Boeing Contributions to the Static Deformation Working Group of the 8th Drag Prediction Workshop

Phillip Jones
Boeing Commercial Airplanes
Flight Sciences – Loads Aerodynamics

Outline

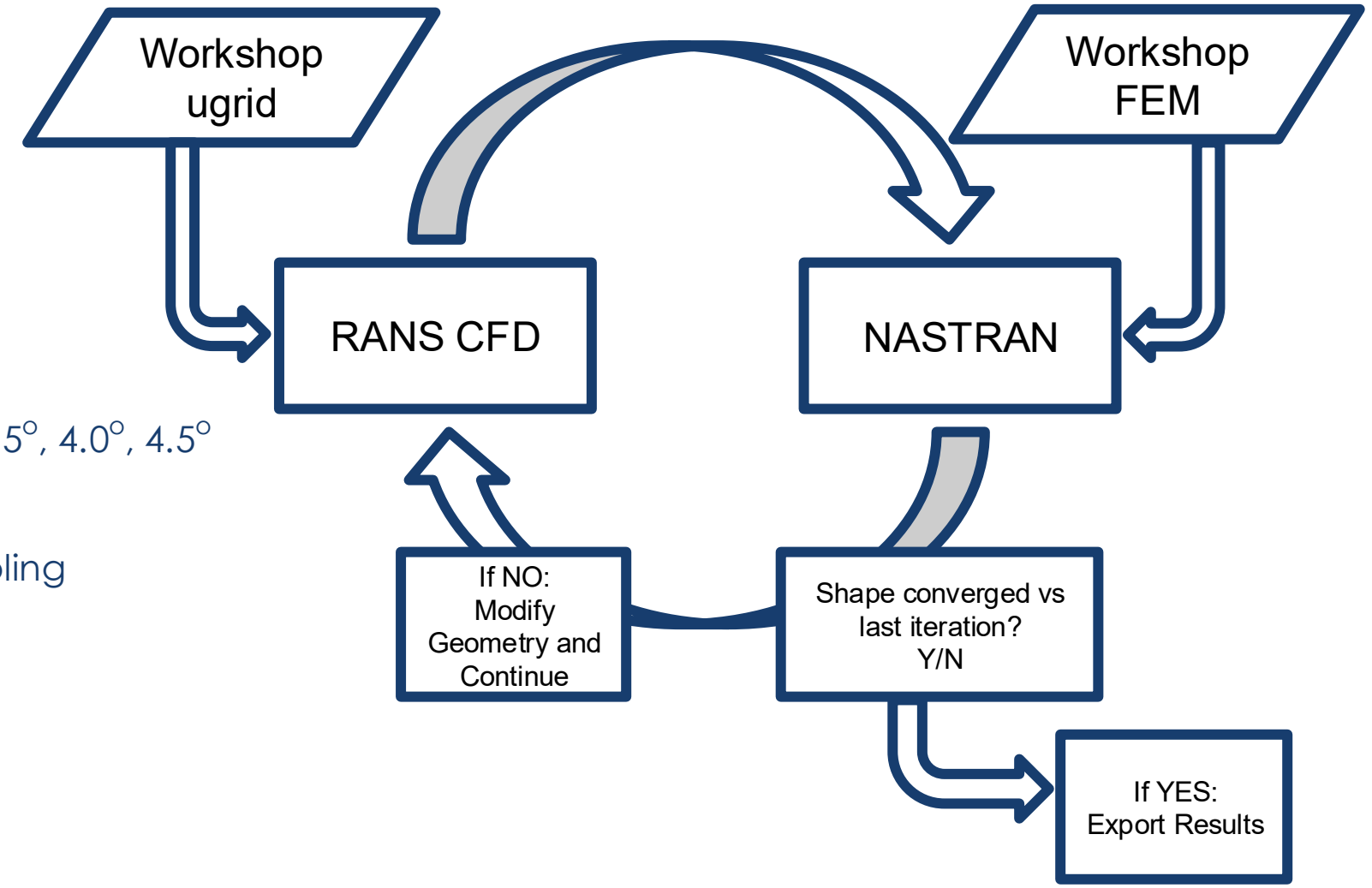
- **Flow/Structural Solvers**
  - FELight
  - NASTRAN
- **Test Cases**
  - Test Case 2a: NASA CRM Wing/Body CL=0.50
  - Test Case 2b: NASA CRM Wing/Body Polar
- **Results**
  - Deflections
  - Force/Moments
- **Conclusions**

Flow/Structural Solvers Utilized

- **FELight**
  - Boeing developed finite element solver
  - SUPG, 2nd-order accurate in space for all equations (fully coupled turbulence equation), BFD2 and SDIRK for temporal disc.
  - Shock capturing, Newton's method with preconditioned GMRes
  - SA, SA-QCR2000, SARC-QCR2000
  - CL matching capabilities
- **NASTRAN**
  - COTS Version 2018.2.1
  - SOL101 Linear Static
  - All solutions used workshop Half Model FEM

