DPW-8 & AePW-4

Static Deformation Working Group

February 21, 2025

dpwaiaa@gmail.com

Administrative Information

- **Meeting schedule**
  - Third Friday of the month; 10:00 Eastern Time (will adjust with US Daylight Saving Time)
- **For questions about the working group, please email** dpwaiaa@gmail.com
- **Websites**
  - Static Deformation Working Group website
    https://aiaa-dpw.larc.nasa.gov/WorkingGroups/Group2/group2.html
  - Geometry/Grid websites
    https://aiaa-dpw.larc.nasa.gov/geometry.html
    https://aiaa-dpw.larc.nasa.gov/grids.html
  - Postprocessing website (including ONERA OAT15A experimental results)
    https://aiaa-dpw.larc.nasa.gov/postprocessing.html
  - Large File Upload
    https://nasagov.app.box.com/f/fd164563283b4e85857d1a0975b0b363

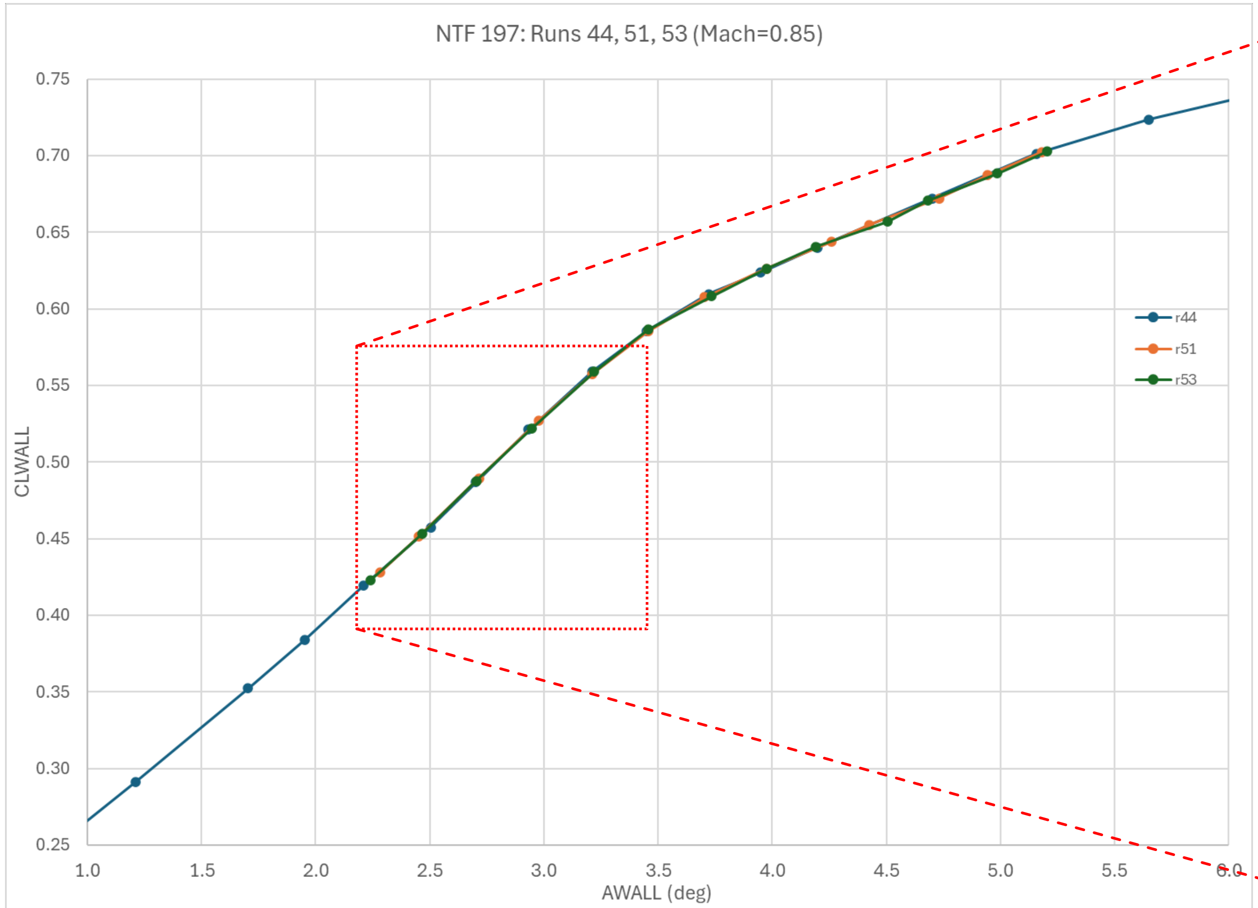
Agenda

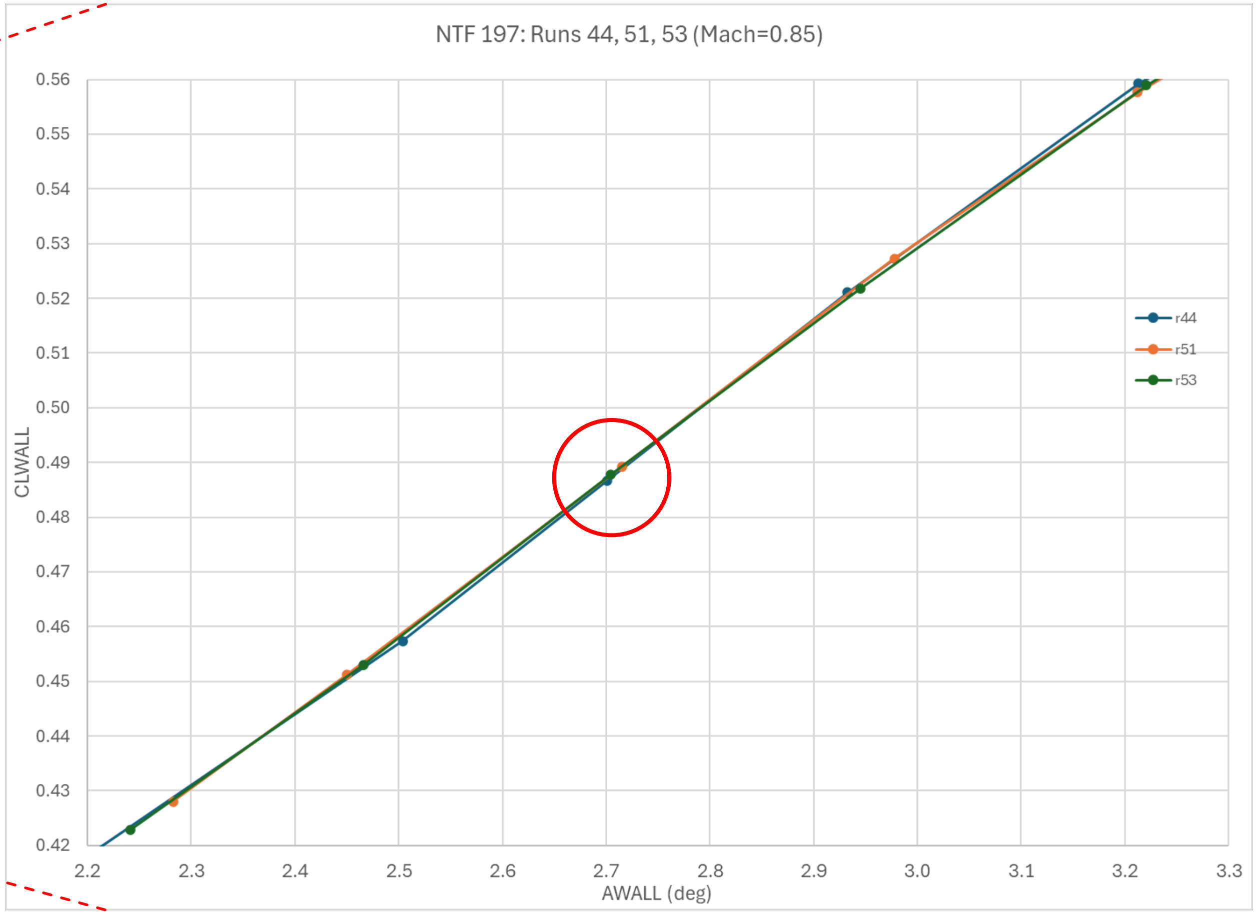
- **NASA CRM Wing/Body Grid Family Status**
  - Grids will be uploaded next week (airplane scale | model scale = 2.7%)
  - https://dpw.larc.nasa.gov/DPW8
    - Static_Deformation/Test_Case_2/Cadence_Grids.REV00
    - Static_Deformation/Test_Case_2/Helden_Grids.REV00
    - Static_Deformation/Test_Case_2/Ames_Grids.REV00
- **Structural Model Creation Status**
  - Half-span FEM
  - Equivalent Beam Model
- **Bret Stanford: Initial aeroelastic simulations with in-house vortex lattice code**
  - Mach 0.85, AoA 3 deg, Qinf 1384 psf
- **Case 2a Discussion**

Test Case 2a: Wing/Body Deformation

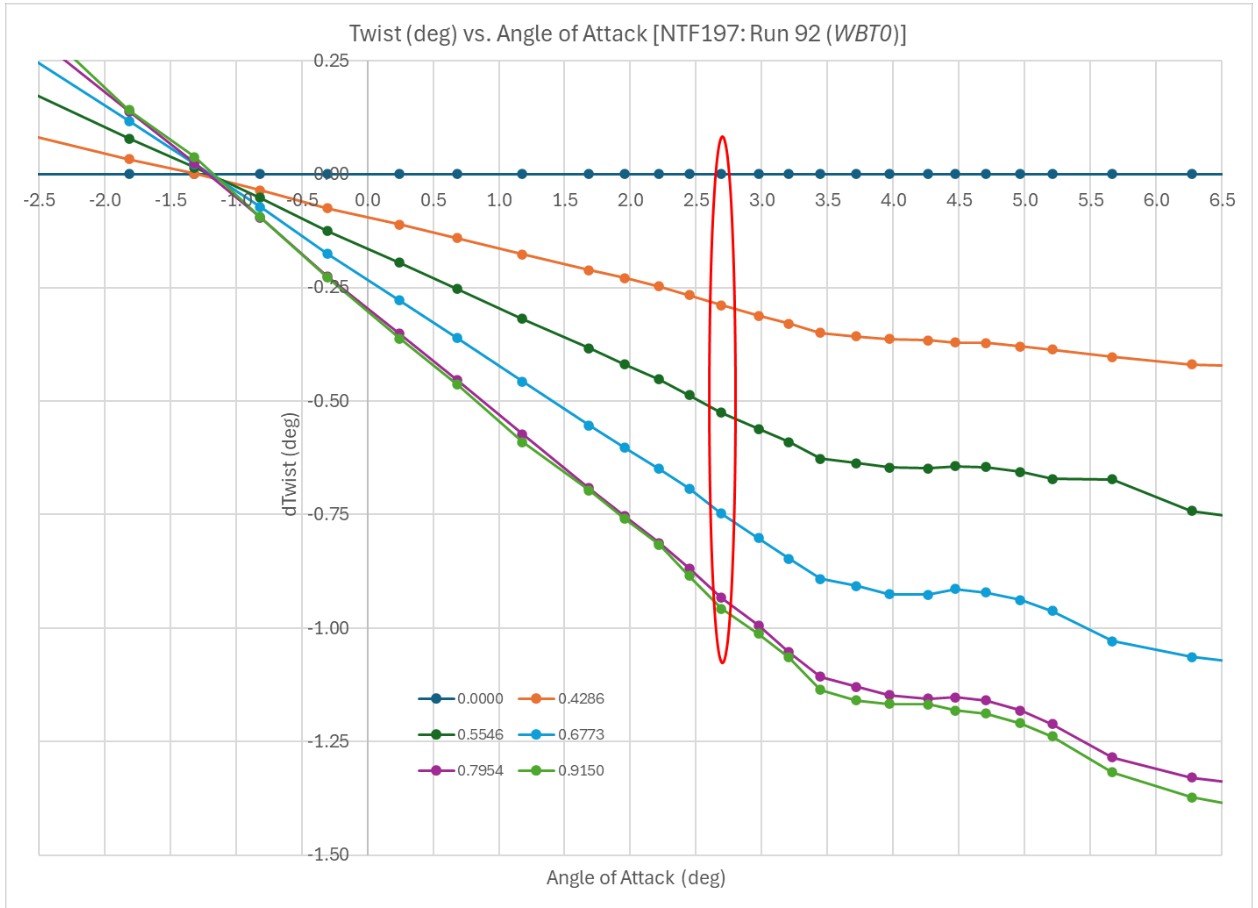
- **CFD/FEM start from unloaded (wind-off) geometry/grid**
- **CRM Wing/Body**
  - Reynolds numbers: 5M (LoQ)
  - Mach Number: 0.85
  - Angle of Attack: 2.70 deg (CL~0.49)
- **Committee-supplied**
  - NASA CRM geometry in jig/unloaded condition
    - Trip location, if tested (optional to use)
  - MSC NASTRAN® finite-element model of the NASA CRM
  - Grid Family (L1:**T**iny/L2:**C**oarse/L3:**M**edium/L4:**F**ine/L5:e**X**tra-fine/L6:**U**ltra-fine)
- **Comparison metrics**
  - Forces / Moments
  - Sectional Twist / Deformation
  - Sectional C_P distribution

