



# Chapter 8

## Mock Truss-Braced Wing Ground Vibration Test using Fixed Base Correction Method

Benjamin Park, Natalie Spivey, Keerti Bhamidipati, Saketh Vegunta, and Samson Truong

**Abstract** A truss-braced wing pathfinder research test article was designed by the Flight Loads Laboratory (FLL) at NASA Armstrong Flight Research Center (AFRC) in Edwards, CA. The Mock Truss-Braced Wing (MTBW) is a scaled aluminum 10-ft test article that consists of a high-aspect ratio swept wing box section supported at mid-span by a main strut, and a smaller jury strut. The MTBW wing box and main strut were attached to a strongback test fixture using interface hardware designed for loads calibration testing. Given the inherent challenges of designing a fixed boundary condition ground vibration test (GVT) fixture for large high aspect ratio wings, and to help develop test techniques for similar future test articles, the Fixed Base Correction (FBC) method developed by ATA Engineering was used to decouple MTBW test article modes mounted to the loads calibration interface hardware and strongback test fixture.

Pre-test Finite Element (FE) analysis showed test article modes drastically coupled with the loads calibration interface hardware and strongback test fixture. Test article modal data was acquired using impact hammer excitation. To implement the FBC method, additional impact hammer data and driving point accelerometer data at the bolted interface locations for the wing root and main strut root were acquired to use those locations as references when computing frequency response functions (FRF). By tapping at multiple bolted interface locations in three orthogonal directions, rigid body rotations were also accounted for to numerically “fix” the test article in all six degrees of freedom. By numerically fixing the test article, the test article modes were decoupled from the rest of the assembly and correlated more closely with the FE analysis when pinning the corresponding locations in the FE model.

**Keywords** Mock Truss-Braced Wing · Modal test · Ground vibration test · Fixed-base correction method

### Background

As a pathfinder research test article, the MTBW, was used to inform loads calibration and ground vibration testing techniques of a truss-braced wing design. The strongback and interface hardware the test article was mounted to was designed primarily for loads calibration. This interface hardware consisted of many parts because traditional methods for loads calibration on a wing do not work with the addition of a main strut as the structure becomes statically indeterminate, thus predicting reaction loads at the wing and main strut roots becomes more complicated.

The test article interface hardware consisted of strategically placed load cells for measuring the reaction loads at the wing and main strut roots. Additional load pins were integrated into the test article to measure the load share at the wing and main strut joint, and jury strut joints. The inclusion of all the load cells resulted in a relatively flexible interface hardware that affected the structural modes of the test article. In addition, the strongback and interface hardware structural modes coupled with test article modes of interest.

The Flight Loads Laboratory [1] (FLL) at NASA Armstrong Flight Research Center (AFRC) employed the fixed-base correction (FBC) method developed by ATA Engineering [2–5] to attempt to decouple the modes of the strongback and interface hardware from those of the test article. Decoupling the test article modes from the modes of the strongback and interface hardware also simplifies correlation to finite element model (FEM) predictions. The FLL previously applied the FBC method utilizing impact hammer excitation at candidate fixed-boundary points [6]. This FBC technique was once again

