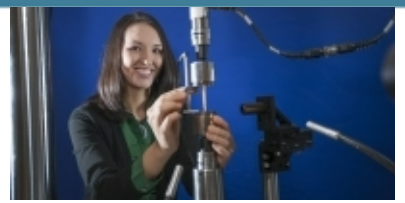
SAND2021-4173C

Boundary Condition Challenges in Dynamic Testing



David Soine, Sandia National Laboratories

April 2021

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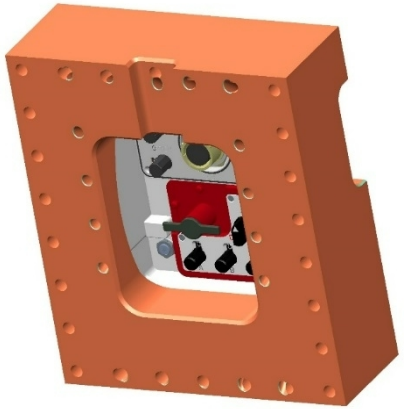
Overview

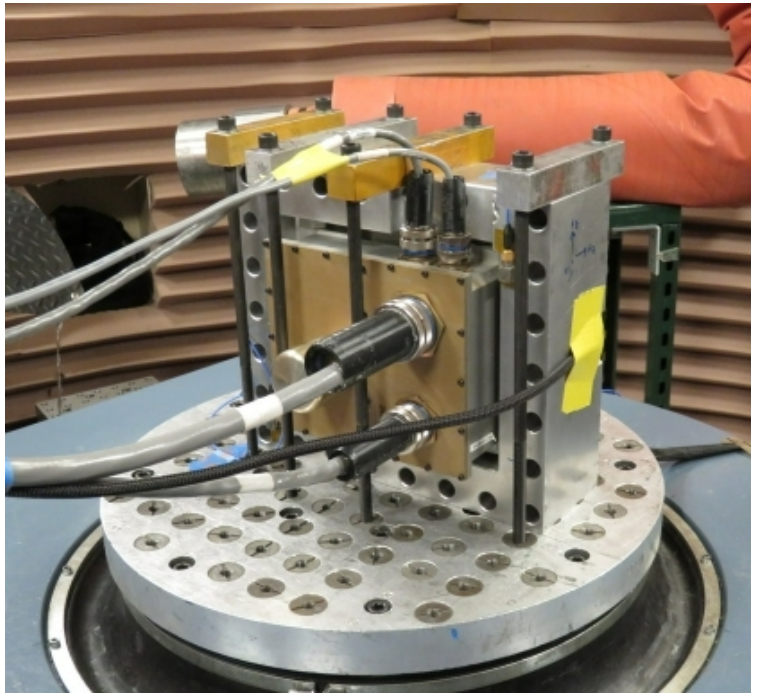
- Component Qualification & Test Boundary Conditions
  - Test Lab Perspective
  - Where do Test Specifications come from?
- Genesis of the Boundary Condition Challenge
- What is the Challenge?
- Box and Bench Example – Traditional Approach
- Current Research Paths

Component Qualification – Test Lab Perspective

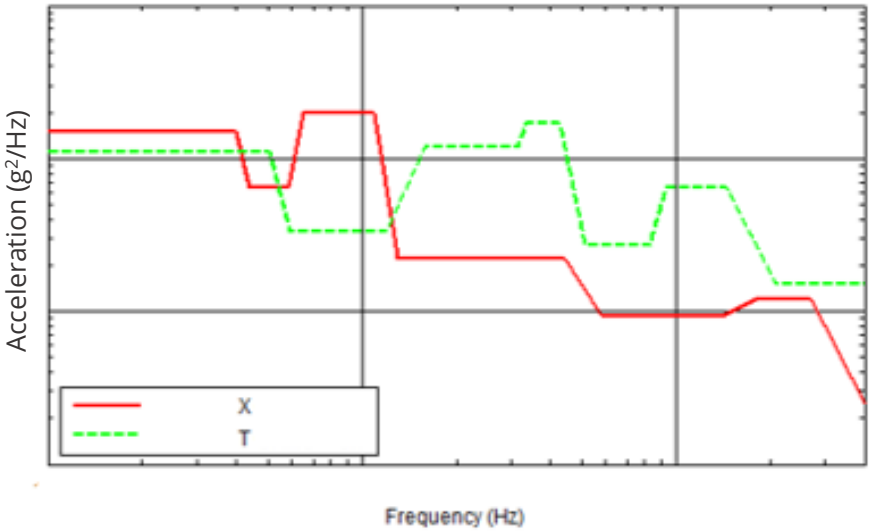
Test Unit



"Stiff" Fixture Design
(Traditional)



Vibe Test on a Shaker Table, Shock Test, etc.

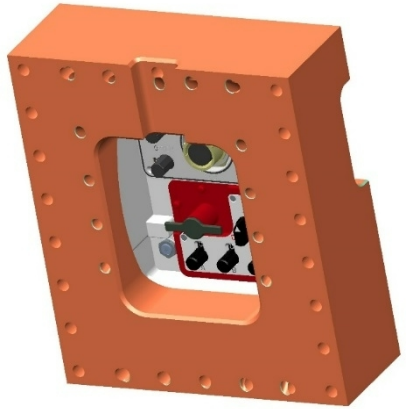


Component Test Specification

- Acceleration Power Spectral Density

Component Qualification – Test Lab Perspective

Test Unit



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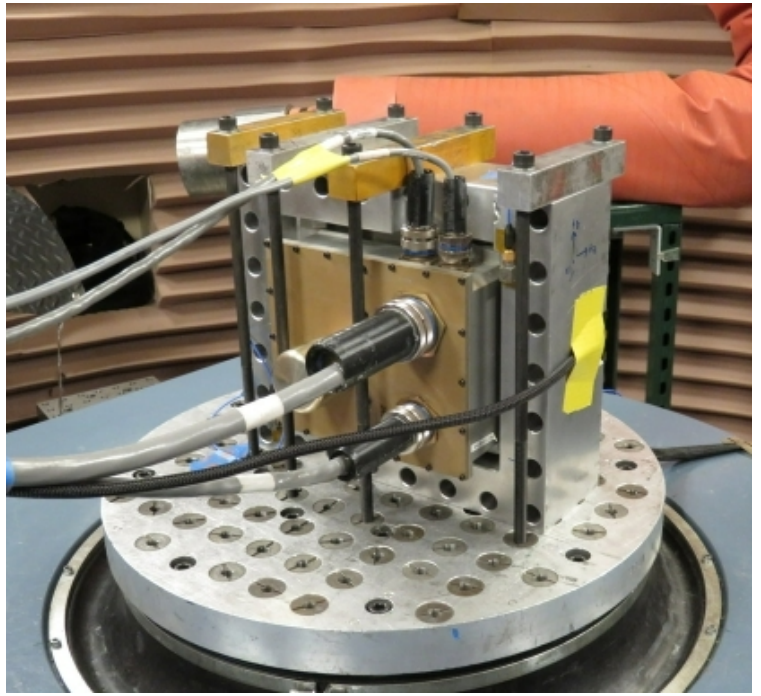

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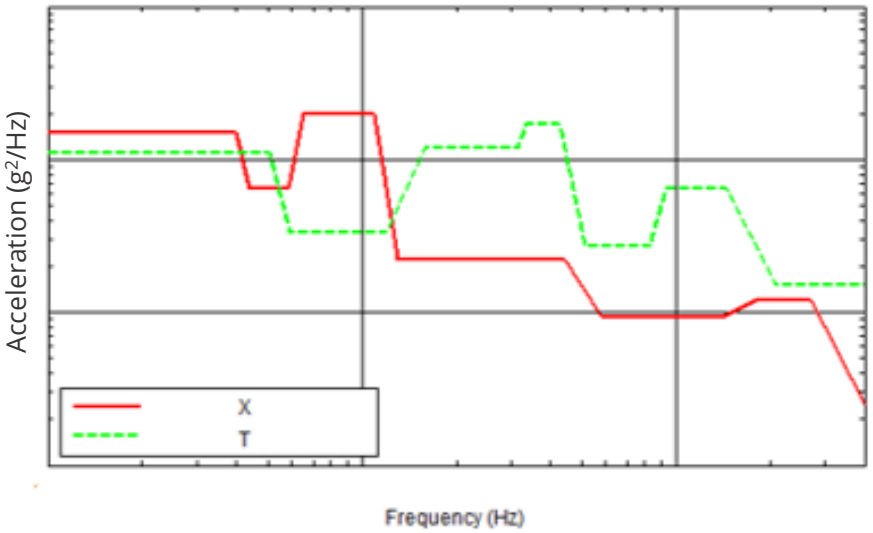
No Component Boundary Condition Information!



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Component Qualification – Test Lab Perspective

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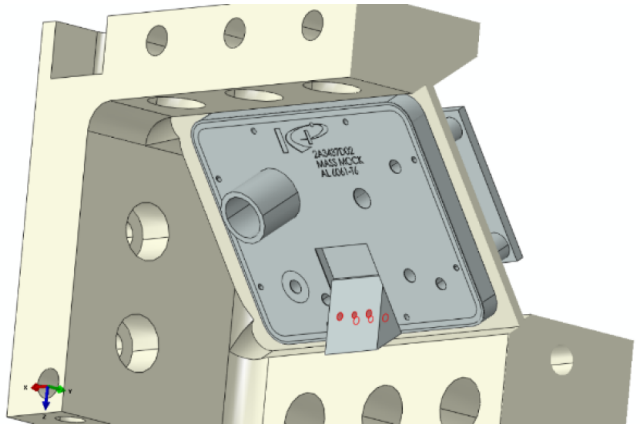
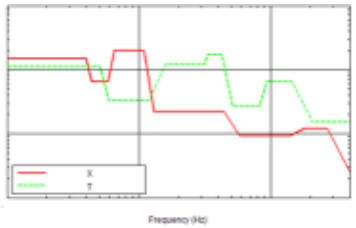


Alternative to a Stiff Fixture:
“Next Assembly” Fixture Design

Shock Test on a Drop Shock Machine, Vibe test, etc.