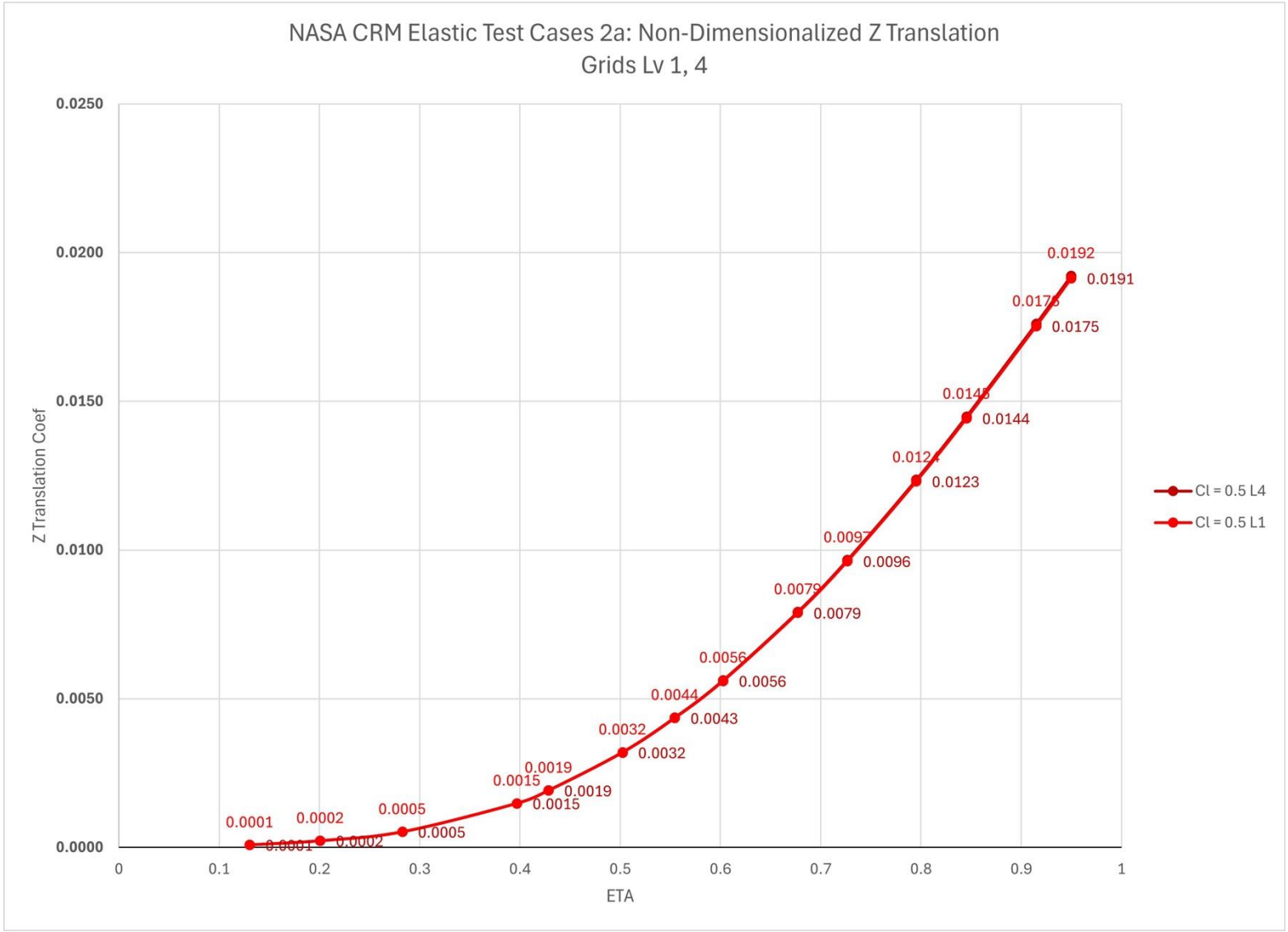
Case 2a/2b: NASA CRM Wing/Body

- **2a Flow Conditions:**
  - Mach 0.85
  - Re_c=5m (based on chord)
  - T_{static}= 506.48 R
  - CL = 0.50
- **2b Flow Conditions:**
  - Mach 0.85
  - Re_c=5m (based on chord)
  - T_{static}= 506.48 R
  - Alpha: -1.5°, 0.0°, 1.5°, 2.5°, 3.0°, 3.5°, 4.0°, 4.5°
- **Modeling:**
  - NLBGS CFD/NASTRAN Loose Coupling
  - SA-neg-RC-QCR2000
  - Sutherland's Law
  - Robust Convergence (~1e-8)



