TOWARDS ACTIVE STRUCTURAL CONTROL STRATEGIES FOR ELECTRONIC ASSEMBLIES IN HIGH-RATE DYNAMIC ENVIRONMENTS

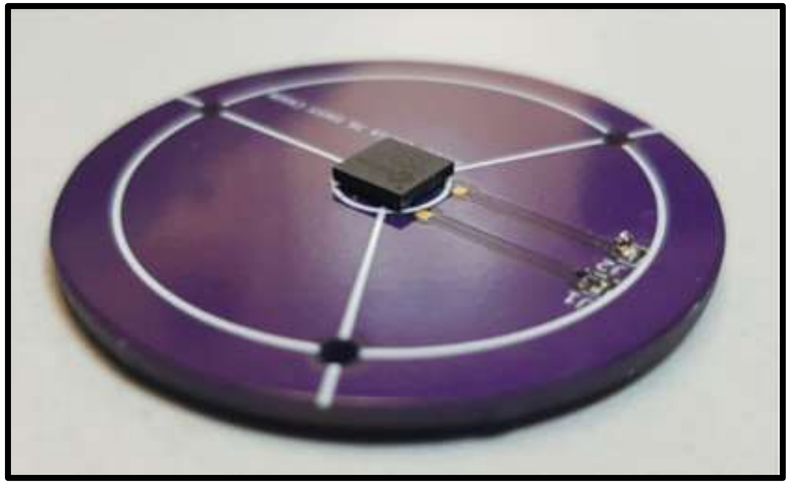
Trotter Roberts[1], Ryan Yount[1], Jacob Dodson[3], Adriane Moura[4], and Austin R.J. Downey[1,2]

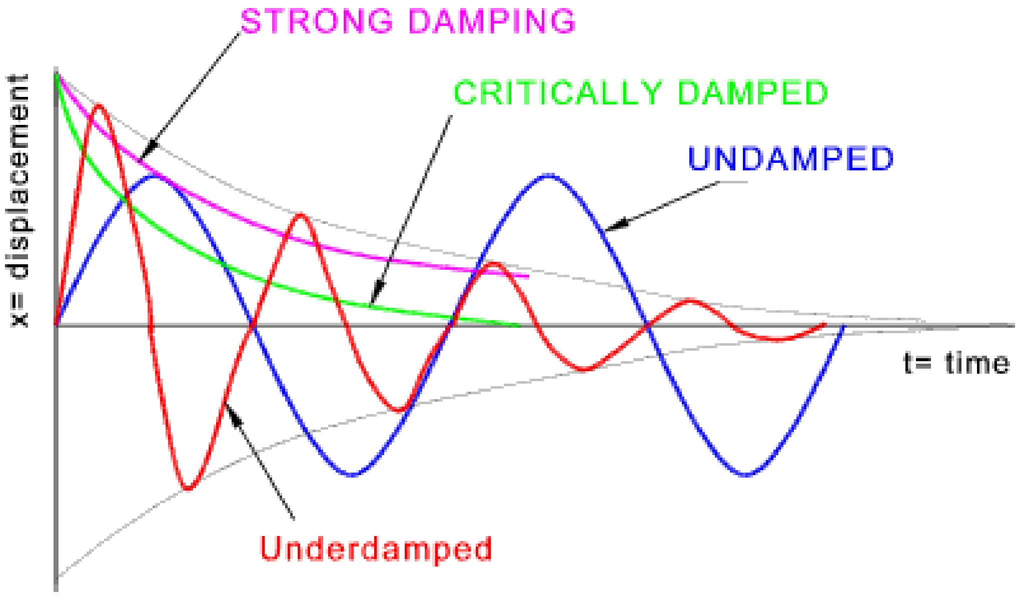
1. University of South Carolina Department of Mechanical Engineering.
2. University of South Carolina Department of Civil Engineering.
3. Air Force Research Laboratory.
4. Applied Research Associates.

UNIVERSITY OF SOUTH CAROLINA

OVERVIEW

- Introduction to High-Rate Impacts
- Project Motivation and Support
- Ongoing Work
  - Shock Testing
  - Board Design
- Focused Study
  - Experiment
  - Simulation
  - Analysis
  - Conclusion
- Future Work
  - Control
  - Placement

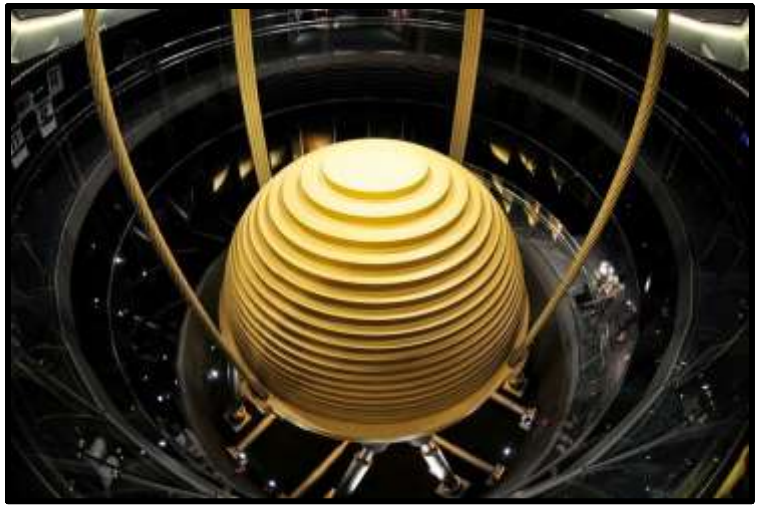


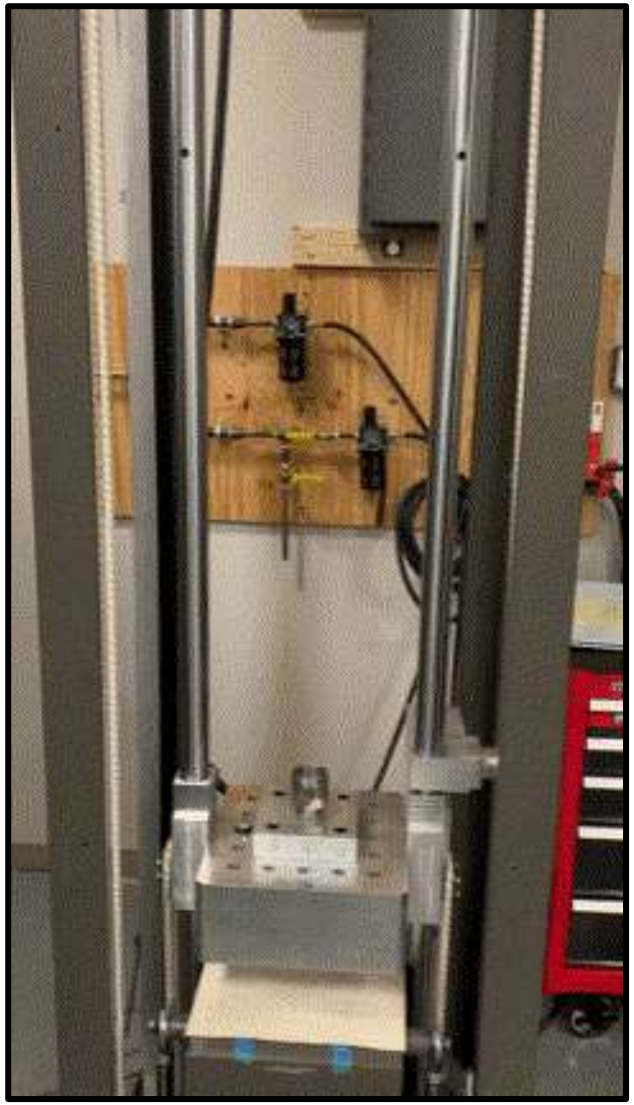


South Carolina

INTRODUCTION

- Mechanical shock occurs when a system undergoes a dramatic and sudden change in acceleration.
- Shock events can cause damage to the system, contributing to objective failure.
- Active control of these systems can dampen shock and prevent damage.
- In the lab, we plan to use piezoelectric pads to provide sensing and actuation.