Component Test Specification

Acceleration Power Spectral Density

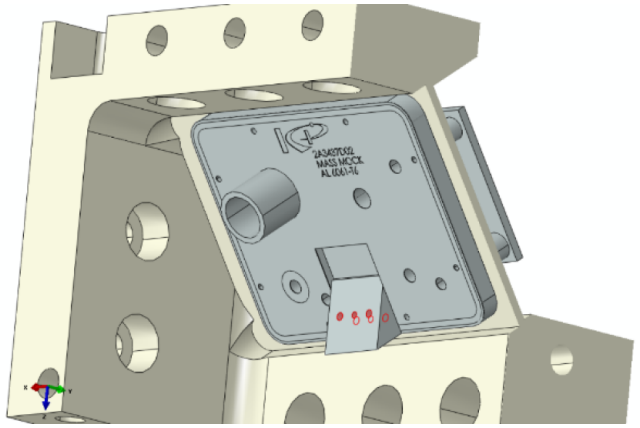
Or

Pulse Shock Specification

How should a “next assembly” fixture be designed?

Component Qualification – Test Lab Perspective

Test Unit



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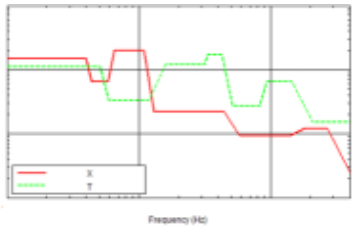


Component Test Specification

Acceleration Power Spectral Density

Or

Pulse Shock Specification

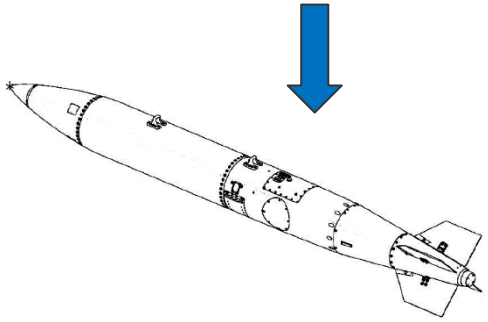
How should a “next assembly”

Is either choice for the Boundary Condition
“right”
“conservative”
“appropriate”

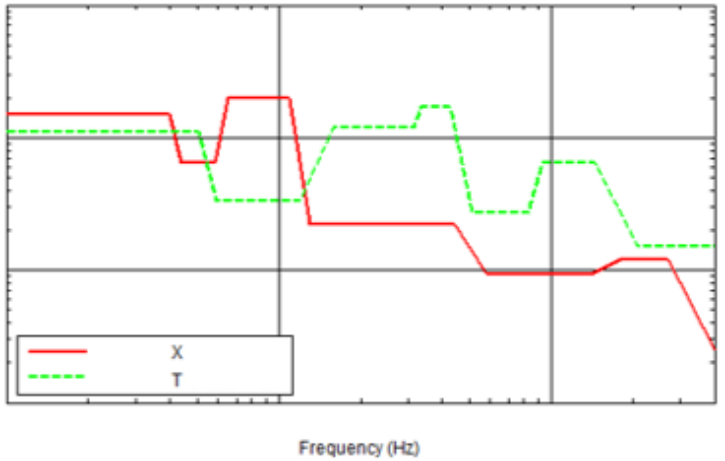
Component Qualification – Where do the test specs come from?

System Level Tests

Acceleration measurements. Usually sparse.



Measurements compiled and analyzed to define the environments to which a system is exposed.



Component-level Test Specifications based on environments.

Acceleration PSD, shock waveform...

Component Qualification – Where do the test specs come from?

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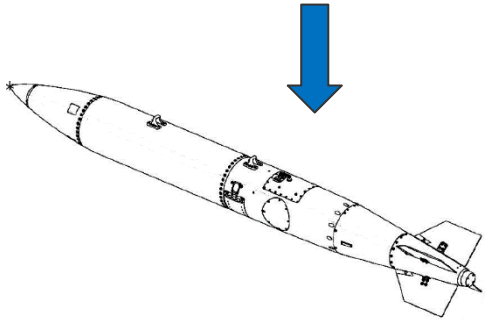

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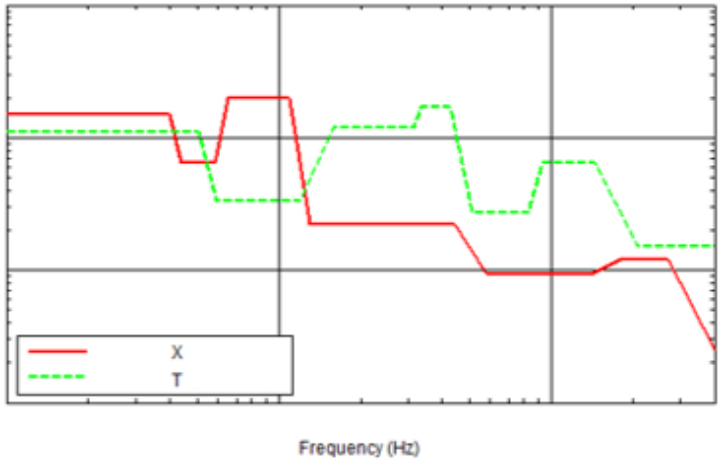


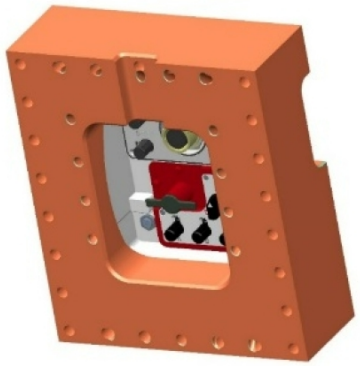
Component-level Test Specifications based on environments.

Acceleration PSD, shock waveform...

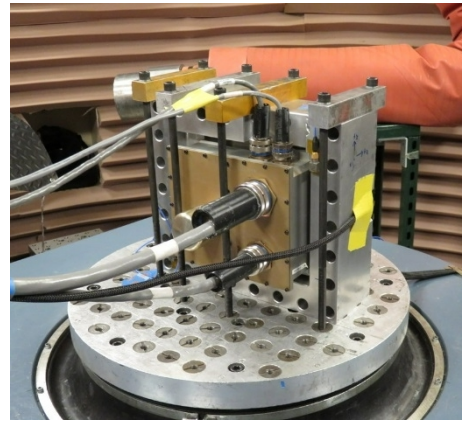
No Component Boundary Condition Information Included - Only Acceleration

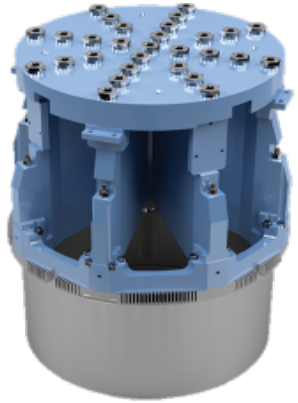
The Reality of Structural Dynamics

≠



Fixture Boundary Conditions



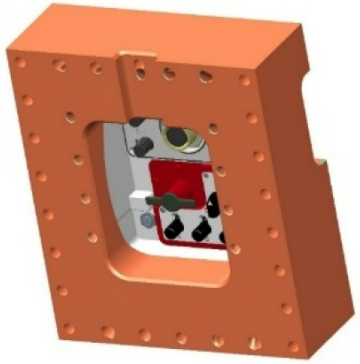


Shaker
Armature

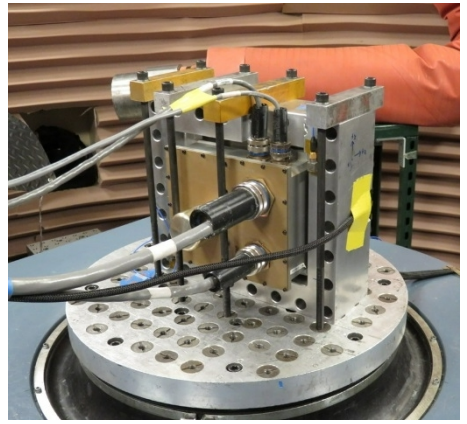
System vs. Qualification Test

- Different Boundary Conditions…
- Different Structural Dynamics
  - Mode Shapes & Natural Frequencies

The Reality of Structural Dynamics



Fixture Boundary Conditions



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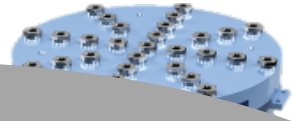
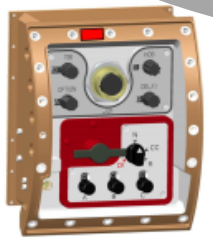


The Boundary Condition Challenge:
a tool to understand these issues.

System vs. Qualification Test
- Different Boundary Conditions
- Different Structural Dynamics
  - Mode Shapes & Natural Frequencies



Genesis of the Boundary Condition Challenge

2016:

3 to 5 people
- Sandia National Laboratories
- Kansas City National Security Campus (KCNSC)

- Structural Dynamics Problem
- How can we engage others?

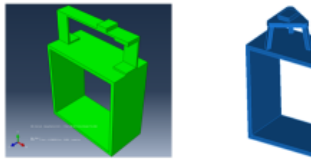
- Try a Round-Robin challenge problem?

Genesis of the Boundary Condition Challenge

Collaborative Research

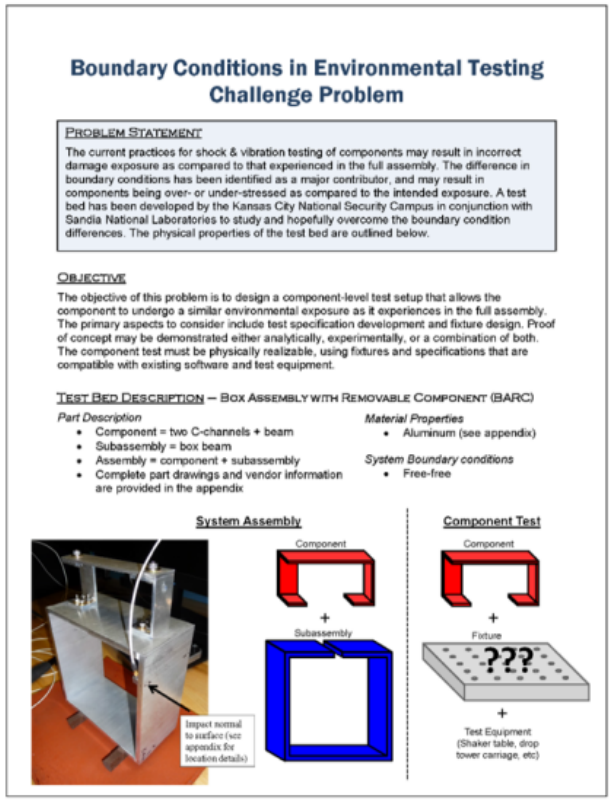
Round-Robin Challenge Problem Concept

- A simple structure to understand the problem
  - A "system" and "component"
  - Easily understood but non-trivial structural dynamics
  - Easy to model
  - Easy to build
  - Easy to test
  - Facilitates Topology Optimization (TO) of fixture
  - Facilitates Additive Manufacturing (AM) of fixture



Fall 2016 - AM prototy

2017: Work Together
- develop the Challenge Problem
- Round-Robin hardware



Boundary Conditions in Environmental Testing Challenge Problem

PROBLEM STATEMENT

The current practices for shock & vibration testing of components may result in incorrect damage exposure as compared to that experienced in the full assembly. The difference in boundary conditions has been identified as a major contributor, and may result in components being over- or under-stressed as compared to the intended exposure. A test bed has been developed by the Kansas City National Security Campus in conjunction with Sandia National Laboratories to study and hopefully overcome the boundary condition differences. The physical properties of the test bed are outlined below.

