Structural Modeling of the CRM

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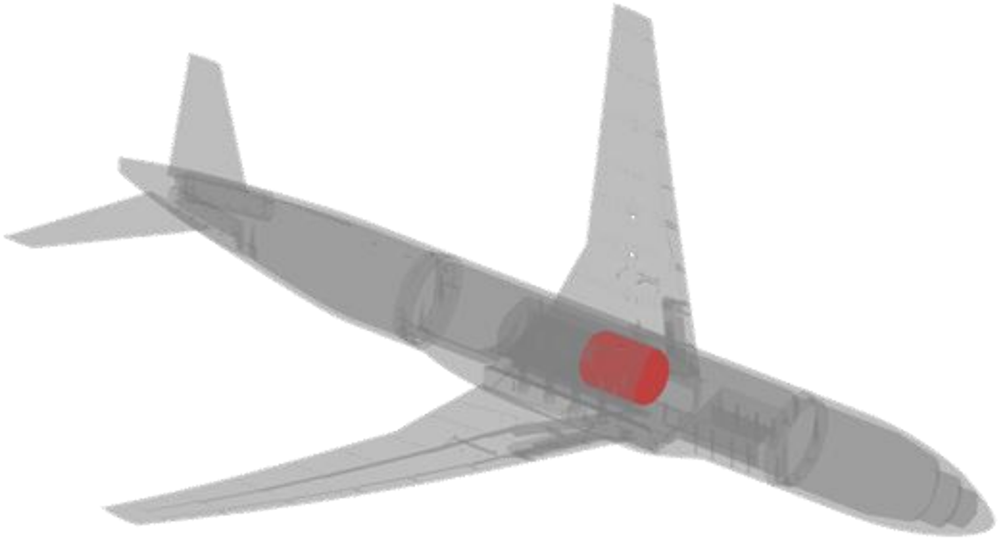
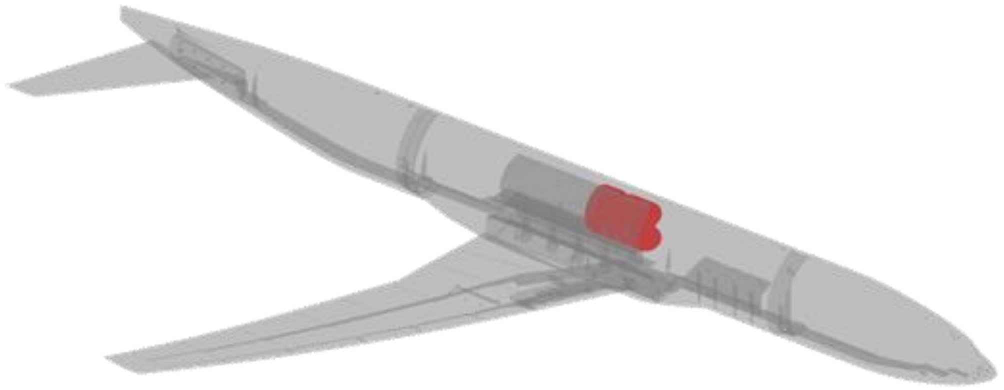
Original FEM

- **Created in 2012 by Erik Tyler at NASA LaRC, for past DPW efforts**
- **Tet-blasted FEM with 10M DOF**
- **Model clamped along a cylinder inside the fuselage**
  - Sting not modeled