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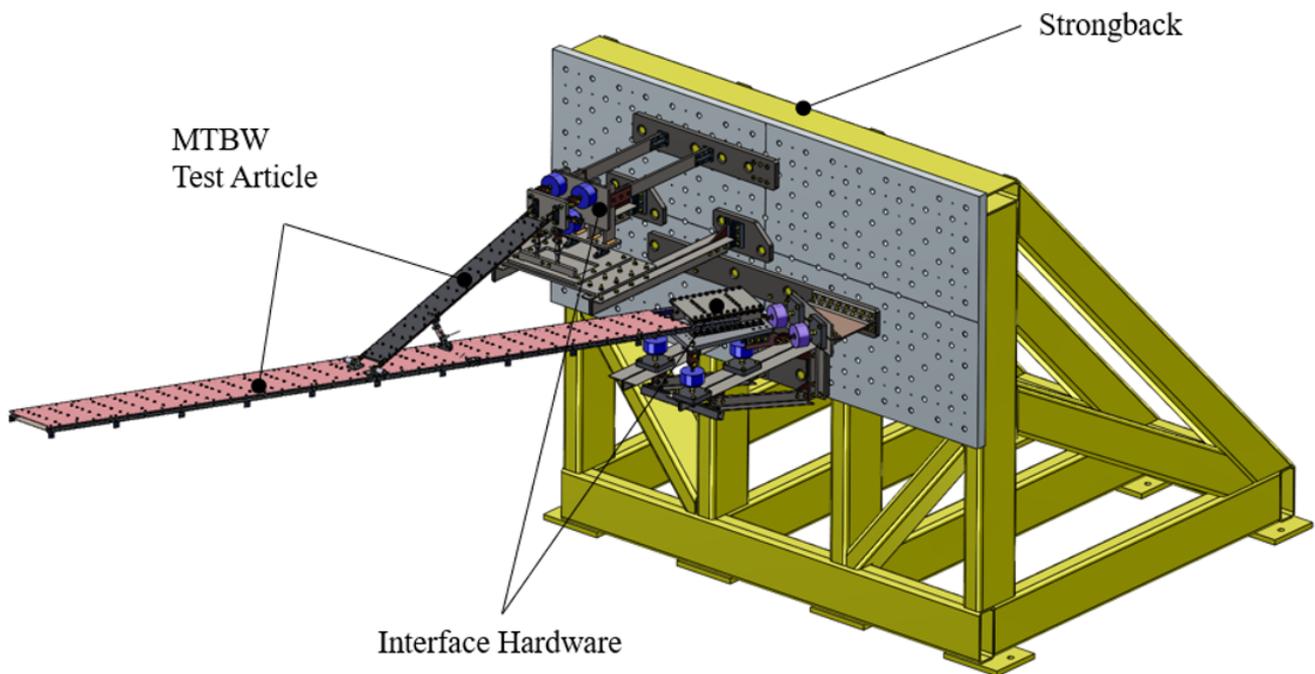
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utilized to numerically “fix” degrees of freedom (DOFs) for the MTBW test, and numerically apply different boundary conditions (BCs) to the test data.

## Test Setup

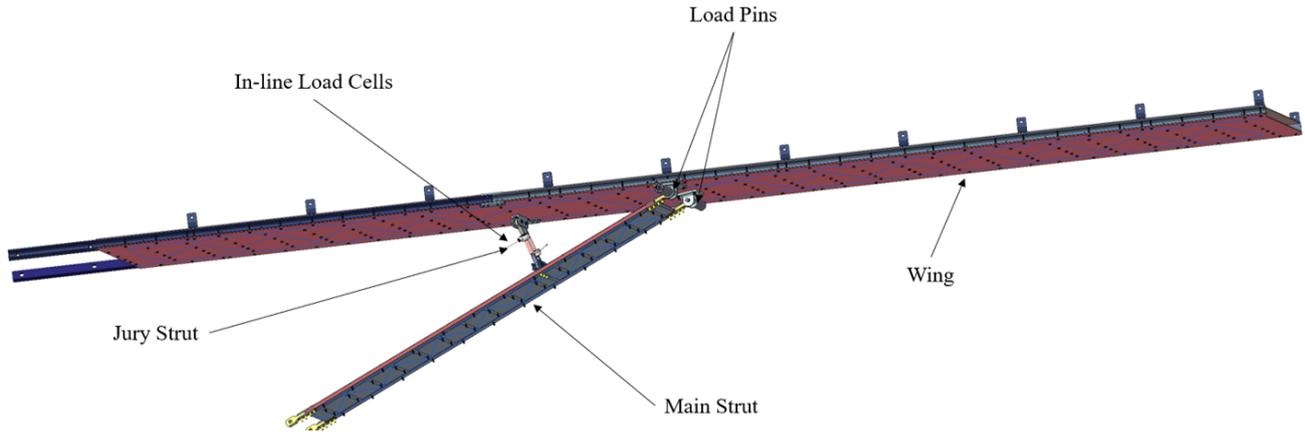
The MTBW GVT was conducted in September 2024 in the NASA AFRC FLL High Bay using impact hammers to excite the test assembly. The test assembly (Strongback + Interface hardware + MTBW test article) was bolted to the floor tracks of the lab high bay at the base of the strongback. The test article was mounted upside down on the strongback for the loads calibration test so the vertical up-load could be simply simulated by hanging weights at various wing and main strut stations. Since the loads calibration test was performed just prior to the GVT, load instrumentation such as strain gage and fiber optic wires were still connected to the test article for the GVT. These additional weights were not accounted for in the pre-test FEM predictions. The FBC method allowed using the same test setup for the GVT as the loads test which significantly reduced the cost of an additional test setup.



