



Computational Aeroelastic Analysis for the Supersonic N+2 Project

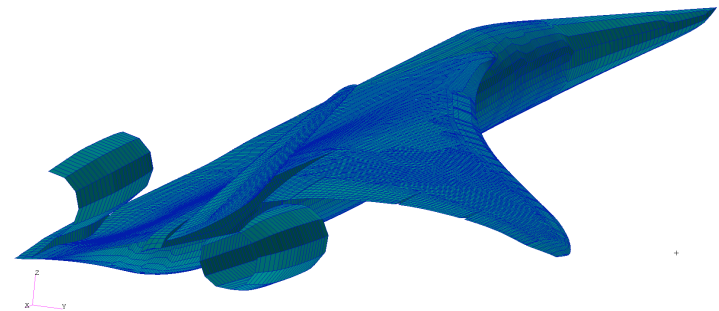
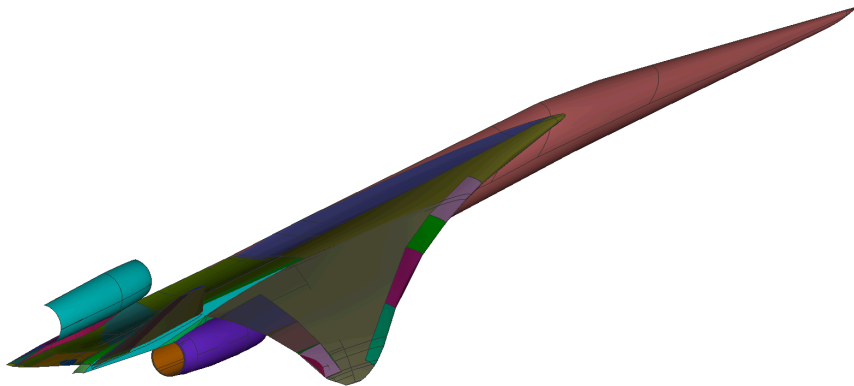
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Aeroelasticity Branch Peer Review

January 27, 2014





Outline

- Objectives
- Lockheed Martin N+2 configuration
- Computational Aeroelastic analysis requirements
- Surface Definition
- Finite Element Model
- Morphing of the surface definition
- Computational Fluid Dynamics grid
- Sample results
- Current work
- Future challenges



Objectives of High Speed N+2 Program

- Follow-on to the NASA Fundamental Aero Supersonics S⁴T project
- N+2 refers to two generations past the current state-of-the-art
- Supersonic cruise aircraft present highly complex nonlinear aeroelastic + flight dynamic phenomena due to –
 - Unique structural configuration
 - Nonlinear aerodynamics
 - Rigid-body effects
- These phenomena have potential to affect –
 - Flutter
 - Gust loads
 - Ride quality
 - Flight dynamics and control
 - Engine performance
 - Static deflections for sonic boom analysis
- Safe, comfortable, and efficient flight of supersonic cruise aircraft will require the ability to computationally predict APSE-related physics



Lockheed Martin N+2 Configuration



Length: 244 ft.
Span: 83 ft. 10 in.
Weight: 320,000 lbs. (TOGW)
Cruise: $M=1.7$
Payload: 80 pax
Range: > 5000 nm





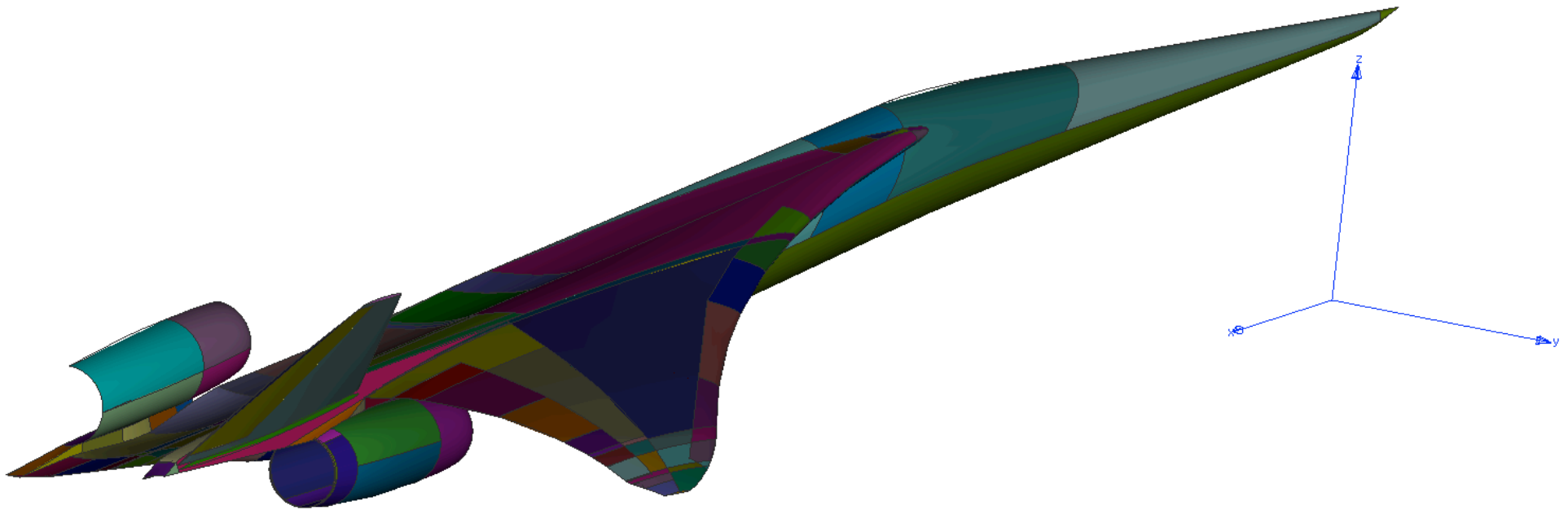
Computational Aeroelastic Analysis Requirements

- High quality surface definition
 - Computer Aided Design (CAD)-based definition
 - International Graphics Exchange Specification (IGES) format
- High quality and realistic structural model
 - Finite Element Model (FEM) used with MSC Nastran
 - Mode shapes interpolated onto the computational surface grid
- Computational grid
 - Used for Computational AeroElastic (CAE) analysis
 - Viscous or inviscid wall spacing
 - With and without engines present
 - Structured (CFL3D) or unstructured (FUN3D) Computational Fluid Dynamic (CFD) flow solver
 - Matrix of flow conditions



N+2 Surface Definition

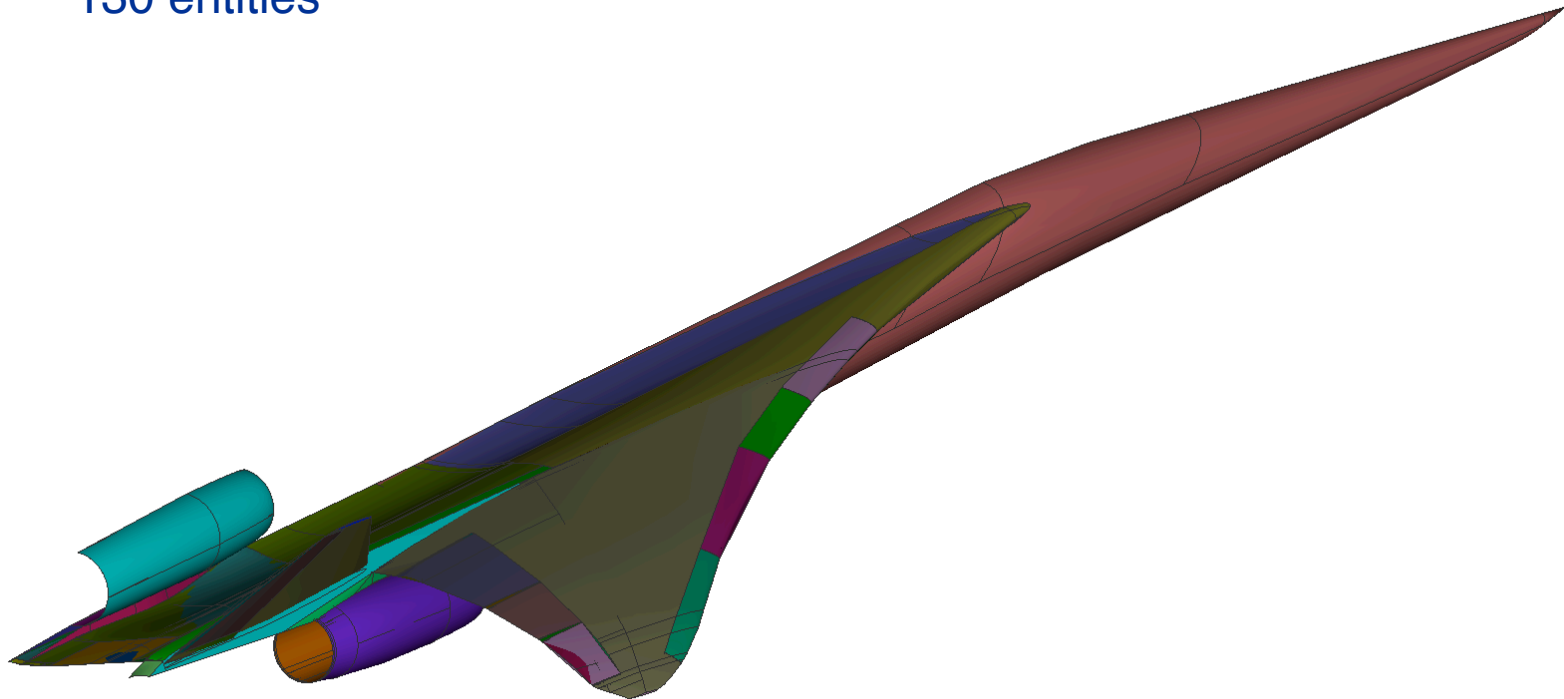
295 entities





N+2 Surface Definition (cont.)

