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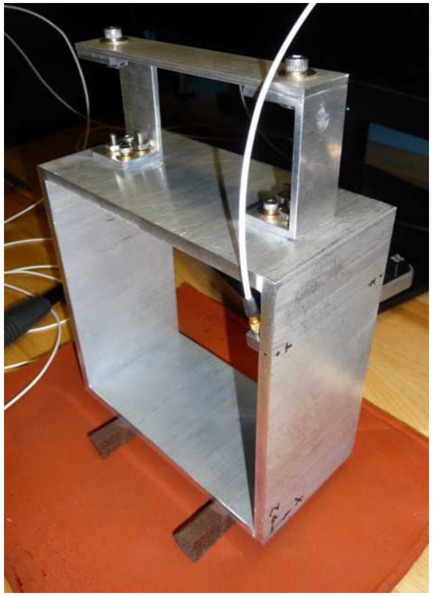

Comparison of Time-Domain Objective Functions in Dynamic Fixture Optimization

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Sandia National Laboratories

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Boundary Conditions in Environmental Testing Challenge Problem

PROBLEM STATEMENT

- Current practices for shock and vibration testing may result in incorrect damage exposures across assembly levels

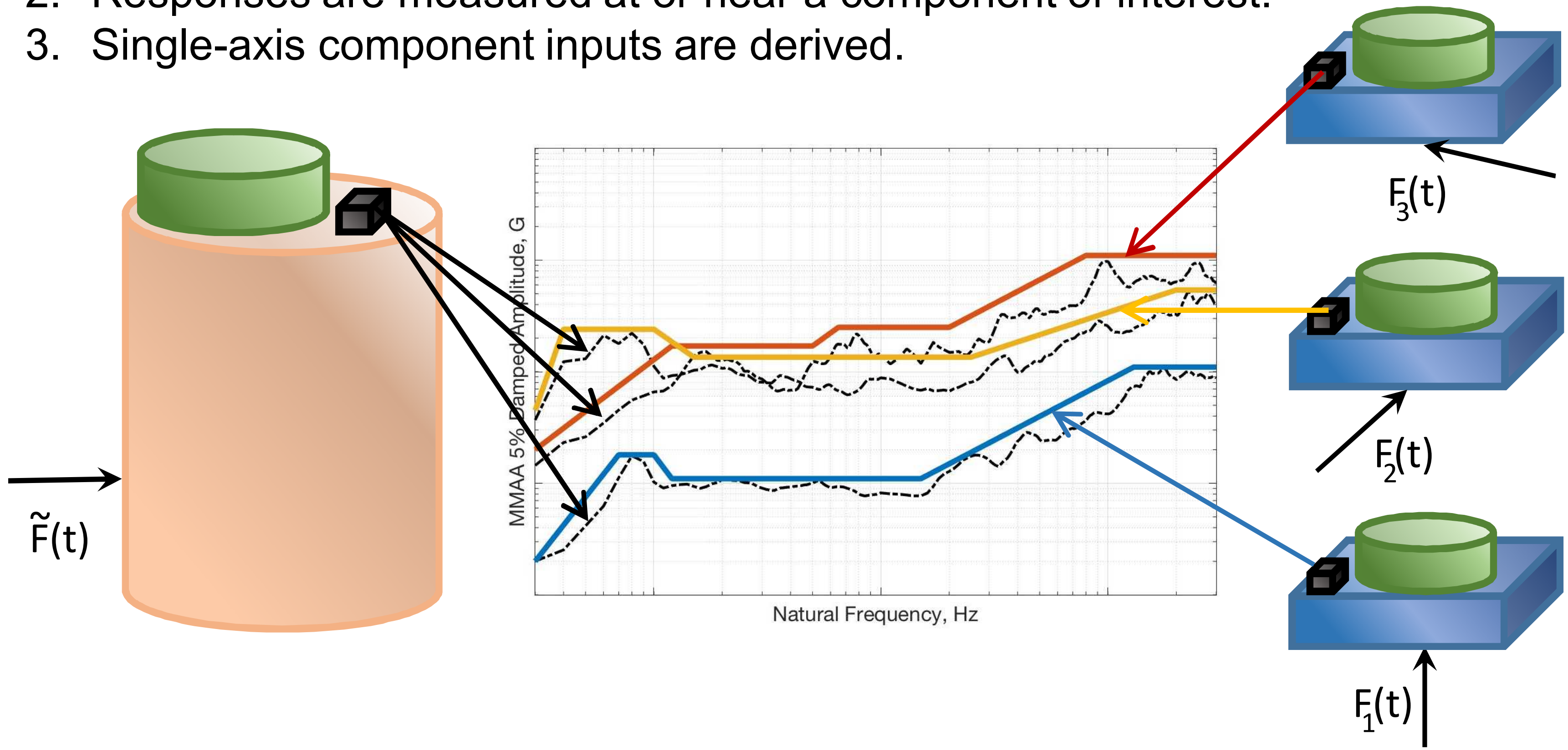
