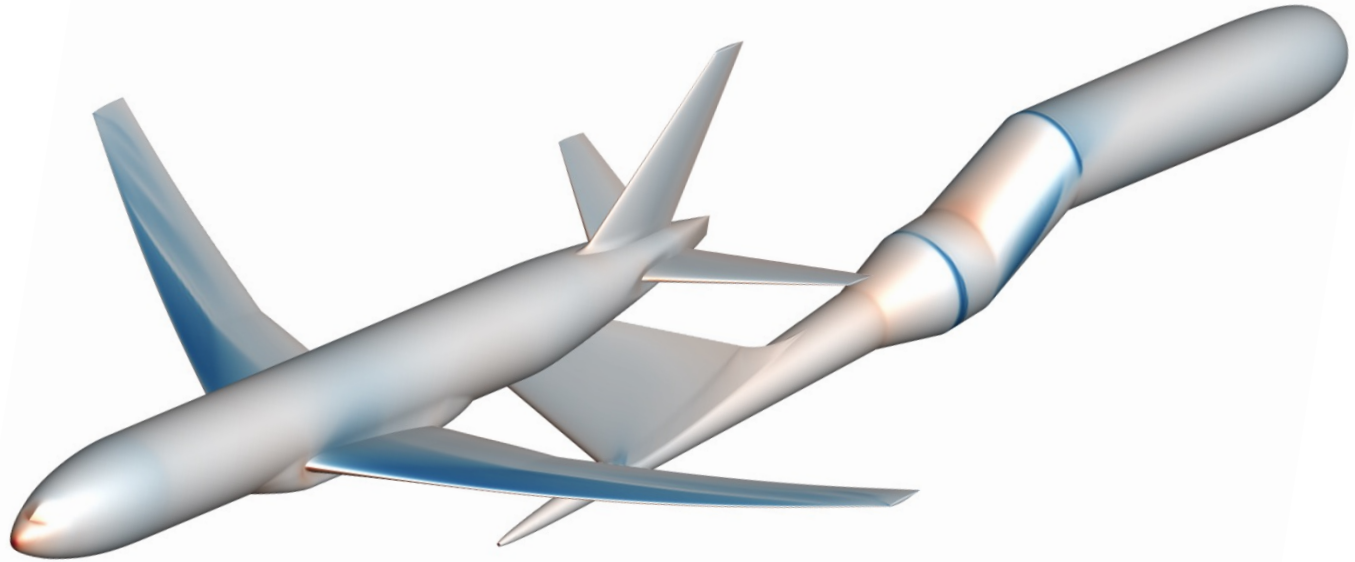
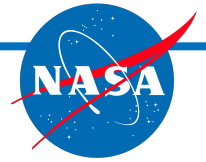
NASA Langley FUN3D Analyses in Support of the 1st AIAA Stability and Control Prediction Workshop



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NASA Langley Research Center

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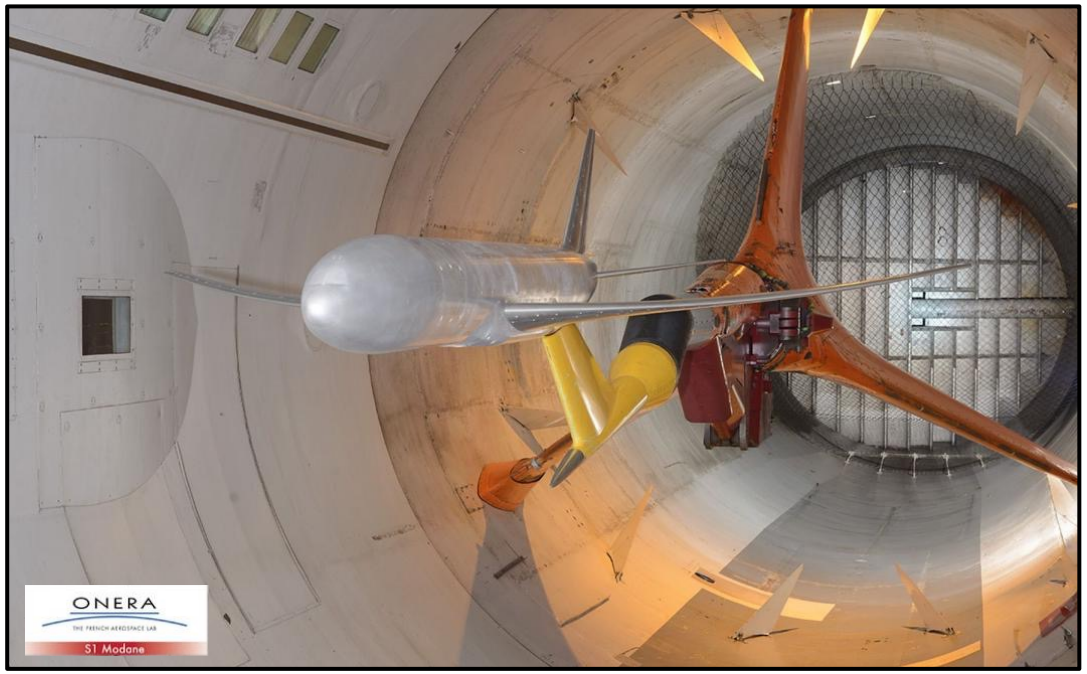
Outline

- Overview
- Computational Approach
- Test Case Results
- Concluding Remarks

Overview

Workshop Motivation

Establish best practices for the prediction of stability & control derivatives with CFD and assess the limitations of these methods when best practices are applied



Workshop Configuration
ONERA Large Reference Model (LRM)
with Data from the ONERA S1MA Wind Tunnel

- **TC1: Verification Study**
- **TC2: Grid Convergence**
- **TC3: Mach Effect on Static Stability**
- **TC4: Wind Tunnel Sting Increments**
- **TC5: Stability Derivative Calculation**
- **TC6: Sideslip Angle Sweep**

Flow Solver

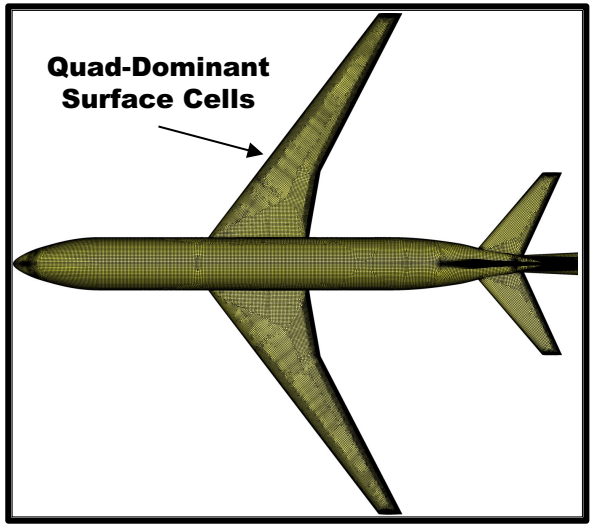
- **FUN3D – Reynolds-Averaged Navier-Stokes (RANS) solver**
  - Node-based, finite-volume discretization
  - Roe's Flux-Difference Splitting (FDS) with no flux limiting
  - Spalart-Allmaras (SA) turbulence model with negative provisions, Rotation/Curvature (RC) correction model, and the Quadratic Constitutive Relation (QCR)

- **Steady-State Solution Strategy**
  - **Step 1: Initialization**
    - 1,000 1st-order iterations with aggressive CFL ramping
  - **Step 2: Convergence**
    - 4,000 2nd-order iterations with moderate CFL ramping
  - **Step 3: C_L-matching** (if needed for test case)
    - 5,000 2nd-order iterations with constant CFL
    - Internal C_L-matching capability employed

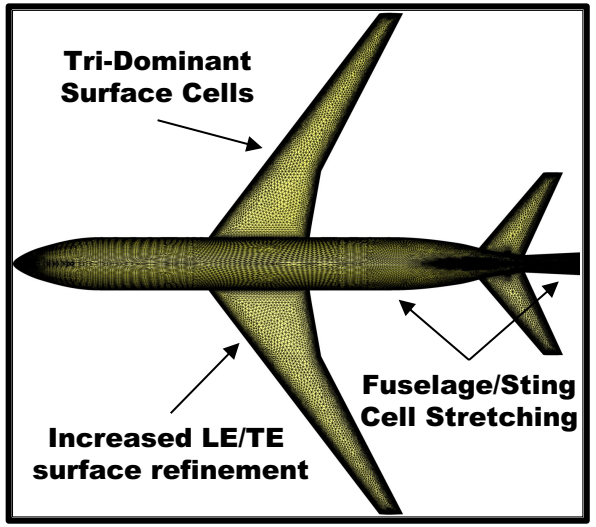
Computational Grids

- **Workshop Grids**
  - Mixed-element, generated by Pointwise
  - Five levels of refinement:
    - Tiny, coarse, medium, fine, extra fine
  - Encountered issues:
    - Asymmetric surface/volume grid
    - Nonideal residual convergence