**Fig. 1** MTBW GVT Test Assembly Structural Components

### *Test article*

The test article consisted of a 10-ft, semi-span wingbox with a sweep angle of 24.7 degrees, a main strut with a dihedral of 17.2 degrees connected to the wing at an angle of 15.7 with the wing, and a jury strut connecting the wing and main strut inboard of the wing and main strut joint. The test article was fabricated using 7075-T6 aluminum. The interface hardware was fabricated using A36 steel. The test article was connected to the interface hardware at the wing root by four bolts, and at the main strut by two pins allowing the strut to rotate about the pin axis. The jury strut consisted of two in-line load cells to measure the axial load through it for the loads calibration test. During the GVT, both in-line load cells and load pins were monitored in real-time to check that the stiffness through the joints remained consistent across all test runs.



**Fig. 2** MTBW Test Article Components

### ***Instrumentation***

The data acquisition system used for the test consisted of Brüel & Kjær LAN-XI hardware and BK Connect software. Several LAN-XI 3053 modules housed in two LAN-XI 3660 11-slot mainframes recorded the 200+ channels needed to acquire the impact hammer and accelerometer response data. PCB 356A16 triaxial accelerometers were used throughout the test assembly, along with 12 PCB 393B04 seismic accelerometers installed on the strongback corners to help capture lower amplitude responses from the stiffer structure. Seismic and triaxial accelerometers were co-located at the strongback corners to assess the data quality of attempting the FBC method on the strongback corners using the two different sensors sensitivities (100 mV/g vs. 1000 mV/g). Table 1 summarizes the GVT node numbering and number of accelerometers used each structural component.

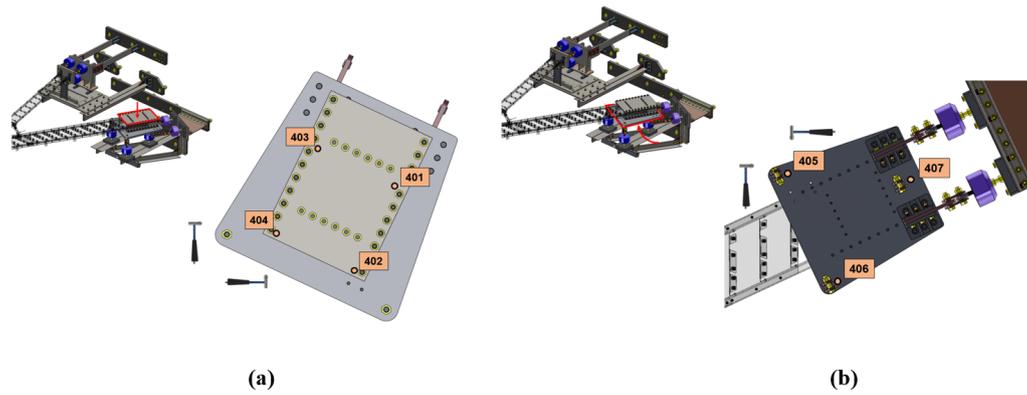
**Table 1** GVT Node Numbering by Structural Component and Accelerometer/Channel Count

<b>Component</b>	<b>Node ID</b>	<b># of Accels</b>	<b># of Channels</b>
Wing	100 series	19	57
Main Strut	200 series	10	30
Jury Strut	300 series	2	6
Interface Hardware	400 series	24	72
Strongback	500 series	12	36
Strongback Corners (Seismic)	600 series	12	12
<b>Total Accelerometers</b>		<b>79</b>	<b>213</b>

