SAND2018-12499C

Boundary Conditions in Environmental Testing Round Robin

PRESENTED BY

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Outline

Motivation

Brief History

The year in review

- Follow up since 2017 Shock and Vibration Symposium
- Recent Work

Open Discussion

Motivation

A main purpose of mechanical dynamic testing is to demonstrate robustness to **service** environments.

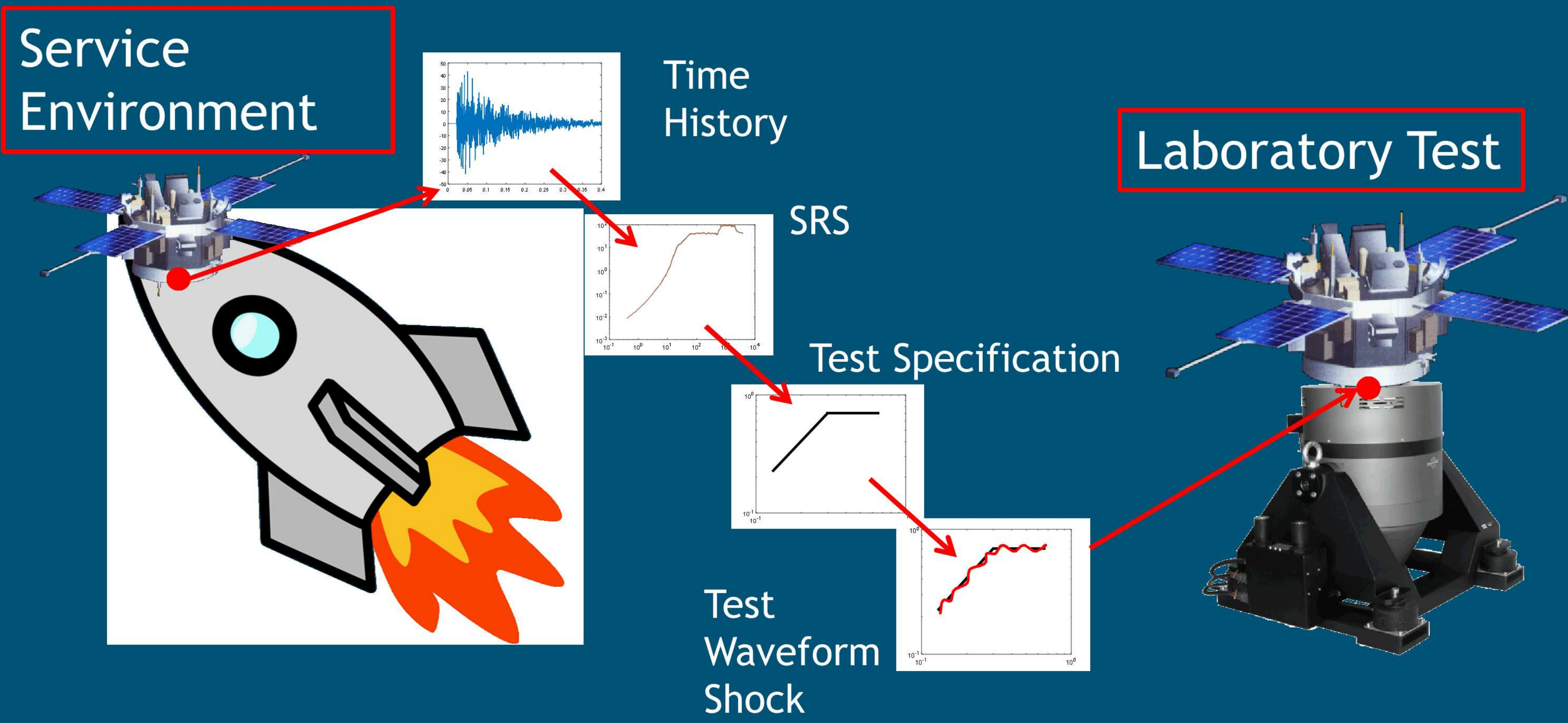
There is likely a difference between the stress field a component experiences in service and in a laboratory test.

- Boundary condition and load inconsistencies
  - Ignore variability for now (unit-to-unit, test loads, service environments)

How do we overcome the differences?

Brief History

Traditional Qualification Test Process



The shaker can match the test specification input - but matching the responses to their service environment responses is secondary

Damage Comes from the Structural Dynamic Response

The response stress field is indicative of damage

The stress field is a result of the accumulation of each modal response of the structure to the input

- This will likely be different in the service environment than in the test setup
  - Stress hot spot locations move and amplitudes change

How do we ensure that designs are robust to the service environment and not just the test setup?

Input Control Approaches

1950s

"Infinite Impedance" testing

1970s-1990s

- Force-Acceleration Method
- Transmissibility Correction
- Force Limiting Dual Control (NASA)

Six-DOF shaker testing

Current Research!

Ignores Test Structure

Includes Test Structure Information

Current Research!

Modal Craig-Bampton Substructuring (Transmission Simulator) (Mayes SNL)

Current Research!

Frequency Based Substructuring/Impedance Modeling (UMass Lowell)

Impedance Modification Approaches

"Infinite Impedance" testing

1950s

- Multi-Modal fixtures

1960s

2000s

- N+1 Next Assembly Fixtures

2000s - Current

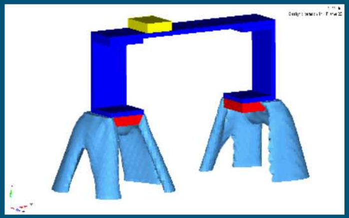
- Adaptive (active) Impedance Test Fixtures

Ignores Test Input

Modify Test Input

Current Research!

- Impedance–Matched Multi Axis Test (IMMAT)
  - Distributed force inputs
  - Component tested in full- or nearly full- assembly



Current Research!

Impedance Modification
+
Input Optimization

Round-Robin Challenge Problem Concept

Team collaboration began in Summer 2016 with engineering rotations between KCNSC and SNL

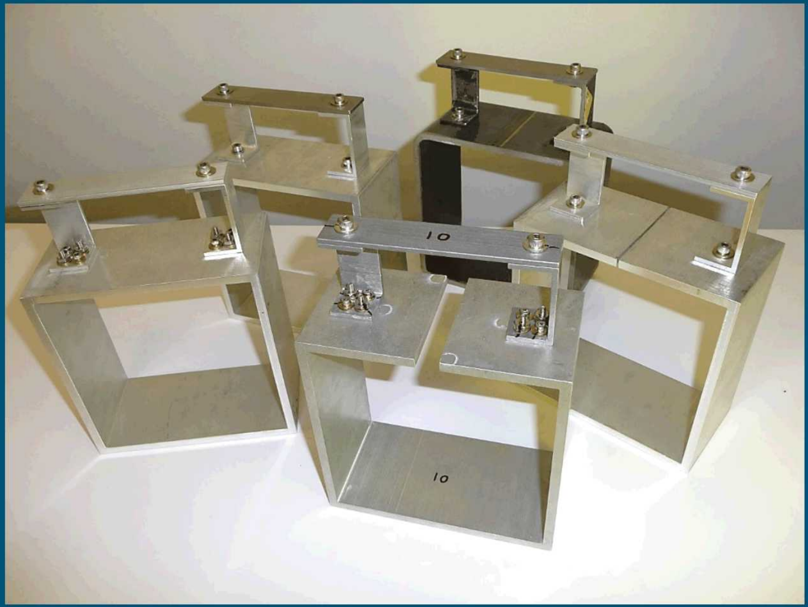
Wanted to formulate a simple demonstration structure

- Easily understood dynamics
- Easy to model
- Easy to build
- Easy to test
- Facilitates Topology Optimization (TO) of fixture

Current Challenge Problem Leaders

- Sandia National Laboratories: Troy Skousen, Tyler Schoenherr
- Kansas City National Security Campus: David Soine, Richard Jones

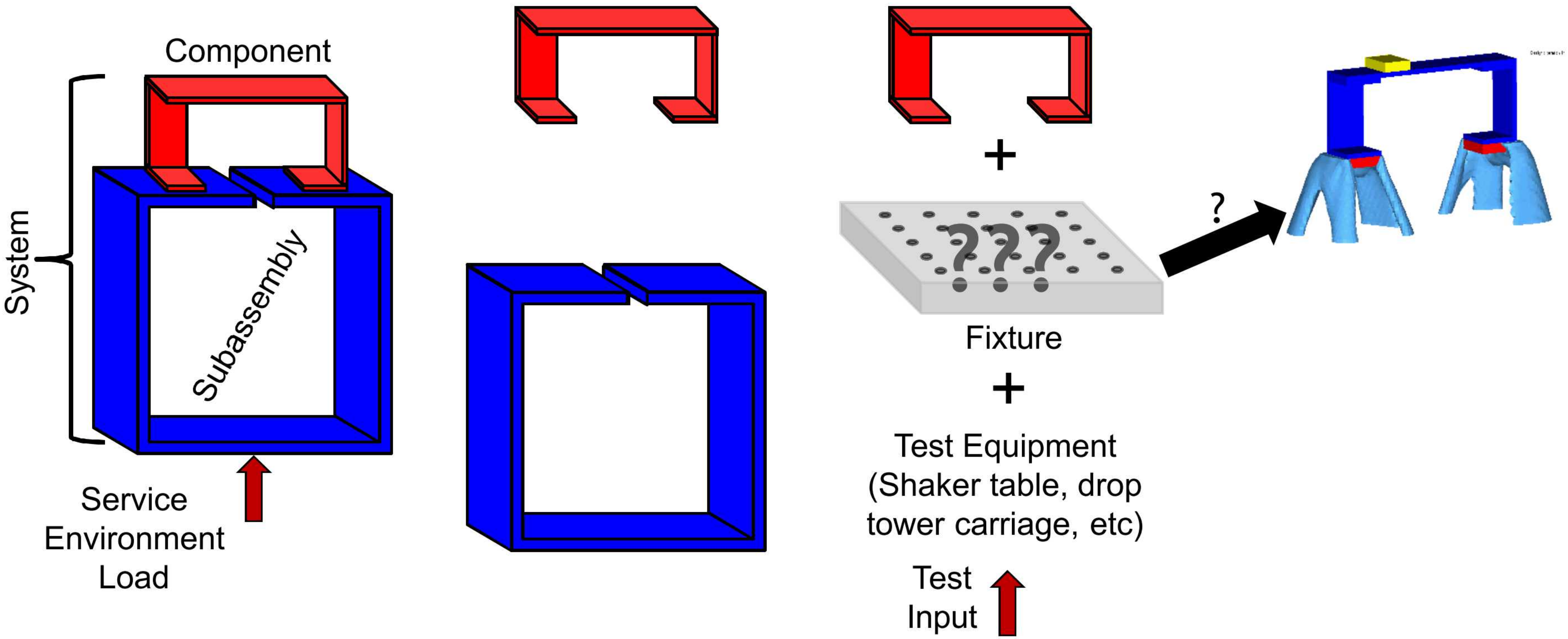
Challenge Problem Hardware



Hardware design evolved from 2016 into 2017

Box Assembly with Removable Component (BARC)