Medium Grid – Workshop



Medium Grid – HeldenMesh



- **Custom Grids**
  - Coarse, medium, and fine mixed-element grids (free-air) generated using HeldenMesh
  - Internal refinement factor allows source scaling, ‘blrefine’ employed to scale boundary layer

	Workshop Grids			Custom Grids			
	y^+	Growth Rate	**Nodes (10^6)**	y^+	r_1	r_2	**Nodes (10^6)**
Coarse	1.00	1.172	**20.3**	1.00	0.200	0.015	**21.1**
Medium	0.87	1.148	**28.3**	0.90	0.140	0.015	**29.1**
Fine	0.76	1.127	**39.5**	0.82	0.102	0.015	**39.6**

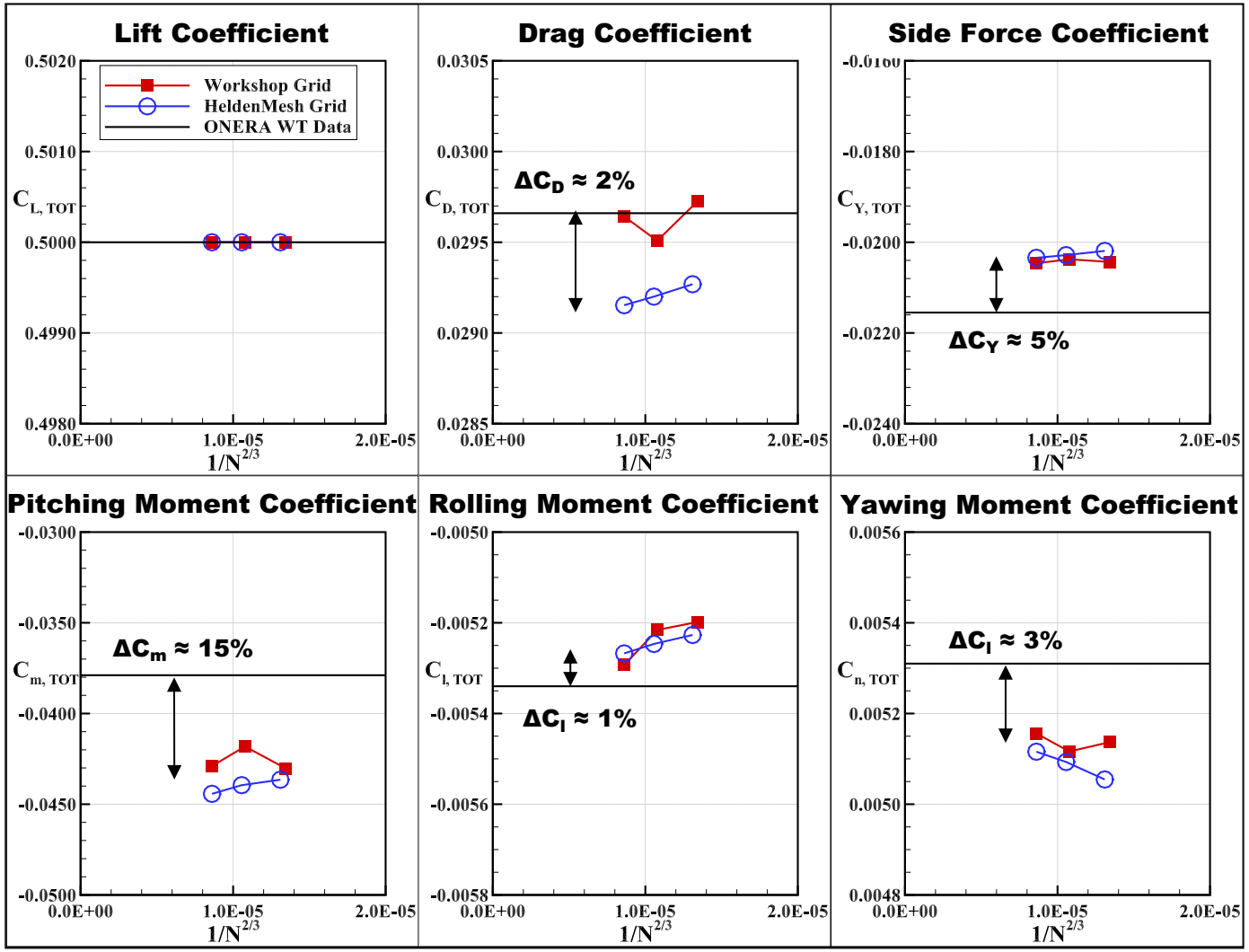
HeldenMesh BL Growth Equation

$$\Delta z_{i+1} = \Delta z_1 + \left[1 + r_1(1 + r_2)^{i}\right]^{i}$$

TC2: Grid Convergence Study

M = 0.83, Re = 4.56 million, β = 1°, C_L = 0.5

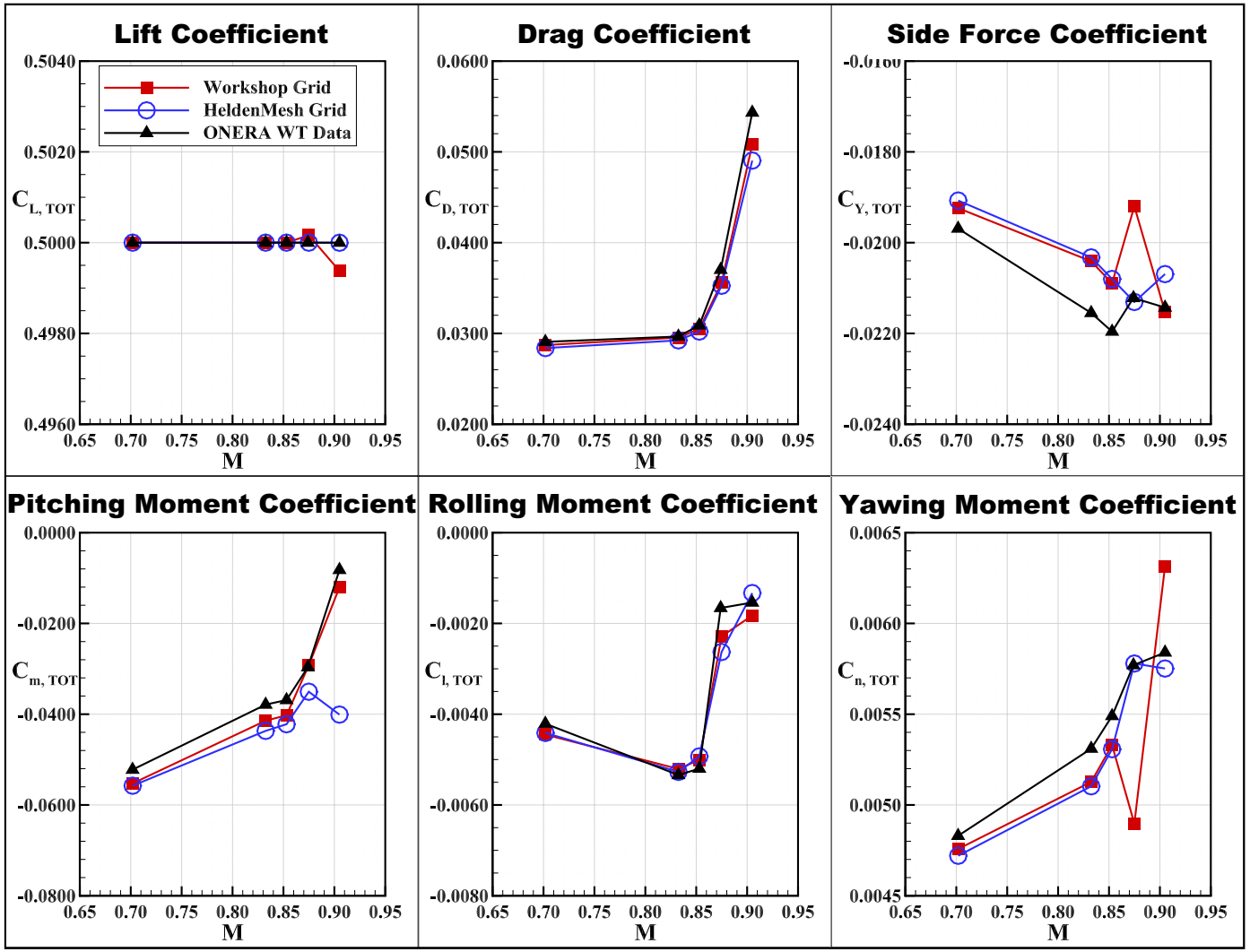
- FUN3D results show general agreement with WT data except for C_m – underpredicted by 15%
- Component-level F&M (not shown) found tail to be largest contributor to variability between grids
- Nonmonotonic trends observed in workshop grids for given solution strategy
- Practical grid-converged solutions may be obtained in future workshops via grid adaptation