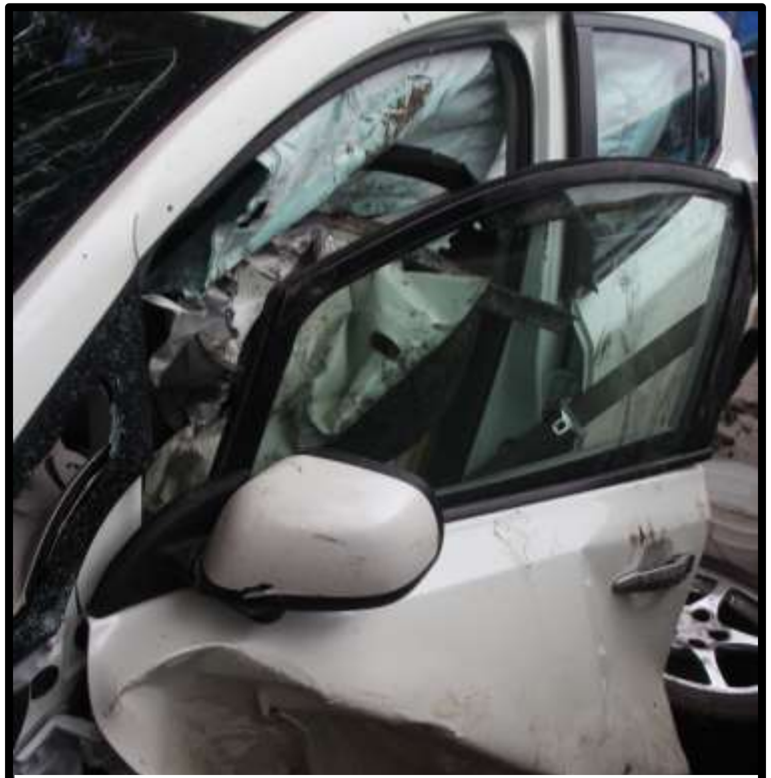




South Carolina

REAL-WORLD APPLICATIONS

Blast Against Civil Structures

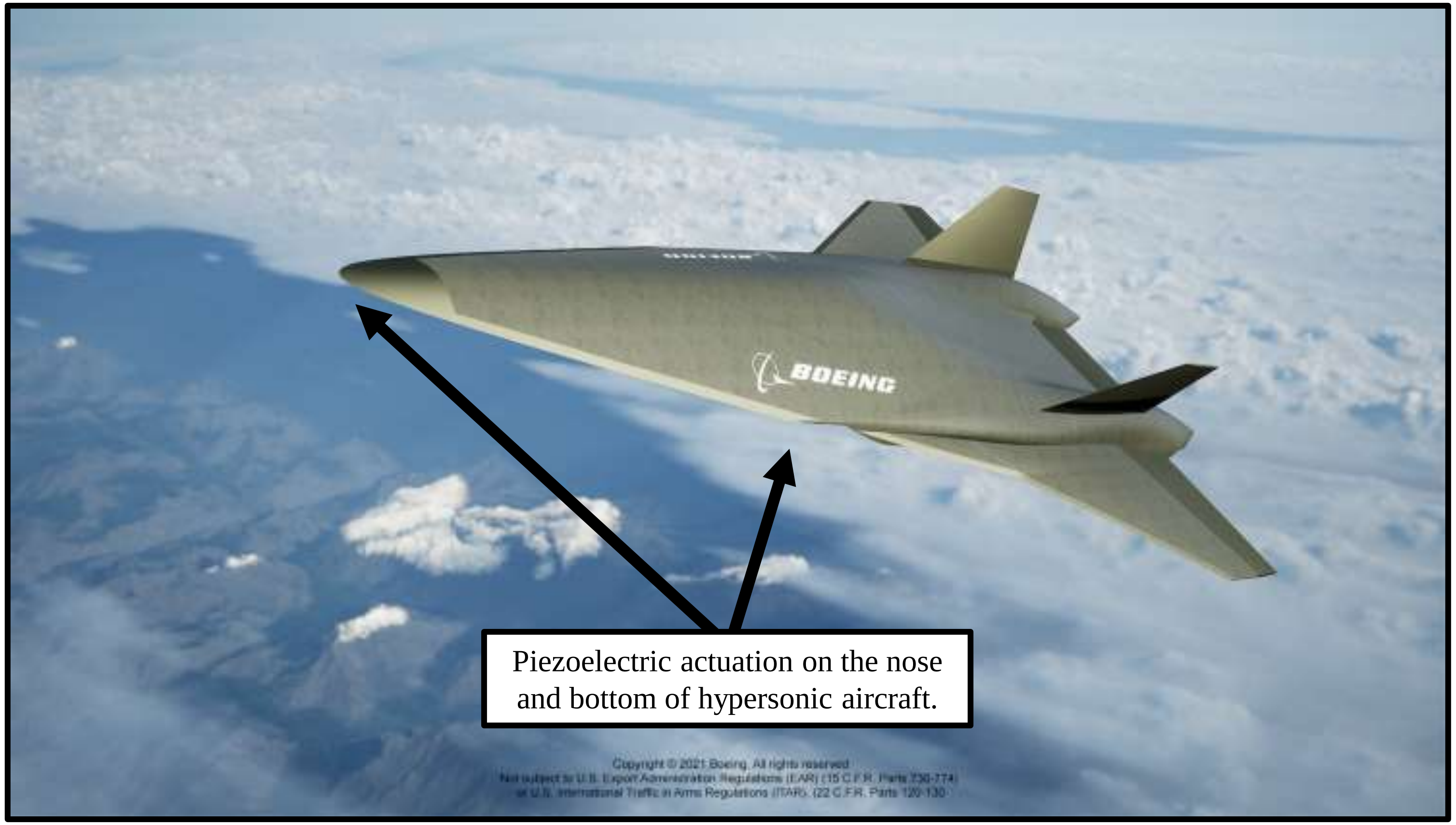


Automotive Impact and Crashes

High-speed Aircraft and Airframes

South Carolina

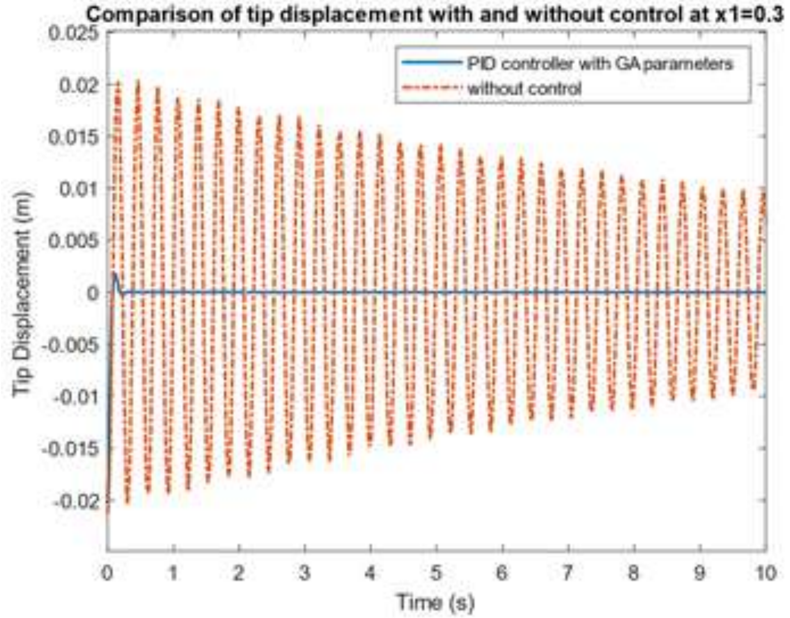
REAL-WORLD APPLICATIONS

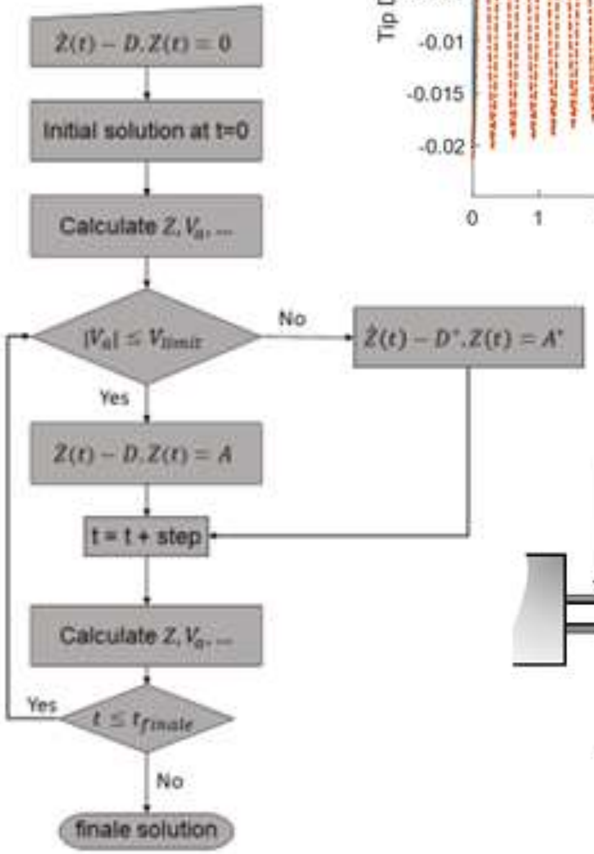


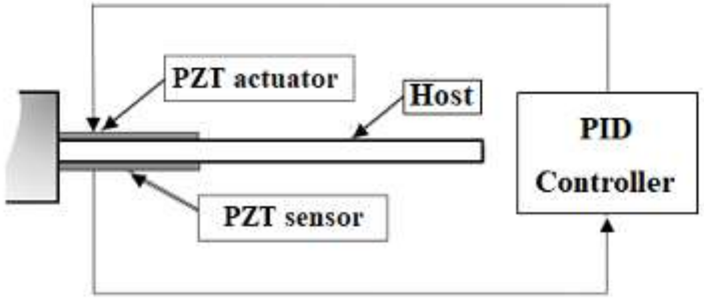
PZT Actuator Patches

ACTIVE CONTROL

- <u>Key Point</u>: Optimized control of cantilever beam vibrations.
- <u>Content</u>:
  - **Study**: Awada et al. (2022)
  - **Conclusion**: The genetic algorithm developed in this study successfully optimizes active control of a smart cantilever beam using piezoelectric actuators, significantly reducing beam vibrations.
  - **Takeaway**: A simple PID controller may demonstrate the potential for stable and efficient vibration control in smart structures.

