Towards Energy-Dense Wing Structures for UAVs Using Structural-Battery Composites

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UNIVERSITY OF South Carolina
NSF NHERI CYBER-PHYSICAL SIMULATION
IMECE 2025-173974
ASME SETTING THE STANDARD
IMECE Track 19-02
NSF REU Poster Competition

Project Objective and Goal

To develop characterization methodologies for custom composite plates in fixed-wing UAV wing applications

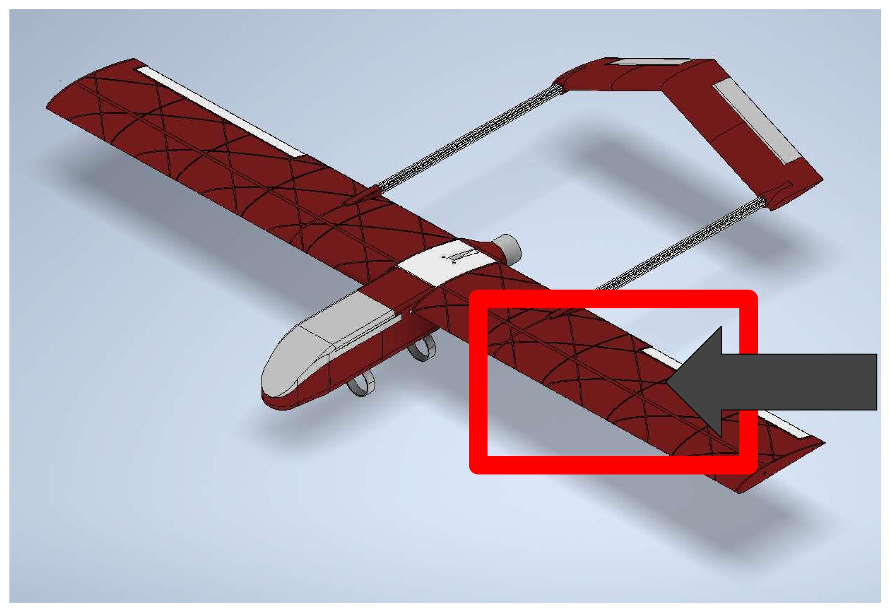


Fig. 1. Fixed-wing UAV model (ARTS-Lab, 2025)

Introduction

- UAVs excel in remote field work (Adawy et al., 2023)
- Composites have increasingly important role in aircraft design optimization
  - Including structural batteries (Jin et al., 2023)
- Aircraft are subject to extensive testing to uphold flight standards (Blasi et al., 2021)
- *A characterization protocol will create a GFRP property database*

Background

- Currently, aerospace composite work is focused on carbon fiber (CFRP)
- Strength-to-weight ratios are key
- Fiberglass (GFRP) composites offer similar properties, but are lower cost and easier to assemble (Ashrith et al., 2023)
- Structural battery composites further aid in design optimization (Jin et al., 2023)

Fig. 2. VARTM setup (left) and a structural battery layup (right).

Preliminary Results: *Error of 7.7%!*

STATIC:

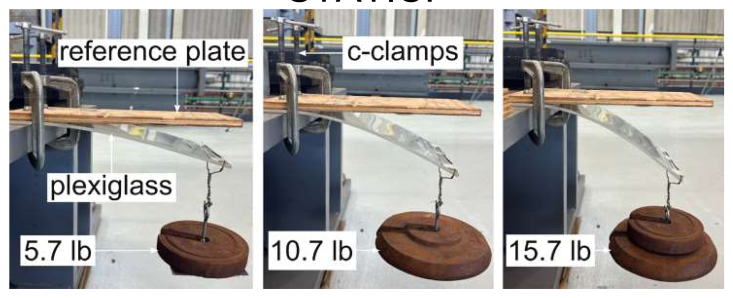


Fig. 3. Preliminary static testing on plexiglass mock specimen.