Challenge Problem: Replicate service environment response in a component test



Modify the Test Input and/or Test Boundary Condition (Transfer Function) to replicate the component response from the service environment

The Year in Review

Challenge Hardware: BARC global reach

Boundary Condition Challenge research initiative – global reach

- FSU
- U Victoria CA
- Siemens
- NEAPCO
- NUWC Keyport
- Orbital ATK
- Chromealloy
- LLNL
- U Dayton
- U Cincinnati
- Northrop Grumman
- NSWC Carderock
- Tom Paez
- The Modal Shop
- NASA
- Emerson
- Cummins
- Thermotron
- U MarylandBC
- Keysight
- FLIR
- Luminar
- Harris
- AberdeenTC
- RedstoneTC
- Lockheed Martin
- MSI DFAT
- Contech Research
- Terry Scharton

- ITA Brasil
- U Brasilia
- U Federal de Uberlandia

- U of L'Aquila IT
- U Rome La Sapienza IT
- Supmeca FR
- U Ljubljana SI
- BOSCH

Boundary Condition Challenge research initiative – global reach

- Hitachi JP

Unlimited Release SharePoint Site

https://connect.sandia.gov/sites/TestBoundaryConditions/

Find models, reports, and other information about the challenge problem

Upload information you have to help others

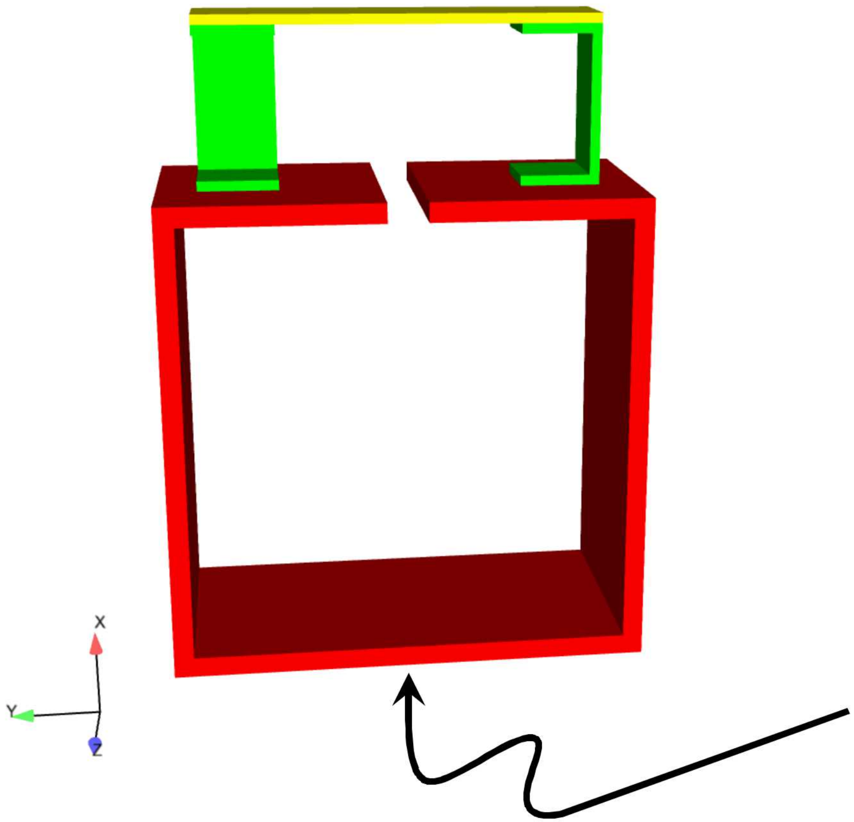
Recent Work

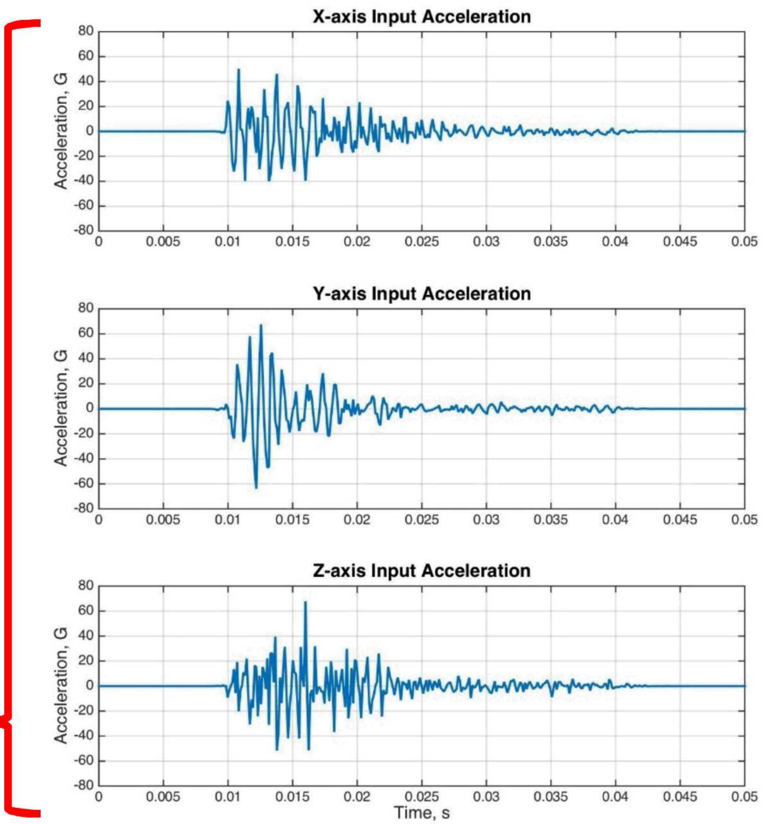
Single Axis Component Test Inputs Analysis

Michael Starr, Sandia National Laboratories, Excerpts from "Comparison of Time-Domain Objective Functions in Dynamic Fixture Optimization" presentation at IMAC 36, February 12 – 15, 2018, Orlando FL.

Objective: Compare responses when defining test input from one location in the assembly