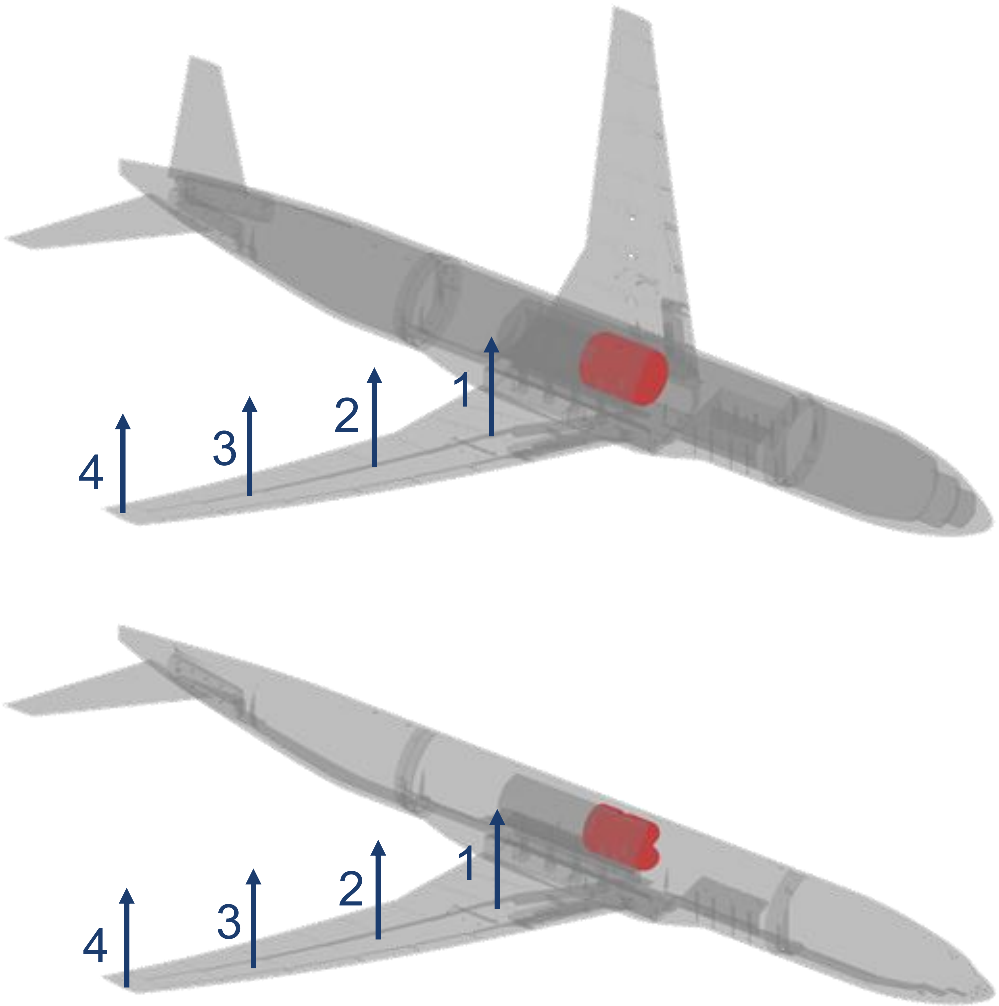
Semi-Span FEM

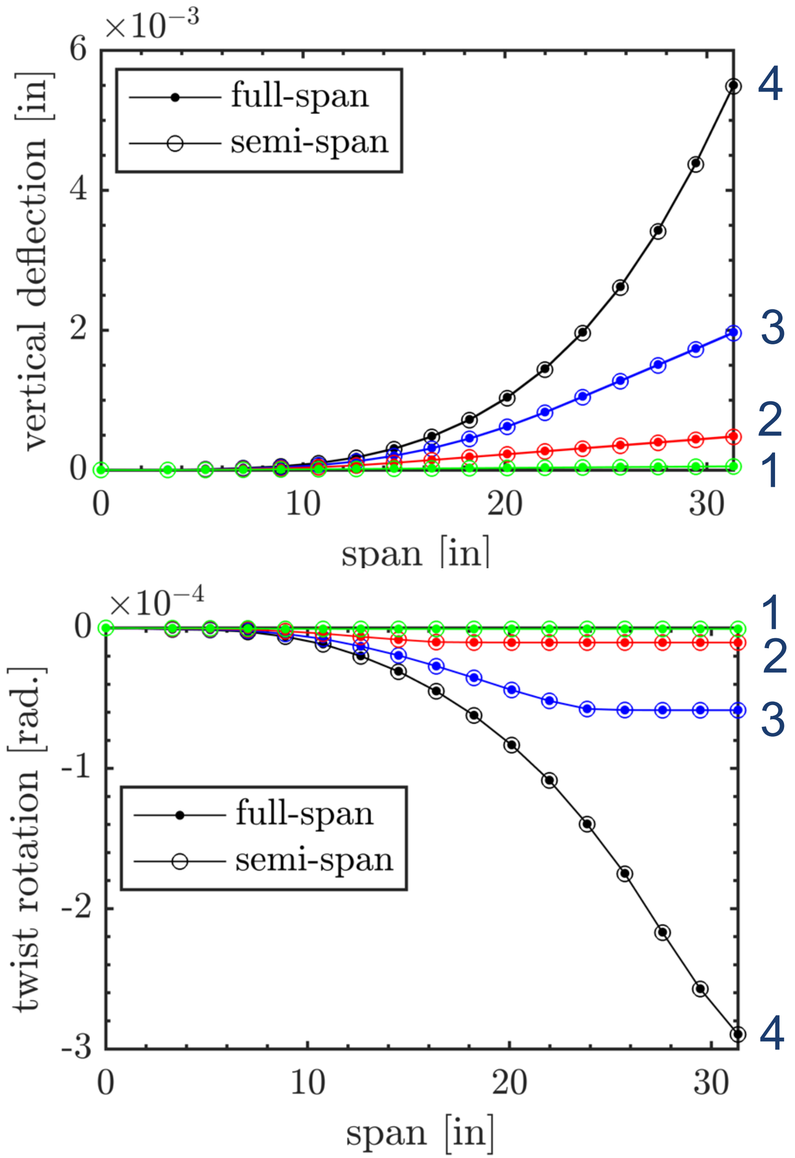
- Since most/all of the CFD modeling is semi-span, a semi-span FEM is also preferred for aeroelastic coupling
- Several tet and rigid-link elements near the centerline (y=0) spanned both y>0 and y<0
- Numerous intrusive fixes needed to the full-span FEM, to create a semi-span version



Full-Span vs. Semi-Span Load Response (1)