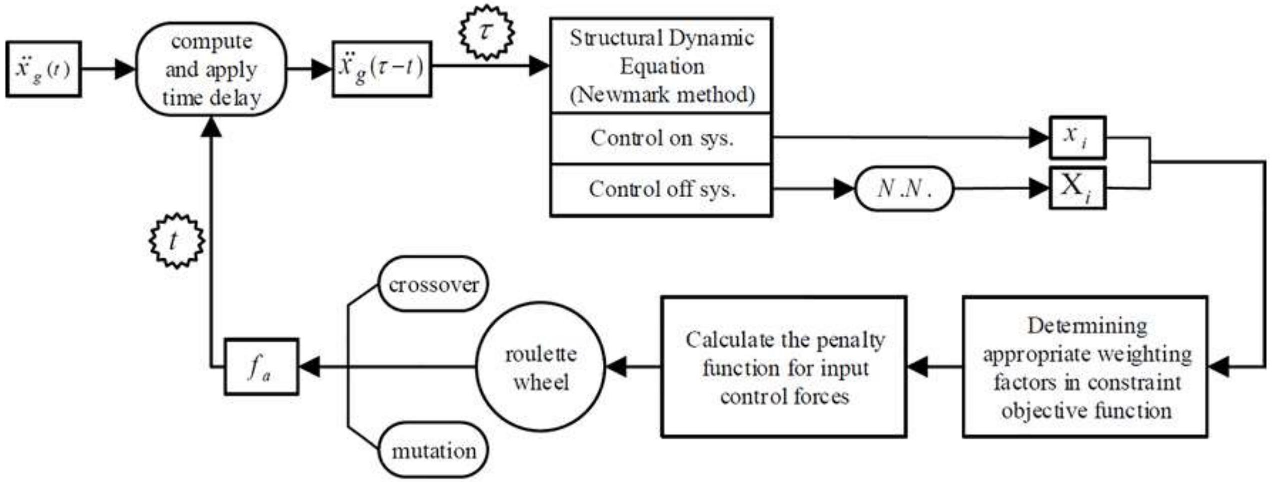






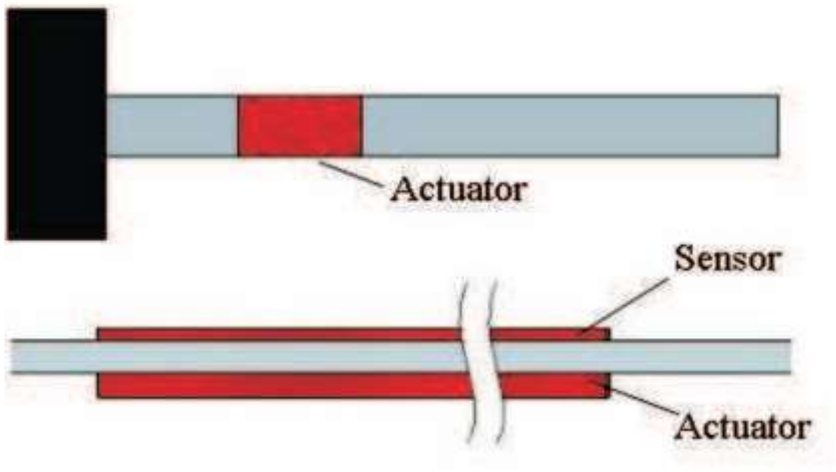
CONTROL STRATEGIES

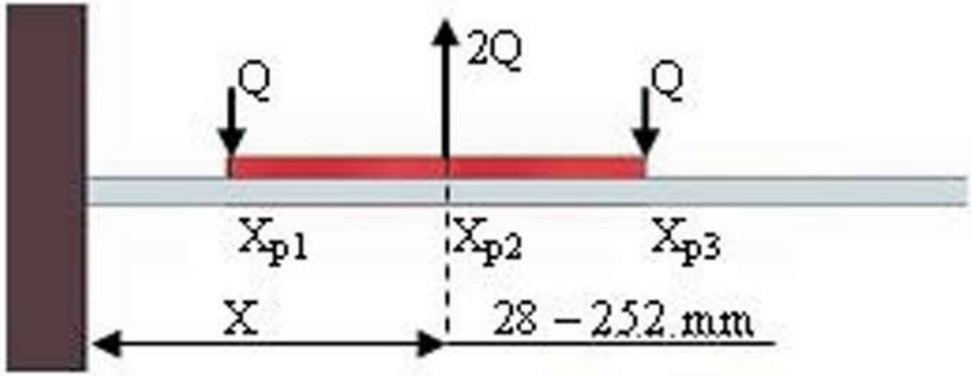
- Key Point: Improved performance in structural control through adaptive algorithms.
- Content:
  - **Study**: Banaei et al. (2023)
  - **Conclusion**: The introduction of dynamic weighting factors in the genetic algorithm's constrained objective function leads to improved vibration reduction in complex, large-scale structural systems.
  - **Takeaway**: This approach enhances the adaptability of control systems in varying conditions, making it more suitable for complex structural applications.

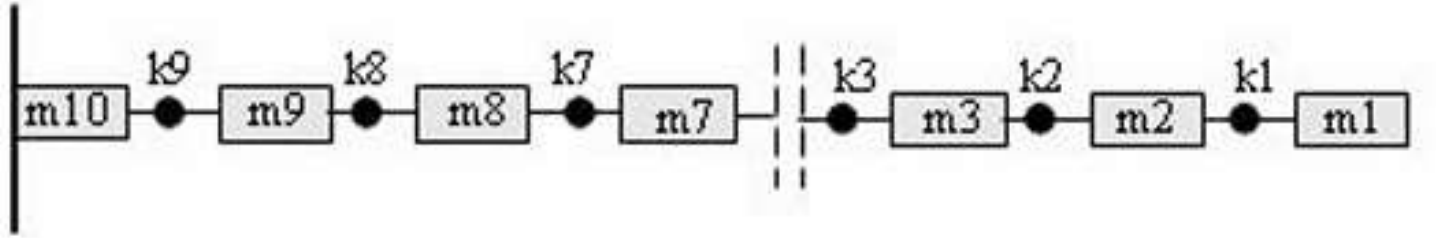


PIEZO ACTIVE STRUCTURES

- Key Point: Application-focused development of piezoelectric actuator systems.
- Content:
  - **Study**: Gosiewski et al. (2023)
  - **Conclusion**: Experimental tests on different configurations of piezoelectric actuators reveal the most effective designs for real-world vibration control applications, offering practical improvements in piezoelectric structure performance.
  - **Takeaway**: Real-world testing of piezoelectric materials and actuator configurations helps refine design parameters for improved vibration control.