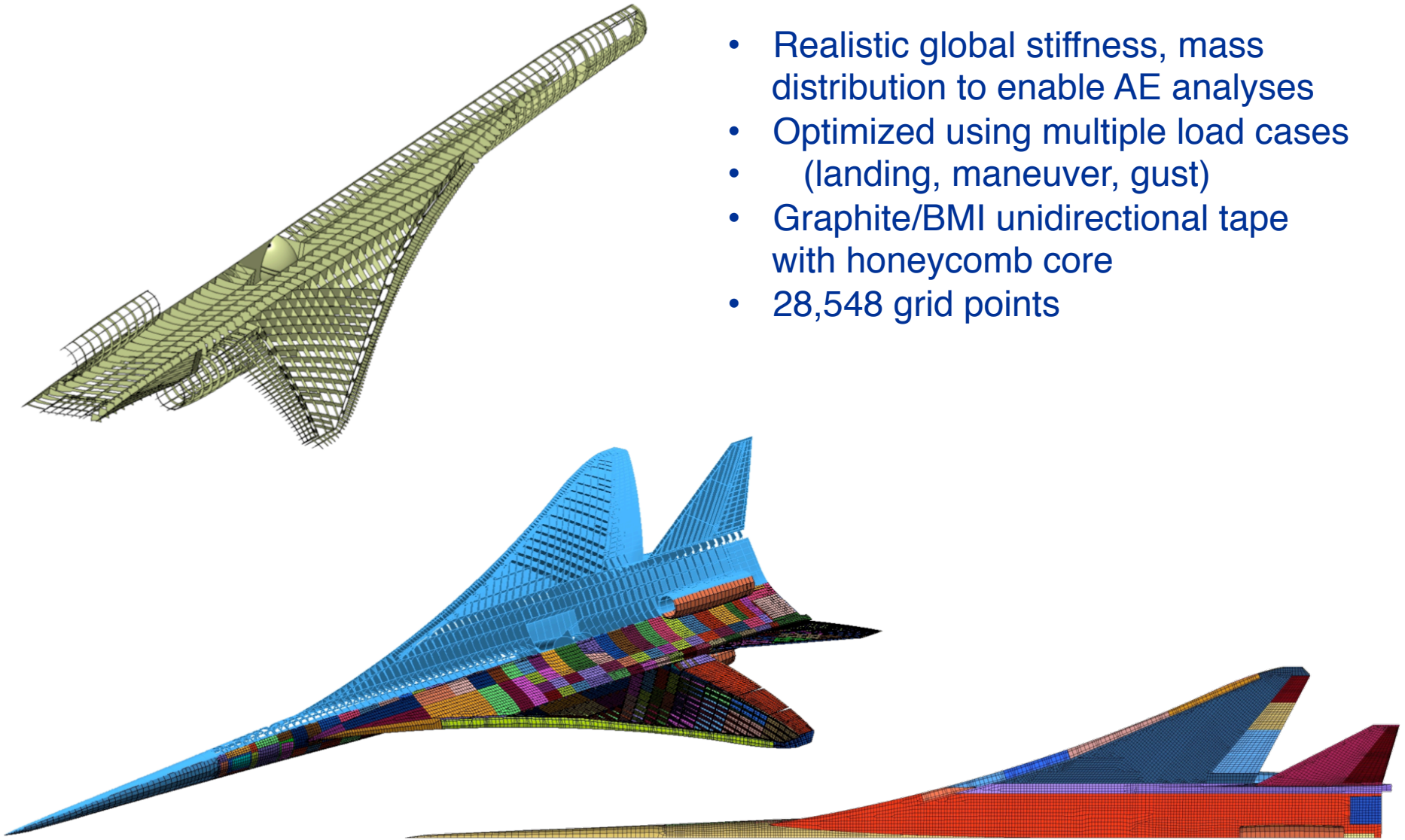
130 entities





N+2 Finite Element Model

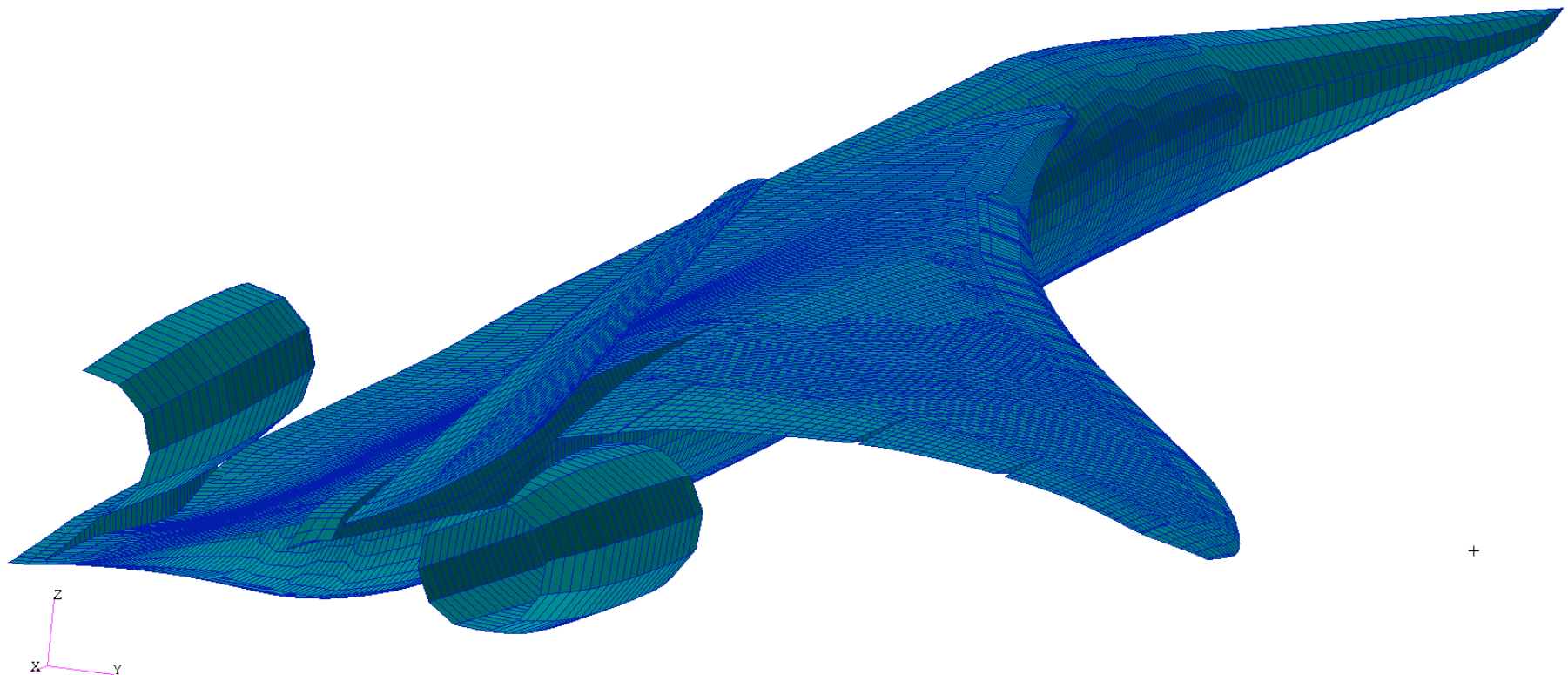
- Realistic global stiffness, mass distribution to enable AE analyses
- Optimized using multiple load cases (landing, maneuver, gust)
- Graphite/BMI unidirectional tape with honeycomb core
- 28,548 grid points





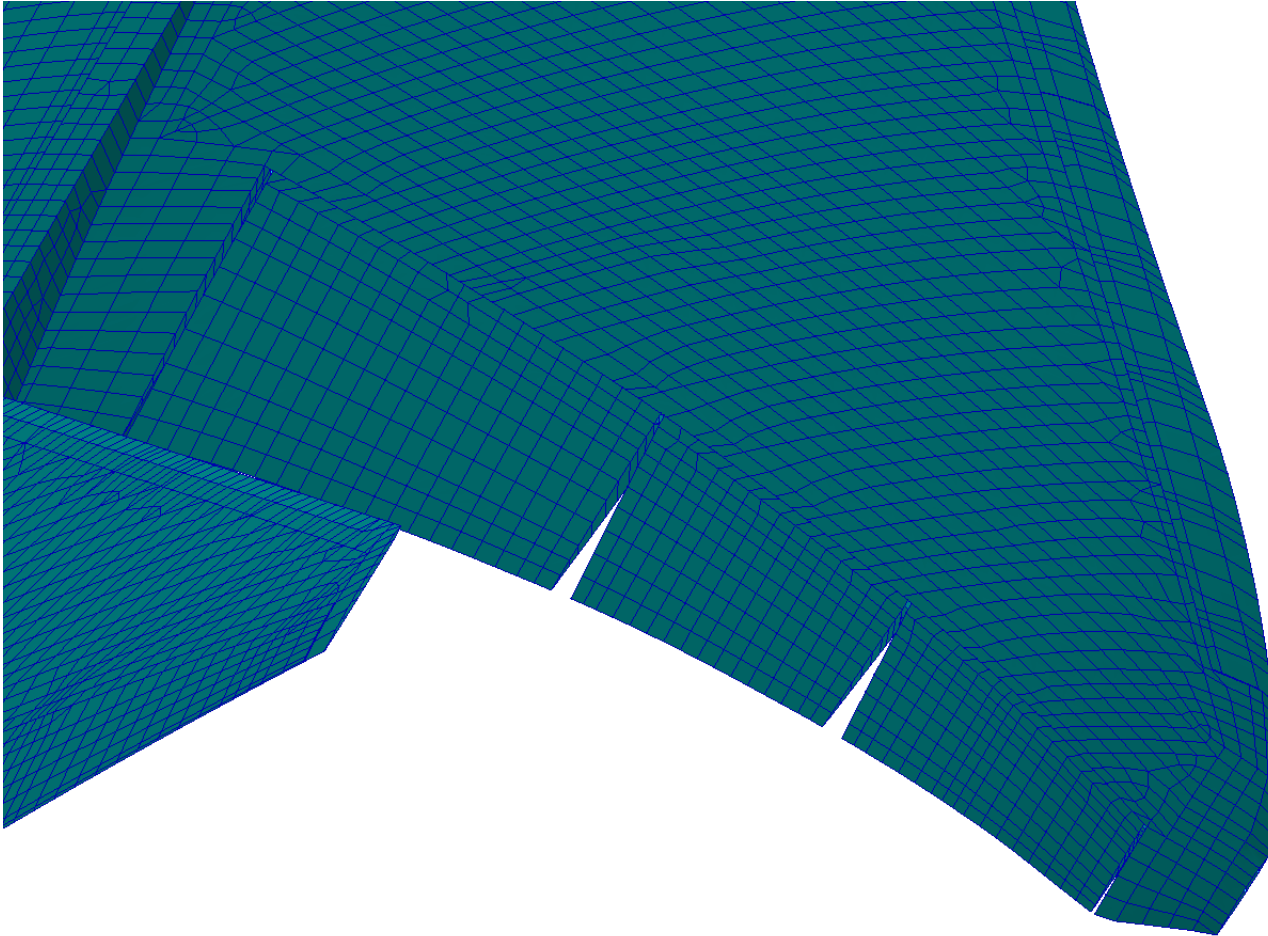
N+2 Finite Element Model Outer Mold Lines

- CAE analysis associated with the FEM Outer Mold Lines (OML)
- Modal deflections interpolated from the FEM to the CFD surface grid