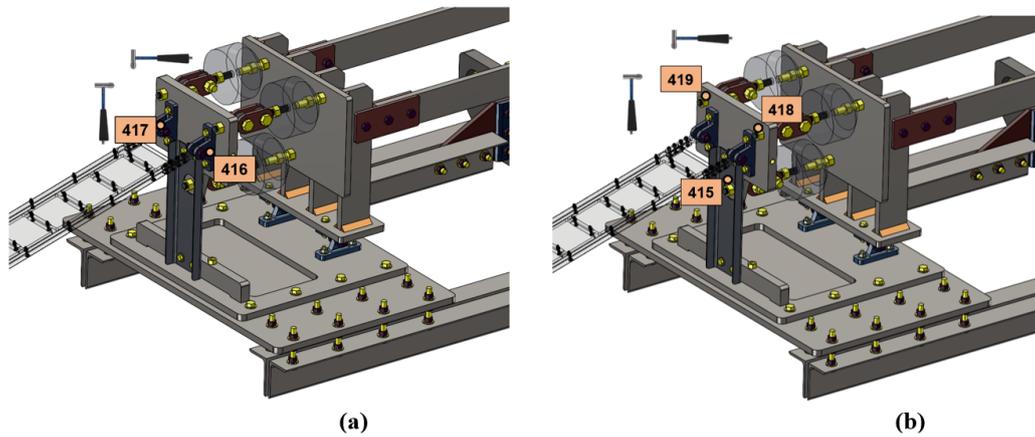
### ***Excitation locations***

Test article excitation was performed using a small Dytran 5850B impact hammer. A large Dytran 5802A impact hammer was used to excite the strongback corners in all three DOF's. For the FBC method, driving point FRF's are needed at DOF's to be numerically fixed, and were acquired by tapping at each candidate "fixed" location corresponding to the DOF. Due to accessibility directly at the bolts that connect the wing spars to the interface hardware, data at two sets of candidate locations to be "fixed" were gathered to attempt the FBC method at the wing root interface. Figure 3 shows the two sets of "fixed" candidate locations at the wing root: the Upper Plate (Nodes 401-404) and the Lower Plate (Nodes 405-407). Taps in each of the X, Y, Z directions were performed at each of these nodes, and triaxial accelerometers were used at each node to obtain driving point FRF's.

At the main strut root, candidate FBC locations consisted of the clevises (Nodes 416,417) and the Back Plate (Nodes 415,418,419) as shown in Figure 4. Taps in each of the X, Y, Z directions were performed at each of these nodes, and triaxial accelerometers were used to obtain driving point FRF's.



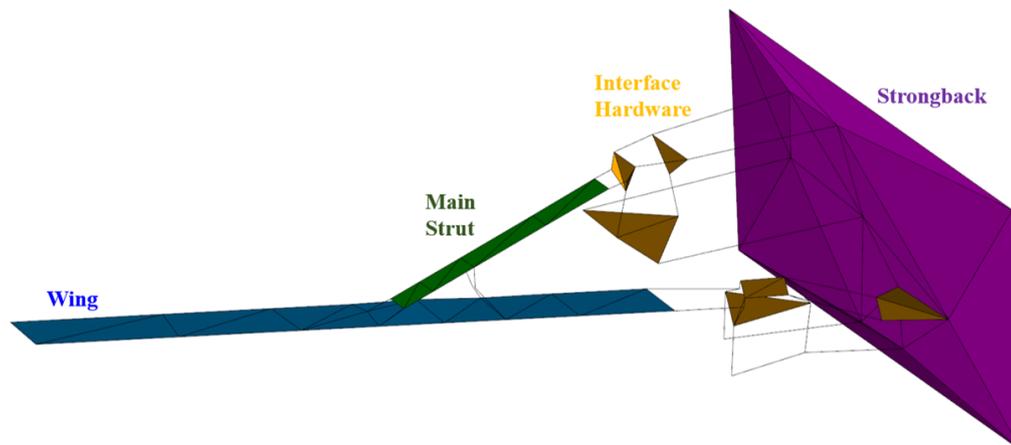
**Fig. 3** Wing Root Fixed Candidate Locations: (a) Upper Plate (401-404), (b) Lower Plate (405-407)



**Fig. 4** Main Strut Root Fixed Candidate Locations: (a) Clevises (416,417), (b) Back Plate (415,418,419)

## Results

Figure 5 shows the GVT test display model (TDM) that was used to visualize the mode shapes from the test. Each structural component is color coded for clarity. The TDM consisted of triangular elements and trachelines connecting nodal locations. Triaxial accelerometers were installed at all node locations.