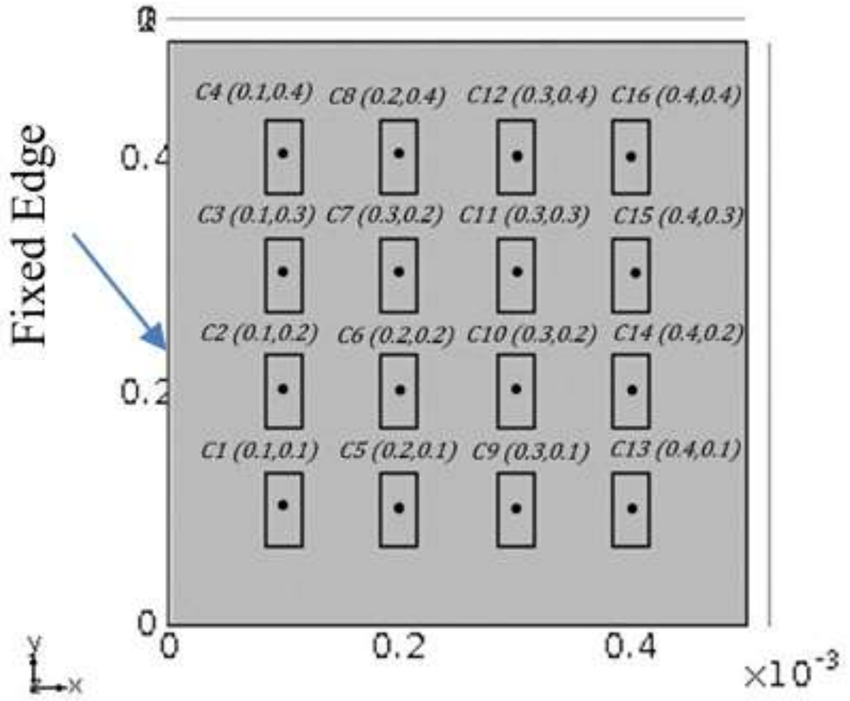






ACTUATOR PLACEMENT

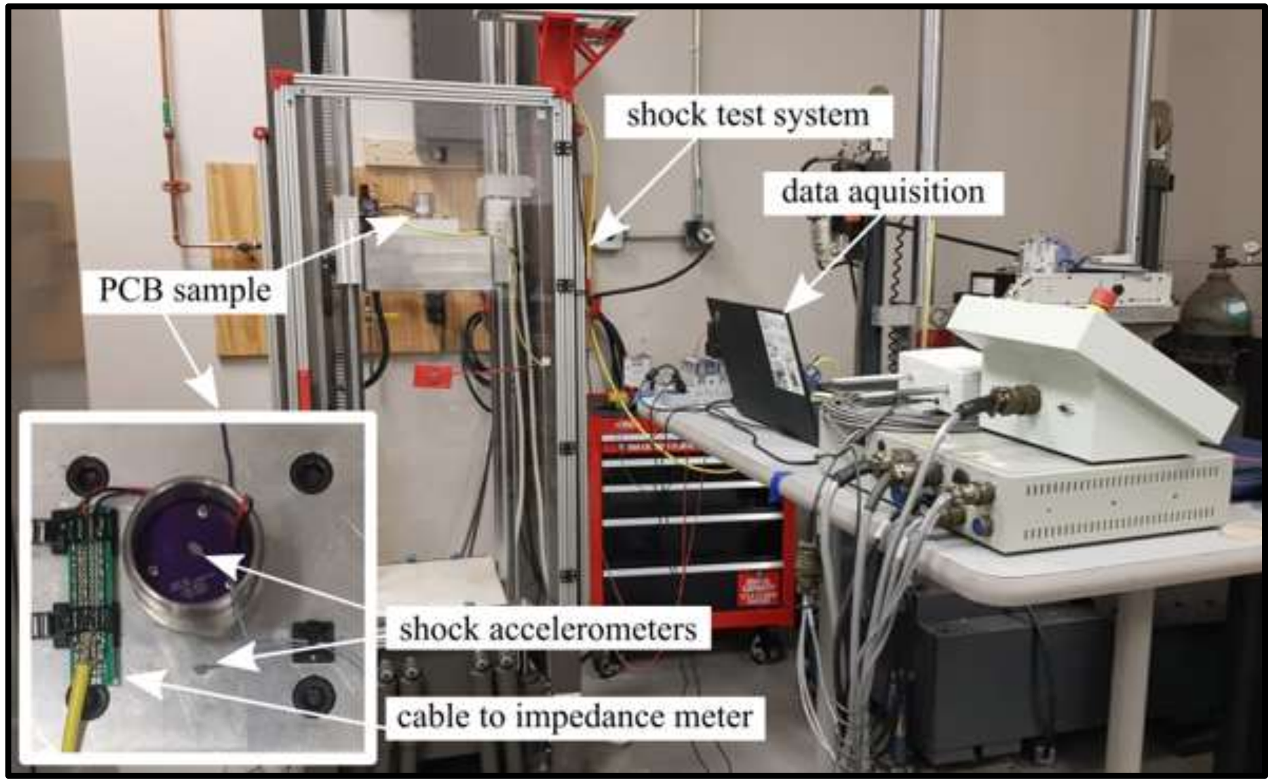
- Key Point: Vibration reduction through strategic placement of piezoelectric patches.
- Content:
  - **Study**: Labanie et al. (2017)
  - **Conclusion**: Finite element analysis (FEA) combined with a parametric sweep optimization method shows that placing piezoelectric patches near the fixed edge of a plate is optimal for minimizing vibration, as it enables actuators to create effective counter-moments that reduce oscillations.
  - **Takeaway**: Understanding where vibrations are most effectively countered, such as near the fixed edge, can inform strategic patch placement, maximizing the efficiency of vibration control systems and enhancing structural reliability.

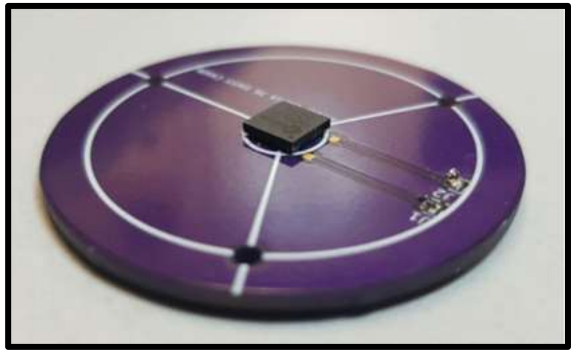


South Carolina

ONGOING WORK

- Various experiments involving shock testing.
  - Mainly using circular PCB focusing on a USAF application.
  - Other testing using cantilever beams, etc.
- To study PCB and onboard component response to shock.
- Dataset creation for future and related studies.

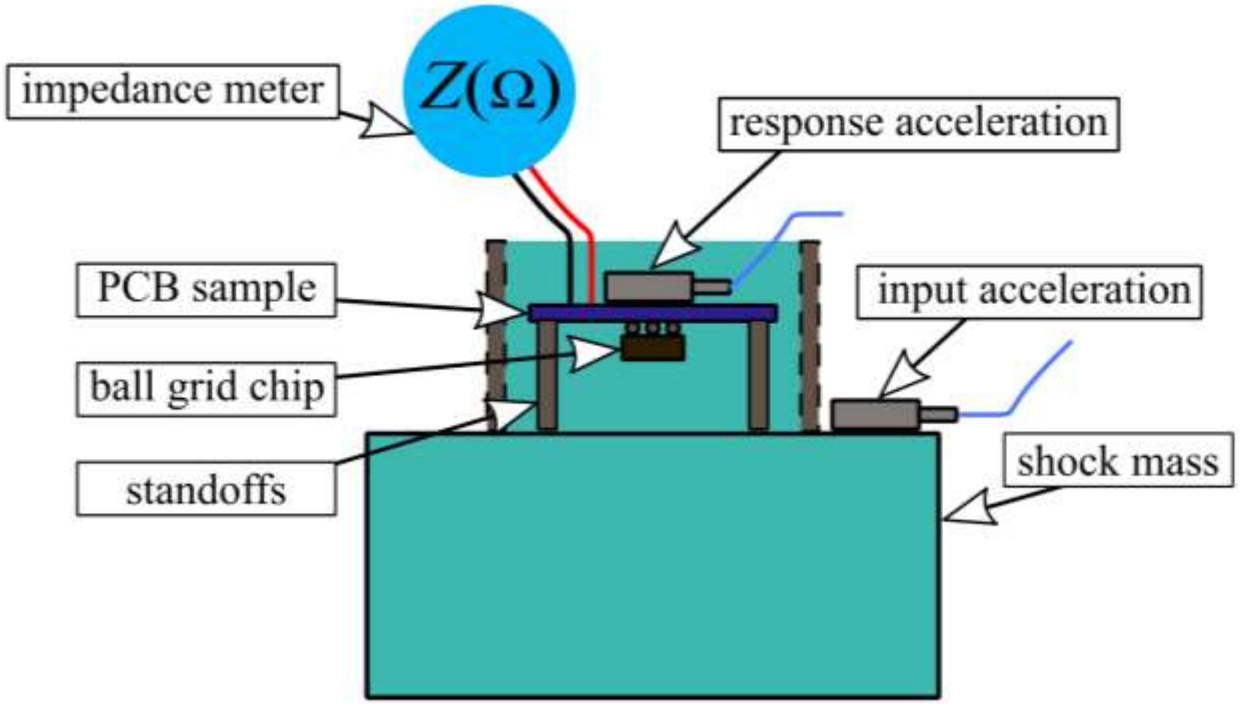


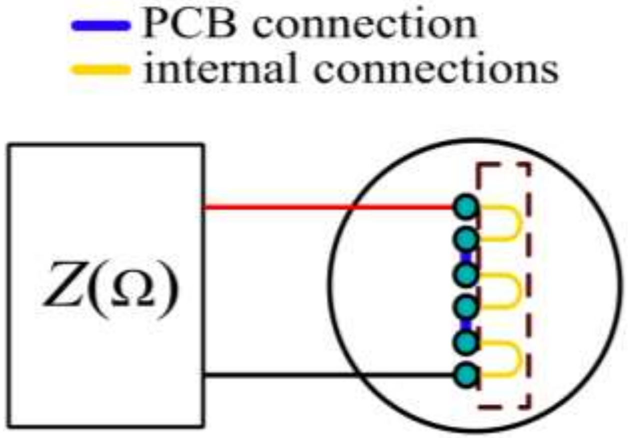


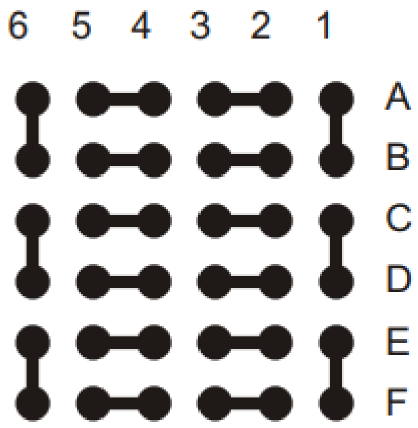
UofSC South Carolina

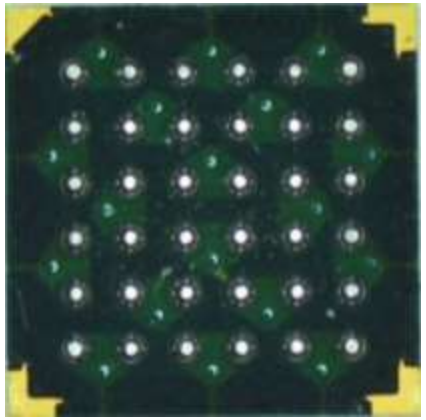
ONGOING WORK

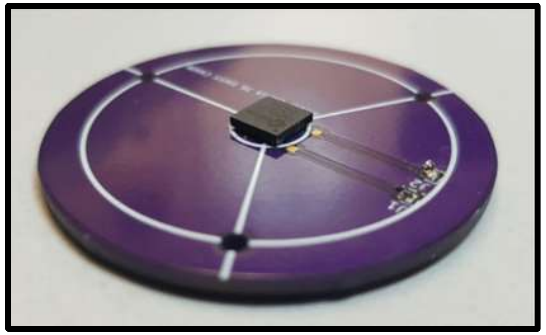
- Printed circuit board design focusing on studying component fatigue rate.
  - Using many different metrics, requiring varying designs of PCB and equipment during experiment.
- Onboard dummy component (BGA) in place of controller.





