Development of a Characterization Methodology for Composite Plates in UAV Wing Applications

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Purpose

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

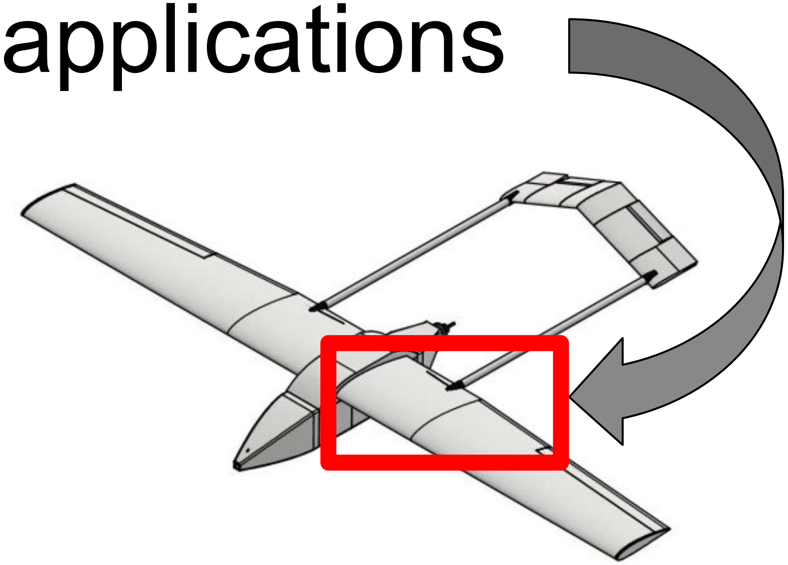

Fig. 1. Fixed-wing UAV model (ARTS-Lab, 2025)

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: Composites

- Currently, aerospace composite work is focused on carbon fiber (CFRP)
- 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)

Background: Static Characterization

- Various loading tests done on across wing (Sullivan et al., 2006)
  - hydraulic actuator
  - whiffletree

Methods: Static Characterization

Measure load vs deflection → Generate y=k*x (least squares) → Identify stiffness, k → Calculate natural frequency, f

- Suspend a series of weights from the free end
- Measure corresponding deflections

- Fit data using least squares estimation method
- Least squares forces an origin of 0

- The slope of the least squares estimation line
- $$\mathbf{k} = \frac{F}{\Delta} = \frac{3EI}{l^3}$$

(Amrita, 2011)

