

# TEST-TO-FAILURE CHARACTERIZATION AND ACCELERATION SIGNAL FEATURE ANALYSIS OF ELECTRONIC SYSTEMS UNDER REPEATED SHOCK LOADING

Trotter Roberts<sup>1</sup>, Hugo Luck<sup>1</sup>, Joud N. Satme<sup>1</sup>, Mohsen Gol Zardian<sup>1</sup>, Sina Navidi<sup>3</sup>,  
Ryan Yount<sup>1</sup>, Austin R.J. Downey<sup>1,2</sup>, and Chao Hu<sup>3</sup>.

University of South Carolina, Columbia, SC 29208

1. Department of Mechanical Engineering.
2. Department of Civil and Environmental Engineering.

University of Connecticut, Storrs, CT 06269

3. Department of Mechanical Engineering.

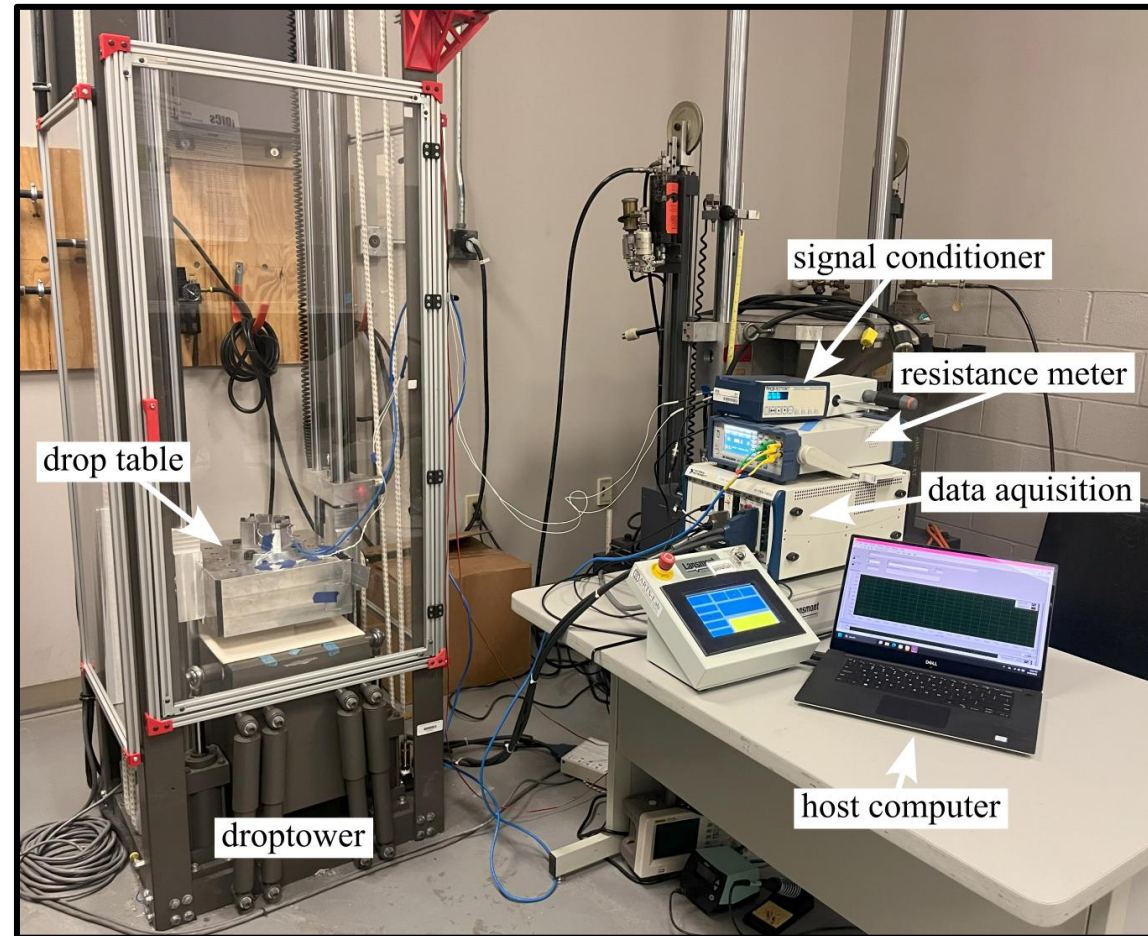


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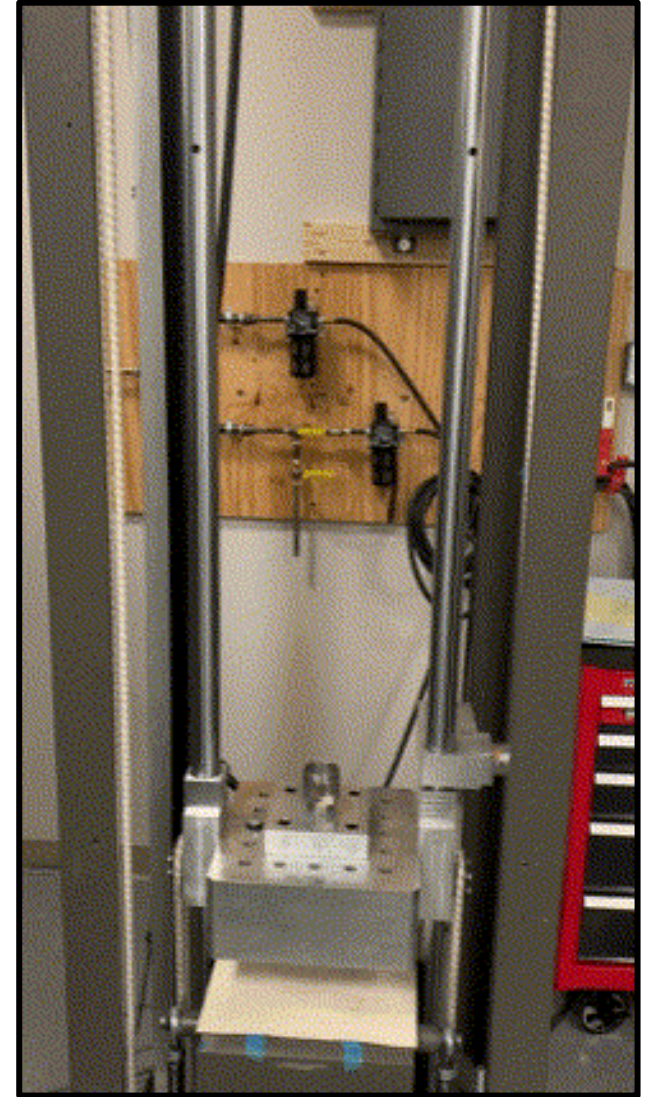
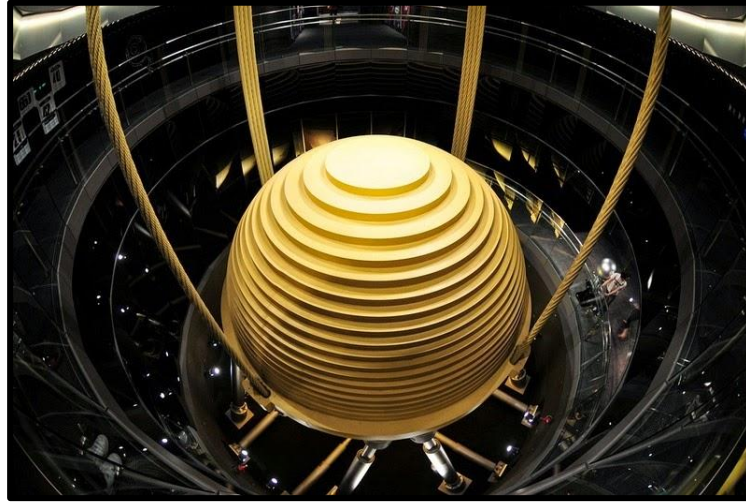
# OVERVIEW

- Introduction
- Ongoing Work
- Project Motivation
- Focused Study
  - Test-to-Failure Setup
  - System Failure
  - Degradation Tracking
  - Feature Analysis
  - Conclusion
- Future Work



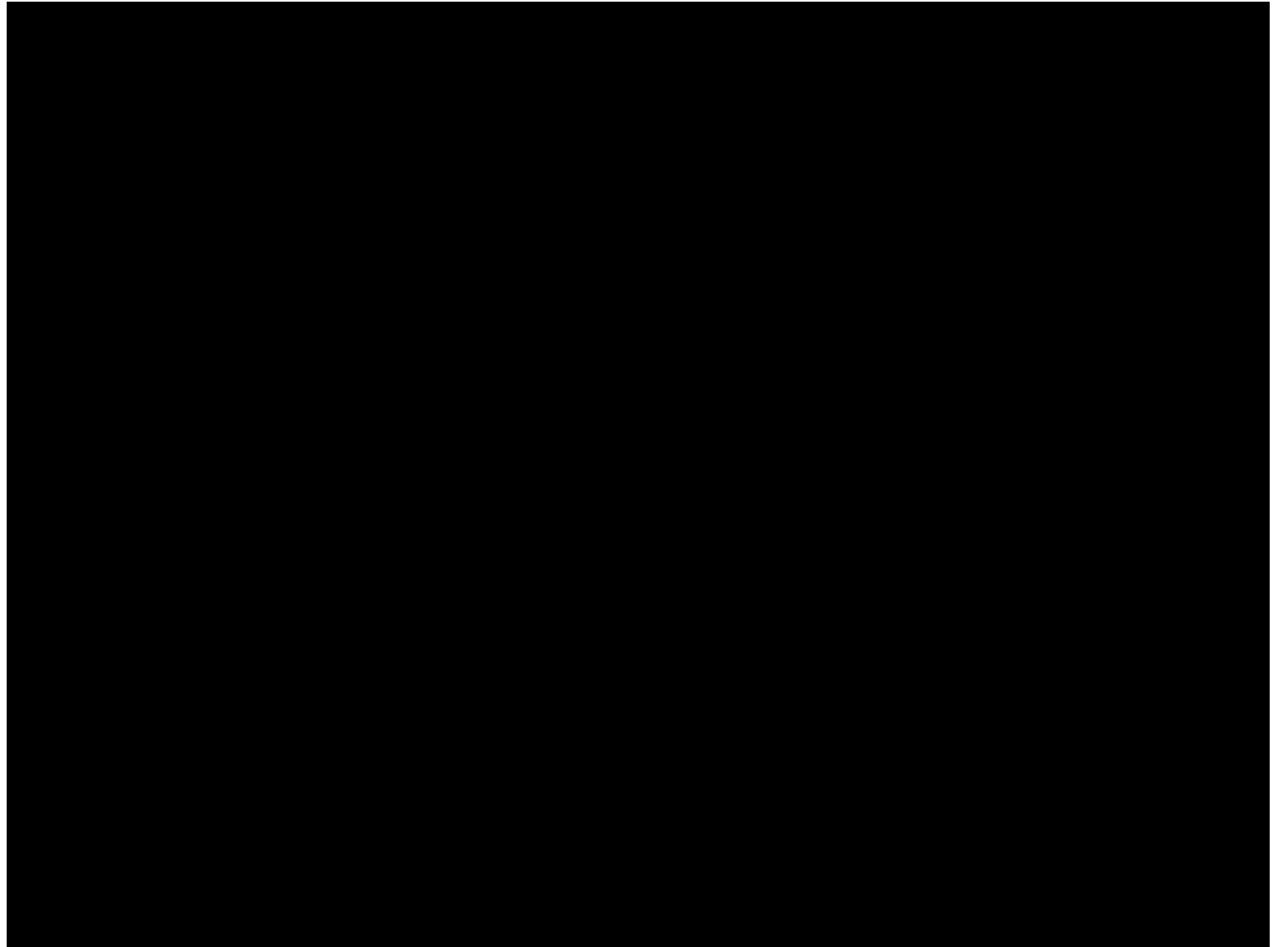
# INTRODUCTION

- 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.