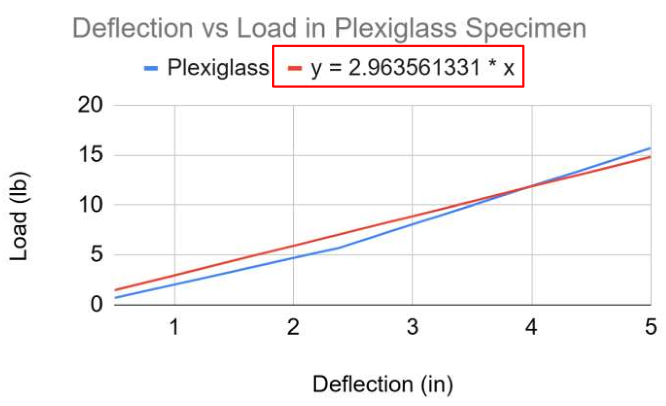


Fig. 4. Graphical least squares estimation of fig. 3 deflection data

DYNAMIC:

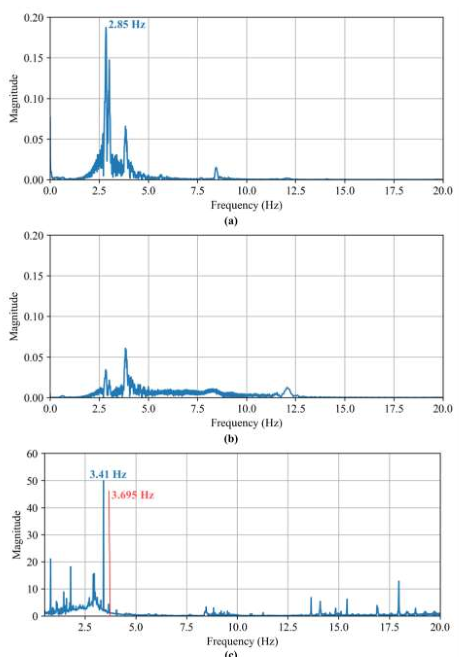


Fig. 5. FFT ratio of plexiglass modal data (fig. 6).

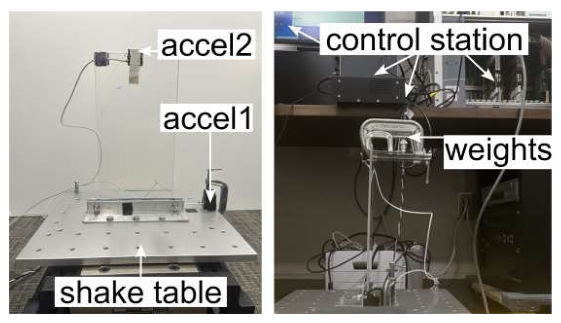


Fig. 6. Preliminary dynamic testing on plexiglass mock specimen.