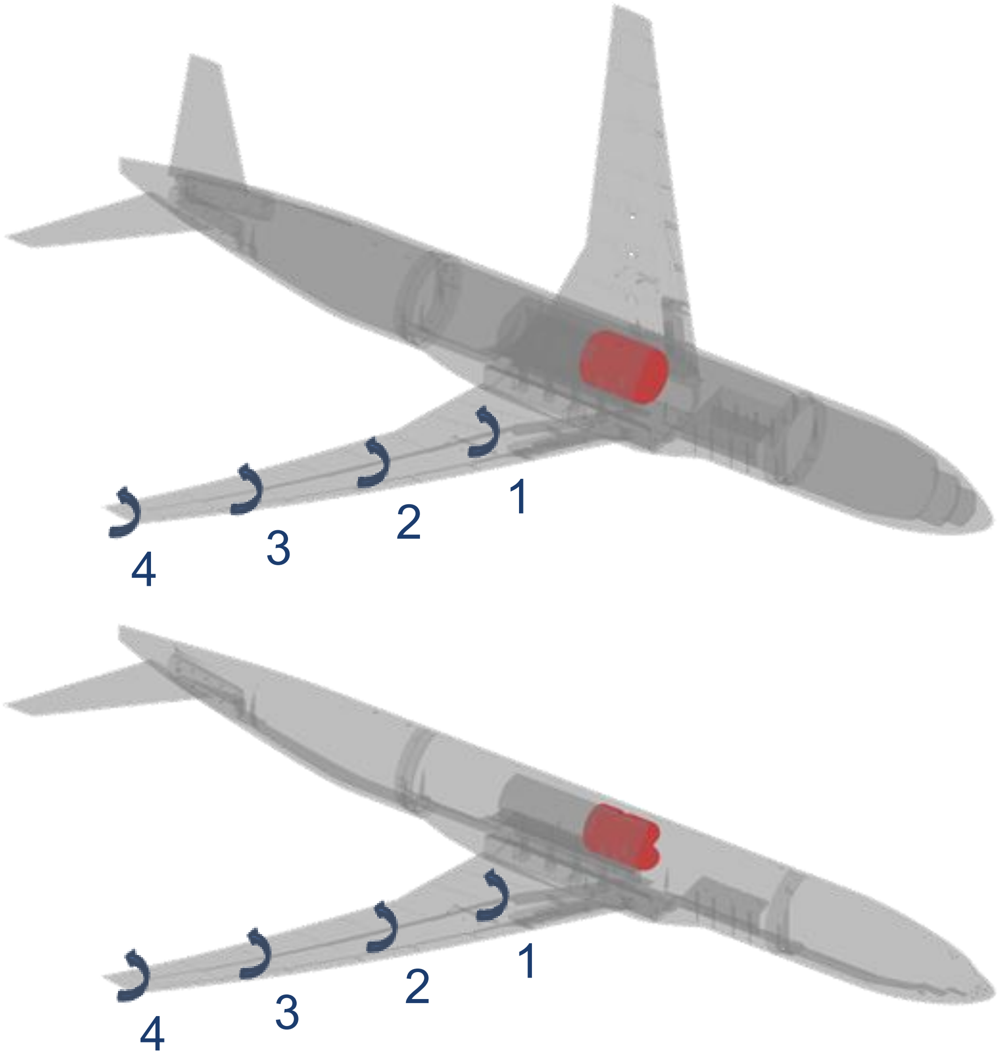
- **Four unit vertical load cases**

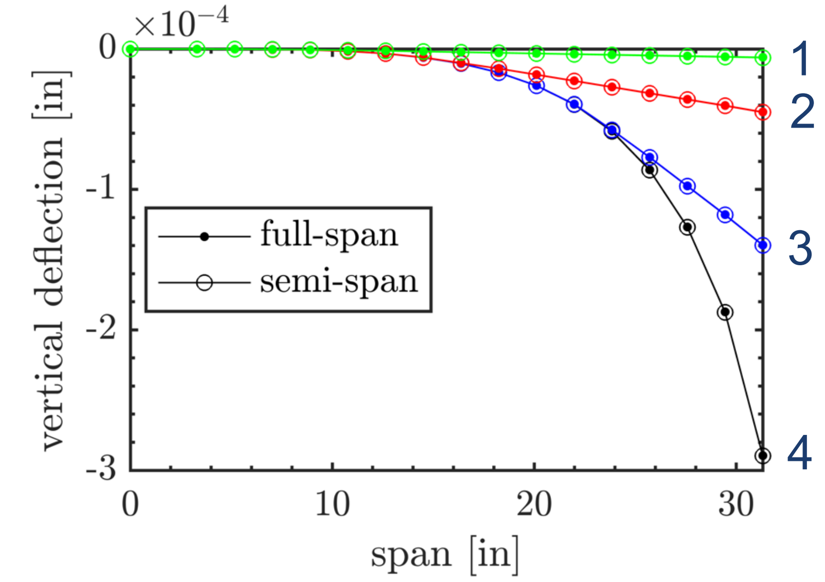


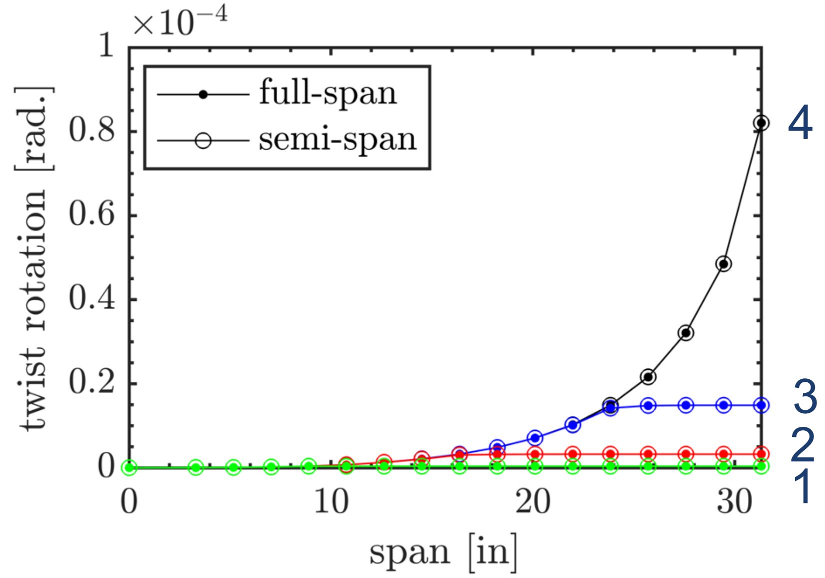


Full-Span vs. Semi-Span Load Response (2)

