# X-57 Cruise Motor GVT using Fixed-Base Correction Technique

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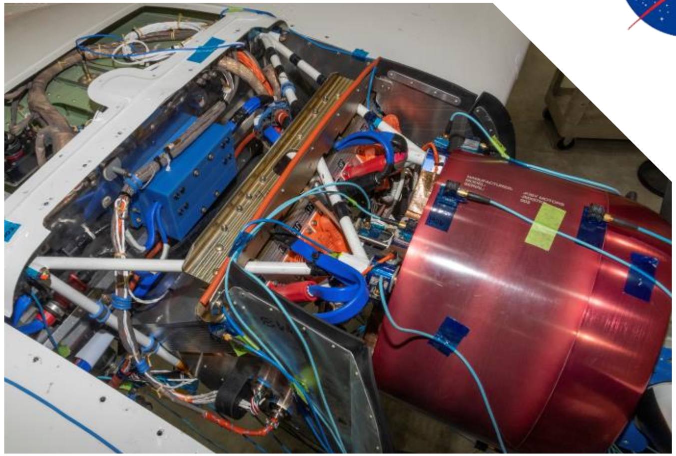
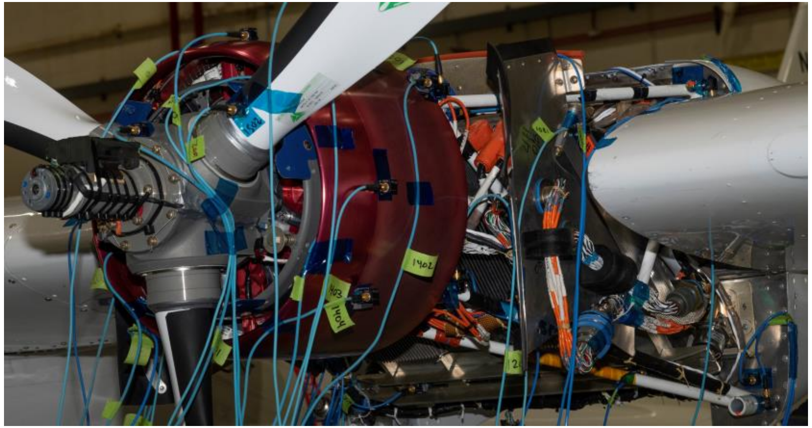
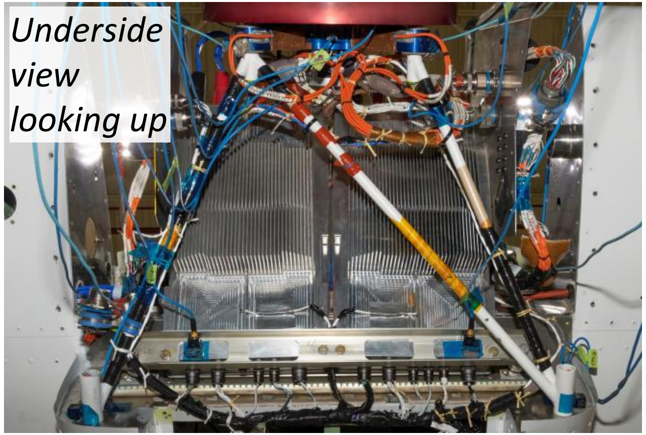
# X-57 Mod II Cruise Motor GVT Overview

- Cruise Motor (CM) GVT – May 2023
  Late project lifecycle effort to inform redesign of cruise motor mechanical interfaces
  - Conducted with motor system installed on aircraft
  - No pre-test predictions available (detailed motor system FEM concurrently developed during GVT)
  - Utilized Fixed-Base Correction (FBC) GVT technique developed by ATA Engineering to separate aircraft modes/contribution from motor system modes



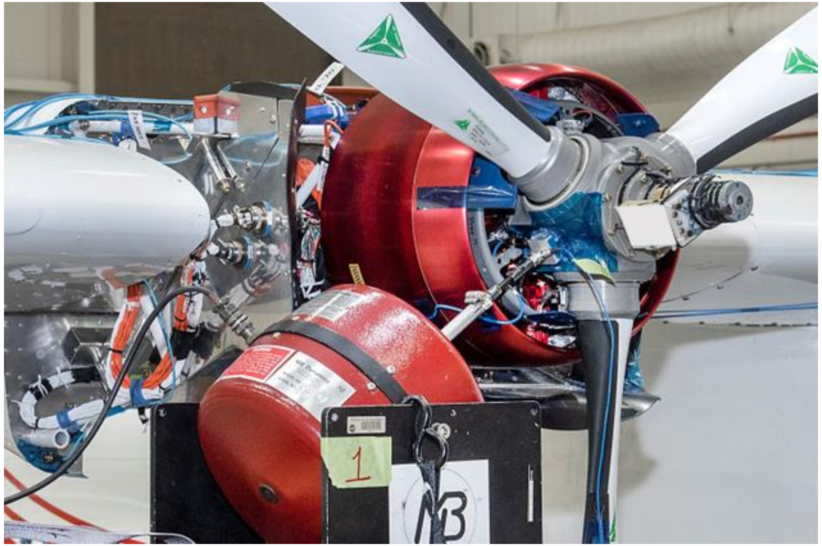




# Previous X-57 Mod II Ground Vibration Test

- Aircraft GVT – Dec. 2019
  *(2021 IMAC XXXIX, submission #10125)*
  - FEM validation for classical flutter analysis
  - On Soft supports – measured aircraft modes
  - Detailed modal assessment of the cruise motor (CM) assembly was not performed