FEM BARC Kinematic and Stress Responses

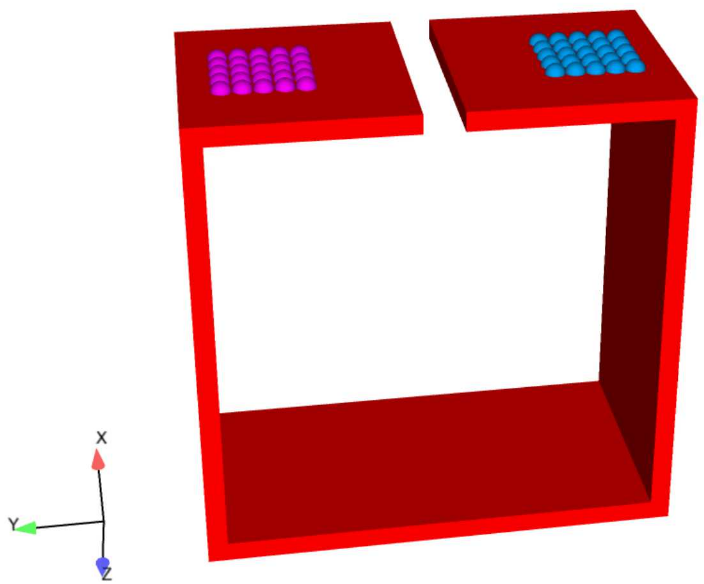


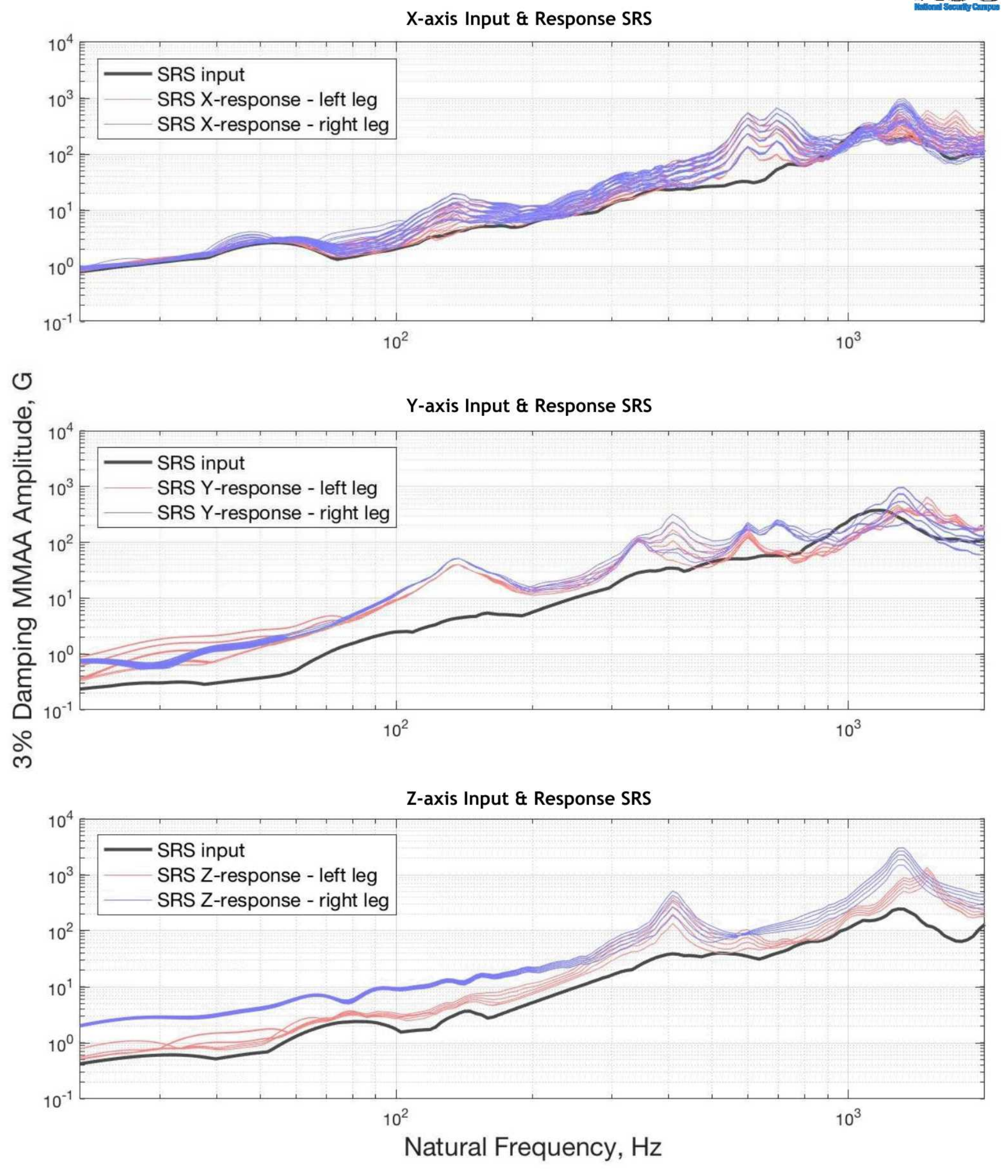


A 3-DOF (arbitrary) transient shock is used to excite the system. Acceleration responses across the component are predicted.

How Sensitive is Response to Location?

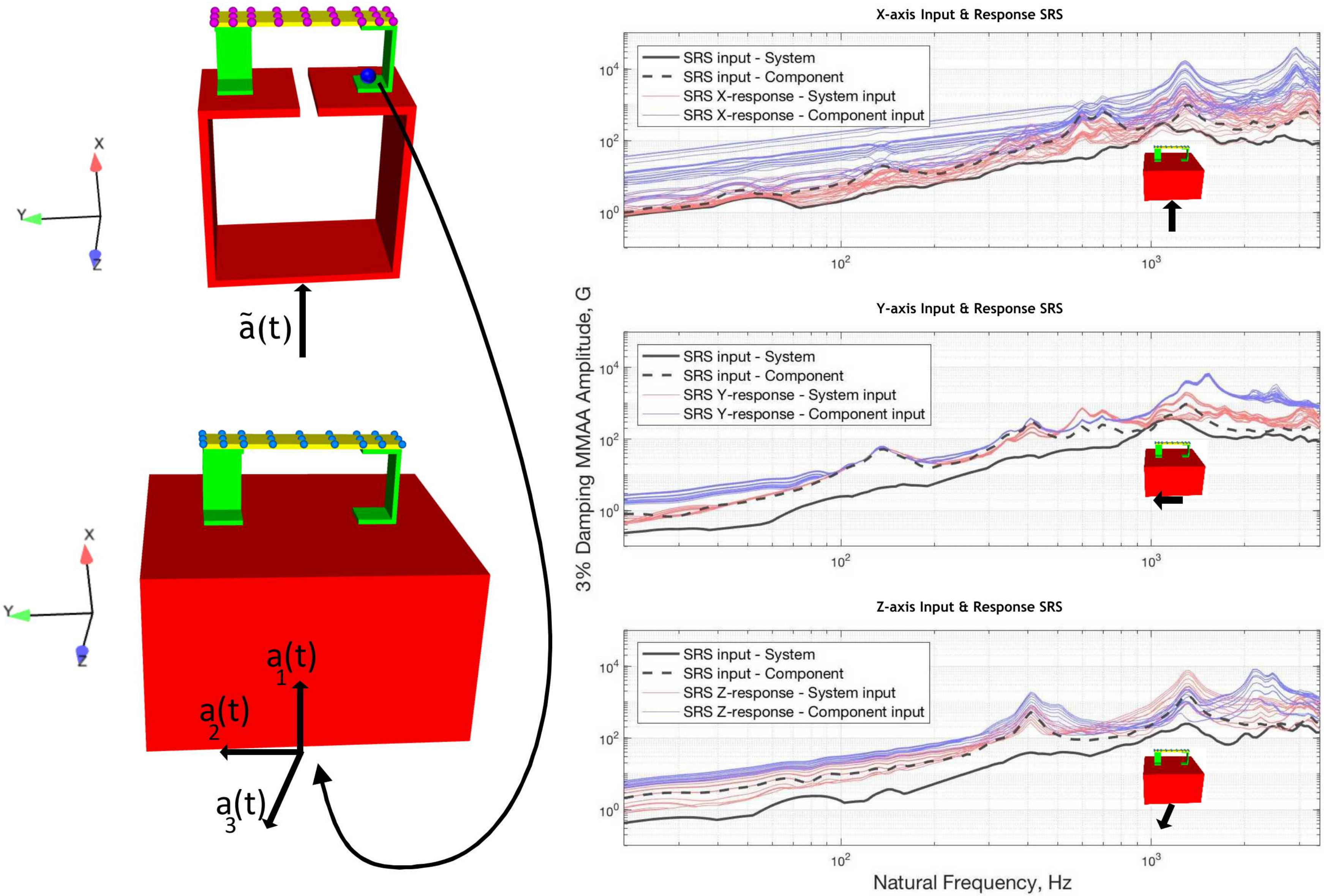
Calculate SRS at families of nodes distributed across the load path into the component.





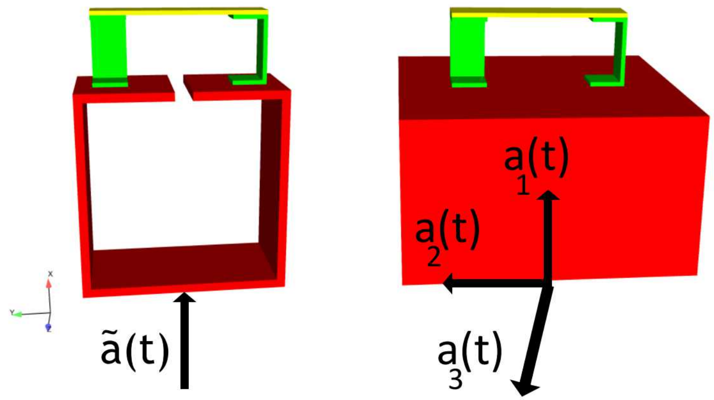
6 to 12 dB response differences across a 1 $inch^2$ area

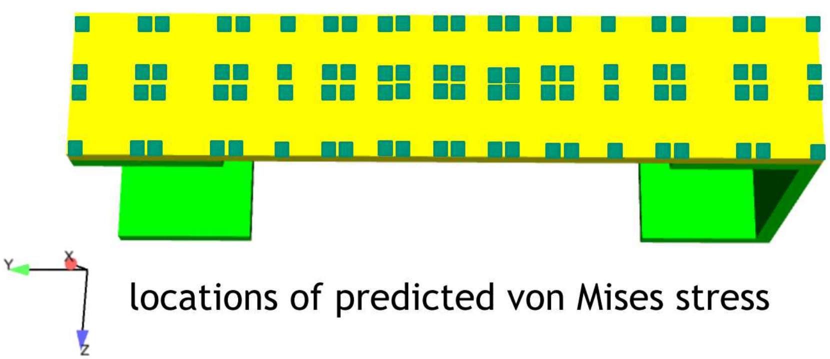
Different Dynamic Responses are Expected; How Relevant are These Differences?



