

Design and Characterization of 3D Printed Optimization-Driven Aeroelastically Scaled Wind Tunnel Model for High Aspect Ratio Flying Wings

Executive Summary

Body Freedom Flutter is a common phenomenon found in high aspect ratio flying wings caused when the first rigid body mode and first bending mode couple[1]. Currently, researchers are looking into active and passive flutter suppression techniques. To facilitate this research, low-cost iterative optimization driven 3D models provide a test bed for creating novel flutter suppression techniques. This poster summarizes the characterization of an aeroelastically scaled 3D printed wind tunnel model through geometric scanning, ground vibration testing, and initial aerodynamic data.

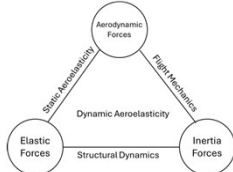


Figure 1. Collar's Triangle: Shows the relationships between the elastic, aero, and inertial forces

Background

- Aeroelasticity** investigates the combined effects of the elastic, inertia, and aerodynamic loads acting on an aircraft[3].
- In **previous work**, an X-56 model was scaled using size optimization to create a dynamically scaled aeroelastic model by matching the first two mode shapes and frequencies. Different optimization zones were used to achieve varying stiffness and mass distribution in the model. The current wing is improved from the previous wing by using aluminum spars instead of 3D printed carbon fiber spars[4].

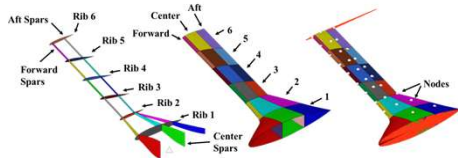


Figure 2. Shows the layout of the internal structure and the different optimization zones. Each color of the wing is a different thickness [4].

Experimental Setup

Assembly and Materials

- The wing is a scaled version of the X-56.
- The spars are made by laser cutting sheet 6061 Aluminum.
- The outer mold line is created by printing on the HP580 Multi-Jet Fusion powder bed printer. The part was broken up into sections due to build volume constraints.
- Permabond TA-4550 Adhesive was used.
- The airfoil sections are slid over the spars.

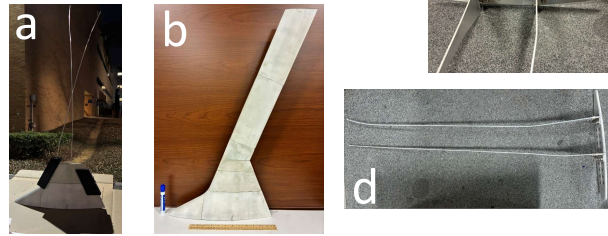
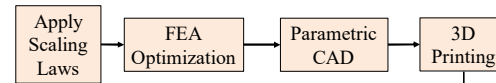


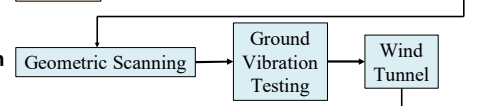
Figure 3. Assembly Photos : a) Mid-Assembly b) Fully Assembled c) Internal Structure d) Internal Structure 30 inches long

Experimental Test Plan

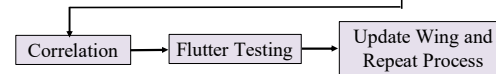
1. Modeling



2. Characterization



3. Testing



Three characterization Tests

- FaroArm Laser 3D Scanning**
 - Creates a point cloud of part to compare back to CAD.
- Ground Vibration Testing**
 - Finds the natural frequency and mode shapes.
 - Test conducted by the Air Force Research Laboratory (AFRL) with a Laser Vibrometer.
- Wind Tunnel Testing**
 - Also completed at AFRL
 - Characterized Lifting, Drag, Pitching Moment Coefficients and Wingtip Deflection
 - 5 to 20 angle of attack sweep at speeds for 12.5m/s 20 m/s, 25 m/s and 30m/s
 - Laser displacement sensor measured deflection



Figure 4. Wing in Wind Tunnel

Experimental Results

Table 1. Comparing Predicted and Experimental Frequencies

	Percent Error of Frequency
Mode 1	33%
Mode 2	20%

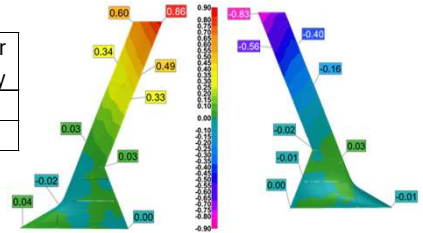


Figure 5. Point Cloud Scans Comparing Wing to CAD Geometry. Scale is in Inches.

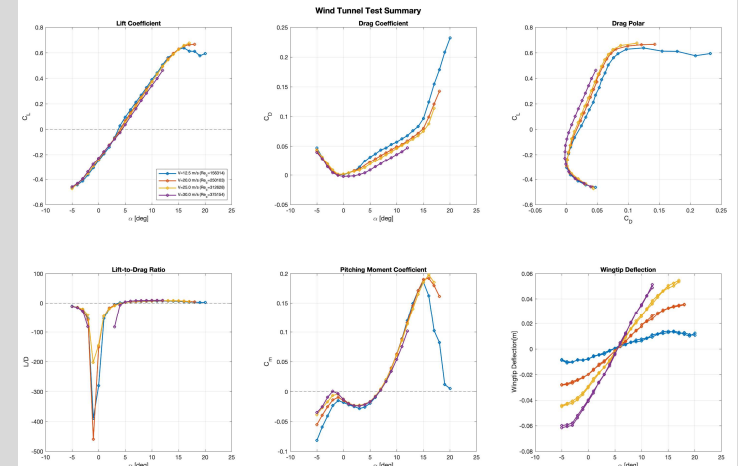


Figure 6. Aerodynamic Data

Conclusions

- The geometric scans shows the dihedral angle is different between the CAD model and the fabricated model. There also appears to be some twist along the span. This is due to the aluminum spars being bent during assembly. A new bending technique would prevent this error.
- The ground vibration test show there is error in the frequency. The next step is to tune the FEA model to the GVT results by adjusting mass and stiffness.
- The aerodynamic data looks reasonable. The lift curve slope looks good. As expected, the highest wing tip deflection occurred at the largest speed.

References

- [1] Penning, K., Zink, S., Wei, P., De La Garza, A., Lowe, M., and Martinez, J., "Aeroservoelastic Analysis of a SensorCraft Vehicle and Comparison with Wind Tunnel Data," presented at the 50th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, 2009. <https://doi.org/10.2514/6.2009-2405>
- [2] Castrale, J., "Whirl Flutter of Turboprop Aircraft Structures," Elsevier Science & Technology, San Diego, UNITED KINGDOM, 2015.
- [3] Bisplinghoff, R. L., Ashley, H., and Halfman, R. L., "Aeroelasticity," Dover, New York, 1996.
- [4] Leevy, M., Gattu, S., Taylor, R. M., McHugh, K., and Jones, N., "Development of a 3D Printed Optimization-Driven Aeroelastically Scaled Wind Tunnel Model for High Aspect Ratio Flying Wings," presented at the AIAA SCITECH 2025 Forum, 2025. <https://doi.org/10.2514/6.2025-0196>

Acknowledgements

I would like to thank the following for support Air Force Research Laboratory (AFRL), Kevin McHugh (AFRL), National Defense Science and Engineering Graduate (NDSEG) Fellowship, David Duke from Lockheed Martin. Wind tunnel data cleared for public release as AFRL-2026-1686.