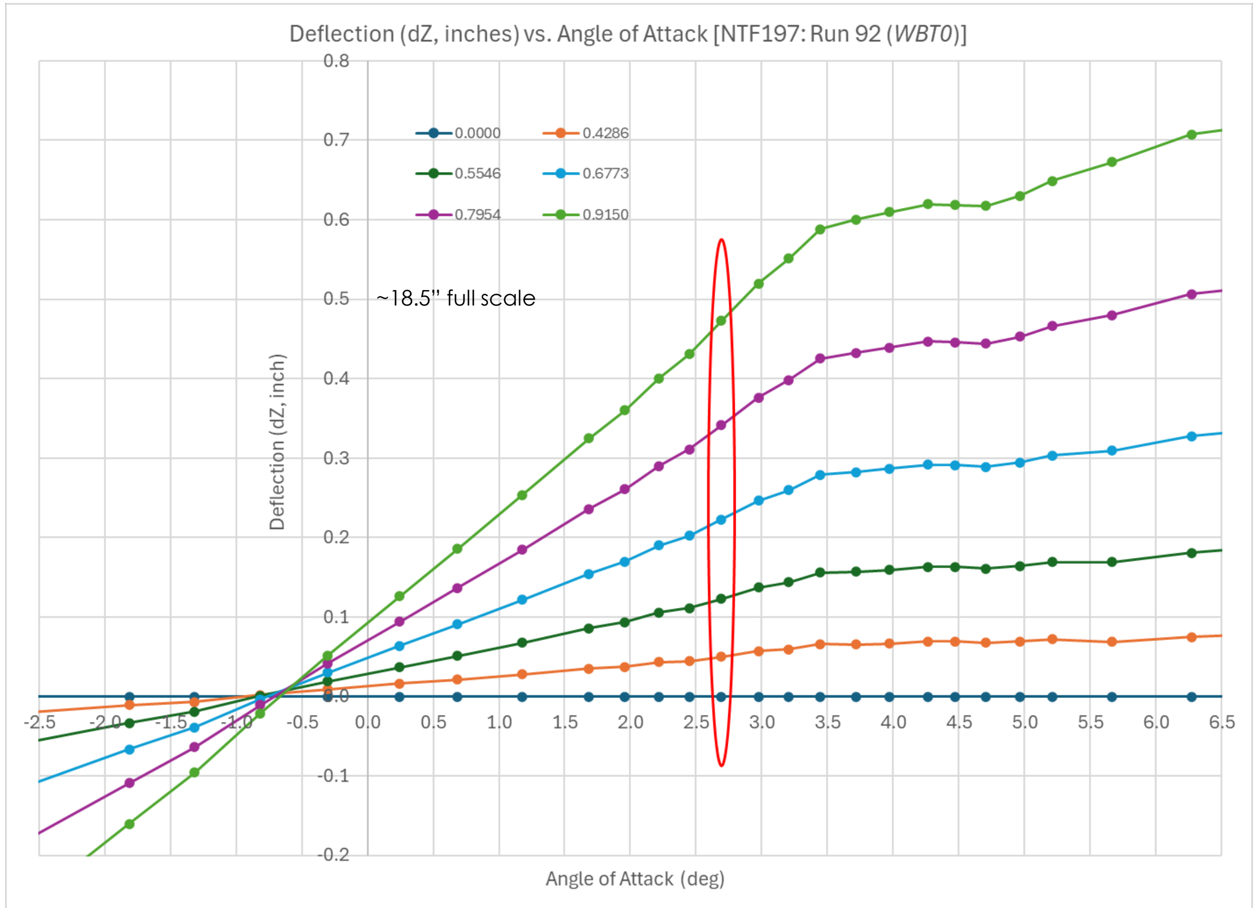
NTF197: Wing/Body [Rey=5M, M=0.85]





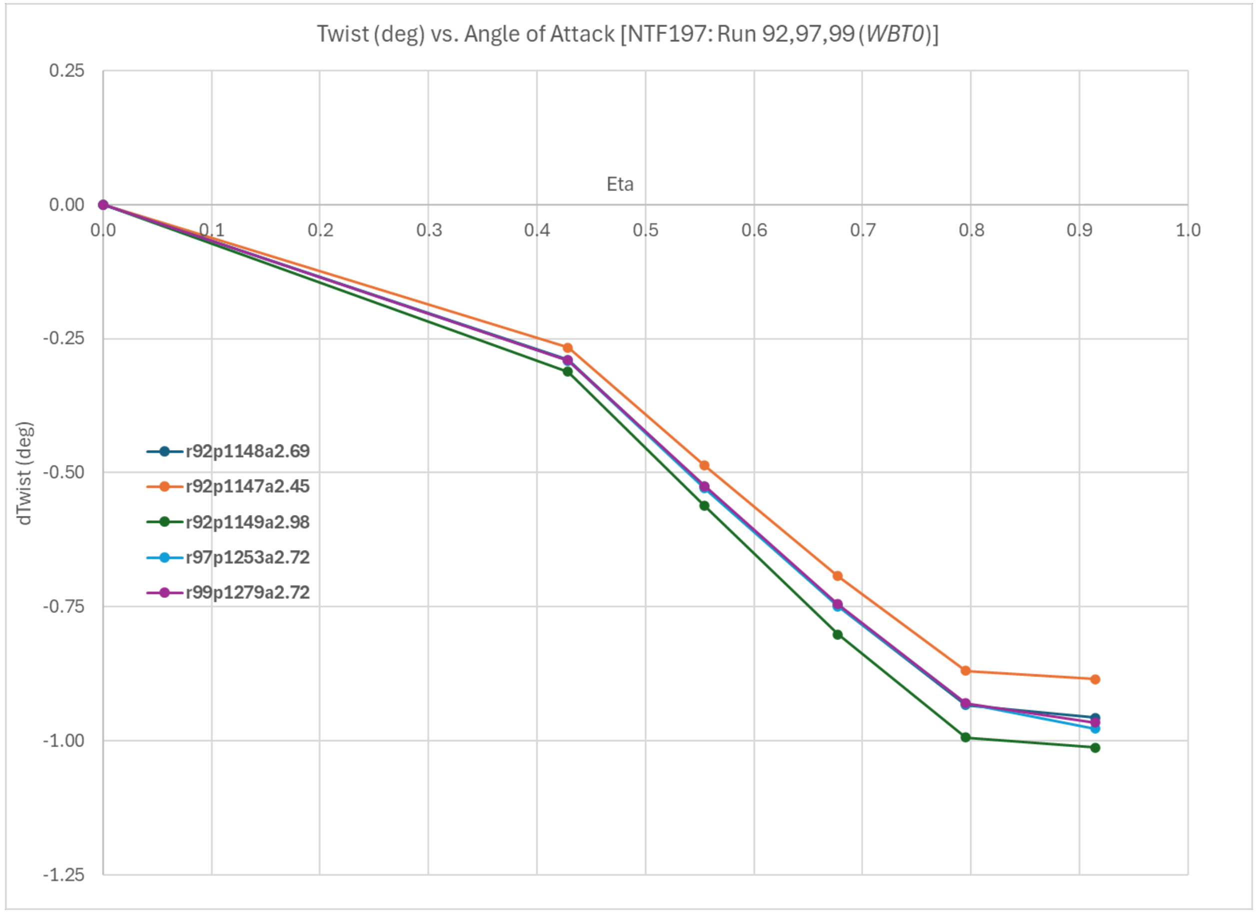
NTF197: Twist & Deformation (ΔZ)

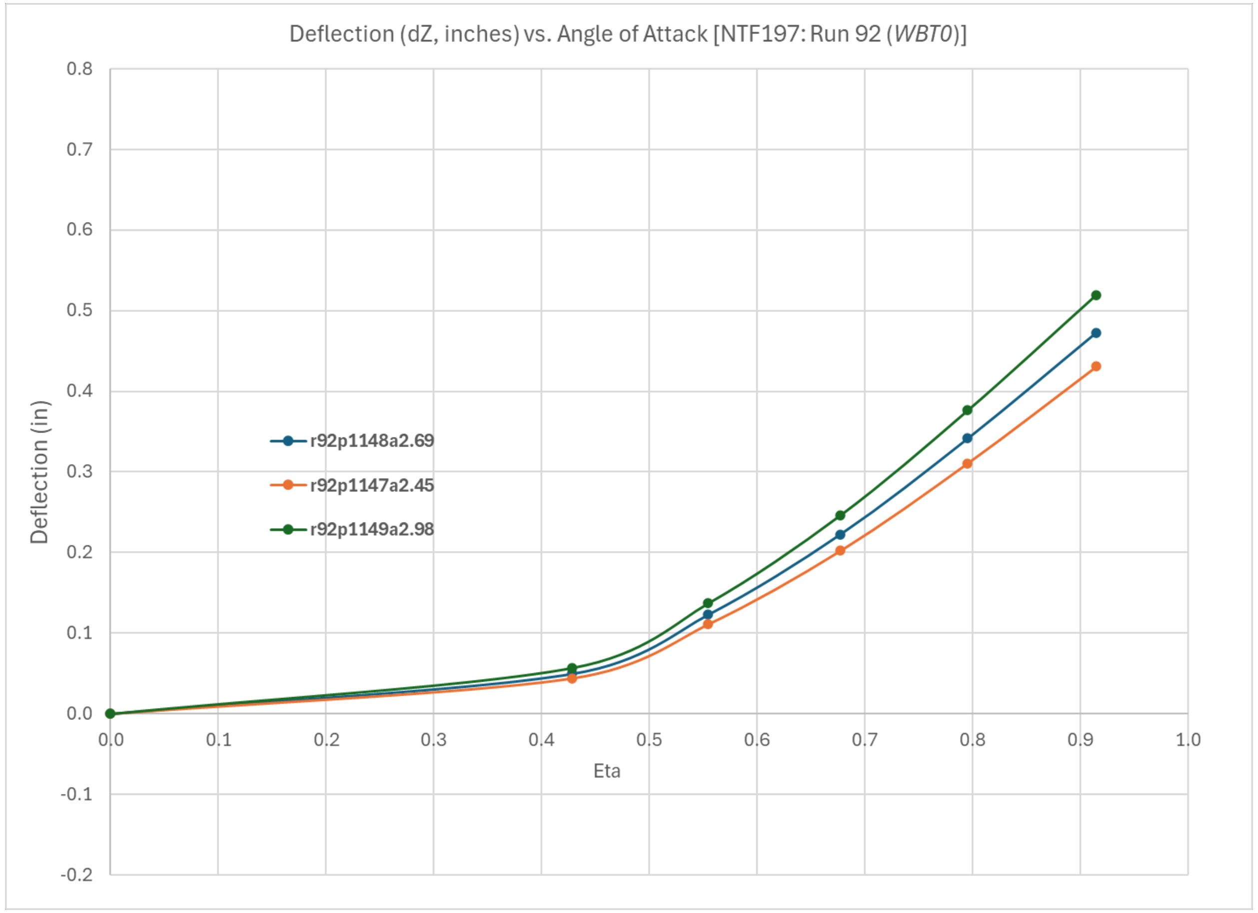




Note: Data shown is for Wing/Body/Tail=0 Configuration

NTF197: Twist & Deformation (ΔZ)