TC3: Mach Number Effect on Static Stability

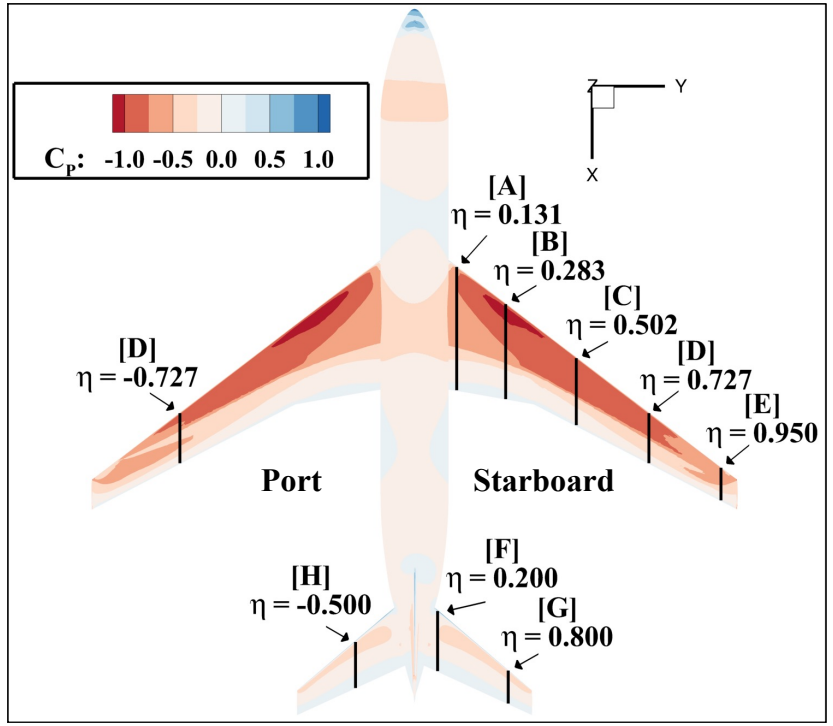
M = [0.7 to 0.9], Re = [4.24 to 4.70] million, β = 1°, C_L = 0.5

- Difficulty in generating C_L- matched solutions for workshop grid at higher Mach numbers
- Drag rise well predicted, but presents challenges at M = 0.90
- Qualitative trend in C_Y and C_m well-predicted but offset in magnitude
- Good agreement in lateral moment coefficients for C_L- matched solutions
- Component F&M shows fuselage and tail variability at M = 0.90

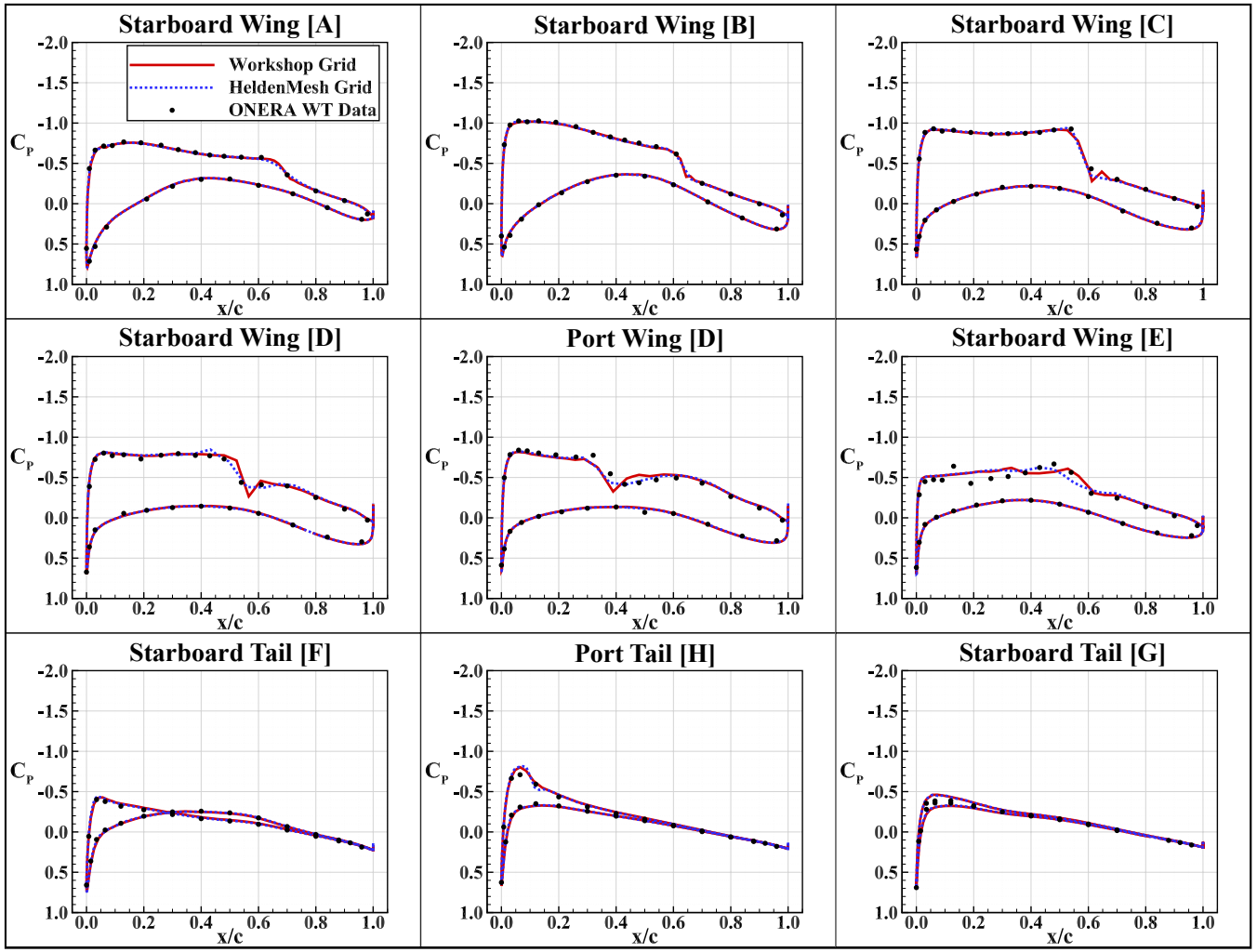


TC3: Mach Number Effect on Static Stability

M = 0.85, Re = 4.60 million, β = 1°, C_L = 0.5

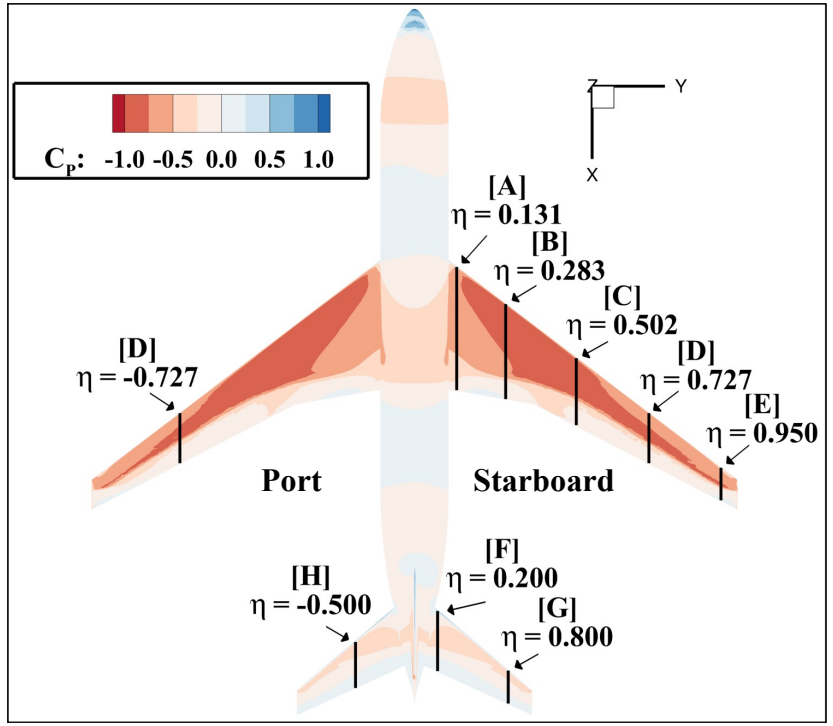


- Favorable agreement between FUN3D and WT pressure data
- Minor variation in shock smearing between grids

