SAND2019-3099C

Comparison of Multi-Axis Testing of the BARC Structure with varying Boundary Conditions

Presented by:

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Outline

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- AM Fixture

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Motivation

Components undergo complex, 3D motion while in service environment.

Our single-axis vibration testing does not necessarily exercise the same failure mechanisms.

Component Boundary Conditions may also be significantly different.

Box Assembly and Removable Component (BARC) was introduced as a challenge problem to allow researchers to collaborate on relatively simple hardware.

Goal

In this work, we wish to begin to understand the effect that the vibration fixture has on component response in a multi-axis vibration test.

Compare vibration responses on the removable component (RC) in a made-up "service" environment to those in a laboratory shaker test using a variety of fixtures.

- Traditional "rigid" plate fixture
- Topology-optimized, additively-manufactured fixture

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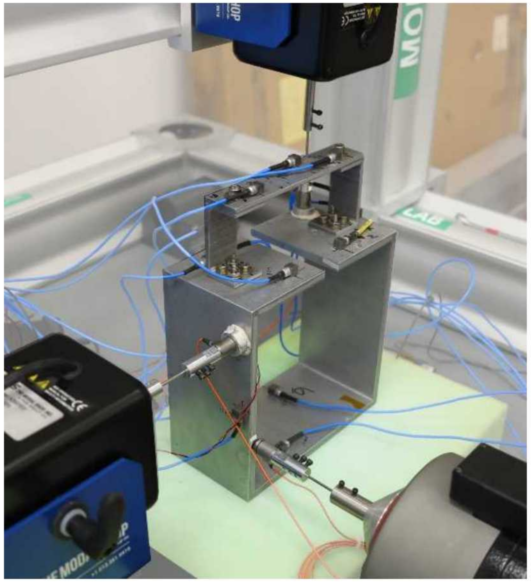
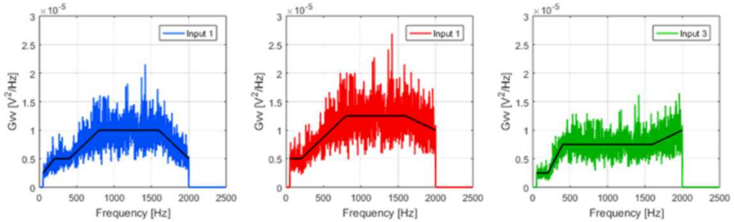
Service Environment

- Created a Service Environment
- 3 shakers attached to the BARC structure
- Representative specification was played into each shaker
- Responses measured at 9 triaxial locations on the removable component.





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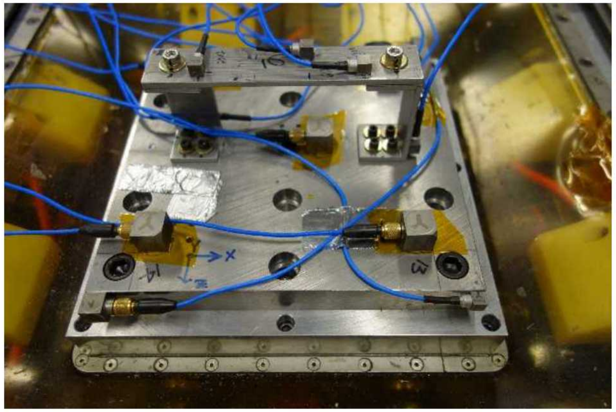
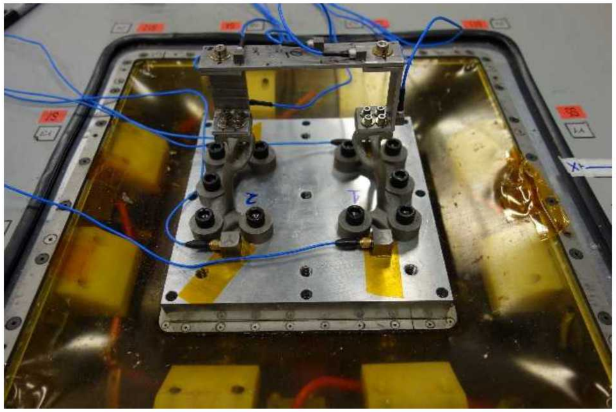
6-DoF Testing

The service environment was reproduced on a 6 Degree-of-Freedom Shaker system with Spectral Dynamics Jaguar Control System.

Jaguar attempted to control the responses at 7 of the triaxial accelerometers.

The part was tested using a traditional “rigid” plate fixture, as well as an additively manufactured fixture designed with topology optimization.