OBJECTIVE

The objective of this problem is to design a component-level test setup that allows the component to undergo a similar environmental exposure as it experiences in the full assembly. The primary aspects to consider include test specification development and fixture design. Proof of concept may be demonstrated either analytically, experimentally, or a combination of both. The component test must be physically realizable, using fixtures and specifications that are compatible with existing software and test equipment.

TEST BED DESCRIPTION – BOX ASSEMBLY WITH REMOVABLE COMPONENT (BARC)

Part Description
- Component = two C-channels + beam
- Subassembly = box beam
- Assembly = component + subassembly
- Complete part drawings and vendor information are provided in the appendix

Material Properties
- Aluminum (see appendix)

System Boundary conditions
- Free-free

System Assembly

Component Test

Component

Subassembly

Fixture

???

Test Equipment (Shaker table, drop tower carriage, etc)

Impact normal to surface (see appendix for location details)

System Environments

- **Suggested Environment – Shock**
  Modal hammer input with nylon tip, approximately 7 lb amplitude with 0.8ms duration[1].
  Input location defined in drawing (see appendix).
  - A set of "truth data" in the system environment will be experimentally measured by the organizers and can be provided upon request. Contact Julie Harvie for more information. This is intended to allow the participants to focus their efforts on designing the component test.
- **Additional Environments**
  Other environments may be investigated as desired but will not be the focus of discussion at this time. Future efforts will focus on random vibration environments.

GUIDELINES FOR ASSEMBLING

Component
- Bolt Torque = 50 inch-lb
- Dry connection (no lubrication)

Assembly
- Bolt Torque = 20 inch-lb
- Dry connection (no lubrication)
- Configure bolts in alternating directions as shown

ORGANIZERS

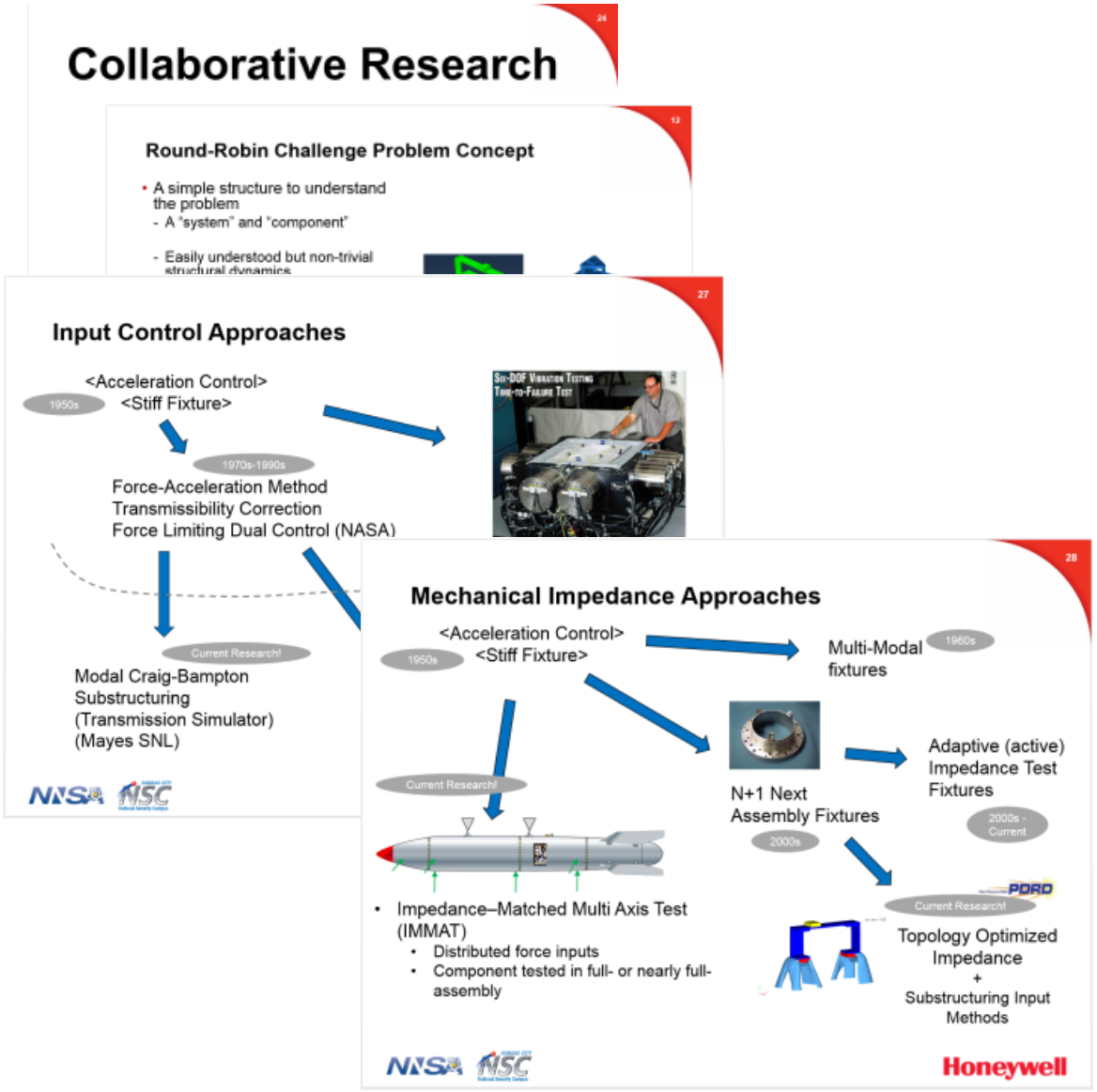
Julie Harvie, Sandia National Laboratories
Tyler Schoenherr, Sandia National Laboratories
Troy Skousen, Sandia National Laboratories
Richard Jones, Kansas City National Security Campus
David Soine, Kansas City National Security Campus

CONTACT INFORMATION

Julie Harvie
Sandia National Laboratories
(505) 284-8292
jharvie@sandia.gov

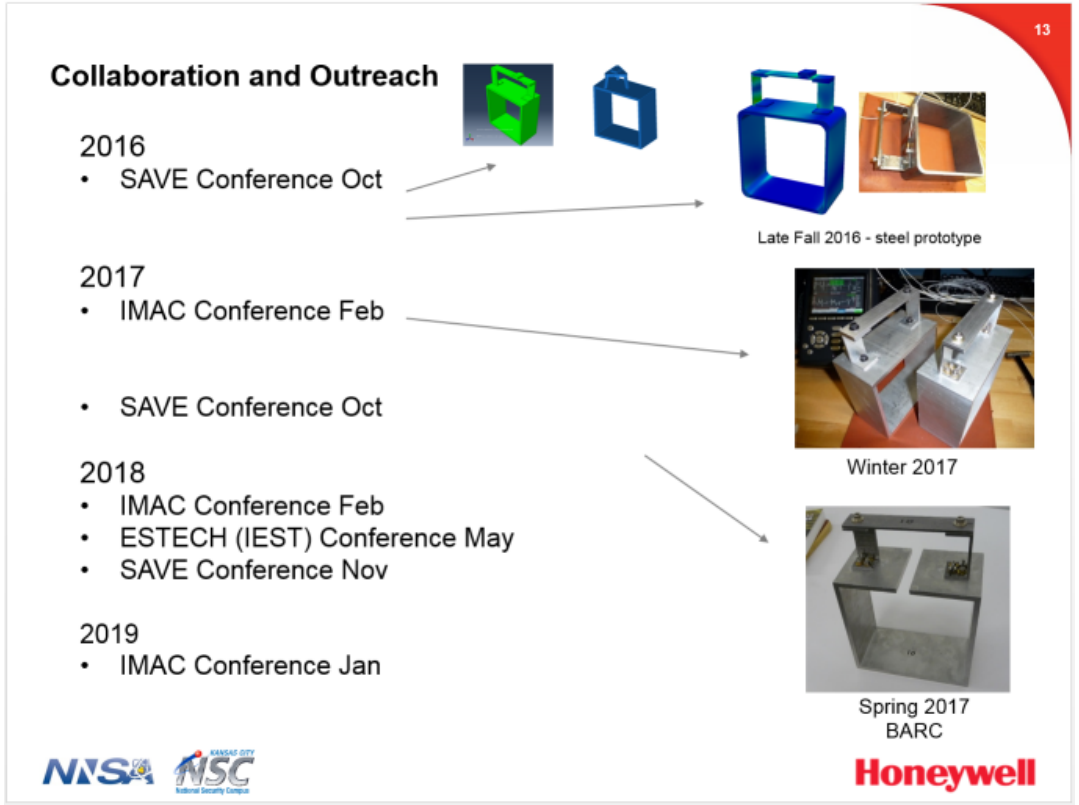
[1] The force input may be approximated analytically using the formula: $F(t) = 7\sin^2\left(\frac{\pi}{0.0008}t\right)$
where F is force in pounds and t is time in seconds. Zero-padding should be used to allow adequate response ring-down and frequency resolution.