Detail of FEM Outer Mold Lines



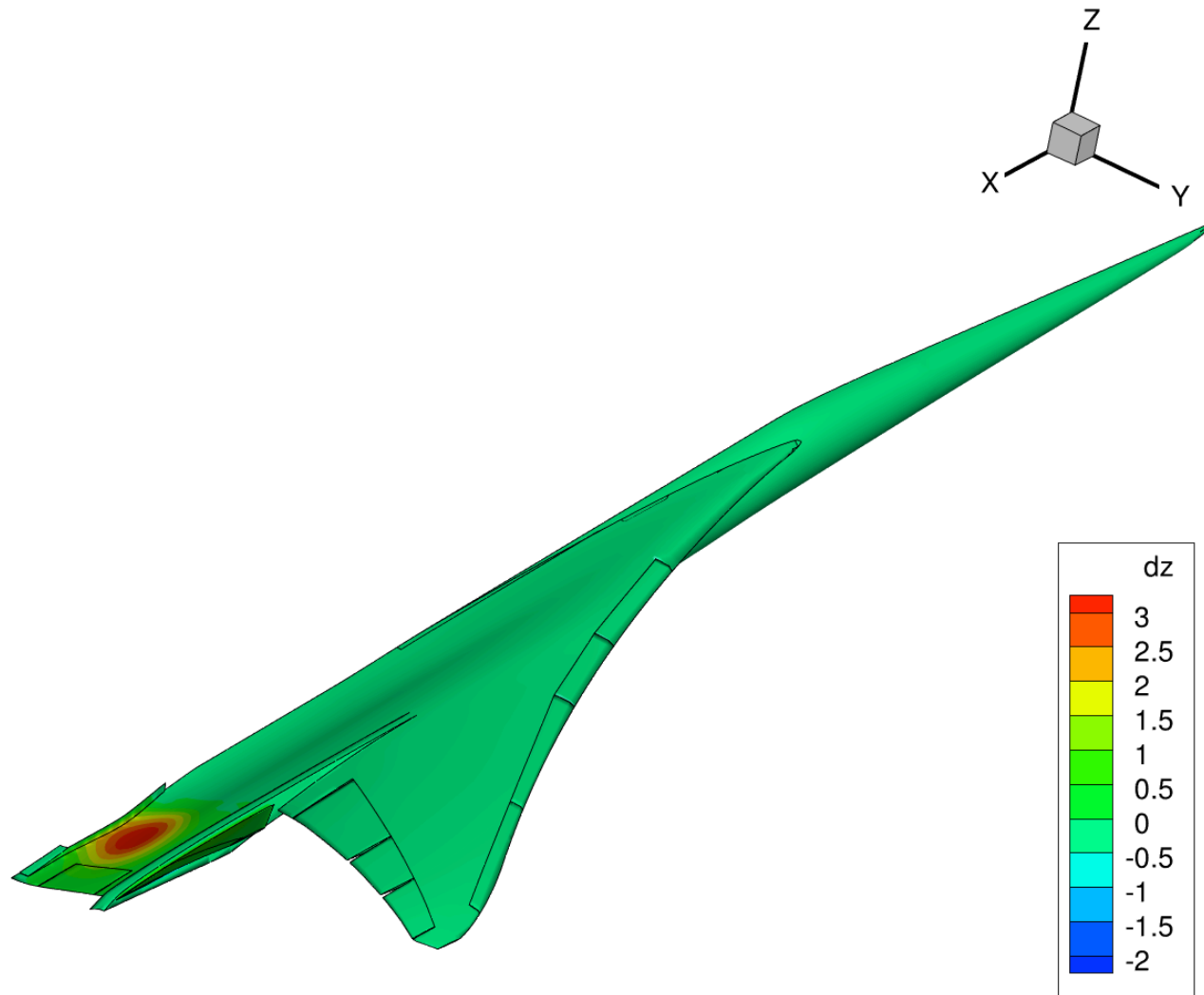


CFD Surface Grid Morphing

- Lockheed Martin performed multiple sizing analyses as the FEM was developed
- One sizing study resulted in the thickening of several areas on the configuration
 - Upper surface of rear fuselage deck
 - Tail
 - Fuselage/lower deck intersection
- Changes in the OML were documented for the FEM, but a new CAD surface definition was not provided.
- Changes in the FEM OML expressed as deflections of the OML nodes