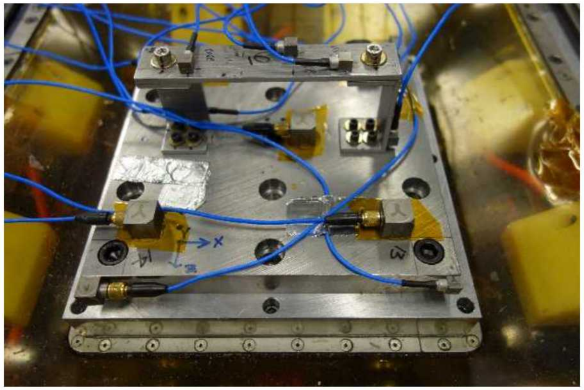


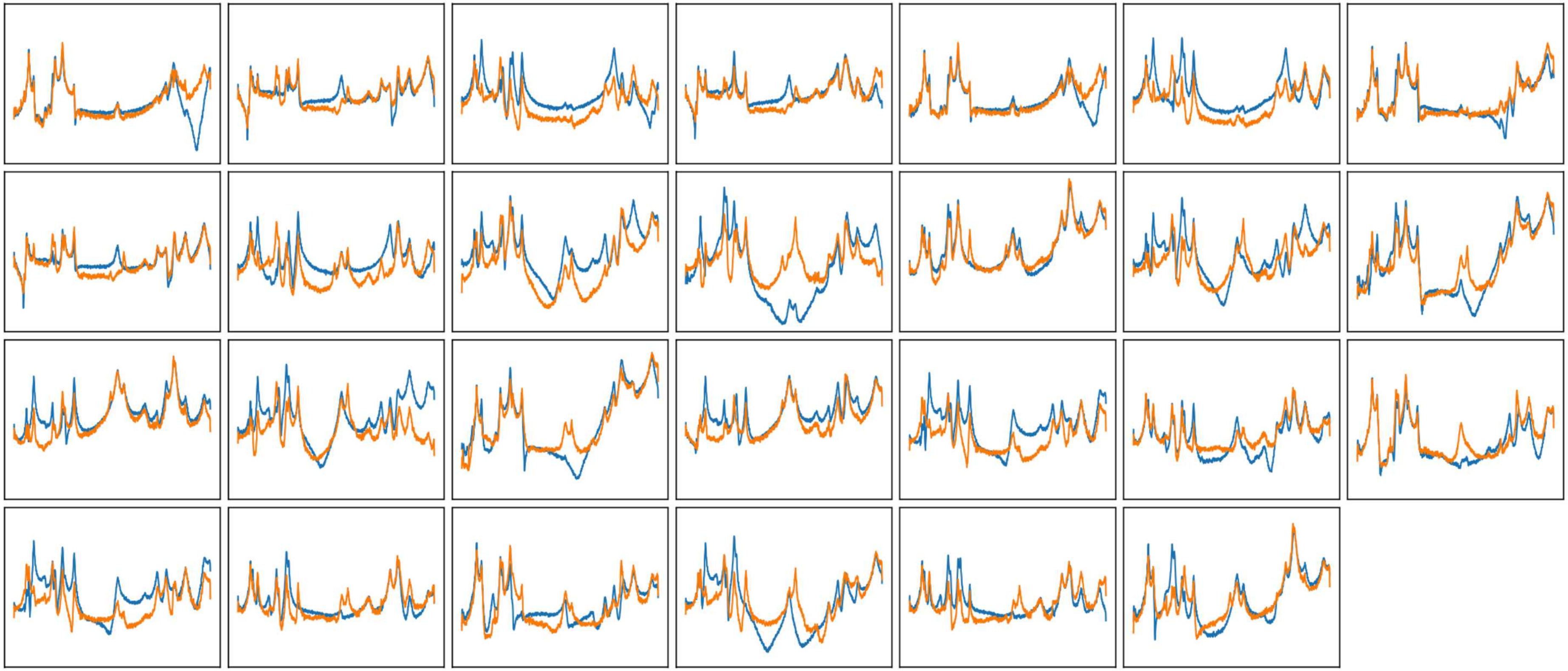


Rigid Fixture Response

Removable component first tested on rigid fixture.

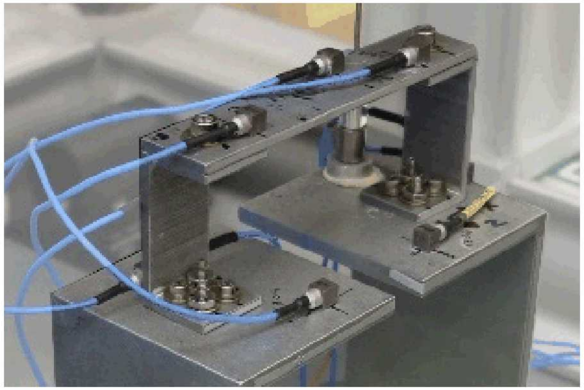
Responses at 27 accelerometer channels were compared to the specification