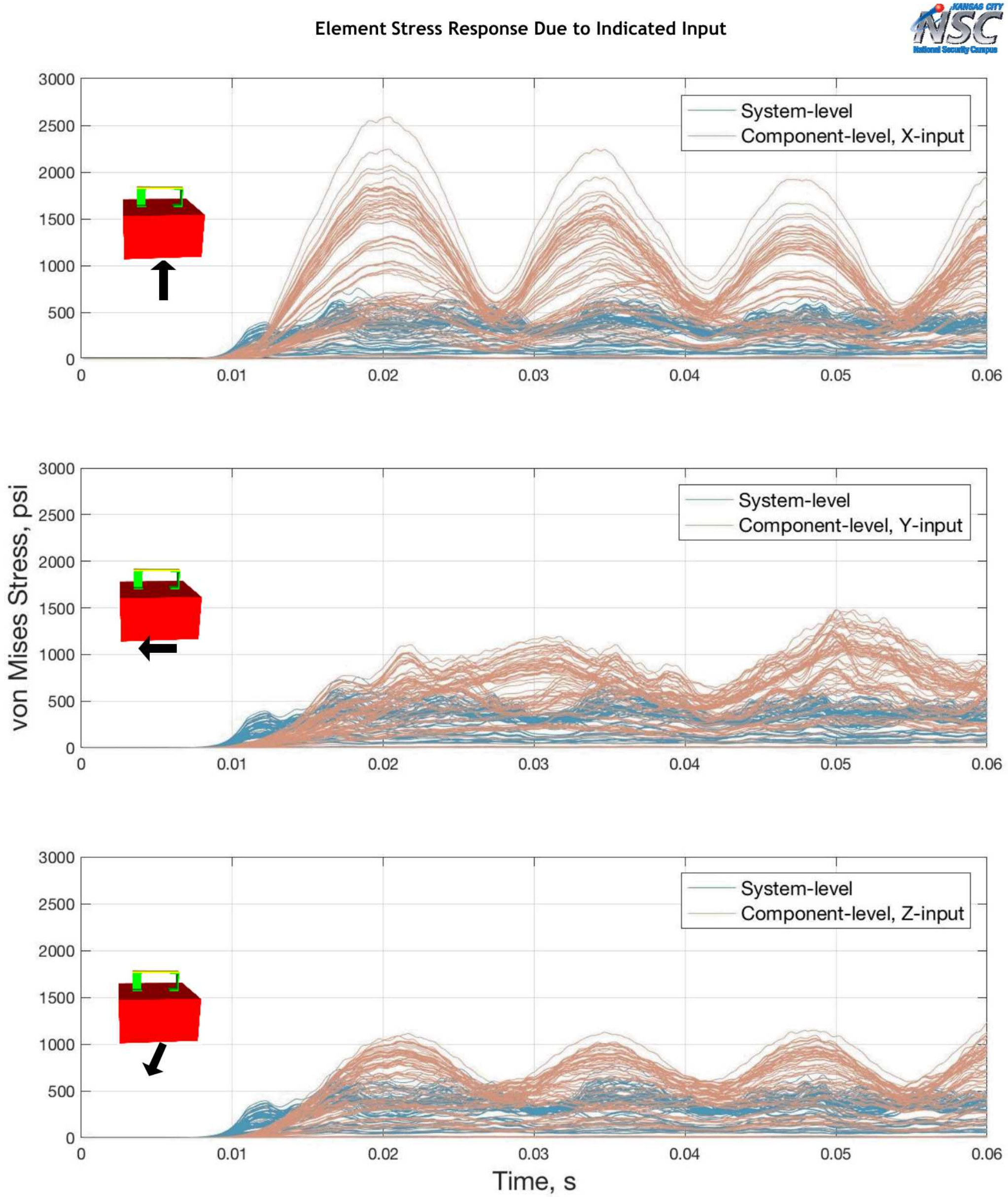
Let’s Look at Some Stress Measures

Calculate time histories of von Mises stress at locations distributed across the top surface of the component.



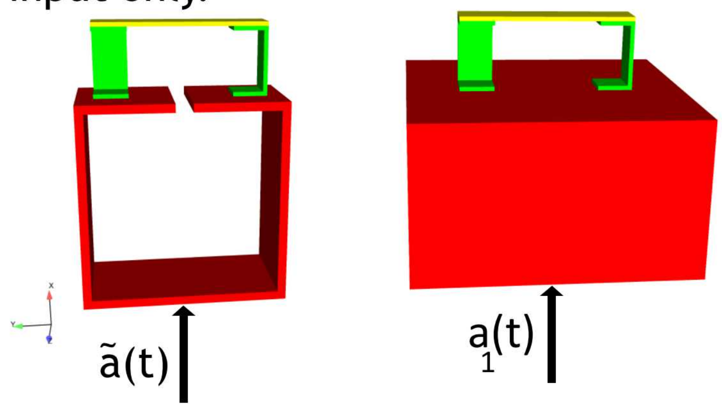


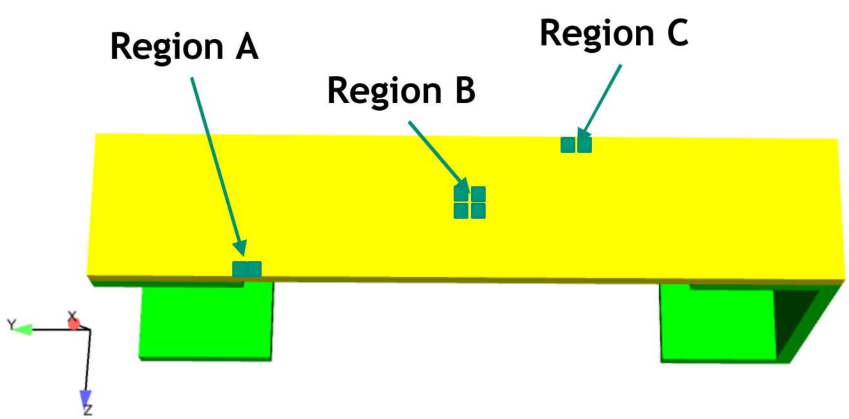
locations of predicted von Mises stress

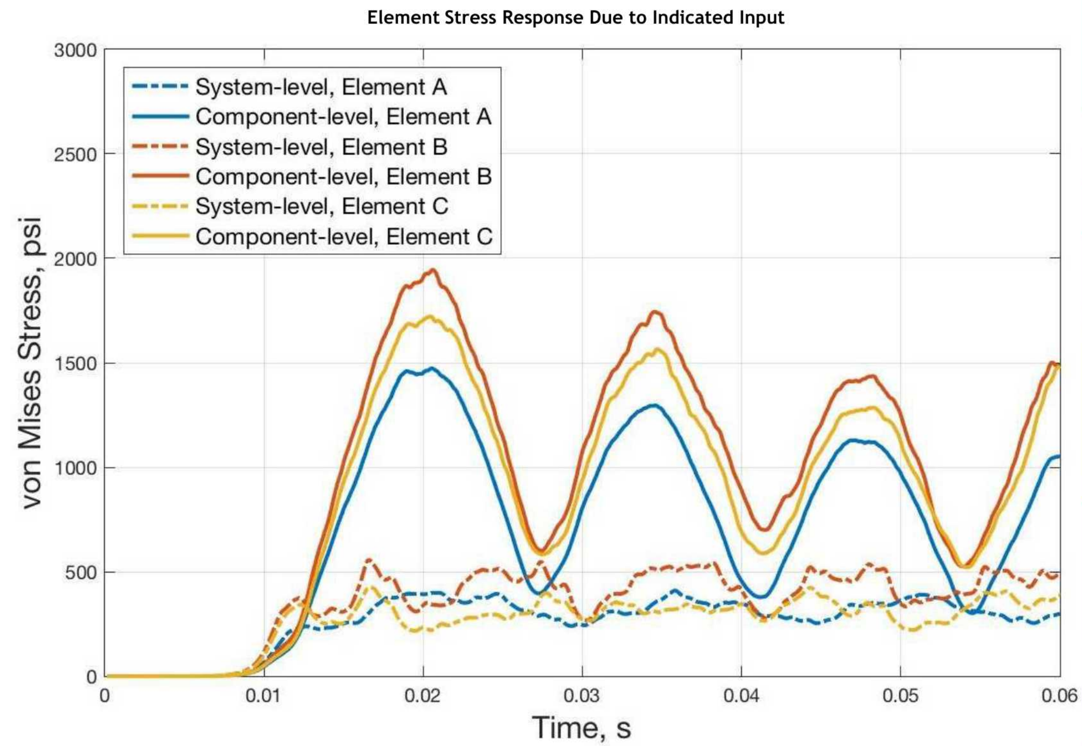


Let’s Look at Some Stress Measures

Here, three regions have been isolated. Predictions are compared between the system-level model and the component-level model. The component-level input was derived from the right load path, x-direction input only.







Example: Takeaway

The response SRS is sensitive to spatial location

Replicating an acceleration at an input location can drive significantly different stresses

Relevant Papers Toward the Solution

Several papers with substructure based optimized inputs

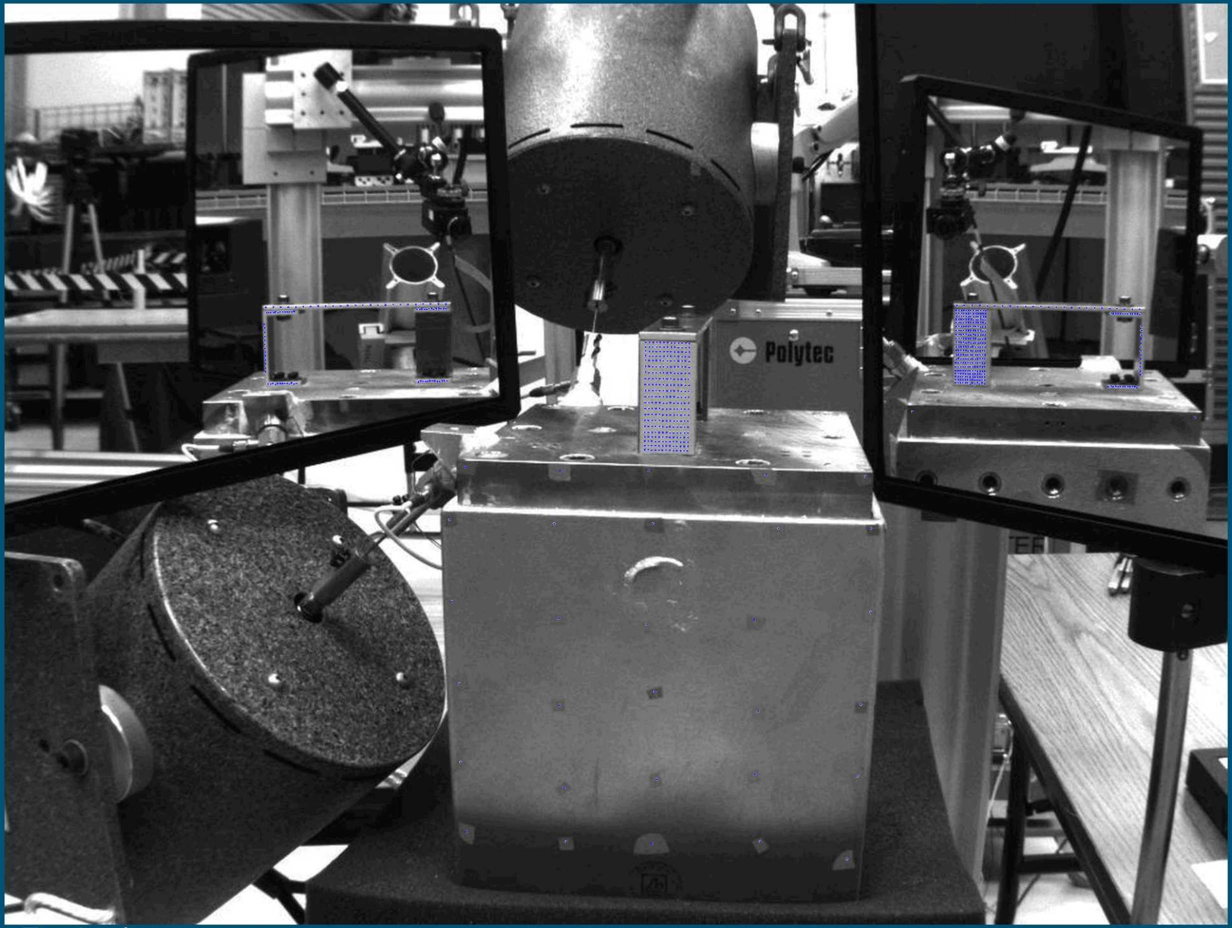
- Harvie, J., "Using Modal Substructuring to Improve Shock & Vibration Qualification", IMAC 36, 2018
- Reyes, J., "Force Customization to Neutralize Fixture-Test Article Dynamic Interaction", IMAC 36, 2018
- Reyes, J., "Adjustment of Vibration Response to Account for Fixture-Test Article Dynamic Coupling Effects", IMAC 35, 2017
- Tyler Schoenherr, Sandia National Laboratories, Adapted from "Derivation of Six Degree of Freedom Shaker Inputs Using Sub-Structuring Techniques" presentation at IMAC 36, February 12 – 15, 2018, Orland FL