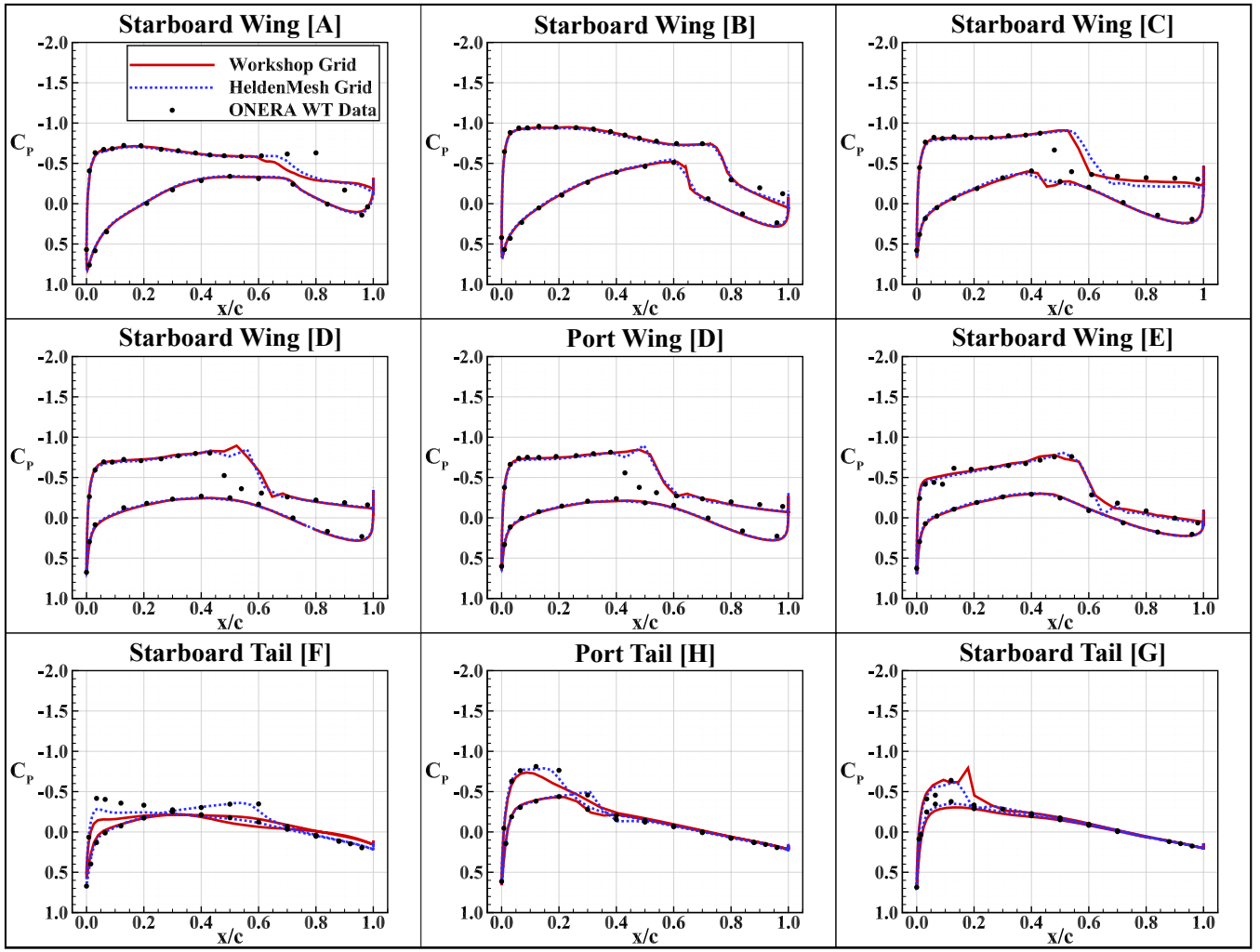


TC3: Mach Number Effect on Static Stability

M = 0.90, Re = 4.70 million, β = 1°, C_L = 0.5

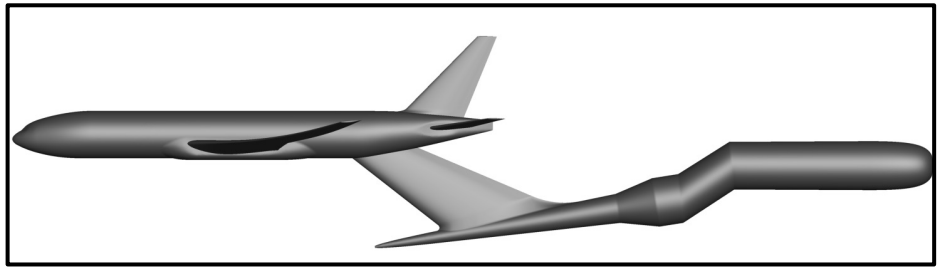


FUN3D data show difficulties in predicting shock location & inboard tail pressures – may benefit from grid adaptation