Experimental Setup & Results: Static Characterization

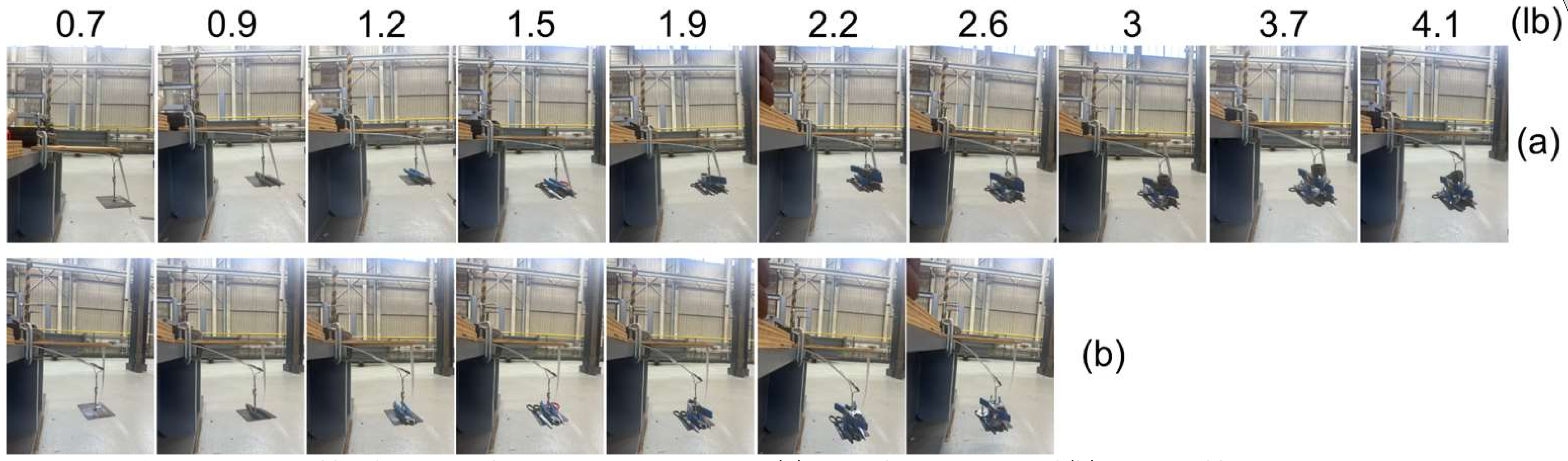


Fig. 7. Sequential load in static characterization set up on (a) control composite and (b) structural battery

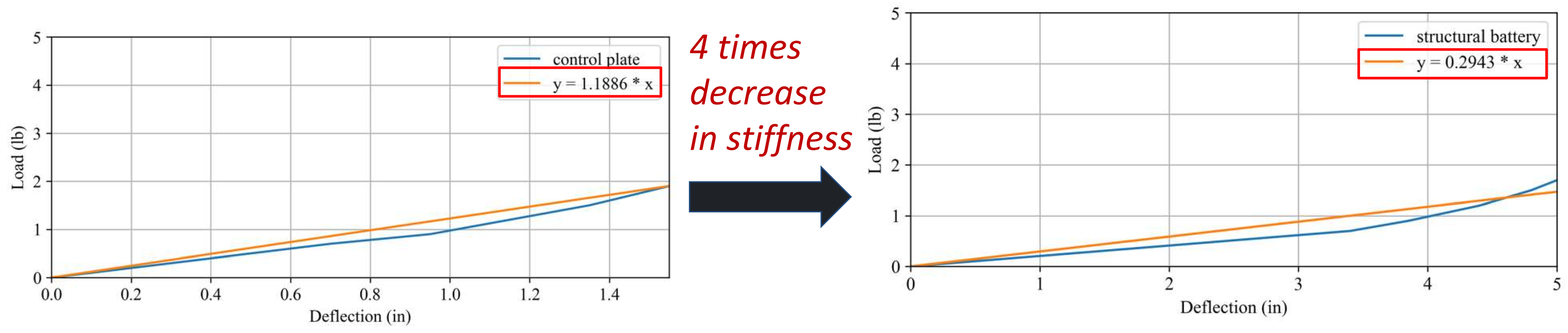


Fig. 8. Stiffness comparison between control composite (left) and structural battery (right)