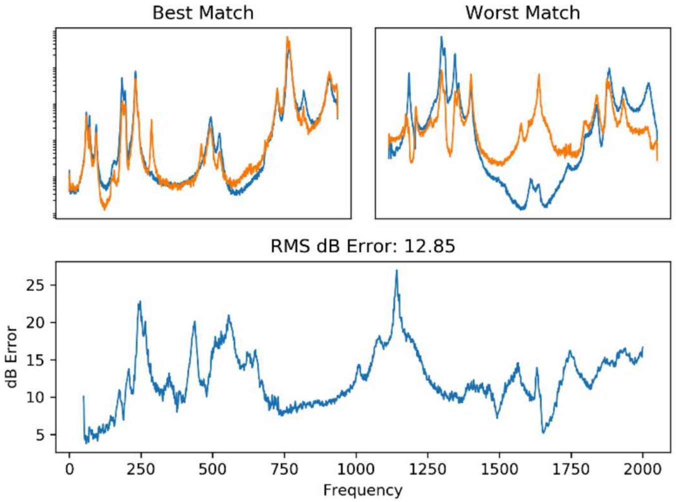




Rigid Fixture Response

- Removable component first tested on rigid fixture.
- Responses at 27 accelerometer channels were compared to the specification
- Best and worst matches as well as dB error over frequency are shown.
- Rigid base excitation does not capture all the motion that occurred in the environment, so we expect errors to be present.





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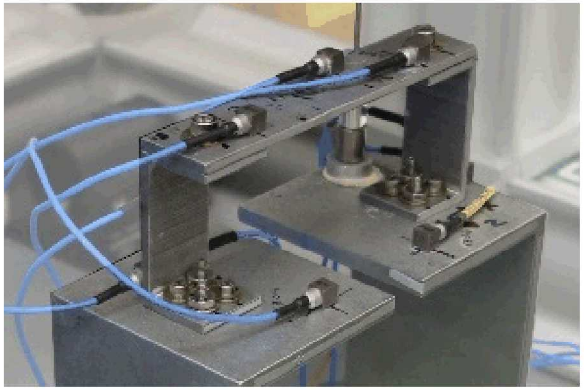
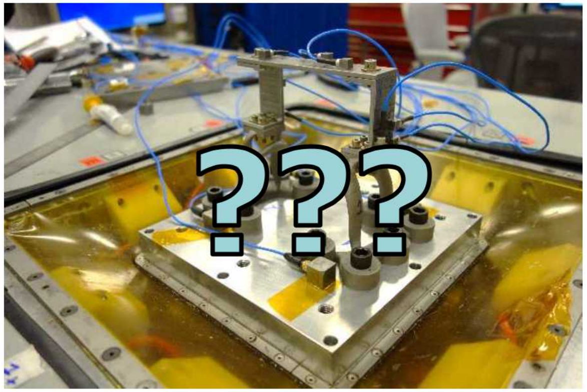
AM Fixture Design

Recognizing that a rigid fixture would not produce the required compliance between the feet, an alternative was sought that included that compliance.

Topology optimization was used to design a fixture that had similar static stiffness to the box structure.

Fixture was additively manufactured due to unique geometry.





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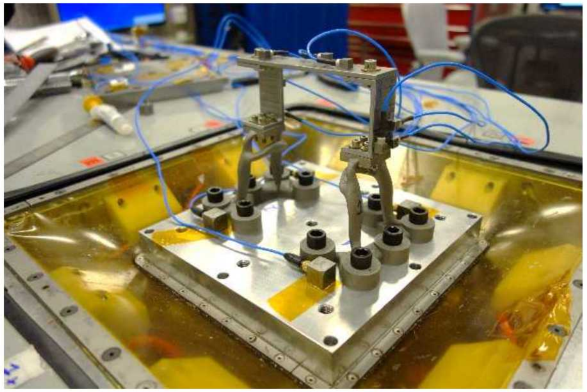
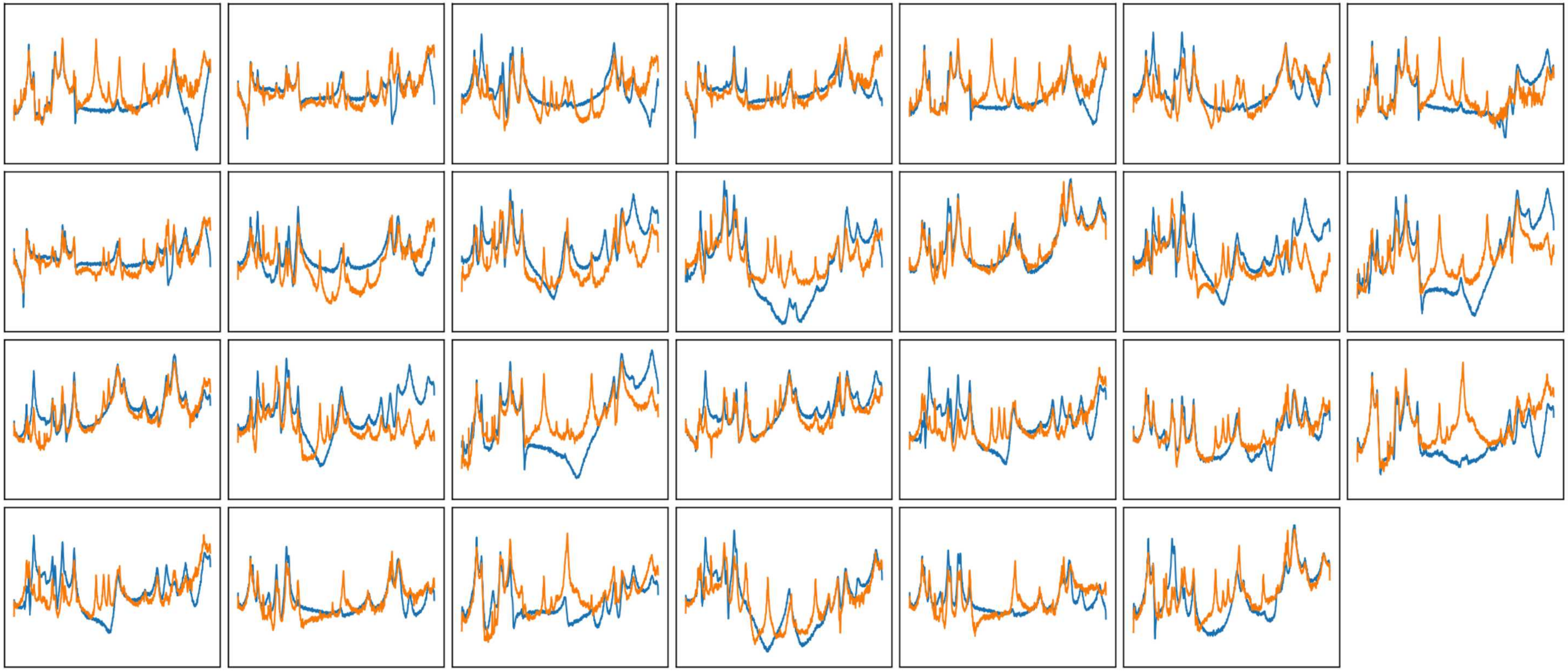
AM Fixture Response