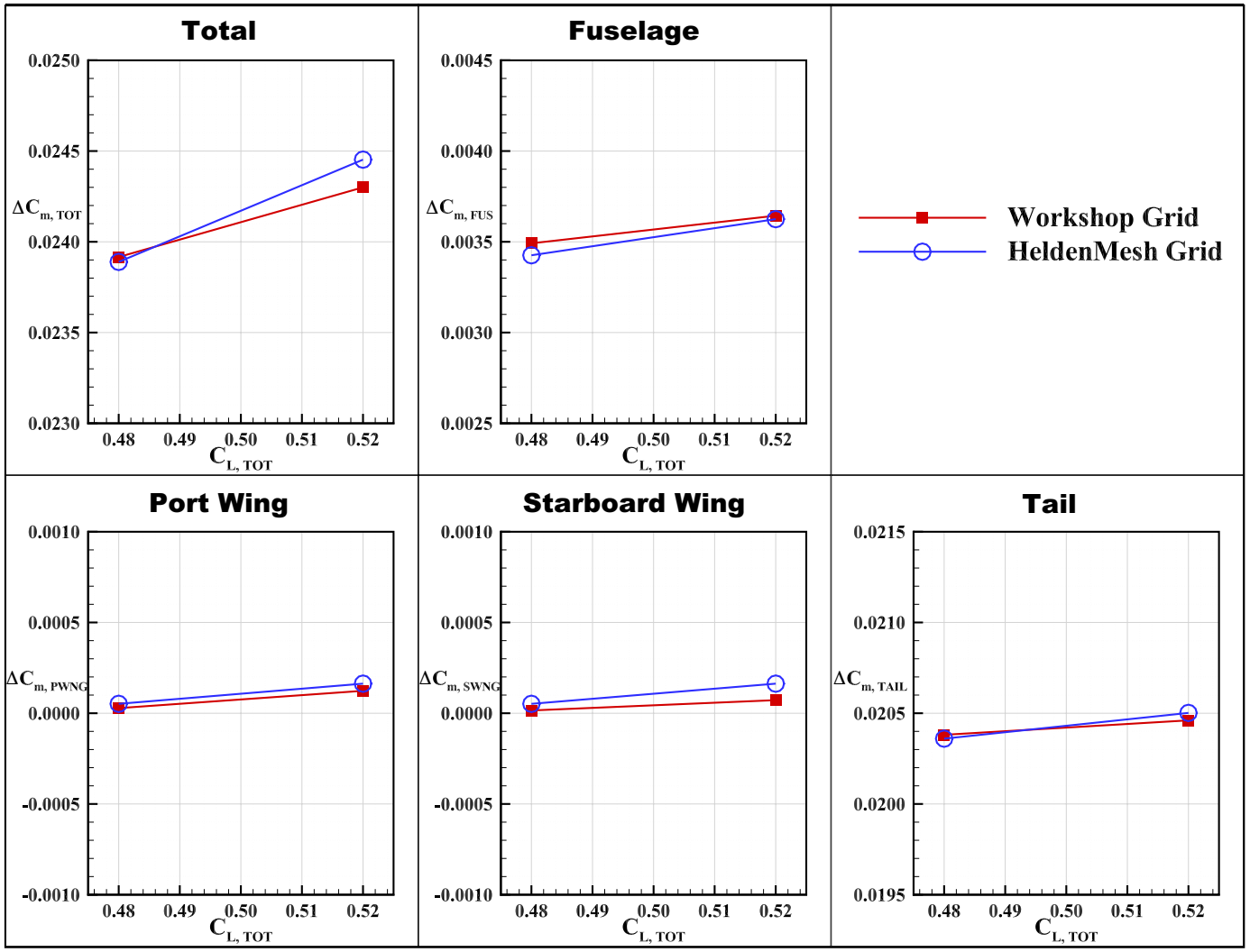


TC4: Wind Tunnel Sting Increments

M = 0.83, Re = 4.56 million, β = 0°



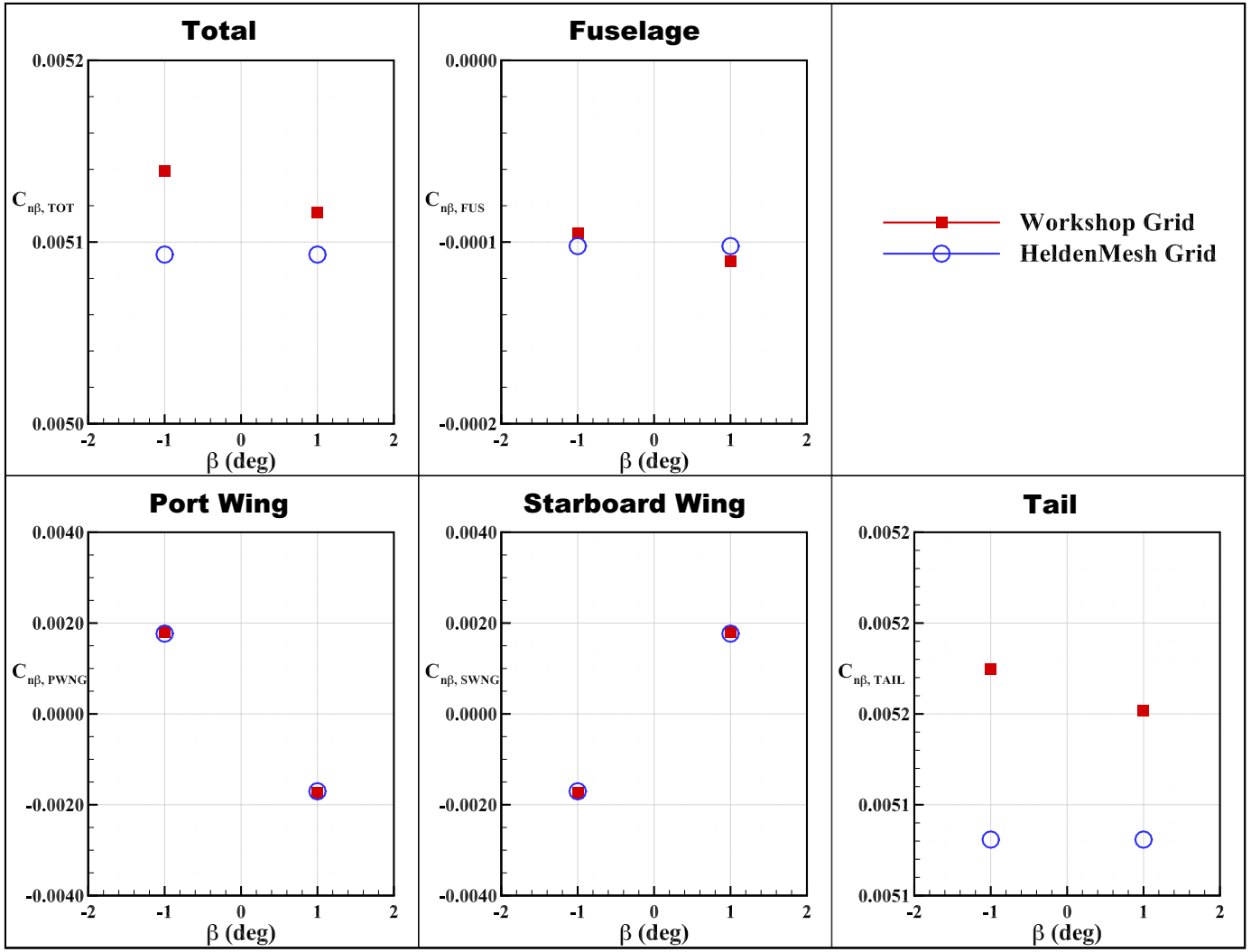
- **Static longitudinal stability increment calculated via slope**
  - Median value of $\Delta C_m/\Delta C_L$ = 0.0119
- **Drag increment (not shown) of 6-counts due to sting**
  - 17-count increase for fuselage
  - 4-count decrease for wings
  - 7-count decrease for tail
- **Lift increment (not shown) observed increase in fuselage/wings to compensate for loss of lift on tail**



TC5: Stability Derivative Calculation

M = 0.83, Re = 4.56 million, C_L = 0.5

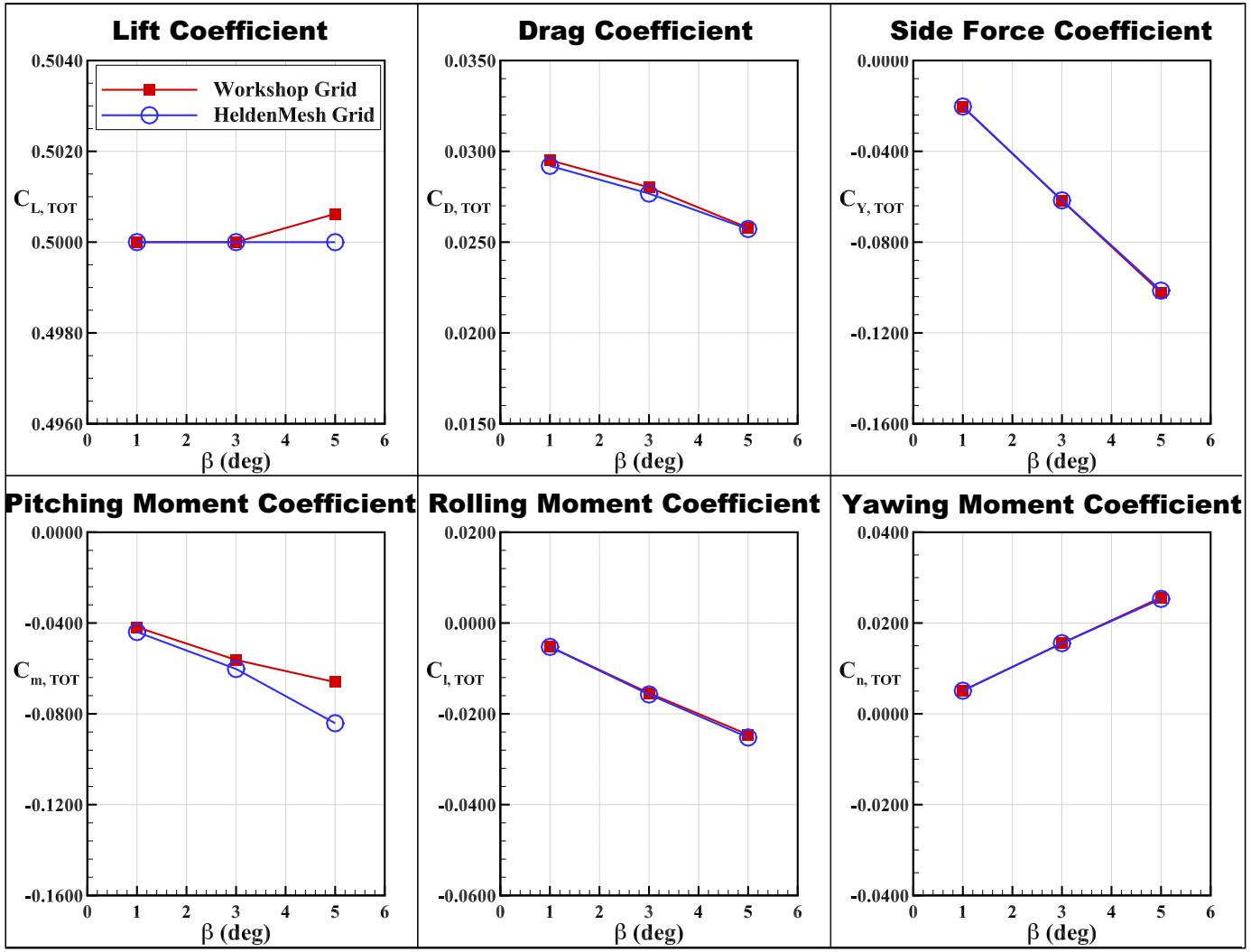
- **Investigated impact of grid asymmetry on lateral stability-derivative predictions**
- **Grid asymmetries propagate to unequal lateral stability derivatives (yawing moment shown)**
- **Magnitude of variations insignificant using adequately resolved grids**
- **Impact may be more significant for future workshop cases**
  - Dynamic motion
  - Nonlinear angles of attack or sideslip