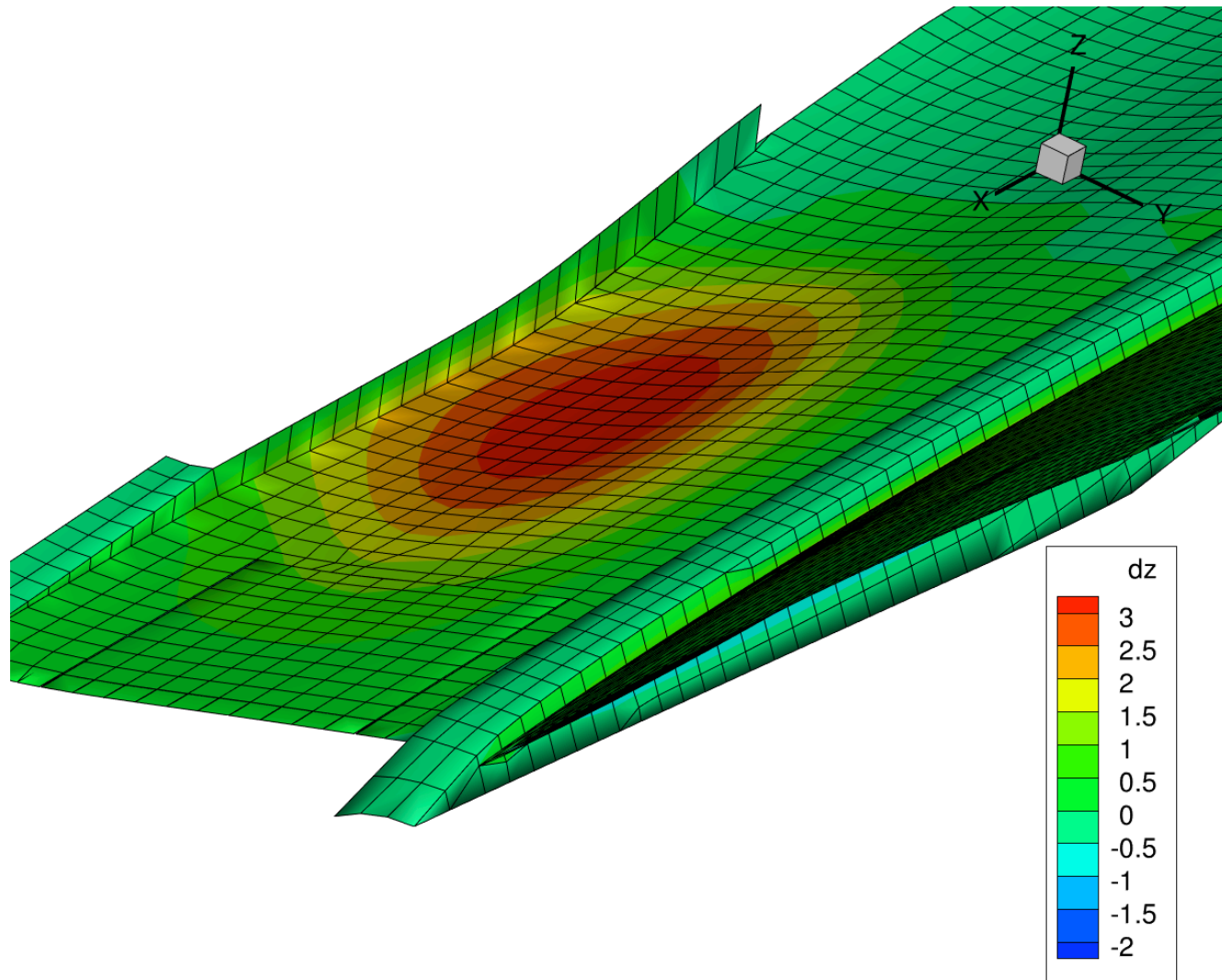


Fuselage Upper Deck Modifications



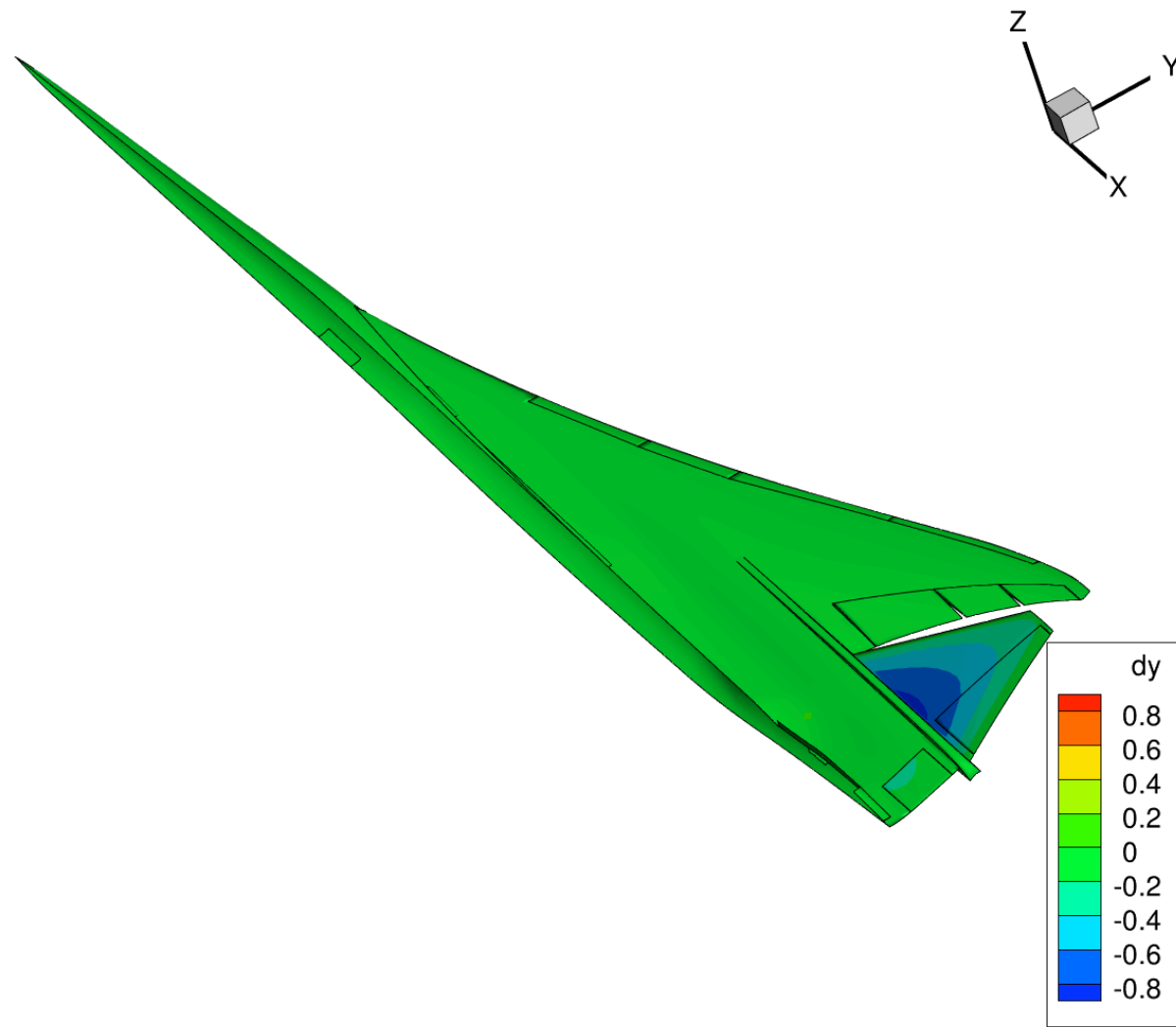


Detail of Fuselage Upper Deck Modifications



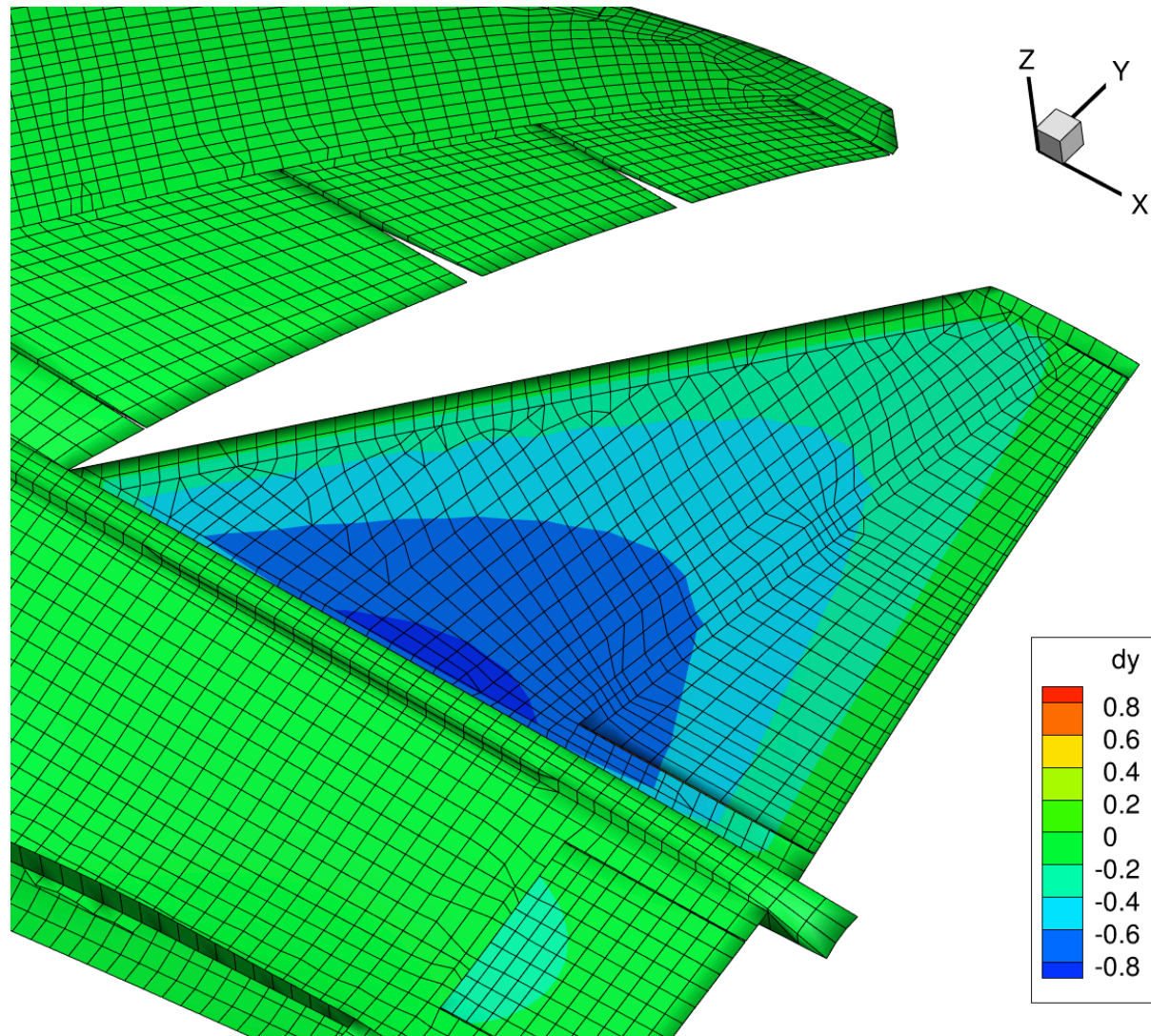


Tail Modifications



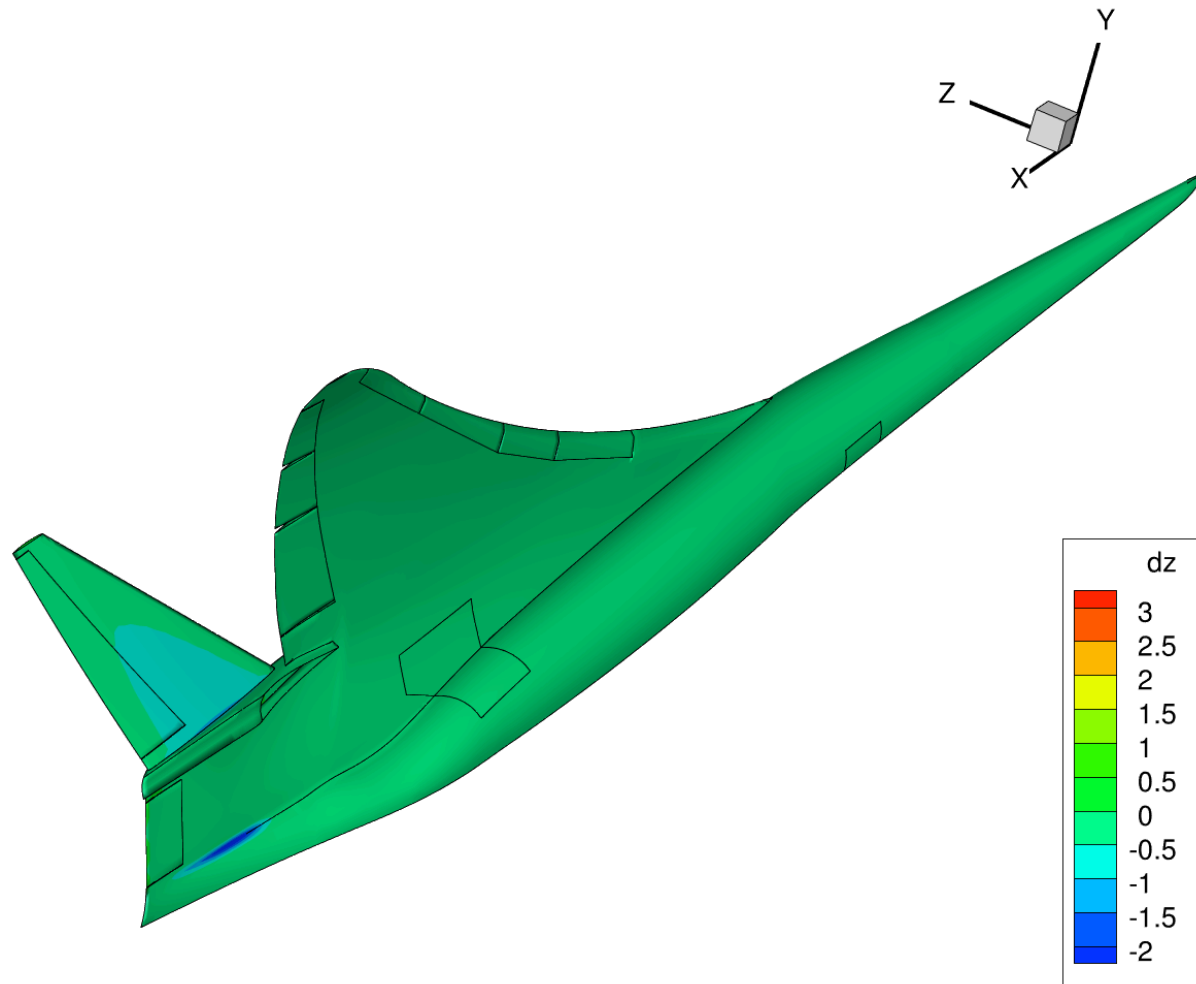


Detail of Tail Modifications



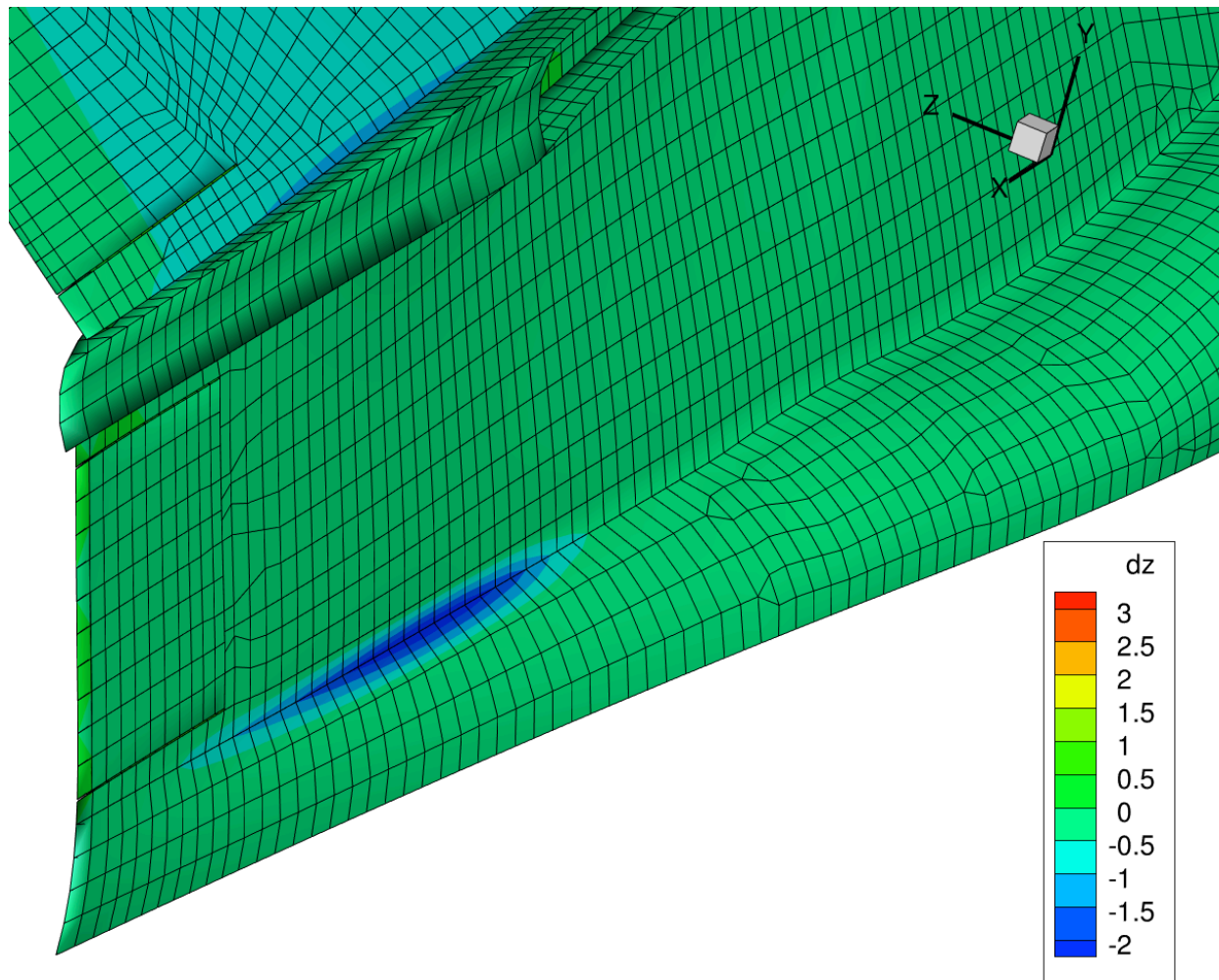


Fuselage Seam Modifications





Detail of Fuselage Seam Modifications



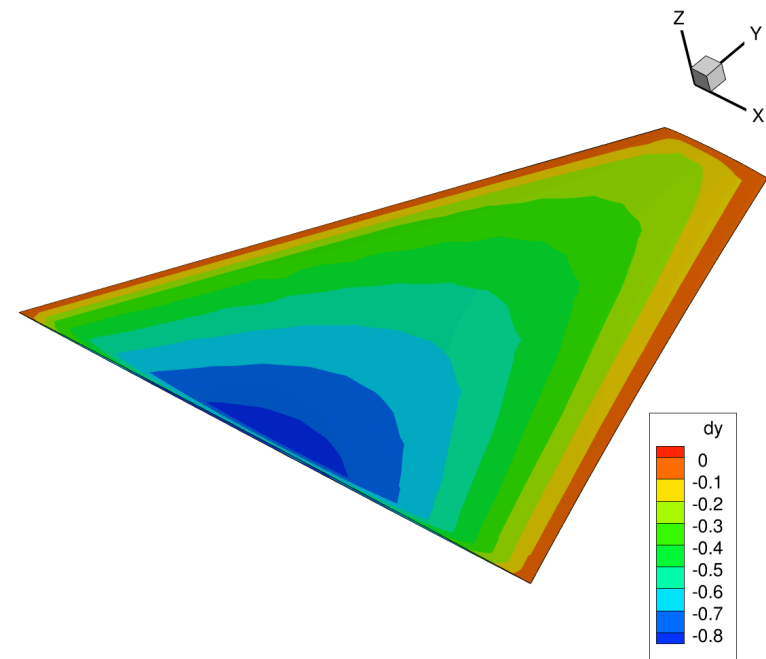
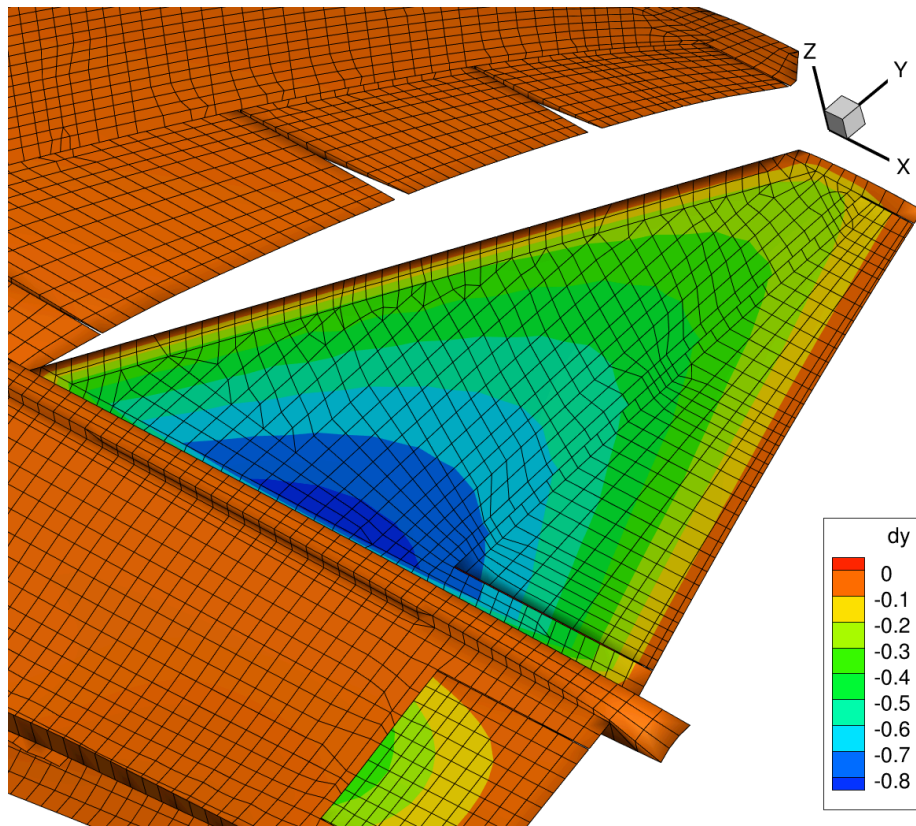


CFD Surface Definition Morphing Procedure

- Changes in FEM expressed as deflections of surface nodes