Genesis of the Boundary Condition Challenge

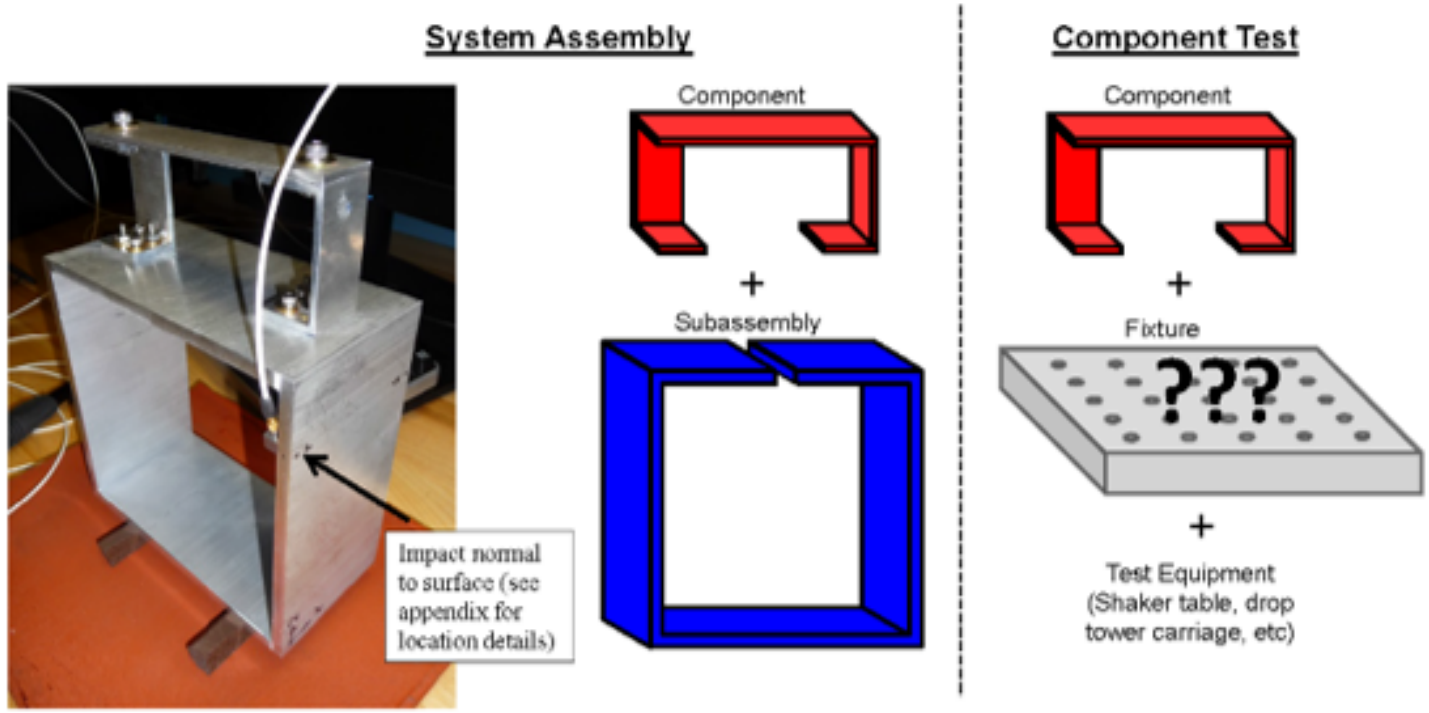


2017-2018:

- Do some homework
- Ask for help



What is the Challenge?



Box Assembly with Removable Component "BARC"

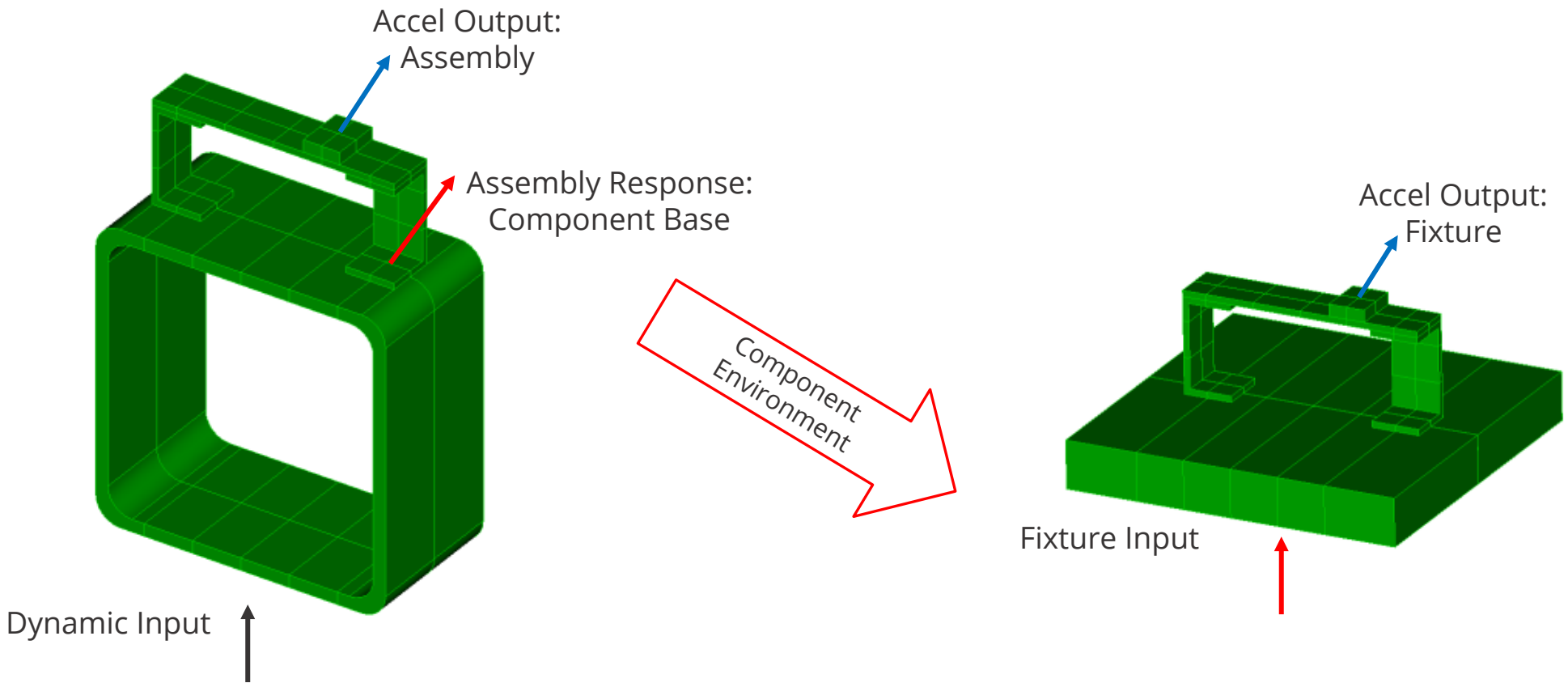
Do a "System Level" test to create "truth data"

Develop:

- Component Fixture
- Test Method

- to replicate the "truth data" at the component level

Box & Bench Assembly Example – Traditional Approach



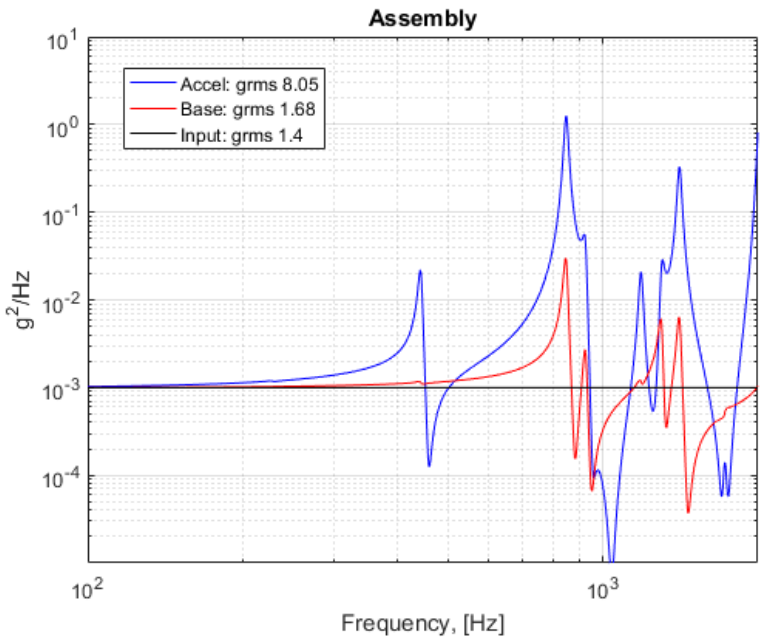
"System Flight Test"

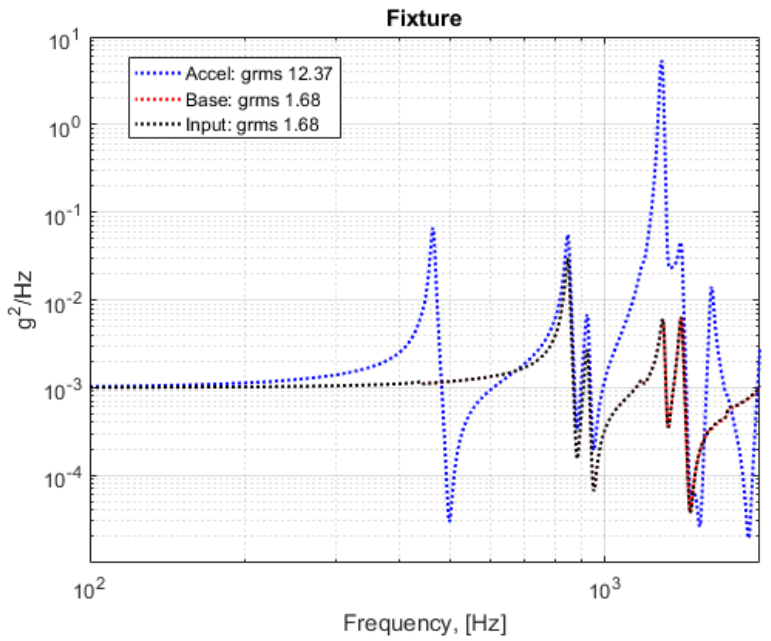
"Component Environmental Test"