The AM fixture did not improve the control.



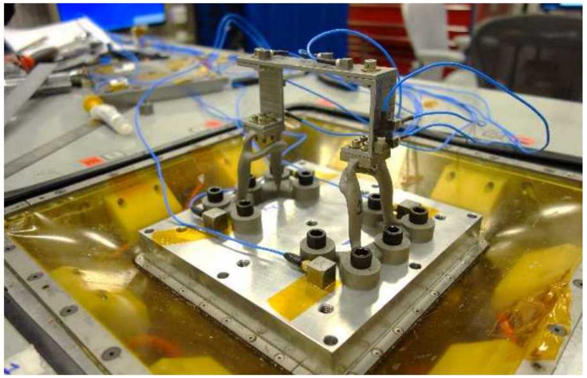


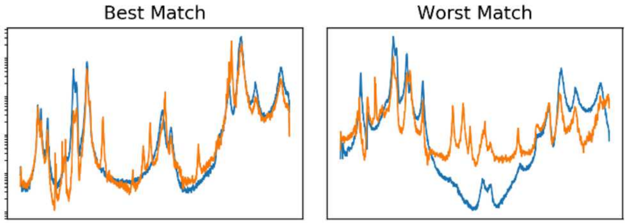
AM Fixture Response

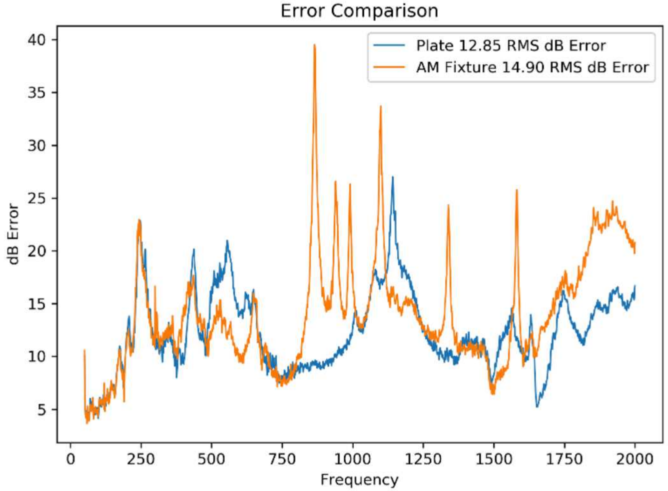
The AM fixture did not improve the control.

The compliance in the structure has introduced a number of modes of the fixture that the control system cannot control.

Both fixtures struggled with some low frequency bands, but the AM fixture has introduced much more error at high frequency







Multi-DoF Specifications

As we investigate Multi-DoF testing methods, we should also think about how specifications are derived.

Given that there will inevitably be small differences between environment and laboratory tests, is matching the acceleration response best? Or some other quantity?

- Strain
- Modal Kinetic Energy

What might this look like?

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Controlling to Modes

Per the finite element model, there are four elastic modes and six rigid body mode in the bandwidth of interest.