OBJECTIVE

- Design a component-level test setup that allows the component to undergo a similar environmental exposure as it experiences in the full assembly.
- The component test must be physically realizable, using fixtures and specifications that are compatible with existing software and test equipment.

What are current practices for deriving specifications down to lower levels of assembly, and how can we quantify the damage?

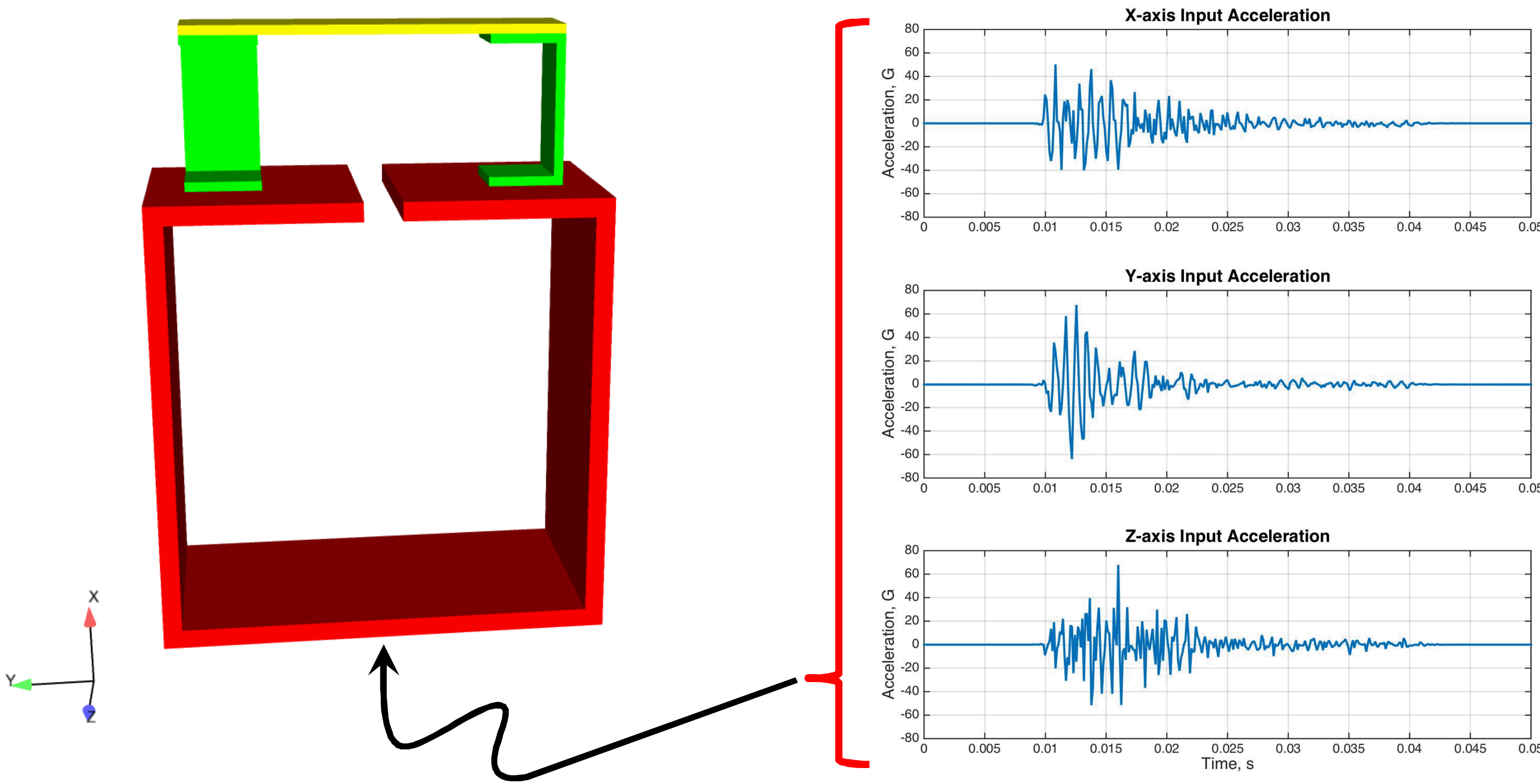
Simple Description of Deriving Test Specifications to Lower Assembly Level