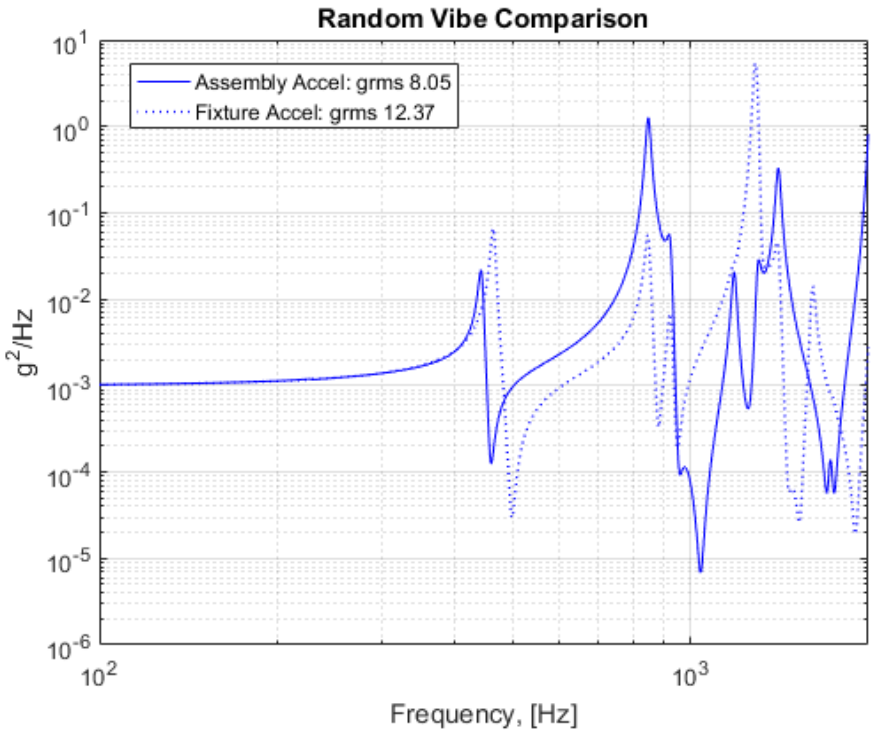
Is the component response "the same" in both cases?

Box & Bench Assembly Example – Traditional Approach

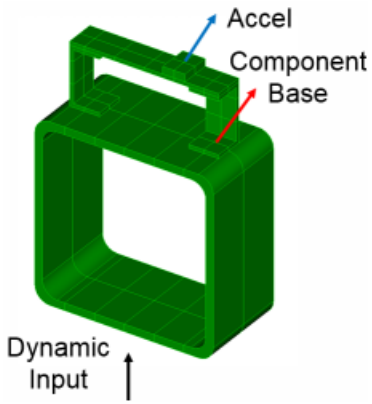
Random Vibe Loading

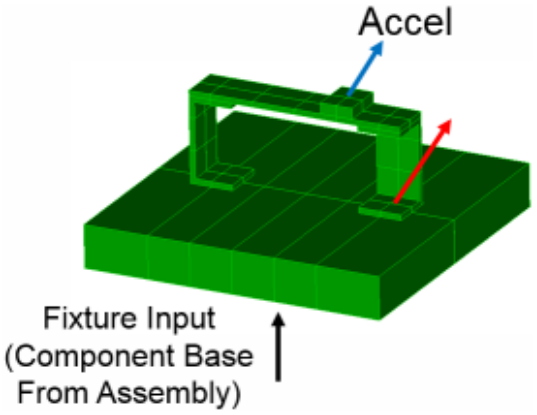






Flat PSD
0.001 g^2/Hz
200 to 2000Hz

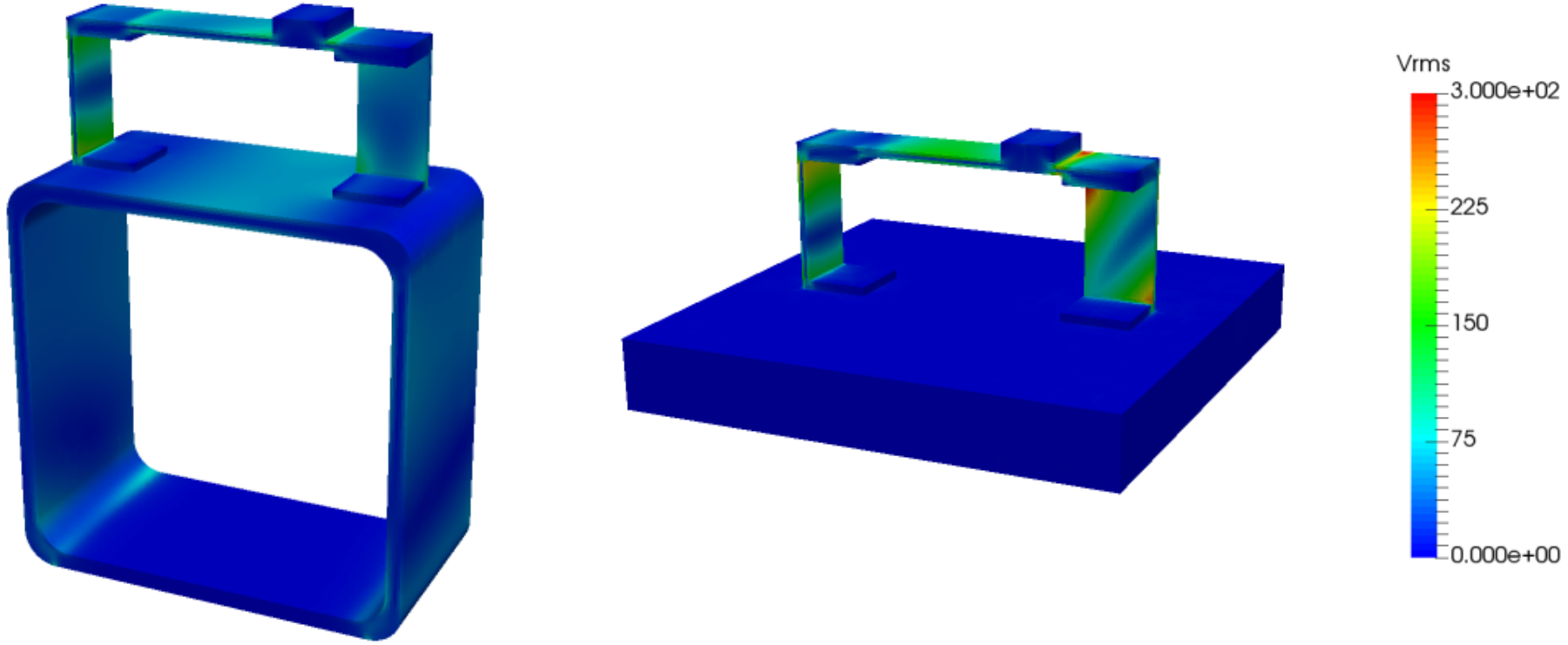




Inconsistent Conservatism

Box & Bench Assembly Example – Traditional Approach

Random Acceleration: RMS Von Mises Stress



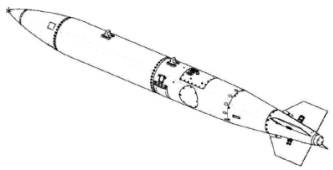
Significantly Different Stress Fields

Boundary Condition Challenge – research paths

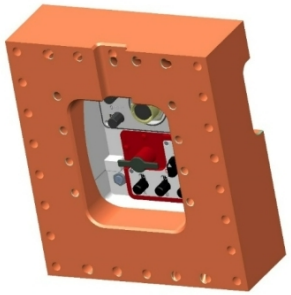
Combining Test and Simulation

- Model driven System Tests
- Multi-Point System ground testing
- Full Field Response: Modal Expansion Strain
- Substructuring to design the component test
- Topology Optimization for dynamic fixtures
- Multi-axis Component testing