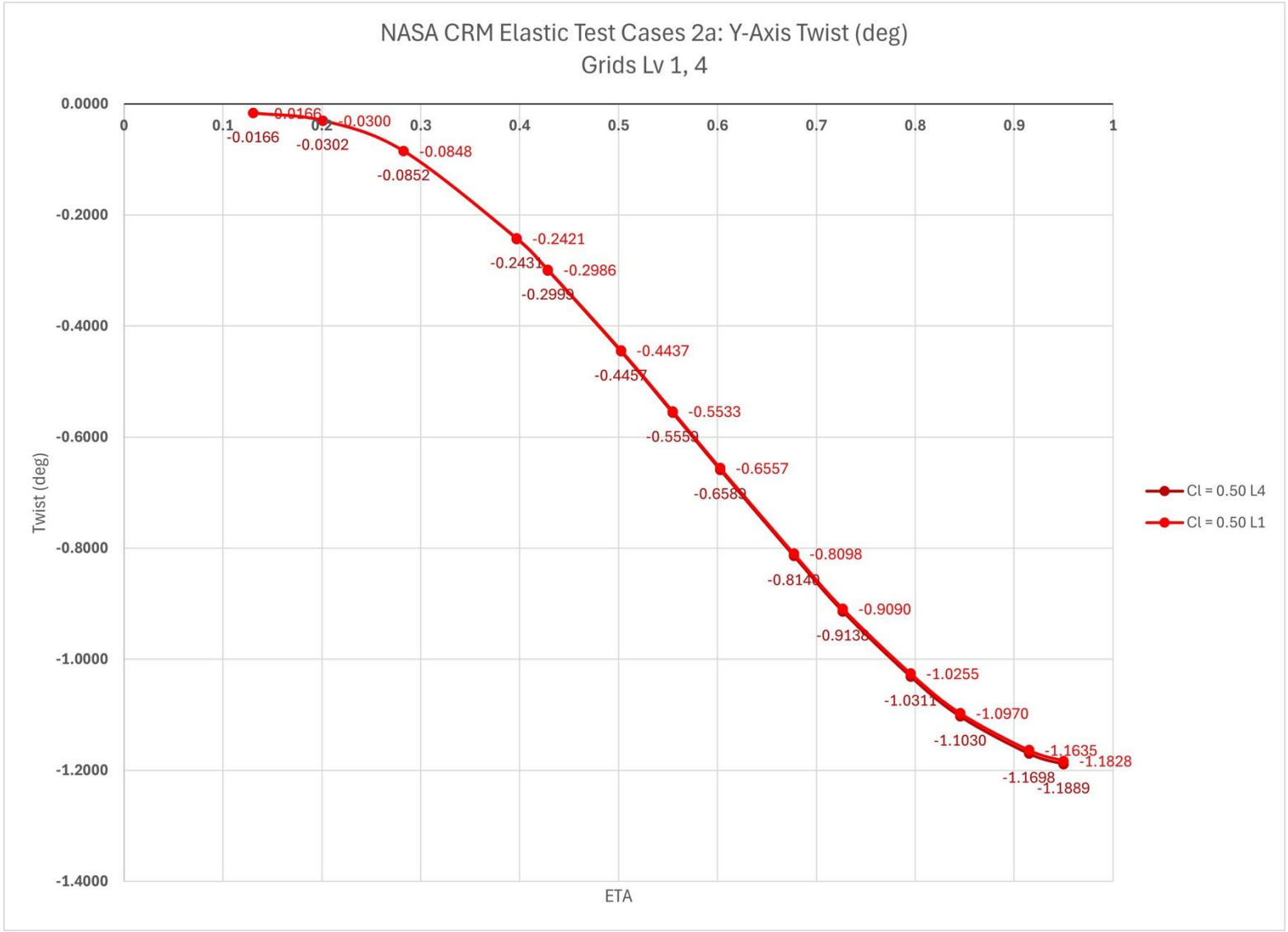
Results: Test Case 2a Z Translation Coef

- **2a NASA CRM Wing/Body**
  - 2 Grids run for Case 2a:
    - L1 (Tiny) and L4 (Fine)
  - L1 (elastic) CL 0.50 achieved at 2.595 deg
  - L4 (elastic) Cl 0.50 achieved at 2.556 deg
  - Results from MONDSP1s averaging streamwise cut node translation about CORD2R Z axis.
  - Global normal vectors.