1. An assembly experiences a field environment.
2. Responses are measured at or near a component of interest.
3. Single-axis component inputs are derived.



It is typically assumed that the manner of derivation of component-level inputs is a conservative characterization of the field environment.

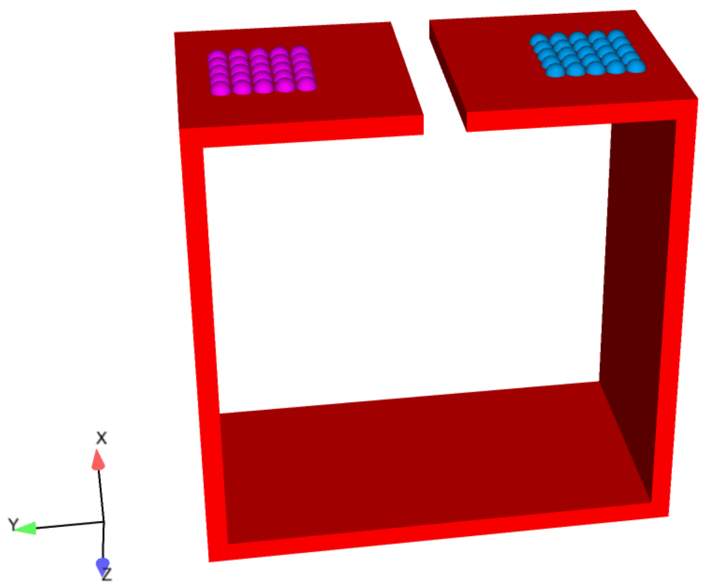
A Numerical Model was Used to Characterize BARCs Kinematic and Stress Responses