- **Four unit twisting load cases**

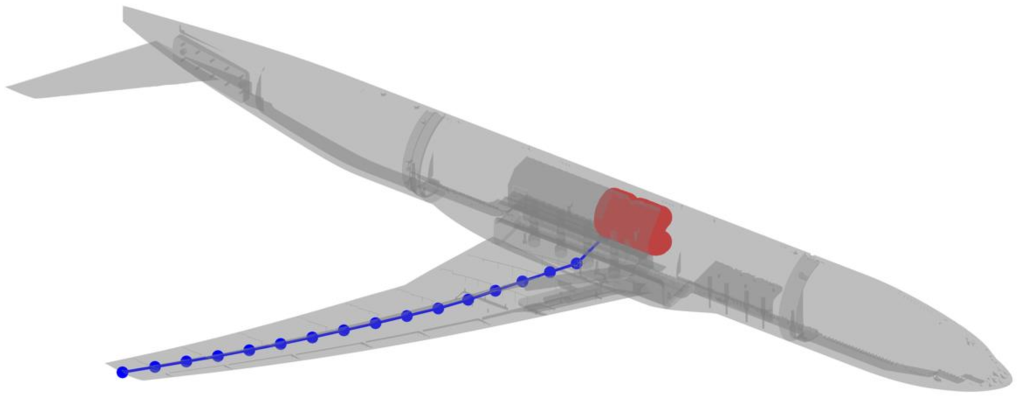






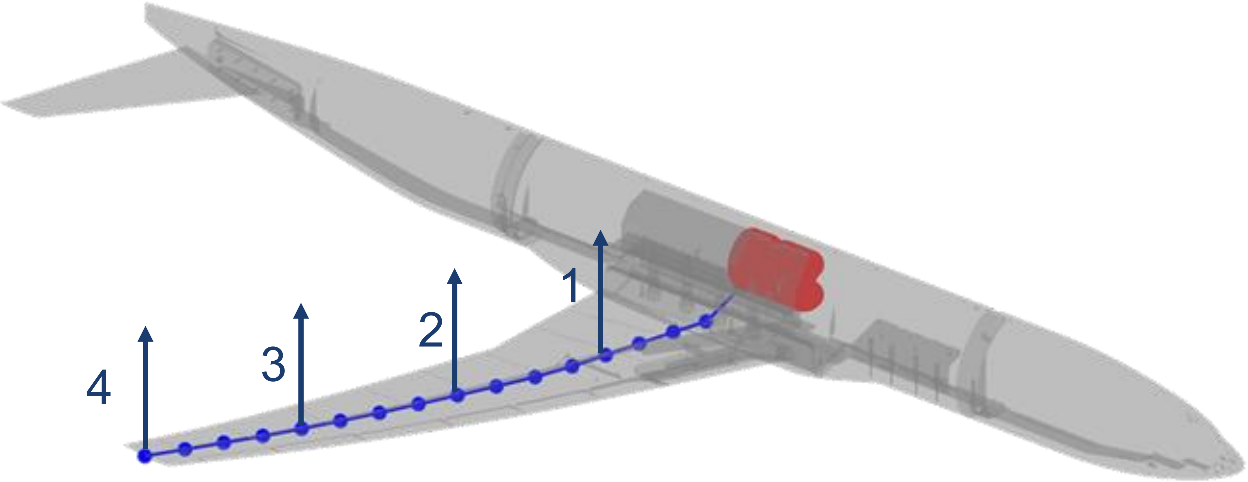
Equivalent Beam Model

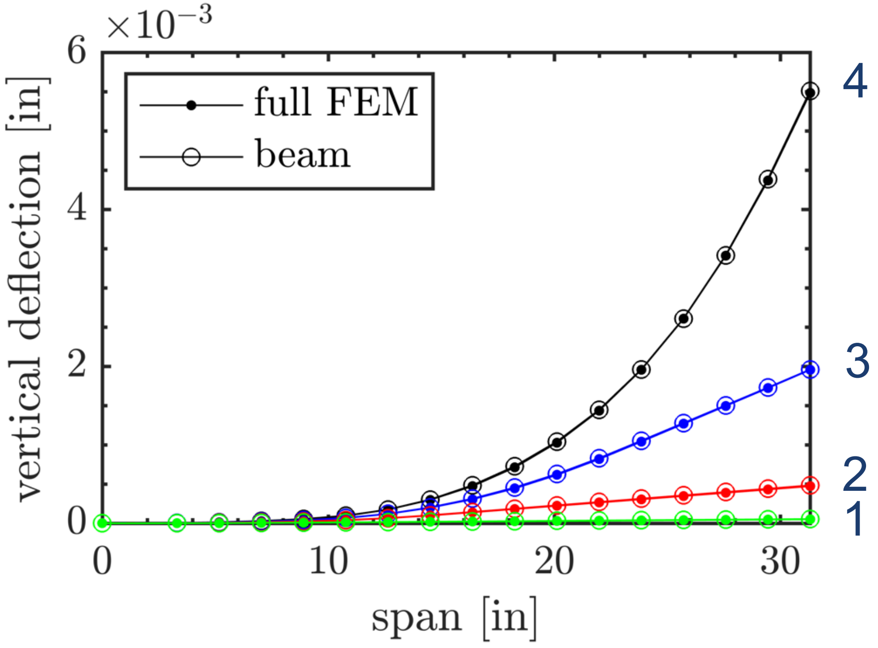
- **Sixteen beam elements through the center of the wing**
- **Fully clamped at node 1**