**Mod II GVT on Bungee Soft Support**



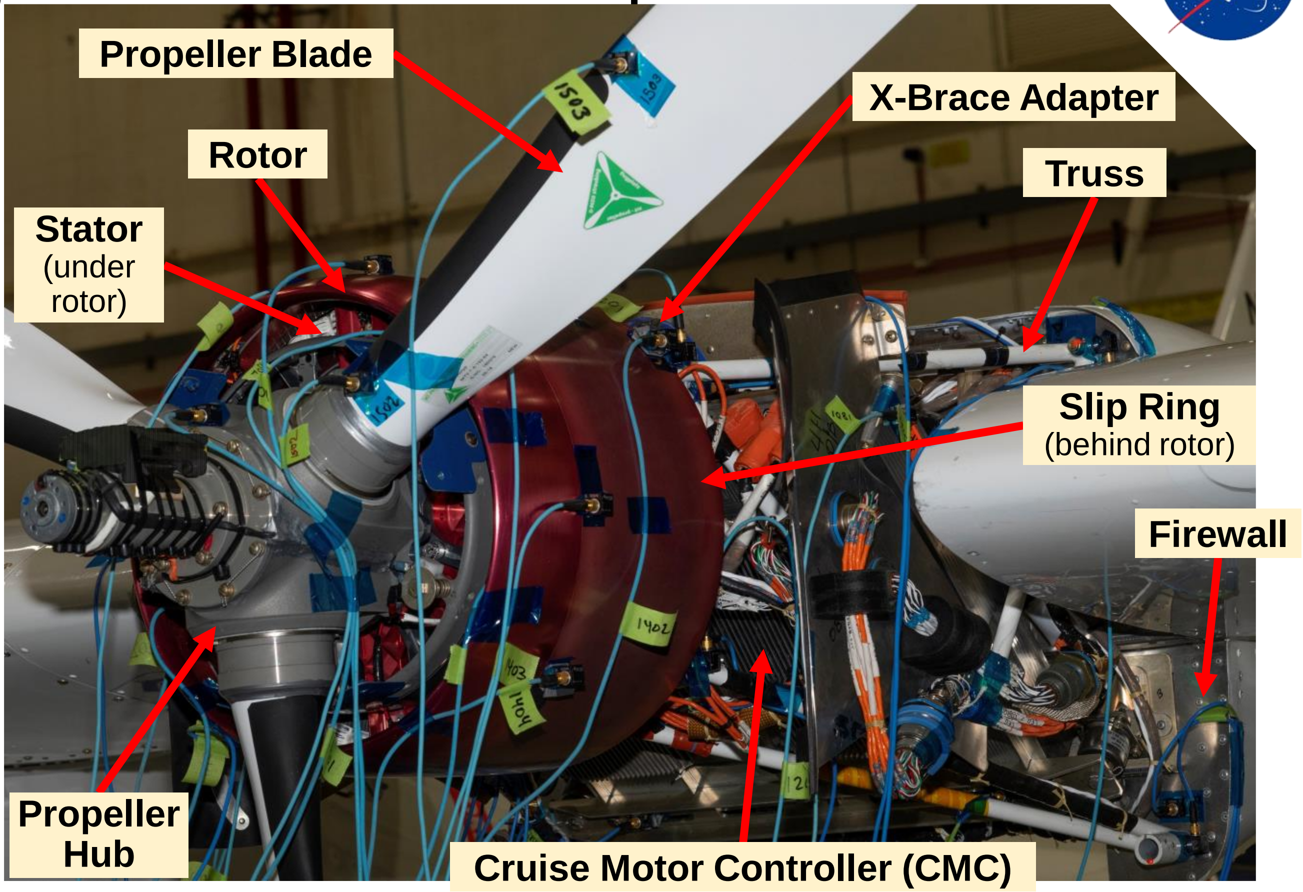
- Single shaker used for CM excitation
- Only firewall, X-brace adapter, and propeller hub center instrumented with triaxial accels (9 accels on motor system)

# Cruise Motor GVT Test Hardware/Configuration

- 37 PCB model T356A16 triaxial accelerometers, measuring 111 DOF
- Data acquisition (DAQ) system consisted of Brüel & Kjær LAN-XI 3050 and 3053 modules (126 available channels), and laptop running BK Connect 2022 v26.1.0.251.
- Testing performed using Dytran 5800B4 impulse hammer w/ soft tip (limited locations to attach shaker)
- Most of the motor installation hardware (wiring, baffling, sensors, etc.) remained attached

# Major Cruise Motor Components

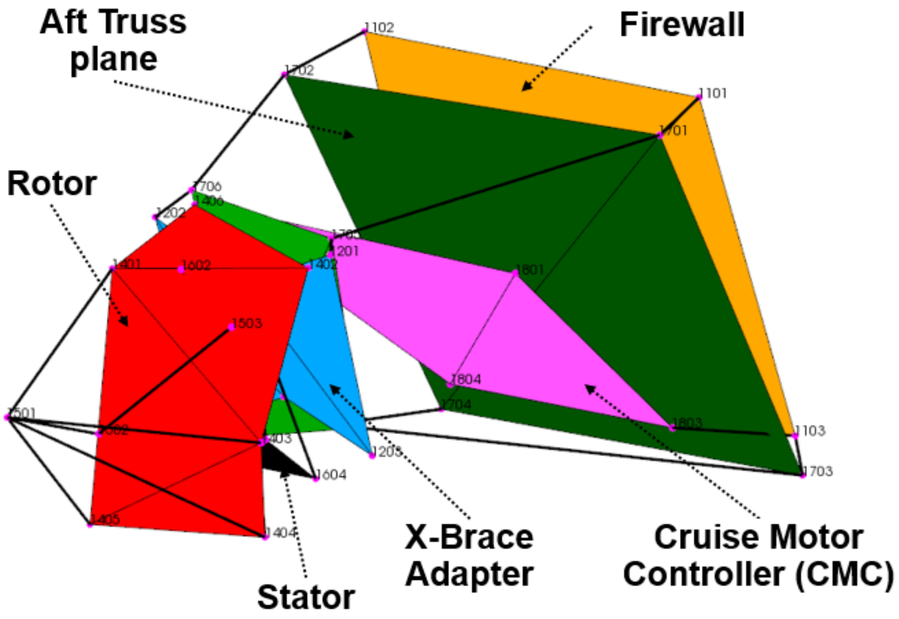
- Redesign focused on rotor/stator
- However, triaxial accels attached to all major CM components to help interpret GVT measurements
- Only portion of single prop blade was instrumented (measured prop modes during previous prop GVT)



