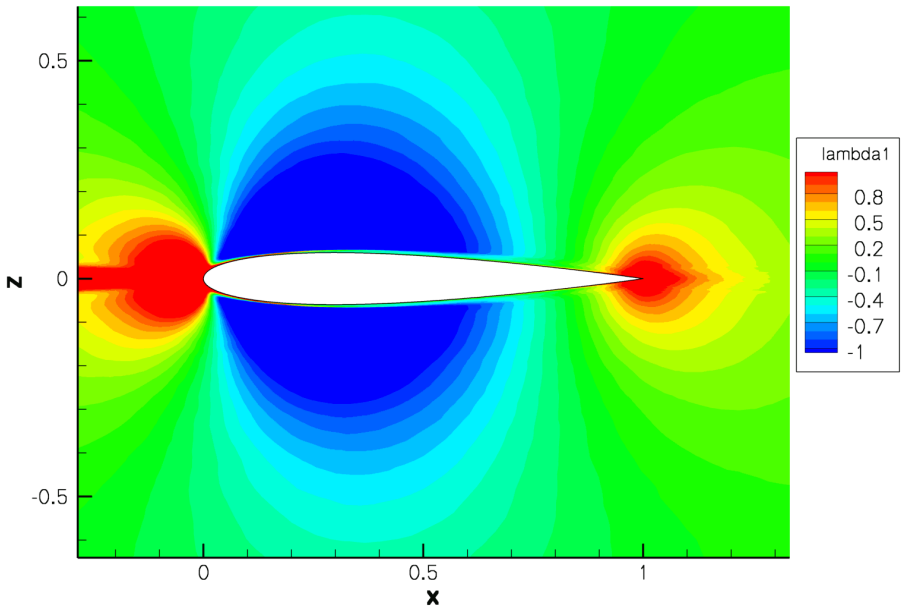


Final Drag Adapted Grid

NACA0012 Density Adjoint



Original Grid

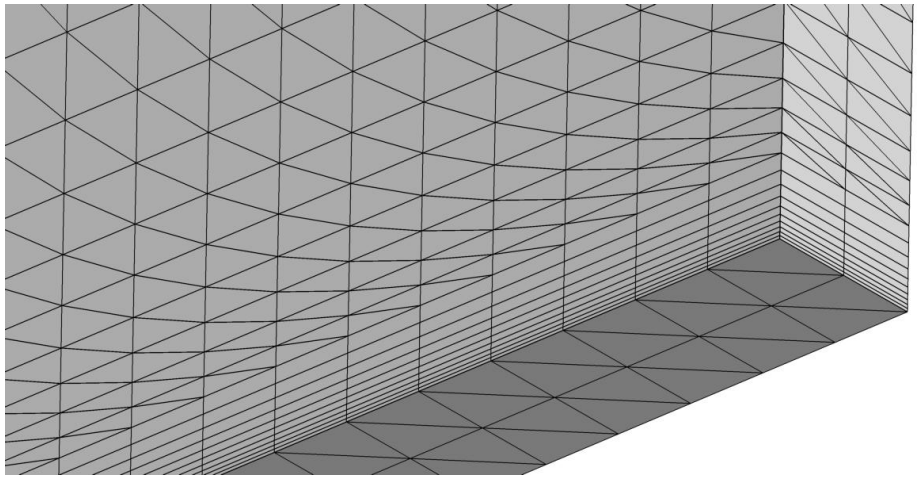


Final Drag Adapted Grid

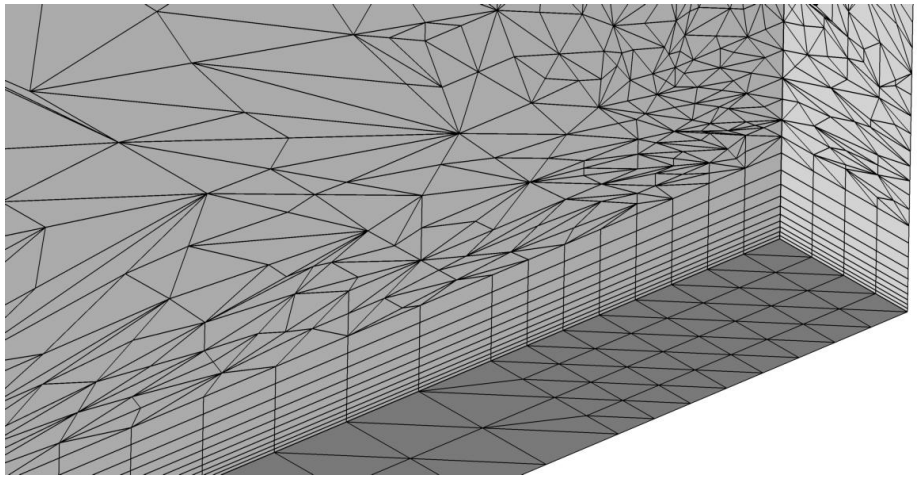
Adapt

- Alternate off body (tets) and near (prism) and adaptation schemes
- Existing parallel tetrahedral adaptation with frozen boundary layer
  - Park and Darmofal AIAA-2008-917
  - Park and Carlson AIAA-2010-168
- Fixed fraction prism subdivision based on isotropic output error estimate
  - Only tangent to surface