Experimental Setup & Results: Dynamic Characterization

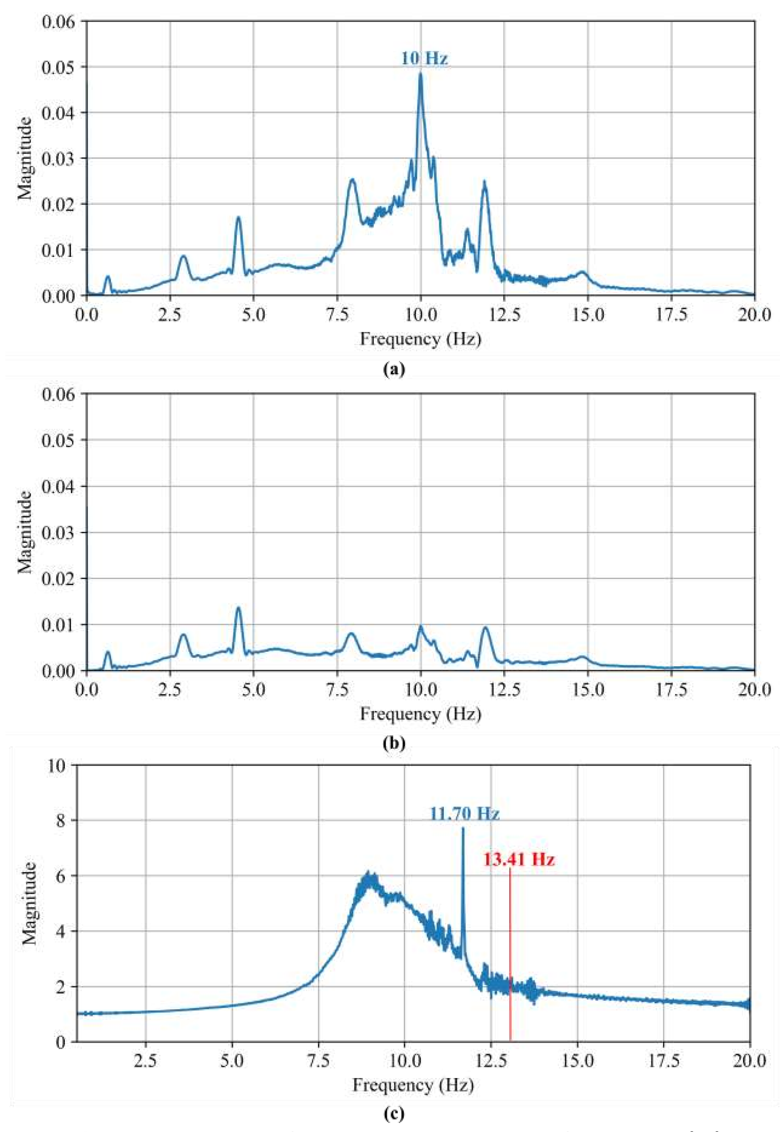


Fig. 10. Control composite FFTs showing (a) plate response, (b) table response, and (c) their ratio with theoretical comparison