TC6: Sideslip Angle Sweep

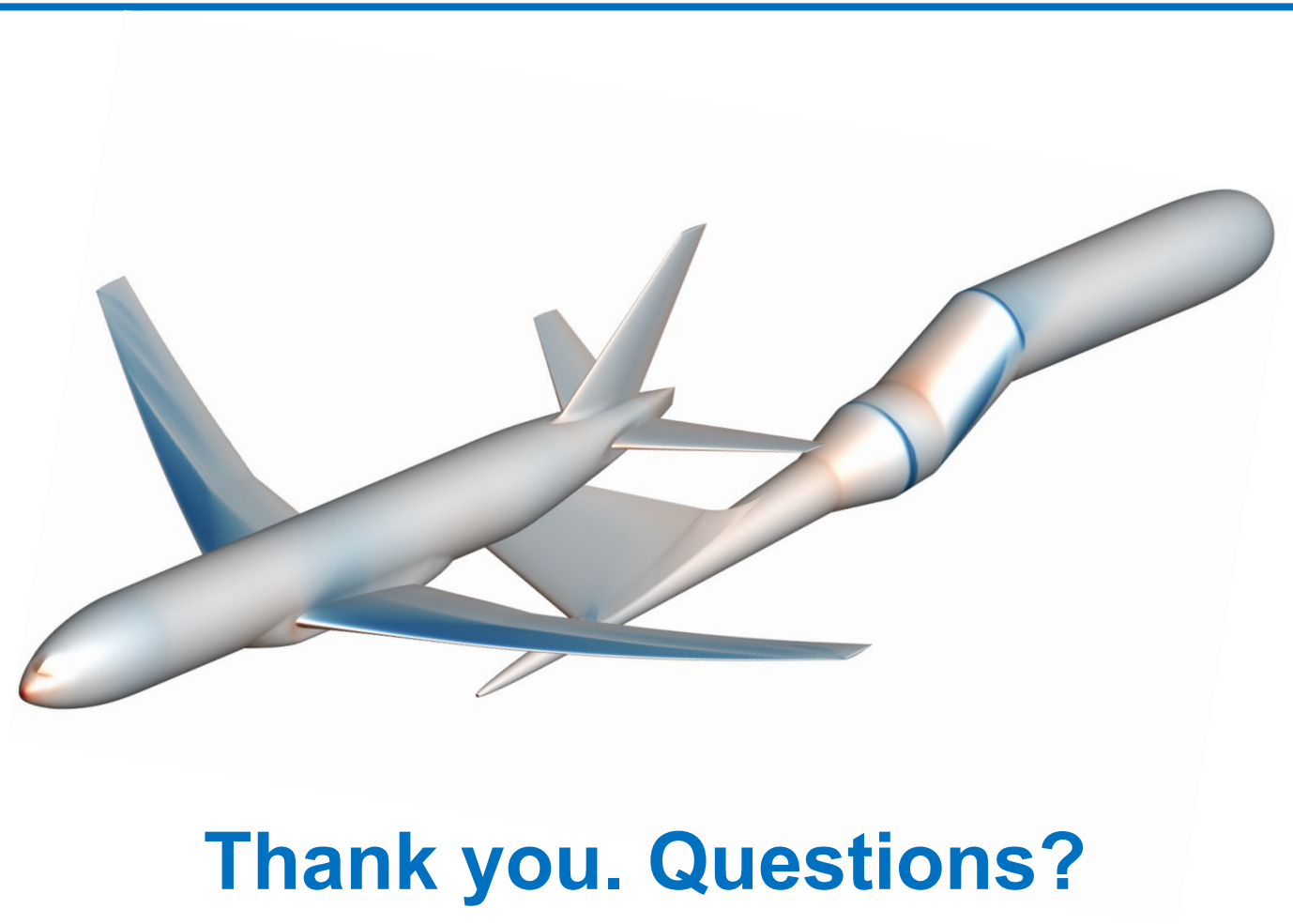
M = 0.83, Re = 4.56 million, C_L = 0.5

- **Sideslip-angle sweep performed for β = 1° to 5° using both grid series**
  - WT data unavailable at higher β
- **Workshop grids encountered convergence difficulties at β = 5°**
- **Relatively linear variation observed in F&M for both grid series**
- **Slightly nonlinear variation in C_m observed beginning at β = 5°**
  - HeldenMesh grid predicts significantly smaller (nose-down) pitching moment relative to workshop grids



Concluding Remarks

- **FUN3D analyses performed in support of the 1st AIAA Stability and Control Prediction Workshop for all test cases**
- **Series of HeldenMesh grids generated for comparisons to workshop grids after encountering convergence issues and observing grid asymmetry**
  - Differences in lateral stability derivatives observed, though small in magnitude
  - Good general agreement when matching grid refinement and solution strategy
  - HeldenMesh results showed need for increased leading- and trailing-edge grid resolution
- **Overall, FUN3D F&M predictions in good agreement with wind tunnel data with exception of pitching moment and M = 0.90 condition**
  - Largest source of variability due to predicting shocks on wing and tail components
  - Suggest exploration of impact of using a limiter on shock location predictions
  - Future workshops may benefit from grid-adaptation studies to resolve transonic flow features



Thank you. Questions?

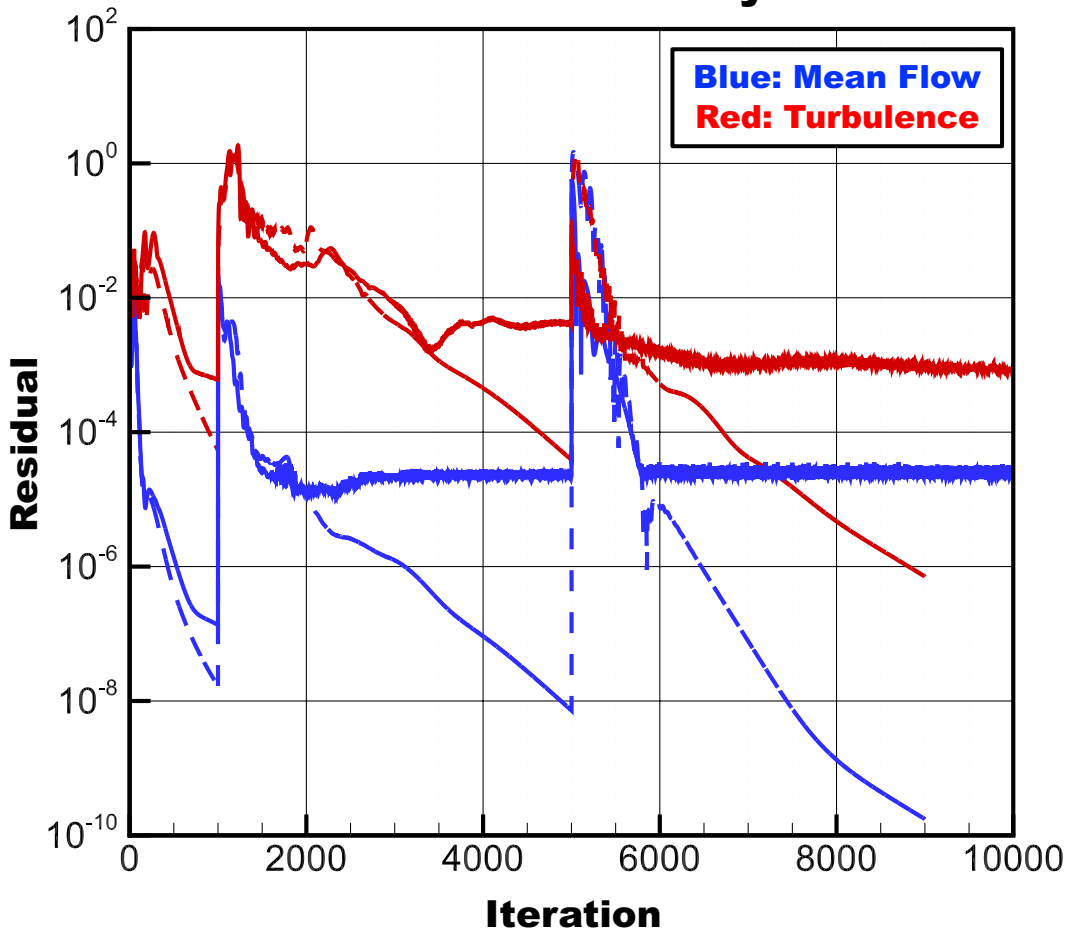
Contact: Brett Hiller <brett.hiller@nasa.gov>