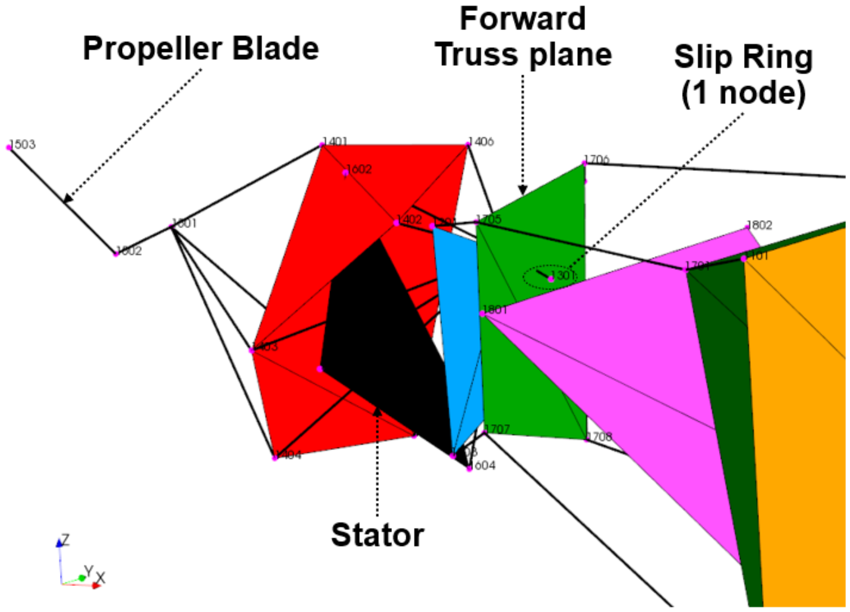
# Test Display Model

- Test Display Model (TDM) built with nodes at each accel location, and connected using lines and tri-elements to aide mode visualization

*TDM – Iso view looking aft towards CM*

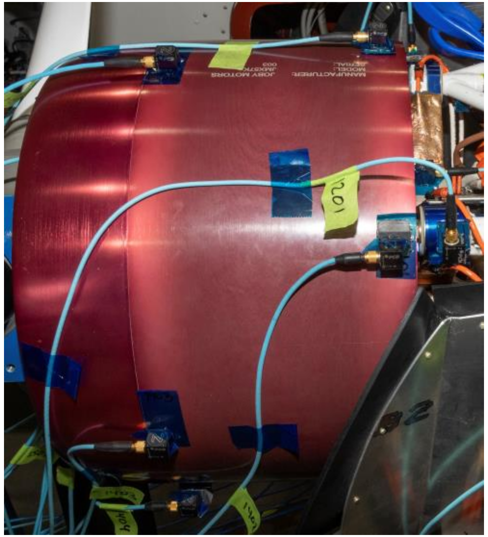


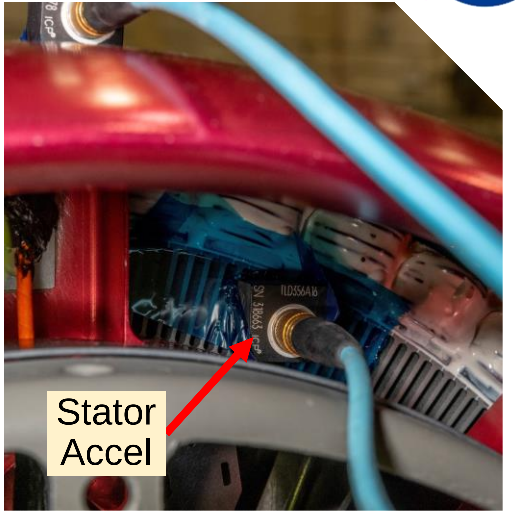

*TDM – Iso view looking fwd from Firewall*

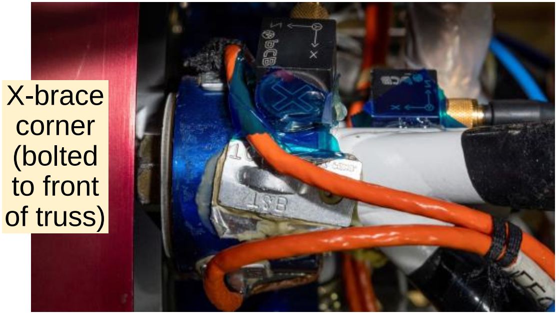


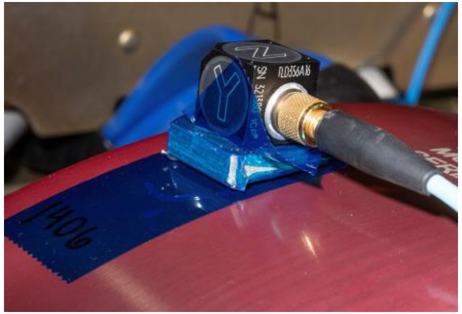
# Accelerometer Installations

- Triax accels attached using hot glue
- Flash breaker tape used to protect CM surfaces
- Utilized angle blocks to orient all accels into aircraft X-Y-Z axes
- Some accelerometers challenging to install
- Accel wire orientations chosen to provide clearance for using impact hammer





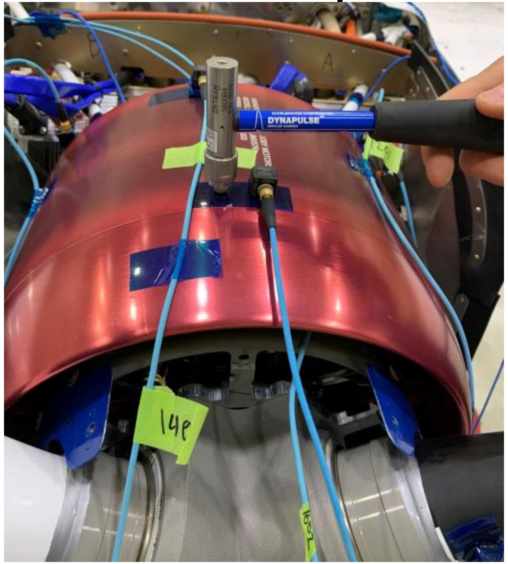



# Test Article Hammer Taps

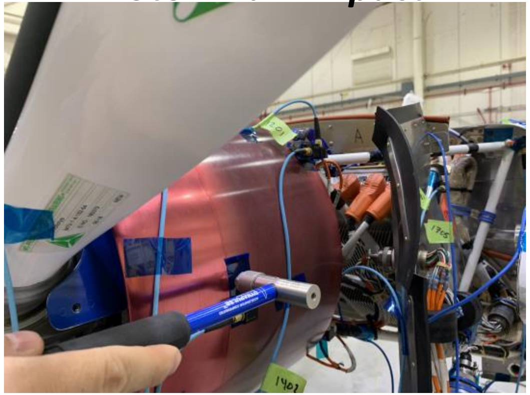
- First excited test article as normal to gather traditional GVT data