- theoretical value,

$$f = \frac{1}{2\pi}\sqrt{\frac{k*g}{\frac{33}{140}W_b + W_t}}$$

- Use correction factor,

$$\frac{f_1}{f_2} = \sqrt{\frac{{l_2}^3}{{l_1}^3}}$$

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

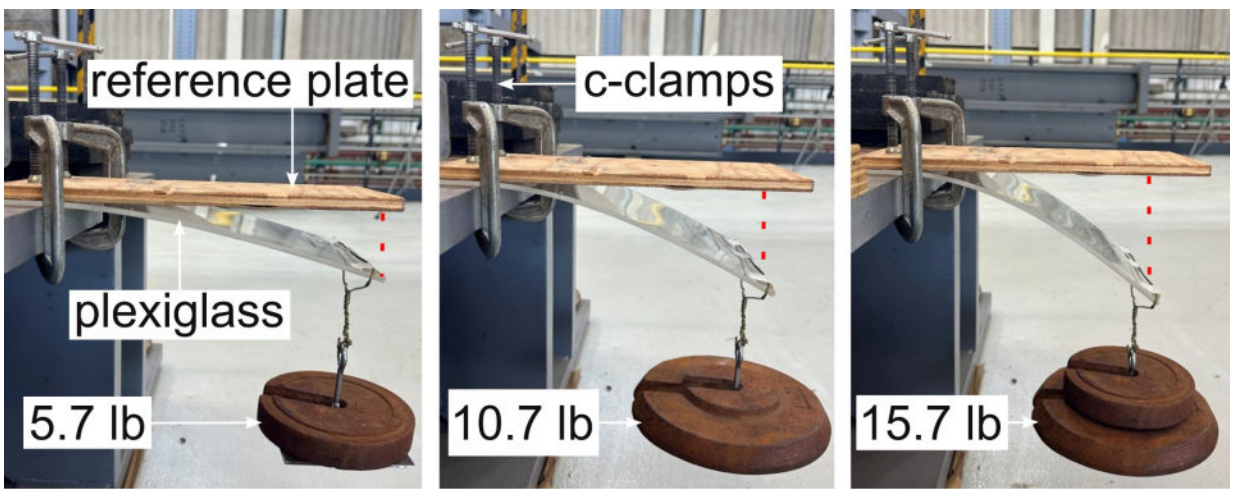

Fig. 2. Static characterization set up

Background: Dynamic Characterization

- General dynamics
  - Ironbird (Blasi et al., 2021)
- Modal
  - Originally, Impact Hammer Test (Saheb & Deepak, 2023)
  - Recently, Ground Vibrations Test (GVT)
  - Shake table (Sullivan et al., 2006)

Methods: Dynamic Characterization

Apply sine wave sweep to shake table → Record accelerations → Analyze FFTs → Compare theoretical and experimental values

- Manually applied between a range of 1 to 20 Hz

- Accelerometer located at the base
- Accelerometer located at specimen tip

- Analyze individually
- Create a FFT ratio (tip/base) to further identify frequency

- Experimental (peak(s) on FFT) vs theoretical (calculated from static results)

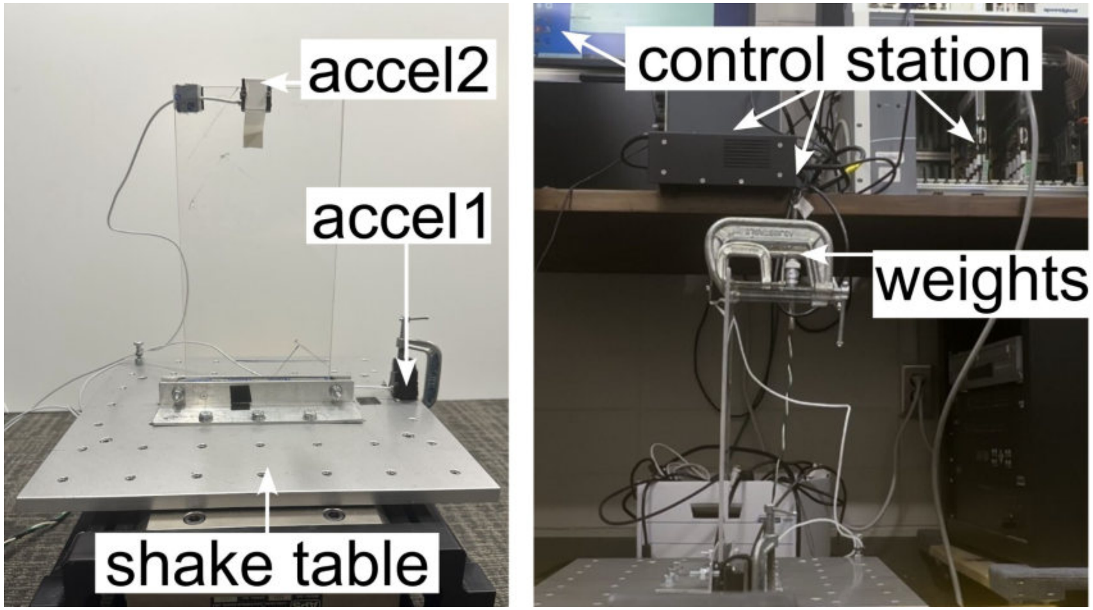

Fig. 3. Dynamic characterization set up

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Preliminary Results

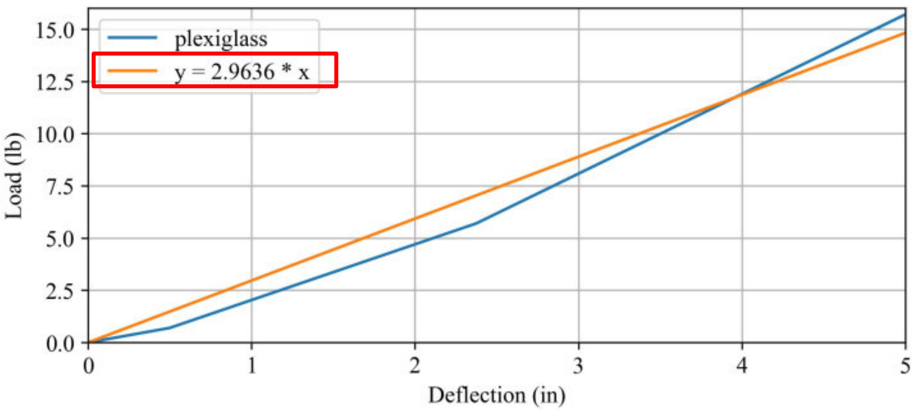

Fig. 4. Graphical least squares estimation of data

Error of 7.7%!