- **Optimization used to tune material properties so that static load response matched the response of the full FEM**
  – EA, EI1, EI2, GJ
  – Elastic offsets of the beam

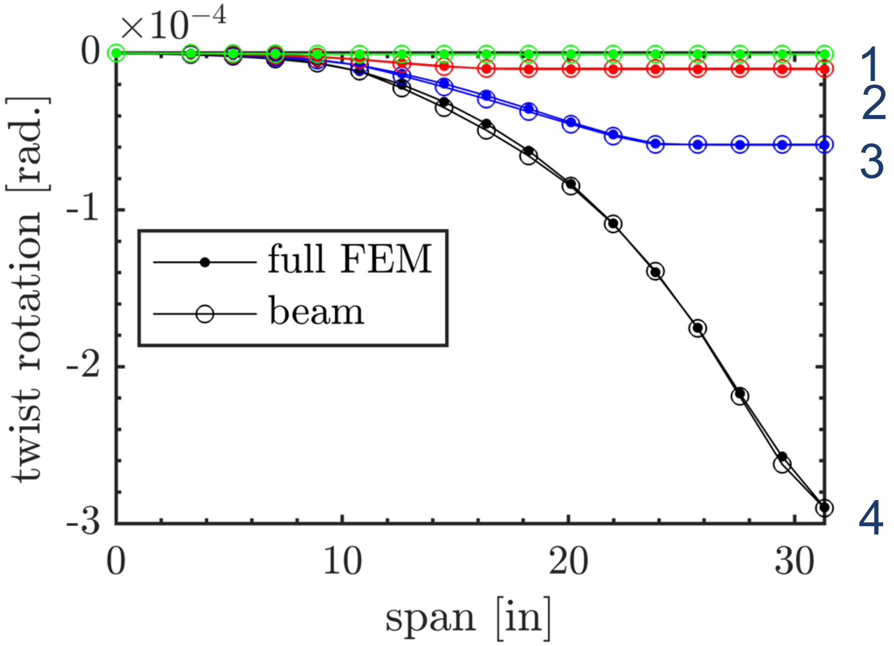


Equivalent Beam Load Response (1)