BARC Modal Testing

And other related work

Dan Rohe, Bryan Witt, and Phil Reu
Sandia National Laboratories

Sandia Modal Test



Testing by
Dan Rohe and
Bryan Witt
from Sandia

Full assembly BARC testing and Component Testing

- On a vibration cube
- Excited with modal shakers attached to the cube and automated modal hammers on the structure directly
- Responses monitored by piezoelectric accelerometers and/or scanning laser vibrometer

BARC modal testing has been going on at several institutions

A paper that compiles several sets of test data by Dan Rohe et al.

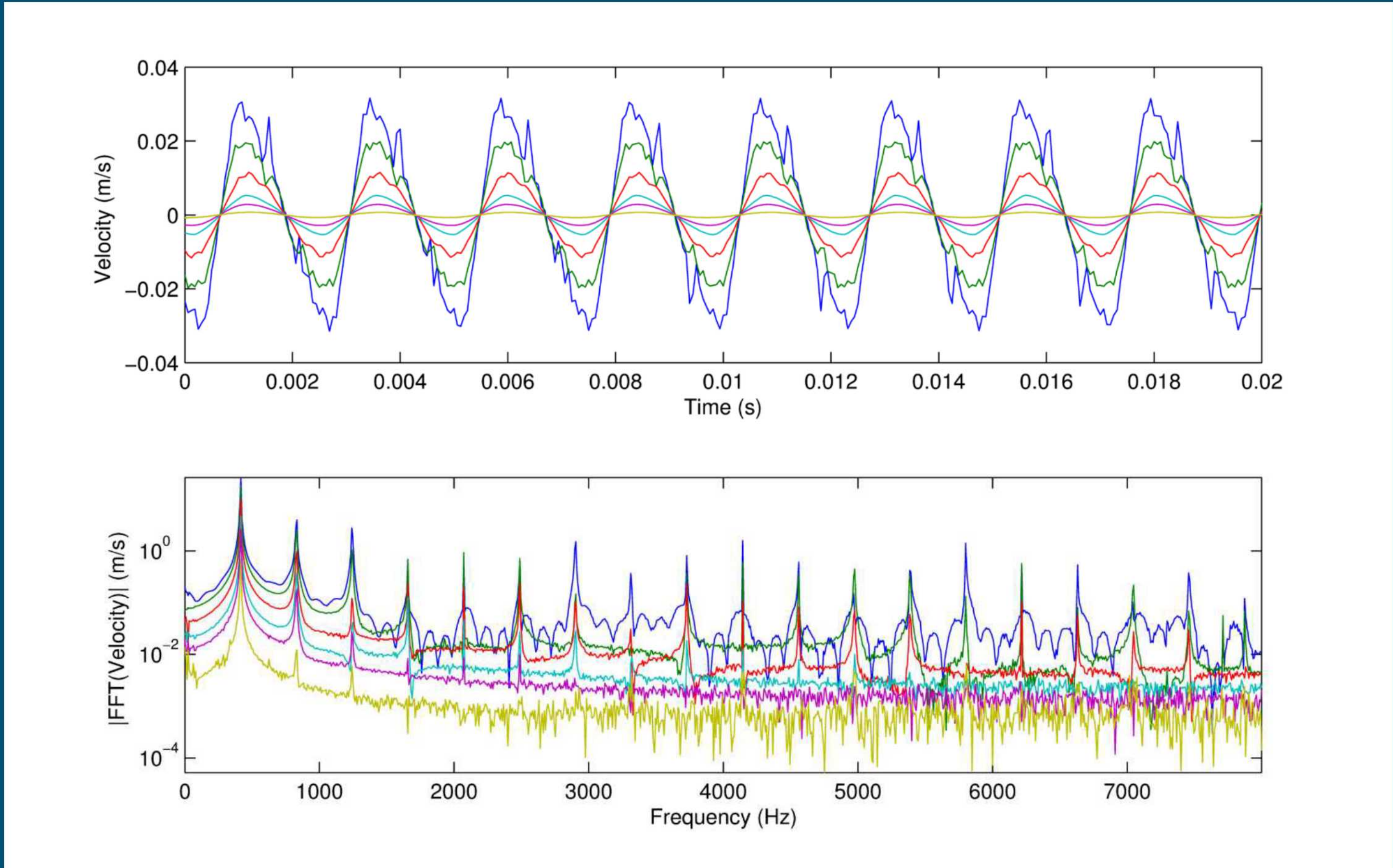
Nonlinear BARC Response

Loading the BARC component with a sinusoidal base excitation force resulted in non-sinusoidal responses with significant harmonics on the side of the component just below the C-channel/top beam interface. The non-sinusoidal response got worse as the level increased.

The non-sinusoidal behavior was repeatable and therefore could not be corrected by averaging.

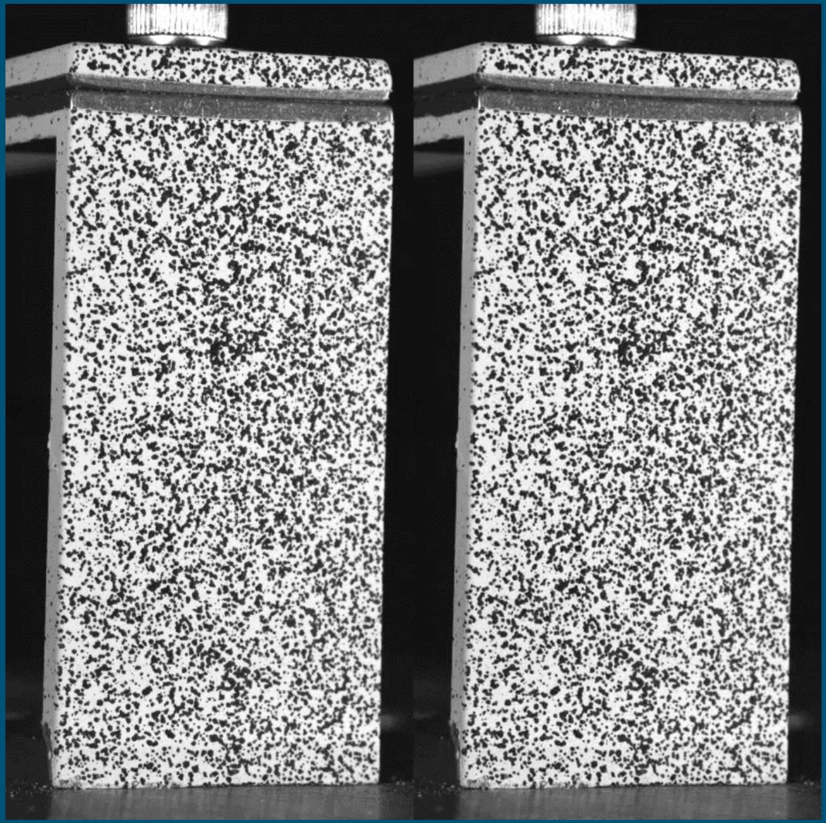
At some DOF, the noise floor of the laser was reached before the harmonics disappeared.

Strangely, points next to each other seemed to have significantly different responses, but they were completely repeatable.



Testing by Dan Rohe and Bryan Witt from Sandia

DIC Motion Magnification



Digital Image Correlation (DIC) data were taken from the BARC.

The DIC measurements were magnified to show the response of the BARC structure to the loads

Image Description

- Left: raw DIC video
- Right: magnified response DIC.
  Note the joint opening up, a likely cause of the nonlinearities

Testing by Phil Reu and Bryan Witt and DIC image magnification by Dan Rohe from Sandia

SEREP Full Field BARC Response

System Equivalent Reduction-Expansion Process (SEREP) is a method that uses measured degrees of freedom and expands them to unmeasured degrees of freedom using the FEM mode shapes as basis vectors.