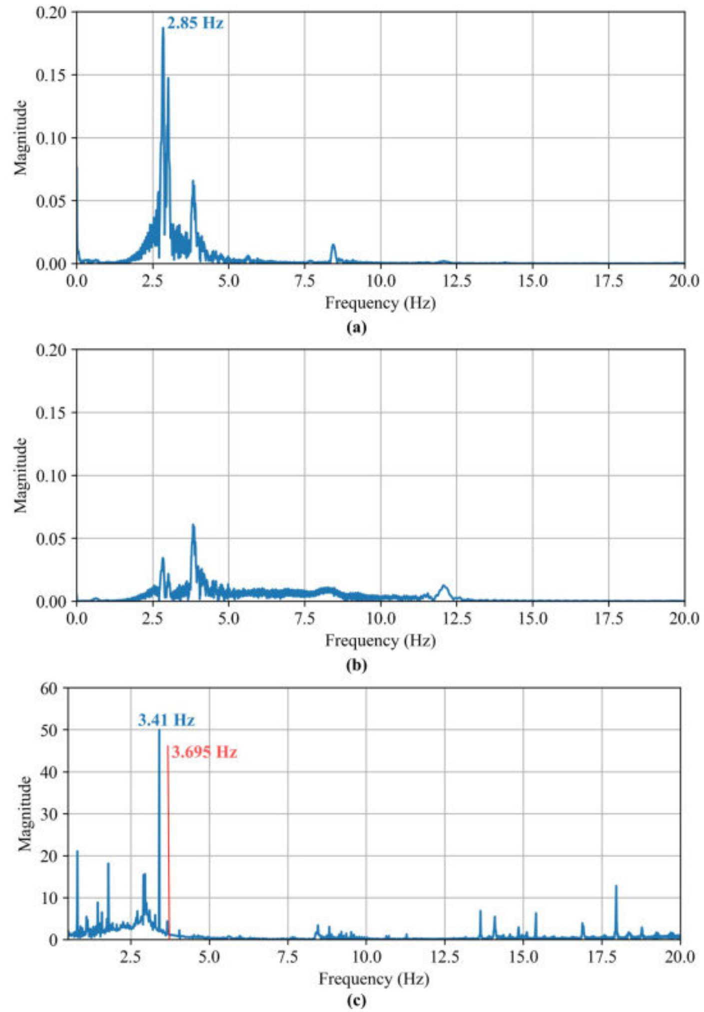

Fig. 5. FFT ratio of plexiglass modal data

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Methods: Overall

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

works together!

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Composite Characterization: Static