Grid Comparison: Convergence History

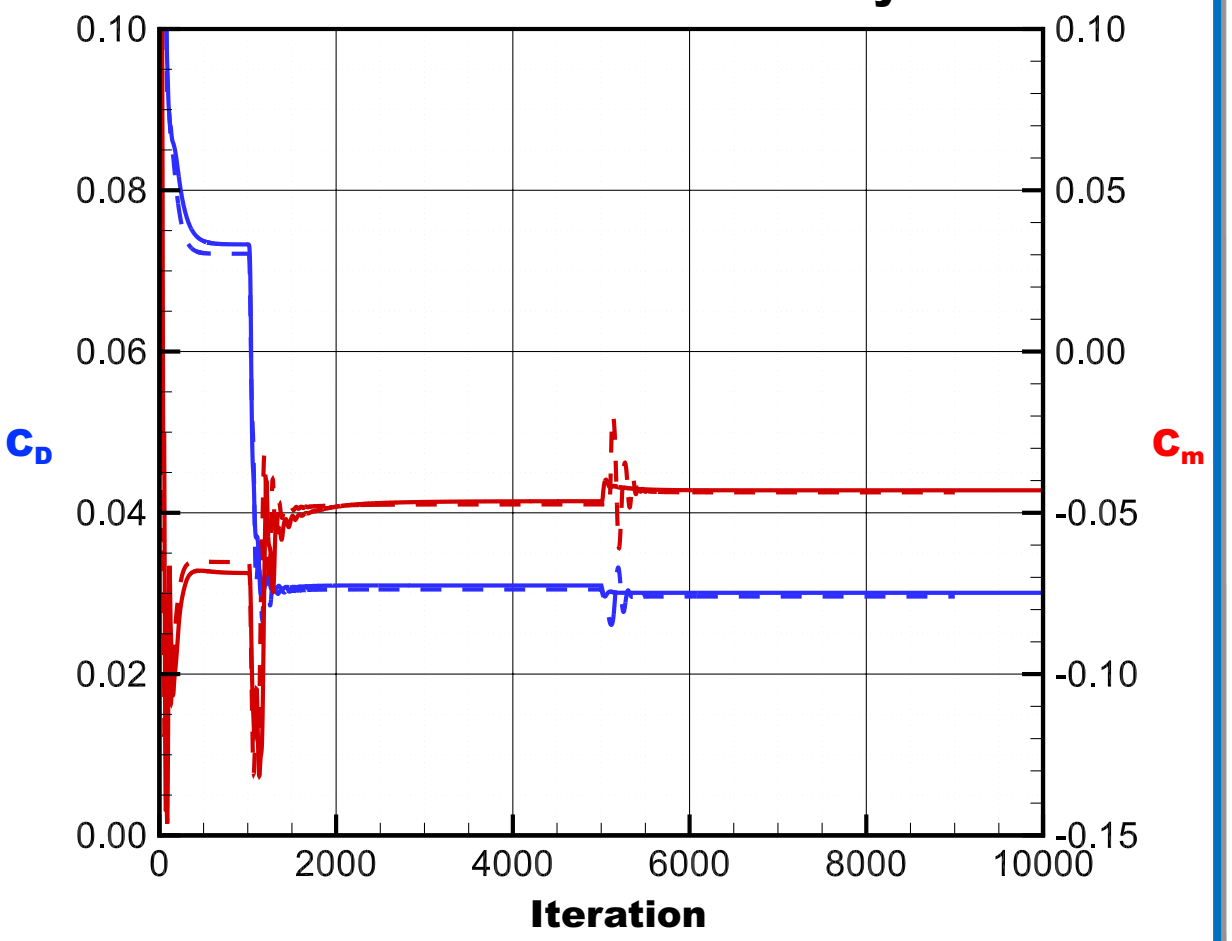
Coarse Grid, M = 0.83, Re = 4.56 million, β = 1°, C_L = 0.5