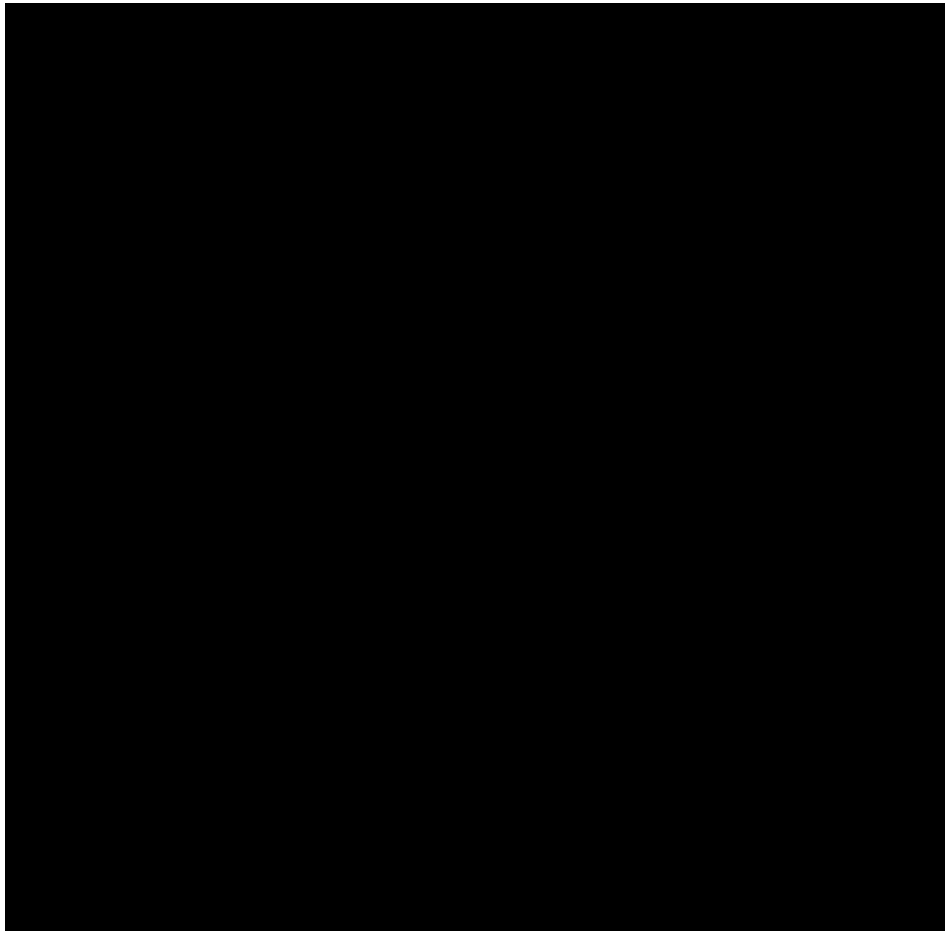


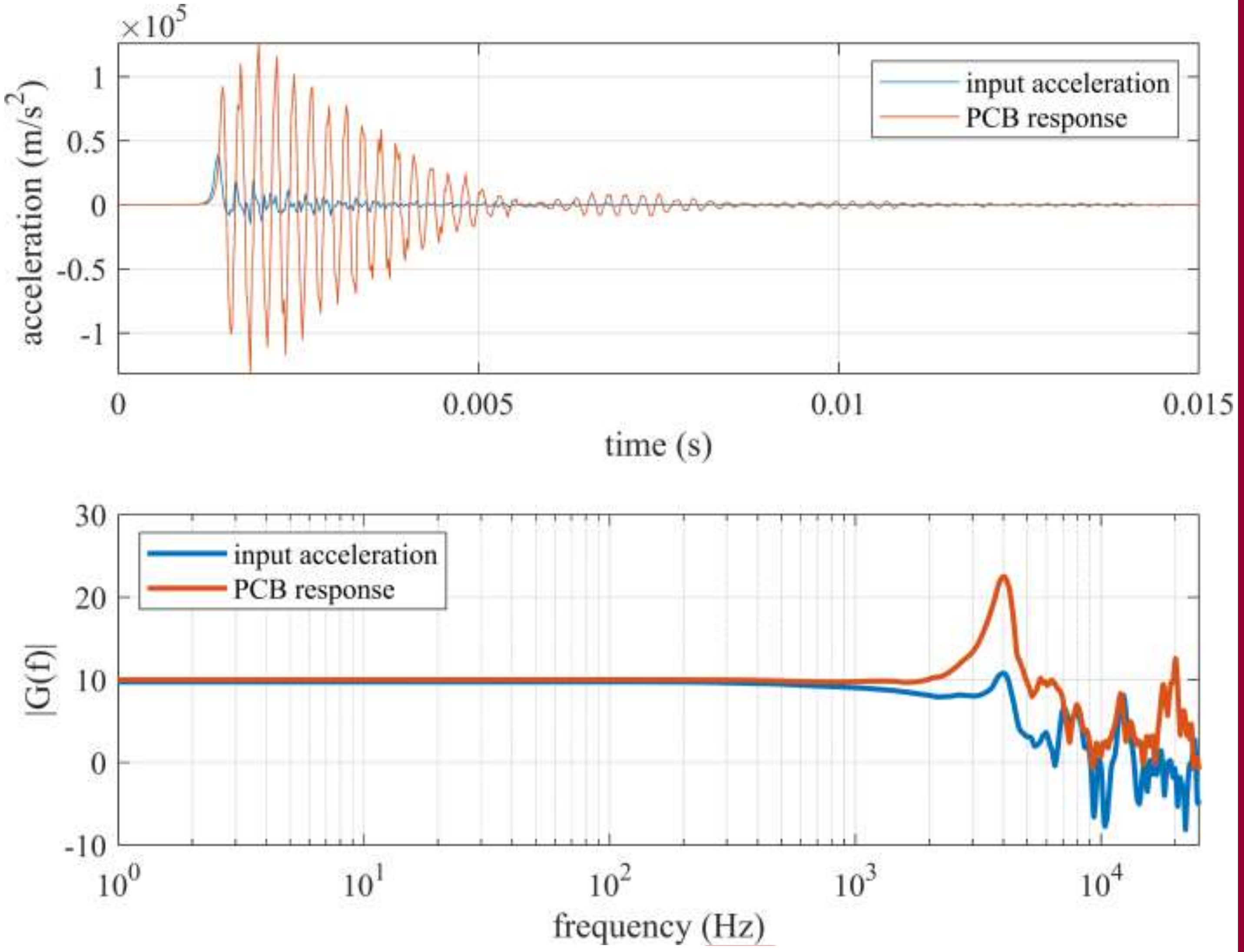




UofSC South Carolina

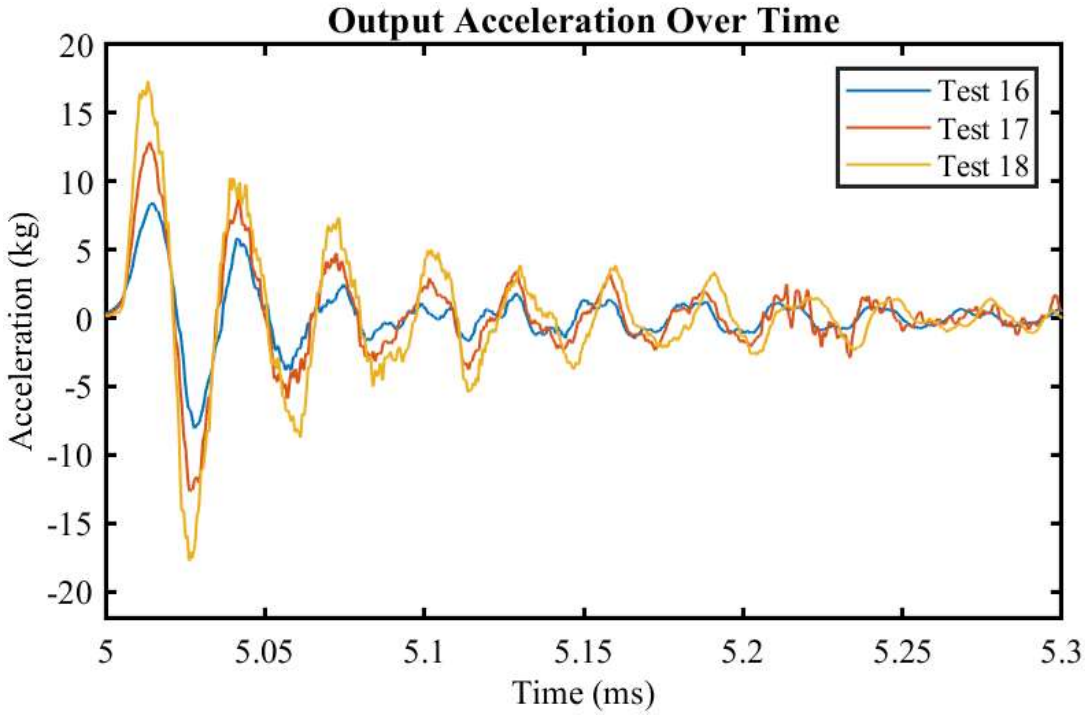
ONGOING WORK



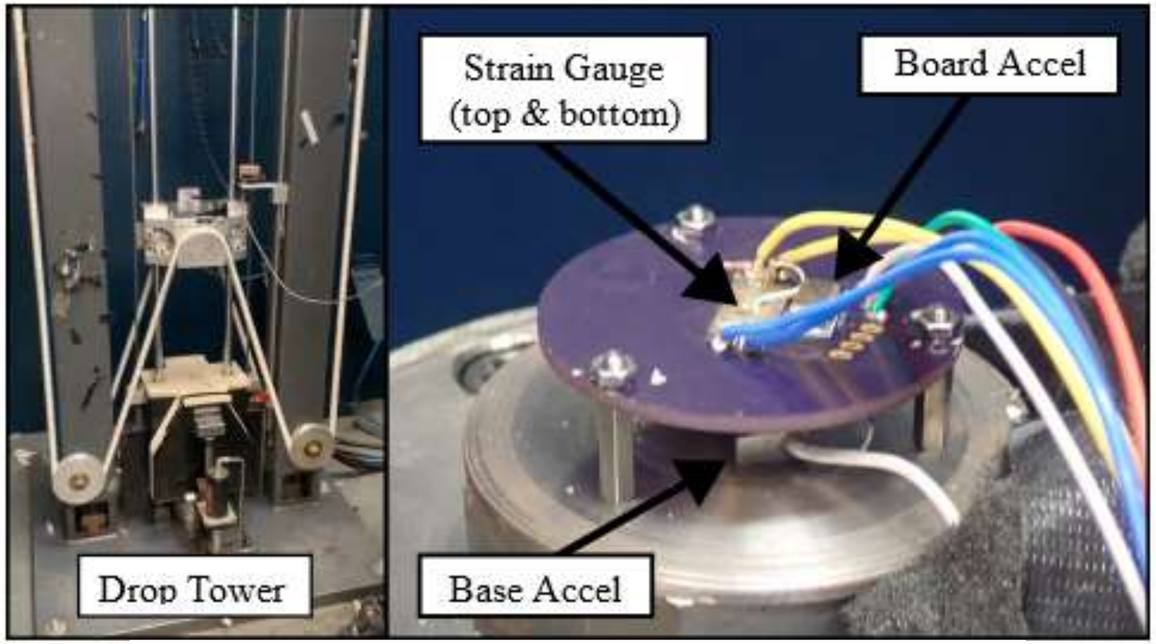


FOCUSED EXPERIMENT

- System at varying drop heights in cyclical succession (low to high).
- Creation of dataset, primarily for system analysis and later use in control strategy development and sensor/actuator placement.



Board Acceleration over Time.



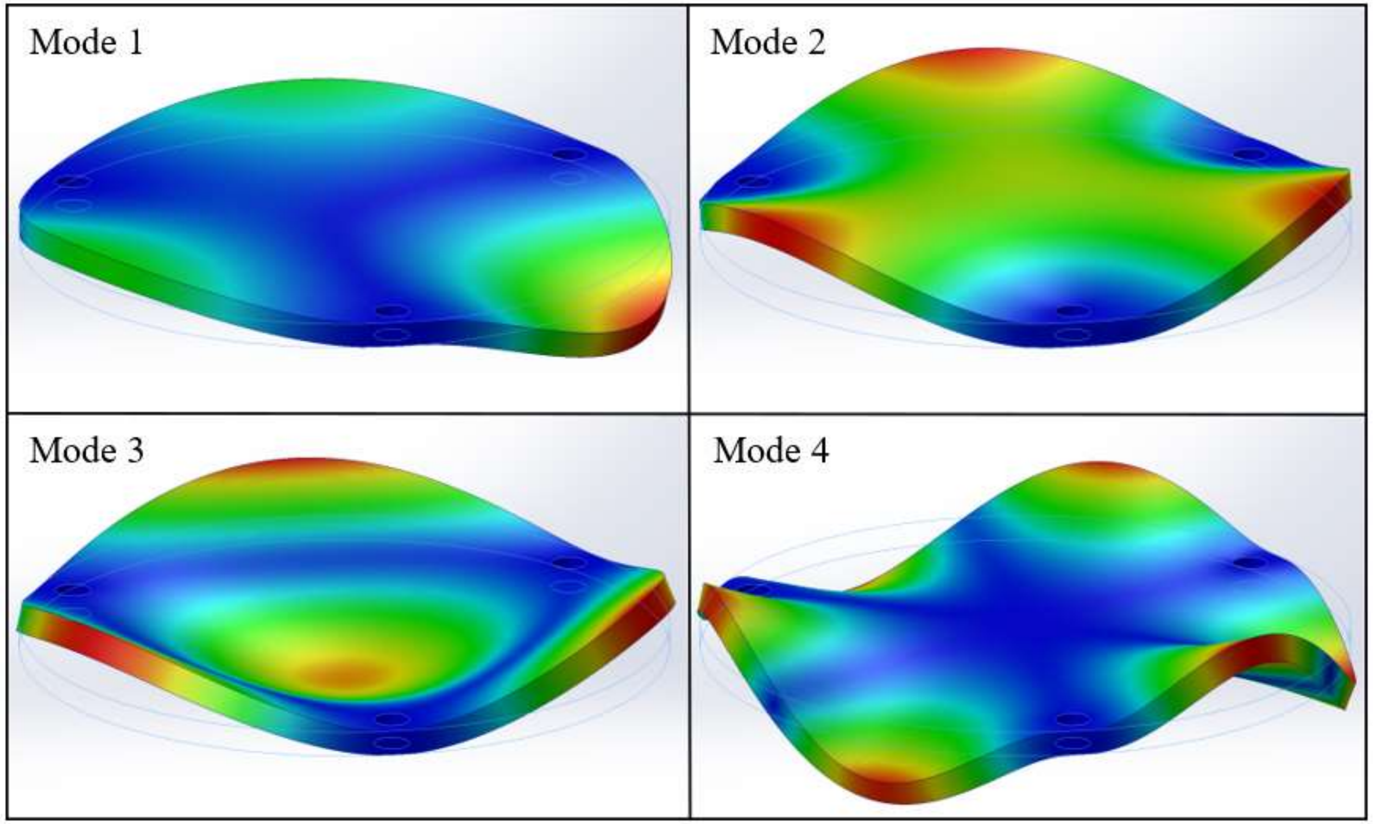
Drop Tower and Tested Printed Circuit Board.

SIMULATIONS