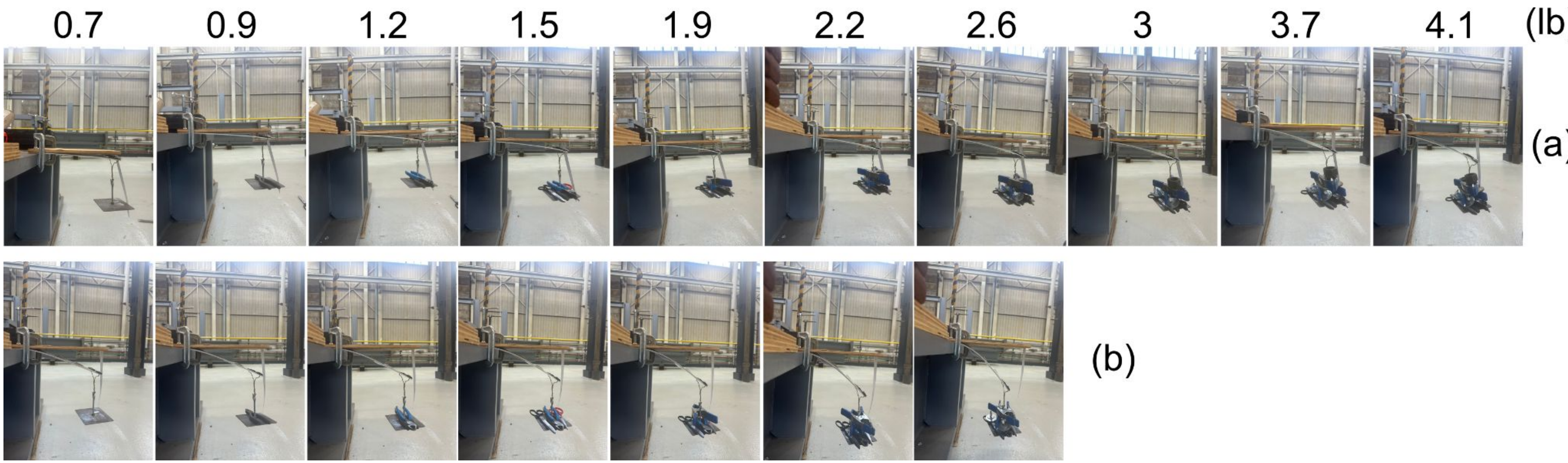

Fig. 6. Sequential load in static characterization set up on (a) control composite and (b) structural battery

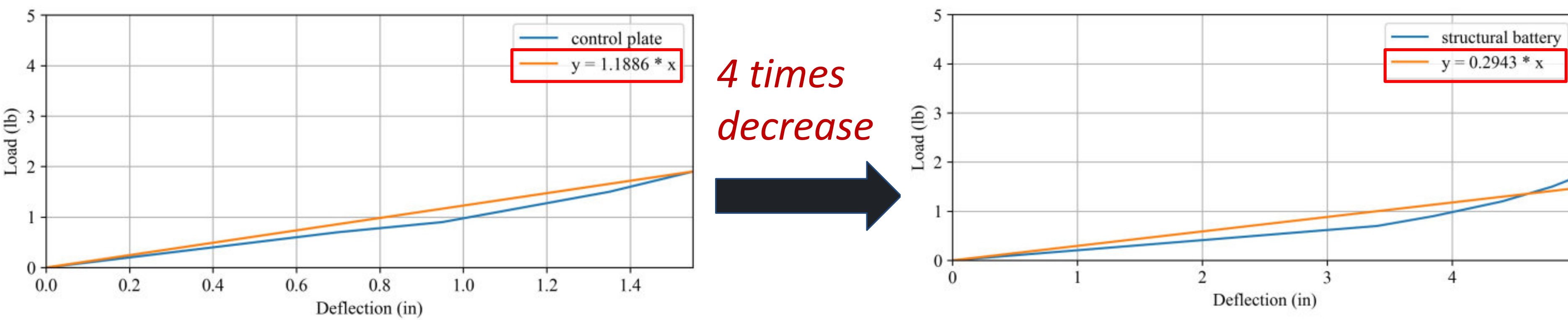

Fig. 7. Stiffness comparison between structural battery and control composite

Composite Characterization: Dynamic

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Composite Characterization: Dynamic