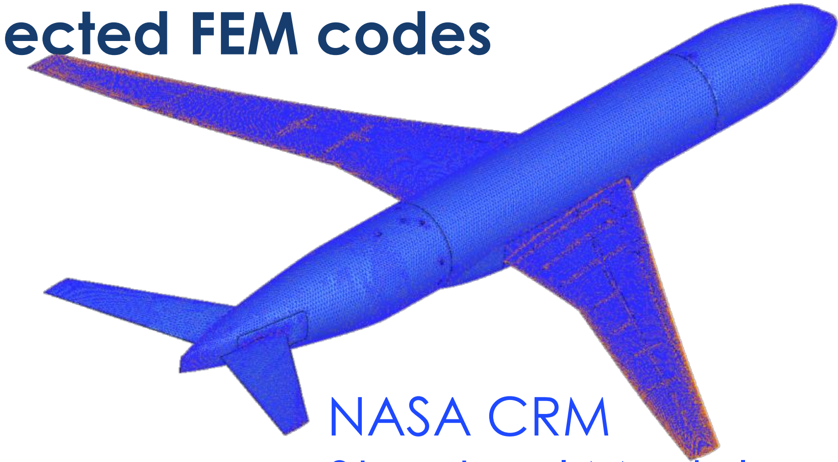




Note: Data shown is for Wing/Body/Tail=0 Configuration

Test Case 1b: FEM Validation

- **Validation of Structural Model for NASA CRM**
  - Tap Test planned for comparison to normal mode solutions of FEM models
  - Static Loads Tests will be conducted to compare deflection measurements (and maybe twist) to Linear Static FEM solutions
- **Users are encouraged to employ best practices for selected FEM codes**
- **Settings**
  - Linear Eigenvalue Analysis (e.g. NASTRAN® SOL103)
- **Conditions**
  - Rigid suspension at sting
- **Grid**
  - MSC NASTRAN® solid 4-node tetrahedral finite-element structural model
  - Model consists of $6.8 \cdot 10^6$ elements, $4.1 \cdot 10^6$ degrees-of-freedom
  - Supplied by NASA Langley's Configuration Aerodynamics Branch
  - Wind tunnel sting will be added as beam model



NASA CRM Structural Model

Test Case 2b: Wing/Body Deformation (polar)

- **CFD/FEM start from unloaded (wind-off) geometry/grid**
- **CRM Wing/Body**
  - Available Reynolds numbers: 5M (LoQ), 20M (LoQ), 20M (HiQ), 30M (HiQ)
  - Range of Mach numbers: 0.70, 0.85, 0.87 (Mcruise = 0.85)
  - Range of Angles of attack: -3.0 – 12.0 deg (AOAcruise ~ 2.75-3.00 deg)
- **Committee-supplied**
  - NASA CRM geometry in jig/unloaded condition
    - Trip location, if tested (optional to use)
  - MSC NASTRAN® finite-element model of the NASA CRM
  - Grid Family (L1:**T**iny/L2:**C**oarse/L3:**M**edium/L4:**F**ine/L5:e**X**tra-fine/L6:**U**ltra-fine)
- **Comparison metrics**
  - Forces / Moments
  - Sectional Twist / Deformation
  - Sectional C_P distribution

Test Case 3: Wing/Body/Nacelle/Pylon

- **CFD/FEM start from unloaded (wind-off) geometry/grid**
- **CRM Wing/Body/Nacelle /Pylon**
  - Available Reynolds numbers: 5M (LoQ)
  - Range of Mach numbers: 0.70, 0.85, 0.87 (Mcruise = 0.85)
  - Range of Angles of attack: -3.0 – 12.0 deg (AOAcruise ~ 2.75-3.00 deg)
- **Committee-supplied**
  - NASA CRM geometry in jig/unloaded condition
    - Trip location, if tested (optional to use)
  - MSC NASTRAN® finite-element model of the NASA CRM
  - Grid Family (L1:**T**iny/L2:**C**oarse/L3:**M**edium/L4:**F**ine/L5:e**X**tra-fine/L6:**U**ltra-fine)
- **Comparison metrics**
  - Forces / Moments
  - Sectional Twist / Deformation
  - Sectional C_P distribution

Key Questions: Static Deformation Working Group

- **What level of accuracy can transonic wing deformations be calculated?**
- **What is the uncertainty in configuration force/moments due to aeroelastic deformation uncertainty?**
- **What are the most efficient/accurate methods for coupling the aero/structural computations?**
  - What are the computational time/accuracy savings between using a full fidelity vs reduced beam structural model?
  - Do modal solutions compare well to direct fluid-structure mapping solutions?
  - Does a full vs symmetry plane solution result in different solutions?
- **What accuracy is lost by using a “lower fidelity” aerodynamic?**

Nominal Schedule

- **June, 2024**
  - First Working Group Meeting ✔
  - ONERA OAT15A geometry release ✔
- **July, 2024**
  - ONERA OAT15A grids released ✔
  - AVIATION in-person meeting ✔
- **November, 2024**
  - All workshop virtual meeting (11/8) ✔
- **January, 2025**
  - SciTech Forum: Mini Workshop 1 ✔
  - CRM Grids Available
- **March, 2025**
  - FEM Validation Data released
- **July, 2025**
  - AVIATION in-person meeting
  - (Special Session: ONERA OAT15a?)
- **Summer/Fall, 2025 (?)**
  - Mini Workshop 2
- **January, 2026**
  - SciTech in-person meeting
- **February, 2026**
  - Delivery of final data set (perhaps alternate submissions prior to this date)
- **June, 2026**
  - Workshop in San Diego, CA

Working Group Meeting Cadence

- **Currently set up for 10:00 Eastern time on third Friday of each month**
  - A suitable meeting time is very difficult for global participants
  - Recurring meeting invite sent

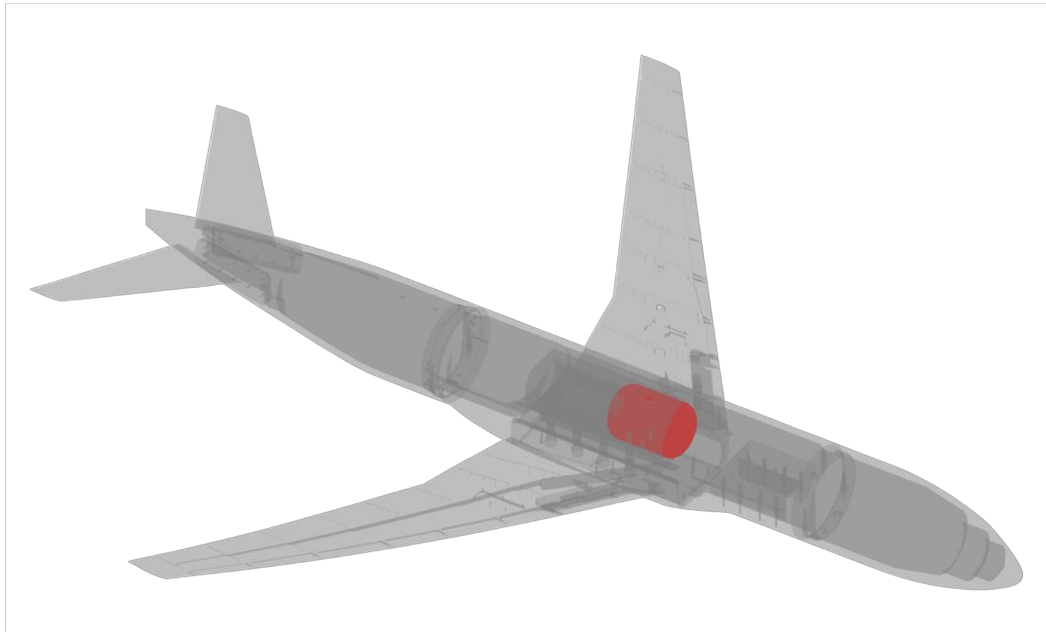
- **Next meeting: Friday, March 21st**
  - Please contact ben.j.rider2@boeing.com if you are interested to present grids or solutions

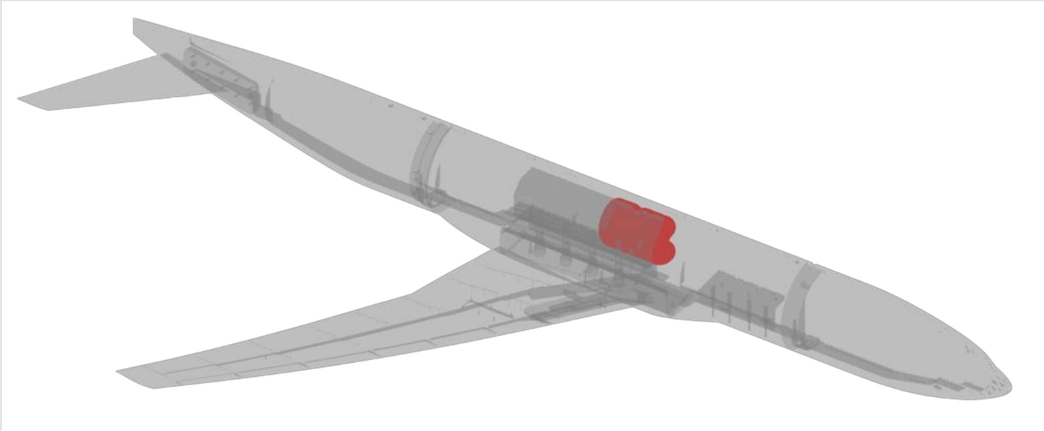
NASA LaRC Update for the Static Deformation WG