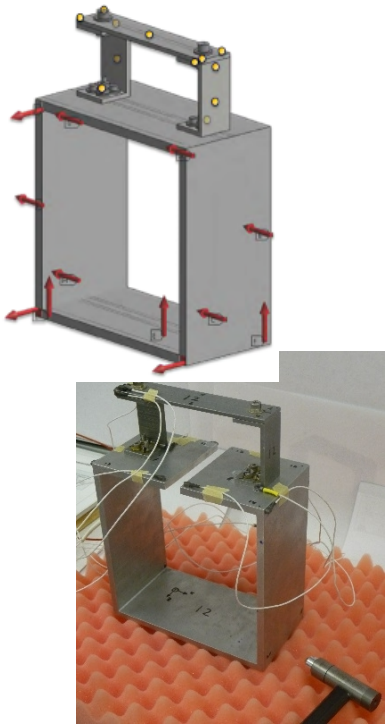
Environments

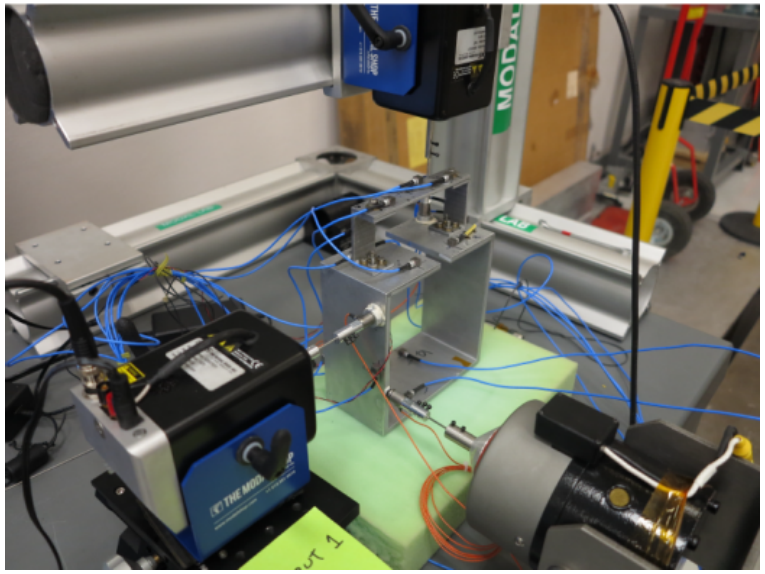


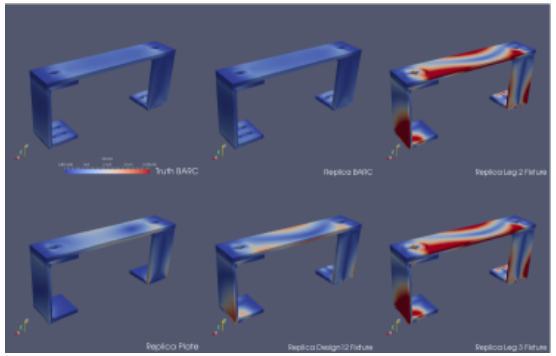
Component Qualification



Boundary Condition Challenge – research paths







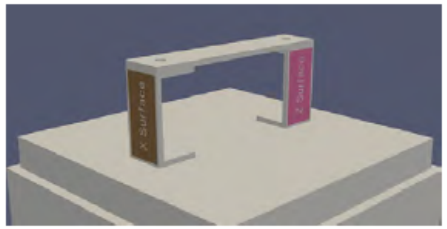


Fig. 12 Area patches where surface strains were calculated

Model driven System Tests

Where to Measure during Flight

Multi-Point System ground testing

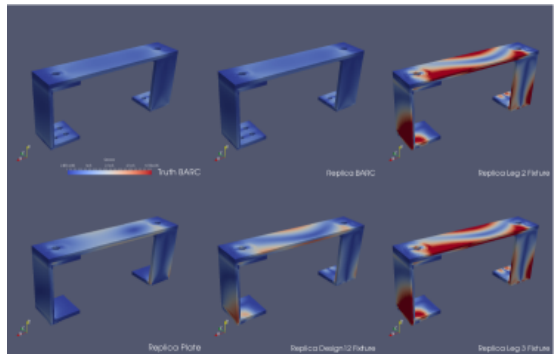
Fill in the blanks from Flight

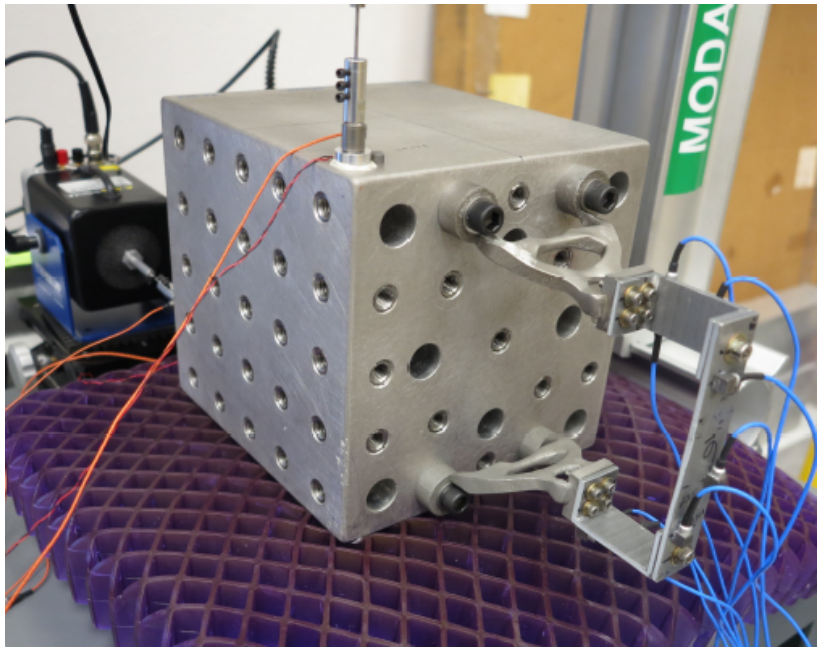
Full Field Response: Modal Expansion, Strain

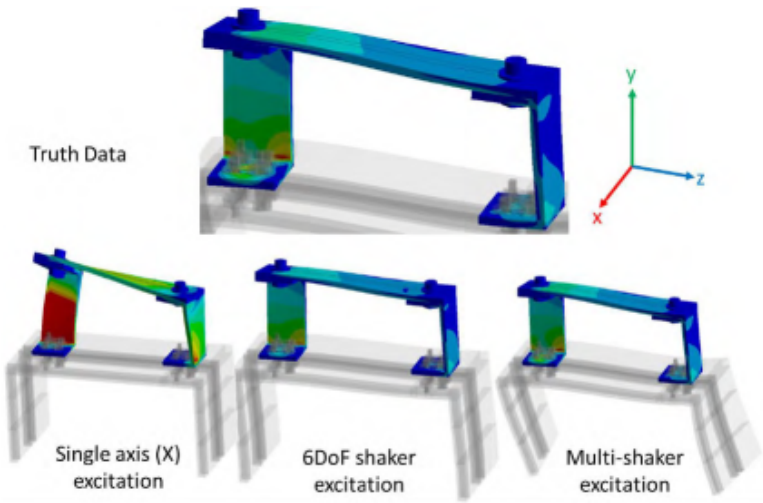
Basis for Qual Environments

Environments

Boundary Condition Challenge – research paths







Full Field Response: Modal Expansion Strain

Substructuring to design the component test

Topology Optimization for dynamic fixtures

Multi-axis Component testing

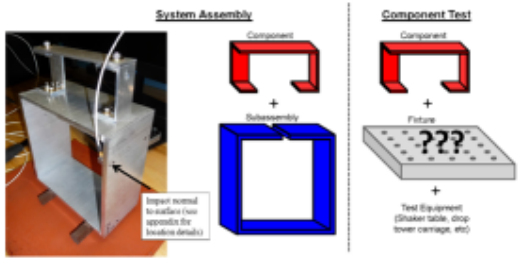
Basis for Qual Environments

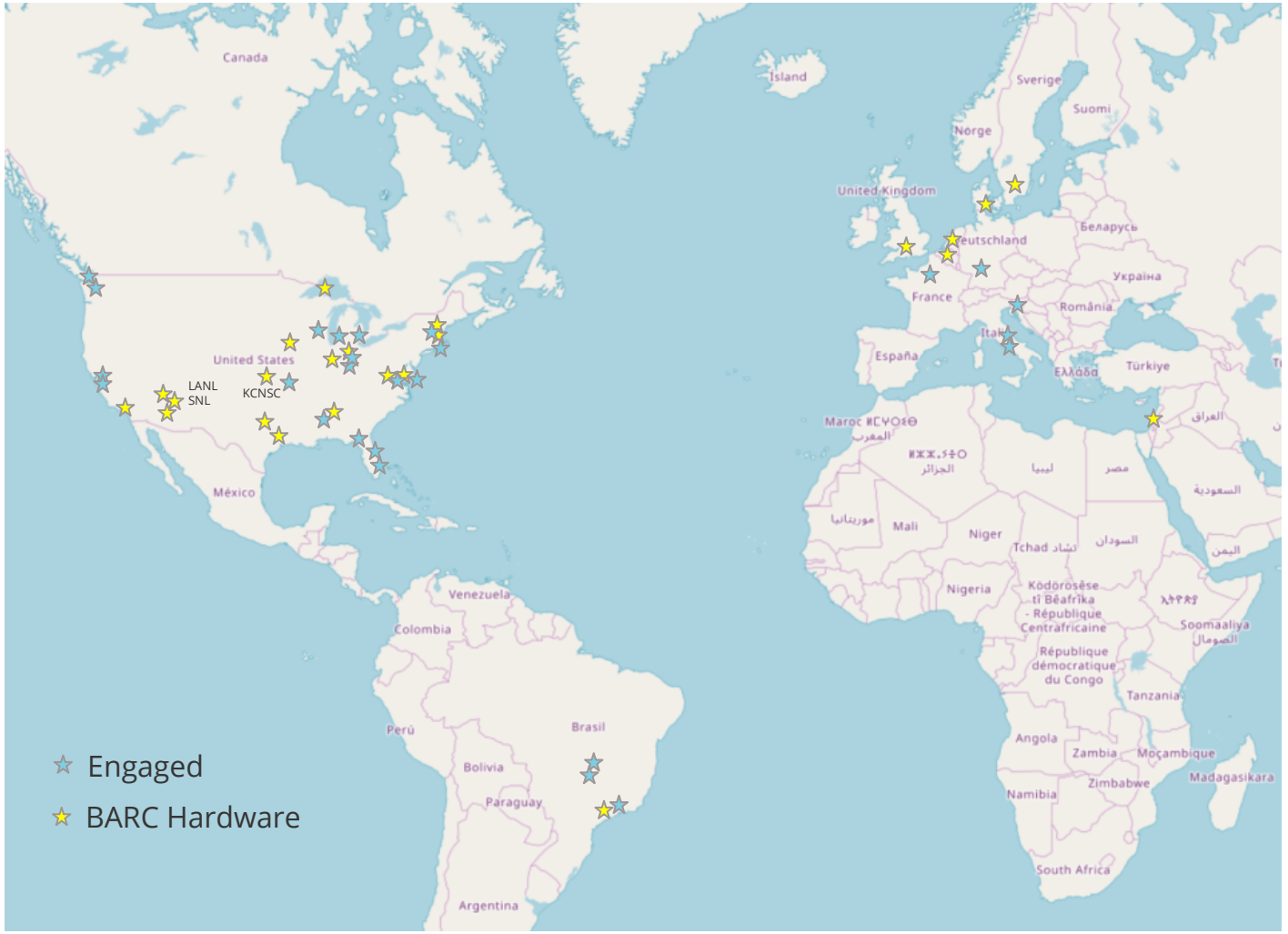
Test and Fixture Design

Higher Fidelity & Known Conservatism

Component Qualification

Boundary Condition Challenge research initiative – fostering worldwide collaboration





60 organizations
- 25 Commercial
- 24 Universities
- 5 NSE sites
- 5 DOD sites
- 1 NASA

14 countries
4 continents

Boundary Condition Challenges in Dynamic Testing

Supplementary Material

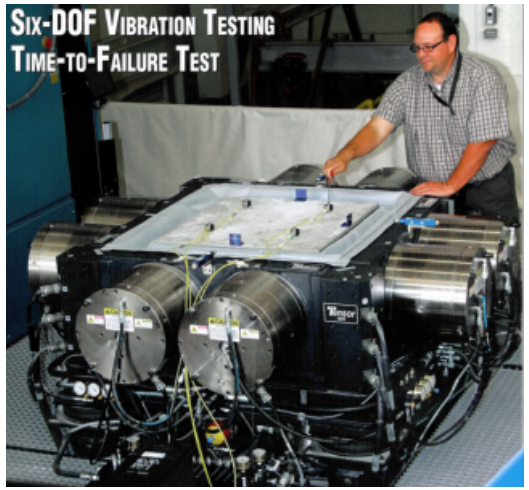
Input Control Approaches

<Acceleration Control>
<Stiff Fixture>

1950s

1970s-1990s

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



Six-DOF shaker testing

Current Research!