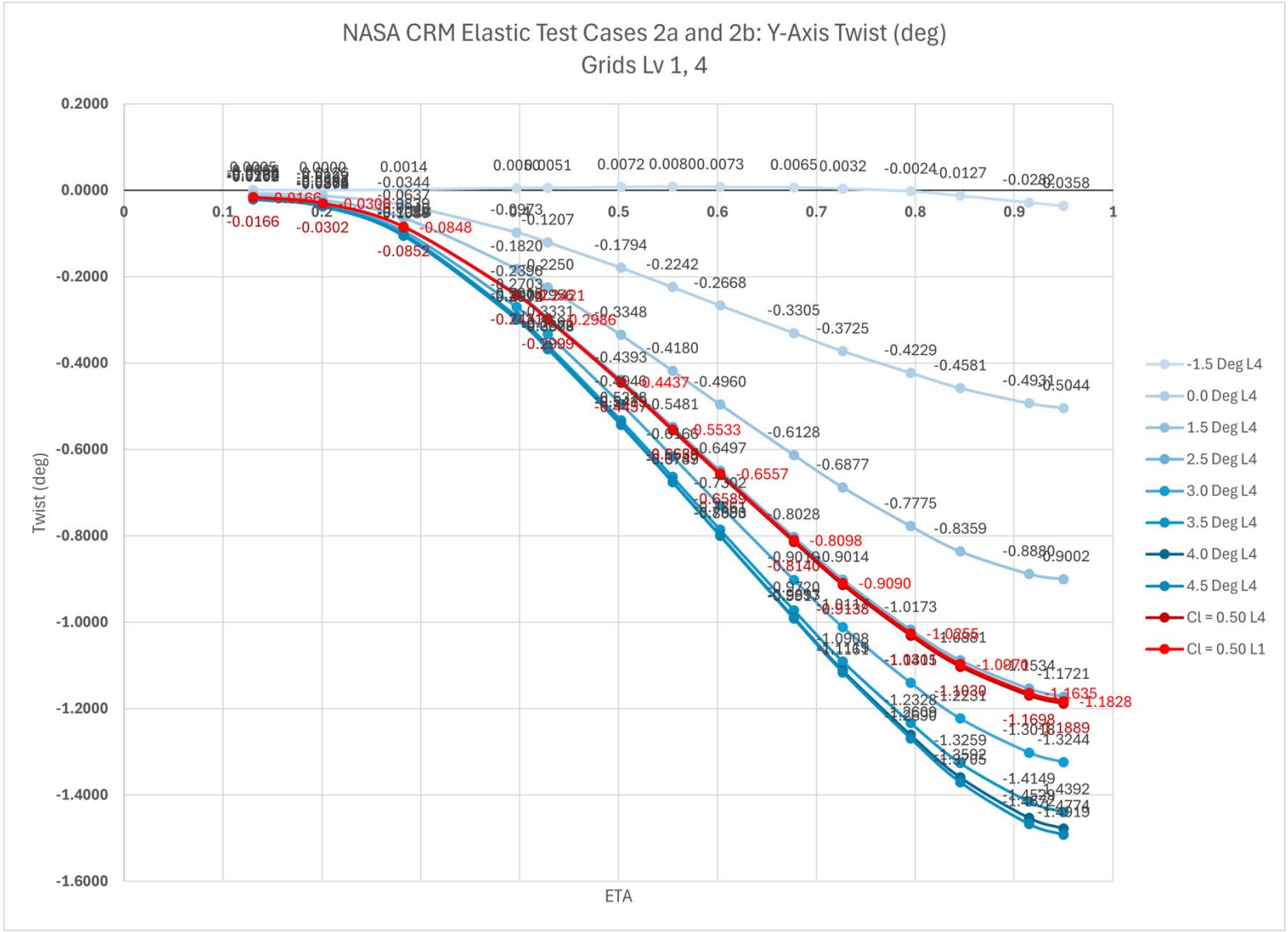
Results: Test Case 2a Twist

- **2a NASA CRM Wing/Body**
  - Results from MONDSP1s averaging streamwise cut node rotation about CORD2R Y axis
  - CORD2Rs located at global Y stations, mid chord, and **Z interpolated from beam model**.
  - Global normal vectors.