Bret Stanford

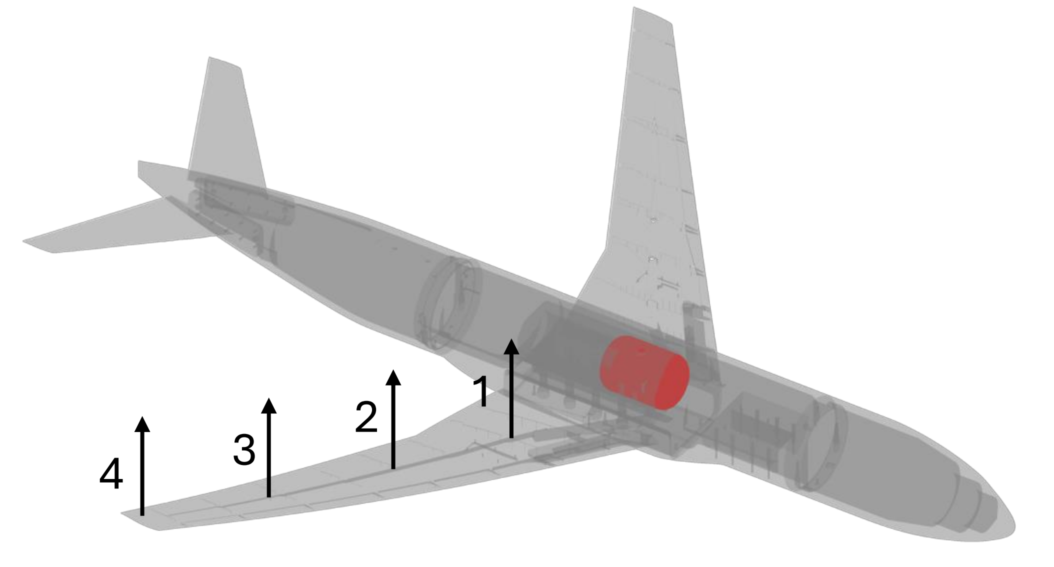
Semi-span FEM

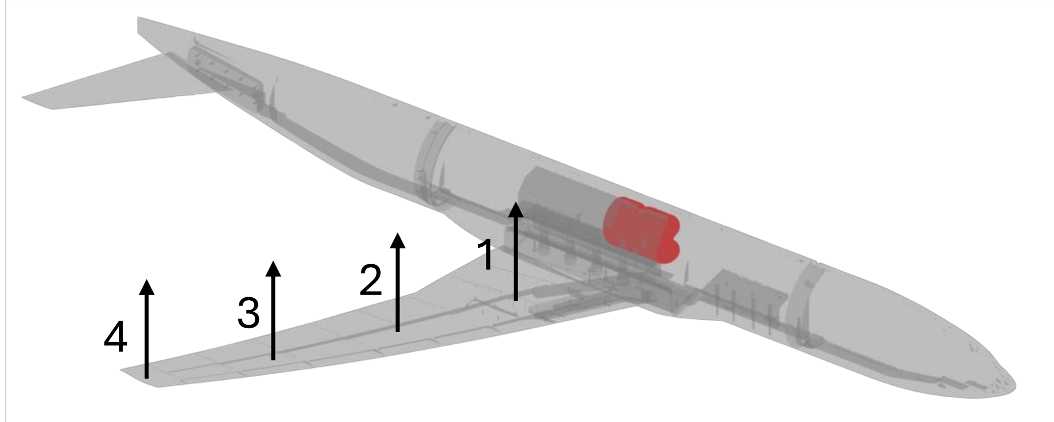
- Several CTETRA and RBE elements near the centerline (y=0) spanned both y>0 and y<0
- Numerous intrusive fixes needed to the full-span FEM, to create a semi-span version