# High-rate Shock

- Increasing survivability of packages in extreme dynamic environments.





# High-rate Structural Monitoring, Damage Detection, Prognostics, and Reactions Working Group



## High-Rate-SHM-Working-Group

High-rate Structural Monitoring, Damage Detection, Prognostics, and Reactions Working Group

👤 2 followers   🔗 <http://www.me.sc.edu/Research/Dow...>   ✉ [austindowney@sc.edu](mailto:austindowney@sc.edu)

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### Popular repositories

<p><a href="#">Dataset-2-DROPBEAR-Acceleration-vs-Roller-Displacement</a> <span>Public</span></p> <p>Acceleration-vs-Roller-Displacement Dataset for DROPBEAR</p> <p>● Python   ☆ 1   🔗 1</p>	<p><a href="#">Dataset-3-High-Rate-In-Situ-Damage-of-Electronics-Packages</a> <span>Public</span></p> <p>Drop Tower shock tests of highly-instrumented electronics package</p>
<p><a href="#">Dataset-4-Univariate-signal-with-non-stationarity</a> <span>Public</span></p> <p>univariate signal with varying levels of non-stationarities</p> <p>● Python</p>	<p><a href="#">Dataset-1-High-Rate-Drop-Tower-Data-set</a> <span>Public</span></p> <p>A data set focused on quad PCBs under shock.</p> <p>● Python</p>
<p><a href="#">Dataset-5-Extended-Impact-Testing</a> <span>Public</span></p>	<p><a href="#">Dataset-1a-Shock-Test-GAN-model</a> <span>Public</span></p> <p>Generating model trained on Dataset 3</p>



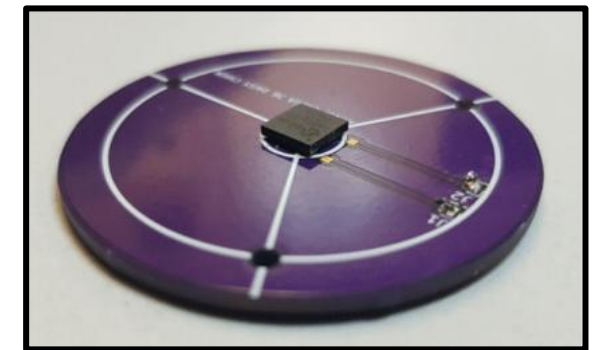
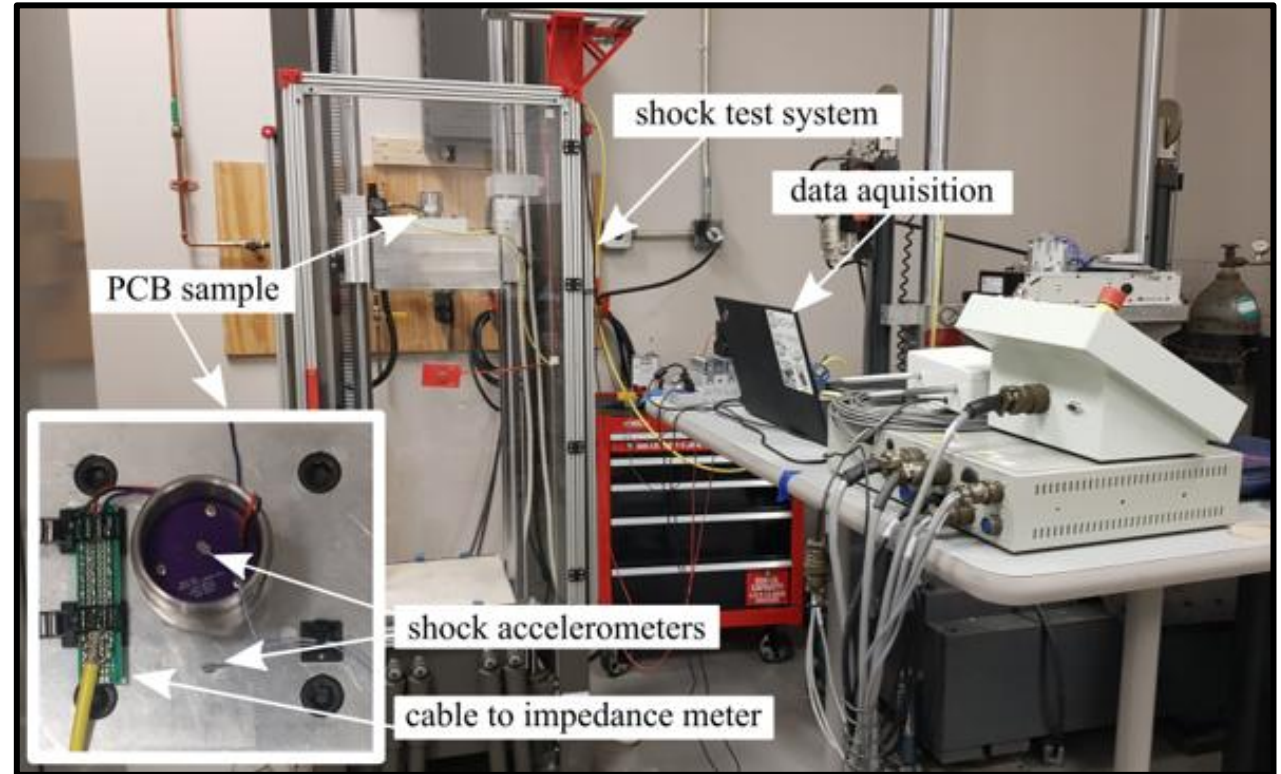
# GitHub



# ONGOING WORK

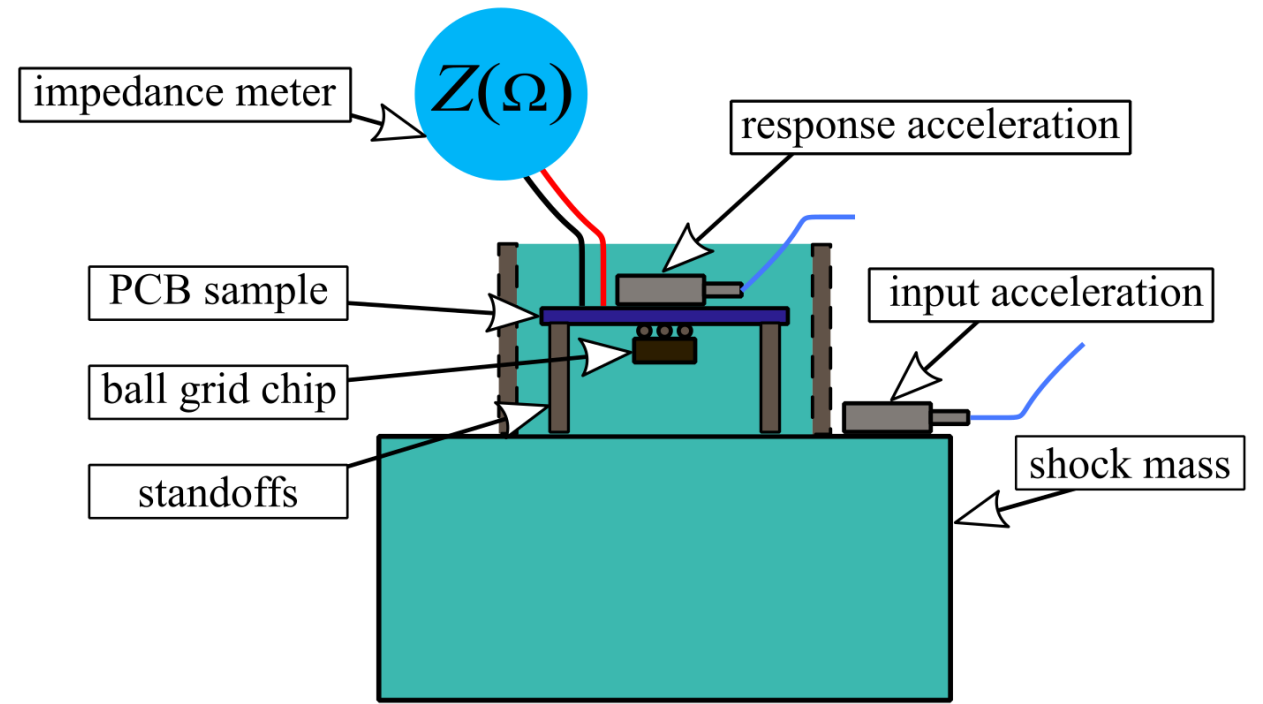
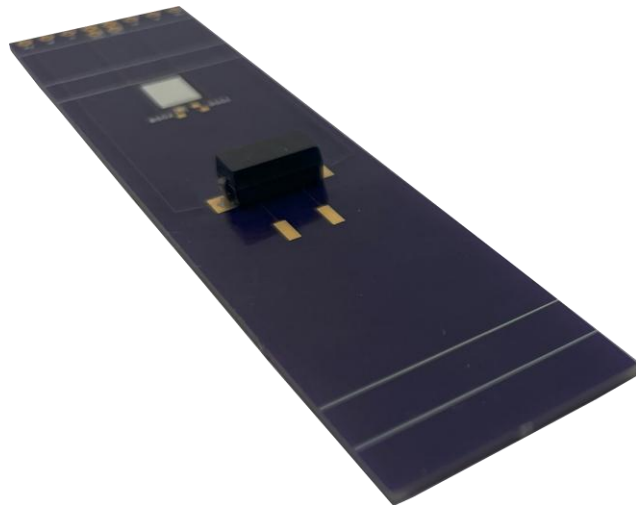
# ONGOING WORK

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

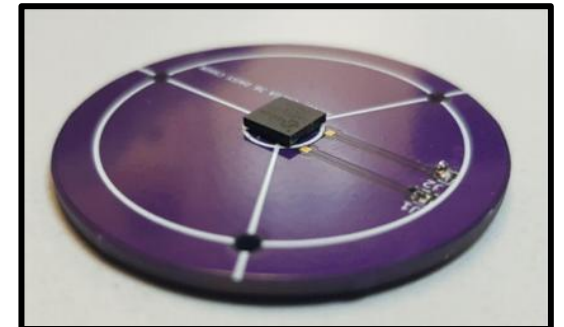
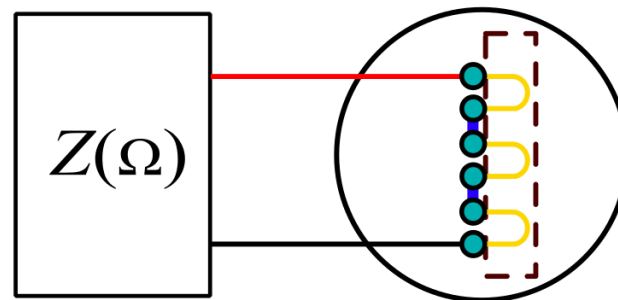


# ONGOING WORK

- 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.