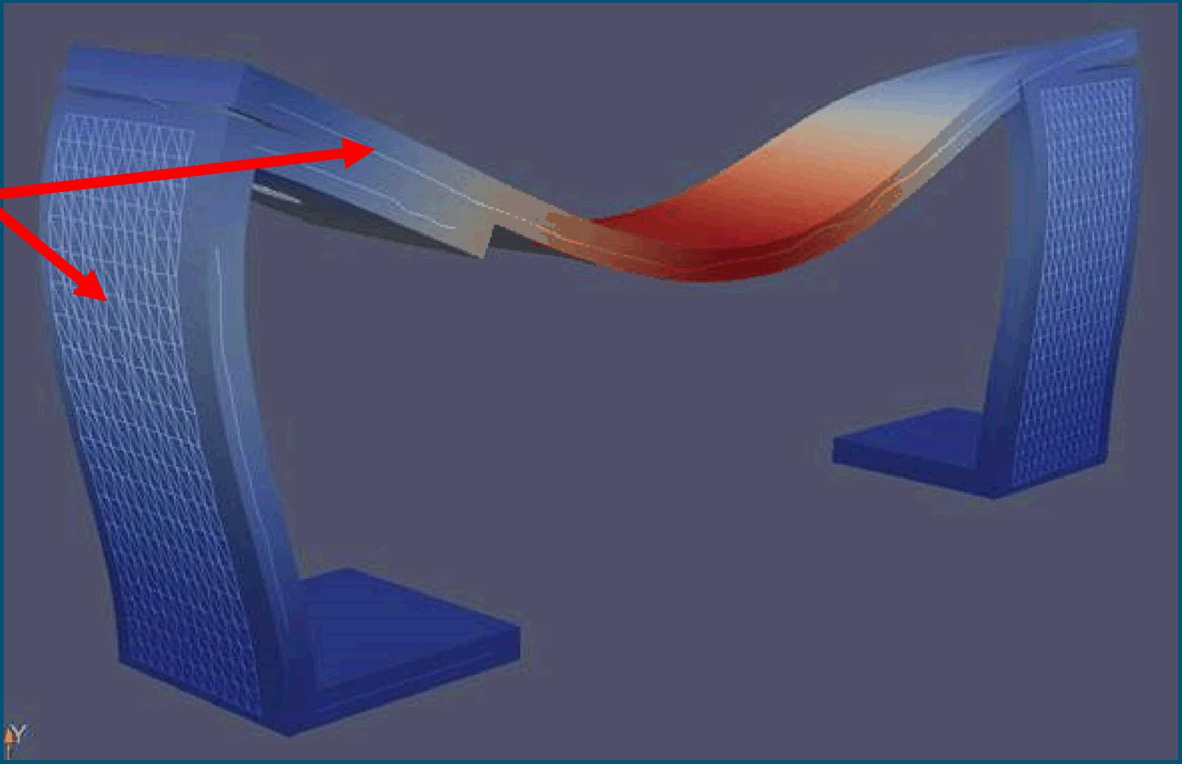
- The FE mode shapes only need to span the space of the measured data and don't need to match the experimental mode shapes

Has potential to be used to define structural responses to service environments for defining laboratory test specifications

Laser Vibrometer Measured data (mesh and lines on surfaces)

Deformation and color contour generated by SEREP

Testing by Dan Rohe, model by Tyler Schoenher, and data analysis by Bryan Witt from Sandia



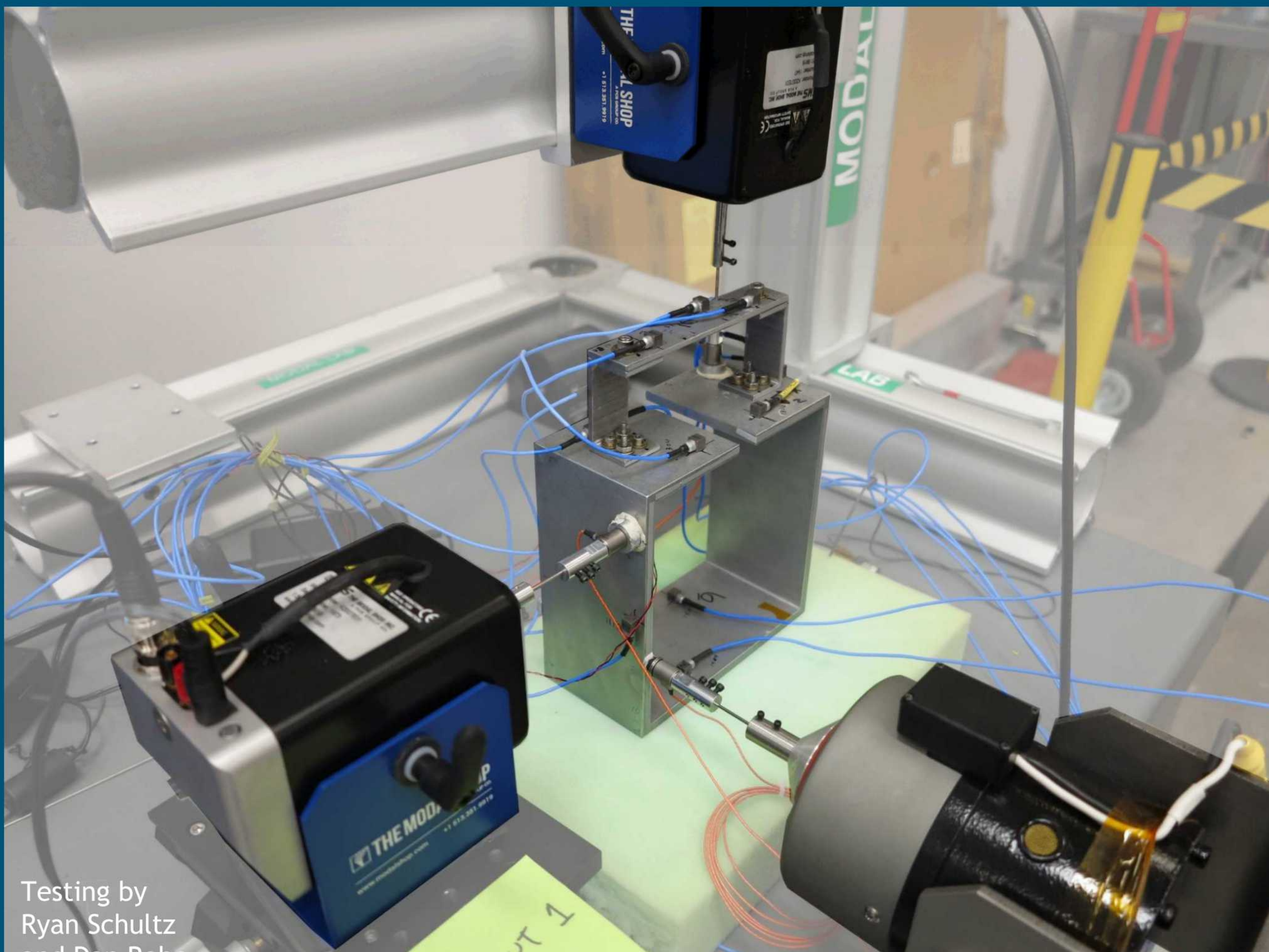
SEREP Reference Paper:
J.C. O'Callahan, P.Avitable, and R.Riemer, "System equivalent reduction expansion process," in Proceedings of the Seventh International Modal Analysis Conference, (Las Vegas, NV), Feb 1989.

MDOF BARC Testing with Topology Optimization, Additively Manufactured Component Fixture

Dan Rohe and Ryan Schultz
Sandia National Laboratories

Richard Jones
Kansas City National Security Campus

MDOF Test on BARC Structure



Testing by
Ryan Schultz
and Dan Rohe
from Sandia

Multi-Degree of Freedom (MDOF) Assembly truth test (pictured)

Component test on with a plate fixture on a vibration cube

Component test on topology optimized additively manufactured fixtures

Topology Optimization Fixture Design

Fixture design by Richard Jones from KCNSC using Optistruct by Altair

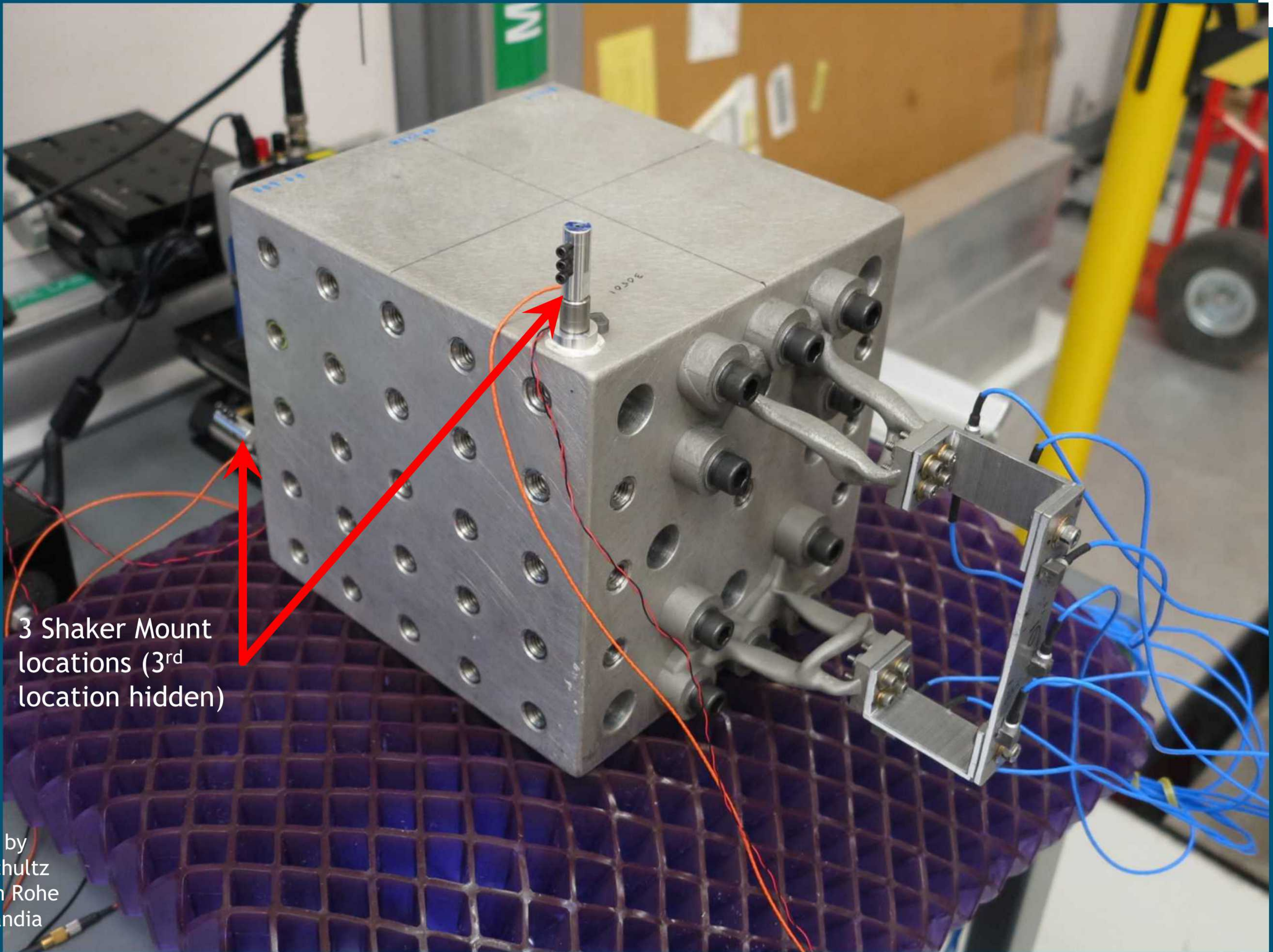
Stiffness Optimized

- Removing the component
- Applying forces to the component foot interface in various directions and capturing the displacement
- Use topology optimization to design a fixture structure that given the same loads, matches the displacement from the box