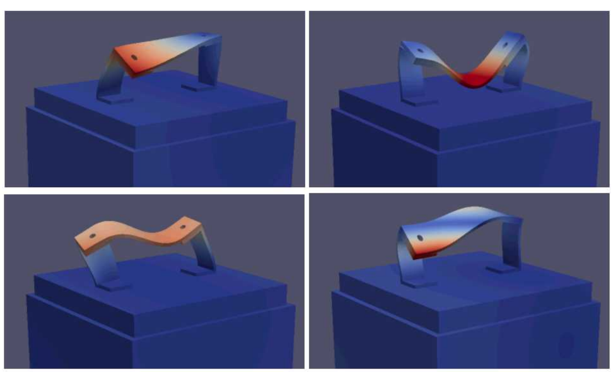
Compute a modal filter T using the 10 finite element mode shapes, and apply it to the specification.

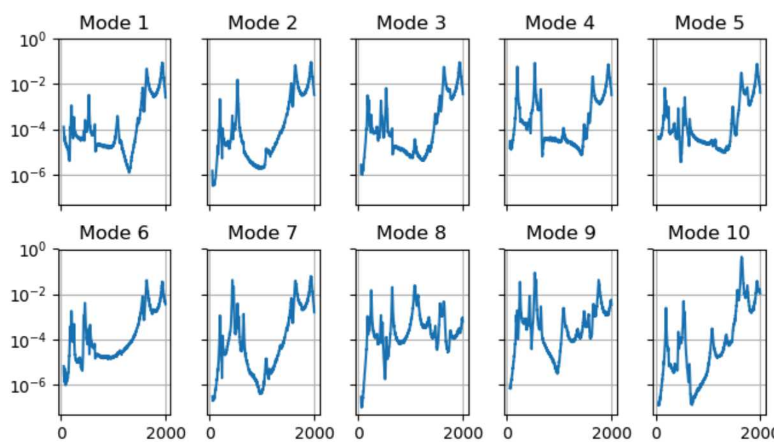
$$x = \Phi q$$
$$q = \Phi^{+} x$$
$$T = \Phi^{+}$$