***Prop Blade X-dir impact***

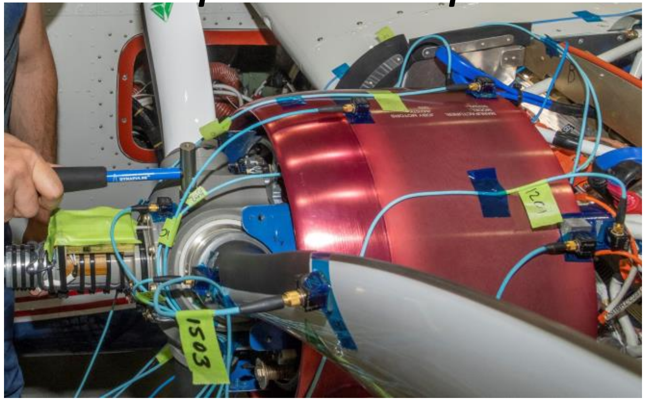

***Rotor Z-dir impact***




***Rotor Y-dir impact***



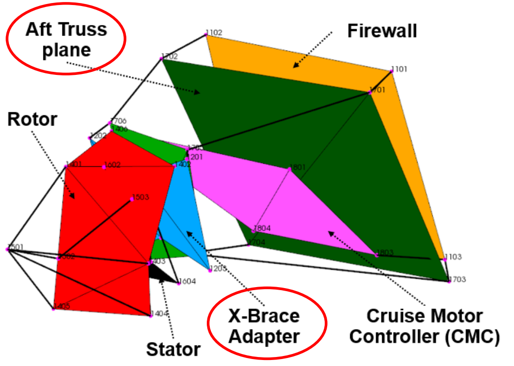
***Prop Hub Z-dir impact***

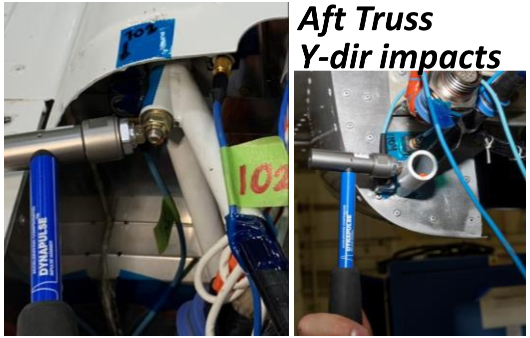


# Additional Hammer Taps for Applying FBC

- Next excited candidate DOFs for numerical FBC
- No changes to accel placement, number of accel measurements, or data acquisition settings between test article and candidate FBC taps
- For CM test (without pretest predictions) attempted “fixing” at two candidate locations (additional 24 taps)
  - X-Brace: X,Y,Z DOFs at 4 corners
  - Motor Aft Truss: X,Y,Z DOFs at 4 aft corners
- Sometimes had to settle for tapping on bolt or other rigidly connected structure near candidate “fixed” DOF

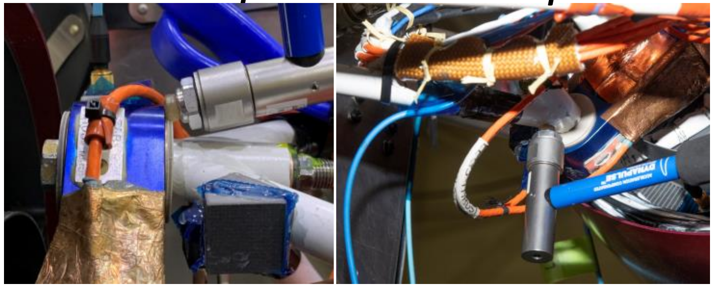
***“Fixing” at Two Candidate Locations***



***Aft Truss Y-dir impacts***

***X-Brace Adapter X-dir & Z-dir impacts***

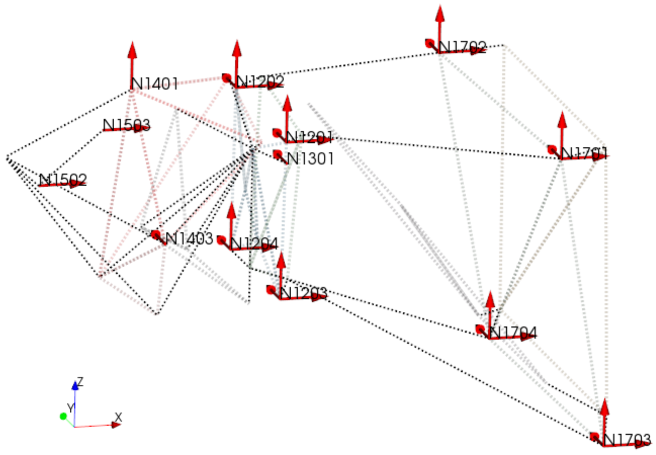


***Aft Truss X-dir impact***

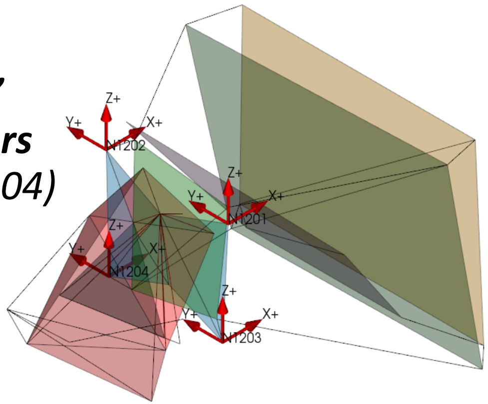
# Tap Locations Visualized on Test Display Model