Currently working on optimizing on dynamic properties

- FRFs
- Mode shapes and frequencies

3 Shaker test with TO AM Fixture on a 7" Vibration Test Cube



Testing by Ryan Schultz and Dan Rohe from Sandia

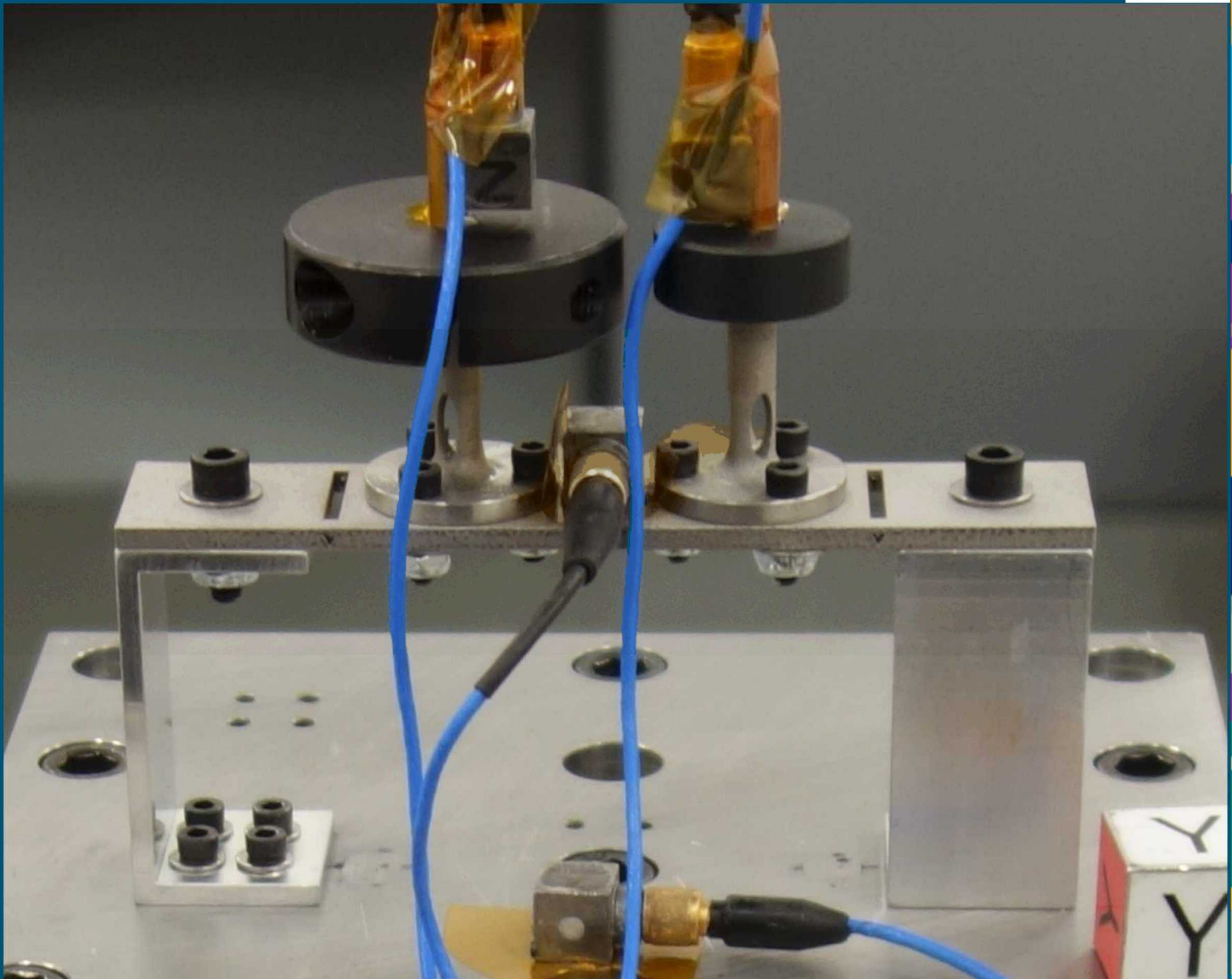
Modified BARC Testing

Alternative design to induce failure

Carl Sisemore, Vit Babuska, Jason Booher
Sandia National Laboratories

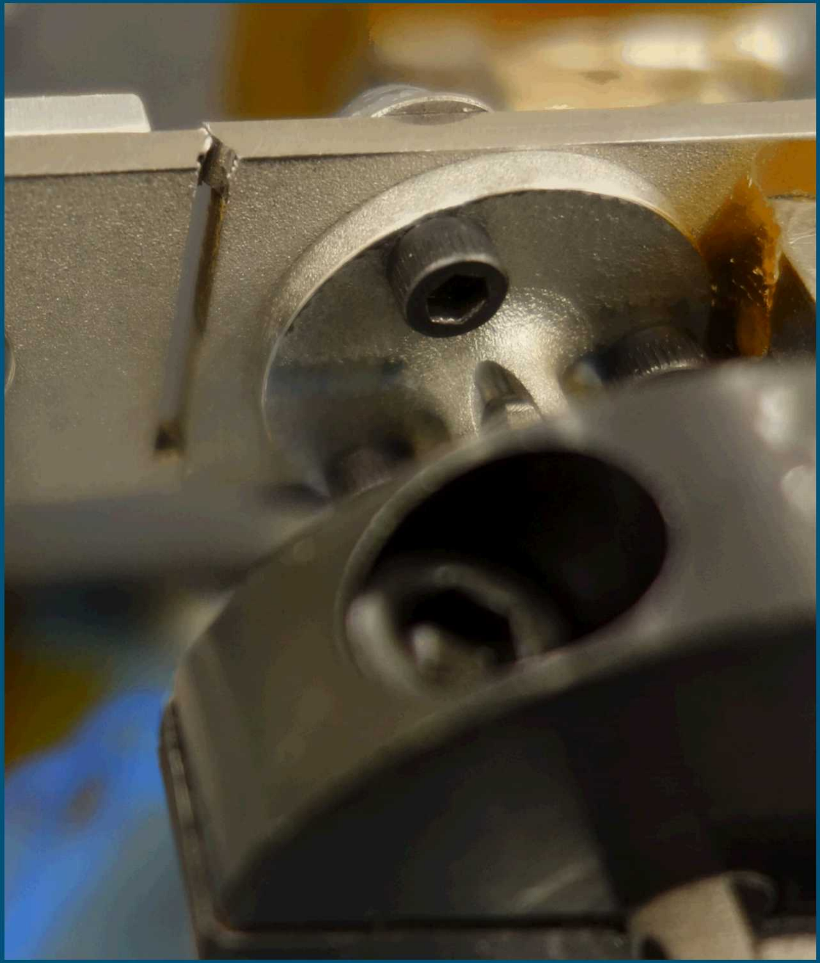
Vibration and Shock Shaker Base Excitation (and Introduce the Hardware)

- Alternative BARC design
  - Add design features to cause failure
- Tested BARC assembly and component by itself
- Parts were not expected to fail, so testing was performed with same hardware in multiple configurations

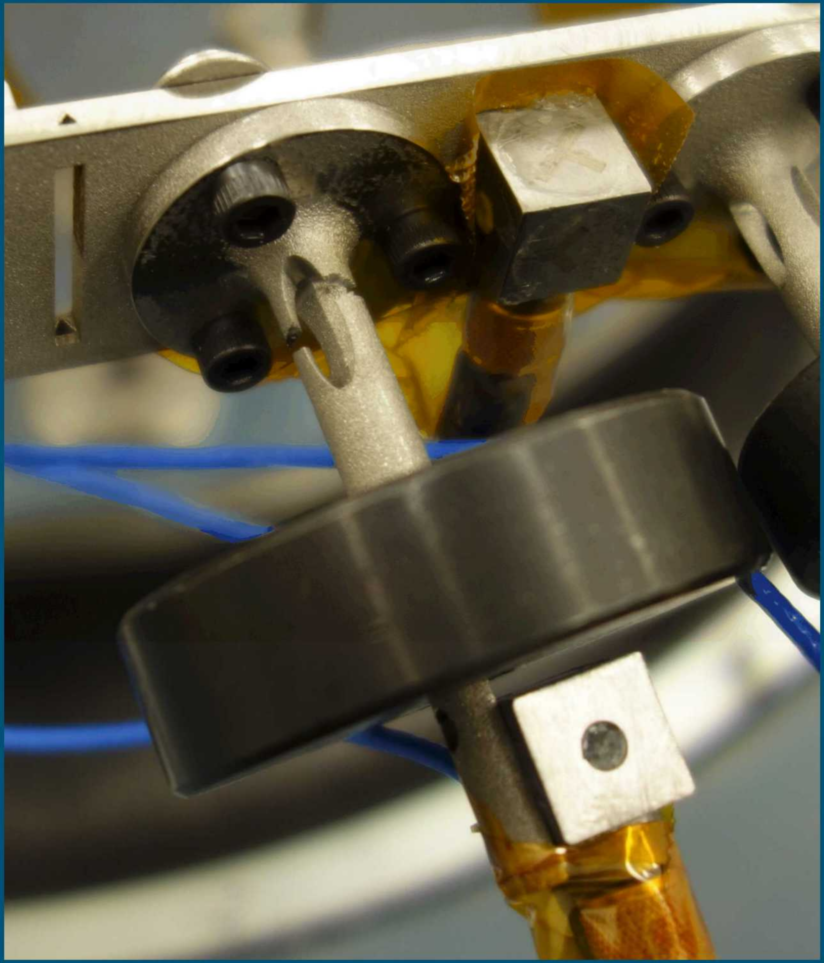


Base Excitation Vibration and Shock

Fatigue Failure of Top Beam (Bridge)