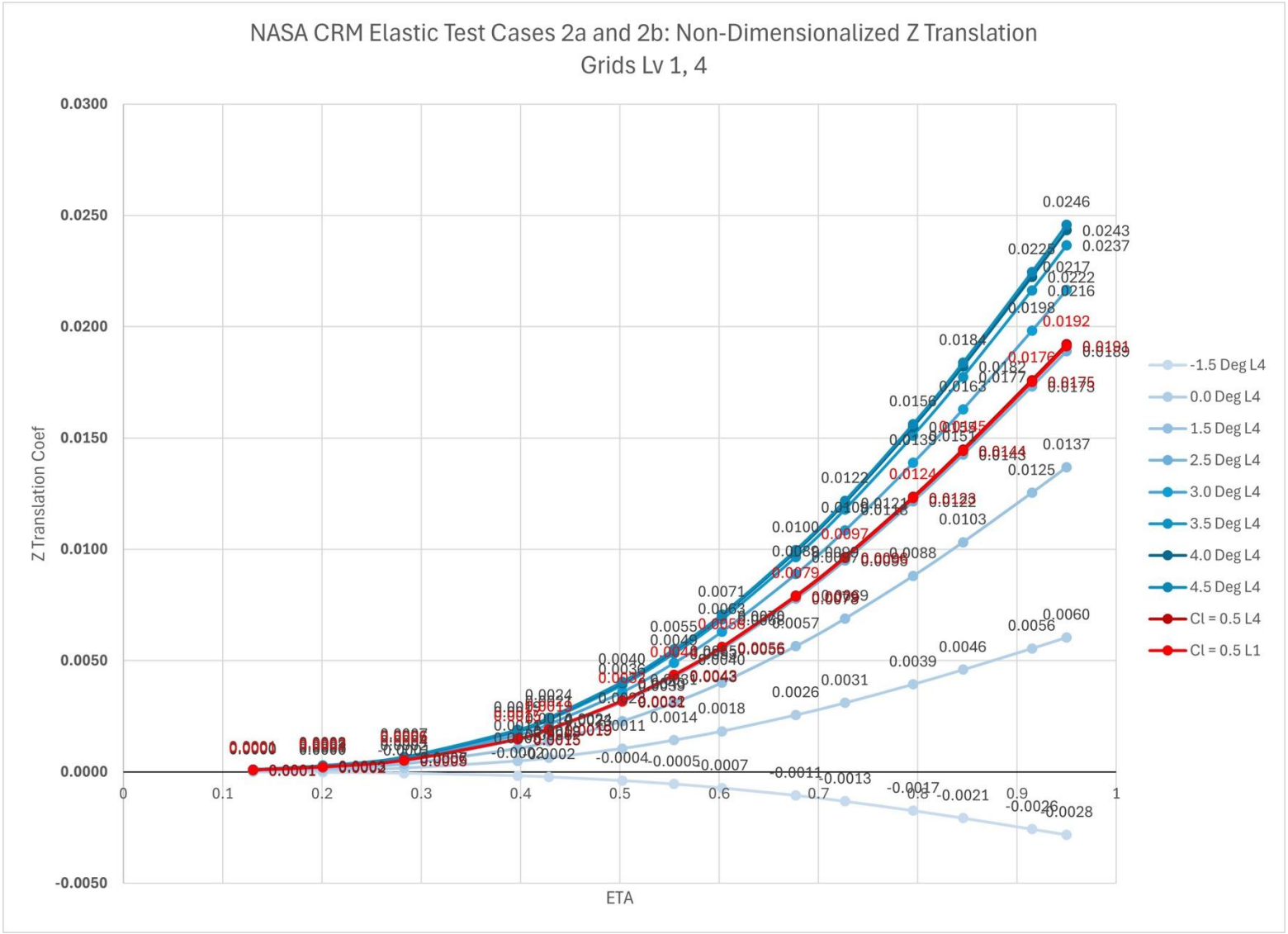
Results: Test Case 2a vs 2b Twist

- **2b NASA CRM Wing.Body**
  - Case 2b run on L4 (Fine) Grid
  - Elastic alpha sweep
  - Identical MONDSP1s as 2a
  - Results family well. As expected, deformation increment falls off over 3.5 degrees, and therefore so does twist.
  - Some questions around alpha -1.5 results. Our solution detects a washout effect outboard of Eta 0.8. Torsion load?