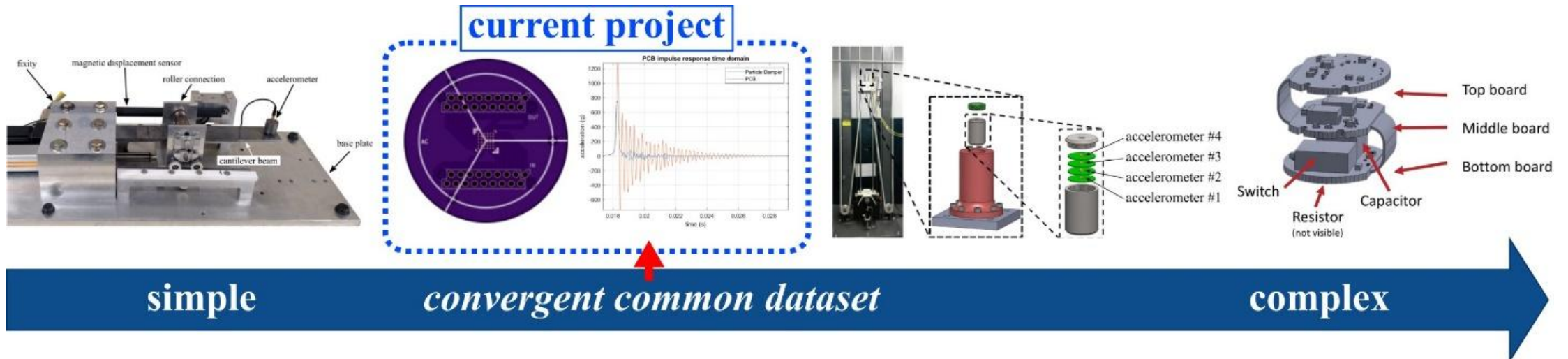
— PCB connection  
— internal connections



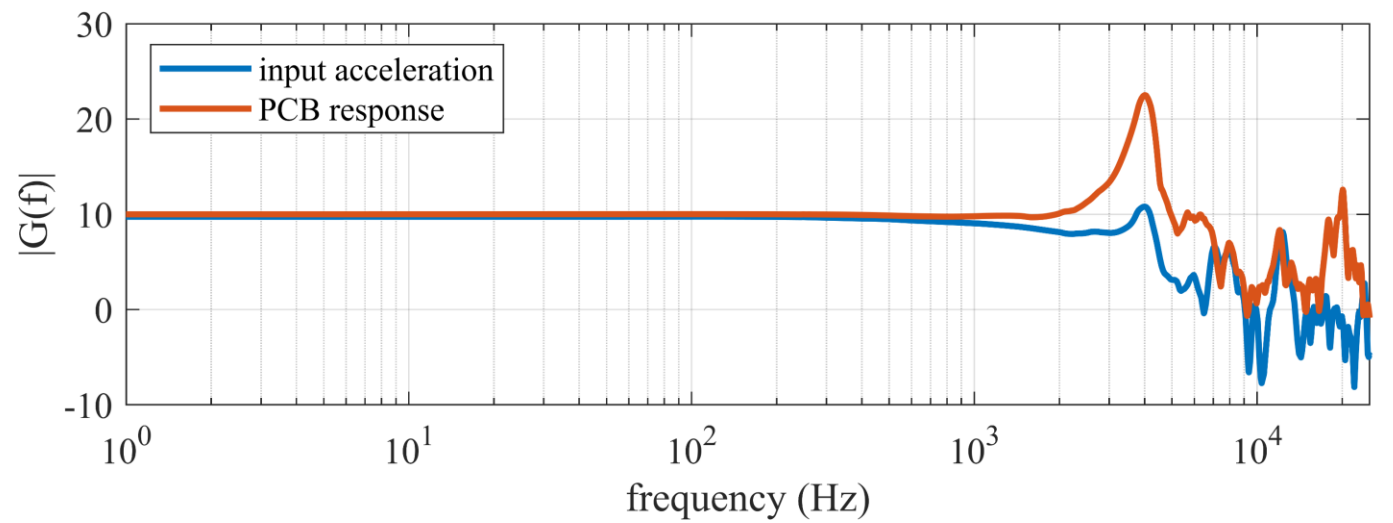
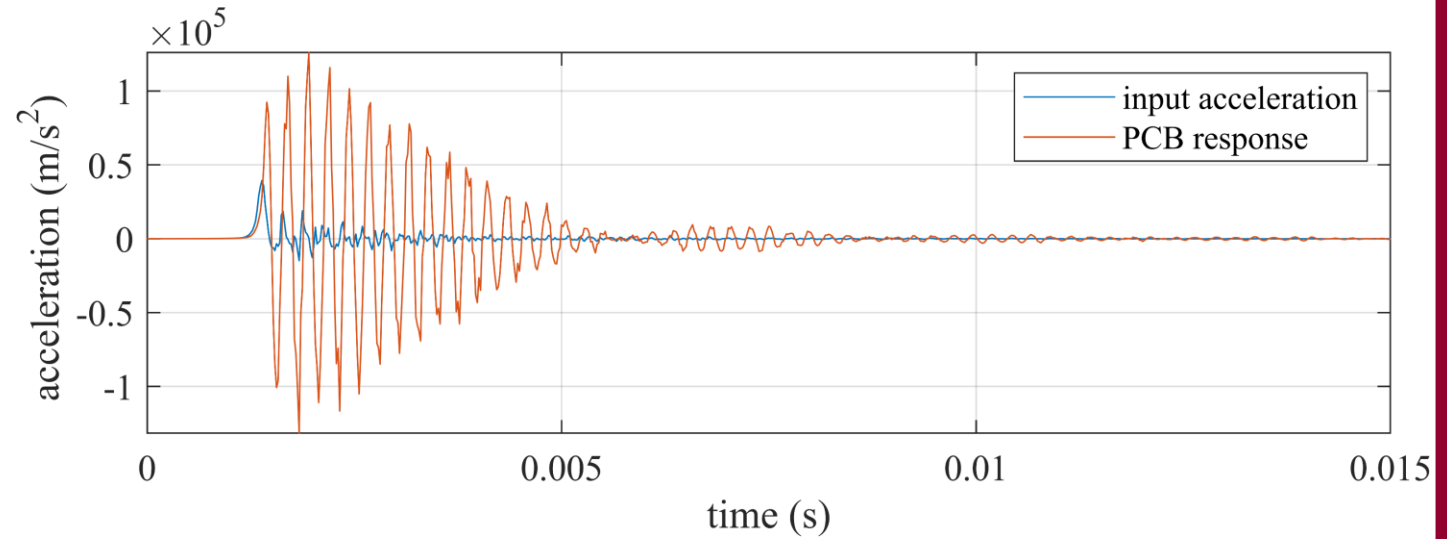
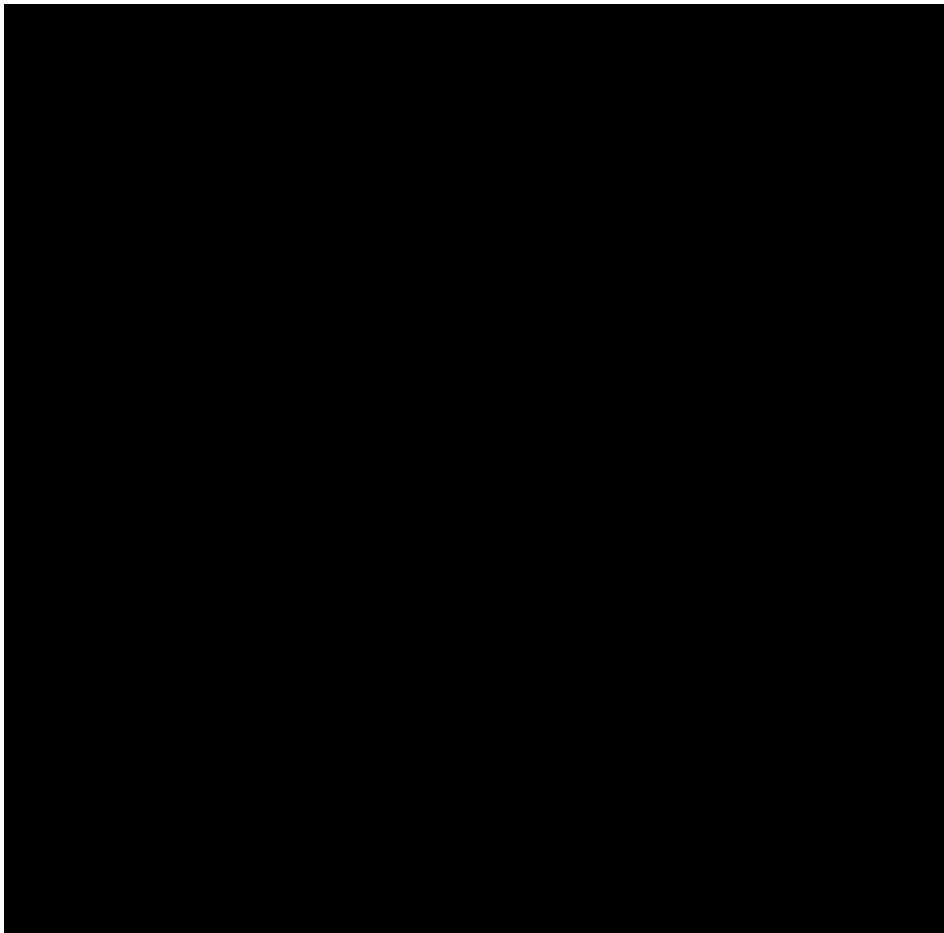
# PRIOR WORK ON COMMON DATASETS

- We have developed several datasets used to investigate the high-rate challenge.
- 3 key traits that a convergence dataset must have:
  1. Relevant target application
  2. Labeled damage features:
  3. Dynamic loading before shock event:

	DoD-relevant target application	Labeled damage features	Dynamic loading before the dynamic event
<b>DROPBEAR</b>	No	Yes	Yes – not a shock event
<b>Instrumented Electronic Boards</b>	Yes – limited relevance	No	No
<b>Representative Electronic Assembly</b>	Yes	Yes– binary case	No
<b>Proposed System</b> <i>(generate the converged common dataset)</i>	Yes	Yes	Yes