Prism Subdivision

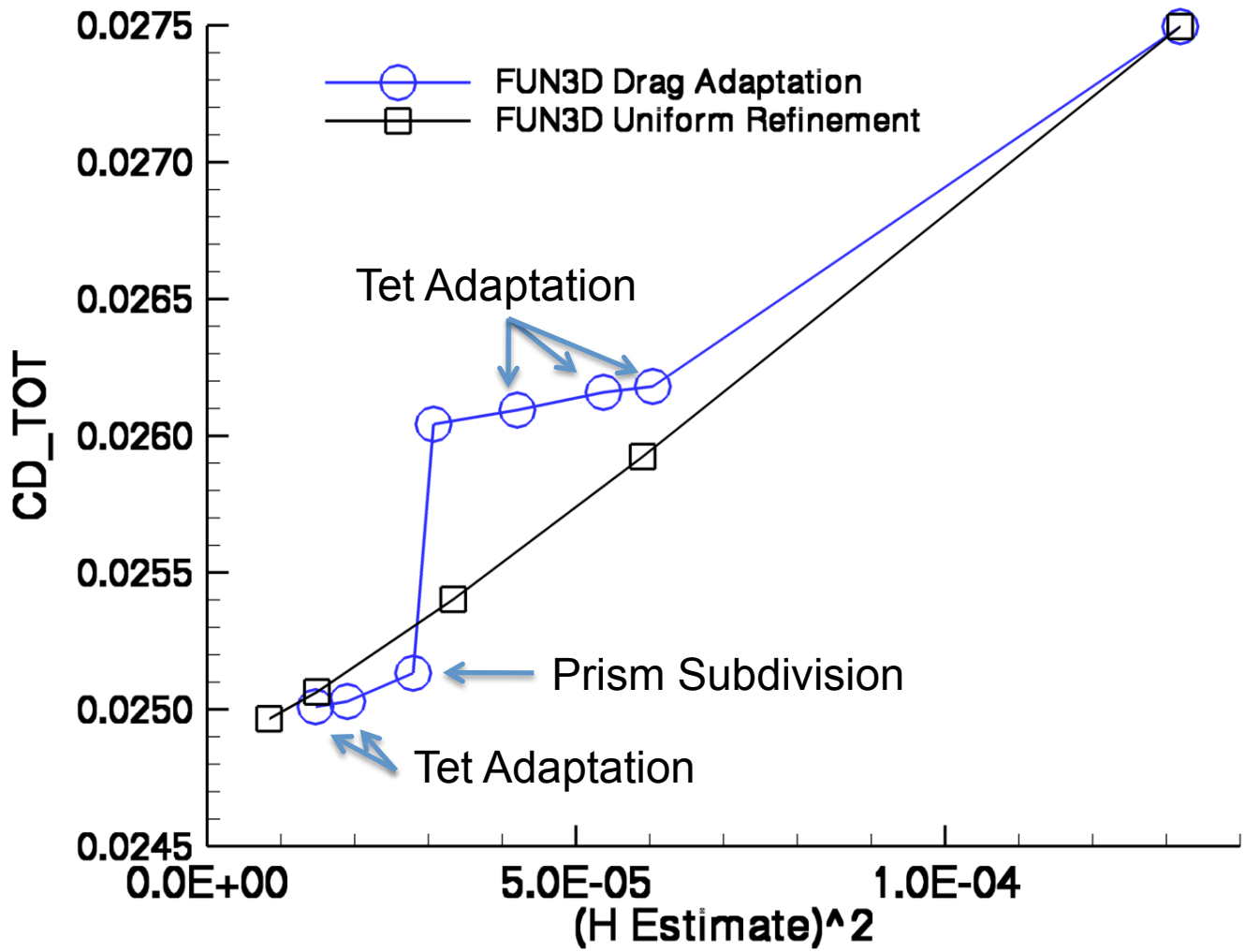


Original Grid

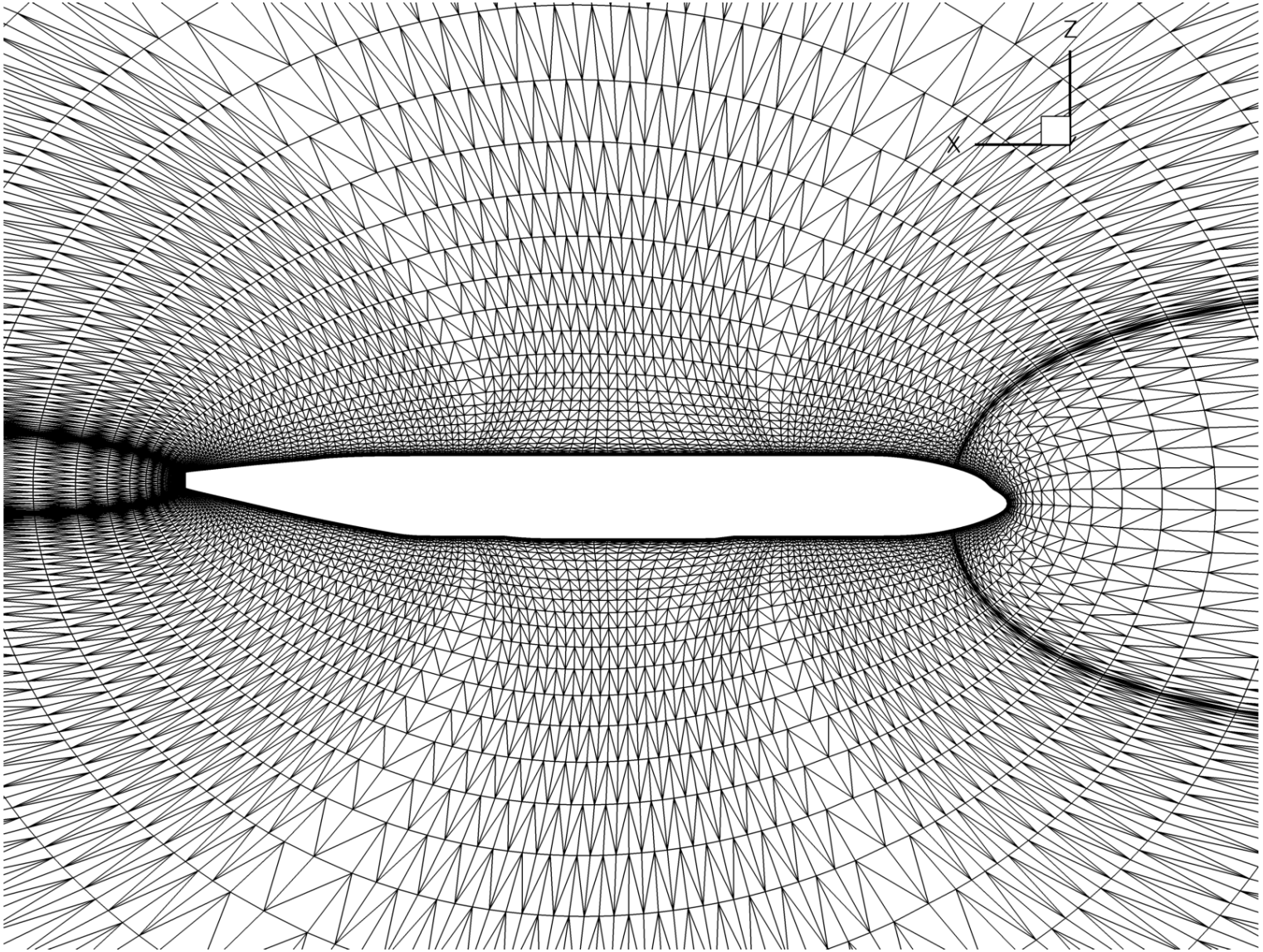


Adapted Grid

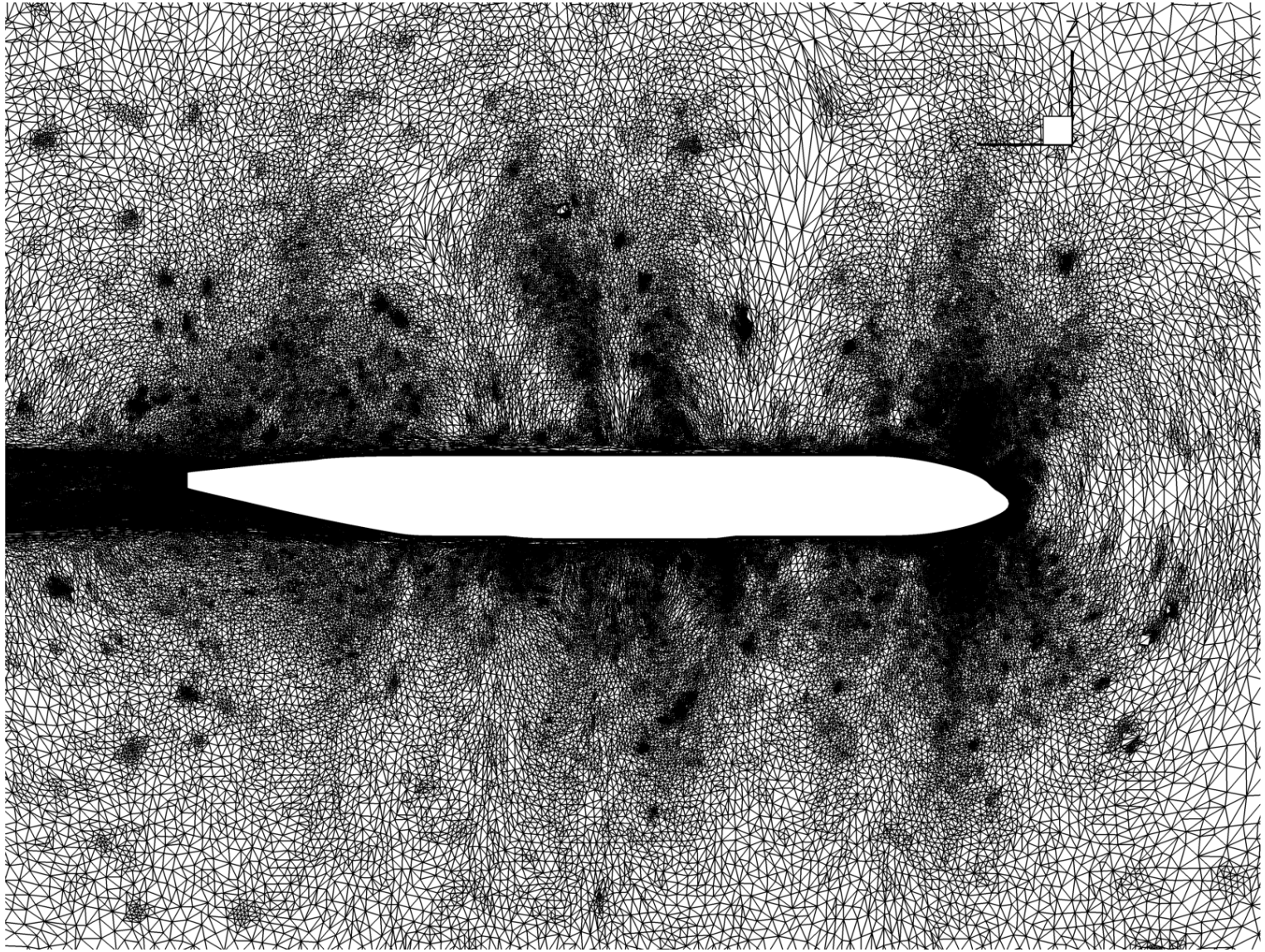
Drag Adpatation



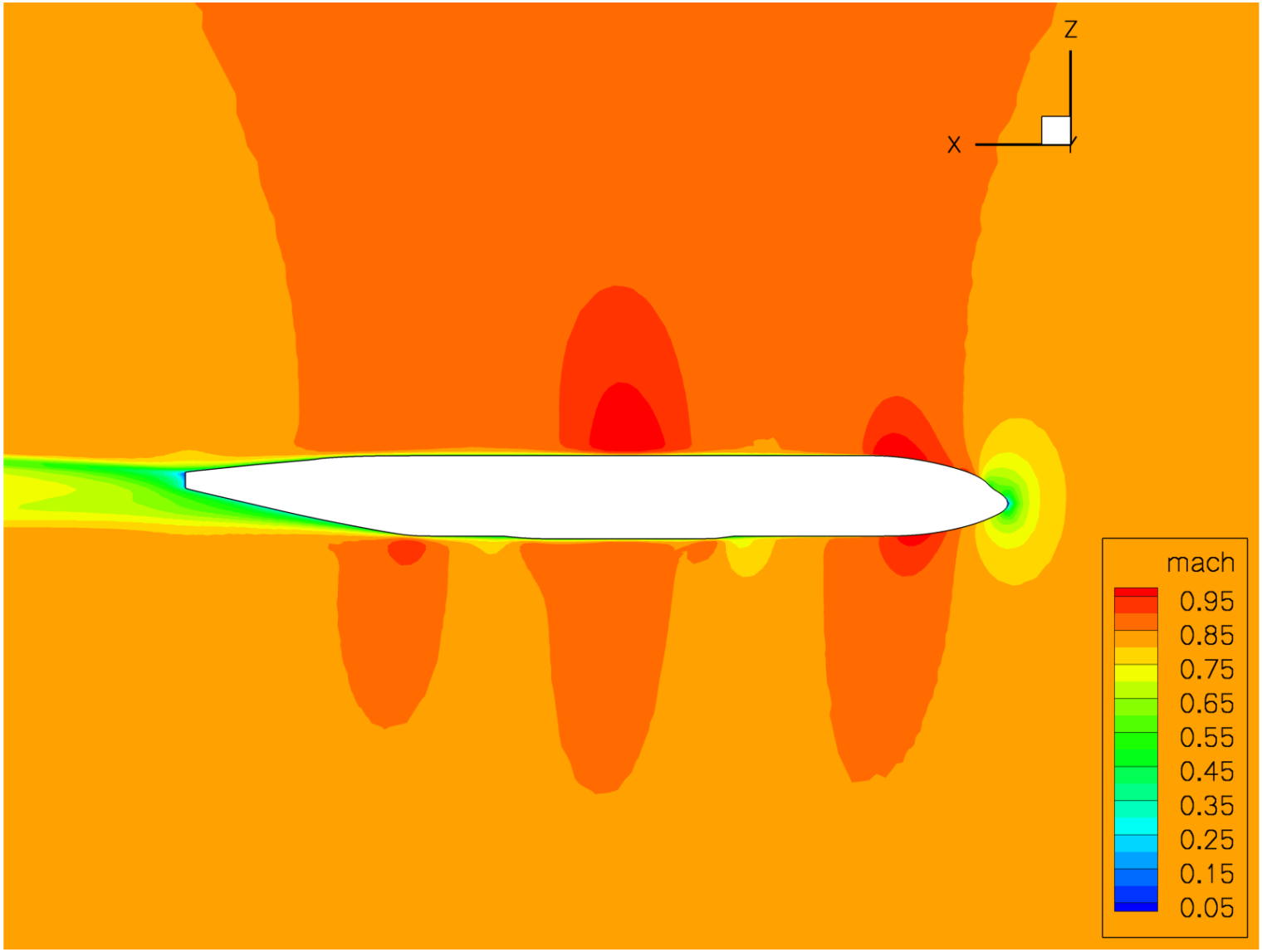
Initial Symmetry Plane Grid