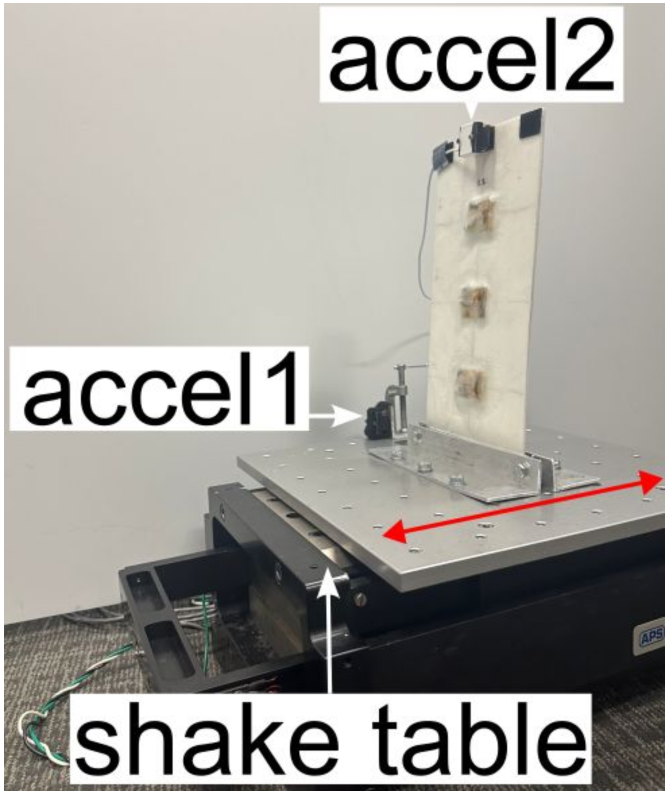


Fig. 8 Labeled modal characterization set up

Composite Characterization: Dynamic

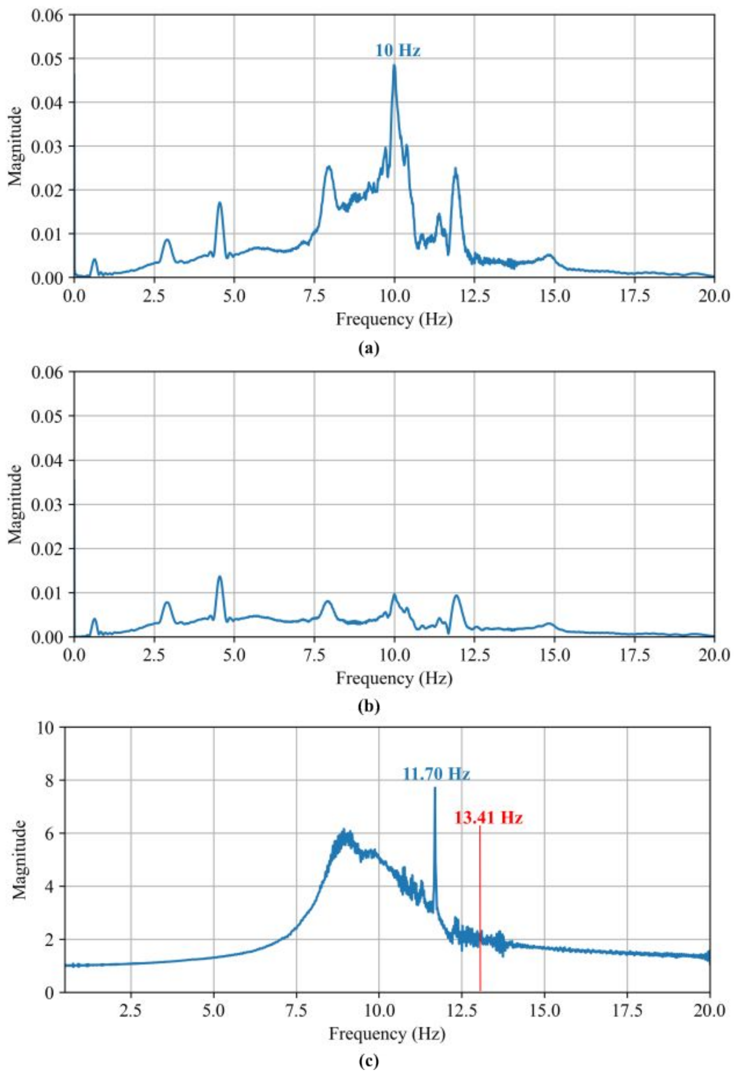


Fig. 9. Control composite FFTs showing (a) plate response, (b) table response, and (c) their ratio with theoretical comparison