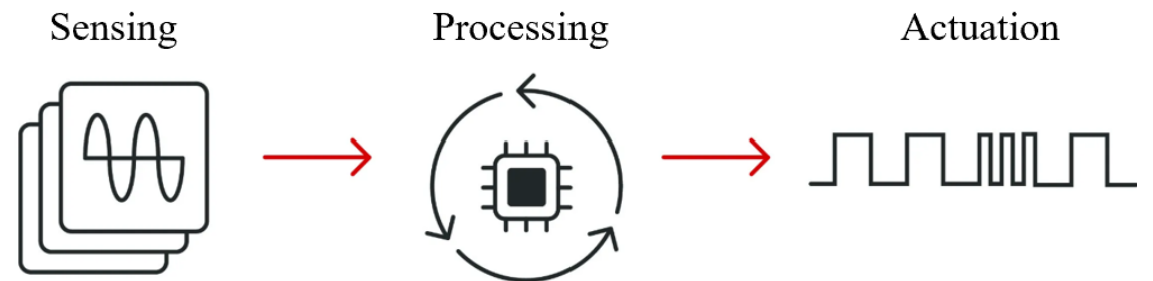


# ONGOING WORK



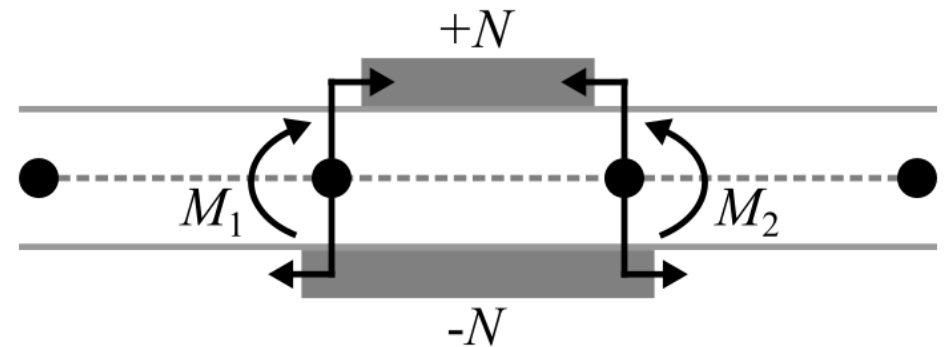
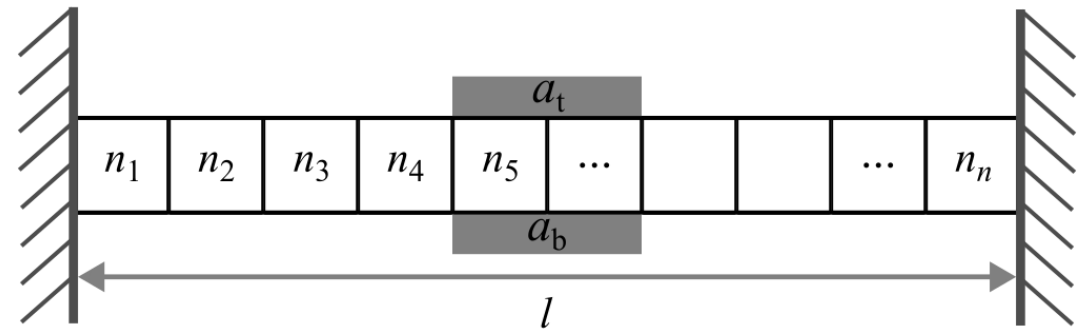
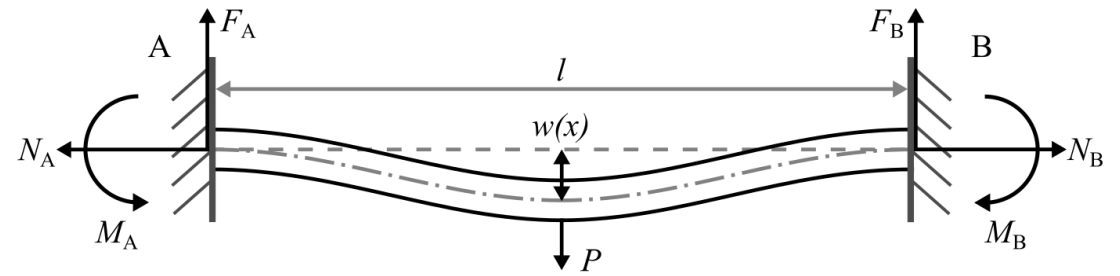
# GOAL: CLOSE THE LOOP FROM MONITORING TO CONTROL?

- Active control of the structural deflection of electronics could:
  - Increase their survivability
  - Increase their serviceability
  - Open them up to new high-shock applications
  - Reduce their packaging constraints
    - Size
    - Weight
    - Thermals



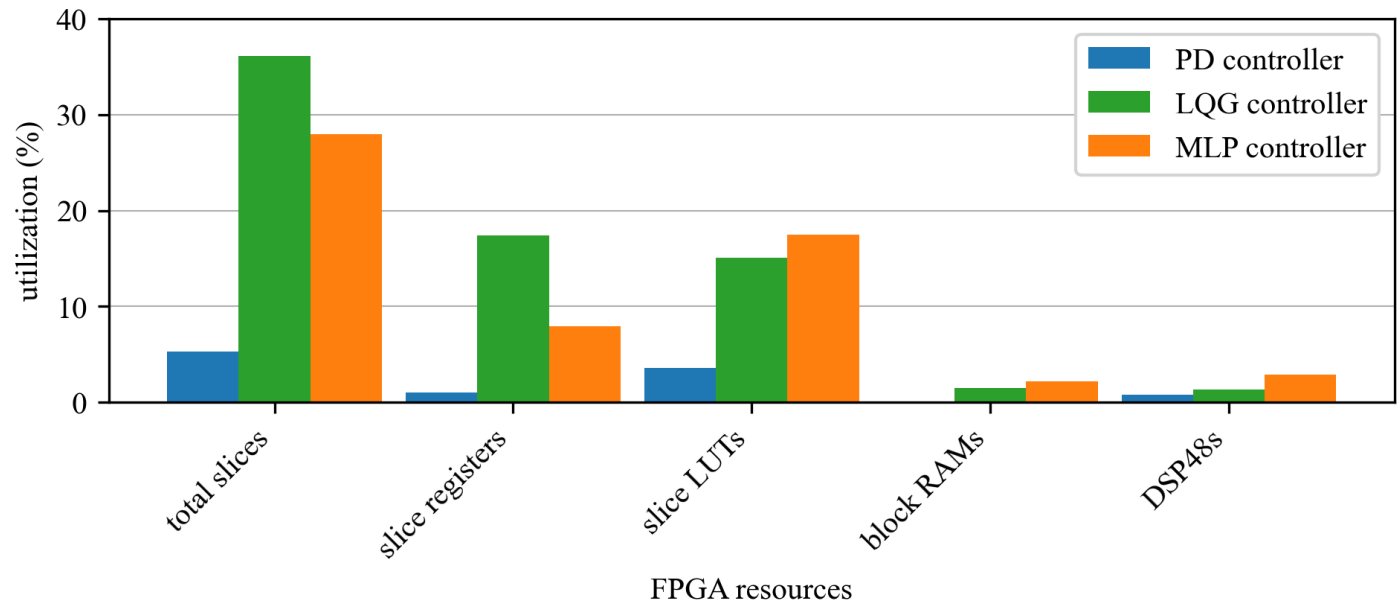
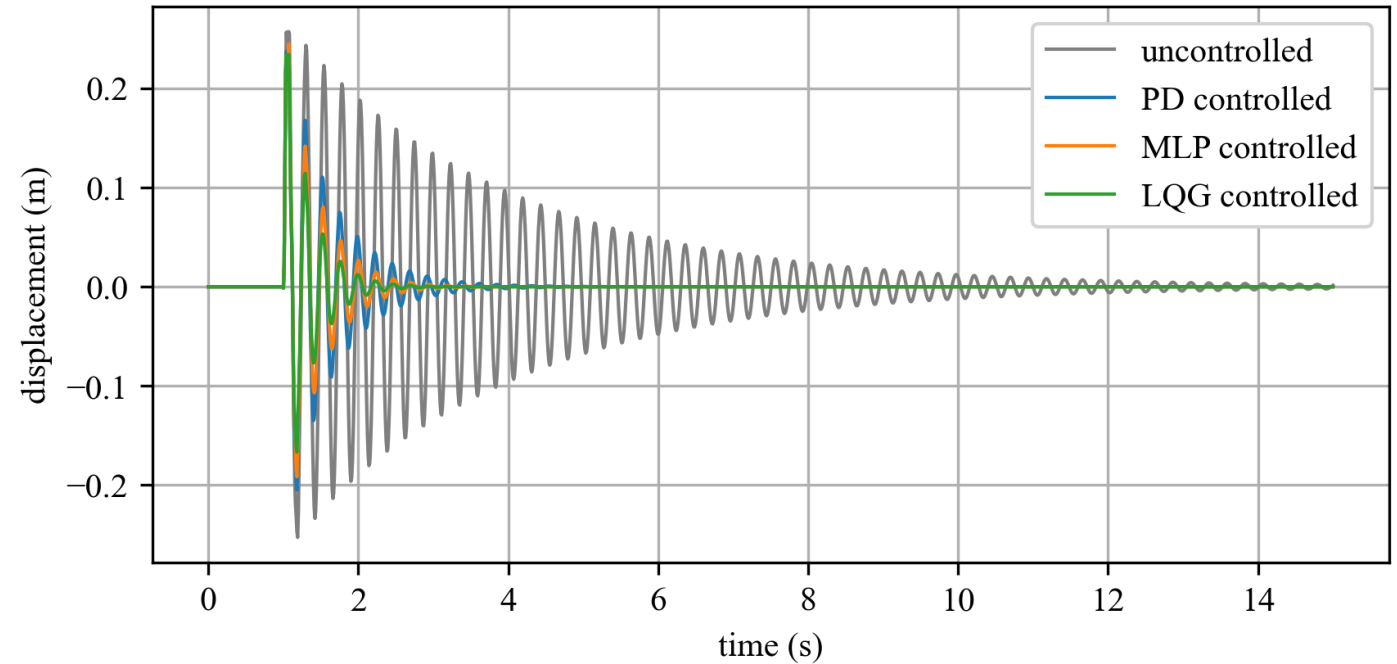
# ONGOING WORK

- 1D Extended Euler–Bernoulli beam with axial, transverse, and rotational DOFs
- Represents a fixed-fixed PCB beam under shock loading ( $\approx 5000$  g, sub-ms pulse)
- Axial and bending coupling included for realistic stiffness behavior
- Moment-based actuation mimics piezoelectric patches bonded top/bottom



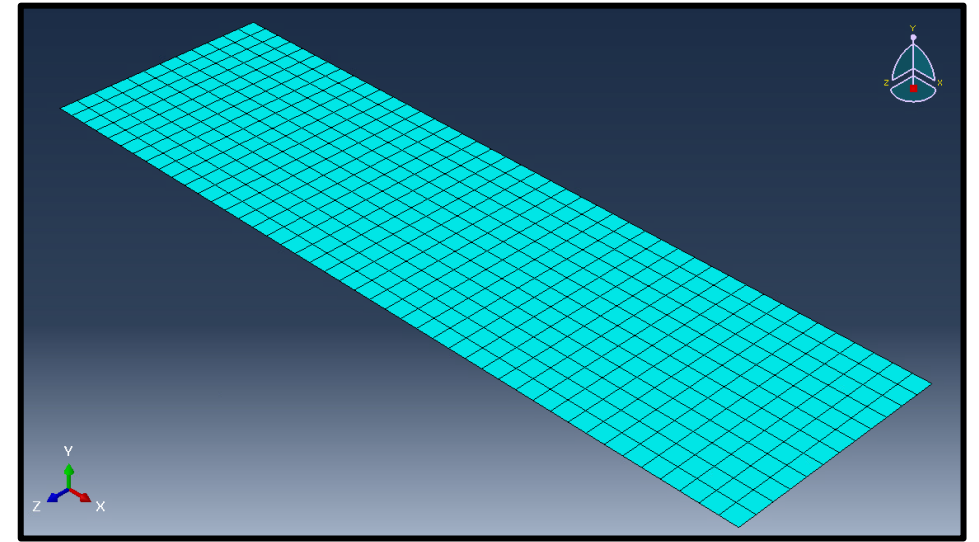
# ONGOING WORK

- FPGA implementation of real-time control for shock environments.
- Resource and performance comparison of PD, LQG, and MLP controllers.
- Learning-based control reduces hardware cost while maintaining damping performance.