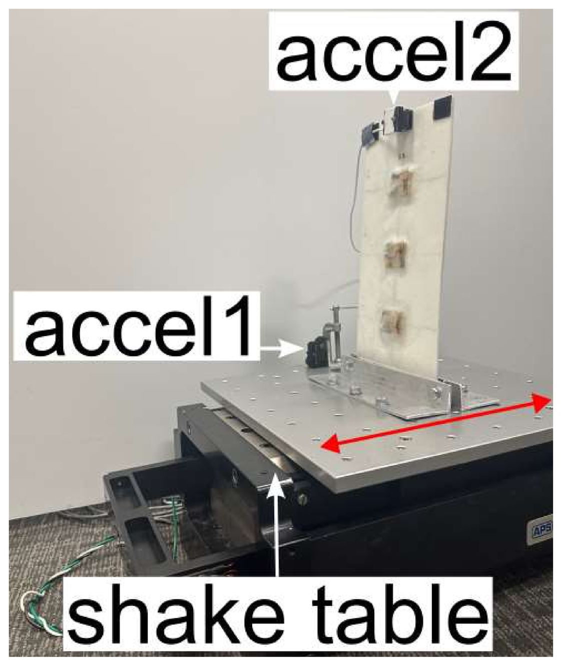


Fig. 11. Labeled modal characterization set up

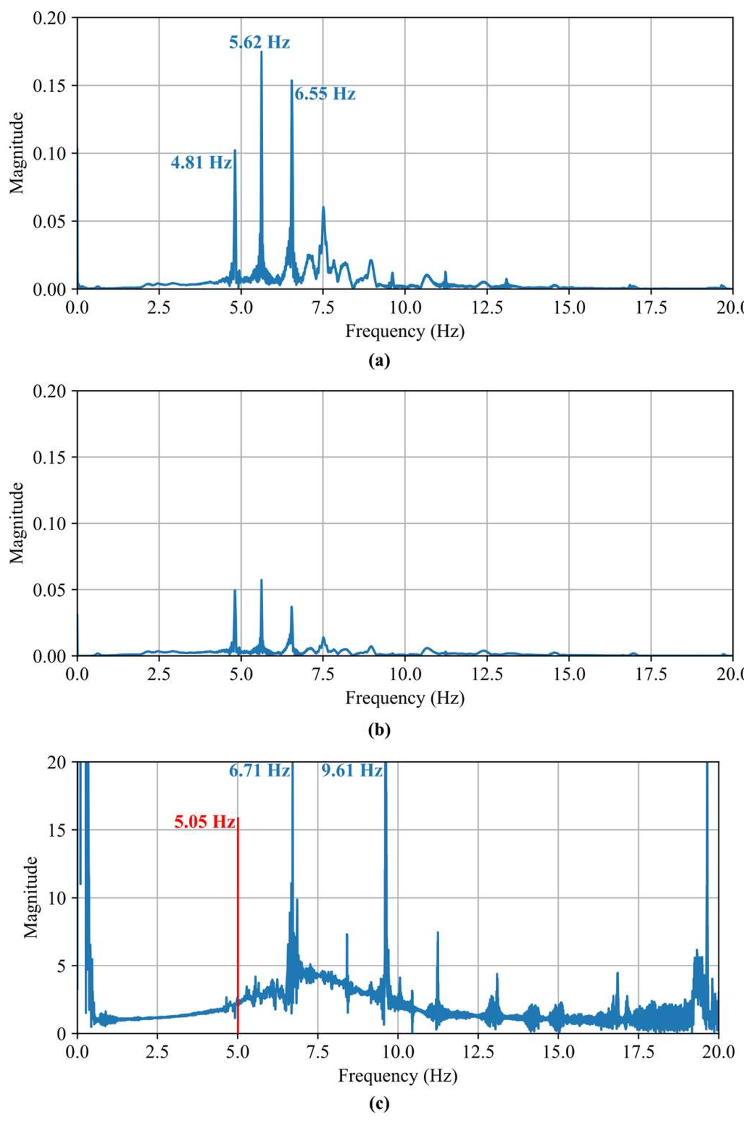
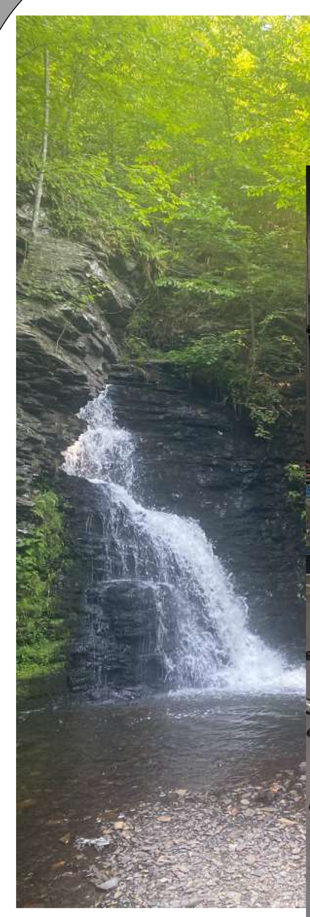
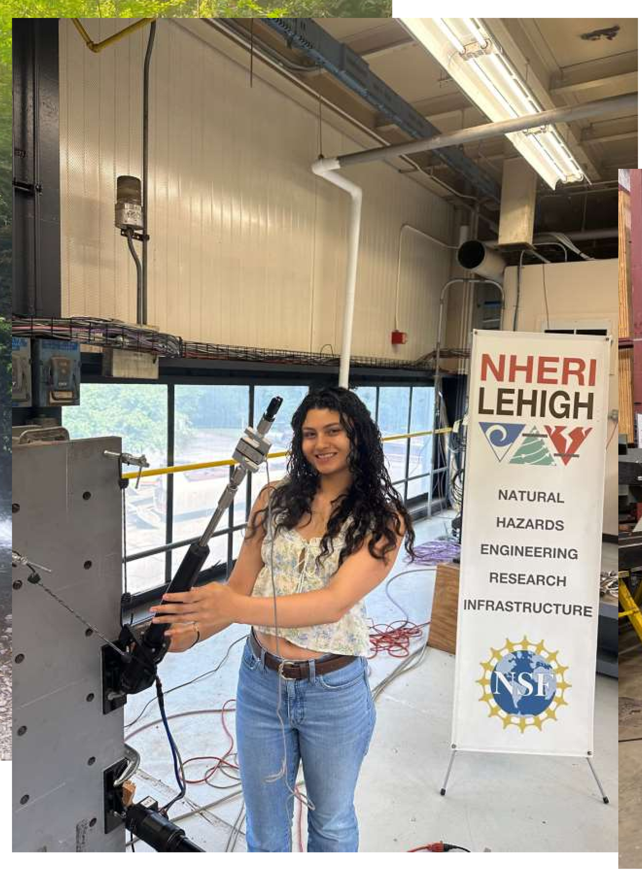