PDRD Plant Directed R&D

Ignores Test Structure

Includes Test Structure Information

Current Research!

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

Current Research!

PDRD Plant Directed R&D

Frequency Based Substructuring/Impedance Modeling (UMass Lowell)

Mechanical Impedance Approaches

<Acceleration Control>
<Stiff Fixture>

1950s

Multi-Modal fixtures

1960s

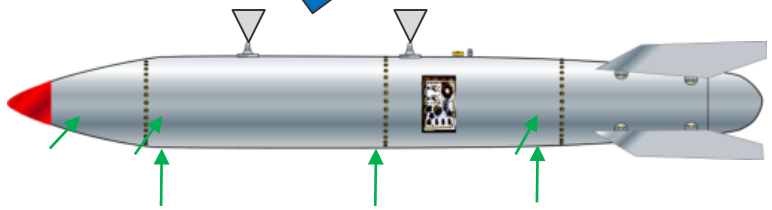
N+1 Next Assembly Fixtures

2000s

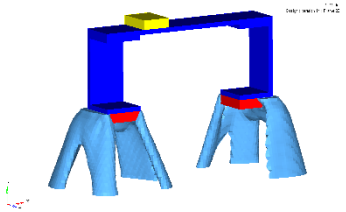
Adaptive (active) Impedance Test Fixtures

2000s - Current

Current Research!



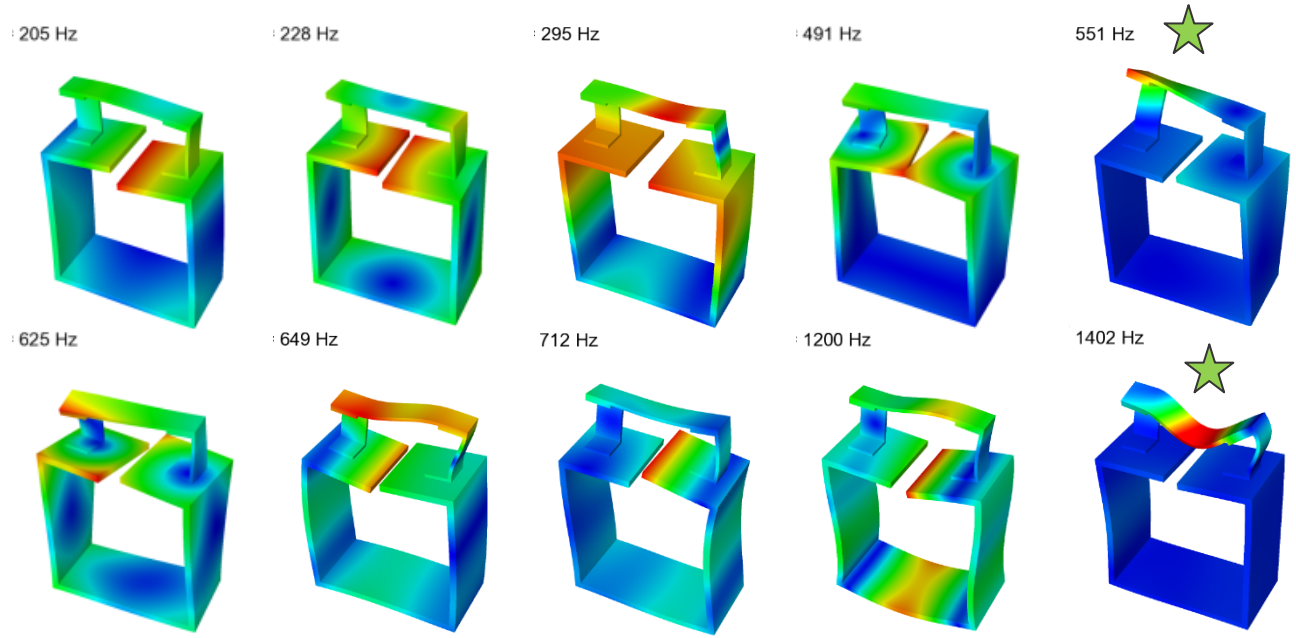
- Impedance–Matched Multi Axis Test (IMMAT)
  - Distributed force inputs
  - Component tested in full- or nearly full- assembly

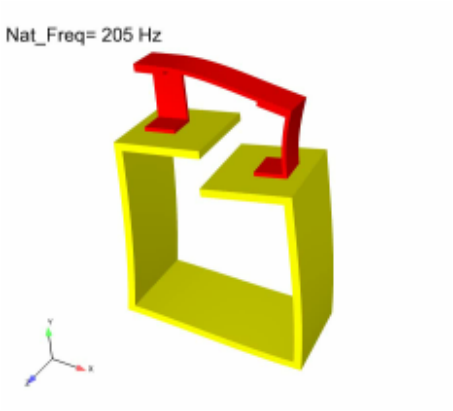


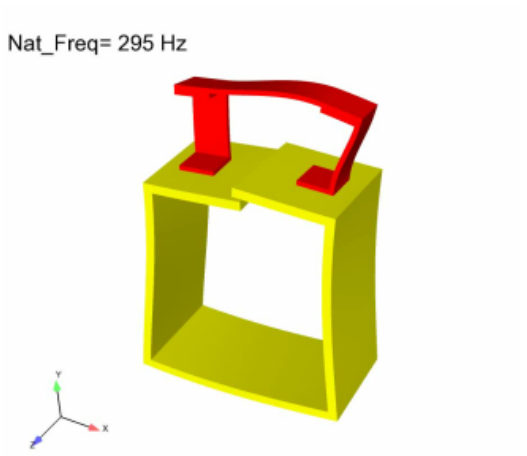
Current Research!

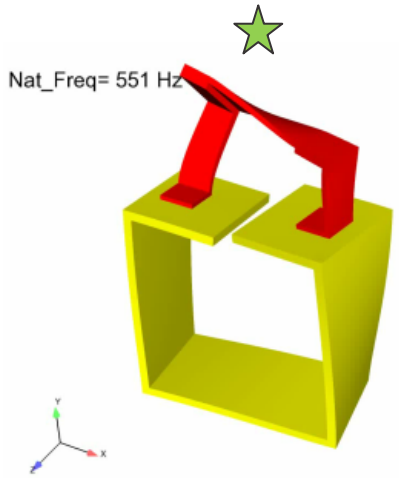
Topology Optimized Impedance
+
Substructuring Input Methods

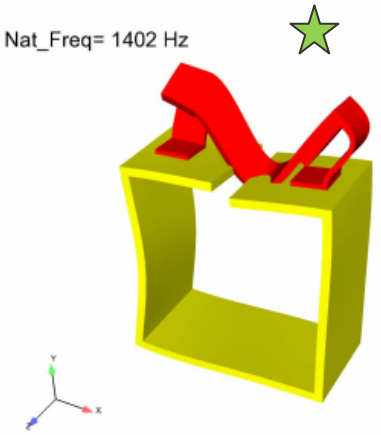
Box Assembly with Removable Component – Mode Shapes



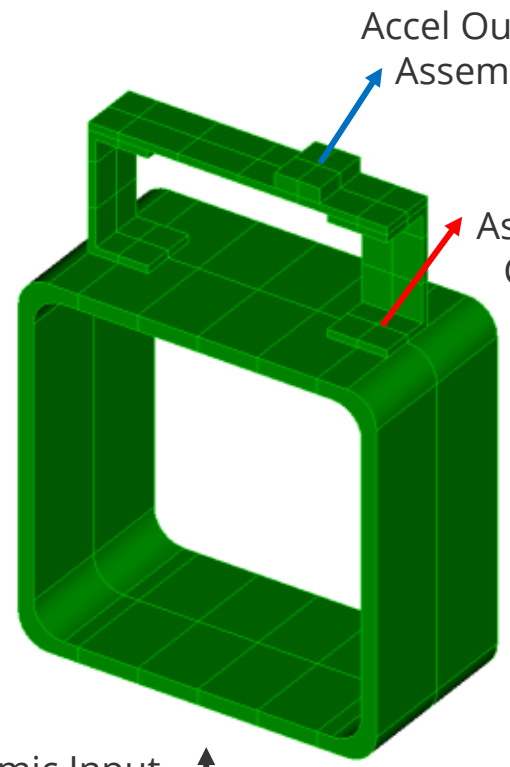


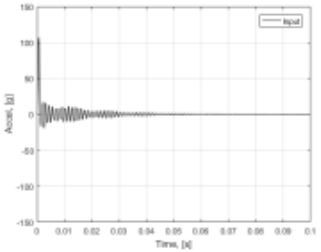


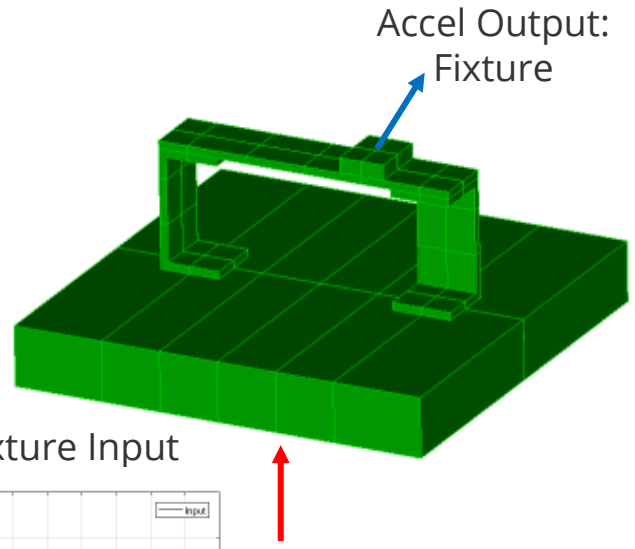




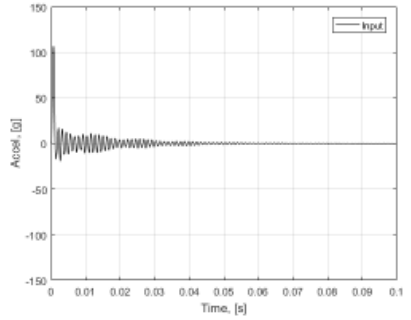
Box & Bench Assembly Example – Traditional Approach