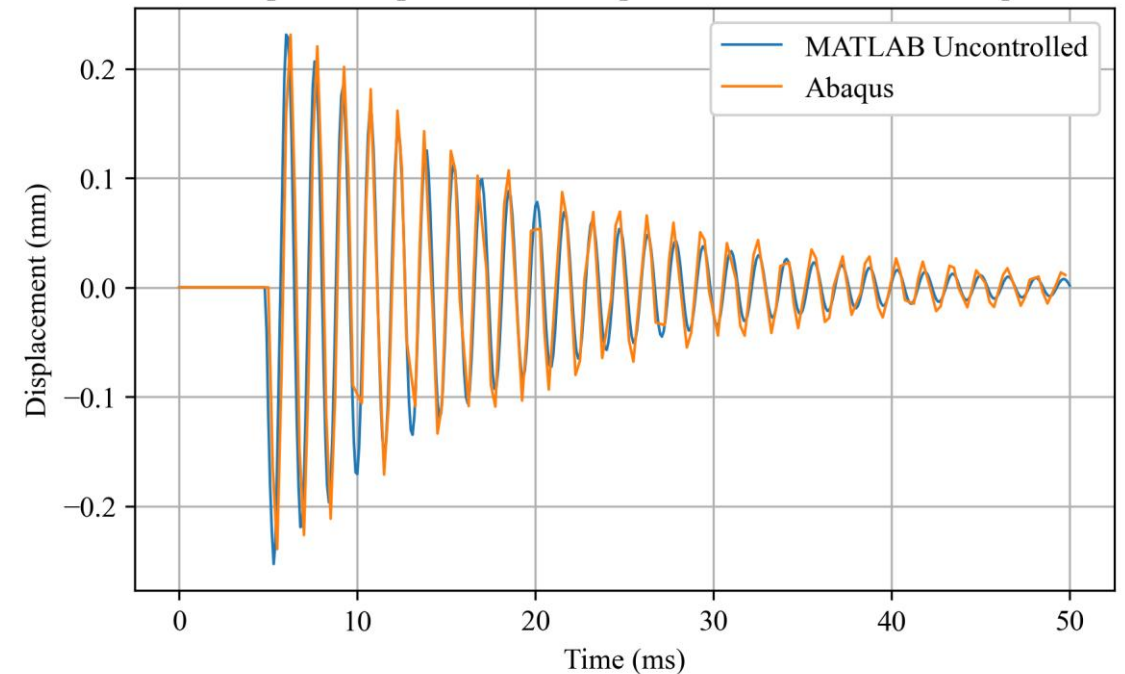


# ONGOING WORK

- A higher-fidelity shell model of the fixed–fixed beam was created to mirror the simplified numerical model.
- Both models were subjected to the same transient impact load to compare displacement responses.
- Midspan deflection histories showed strong agreement, confirming that the simplified formulation captures the dominant bending dynamics.



Midpoint Displacement Comparison: MATLAB vs Abaqus



**MOTIVATION**

# REAL-WORLD APPLICATIONS



**Blast Against Civil Structures**

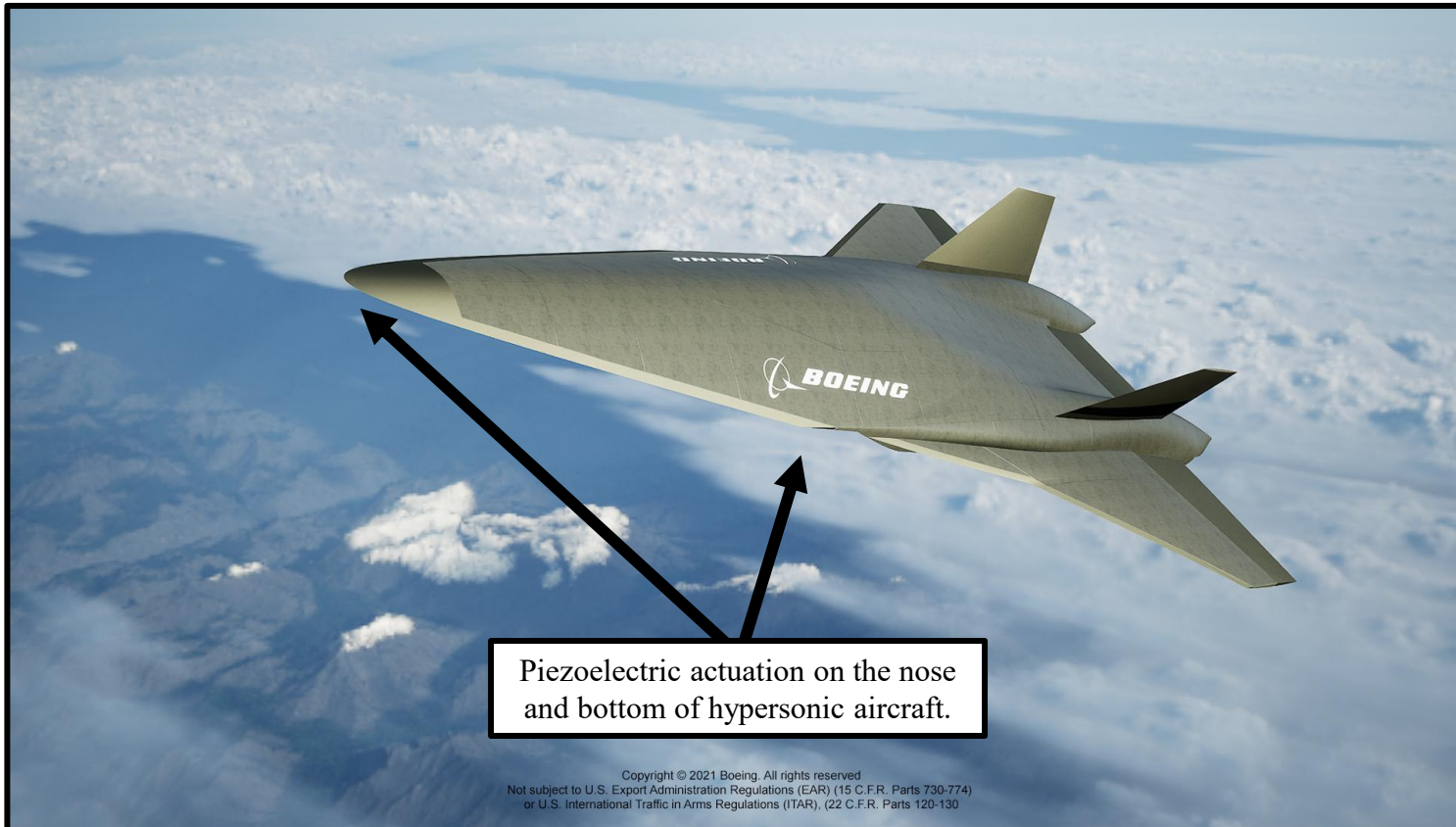


**Automotive Impact and Crashes**



**High-speed Aircraft and Airframes**

# REAL-WORLD APPLICATIONS

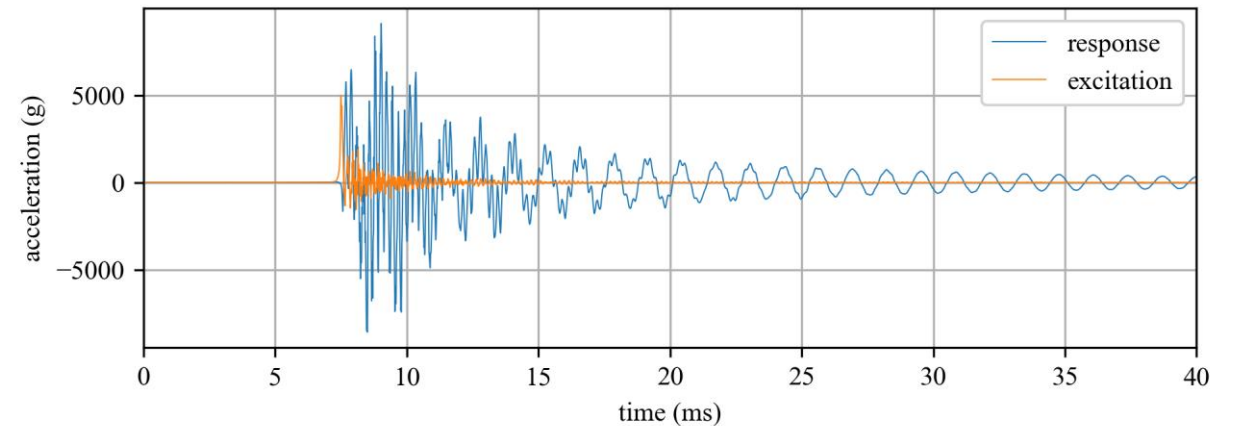
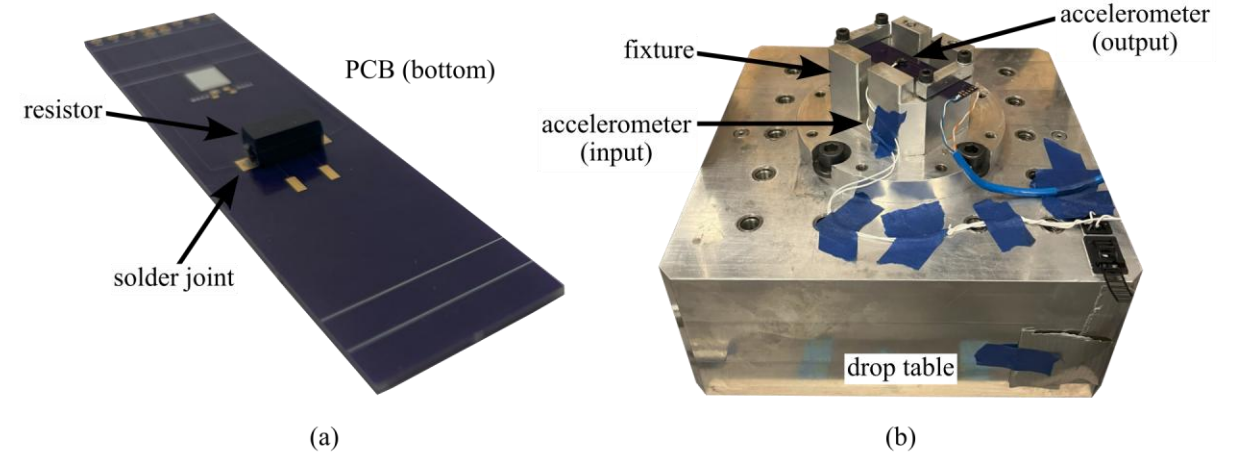