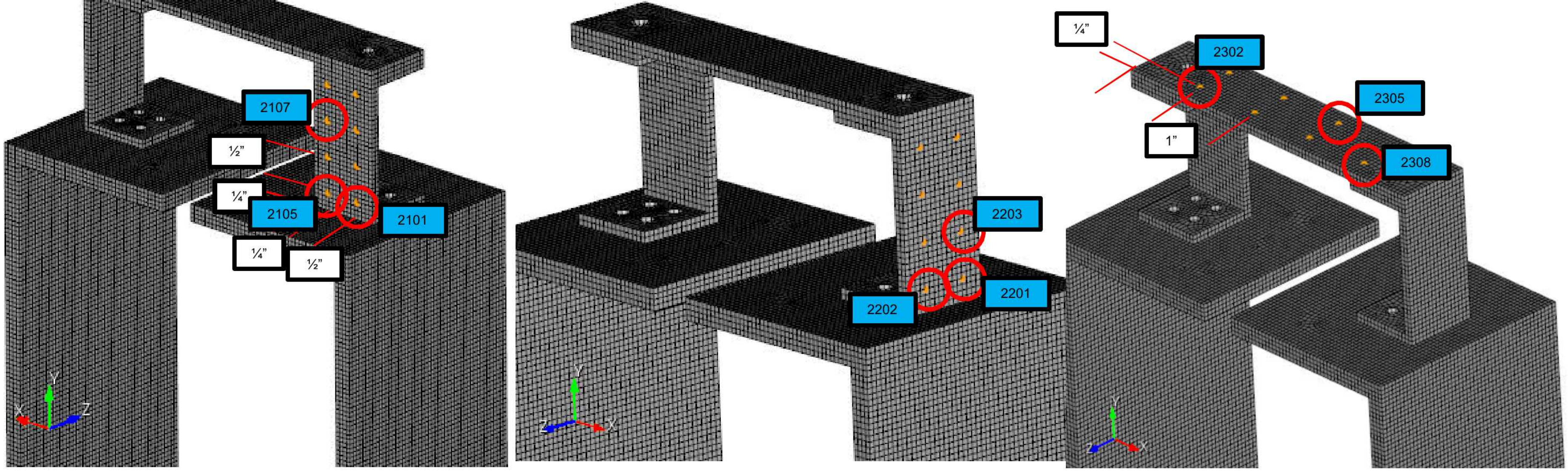
$$G_{qq} = T G_{xx} T^{*}$$

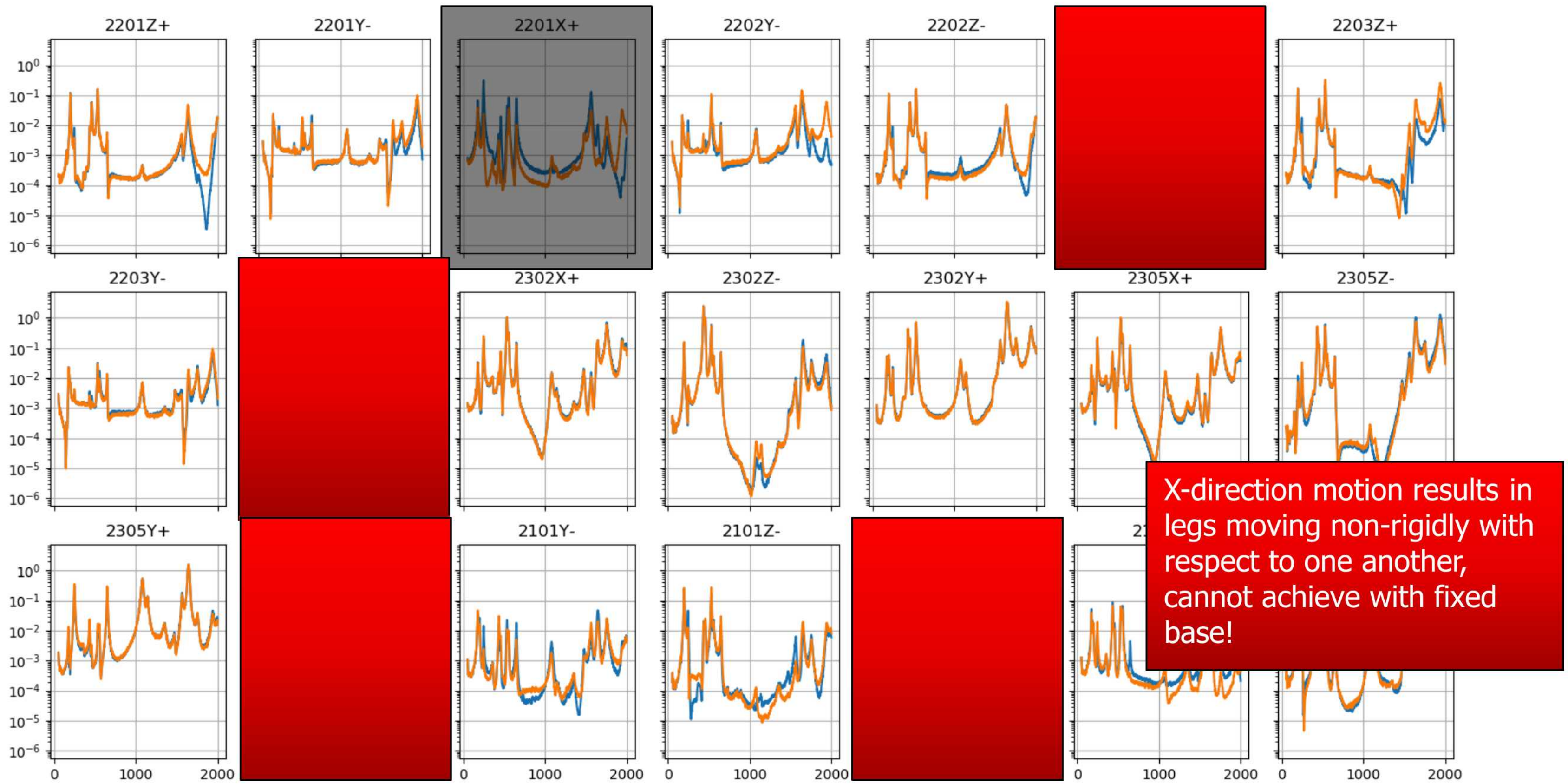
This specifies how to control each *mode* of the finite element model to achieve the closest response possible to the original spec.

Projecting the responses through the modal filter gives us a *best case response*, i.e. how well do the modes span the space of the test.