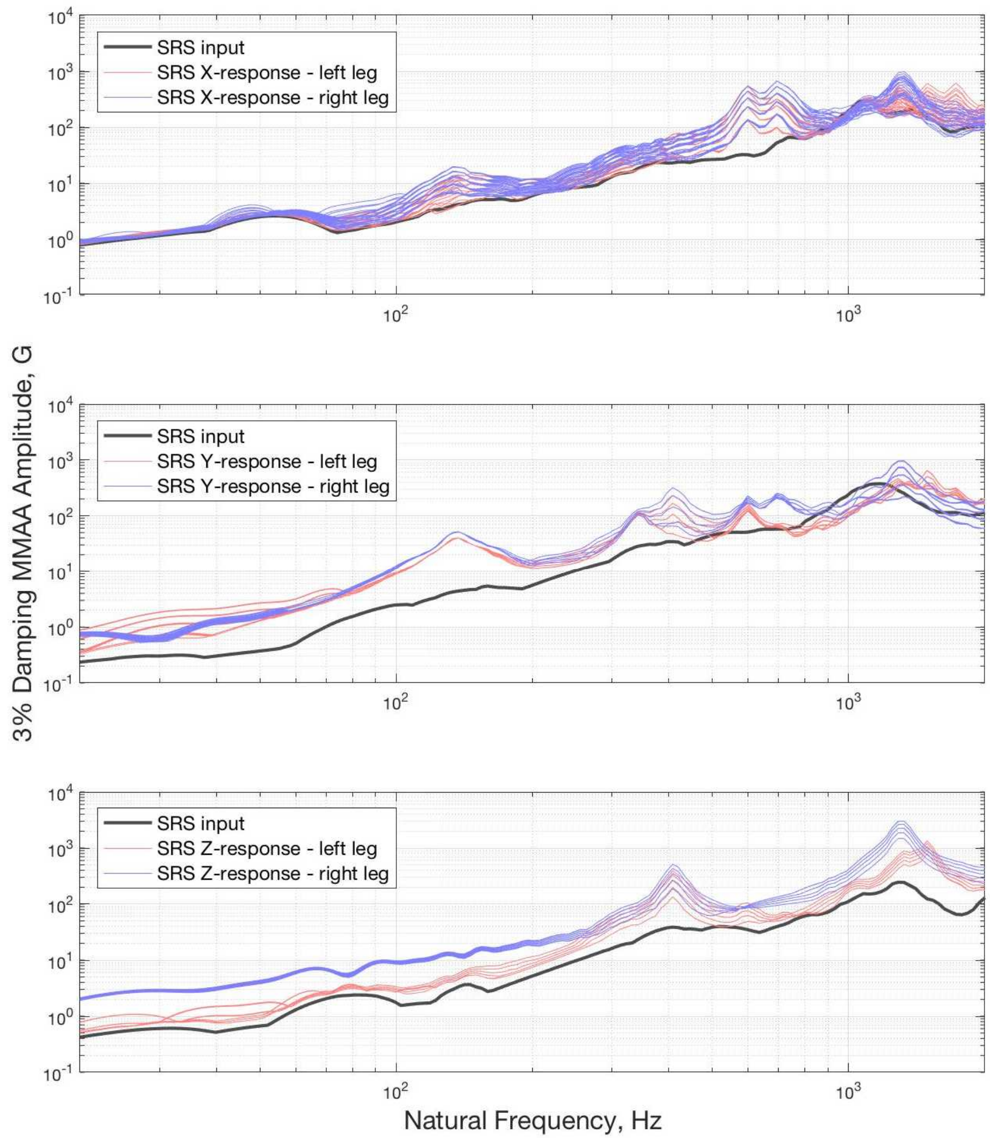


A 3-DOF (arbitrary) transient shock is used to excite the system. Acceleration responses across the component are predicted.

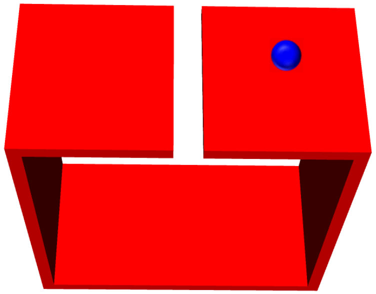
How Sensitive is Response SRS to Spatial Location?

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

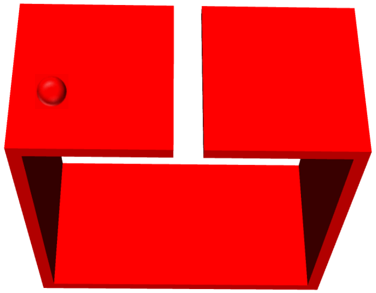




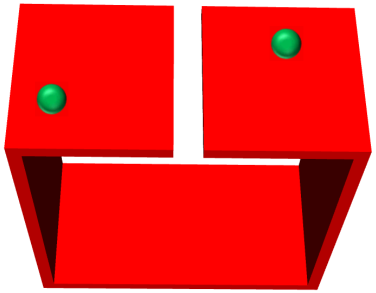
What are the Criteria We Should Employ to Select the Correct Component Inputs?