PZT Actuator Patches

# FOCUSED STUDY

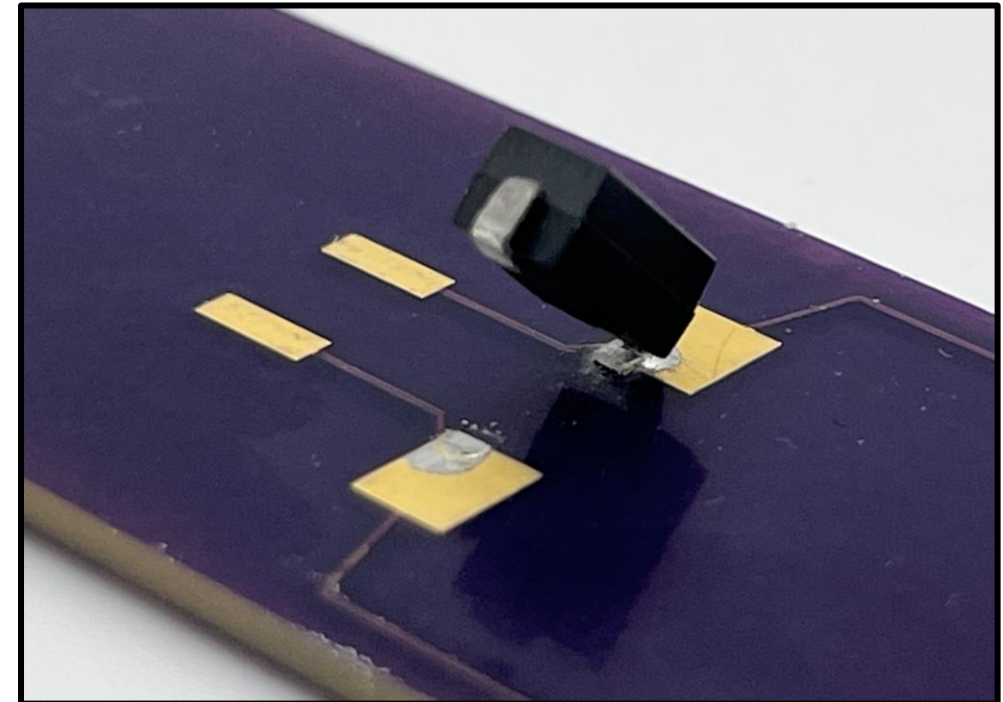
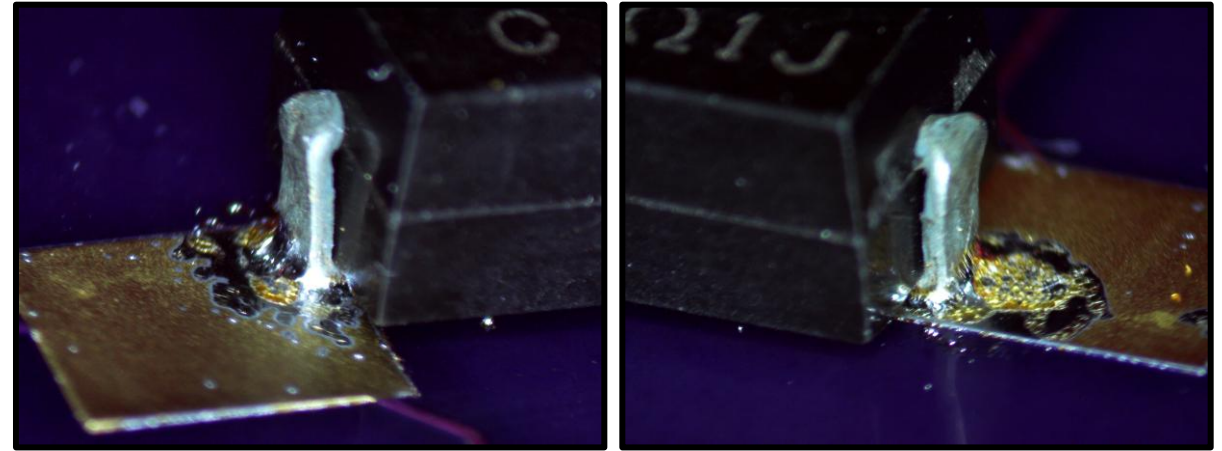
# TEST-TO-FAILURE SETUP

- Printed circuit boards mounted as fixed–fixed beams with a surface-mount resistor at midspan
  - 175Tg FR4
  - $25.40 \times 76.20 \times 1.60$  mm
  - 100 m $\Omega$ , 1 W resistor
- Subjected to repeated shock loading at constant impact energy
  - 5000 g and 0.2 millisecond pulse duration (9.8 m/s is a moderate car crash)
  - 12-inch drop using bungees, 1/16<sup>th</sup> inch felt
- Acceleration measured at the fixture and board midspan to capture input–response behavior.



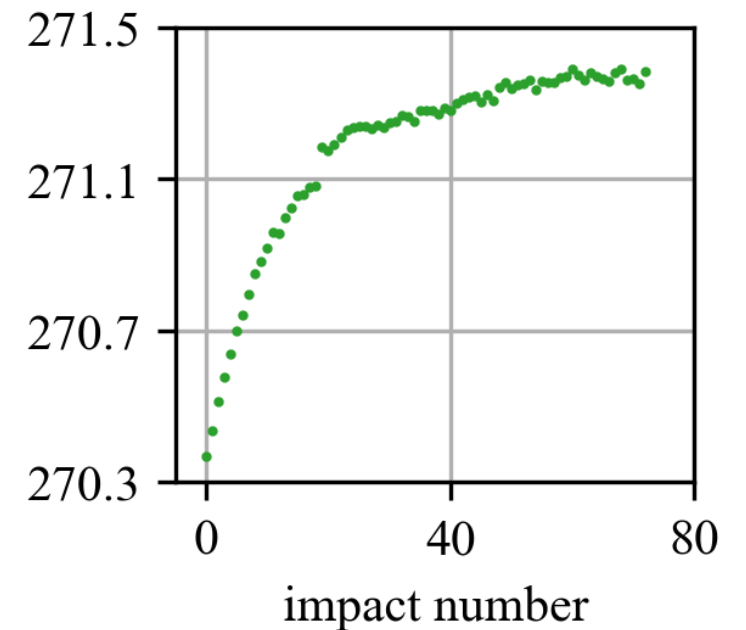
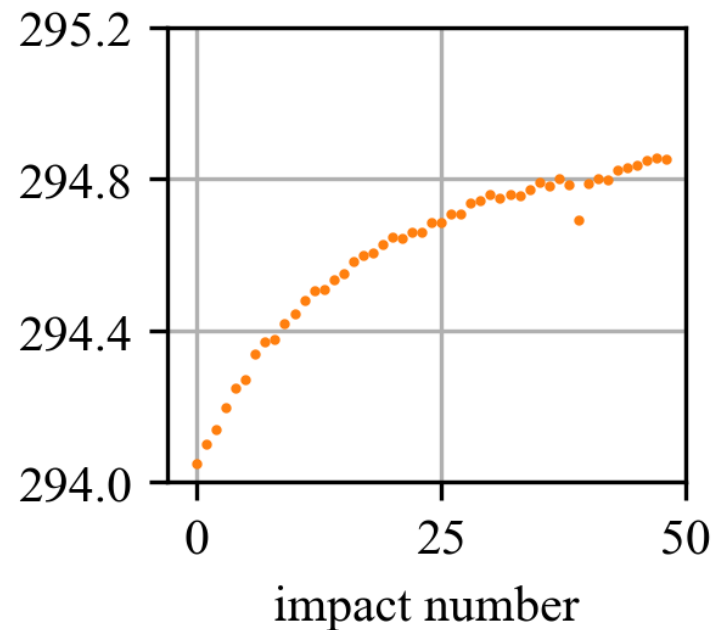
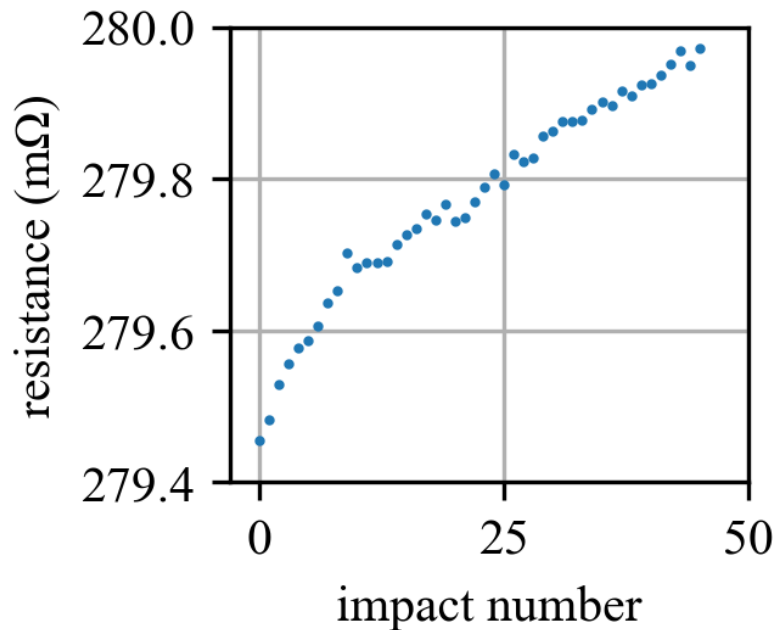
# SYSTEM FAILURE

- Repeated high-g impacts causes crack initiation and growth in solder joints connecting surface-mount resistors.
- Resistor eventually lifted or detached as solder joints fractured.
- PCB substrate remained intact, failure isolated to solder fatigue.
- Consistent failure mode observed across all tested boards.



# DEGRADATION TRACKING

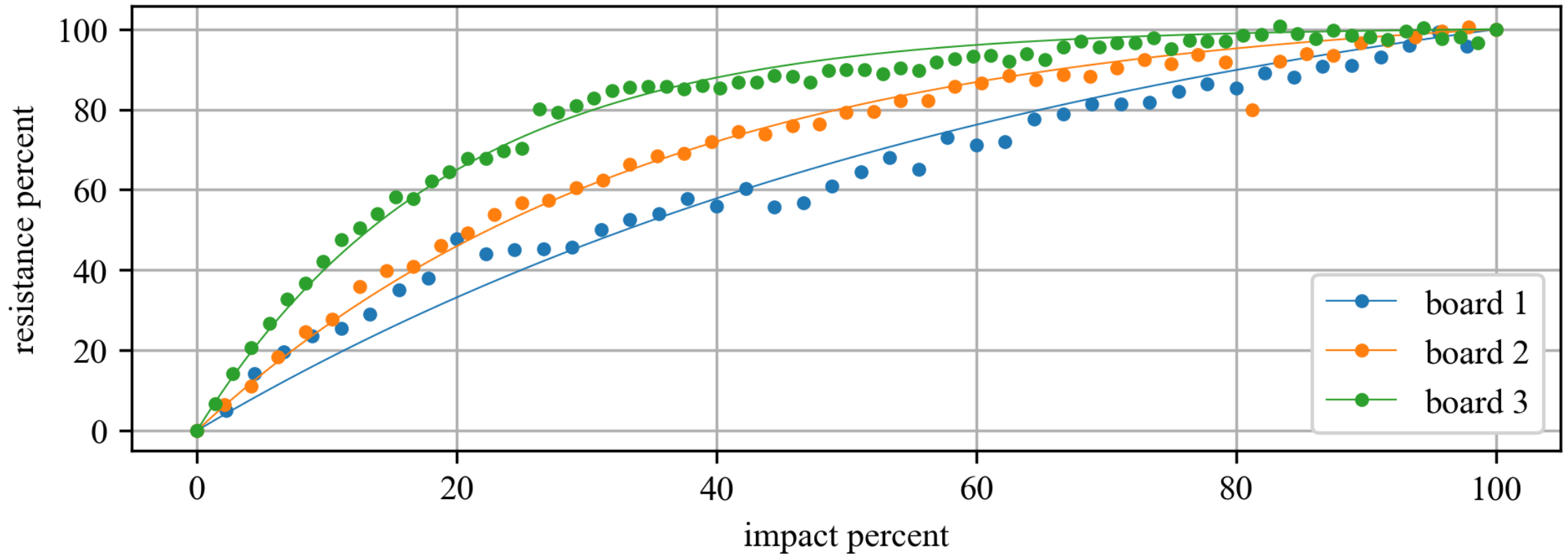
- Electrical resistance monitored after each impact to track solder joint and trace degradation.
- Resistance trends revealed gradual increases until near failure, corresponding to crack initiation in solder joints.