- Same format as modal deflection from FEM analysis
- Interpolation utility used for interpolating modal deflections can be used to interpolate surface node deflections onto the CFD surface definition
 - CFD surface definition exported as very high resolution structured surface grids
 - Surface node deflections interpolated from FEM to the surface grids
 - Modified surface grids created by adding the deflections to the original definitions
 - Surface grids converted back to IGES format and used for the creation of the unstructured CFD grids

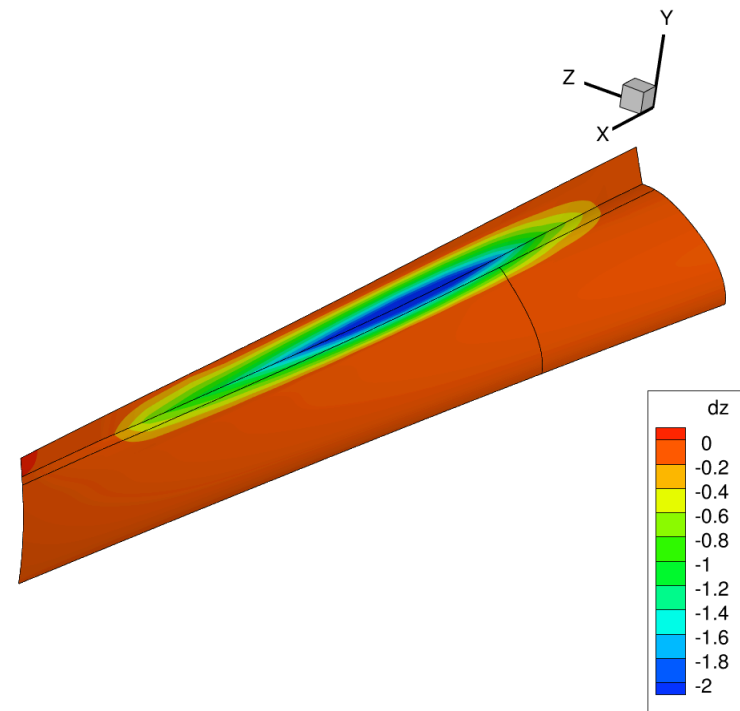
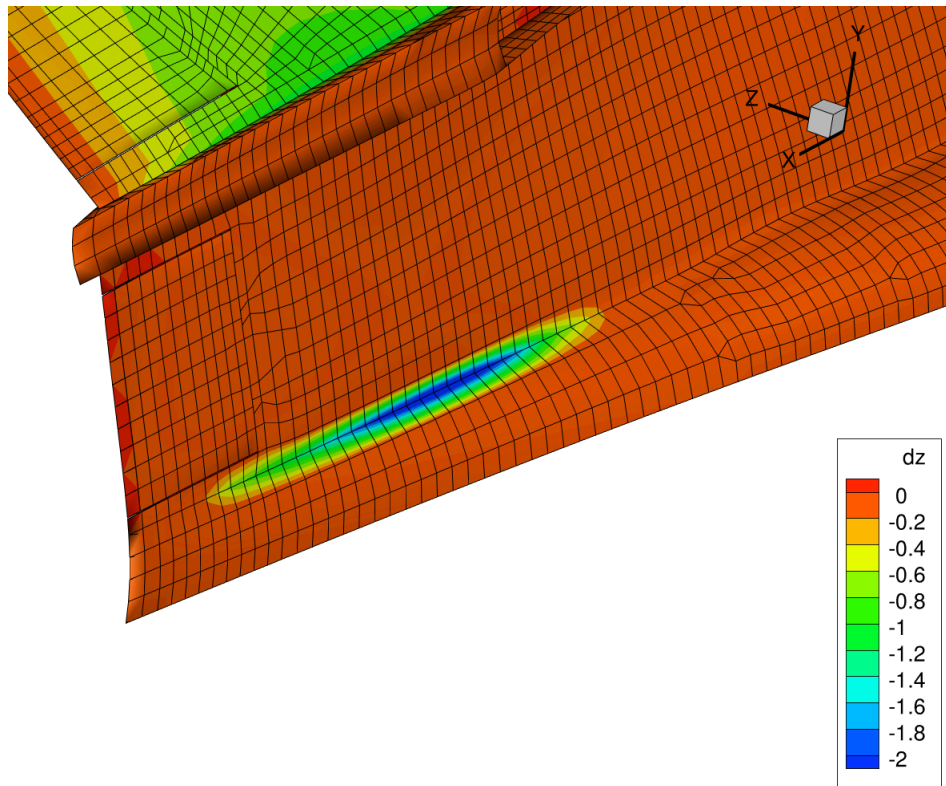