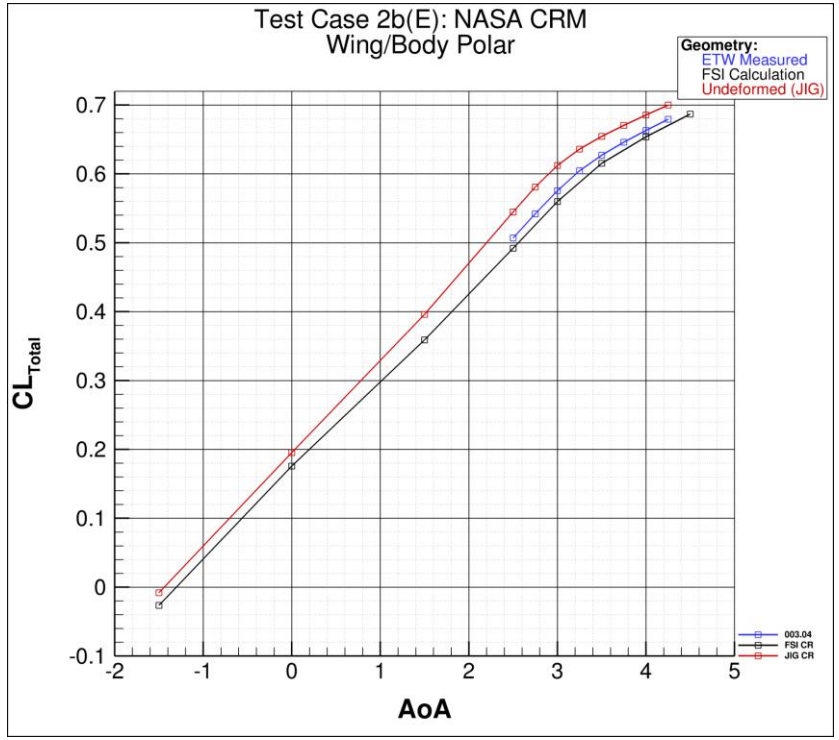
Results: Test Case 2a vs 2b Z Translation Coef

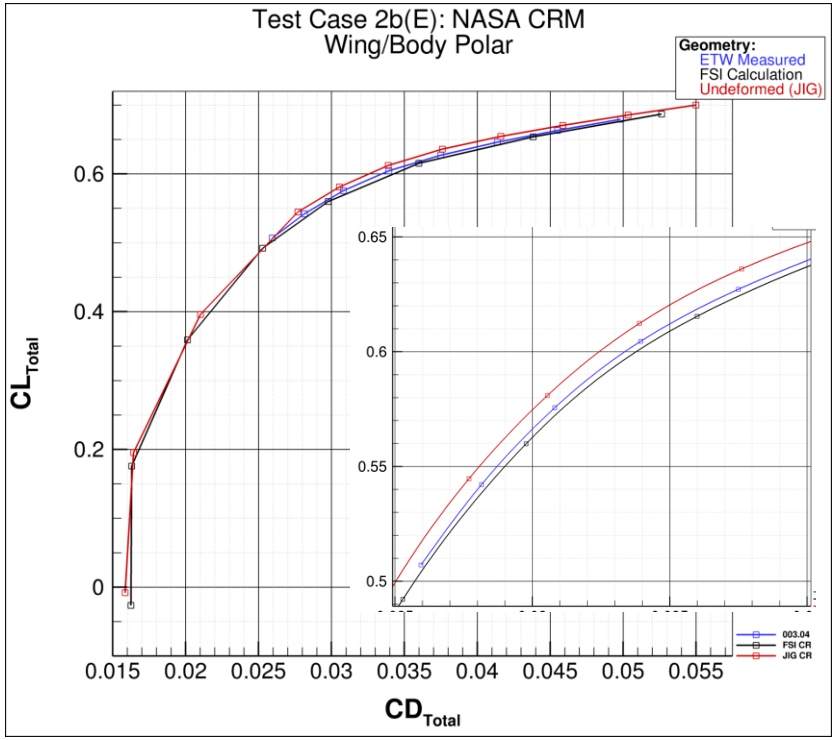
- **2b NASA CRM Wing.Body**
  - Case 2b run on L4 (Fine) Grid
  - Elastic alpha sweep
  - Identical MONDSP1s as 2a
  - As with twist, Z translation increment falls off over 3.5 degrees.
  - Run at -1.5 degrees continues to deflect downward outboard of Eta = 0.8 (as we would expect!). Points to a strong torsion in our solution.