- Simulation dimension taken from PCB design and 175Tg FR4 material properties. The system is fixed from 3 holes on the outer edge.
- Finite Element Analysis (FEA) was used to find theoretical natural frequencies and mode shapes of the system.

Diameter	Thickness	Hole Placement	Density	Young's Modulus	Poisson Ratio
1.625 in	0.063 in	1.450 in	3.687 slug/ft³	2.698e+6 PSI	0.2

System Specifications used in Simulations.

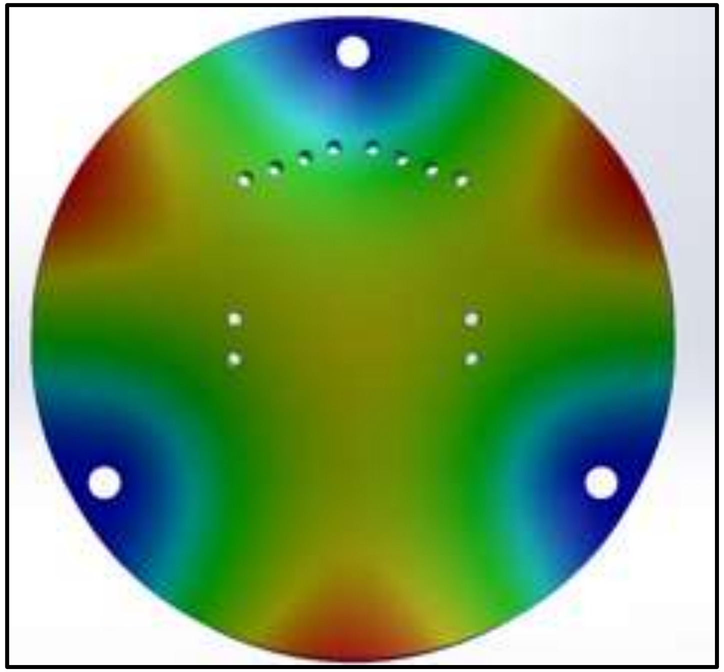


	Mode 1	Mode 2	Mode 3	Mode 4
Frequency	3681 Hz	3909 Hz	5671 Hz	10316 Hz

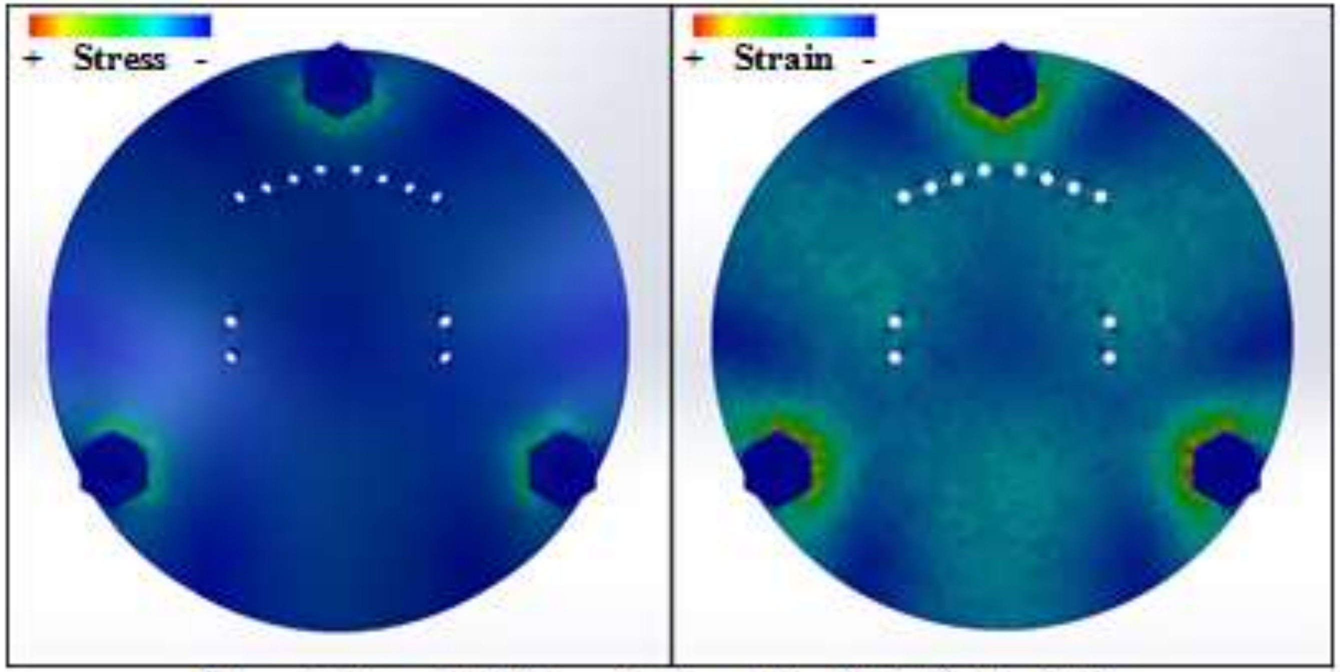
Simulated Mode Shapes and Natural Frequencies.