- **Four unit vertical load cases**

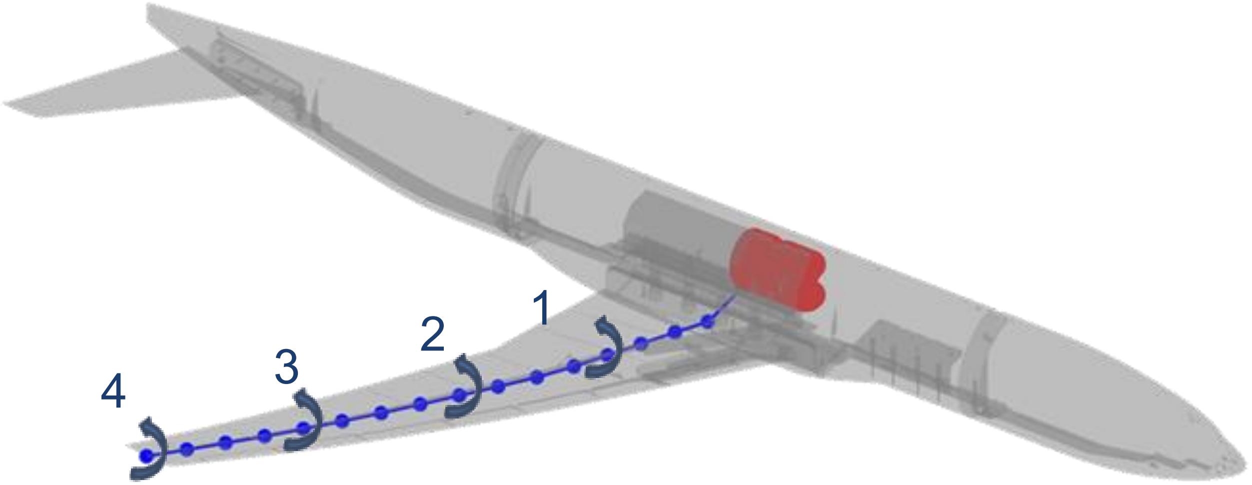


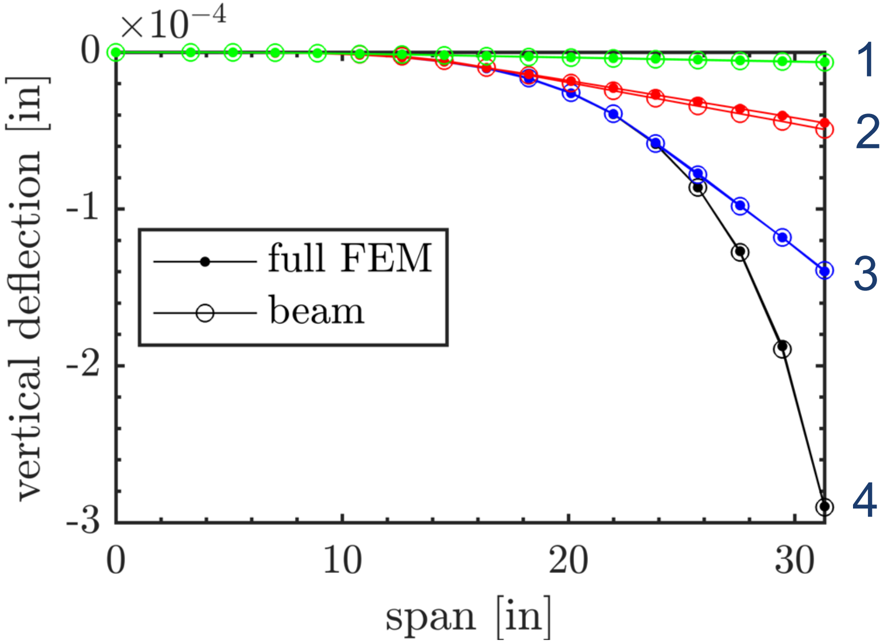


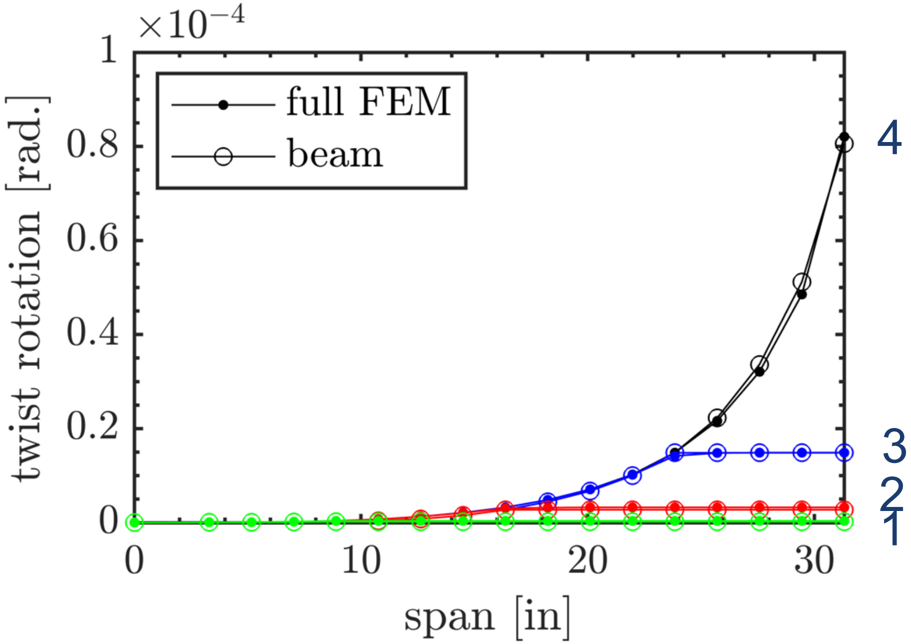


Equivalent Beam Load Response (2)