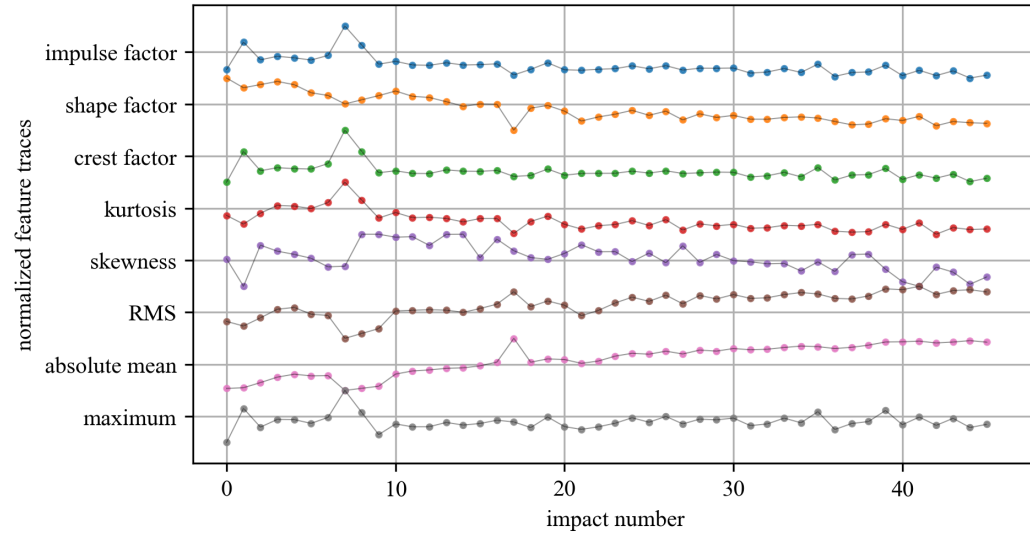
# DEGRADATION TRACKING

- Developed a simple equation to represent the estimated ground truth state ( $y$ ) for a given impact ( $x$ ).

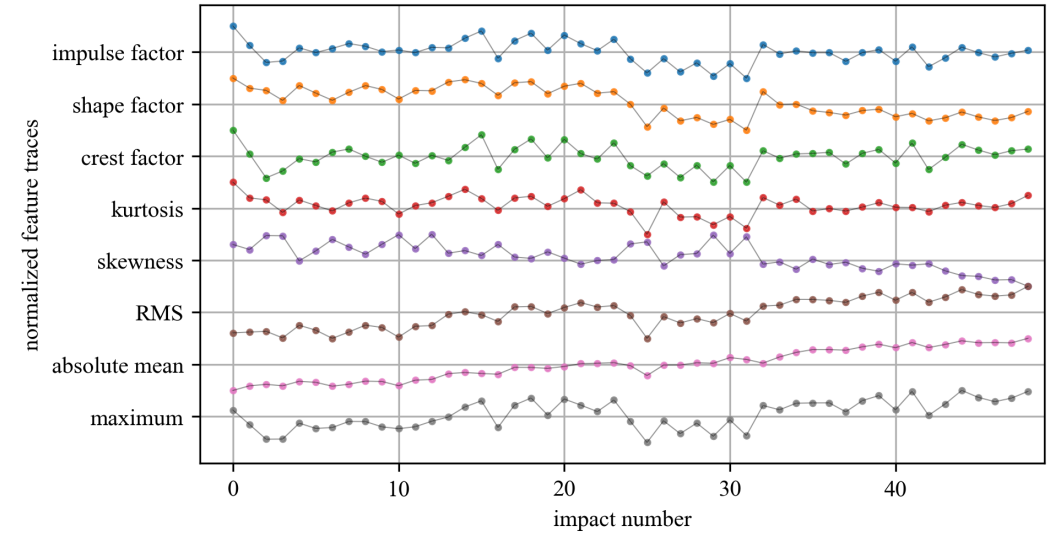
$$y(x) = \frac{100(1 - e^{-bx})}{1 - e^{-100b}}$$



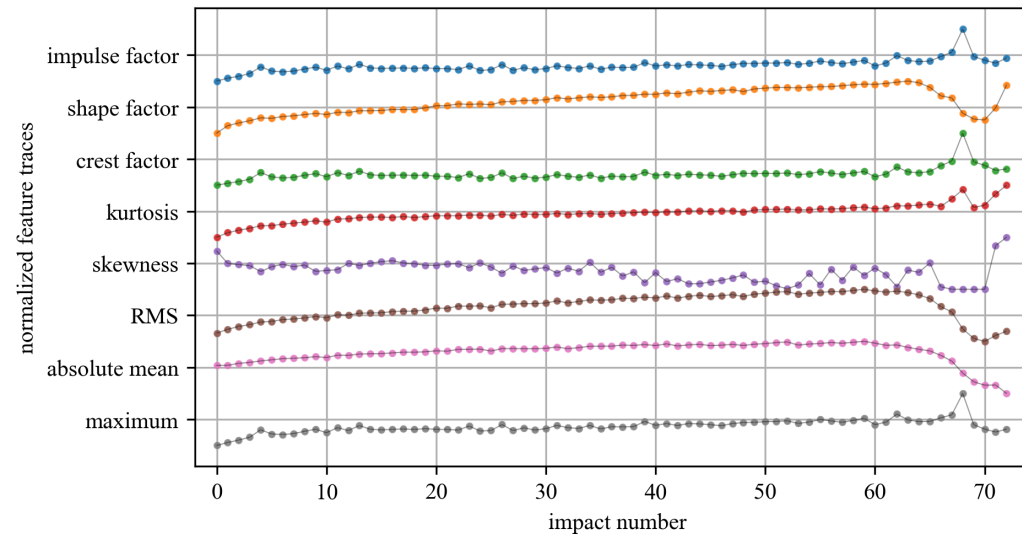
### Board 1



### Board 2

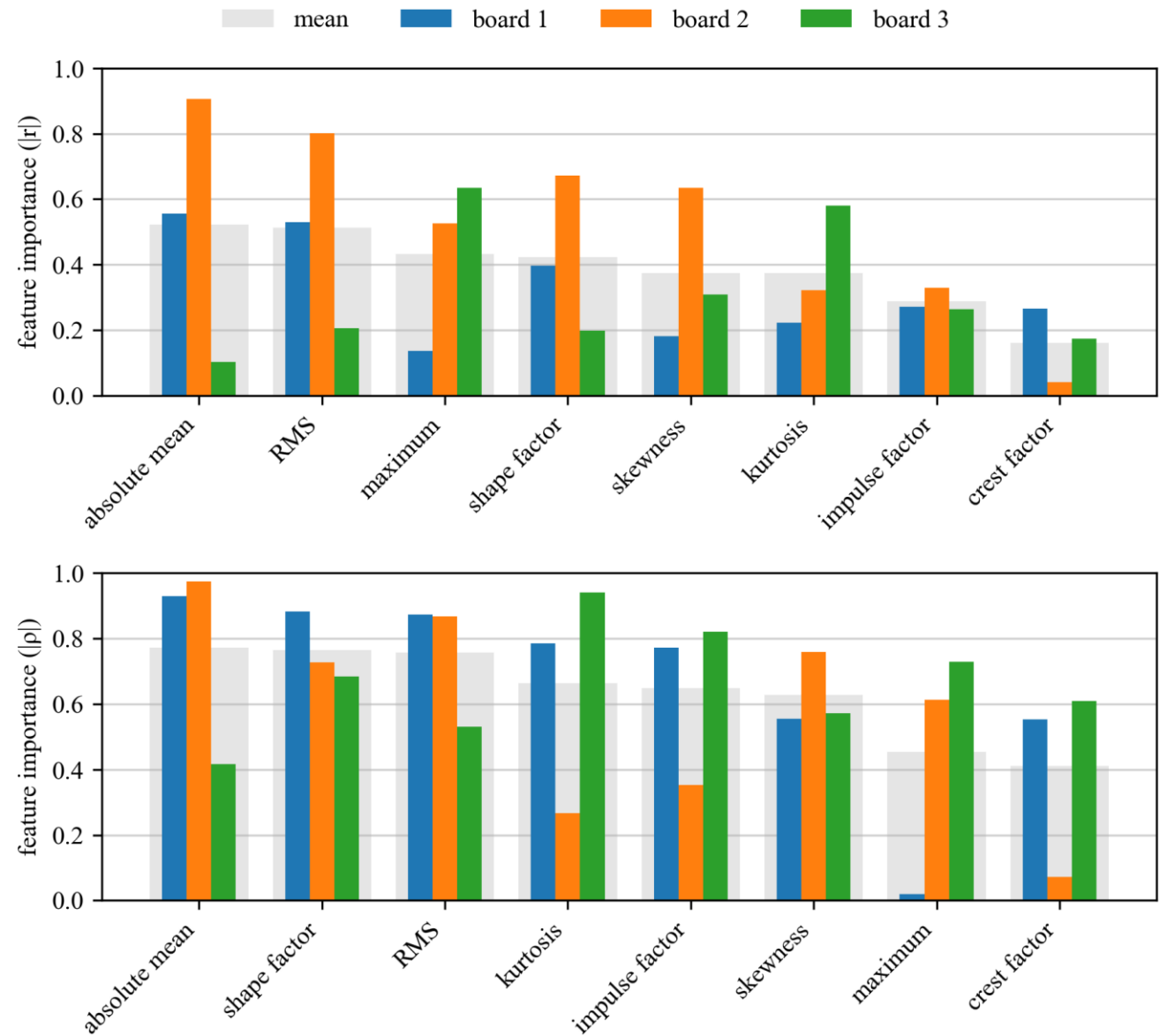


### Board 3



# FEATURE ANALYSIS

- Extracted time-domain acceleration features across repeated shock events.
- Computed Pearson (linear) and Spearman (monotonic) correlations with resistance-based damage trends.
- Absolute mean, RMS, and shape factor consistently exhibited the strongest correlation with cumulative damage across boards.