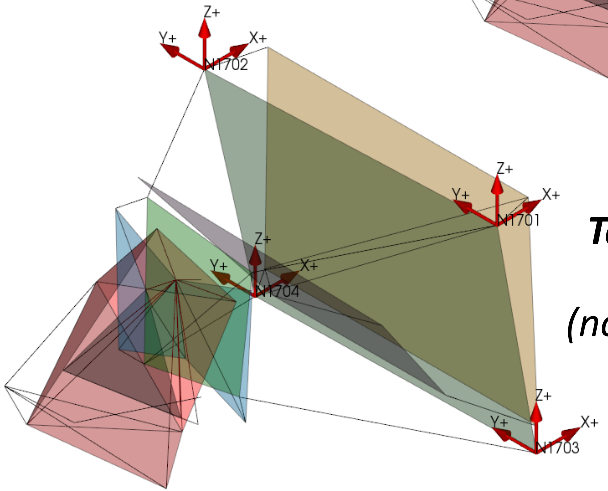
*Total of 29 hammer taps tests*

- *5 test article taps (traditional tap test)*
- *12 taps at 1st candidate fixed loc*
- *12 taps at 2nd candidate fixed loc*



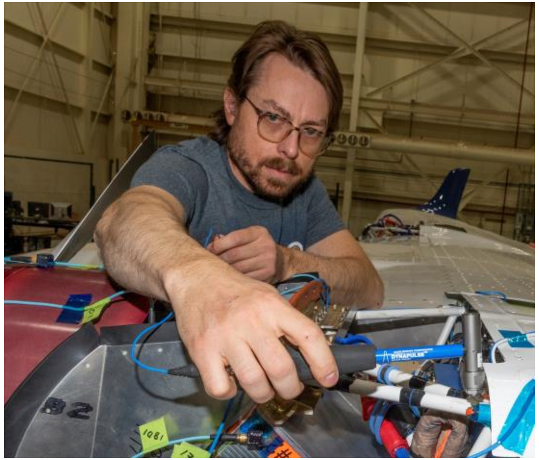

***Taps to "fix" X-Brace corners***
*(nodes 1201-1204)*



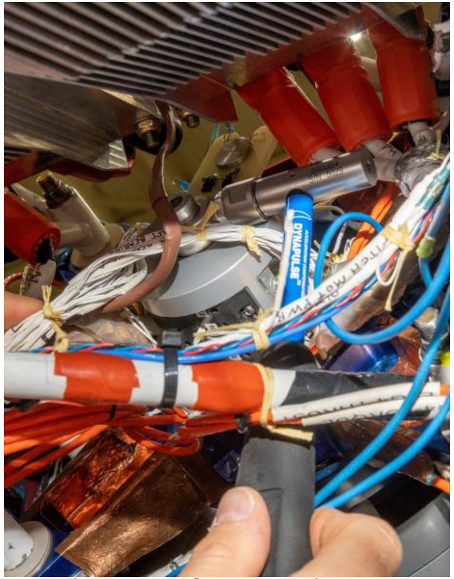




***Taps to "fix" Aft Truss corners***
*(nodes 1701-1704)*

# Some Taps Were More Challenging



*Don’t lean on the motor or aircraft…*




*Plenty of room here..*


*We will call these Z-dir taps*


*We’re going to need to order replacement hammer tips*

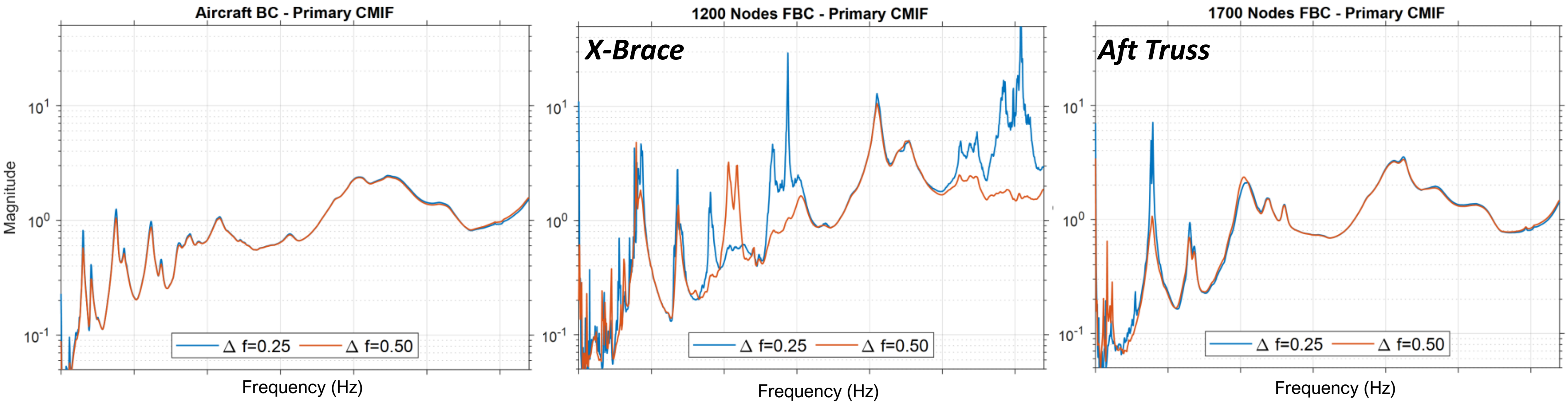
# Fixed Base Correction using SMURF

- Fixed Base Correction technique uses acceleration as references at specified locations to numerically create a "fixed" boundary condition
  - Calculate A/F using $H_1$ (typical FRF)
  - Perform partial inversion of the FRF matrix for locations to be fixed
  - Calculate updated FRF using Accelerations as references instead of Forces

- ATA's IMAT software enables inverting FRFs at candidate fixed base correction (FBC) points using extensions implemented in Structural Modification Using Frequency Response Function (SMURF)