- **Four unit twisting load cases**

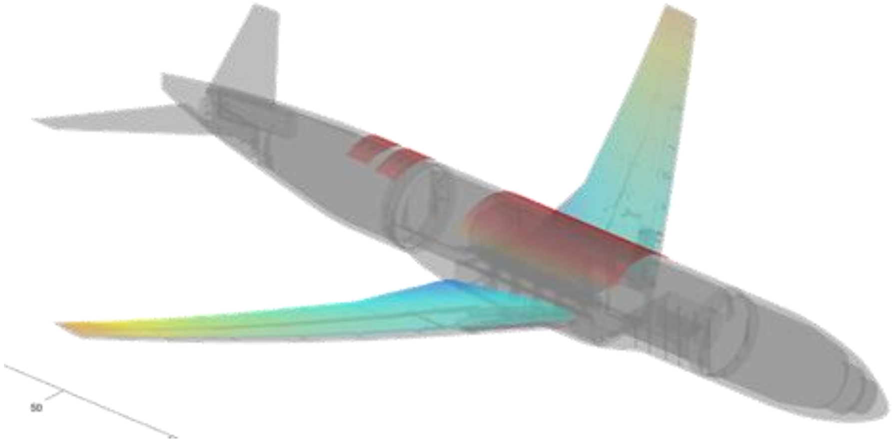






FEM Validation

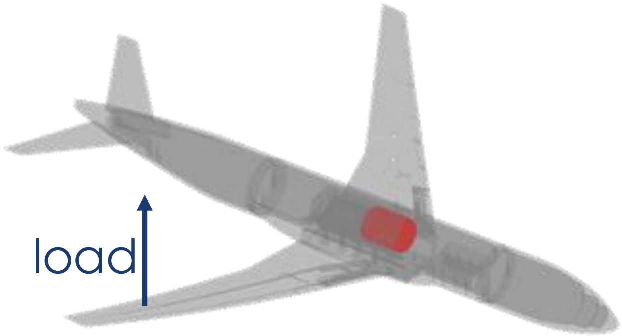
- April 2025: static loads test of the CRM model structure
- Digital image correlation (DIC) was used to track model deformation under loads, with a speckle pattern adhered to the two wings and fuselage

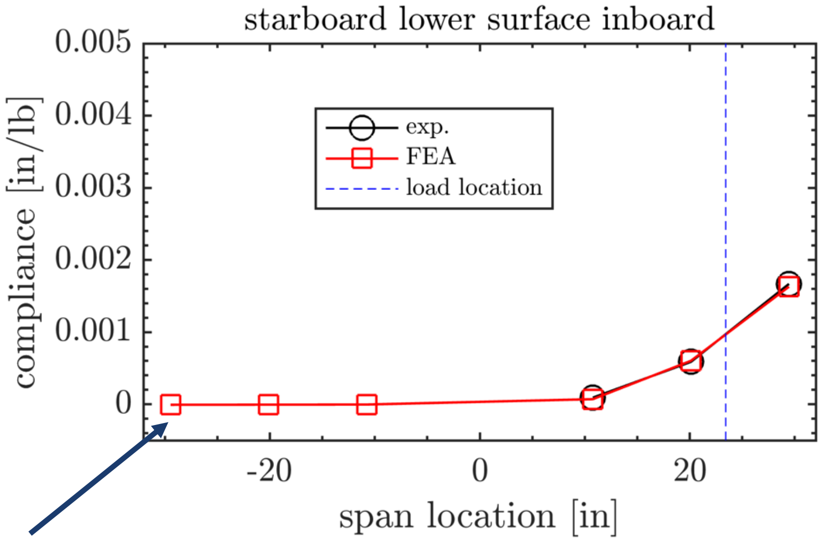


DIC data (colors) superimposed upon the FEM (gray)

Structural Compliance Response Comparisons

- **Apply a series of point loads at a given span station**
- **DIC measures full-field displacement data, but we only look at vertical displacements at 6 points:**
  - 2Y/b = [-0.93, -0.64, -0.34 0.34, 0.64, 0.93]
- **At each point, we fit the DIC results to a linear curve, and the slope of that line is the compliance: in/lb**
- **Compare compliance at each point to the FEM result**

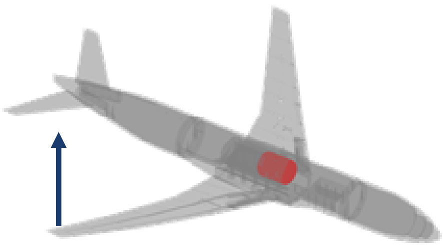


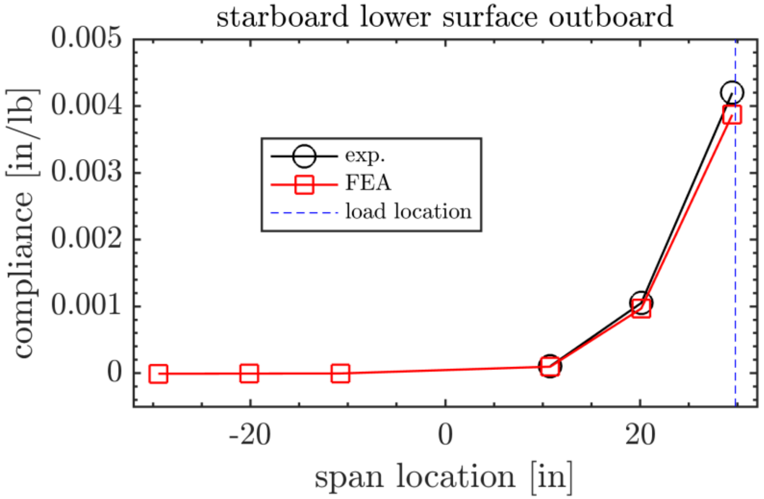


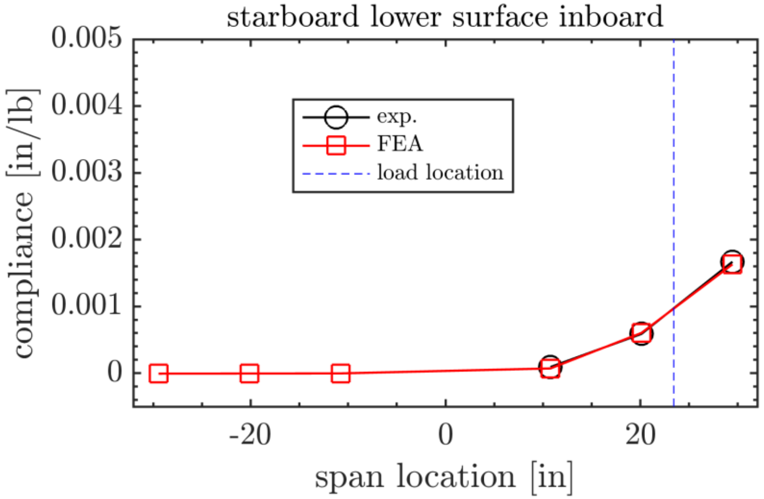
~0 compliance: very little structural communication between starboard and port