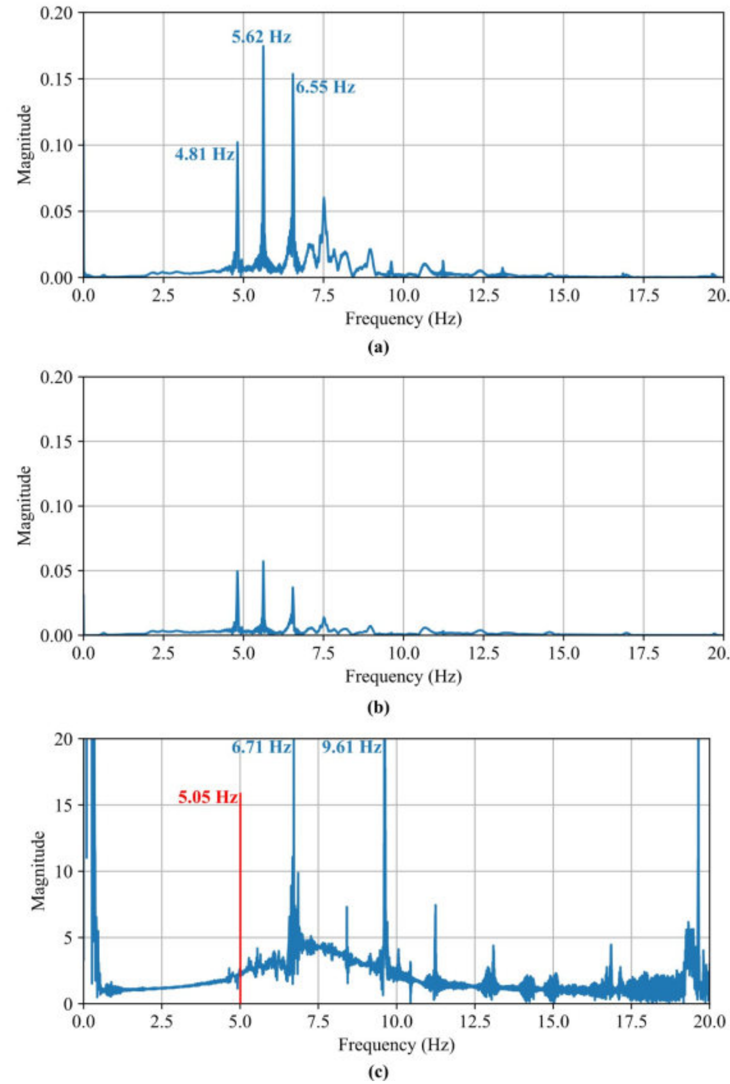


Fig. 10. Structural battery composite FFTs showing (a) plate response, (b) table response, and (c) their ratio with theoretical comparison

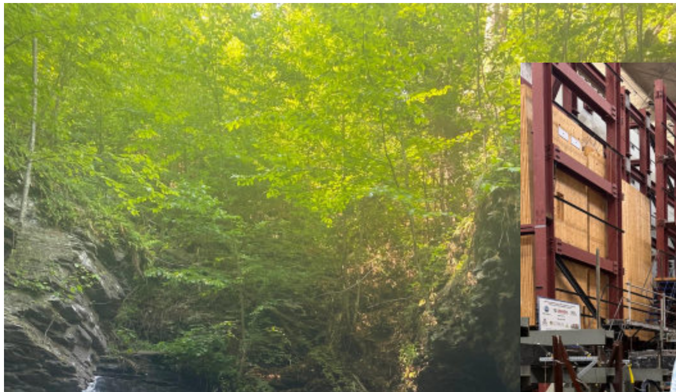
Conclusion

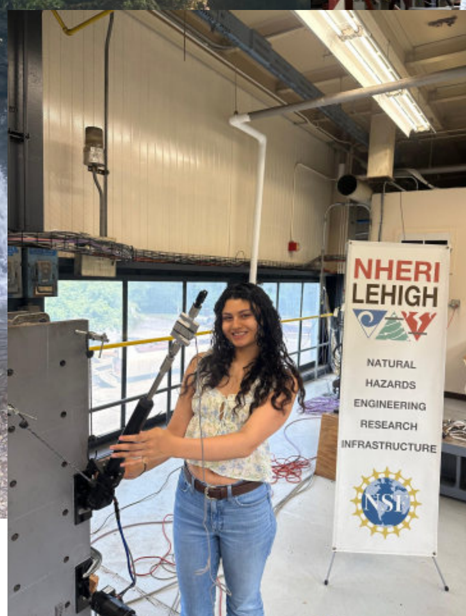
- Method validated by accurate results
- Groundwork for future testing & UAV design
- Additional testing needed
  - Reasons for false peaks, frequency leakage
  - Effects of composite composition, delamination

Future Research

- Methodology with improved accuracy
  - digital inputs, actuators, hybrid simulation
- Improved composites
  - Less delamination
  - Even, leveled layers
- Predict flight capabilities
- Build & test custom UAVs

My Experience at Lehigh's RTMD





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Learning Outcomes

TOP TAKEAWAYS:

1. Research takes time
2. Numbers don't lie
3. Can of worms

NATURAL HAZARD APPLICATION:

- Improve remote field work related to natural hazards

FUTURE PLANS:

- Plans to attend the University of South Carolina for a Master of Science in Mechanical Engineering

Acknowledgments

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