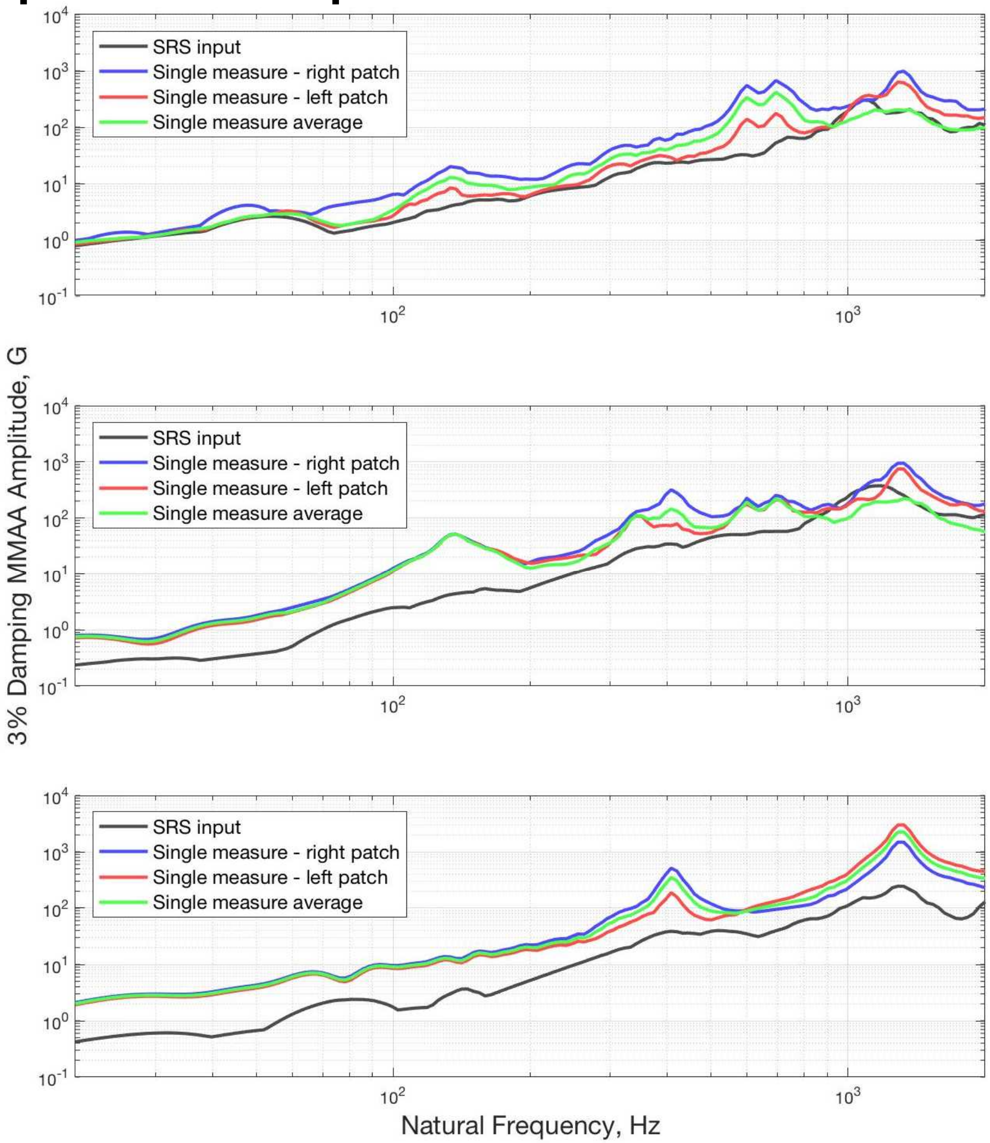
right load path



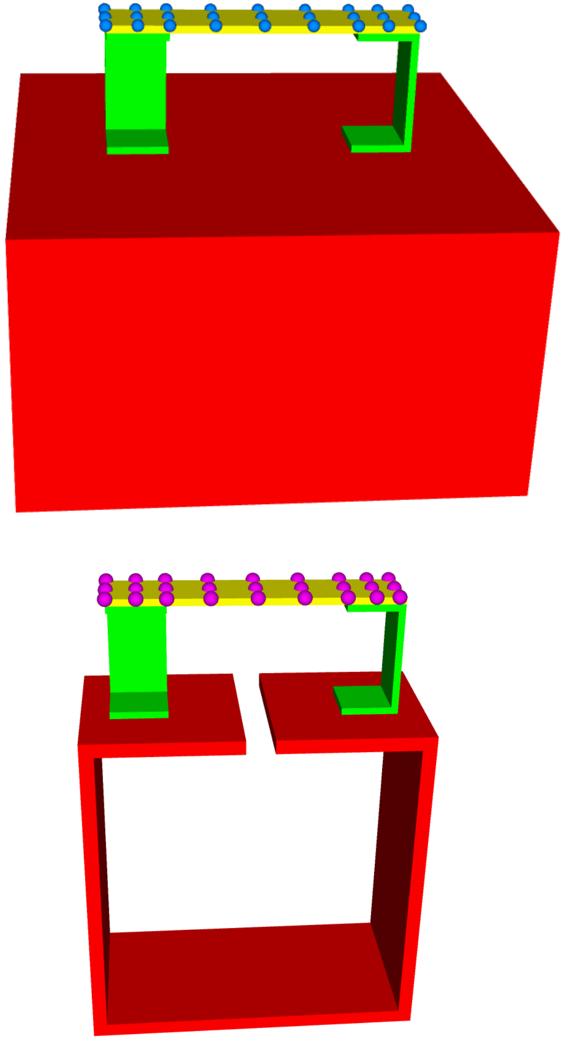
left load path

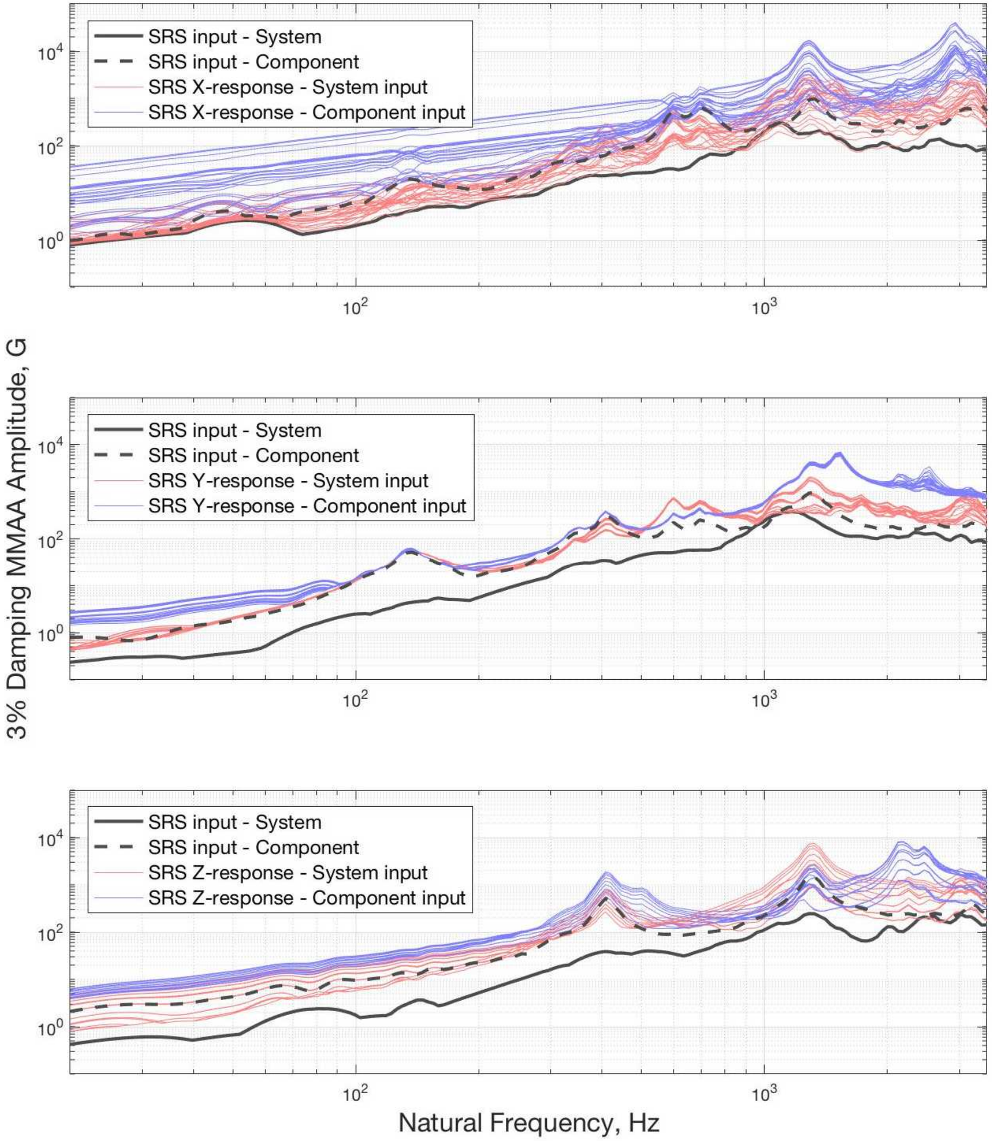


right and left mean



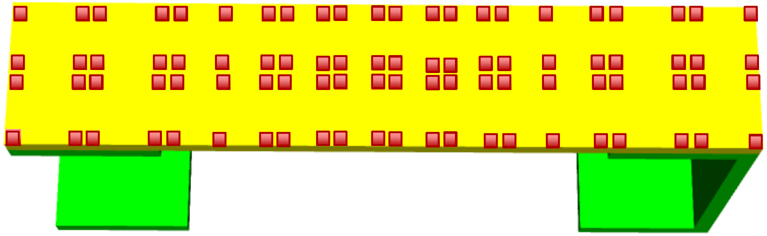
Different Dynamic Responses are Expected; How Relevant are These Differences?