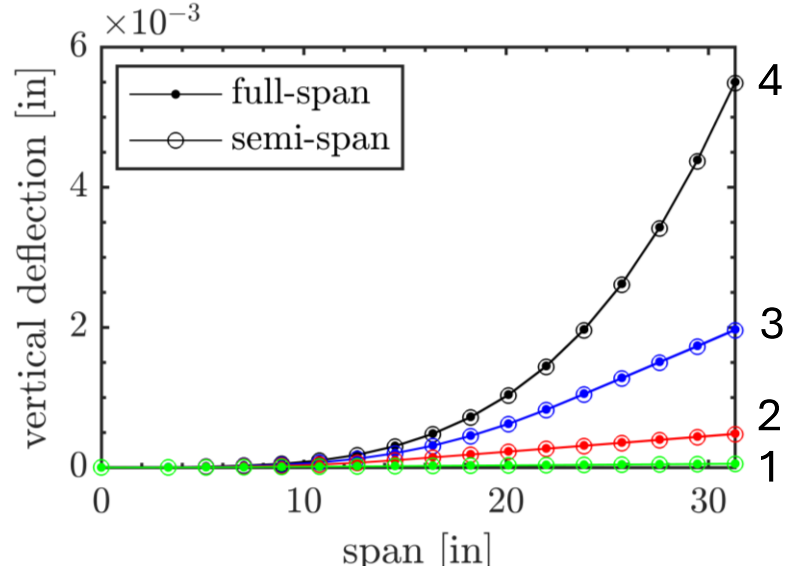


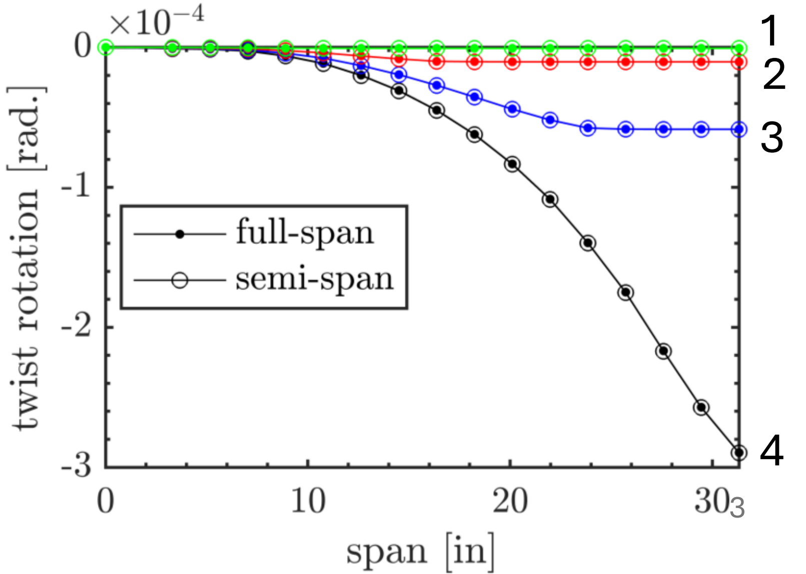


Full-Span vs. Semi-Span Load Response: Four Unit Vertical Load Cases

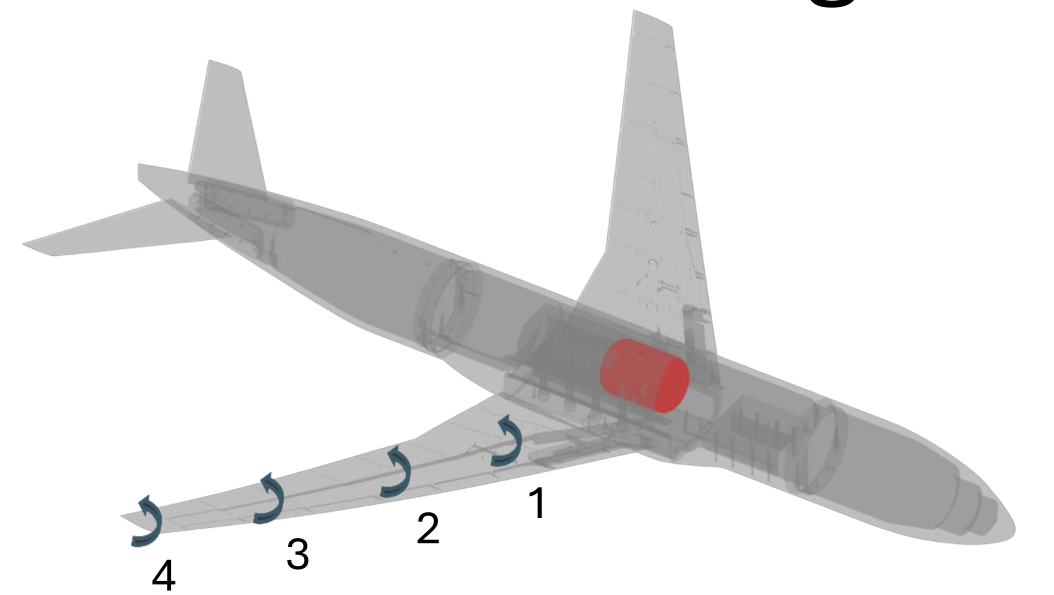


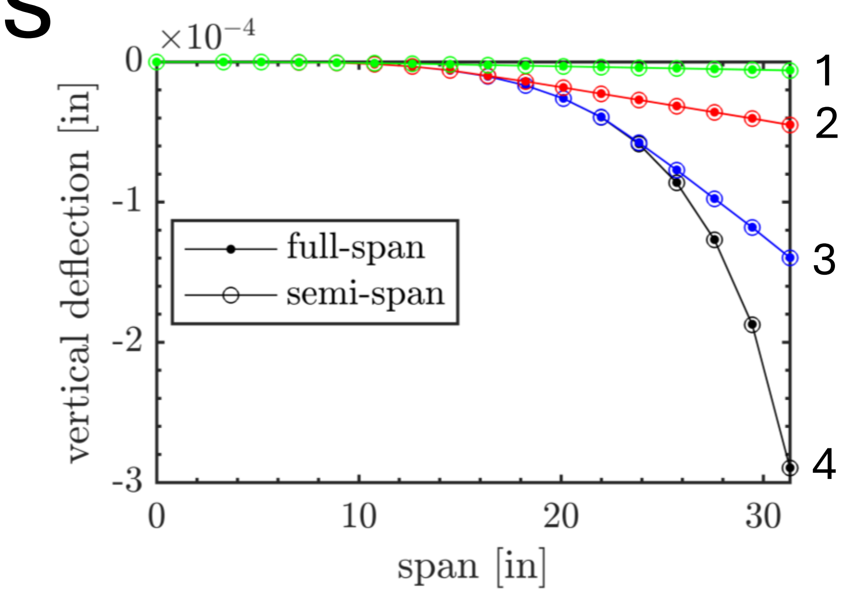


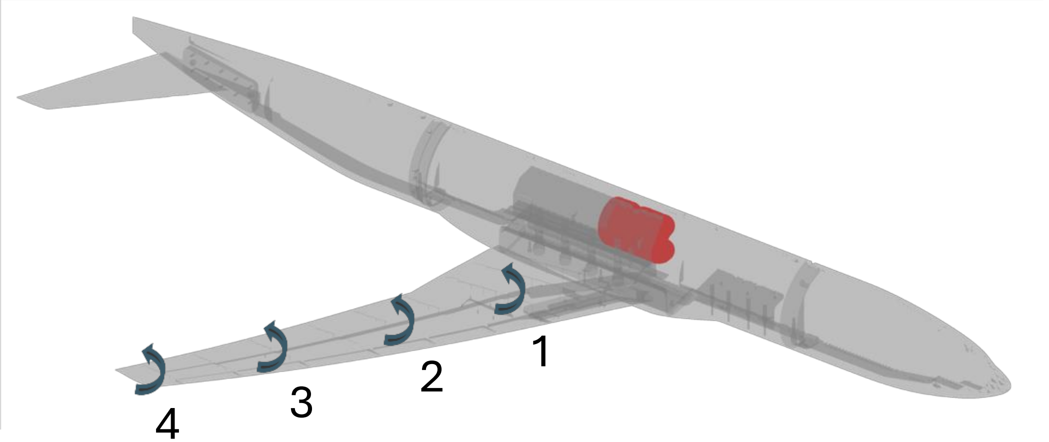


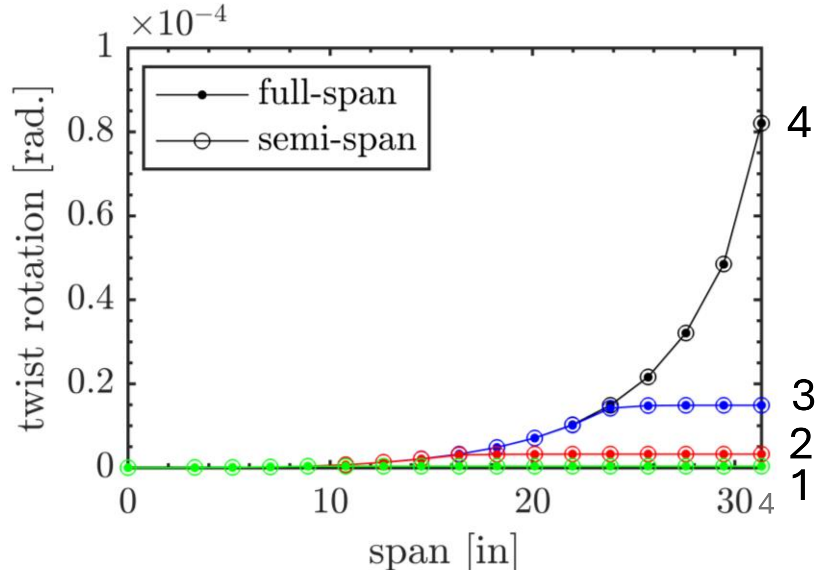


Full-Span vs. Semi-Span Load Response: Four Unit Twisting Load Cases



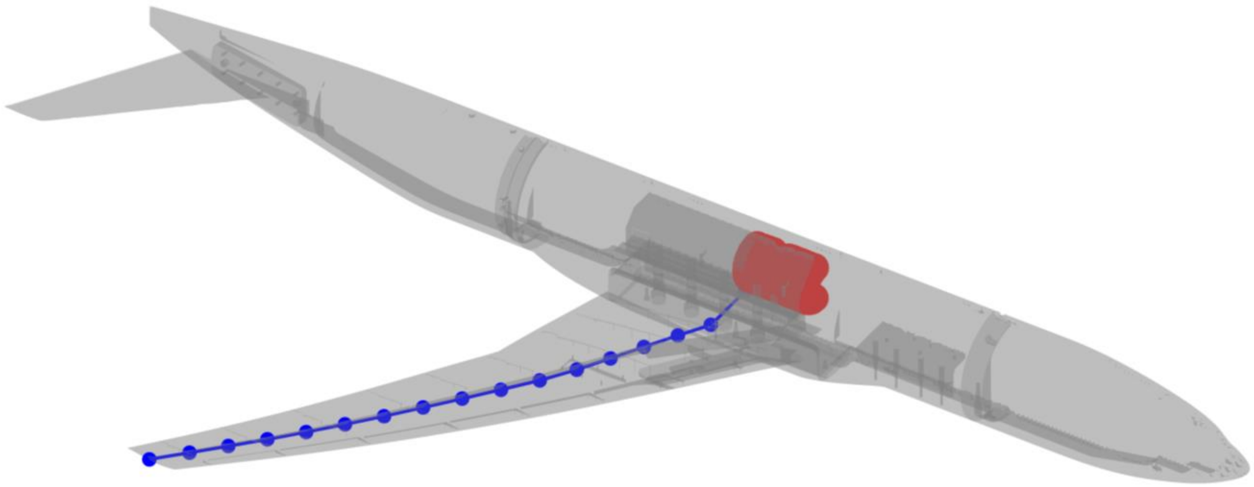




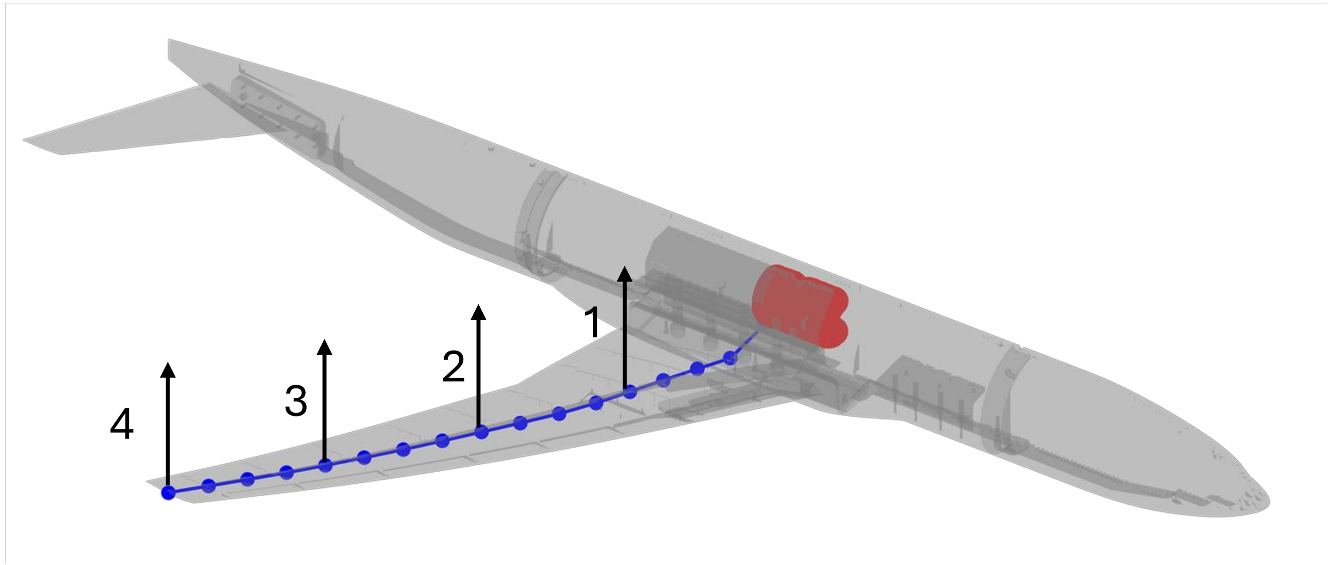


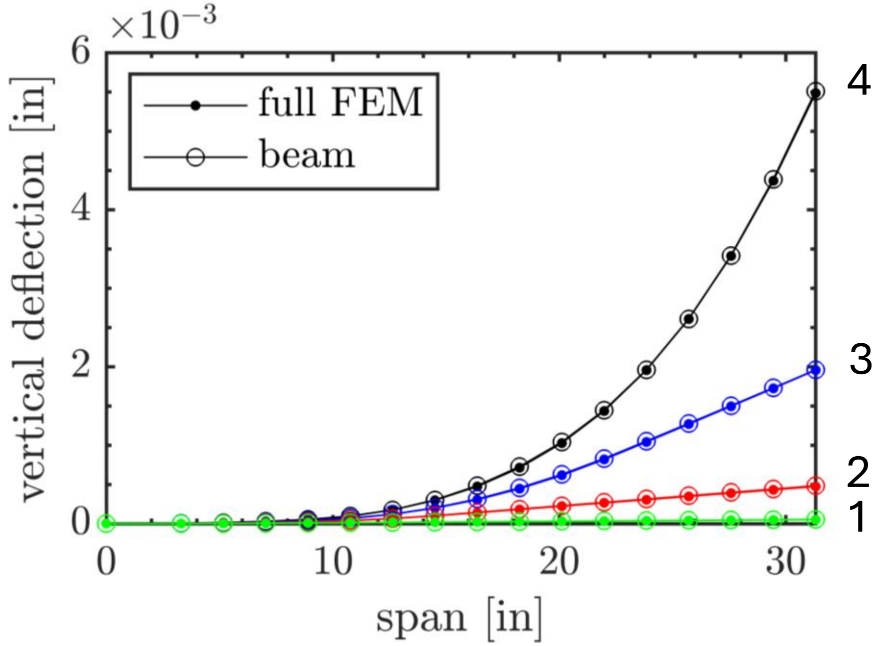
Equivalent Beam Model

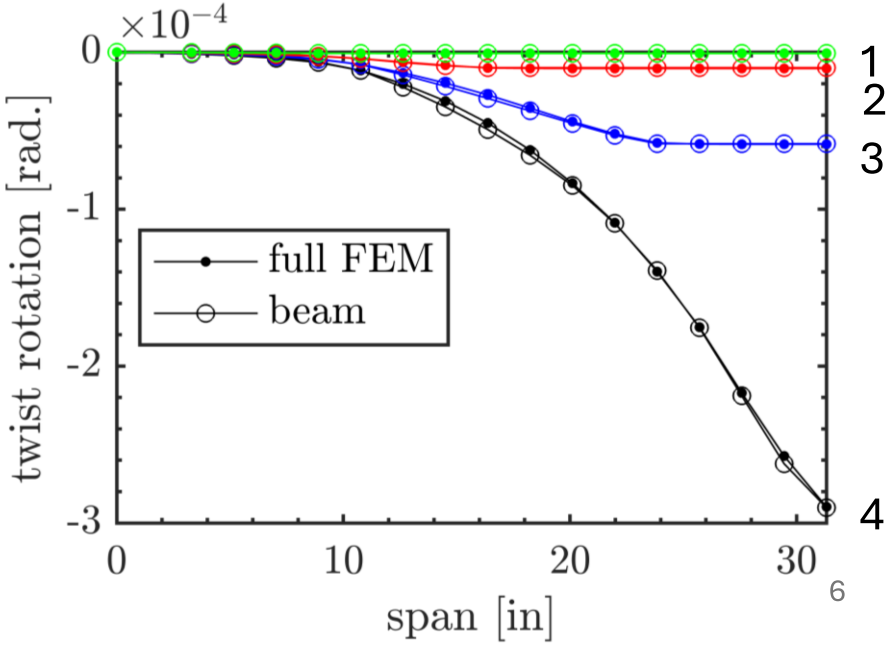
- Sixteen beam elements through the center of the wing
- Fully clamped at node 1
- Optimization used to tune material properties so that static load response matched the response of the full FEM
  - EA, EI1, EI2, GJ
  - Elastic offsets of the beam