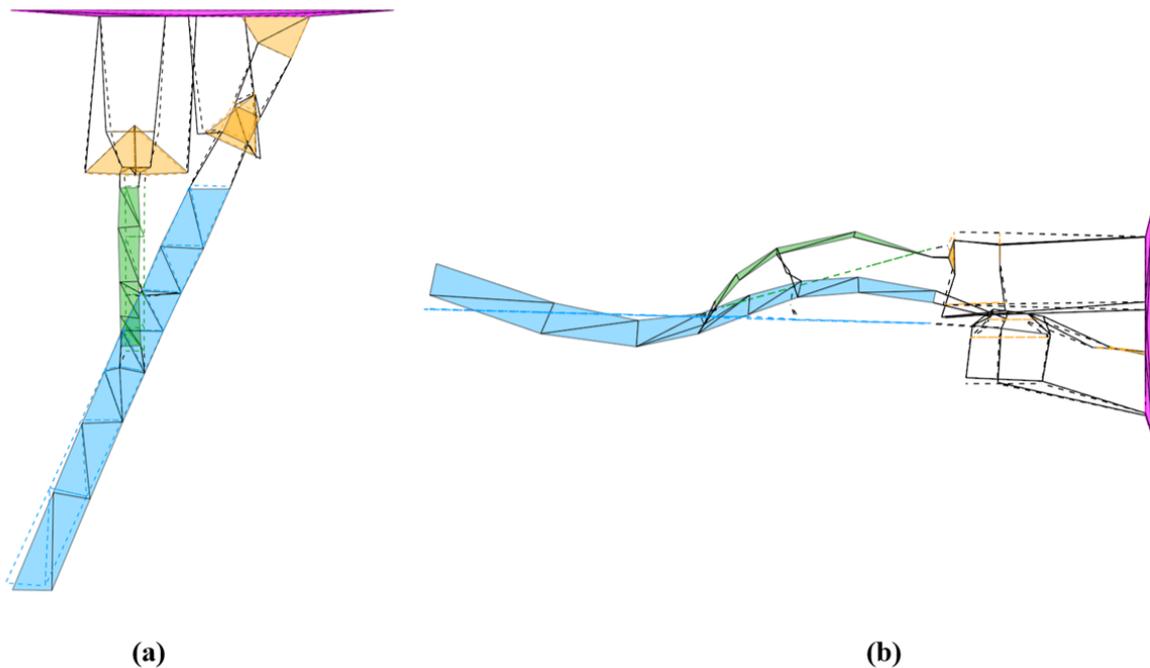
**Fig. 5** GVT Test Display Model

### **Baseline modes**

Baseline test runs, which are more traditional GVT runs, were performed with the small impact hammer at the wingtip, using excitation in both vertical and fore/aft directions. The first wing bending mode was observed at 6.3 Hz and second wing bending (with some main strut bending) was observed at 12.2 Hz. Third wing bending with strut vertical bending observed at 33 Hz. This mode is highlighted for comparison between baseline and FBC results.

The baseline test mode shape for wing third bending with strut vertical bending is shown in Figure 6. Dashed lines represent the undeformed test shape, and the solid lines represent the deformed test shape. The interface hardware substantially displaces (represented by black tracelines and yellow triangles), yielding significant modal coupling between the test article and interface hardware.

A review of ambient accelerometer data showed that for excitation at the wingtip, many accelerometer responses on the interface hardware were within or close to the noise floor up to about 20 Hz but had better separation above 20 Hz. Thus, for clarity, the mode shape at 33 Hz is used for illustration of the FBC method in the following figures.