Tail Deflection Interpolation



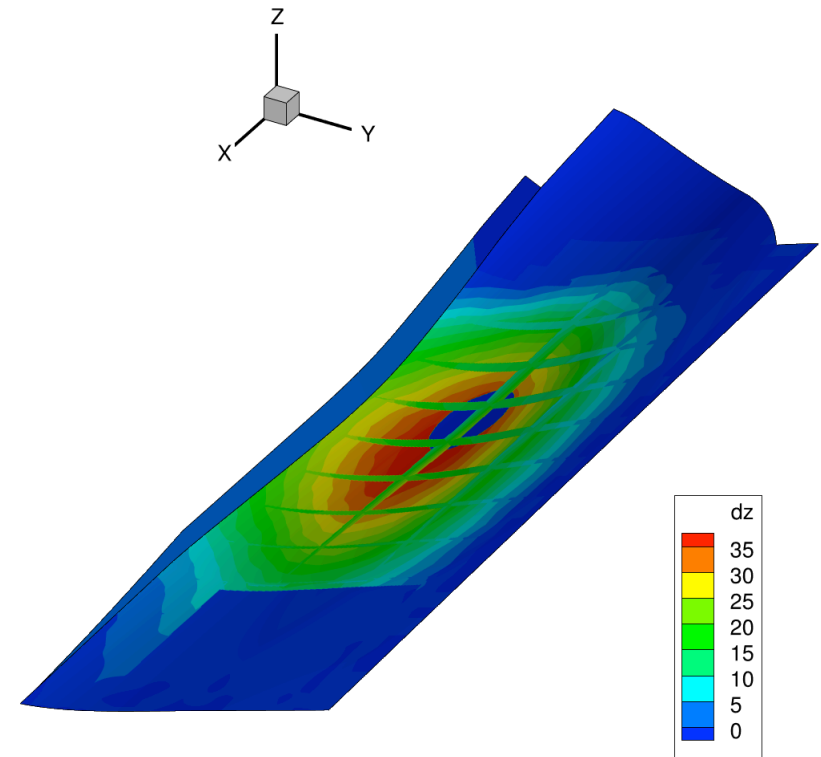
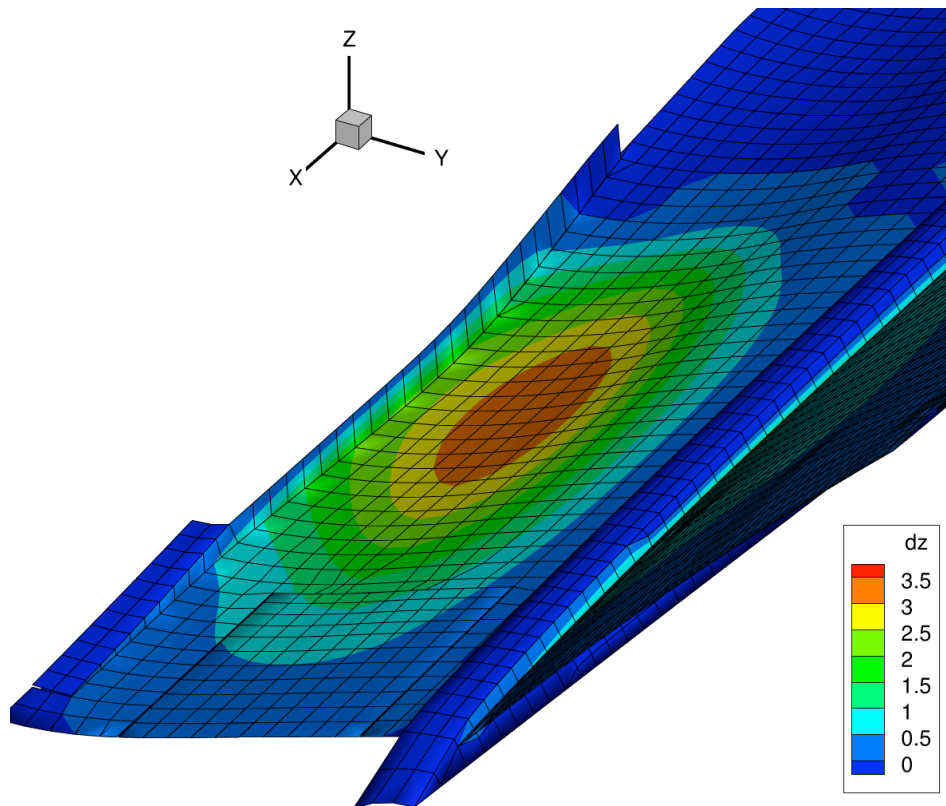


Seam Deflection Interpolation





Deck Deflection Interpolation



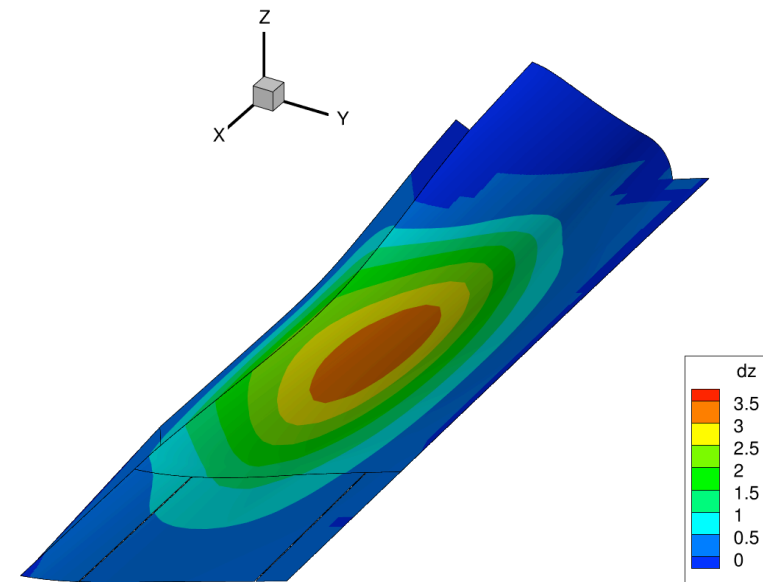
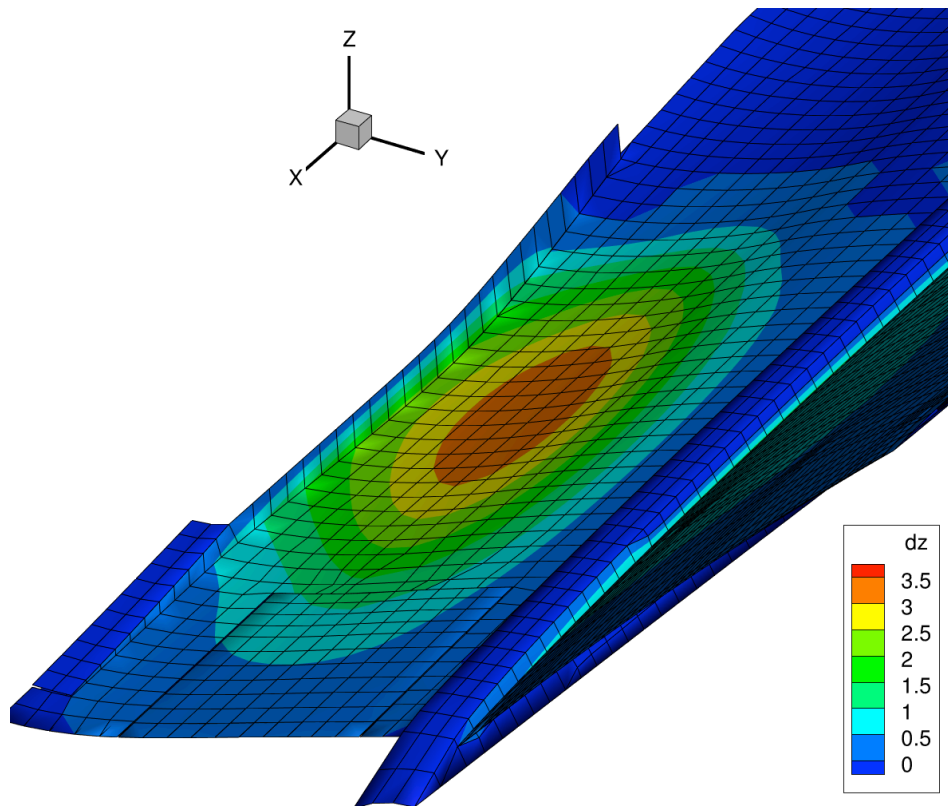


Deck Interpolation Issues

- Internal structure bleeding through to OML
- Solved by creating an FEM mesh containing only OML surface nodes and elements for use as the input to the interpolation utility
- Lower surface bleeding through to the upper surface
- Solved by breaking the surface node input mesh into upper and lower surfaces



Final Deck Deflection Interpolation





CFD Grid Generation

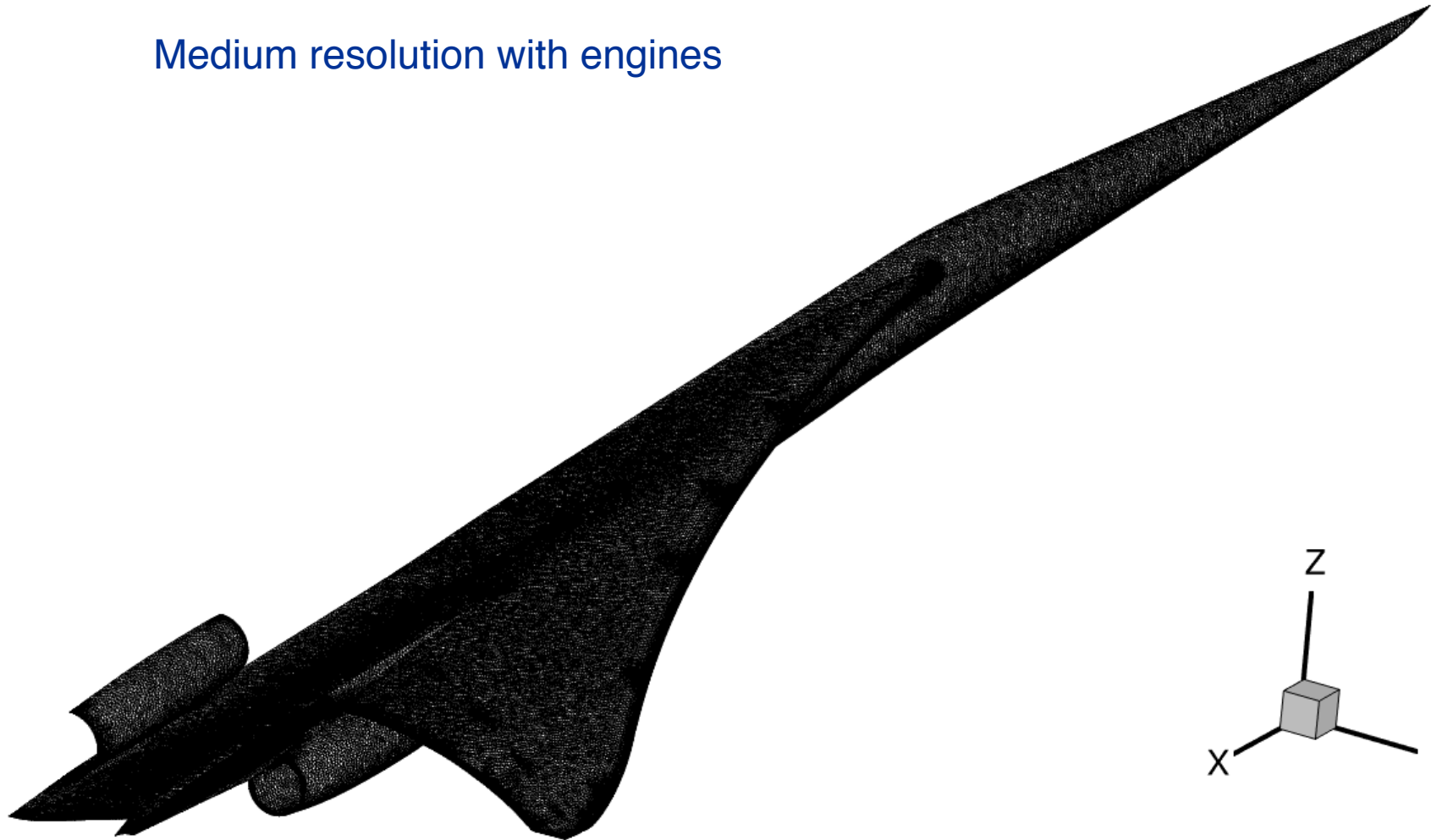
- Unstructured grids generated using Pointwise
- With and without engines
- Inviscid and viscous normal spacing
- Fine (ds = 3 in) and Medium (ds = 6 in) surface resolution
- Control surface gaps faired over

With Engines	Grid Points (Millions)	Tetrahedra (Millions)	Without Engines	Grid Points (Millions)	Tetrahedra (Millions)
Fine Inviscid	2.17	12.10	Fine Inviscid	1.91	10.40
Fine Viscous, dn=0.02	7.74	45.32	Fine Viscous, dn=0.02	6.77	39.44
Fine Viscous, dn=-0.002	8.88	52.08	Fine Viscous, dn=-0.002	7.67	44.76
Medium Inviscid	0.99	5.59	Medium Inviscid	0.99	0.90
Medium Viscous, dn=0.02	2.67	15.56	Medium Viscous, dn=0.02	2.67	13.61
Medium Viscous, dn=-0.002	2.85	16.64	Medium Viscous, dn=-0.002	2.85	14.35