Workshop: ——
HeldenMesh: - - - -

Residual History

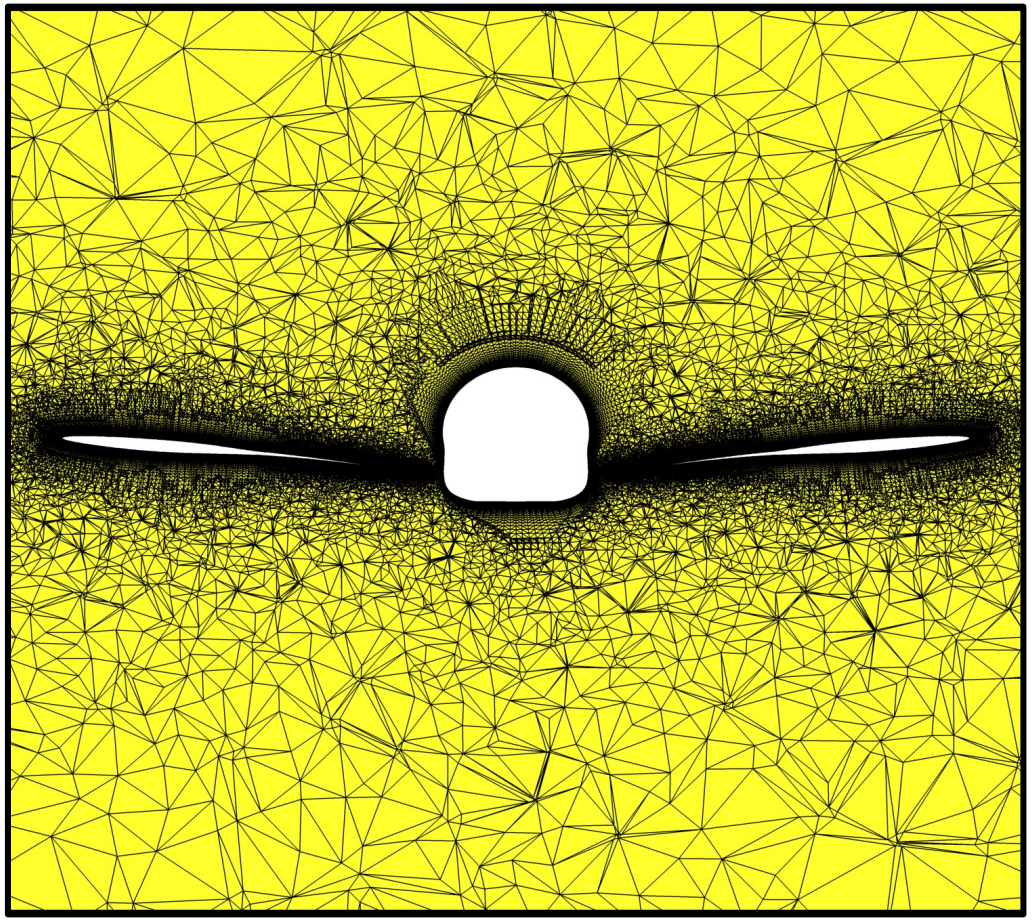


F&M Coefficient History

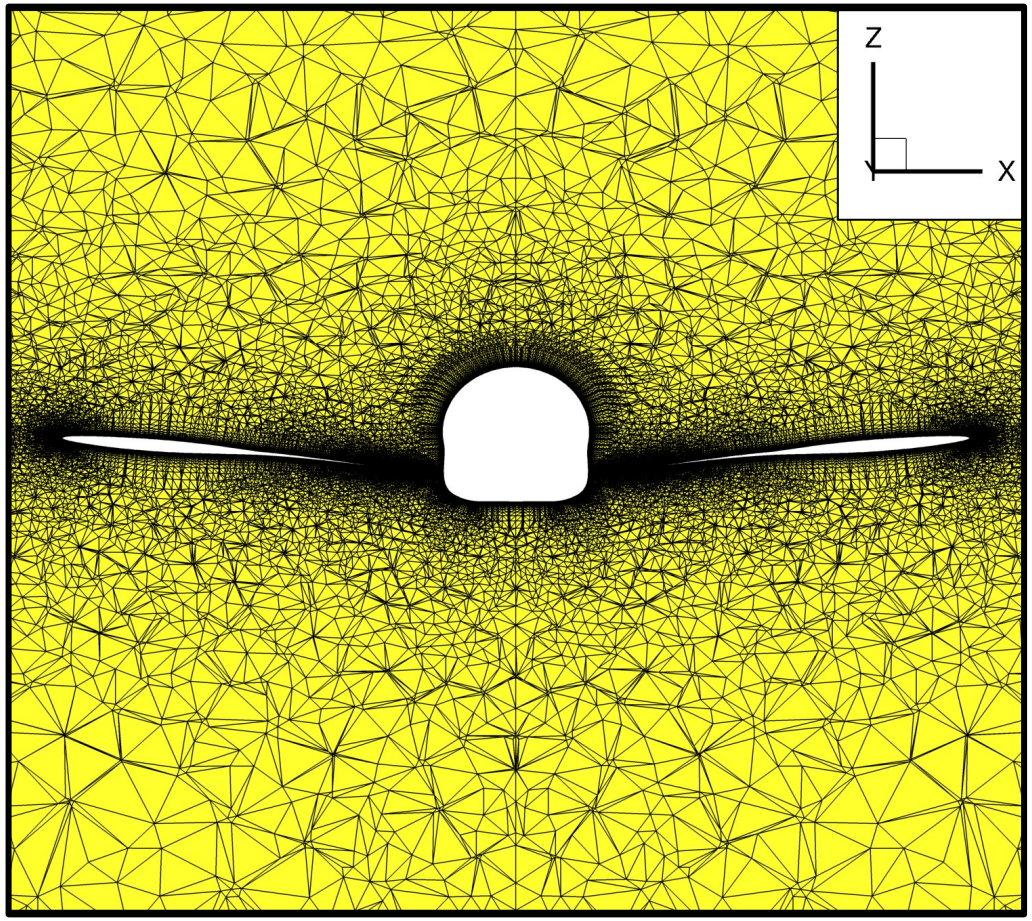


Grid Comparison: Asymmetry Observation

Medium Grid – Workshop

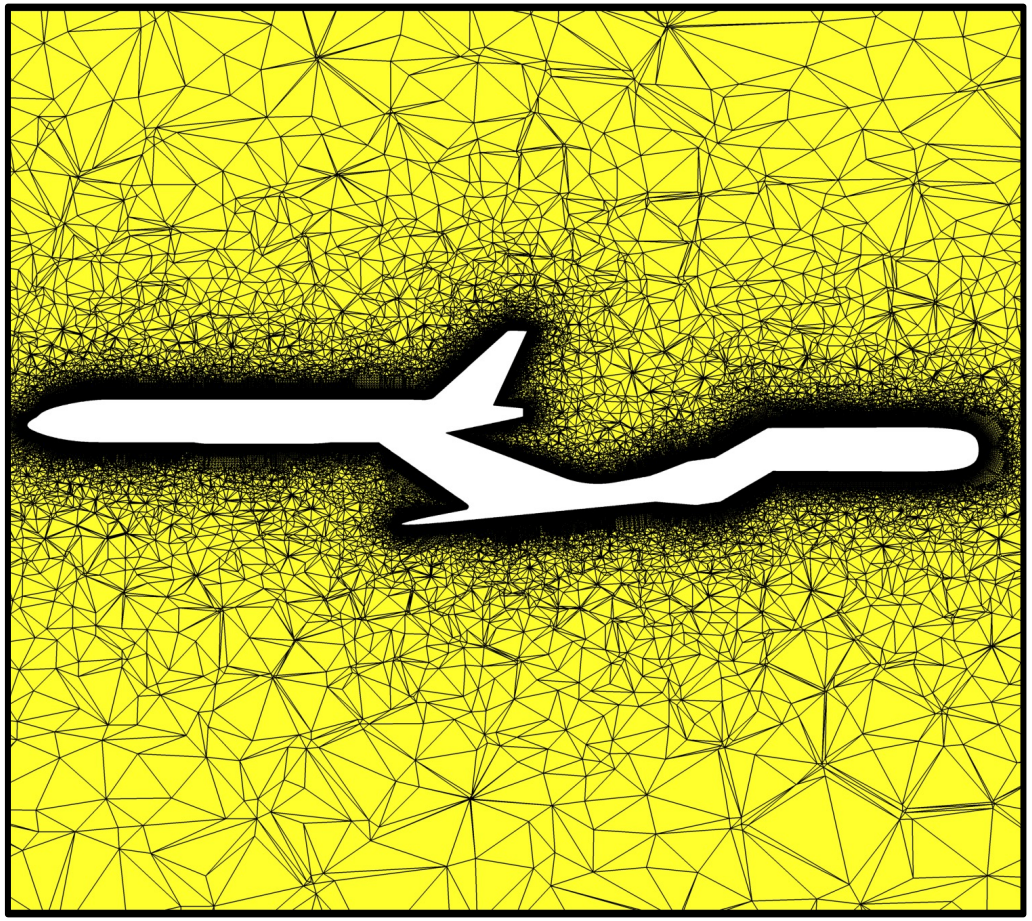


Medium Grid – HeldenMesh

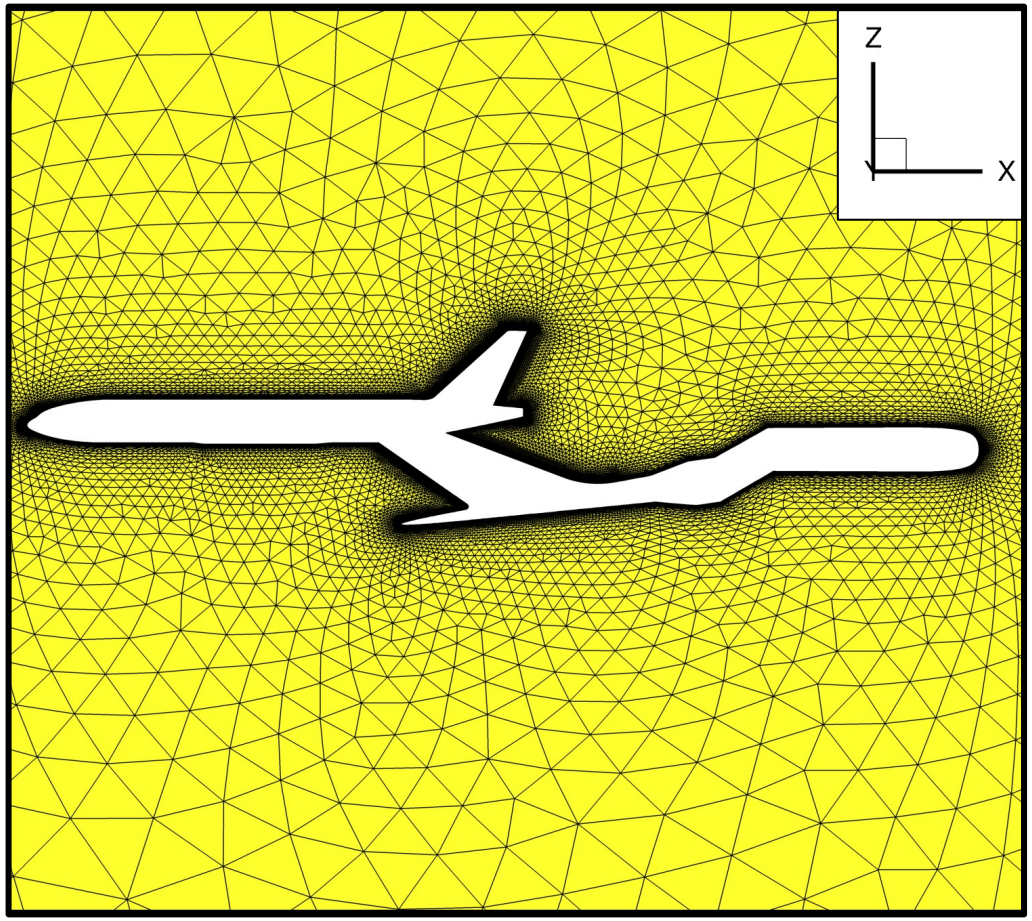


Grid Comparison: Asymmetry Observation

Medium Grid – Workshop

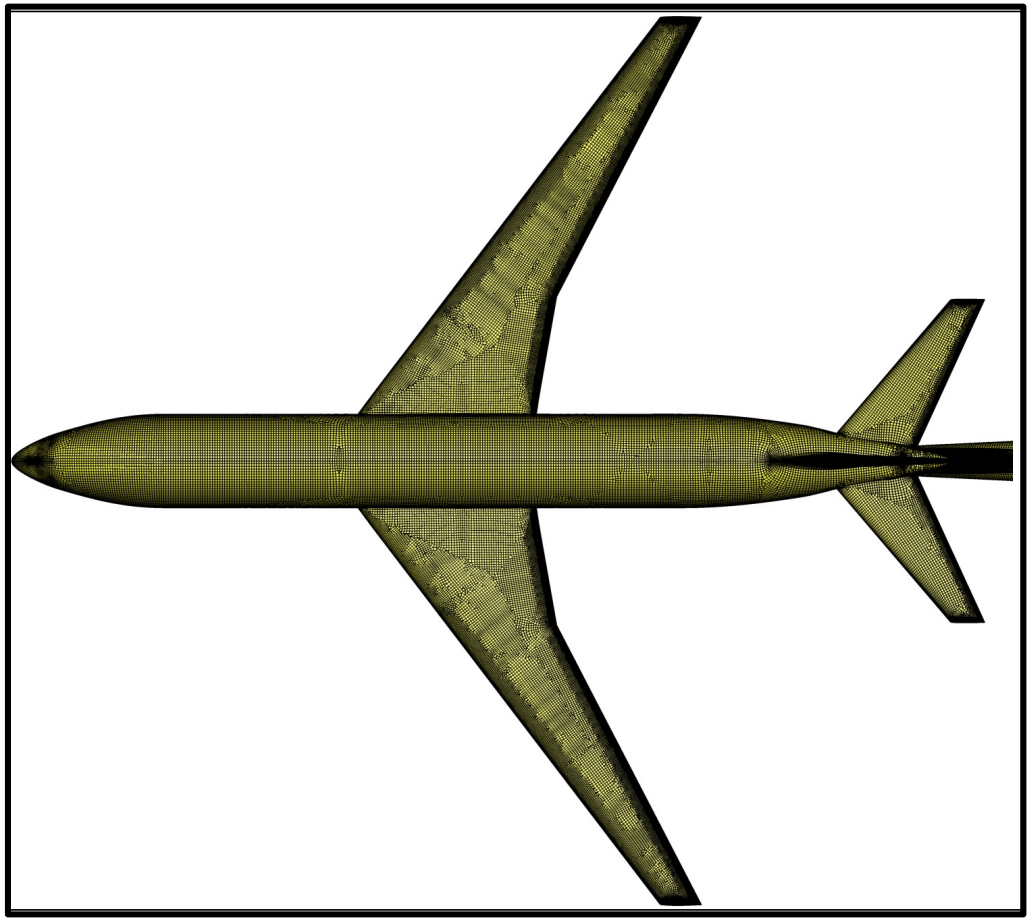


Medium Grid – HeldenMesh



Grid Comparison: Asymmetry Observation

Medium Grid – Workshop



Medium Grid – HeldenMesh