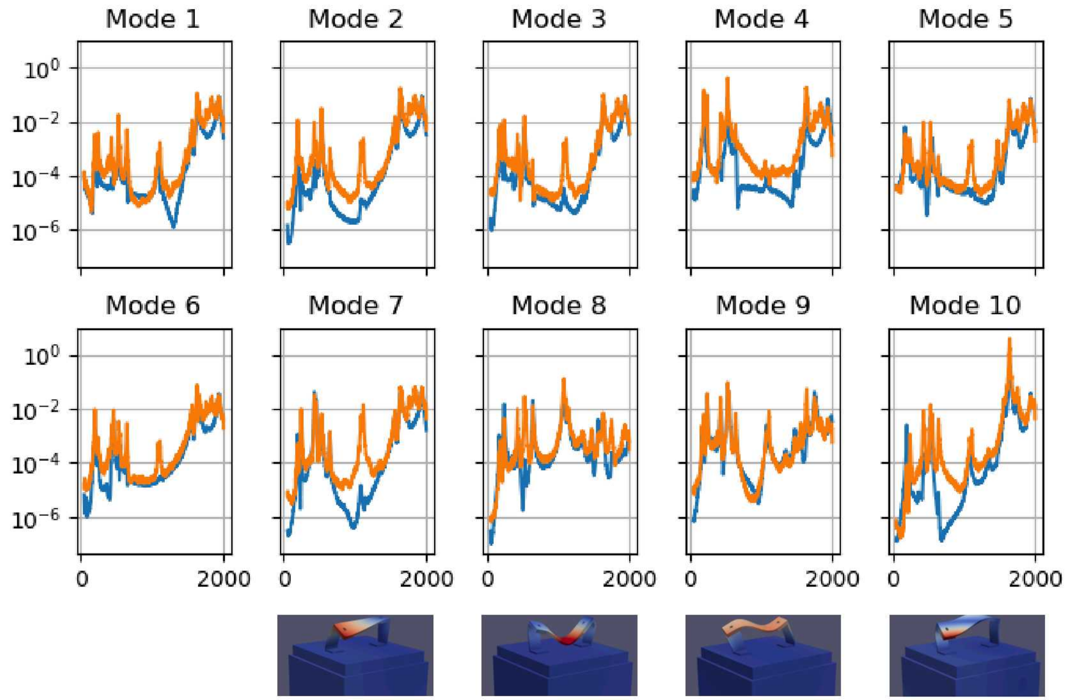



2107
½"
¼"
2105
2101
¼"
½"
2203
2201
2202
¼"
2302
2305
1"
2308


2201Z+
2201Y-
2201X+
2202Y-
2202Z-
2203Z+
2203Y-
2302X+
2302Z-
2302Y+
2305X+
2305Z-
2305Y+
2101Y-
2101Z-
X-direction motion results in legs moving non-rigidly with respect to one another, cannot achieve with fixed base!

Controlling to Modes

Use the same modal filter on the response degrees of freedom to compute each modal response and how it compares to the spec in the control system (implemented using the input transformation matrix in Jaguar)



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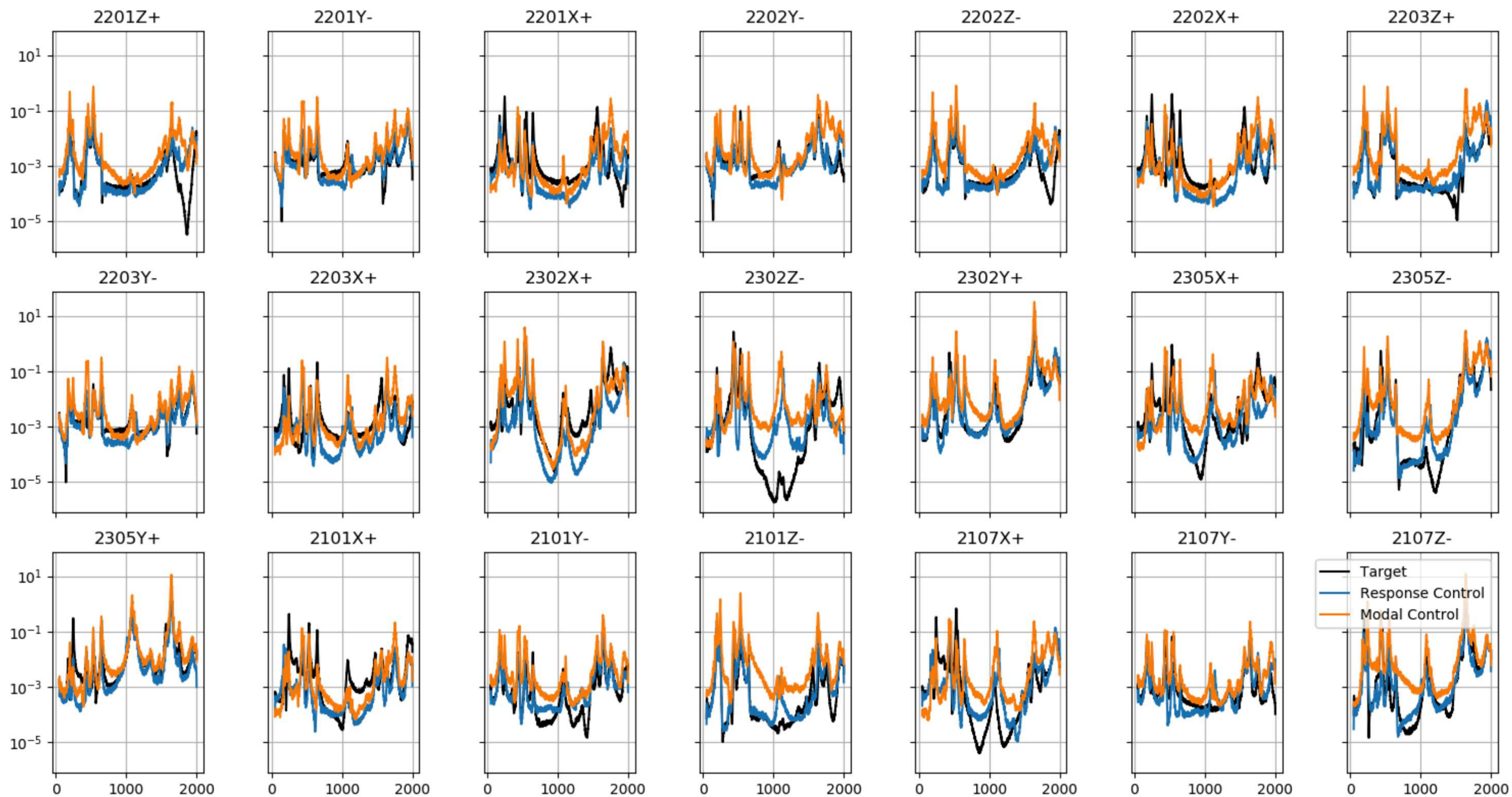
Comparison between Response and Modal Control