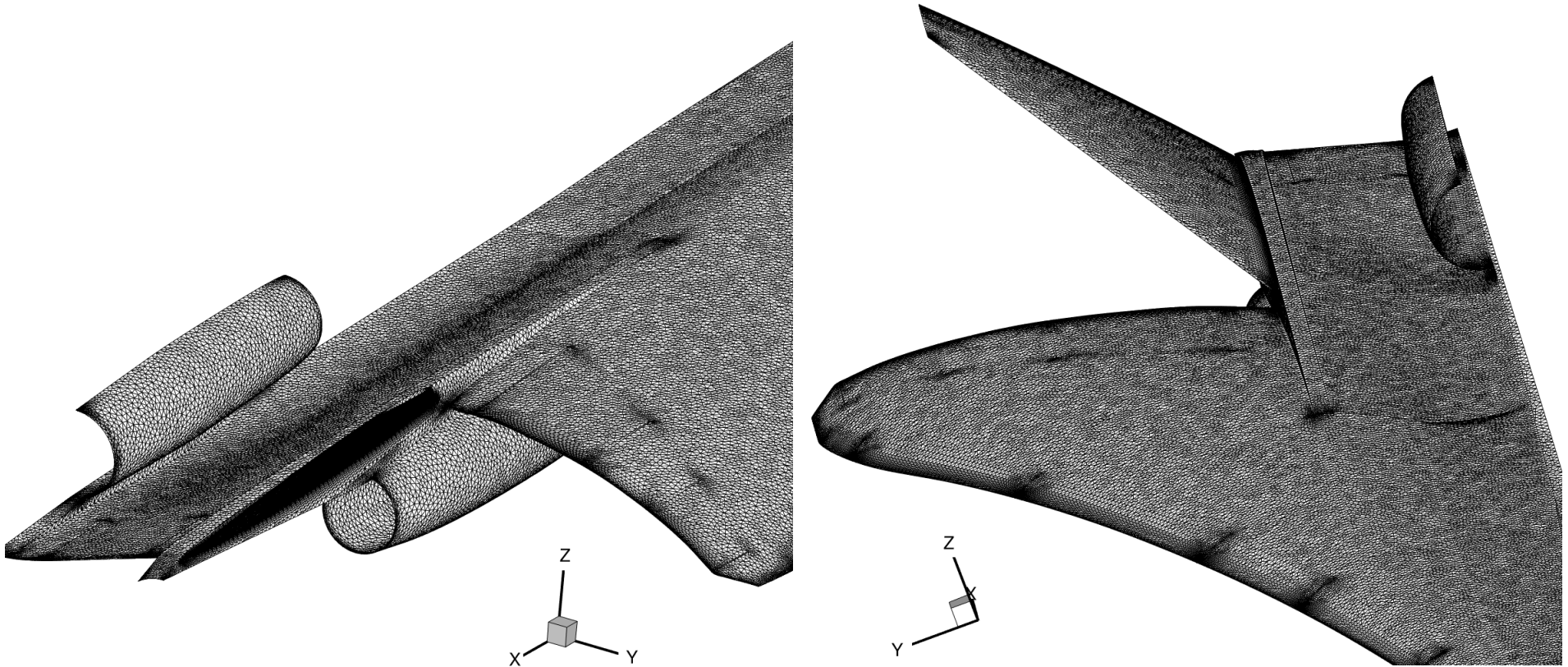
CFD Surface Grid

Medium resolution with engines



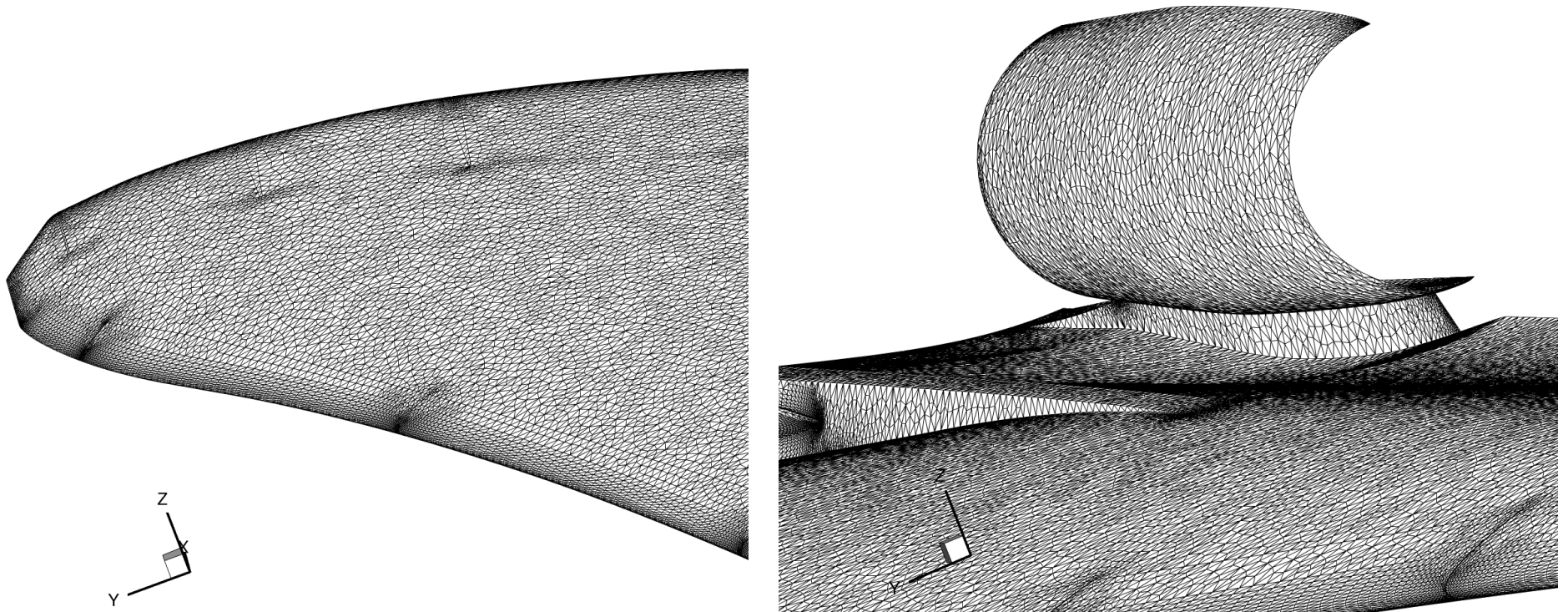


Surface Grid Detail





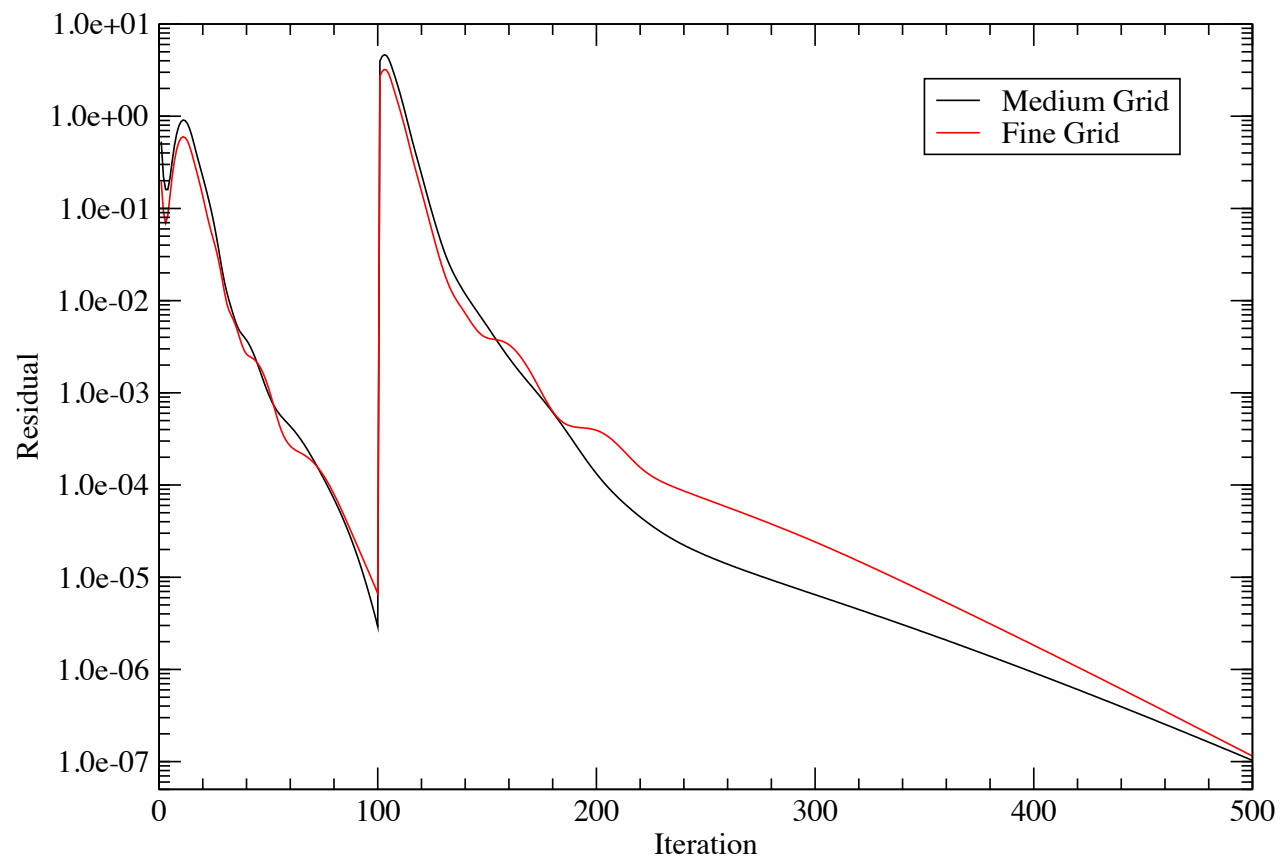
Surface Grid Detail (cont.)