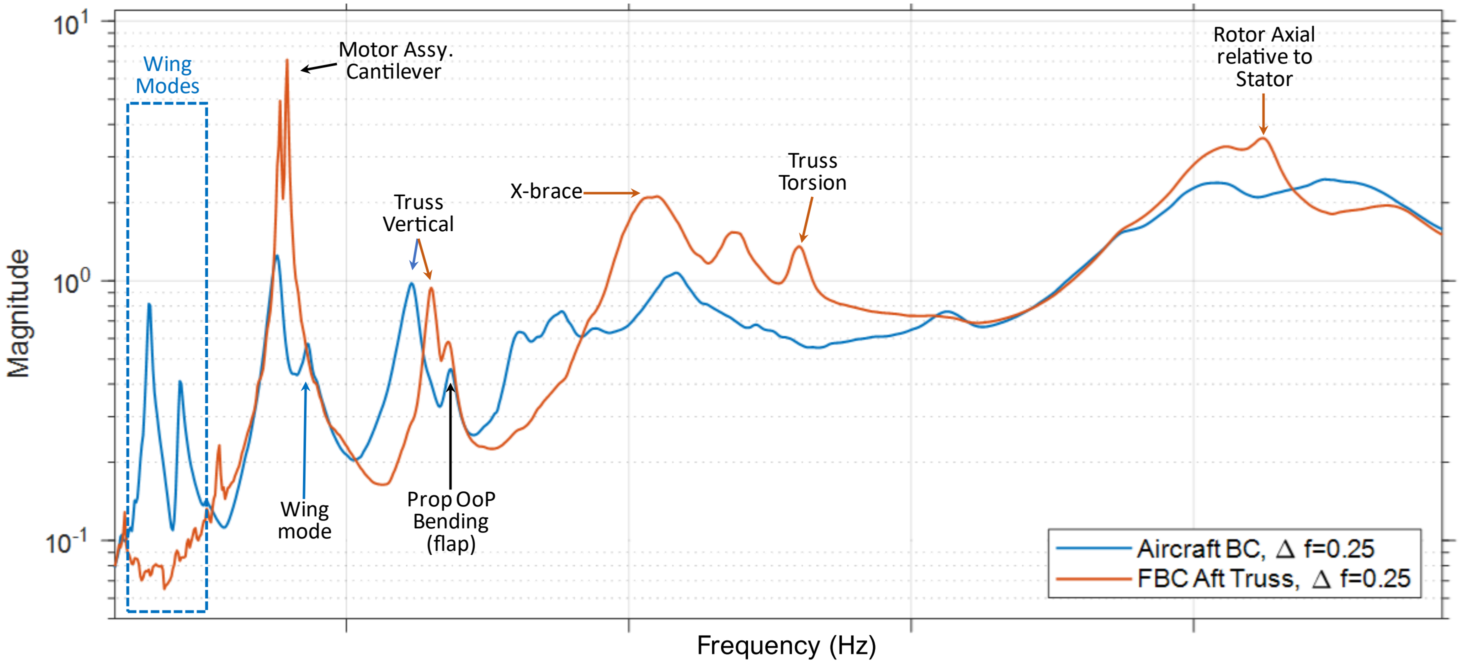
# CMIFs before/after IMAT SMURF Calculations

- FBC frequency response functions (FRFs) can be noisy if too many DOF are fixed
- FBC FRFs can also be too noisy if Δf is too tight → increase Δf by using a shorter frame length
  - For X-57 CM attempting FBC at X-brace (1200 Nodes) resulted in the noisiest FRFs



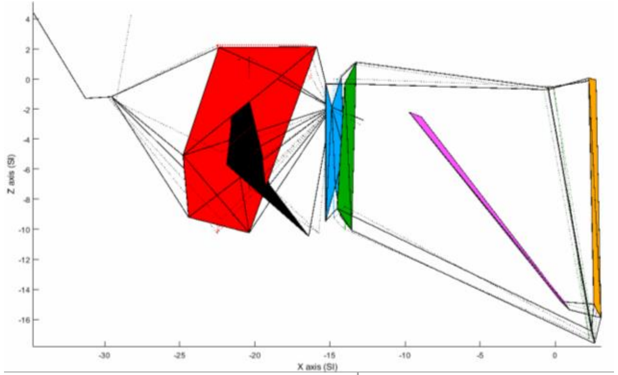
# CMIF Results using FBC Technique at Aft Truss

- CMIF using data from two excitations: [1] Z-dir on top of rotor, [2] X-dir at prop blade root
- FBC removes wing modes, and makes easier to pick out higher frequency motor system modes



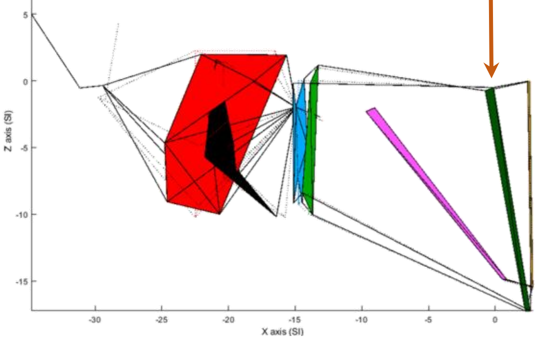
# Mode Shapes from Aft Truss FBC

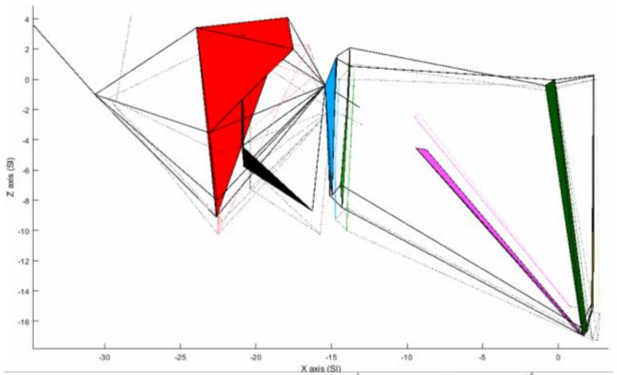
- Mode animations for Motor Assy. Lateral Cantilever, and Truss Vertical visualize fixed correction applied to aft truss nodes