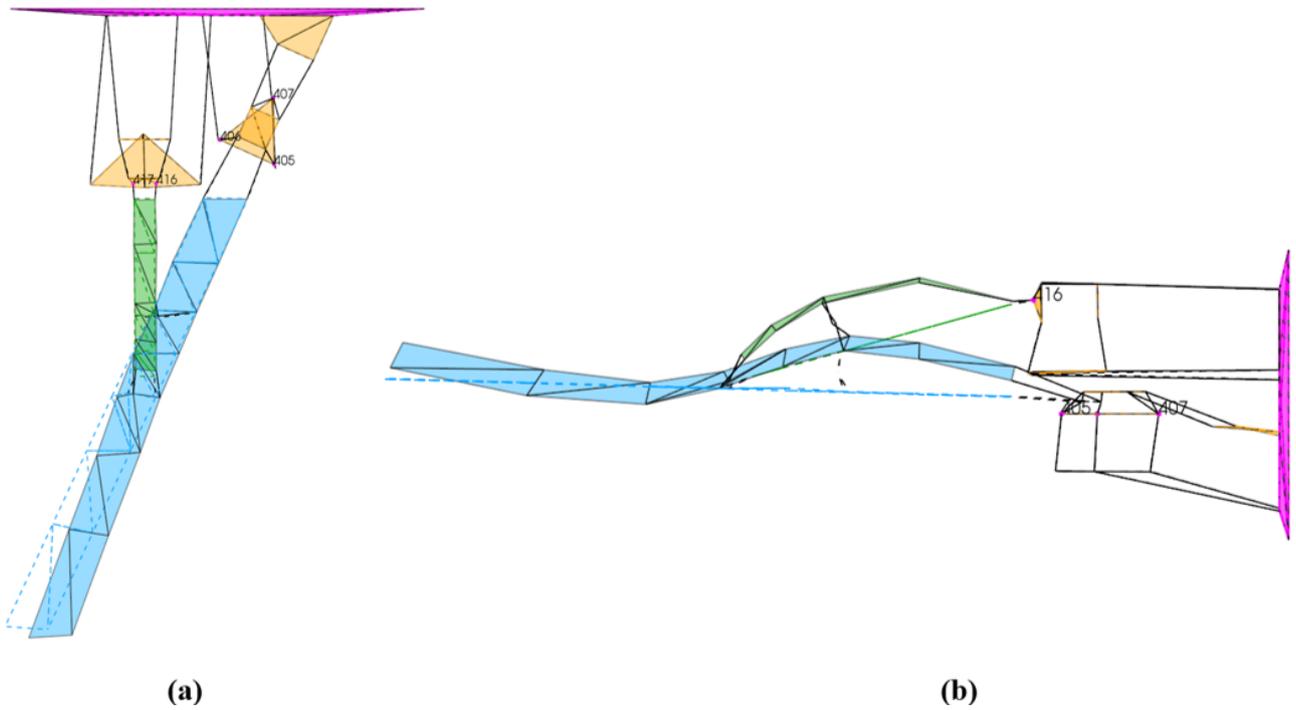


**Fig. 6** Baseline Wing Third Bending with Strut Vertical Bending (33 Hz) Test Mode (without FBC): (a) Top View, (b) Side View