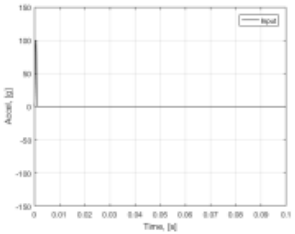




Fixture Input



Dynamic Input



100g, 1ms
acceleration pulse

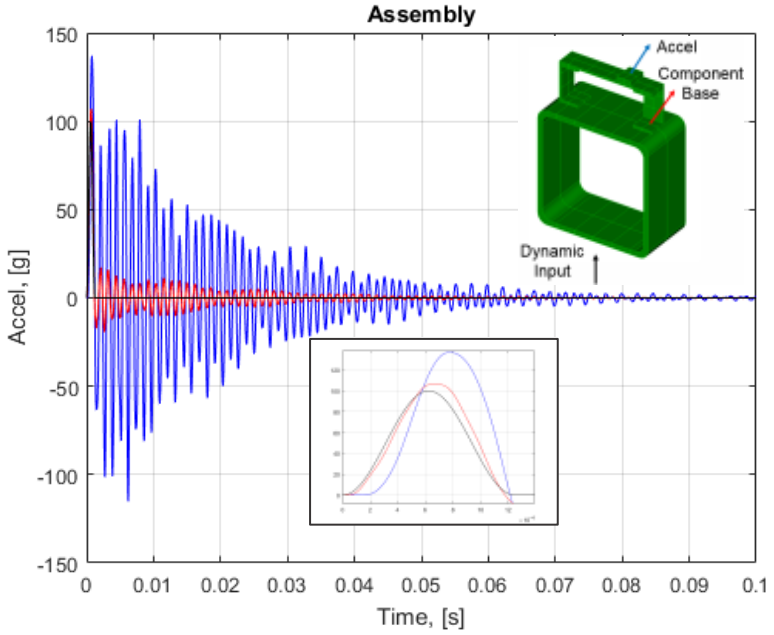
"System Flight Test"

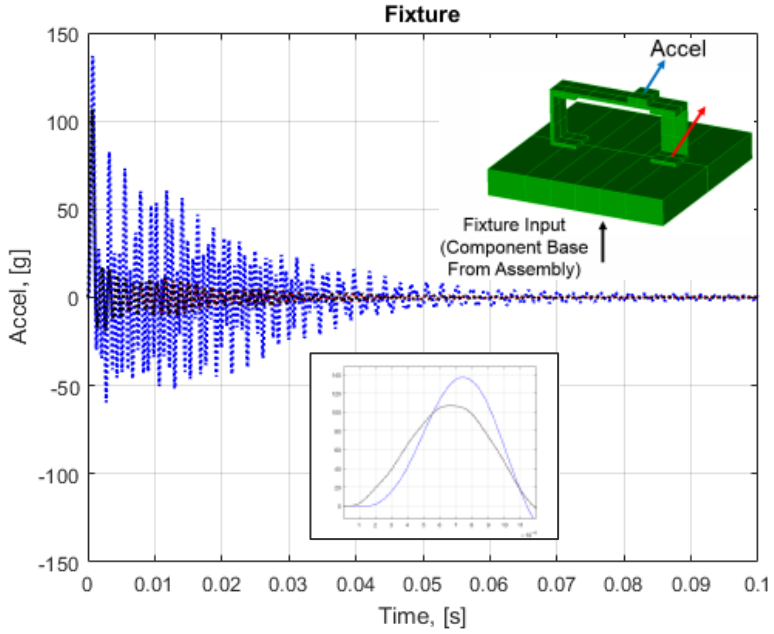
"Component Environmental Test"

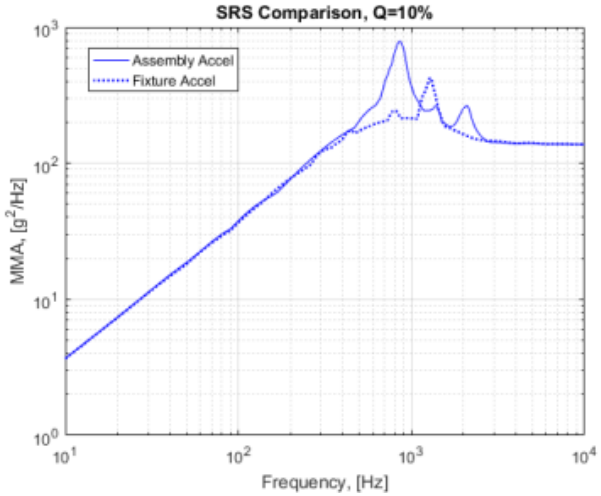
Box & Bench Assembly Example – Traditional Approach

Acceleration Pulse Load

100g, 1ms acceleration pulse

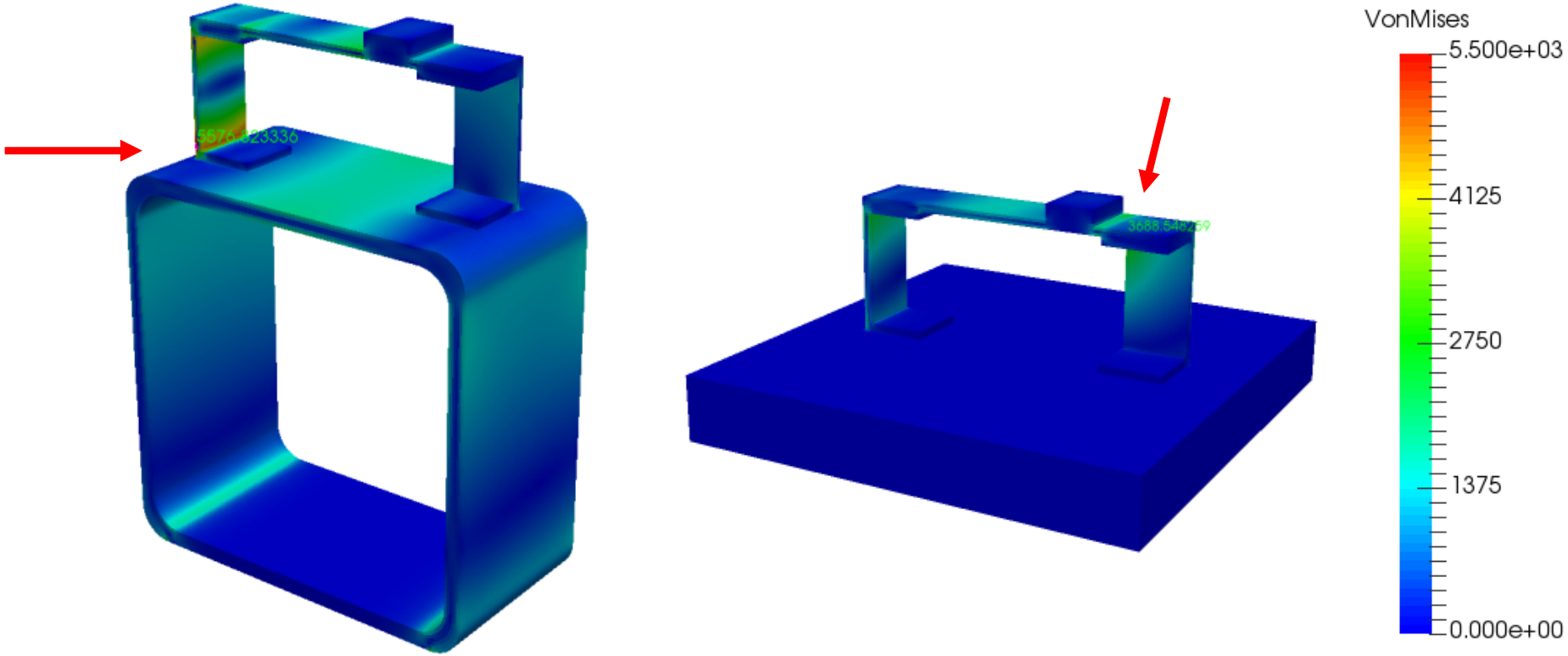






Box & Bench Assembly Example – Traditional Approach

Acceleration Pulse: Max Von Mises Stress

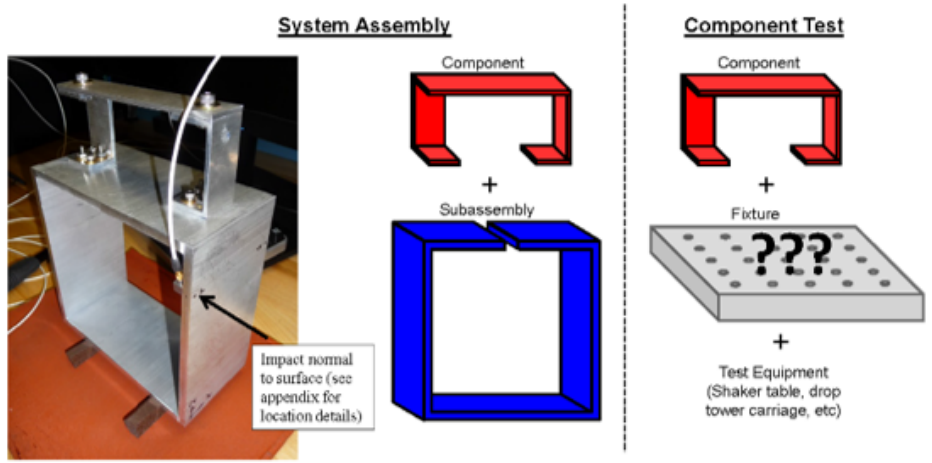


Maximum Stress is in a Different Location!

Boundary Condition Challenge – research paths

Combined Test and Simulation at all levels

- Model driven System Tests
- Multi-Point System ground testing
- Full Field Response:
  - Acceleration and Strain
  - Modal Expansion
  - Laser Vibrometry, DIC
- Substructuring to design the component test
- Topology Optimization for dynamic fixtures
- Multi-axis Component testing



Abstract

The Boundary Condition Challenge, initiated in 2017 by researchers from the DOE's Kansas City National Security Campus and Sandia National Lab, was designed to engage structural dynamics experts on reducing the risk of inaccurate conservatism related to test fixture design in shock and vibration testing. The seemingly simple challenge problem and easy-to-obtain hardware has become a powerful focal point for research in ground vibration testing.

References

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Soine, D.E., Jones, R.J. Jr., Harvie, J.M., Skousen, T.J., Schoenherr, T.F., *Designing Hardware for the Boundary Condition Round Robin Challenge*, IMAC 36 Proceedings, 2018.