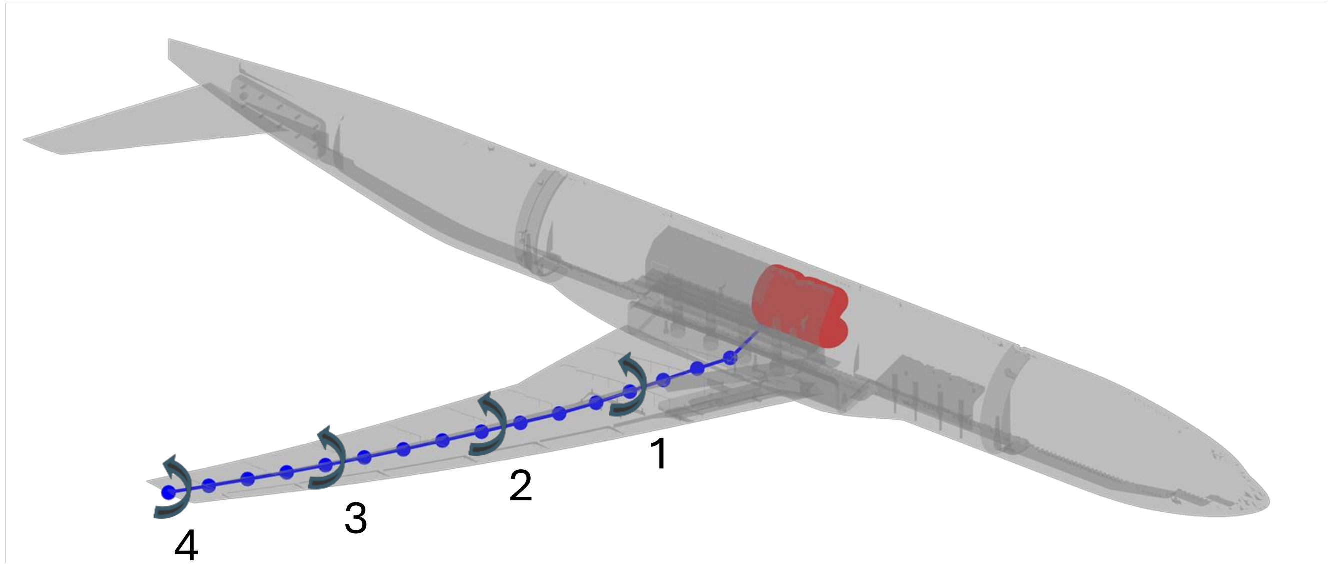
Four Unit Vertical Load Cases

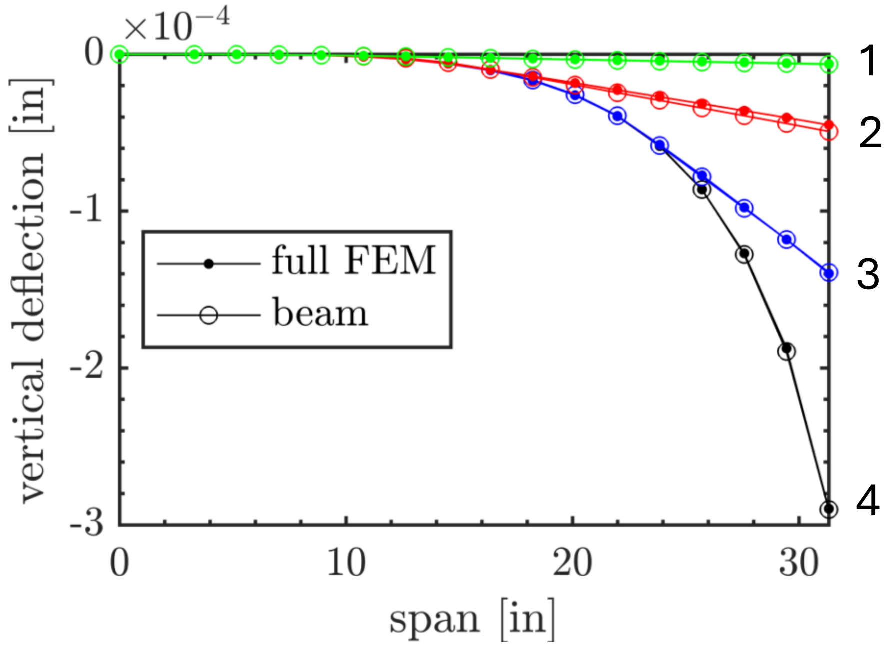


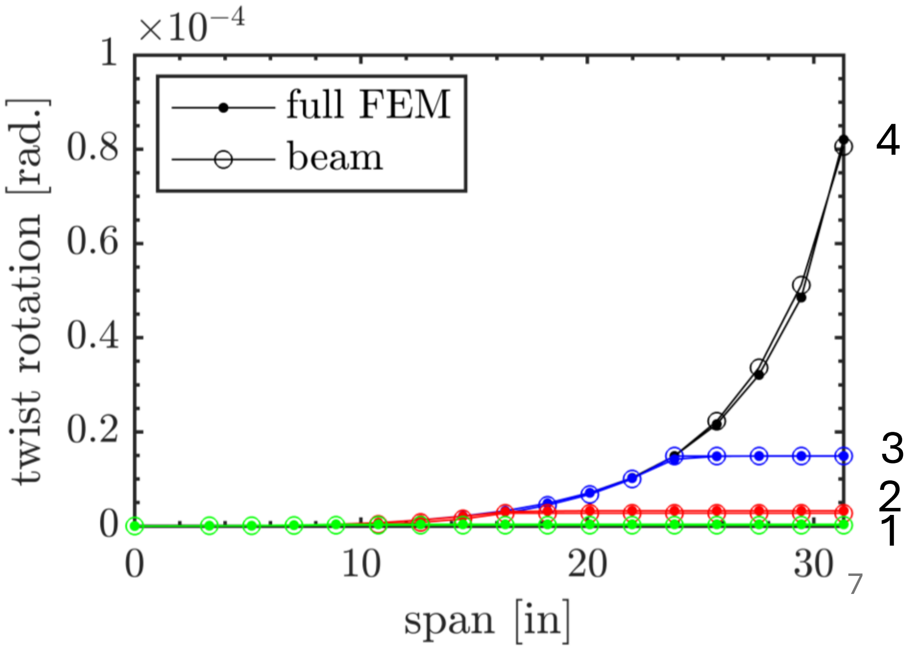




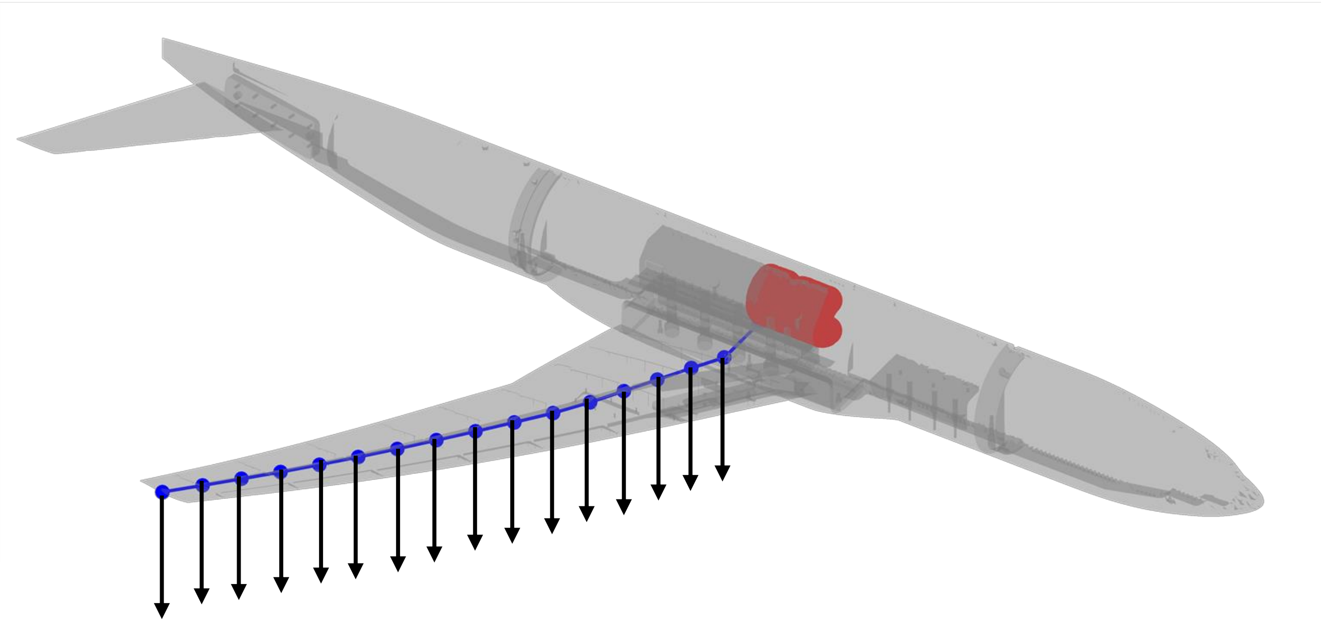
Four Unit Twisting Load Cases

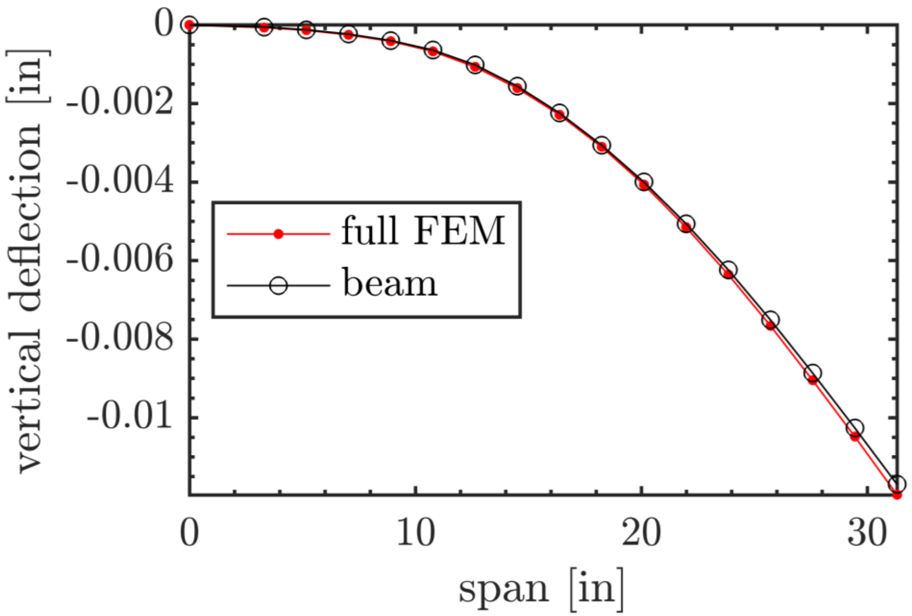


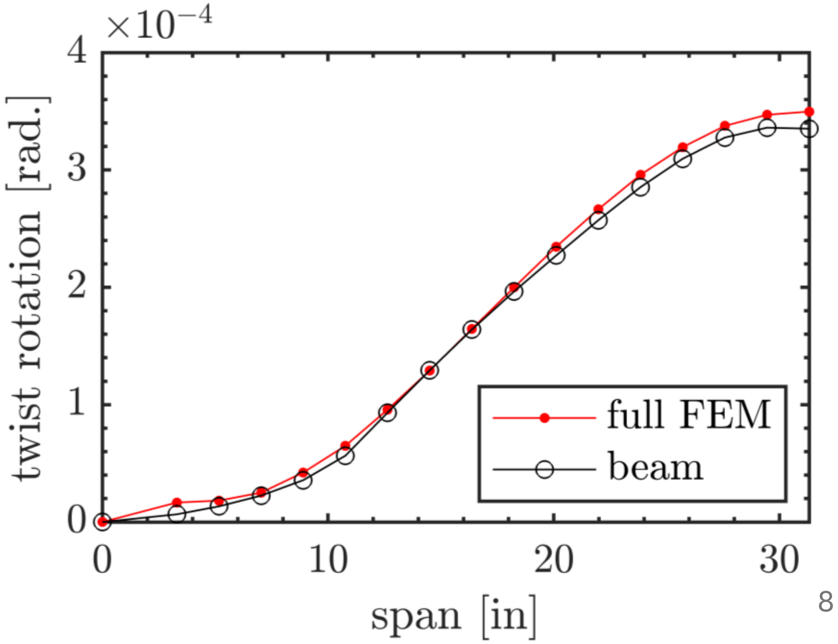




Self-Weight Load Case







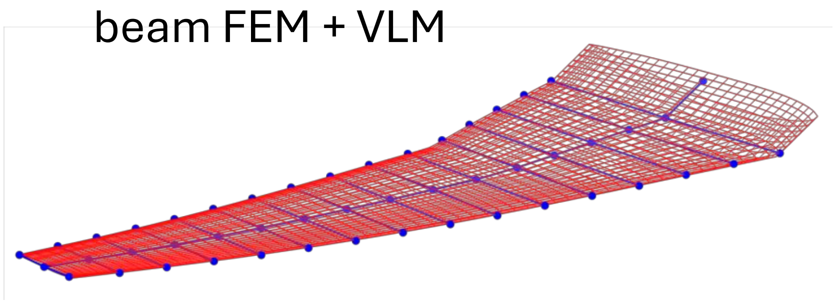
MPhys

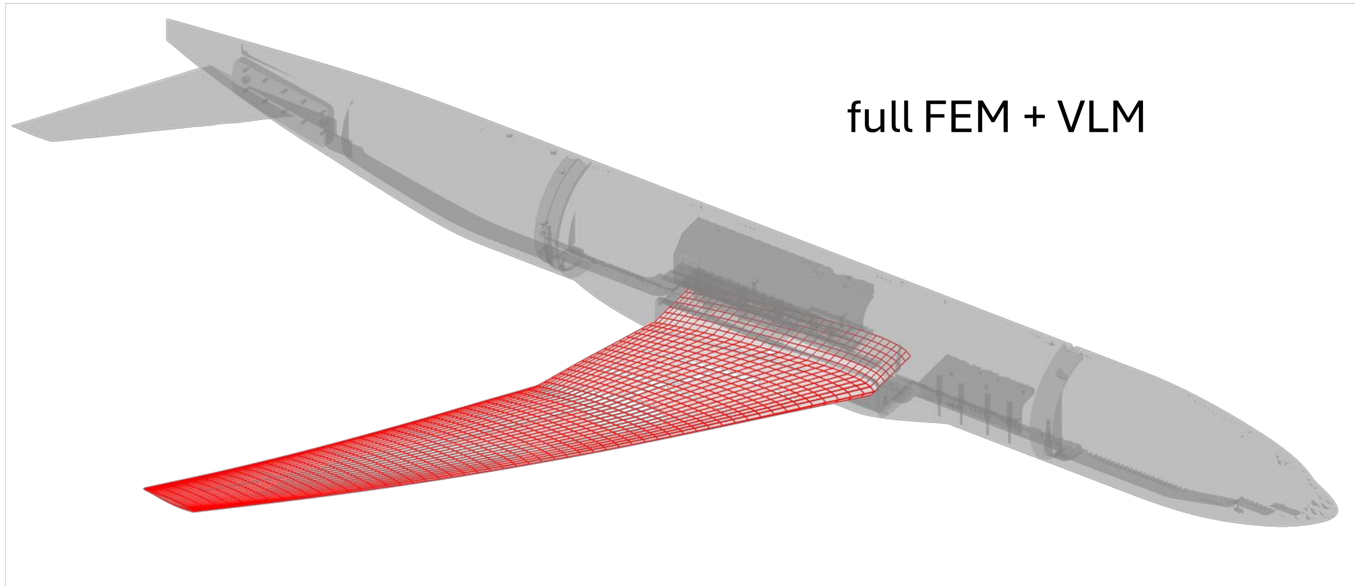
- Open-source tool which facilitates multidisciplinary analysis and optimization
  - A library of helper classes that work inside OpenMDAO
  - https://github.com/OpenMDAO/mphys
  - https://github.com/OpenMDAO/OpenMDAO
  - Yildirim et al, “MPhys: a Modular Multiphysics Library for Coupled Simulation and Adjoint Derivative Calculation”, *SMO*, 2025