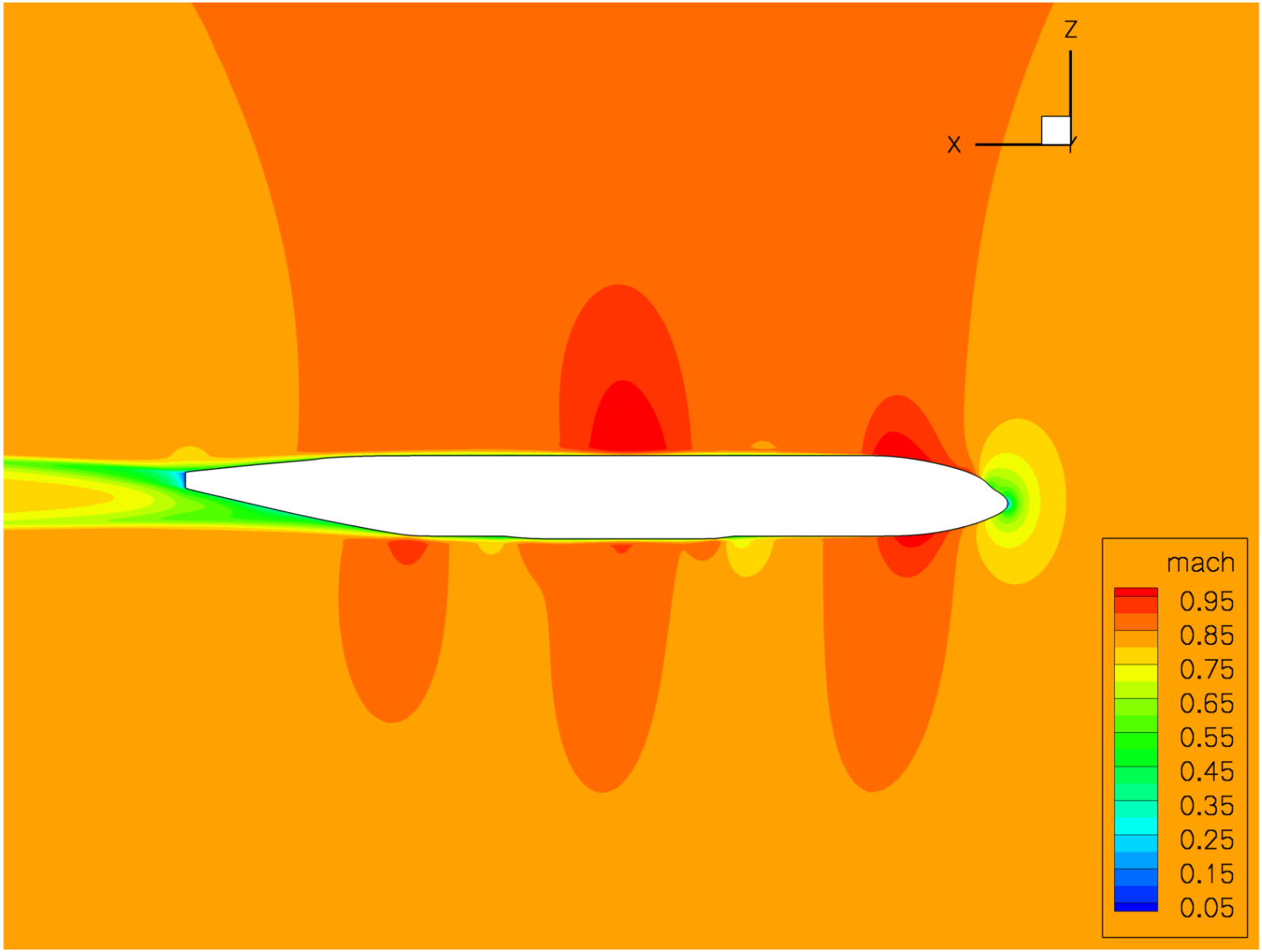
Adapted Symmetry Plane Grid



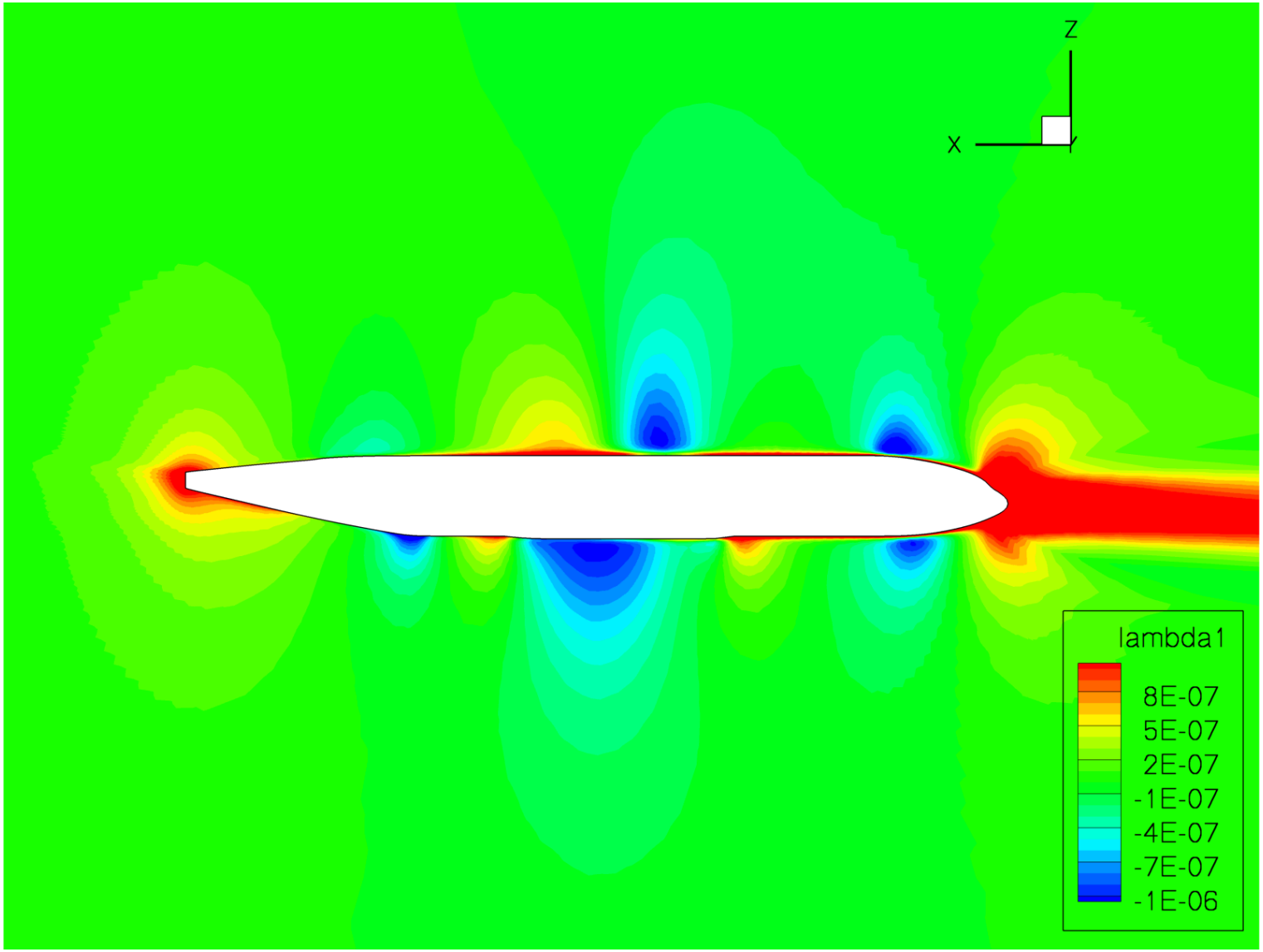
Initial Symmetry Plane Mach



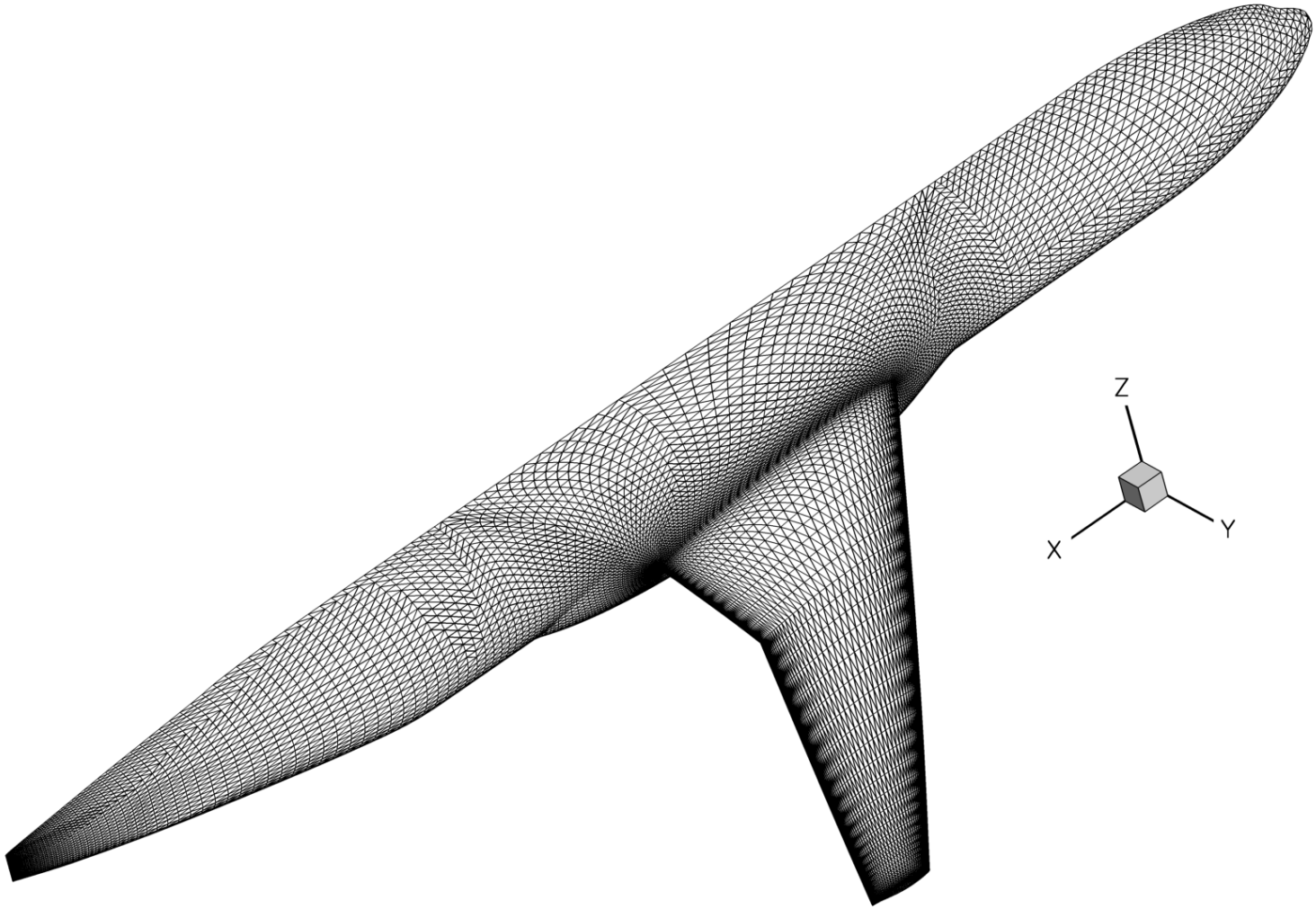
Adapted Symmetry Plane Mach



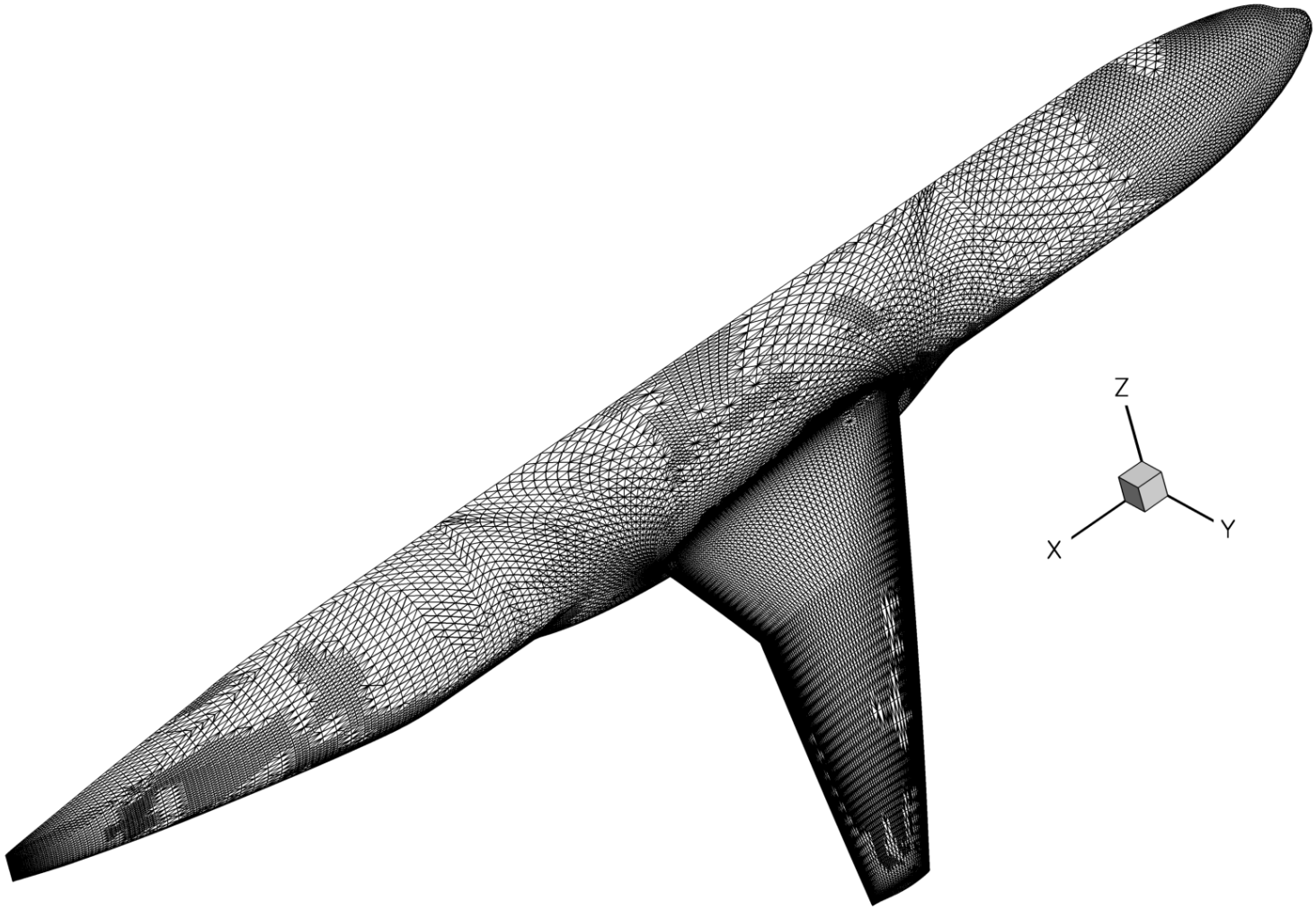
Initial Symmetry Density Adjoint



Initial Surface Grid



Adapted Surface Grid



Summary

- Uniform grid refinement study showed approximately 1 count of drag difference between FUN3D and CFL3D
- Buffet study at low angles of attack showed small differences between FUN3D and CFL3D
- Buffet study at high angles of attack showed significant difference in wing root flow separation, forces, and moments

Summary

- 3D error estimation technique was exercised on the 2D turbulence validation case
- Starting from a coarse inviscid grid, drag was accurately predicted by the final adapted grid
- The availability of adaptive grid mechanics makes triangular 2D adaptation possible

Summary

- Successive applications of unstructured tetrahedral adaptation and prism subdivision was applied to the Level 1 CommonHybrid grid
- Prism subdivision had a large effect on drag
- Adapted grids trended toward uniformly refined grid drag value
- 3D grid adaptation mechanics with greater flexibility may improve results

Acknowledgments

- Jim Thomas, Boris Diskin, Mark Carpenter for convergence improvements
- Eric Nielsen for negative SA model changes in the adjoint solver
- FUN3D Development team
- Fundamental Aeronautics Program Supersonics, Subsonic Rotor-wing, and Subsonic Fixed-wing Projects