Fig. 12. Structural battery composite FFTs showing (a) plate response, (b) table response, and (c) their ratio with theoretical comparison

REU Experience and Highlights

Always learning, always exploring!





Methodology

STATIC CHARACTERIZATION

1. Take weights and measure tip deflections
2. Generate y=k*x curve using least squares
3. Identify stiffness, k
4. Calculate natural frequency

DYNAMIC CHARACTERIZATION

1. Apply sine wave sweep to shake table
2. Record base and tip accelerations
3. Analyze FFTs for natural frequency, f
4. Compare experimental vs theoretical value

Identifies stiffness,

$$k = \frac{F}{\Delta} = \frac{3EI}{l^3}$$

Identifies natural frequency,

$$f = \frac{3.5156}{2\pi}\sqrt{\frac{k * g}{3 * W}}$$

Conclusion

- Method validated by accurate results
- Groundwork for future testing & UAV design
- Additional testing needed
  - Reasons for false peaks, frequency leakage
  - Effects of composite composition, delamination

References

Adawy, M., et al. 2023. "Design and fabrication of a fixed-wing Unmanned Aerial Vehicle (UAV)." Ain Shams Eng. J. 14 (9), 102094. https://doi.org/10.1016/j.asej.2022.102094

ARTS-Lab. 2025. "SWIFT-UAV: Scientific Workhorse for In-flight Field Tests – UAV," Github. https://github.com/ARTS-Laboratory/SWIFT-UAV

Ashrith, H. S., T. P. Jeevan, and J. Xu. 2023. "A Review on the Fabrication and Mechanical Characterization of Fibrous Composites for Engineering Applications." MDPI: J. Compos. Sci., Special Issue 7 (6), 252. https://doi.org/10.3390/jcs7060252

Blasi, L., et al. 2021. "Modeling and Control of a Modular Iron Bird." MDPI: Aerospace, Special Issue 8 (2), 39. https://doi.org/10.3390/aerospace8020039

Jin, T., G. Singer, K. Liang, and Y. Yang. 2023. "Structural batteries: Advances, challenges and perspectives." *Mater. Today* 62, pp. 151-167. https://doi.org/10.1016/j.mattod.2022.12.001

Saheb, K., S. Deepak. 2023. "Free vibration analysis of a laminated composite plate using experimental modal testing." In *Proc., Mater. Today, 2nd International Conference and Exposition on Advances in Mechanical Engineering* 72 (3): pp. 1573-1583, edited by S. Lahane et al, 645-1984. https://doi.org/10.1016/j.matpr.2022.09.390

Sullivan, R. W., Hwang, Y., Rais-Rohani, M., & Lacy, T. (2009). (PDF) structural testing of an ultralight UAV composite wing. https://www.researchgate.net/publication/268477156_Structural_Testing_of_an_Ultralight_UAV_Composite_Wing

vlab.amrita.edu,. (2011). Free Vibration of a Cantilever Beam with a Lumped Mass at Free End. vlab.amrita.edu/?sub=3&brch=175&sim=1078&cnt=1

Acknowledgments

This research is supported by the U. S. National Science Foundation under the NHERI Network Coordination Office Grant No. 2129782 and the Real-time Multi-Directional Natural Hazards Simulation Facility (RTMD) at Lehigh University No. 2037771. Special thanks to Dr. James M. Ricles and Dr. Liang Cao for their expertise and guidance as well as to Dr. Austin R. J. Downey for his continuous support. I'd also like to thank my 2025 NHERI REU cohort.