SIMULATIONS

- Strain, stress, and displacement simulations identified high-activity regions.
- Comparison of plots helps to determine the most effective locations for piezo placement.



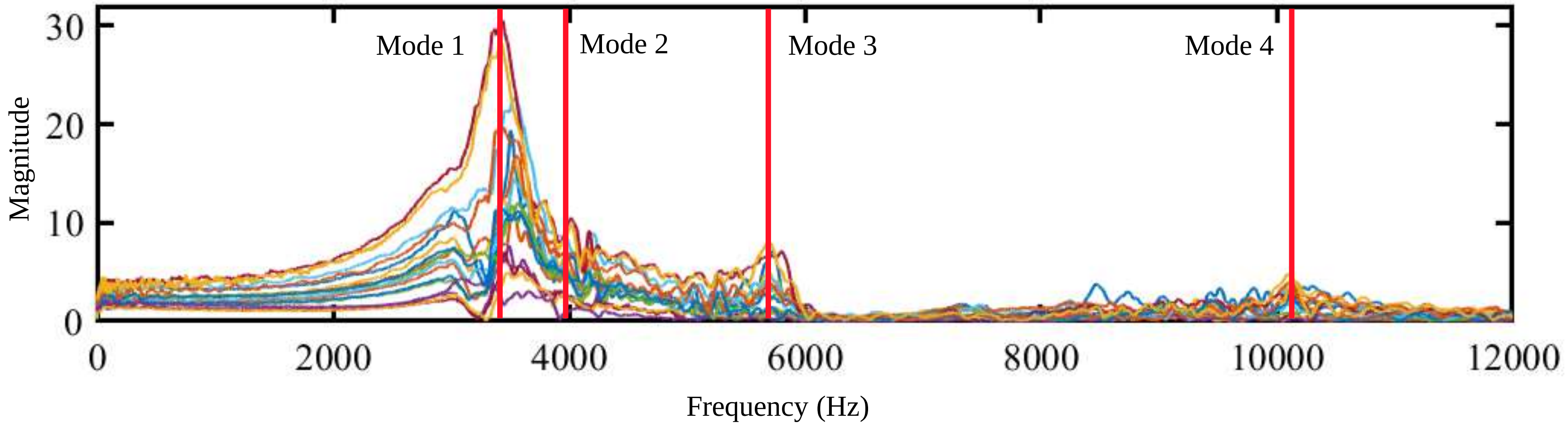
Displacement Magnitude



Simulated Stress (left) and Strain (right) Magnitude.

ANALYSIS

- Data processing to confirm simulation accuracy (FFT, FRF, and Coherence).
- Natural frequency comparison.



System Response Fast Fourier Transform

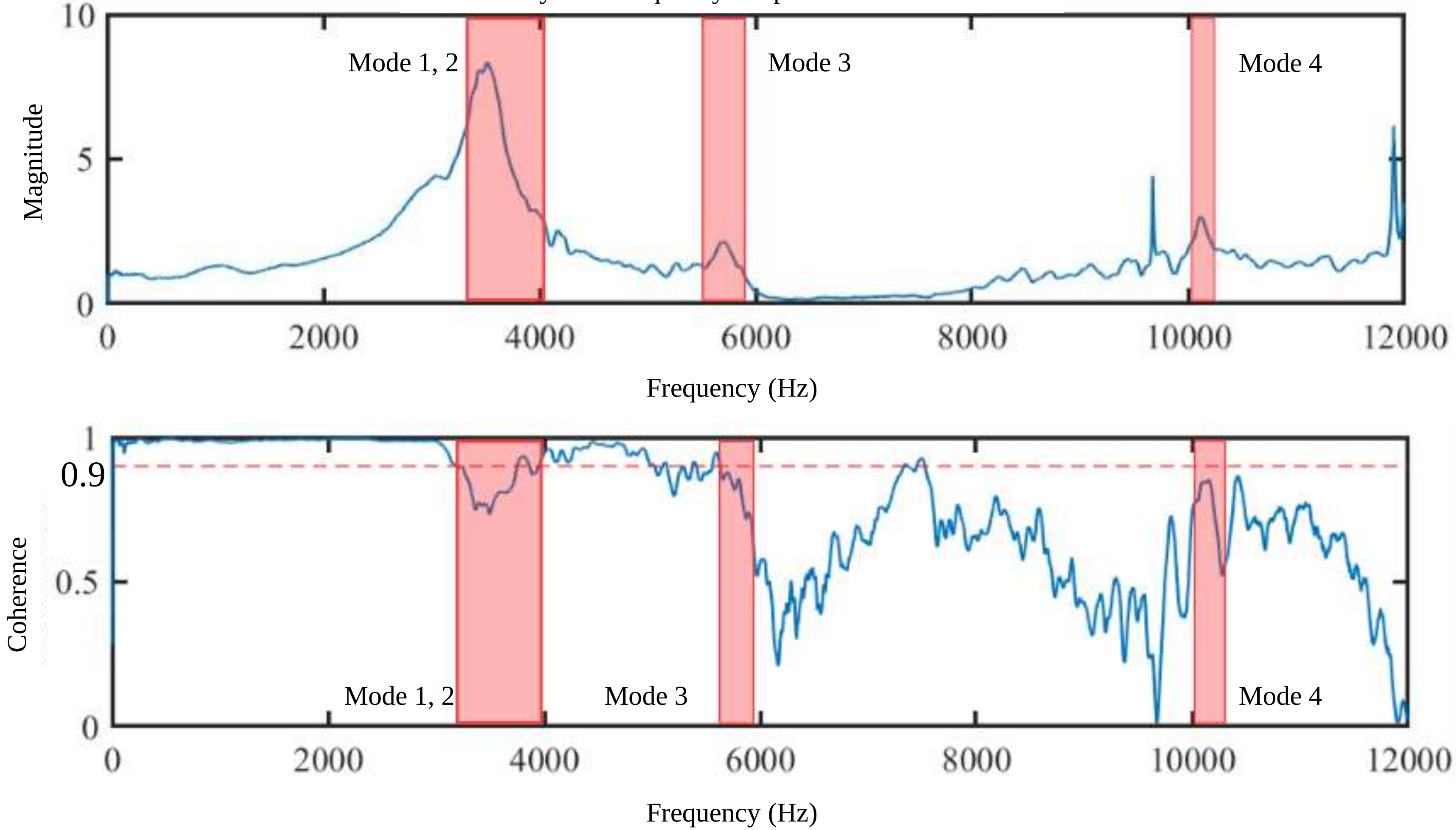
	Mode 1	Mode 2	Mode 3	Mode 4
Simulated Frequency	3681 Hz	3909 Hz	5671 Hz	10316 Hz
Experimental Frequency	3600 Hz	4000 Hz	5800 Hz	10200 Hz
Margin of Error	2.20 %	2.33 %	2.27 %	1.13 %