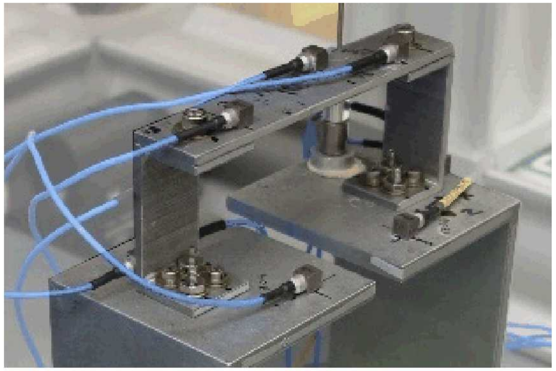


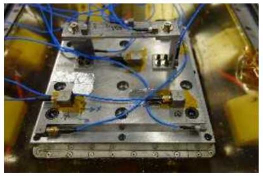
Conclusions

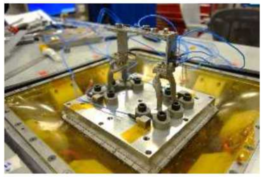
Rigid base control was not adequate to reproduce the responses from the service environment.

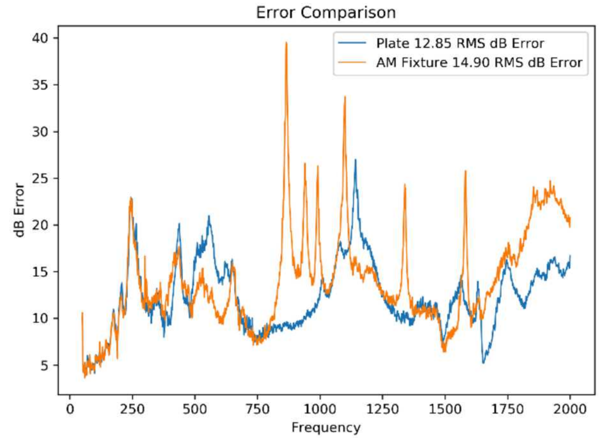
Need to be able to control both feet of the RC independently.

The topology-optimized fixture performed worse than the simple plate fixture; likely need to optimize on dynamic quantities rather than static deflections.









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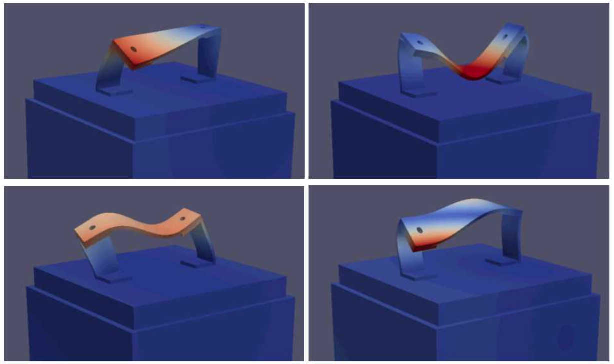
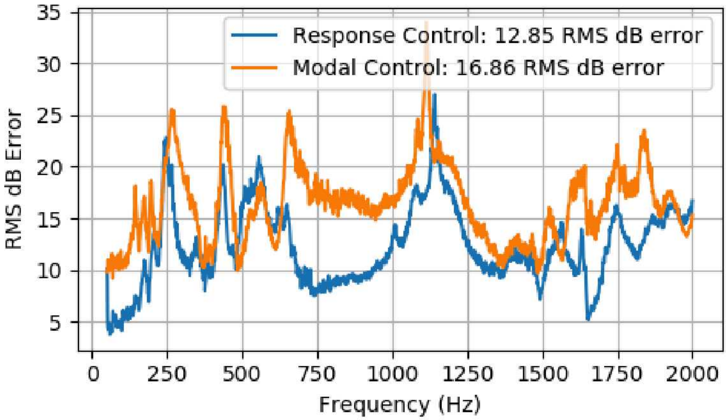
Conclusions

Modal control can be implemented in the Jaguar control system via the Input Transformation Matrix.

When controlling directly to modal quantities, if the modes do not span the space of the desired response, you are already out of luck.

Combined with finite element expansion, this may allow more flexible control strategies.





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