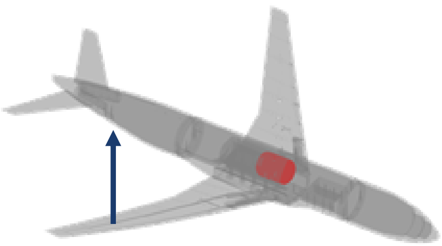
largest compliance, b/c furthest away from wing root

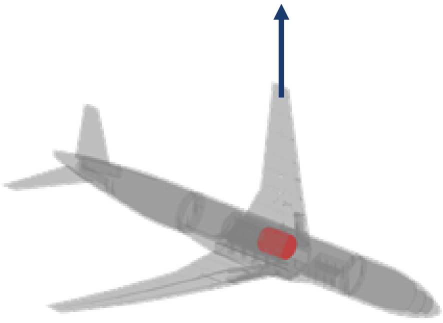
Structural Compliance Response Comparisons (2)

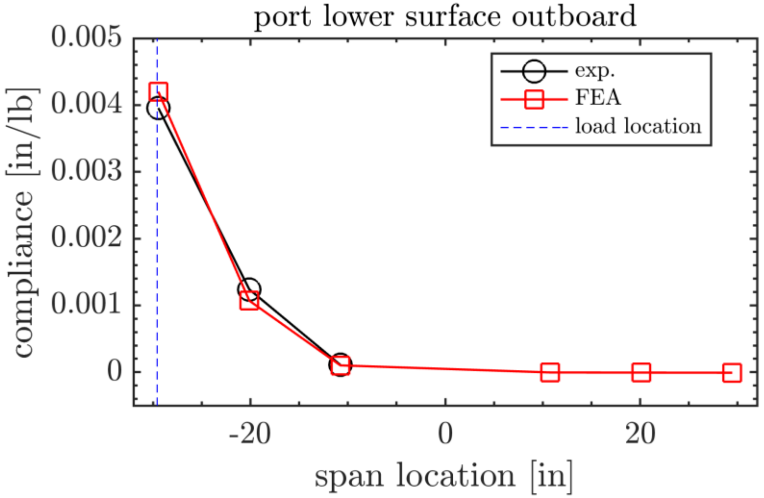


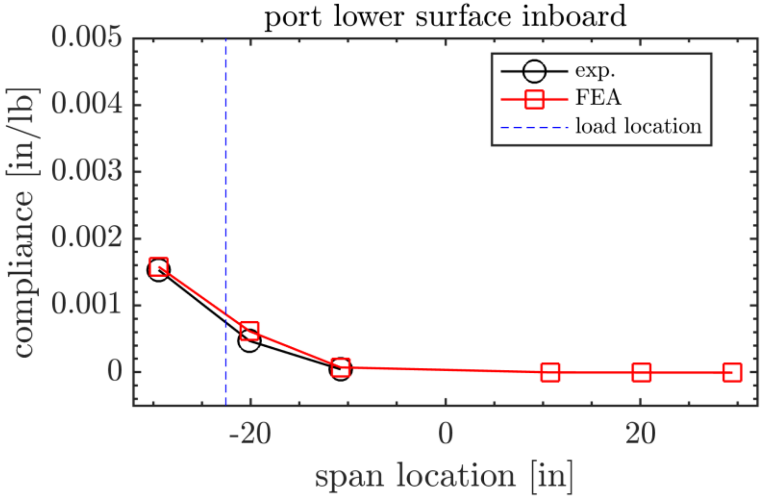


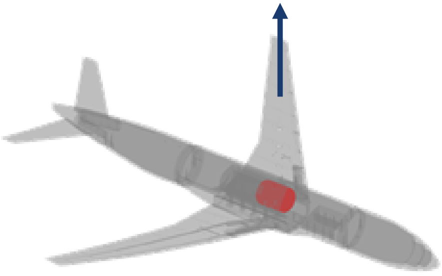












Primary Take-Aways

- **The FEM is *<u>~8% too stiff</u>* on the starboard side, but *<u>~6% too flexible</u>* on the port side**
- **Testing uncertainties:**
  - We were very worried about scratching the wing, and so applied the weight pan tip to a pad on the wing: this made it difficult to precisely measure the x/y/z of the load location
  - There was large rolling motion from the sting, both rigid-body and flexible, and this had to be subtracted-off
- **Another consideration: the FEM is ~7% stiffer on the starboard side than the port side: it's unclear how realistic that is, and this test was not precise enough to validate it**