Simulated vs Experimental Natural Frequencies and Margin of Error

South Carolina

ANALYSIS

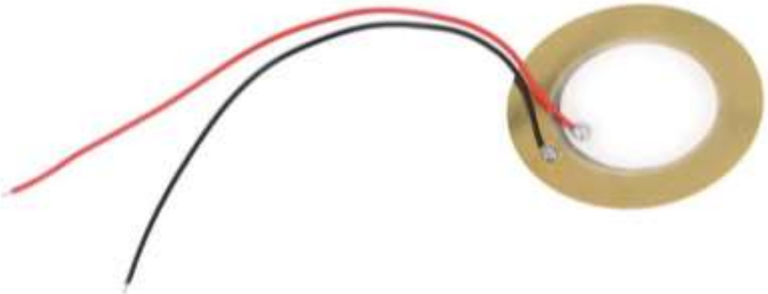
System Frequency Response Function

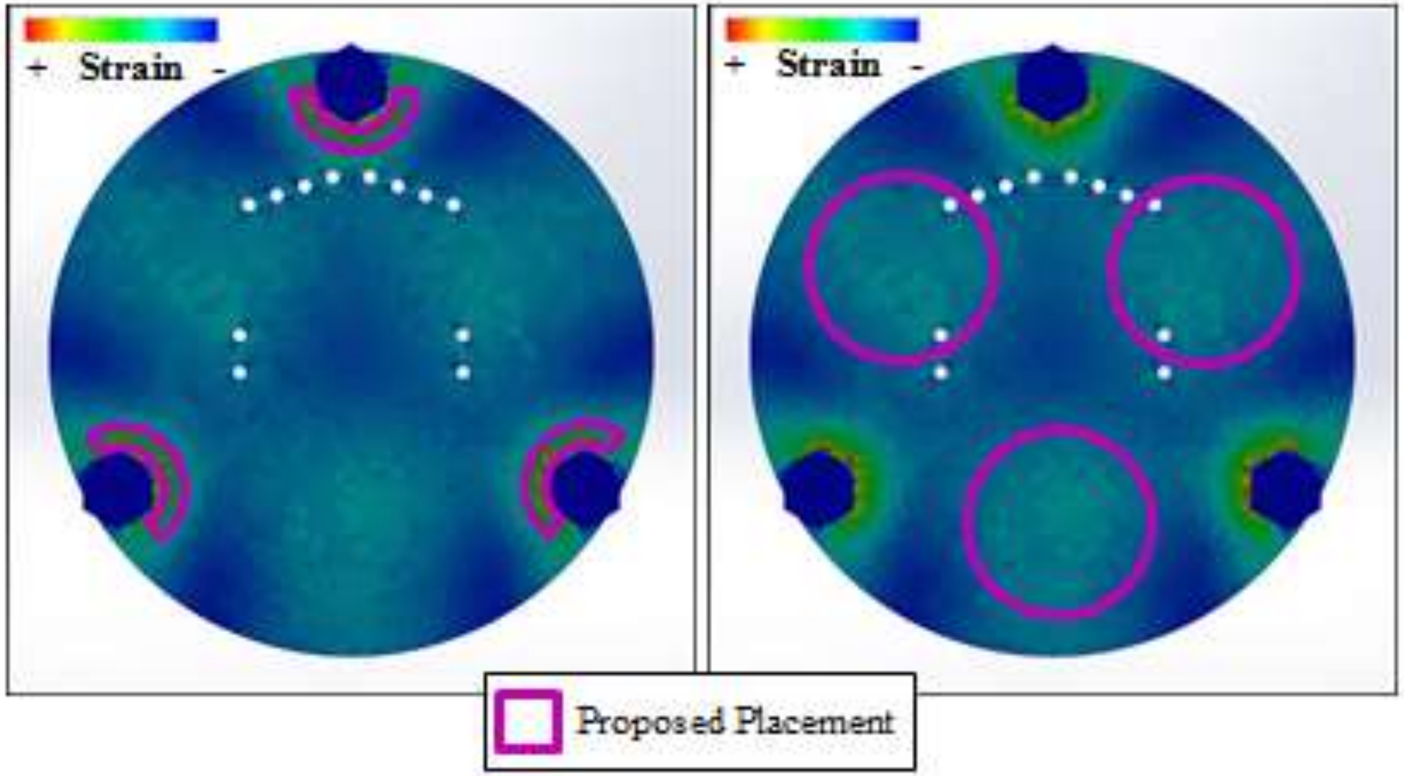


System Coherence

CONCLUSION

- Placing piezo pads in high-strain areas maximizes in-plane displacement, improving vibration dampening and system response.
- Sensors in high-strain regions enhance feedback accuracy, allowing for more efficient real-time control and system stabilization.
- Alternative placement will be tested in lower-strain/high-displacement areas to compare overall performance and confirm the effectiveness of the optimal locations.

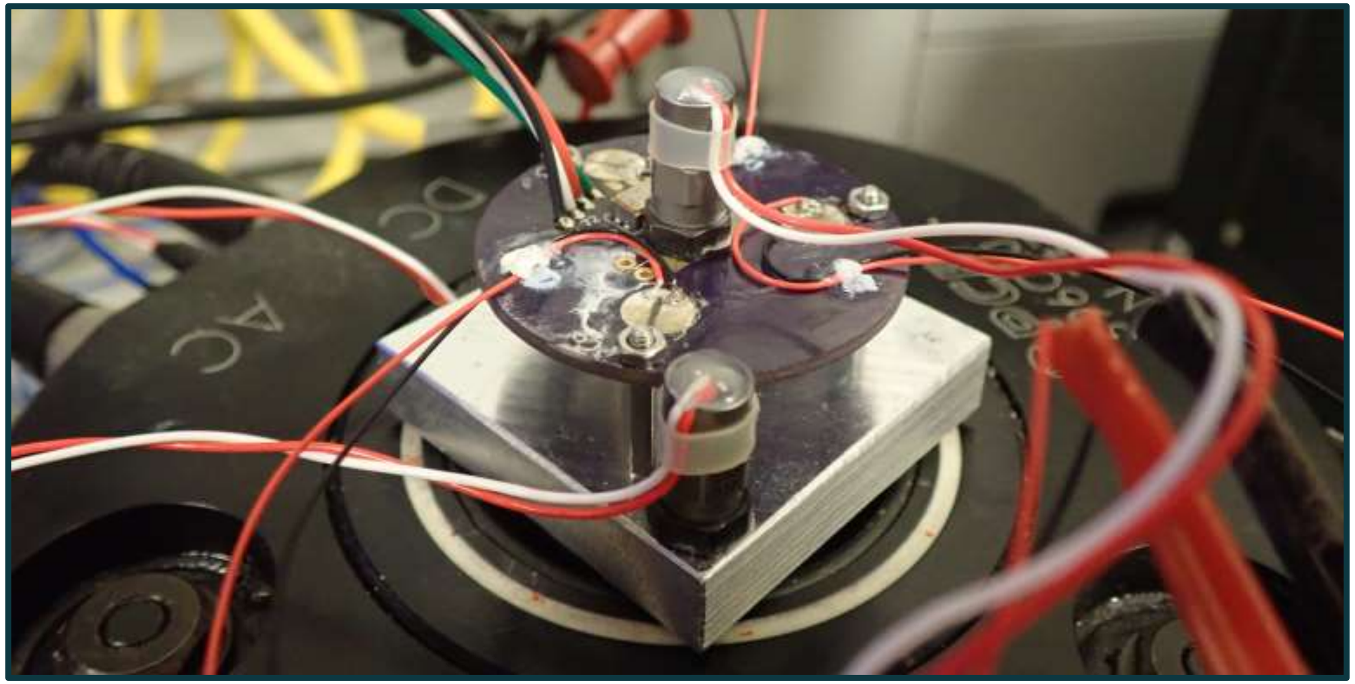


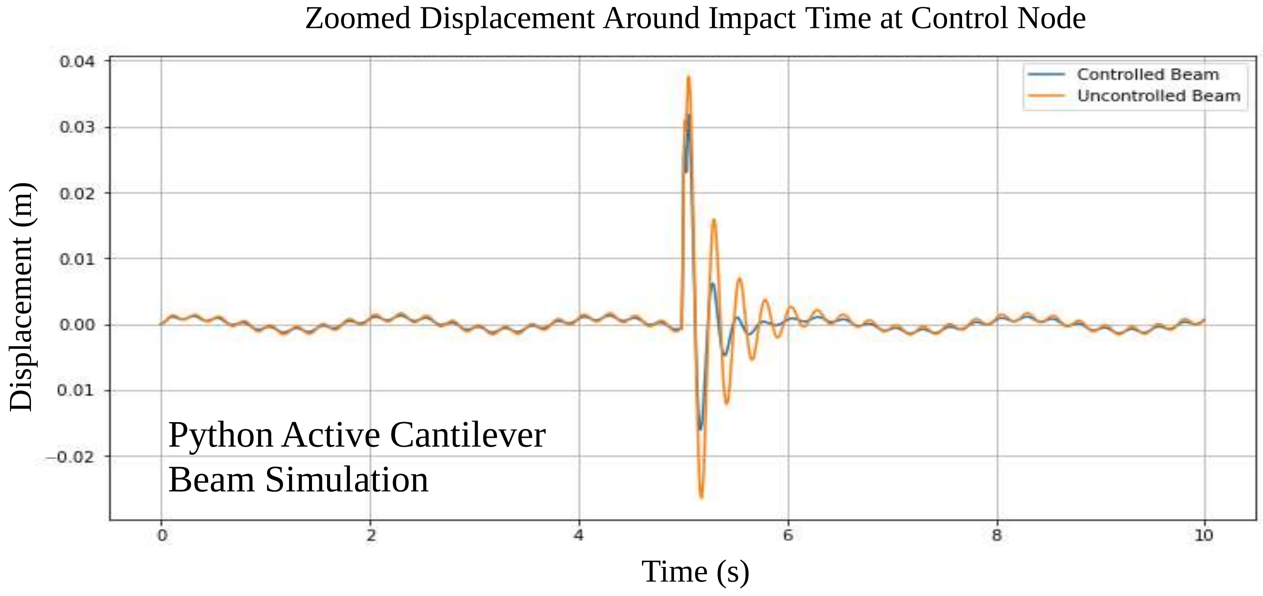


Proposed (left) and Possible Alternative (right) Piezo Placement for Optimization.

FUTURE WORK

- Progress toward control strategies.
  - LabView FPGA used for real-time implementation of control strategies.
  - Coded simulations for system behavior modeling and optimization.
  - Simulink for system-level simulations and control design.
- Piezoelectric sensing and actuation experimentation, improvement, and performance optimization.





QUESTIONS?

This material is based upon work supported by the United State Air Force through the Air Force Research Laboratory (AFRL) Scholars Program. Additional support is provided by the National Science Foundation grant numbers 1937535, 1956071 and 2237696 with additional support from the Air Force Office of Scientific Research (AFOSR) through award no. FA9550-21-1-0083. Any opinions, findings conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation, or the United States Air Force. (Distribution A. Approved for public release; distribution unlimited (AFRL-2024-5026))