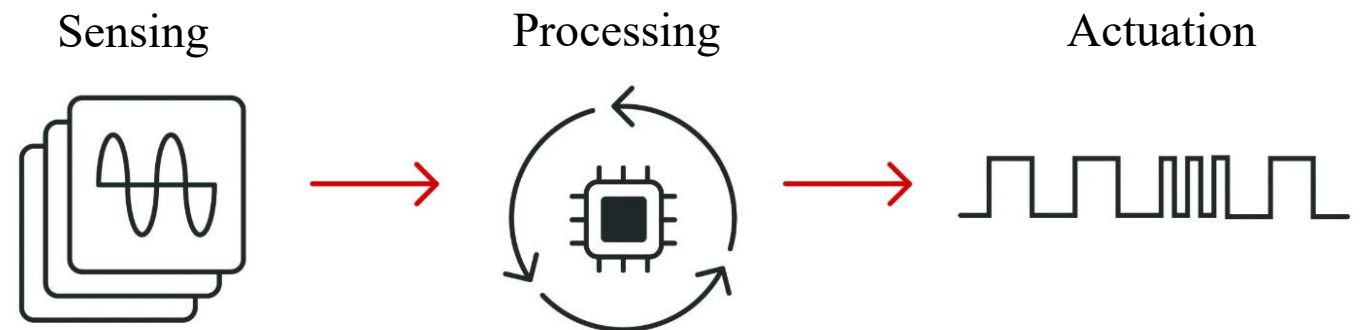
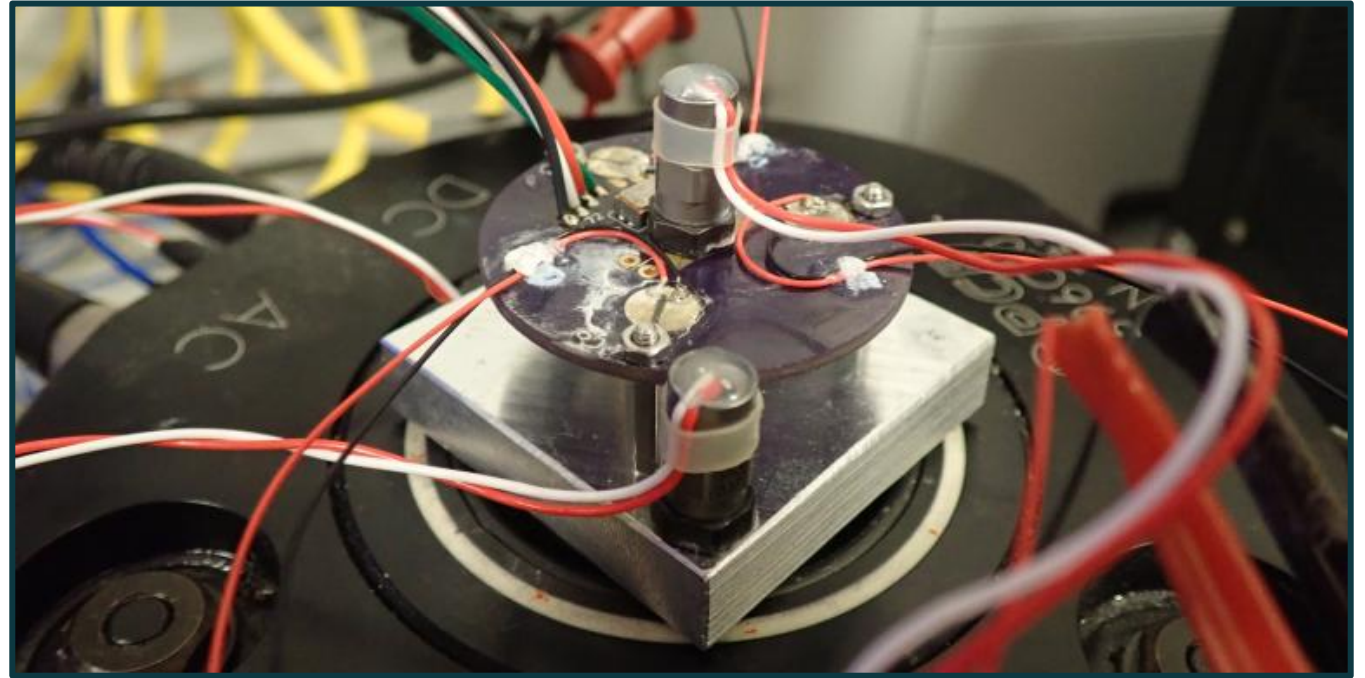


# CONCLUSION

- Developed a repeatable test-to-failure shock framework for electronic systems.
- Demonstrated a consistent link between dynamic acceleration response and progressive electrical degradation.
- Identified absolute mean, RMS, and shape factor as reliable indicators of cumulative damage under repeated shock loading.
- Established a foundation for real-time condition monitoring and learning-based damage detection in high-rate environments.

# FUTURE WORK

- Improvement of simulation models.
- Optimization of learning-based control strategies.
- System analysis.
- Dataset collection.
- Real-time FPGA experimentation.
- Piezoelectric sensing/actuation experimentation.



# DISCUSSION



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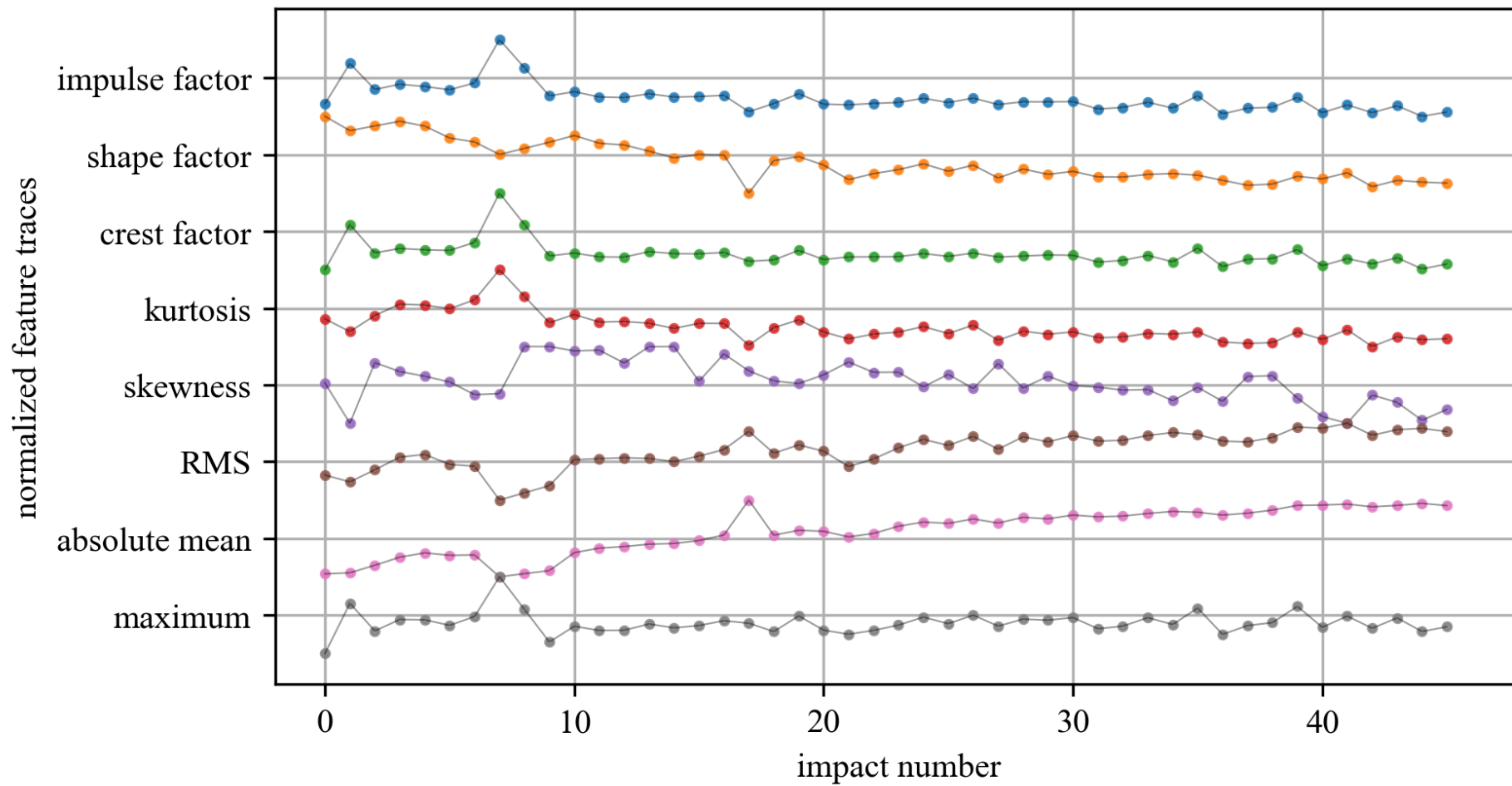


**High-rate Structural Monitoring,  
Damage Detection, Prognostics,  
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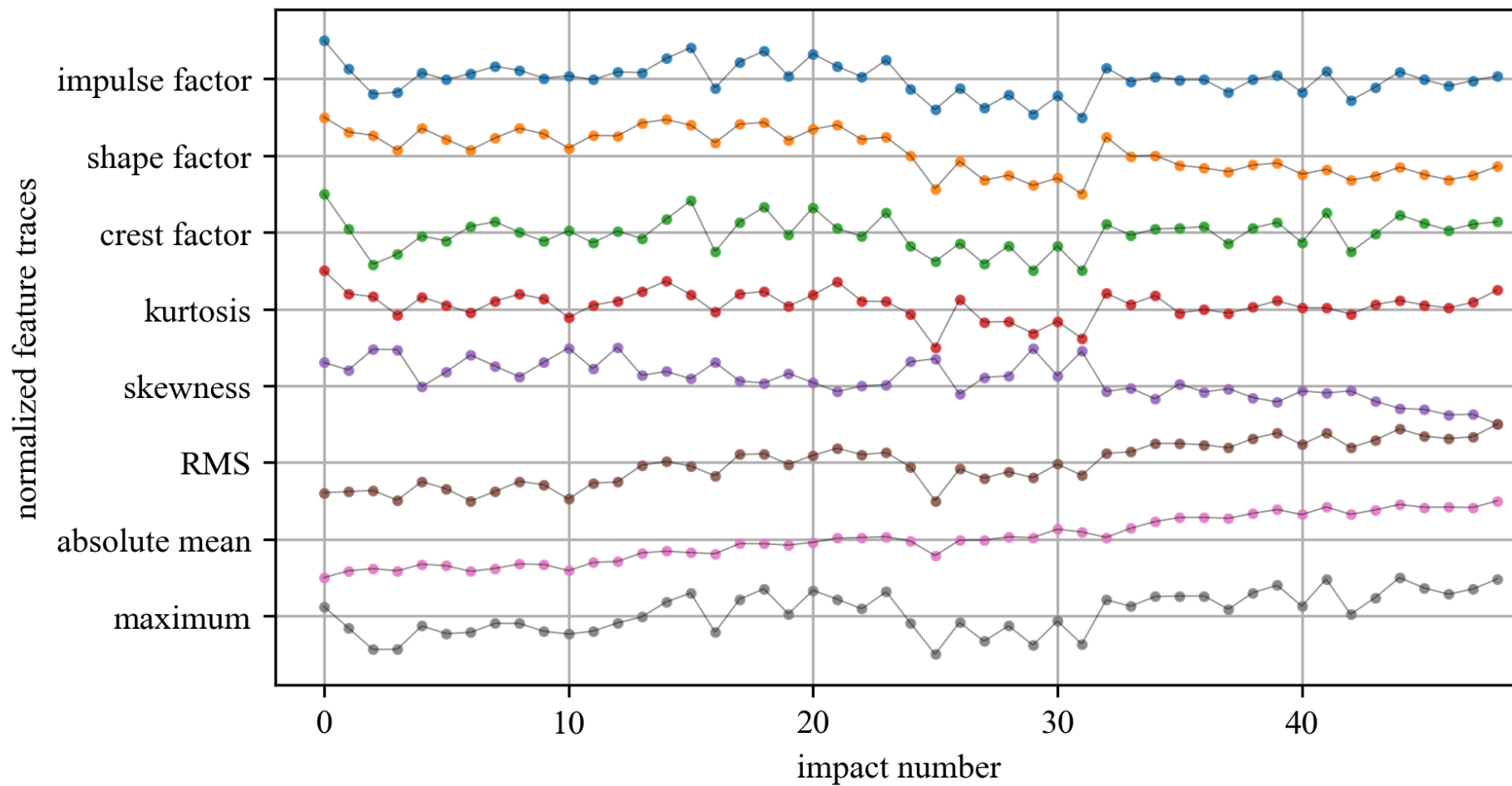


**Austin R.J. Downey**  
austindowney@sc.edu

# BOARD 1



# BOARD 2



# BOARD 3