- We use MPhys for static aeroelastic coupling (NLBGS)
  - Users must write Python-based “builders” for each solver

- MSC Nastran for structural analysis (sol-101)
- A vortex lattice method (VLM) for aerodynamic analysis
  - We will switch to FUN3D / RANS, once the grids are available
- MELD (Matching-Based Extrapolation of Loads and Displacements)
  - https://github.com/smdogroup/funtofem

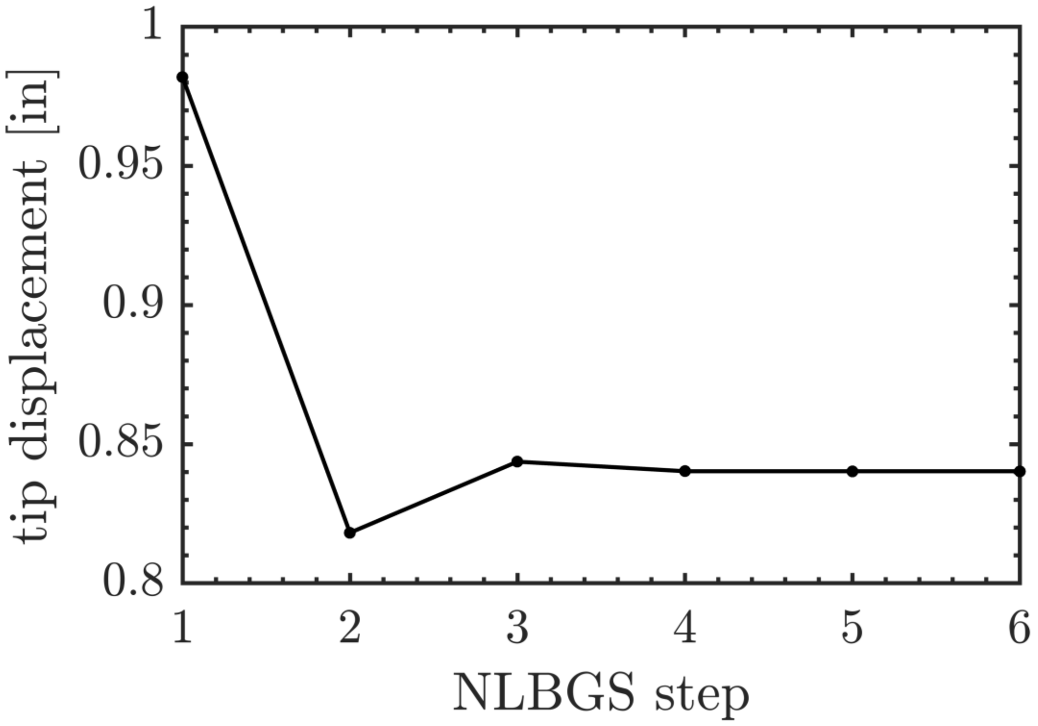
MPhys Coupling of Structural Models to VLM

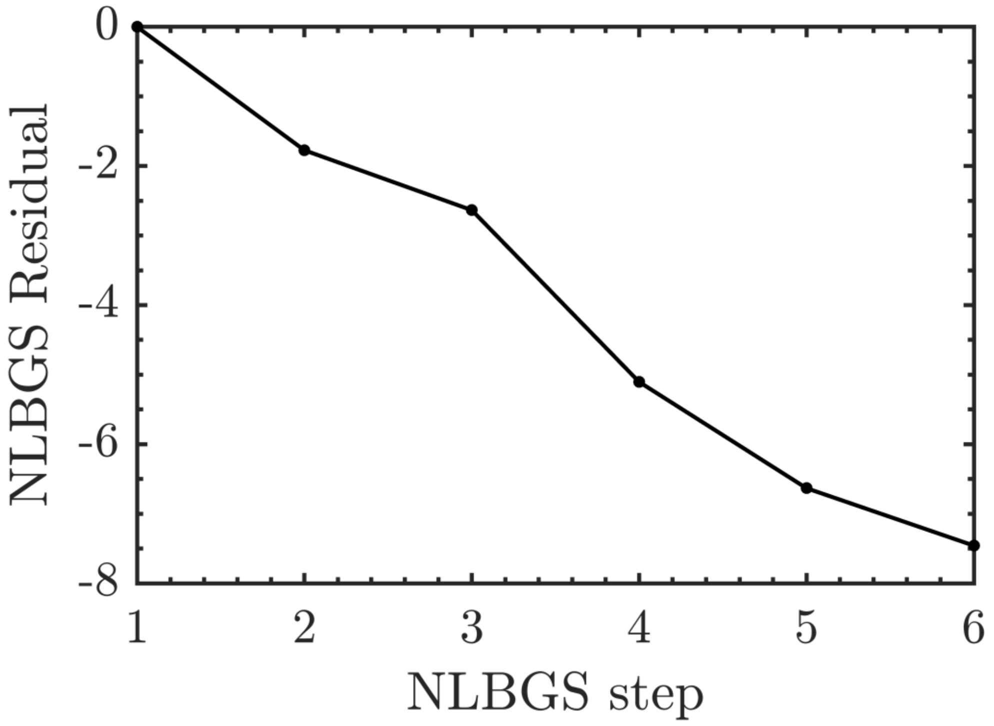




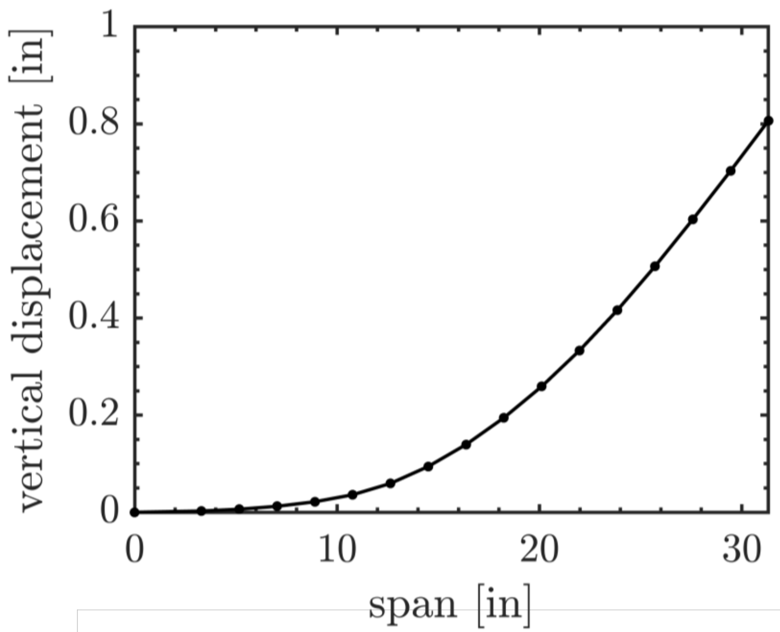
- VLM aerodynamics at the fuselage are not properly modeled: should be using non-lifting body elements
- “Spokes” rigidly connected to beam nodes, to facilitate MELD transfer
- Inertial loads superimposed onto aerodynamic loads