*aft truss nodes fixed*

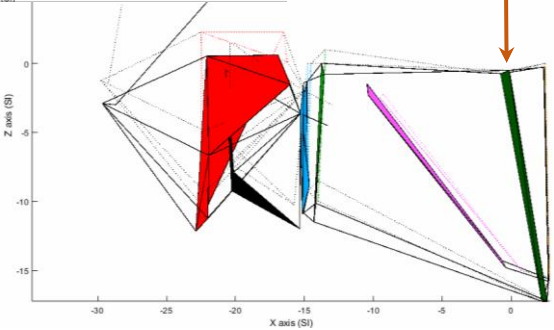
Motor Assembly Lateral Cantilever original (above), after FBC (right)



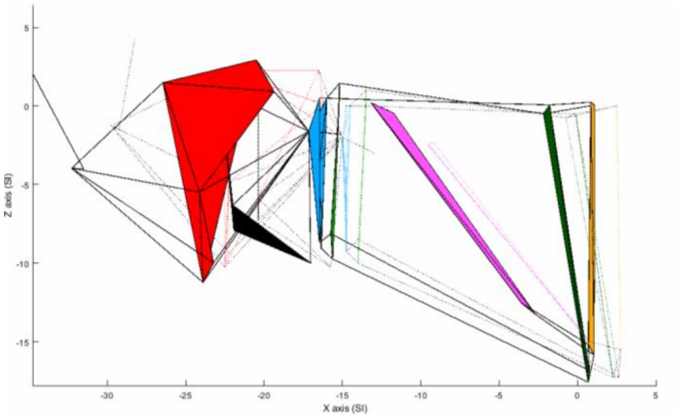

*aft truss nodes fixed*

Truss Vertical original (above), after FBC (right)

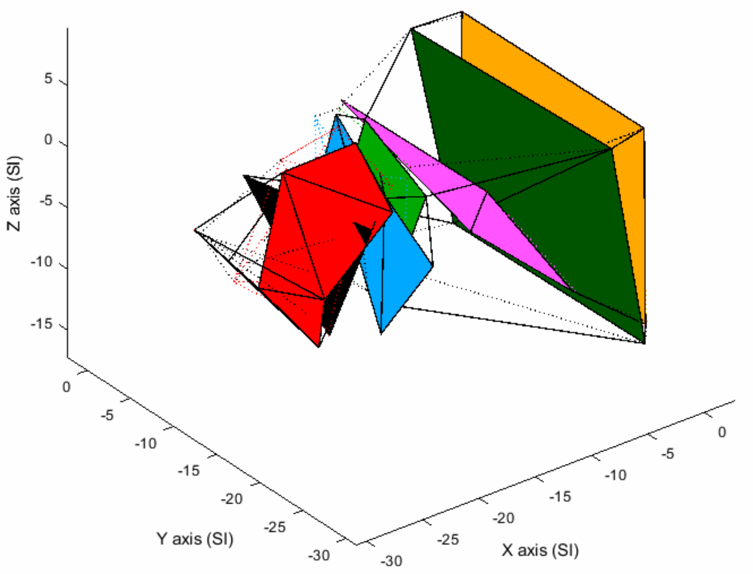


# Mode Shapes from Aft Truss FBC cont.

- Animations for modes missing in either aircraft BC data, or aft truss FBC data



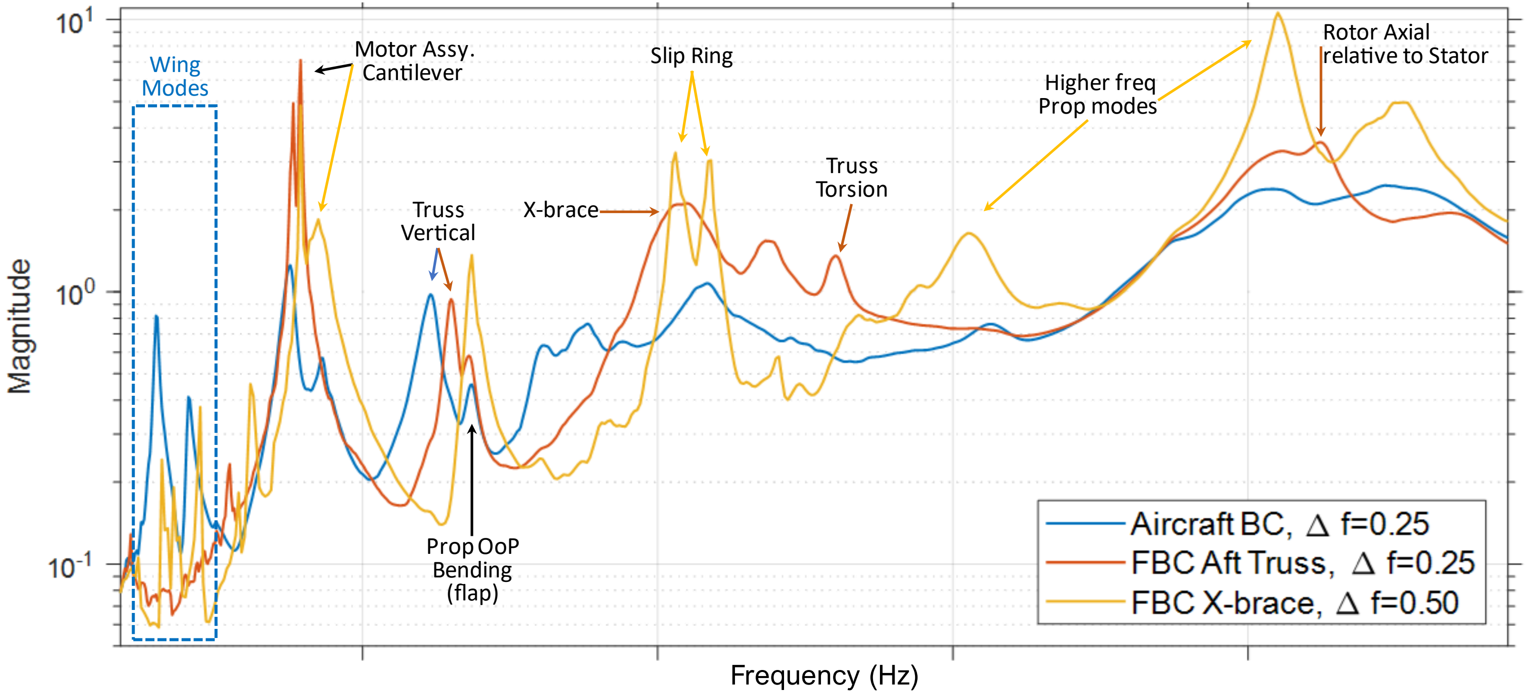

Higher frequency wing mode within frequency range of interest. Does not appear after FBC is applied.