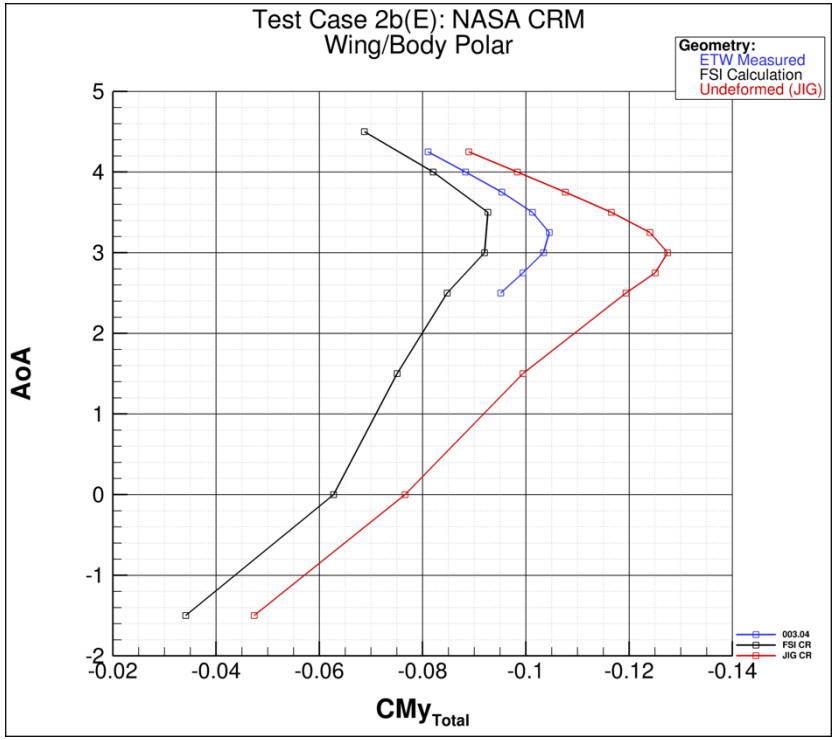


Results: Test Case 2b

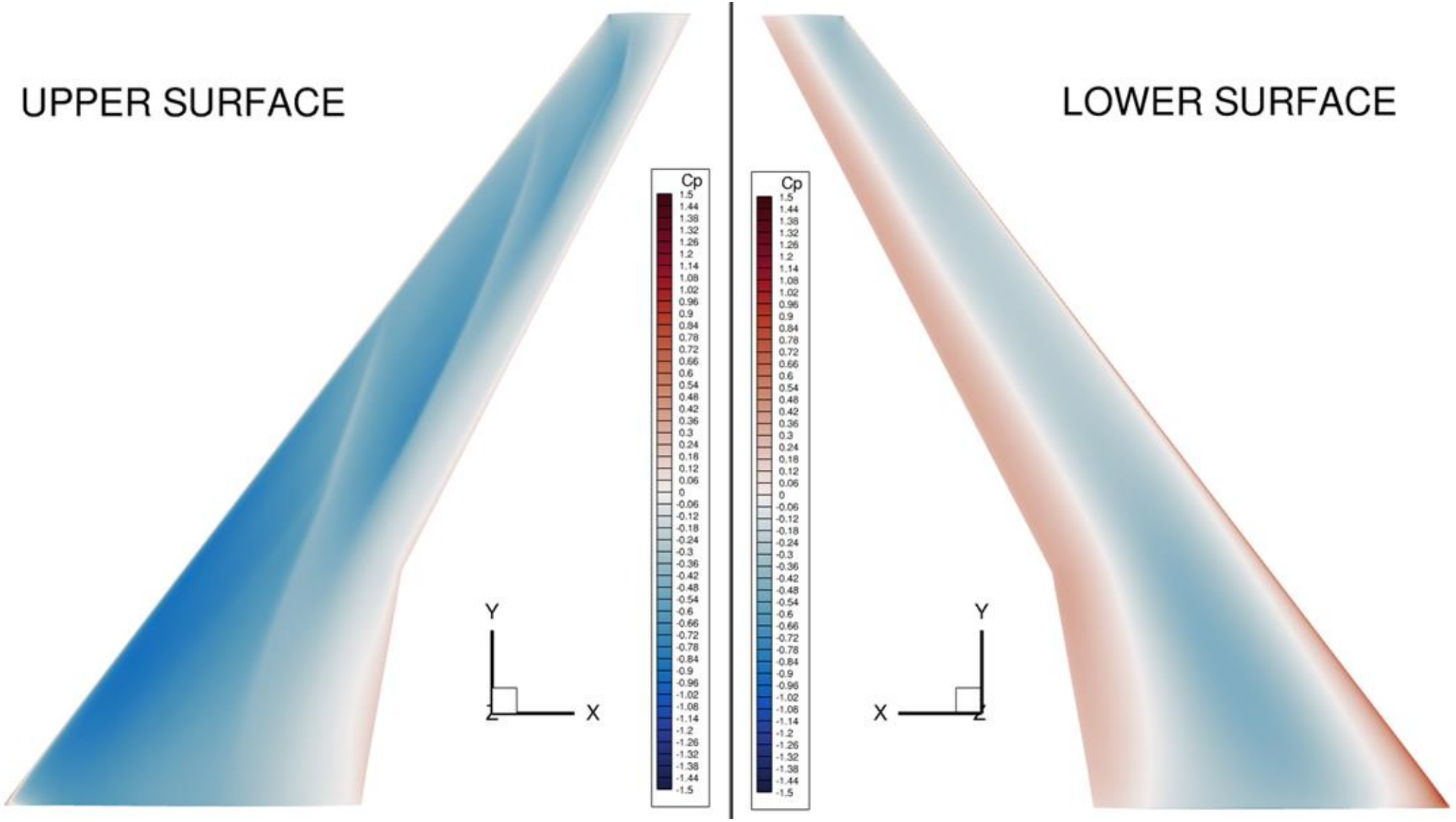
- **NASA CRM Wing/Body Polar**
  - Undeformed (Jig)
  - Grid 4 Aero-Structural calculation (FSI)
  - ETW measured deformation