Residual History

Inviscid With Engines, Mach = 1.70, $\alpha = 2.1$ degrees

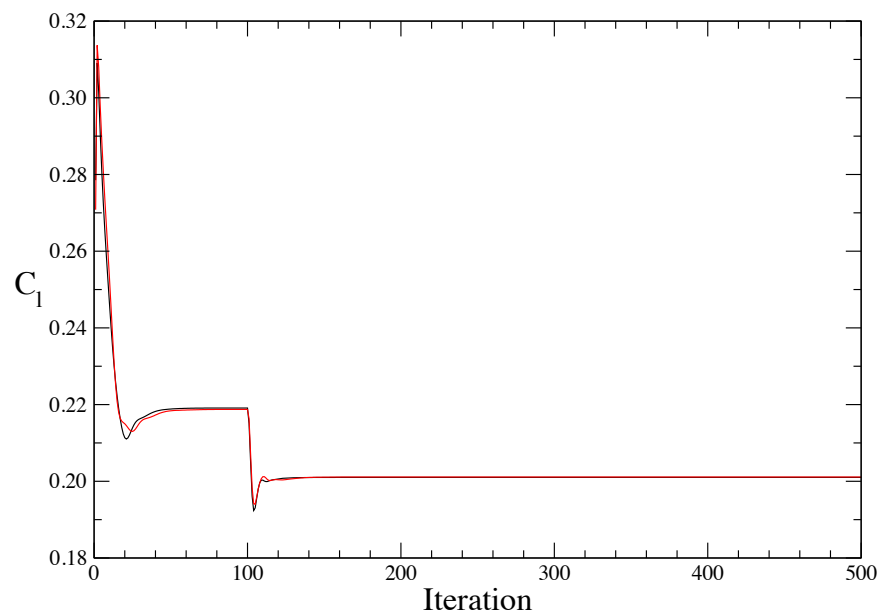




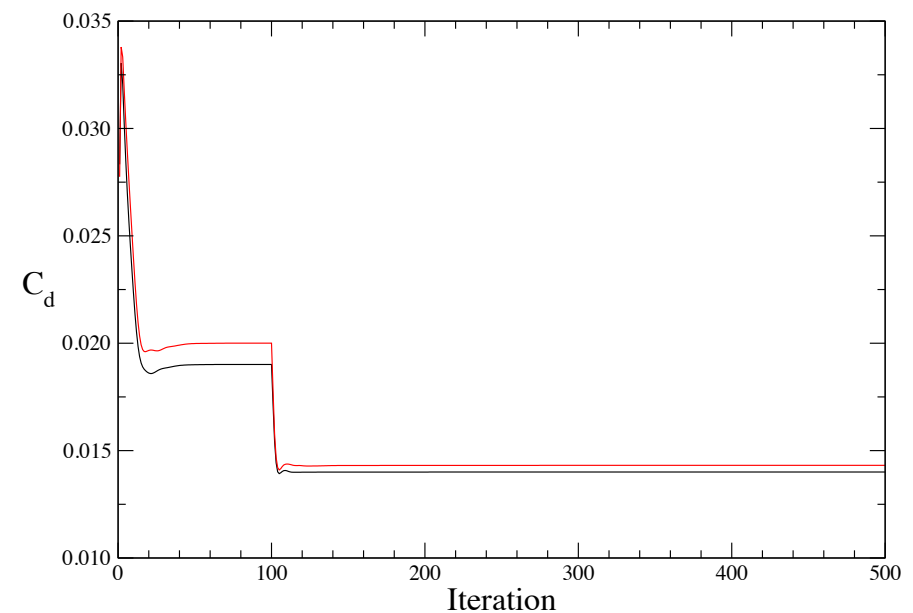
Force History

Inviscid With Engines, Mach = 1.70, $\alpha = 2.1$ degrees

Lift



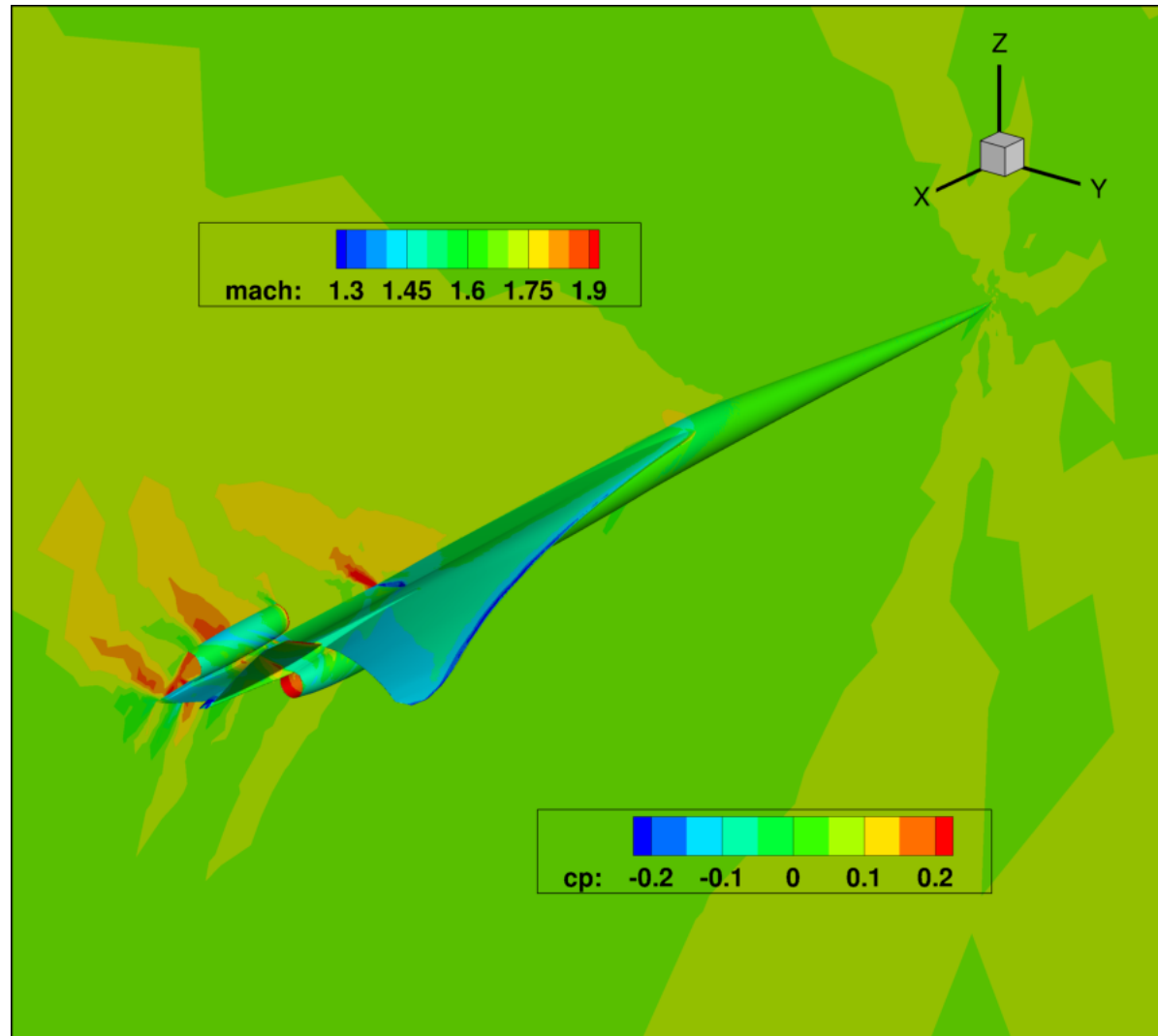
Drag





Pressure and Mach Contours

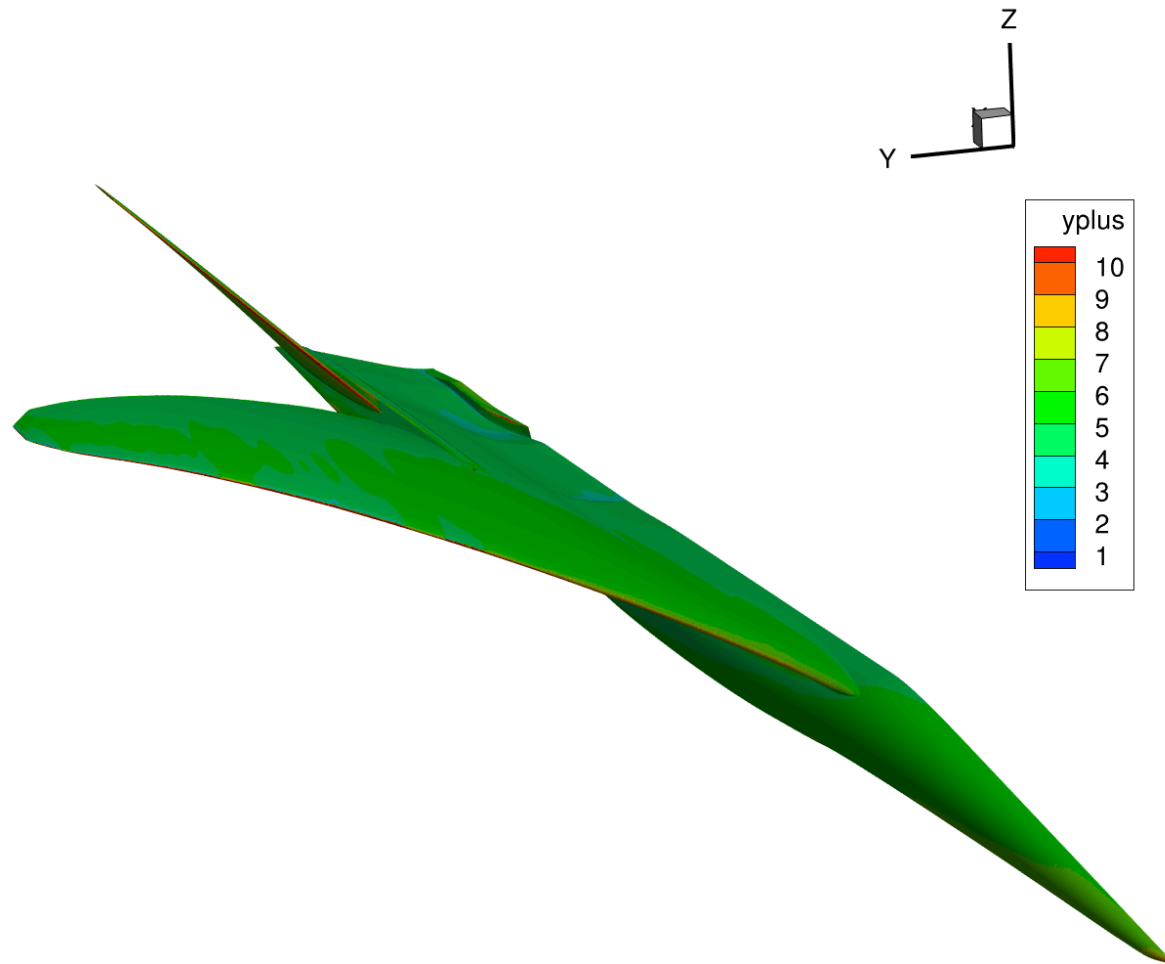
Inviscid Fine Grid, Mach = 1.70, $\alpha = 2.1$ degrees





y+ Contours

Viscous Fine Grid, Mach = 1.70, $\alpha = 2.1$ deg. $Re = 1.66 \times 10^5/in.$





Current Work

- Adjustment of the CFD surface grid to improve grid quality
- Viscous grid normal spacing study
- Interpolation of mode shapes to the CFD surface grid
- Generation of test condition matrix



Future Challenges

- Rigid body modes will require trimming of the configuration using multiple control surfaces
- Control surface gaps and deflections
- Static aeroelastic solutions for use in sonic boom analyses
- Full dynamic aeroelastic analyses (flutter)
- Improved engine definition to include realistic inlet and nozzle



Concluding Remarks

- Preliminary work needed for CAE analysis has been completed
- Sample steady-rigid computations have been completed
- Setup for static and dynamic aeroelastic analyses is progressing
- Pieces are in place to begin detailed CAE analyses throughout the flight regime