Truss torsion mode, only identified after FBC was applied.

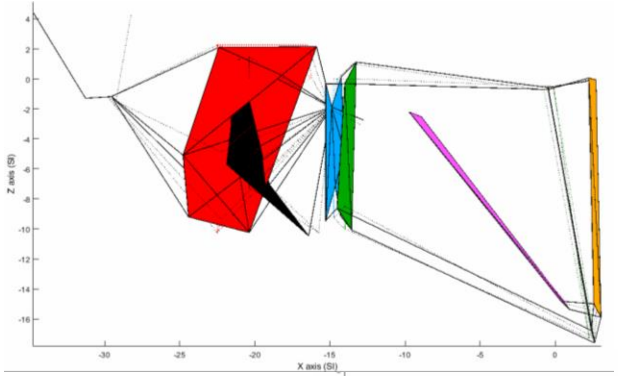
# CMIF Results using FBC Technique at X-Brace

- Applying FBC at X-Brace yielded much noisier FRFs



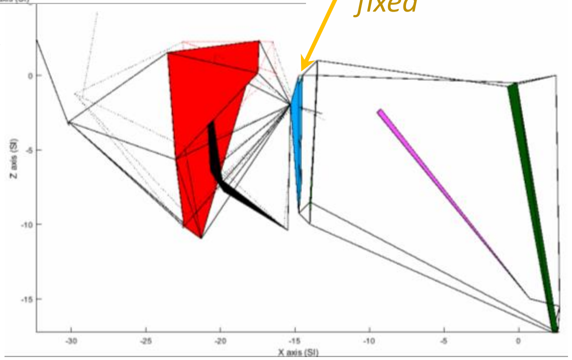
# Mode Shapes from X-Brace FBC

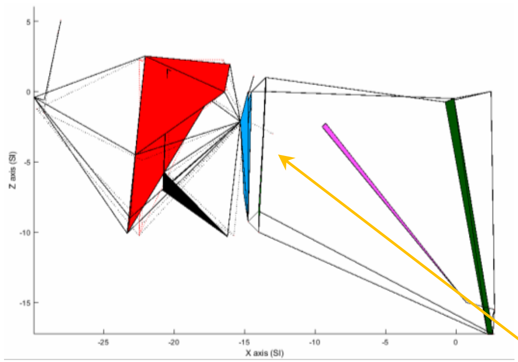
- Mode animation for Motor Assy. Cantilever after X-brace FBC (left); possible indication of X-brace flexibility contribution to cantilever mode
- Slip Ring Modes more prominent after X-Brace FBC correction applied




*X-brace corner nodes fixed*

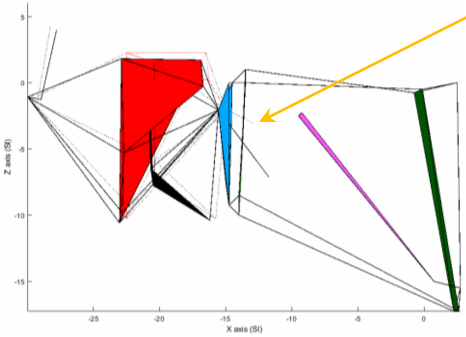
Motor Assembly Cantilever original (above), after X-Brace FBC (right)




Slip ring modes from X-Brace FBC

*Slip ring*



# Conclusions

- Fixed-Based Correction (FBC) technique can be utilized with impact hammer GVTs using ATA Engineering's IMAT tool suite; shaker excitation not required; much faster/simpler
- FBC technique successfully removed aircraft modes when GVT data was numerically "fixed" at the aft cruise motor truss
- FBC technique can greatly aide test engineer's understanding of the system under GVT when pretest predictions are not available
- FBC technique provides option to develop a simpler FEM
  - Did not need to model truss/wing firewall interface stiffness in cruise motor FEM for the planned rotor/stator redesign effort
- Continued utilization of impact hammer FBC technique on future tests will help build up knowledge of best-practices, and conditions under which good test data can be acquired
  - Ideal for test articles attached to a test stand, strongback, or when only interested in part of a structure

# Acknowledgements

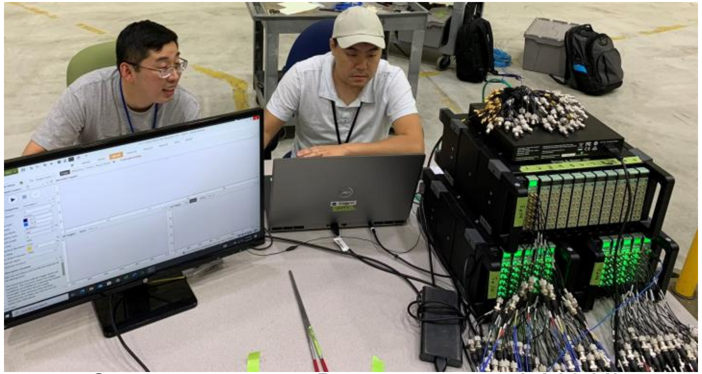
*Special Thanks to*

**Kevin Napolitano (ATA Engineering)**

**James Winkel (NASA LaRC)**

for guidance on applying the impact hammer fixed base correction test technique

<u>AFRC X-57 Cruise Motor GVT team</u>



Samson Ben *LAN-XI*


Scott Natalie Keerti