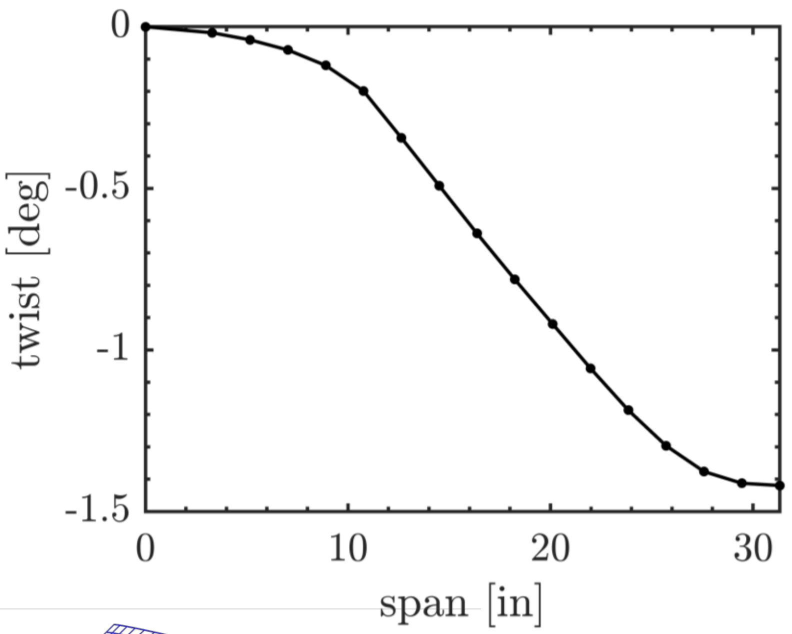
Typical NLBGS Convergence

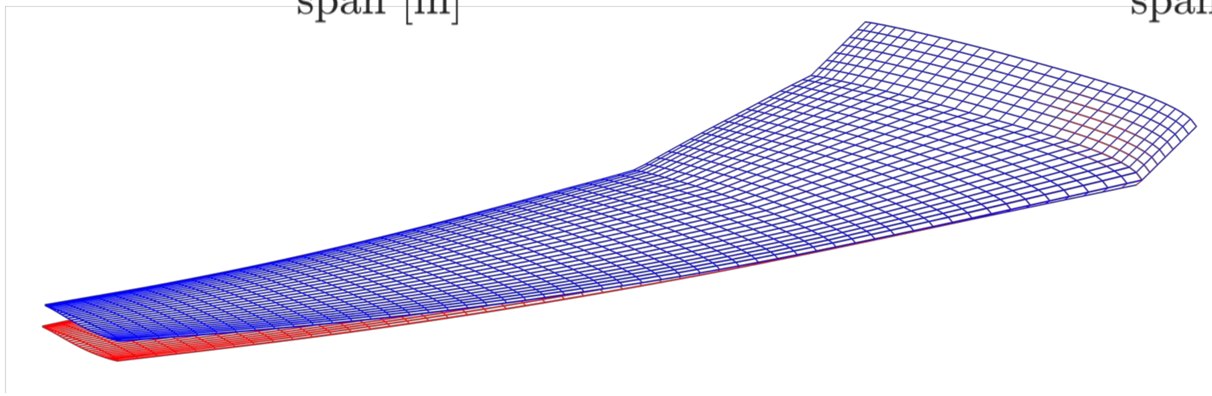




NTF Run 192: Mach=0.85, AoA=3 deg, Qinf=1384 psf

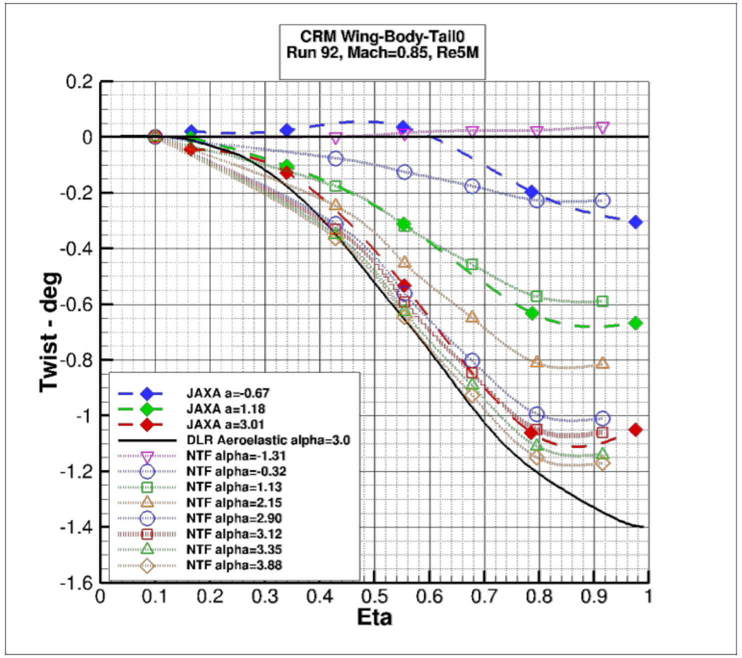






NTF Run 192: Mach=0.85, AoA=3 deg, Qinf=1384 psf

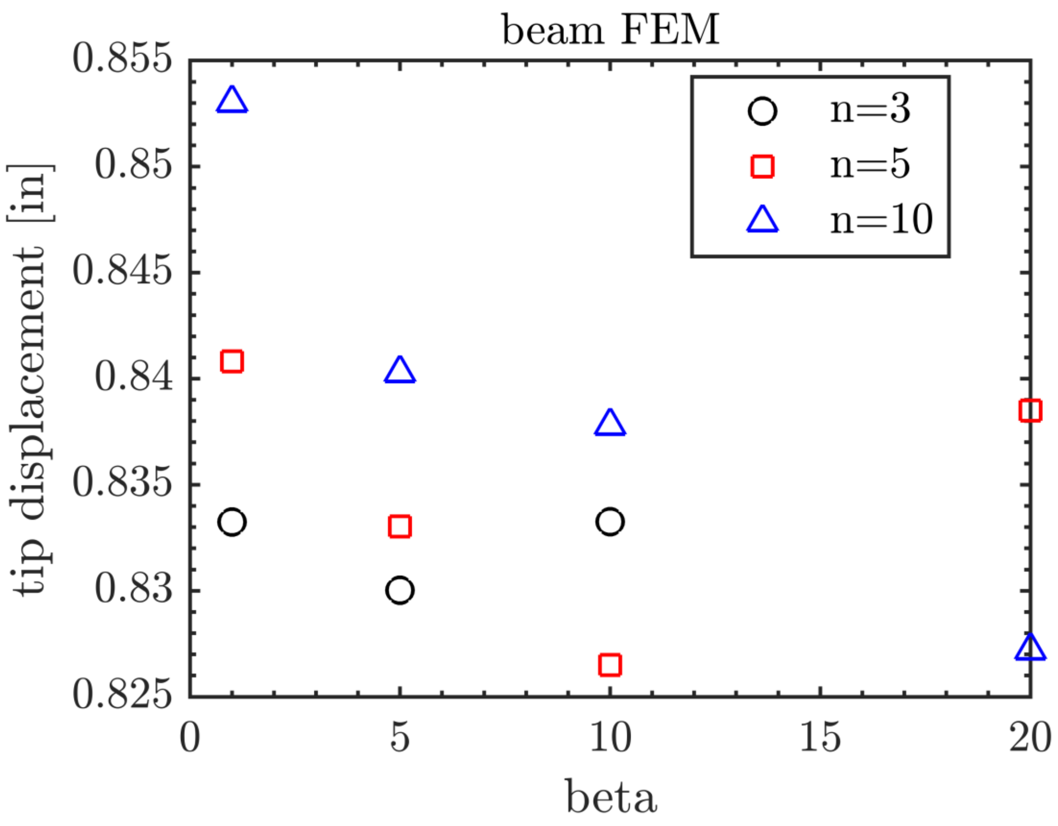
	tip displacement [in]	tip twist [deg]
beam + VLM	0.806	-1.42
full FEM + VLM	0.799	-1.44
DLR prediction	~ 0.75	~ -1.4
NTF	~ 0.64	~ -1.05

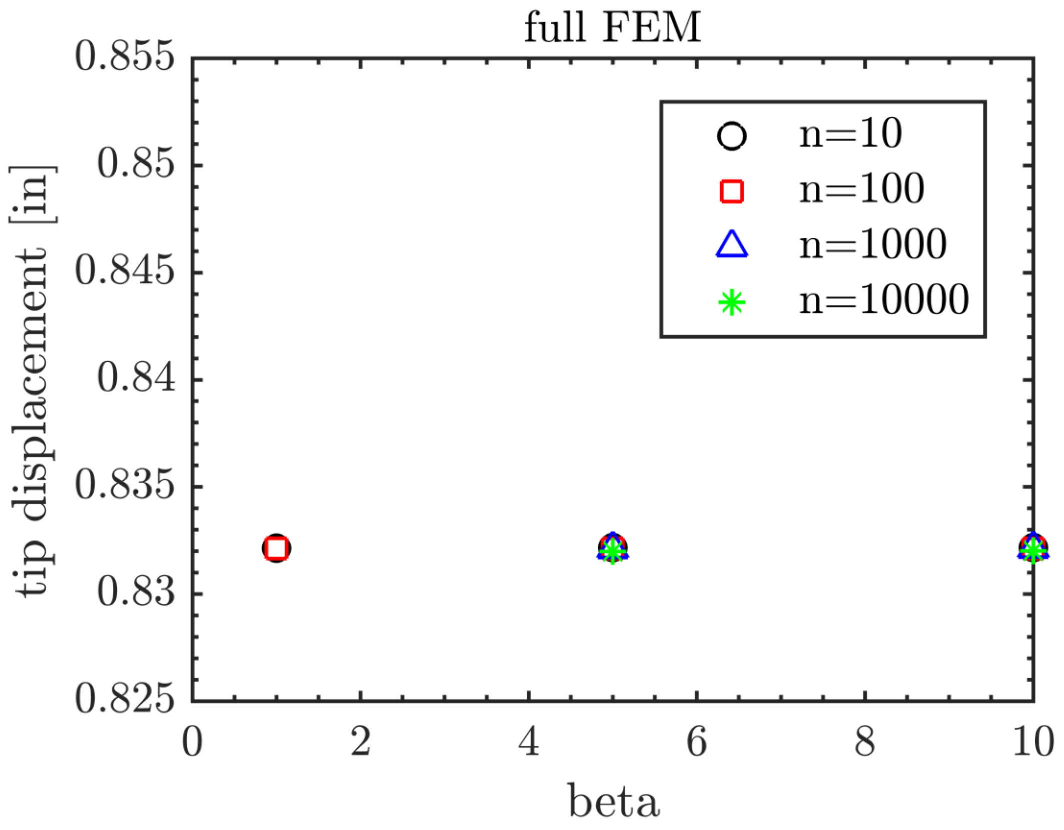


Sensitivity to MELD Parameters

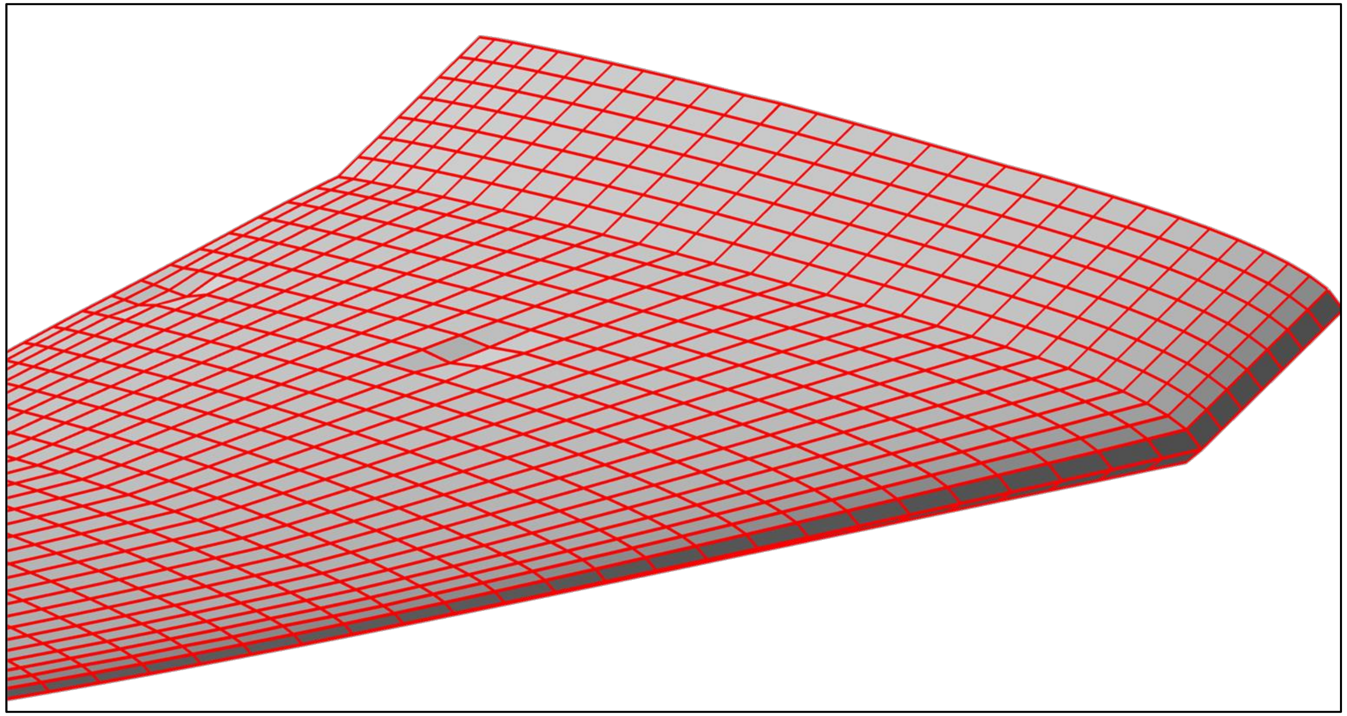
- MELD uses weighted least-squares minimization to compute motion of aero nodes, due to the motion of nearby structural nodes
- n: how many nearby structural nodes are included for each aero node
- β: decay parameter which governs the weighting of farther-away structural nodes

Sensitivity to MELD Parameters





Sensitivity to MELD Parameters



example of dimples in the VLM mesh when coupled to the beam FEM
β =5, n = 5