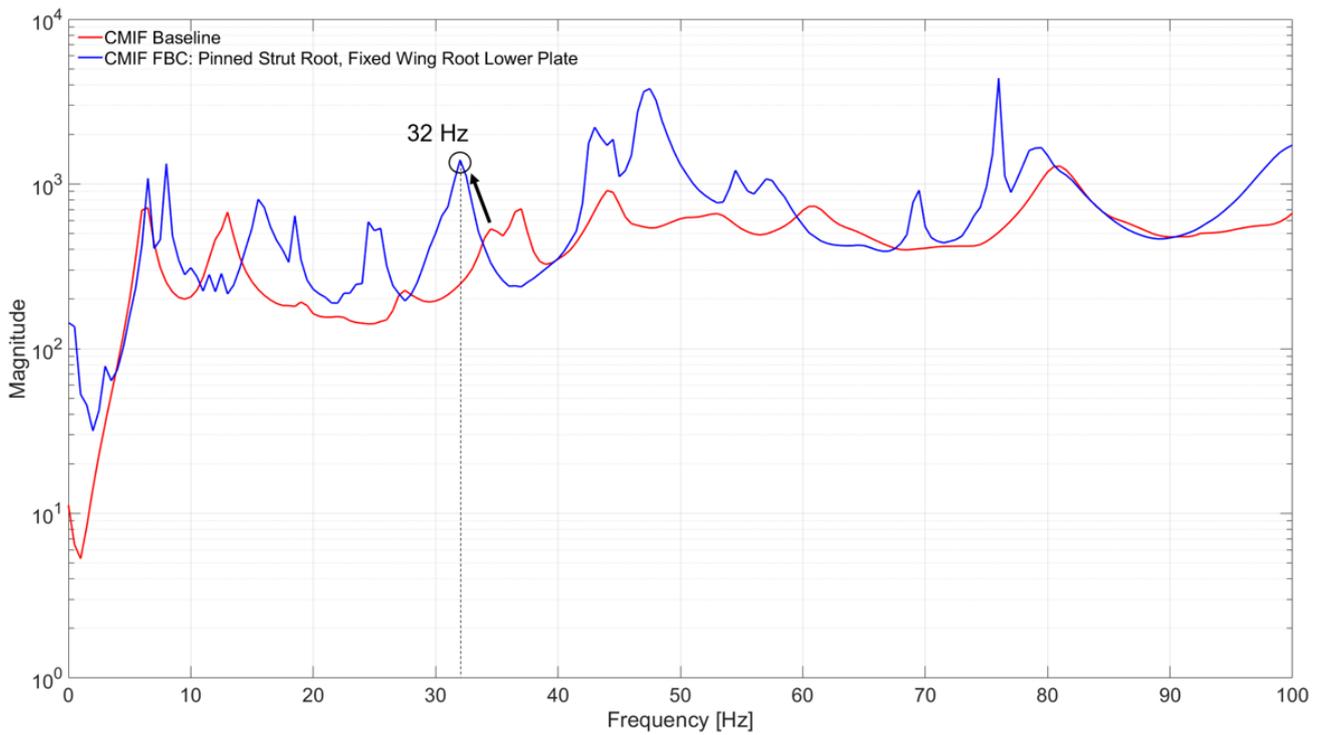
### **FBC with pinned BC at strut root Clevis and fixed BC at wing root lower plate**

To implement the FBC method time histories from the BK Connect software were imported into ATA Engineering's IMAT (Interface between MATLAB®, Analysis, Test) software to compute the FBC FRF's [2–5]. The FBC method was attempted at the Strut Root Clevises (Nodes 416,417) and Lower Plate (Nodes 405-407) of the wing root. This “fixed” boundary condition resulted in the smallest displacement in the interface hardware behind the fixed locations, which now appear to not be moving and modes are decoupled from the test article modes. The MTBW test article mode shape before and after applying FBC appears largely the same while mode frequency shifts down slightly from 33 to 32.3 Hz.

Figure 8 shows a Complex Mode Indicator Function (CMIF) overlay for the baseline results (red) with the FBC results (blue). The mode shape of interest shown in the previous figures is annotated in the plot. A shift in the frequency and cleaner peak is observed due to the FBC method. Curve-fitting for the lower frequency modes below 20 Hz requires further investigation as the noise in the interface hardware FRF's presents difficulty in extracting the FBC modes. Using the PCB 393B04 seismic accelerometers at this fixed location would most likely clean up the FRF data below 20 Hz, but this was not attempted for this test.



**Fig. 7** Wing Third Bending with Strut Vertical Bending (32.8 Hz) Test Mode for FBC at Lower Plate: (a) Top View, (b) Side View



**Fig. 8** CMIF Comparison between Baseline Results (Red) with FBC Results (Blue)

## Conclusion

Utilizing the FBC method significantly reduced the displacement of the interface hardware by fixing the wing and strut root locations of the test article. In general, the frequencies went down from the baseline frequencies per corresponding mode shape. Some residual mode shape displacement at the interface hardware could be due to data quality or over-constraining the fixed locations. Further investigation is required to reduce the number of DOF's at the fixed locations to see if the mode shape displacements at the interface hardware decrease.

Challenges with applying the FBC method at low frequencies can be attributed to the sensitivity of accelerometers, the environment in which the test is conducted, the source of excitation etc. It can be difficult to obtain clean FRF's after applying the FBC method if there is insufficient separation in between accelerometer responses and the noise floor at the nodes where the correction is applied.

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