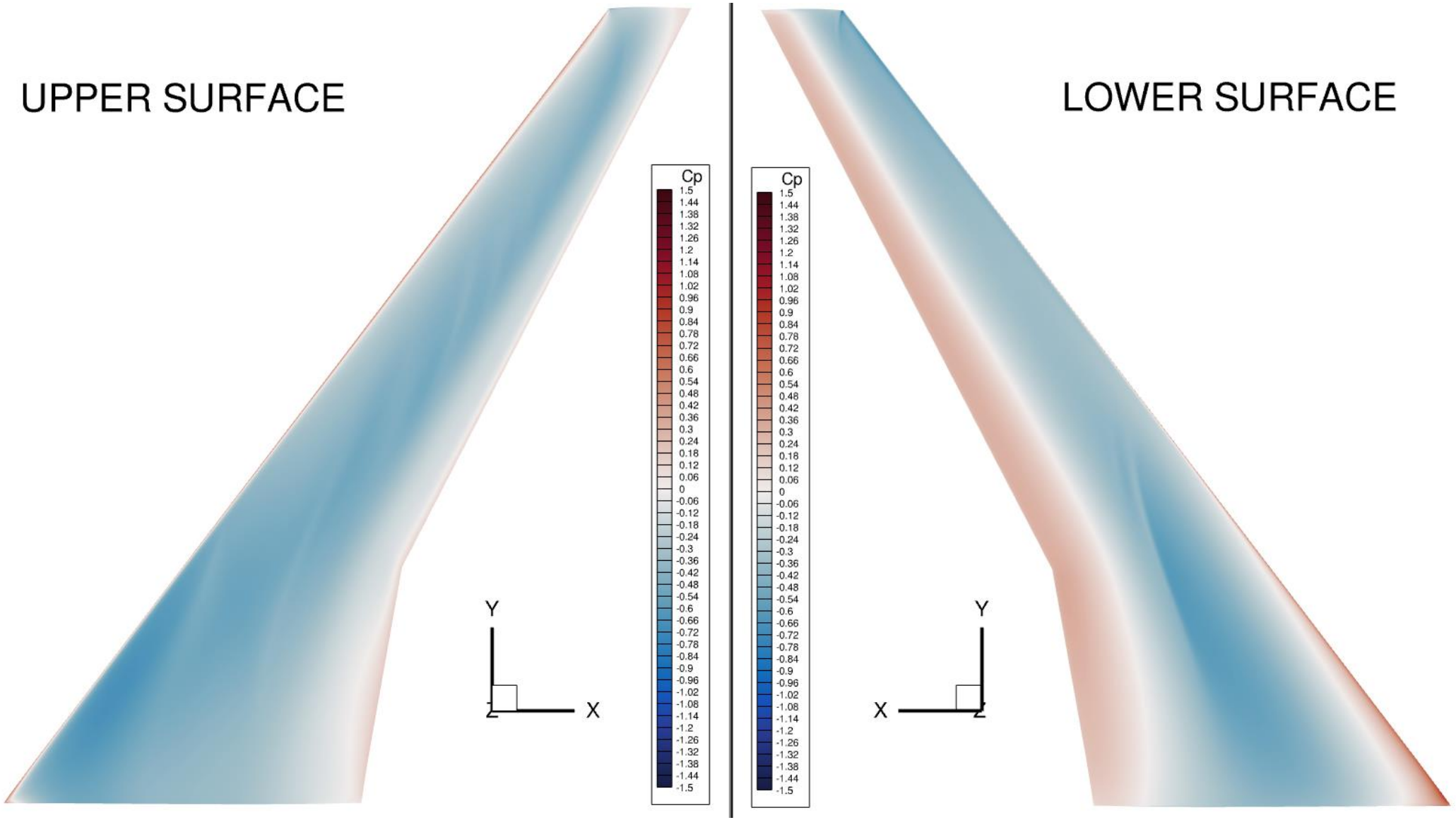




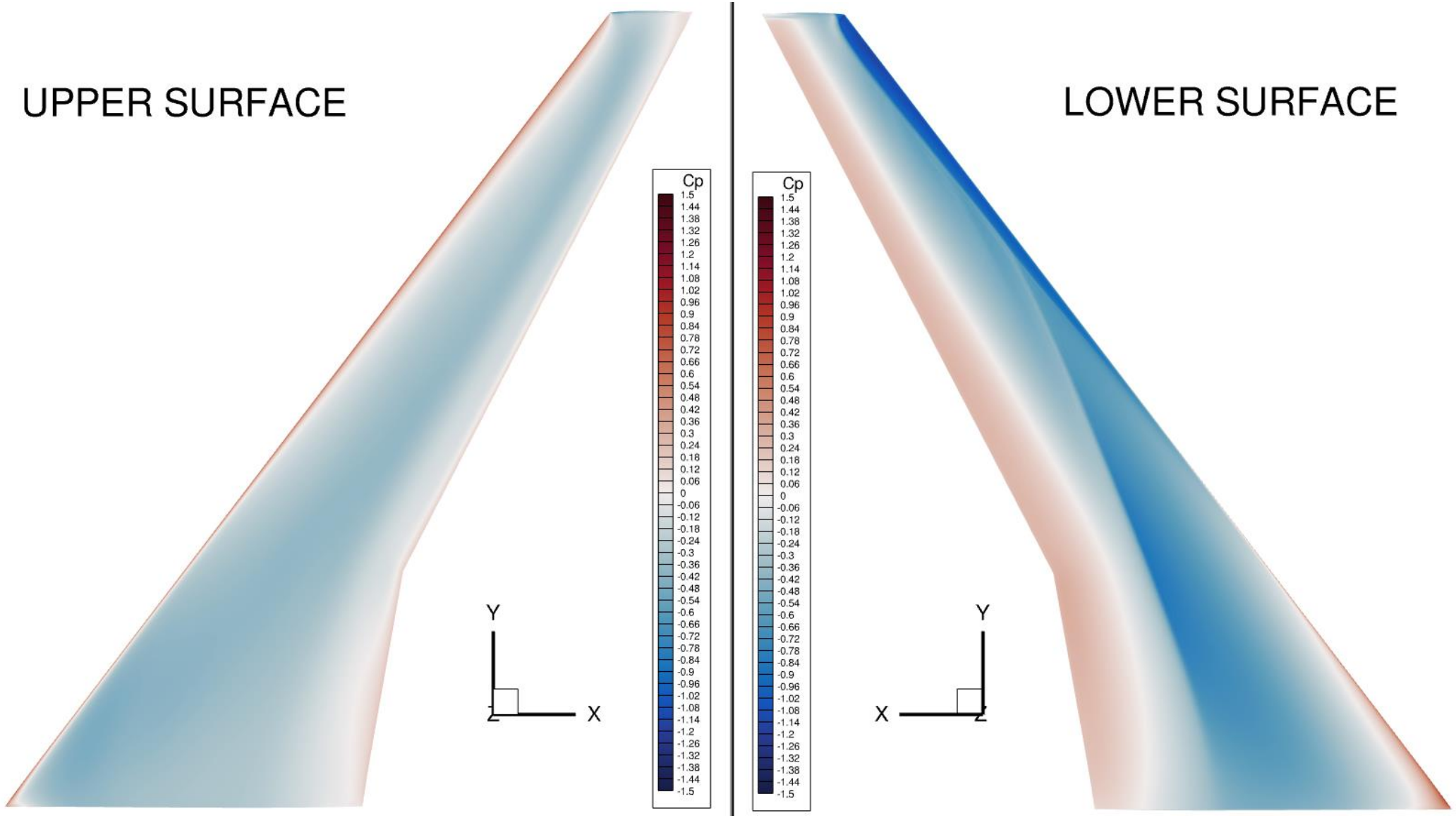
Results: 2b Cp Contour: L4, 1.5 deg



Results: 2b Cp Contour: L, 0.0 deg



Results: 2b Cp Contour: L,-1.5 deg



Conclusions

- **Small elastic deformations of a stiff model create measurable differences**
  - Results scatter aside, WT model elastics are important to successful validation of CFD, and interpretation of test data
- **A gap still exists between elastic CFD and WT Results**
  - Potential sources of uncertainty vs test include:
    - FEM stiffness differences from ETW model contribute to uncertainty.
    - CFD was run in free air, which negates WT section effects such as variations in inflow vector.
    - Structural analysis should be run with inertial forces: Small but not insignificant.
  - The devil is in the details: The road to precision likely paved with many small effects adding up to larger results

Acknowledgements

- Thank you to my colleagues who contributed data, provided support in running these cases, or provided very helpful discussion and feedback.

- Many Thanks to my organization for prioritizing our involvement in DPW efforts!