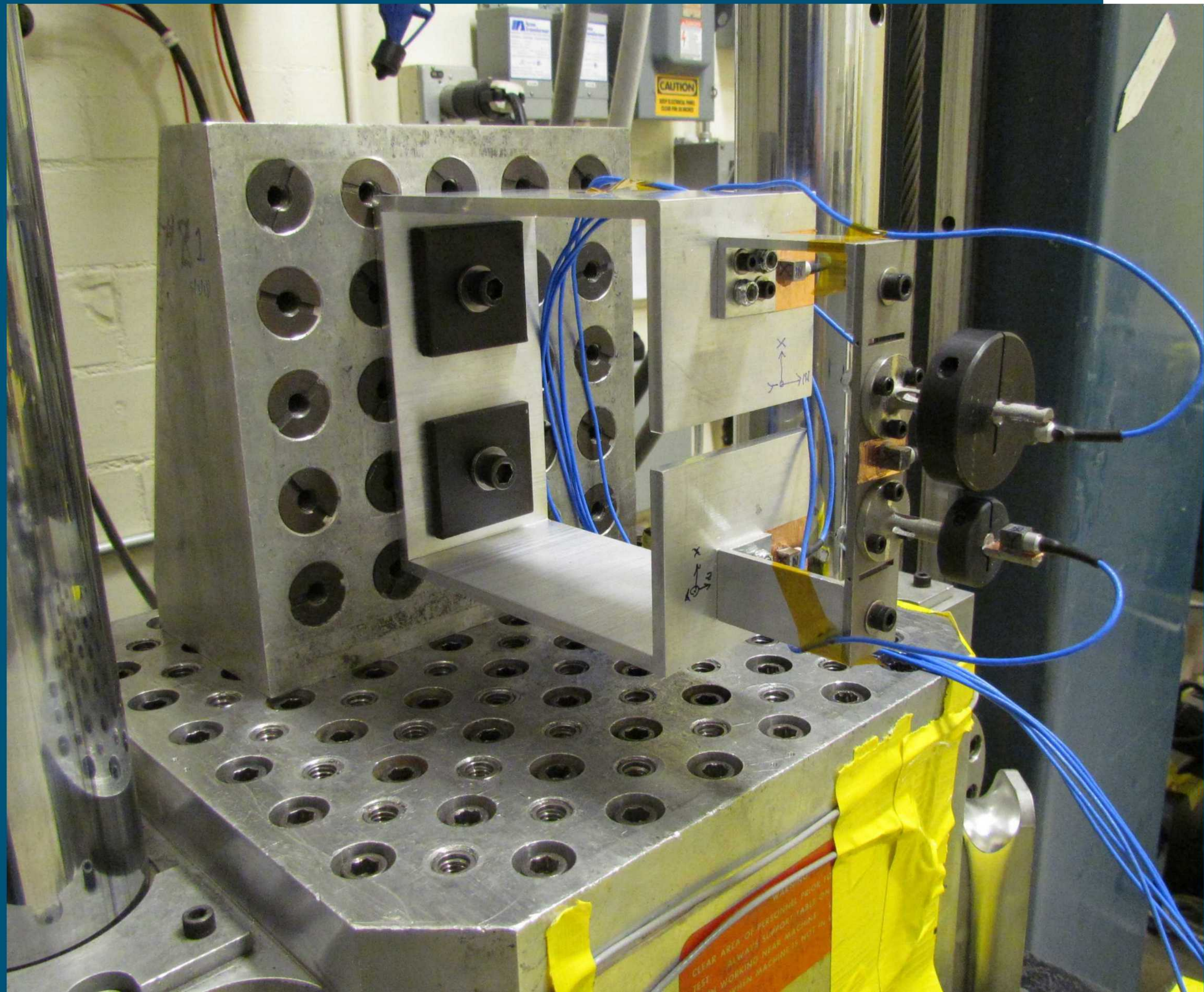


Fatigue Failure of Inverted Pendulum (Tower)



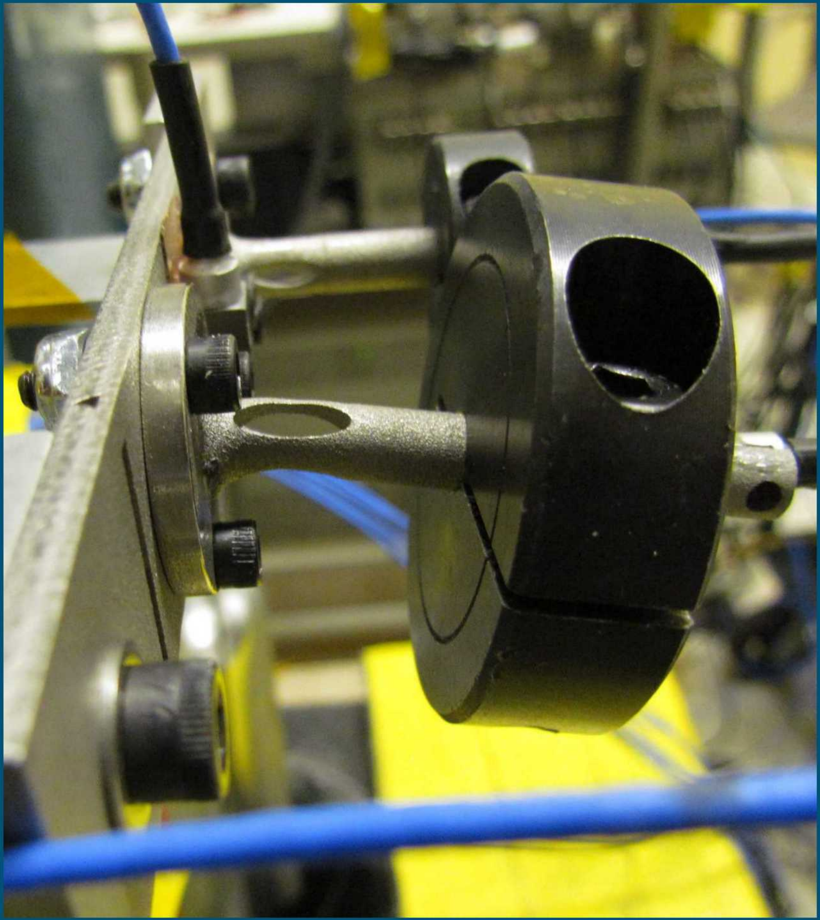
Drop Shock Test of Modified BARC

- Tested BARC assembly and component by itself
- Increased test drop height until failure (yield)

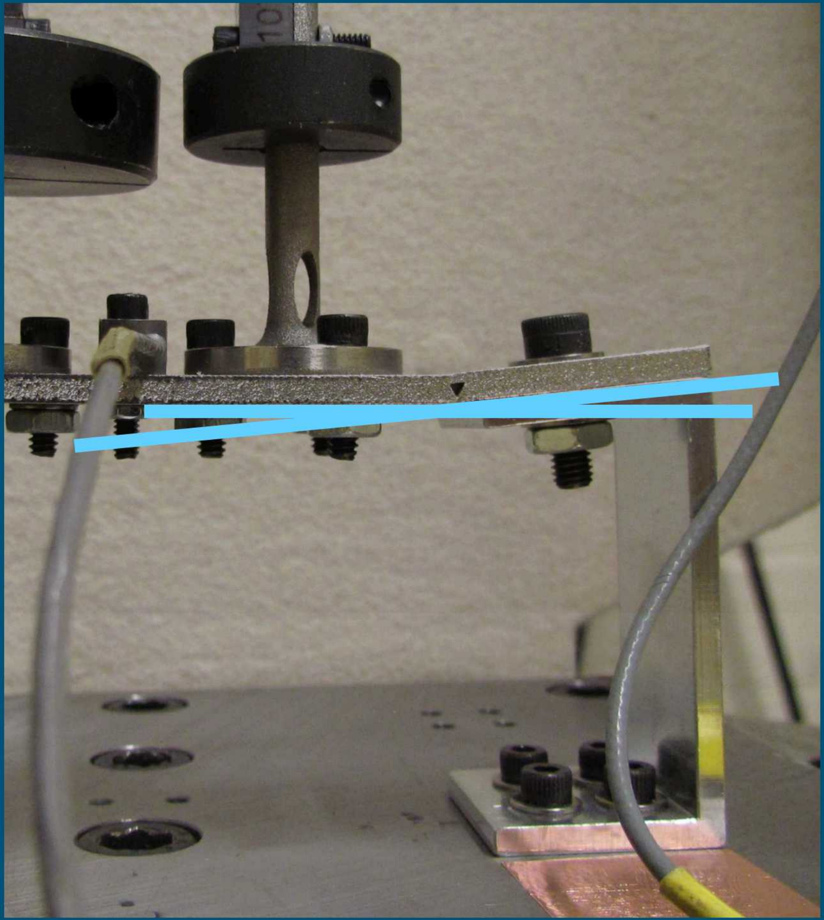


Drop Shock Test

Permanent Deformation of Inverted Pendulum



Permanent Deformation of Top Beam



Discussion

Questions or concerns about the challenge problem.

Tell us about your experience.

- Do you have case studies to share?

Please join us.

- Distribution list
- Do your own study (would you like a copy of the BARC hardware?)
- Publish (including SAVE)
- Join the SharePoint site
- Are there other research paths to investigate?

Potential Discussion Topics

Smart Dynamic Testing Community of Practice
- Focus on: Characterizing Environments, Boundary Conditions, MDOF Testing, and Test Optimization

Should qualification evidence from laboratory tests demonstrate that they exercise …
- The same damage mechanisms as service environments?
- Damage at the same physical location in the design as service environments?

What technology developments are needed to do it better.
- Are there gaps in characterizing the service environment?
- Do the common test specifications (PSD, SRS, etc.) communicate sufficient information?
- What is the appropriate test design guidance (e.g. fixture design, advanced test methods (E.G.: 6DOF, IMMAT), etc.)?