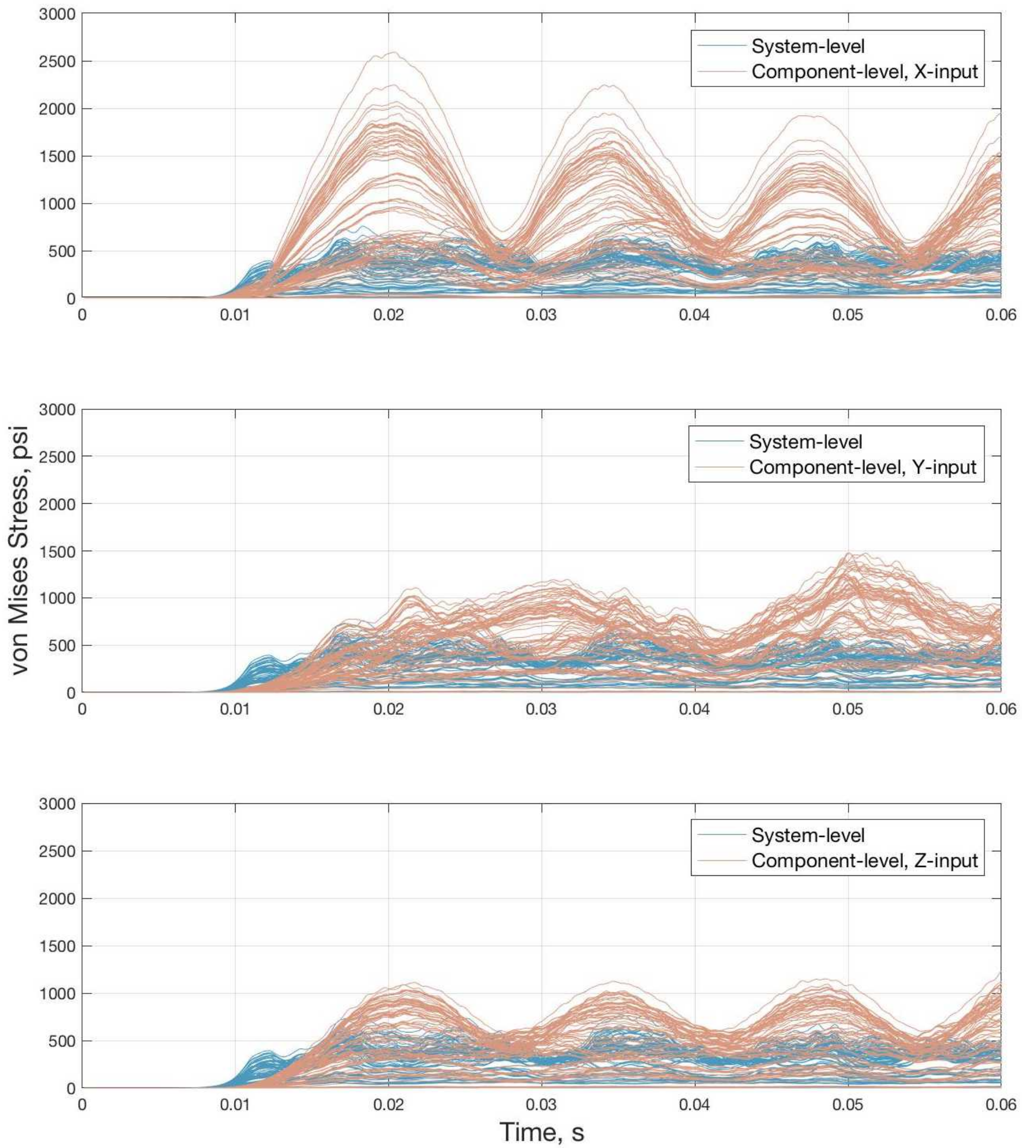


Let’s Look at Some Stress Measures

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

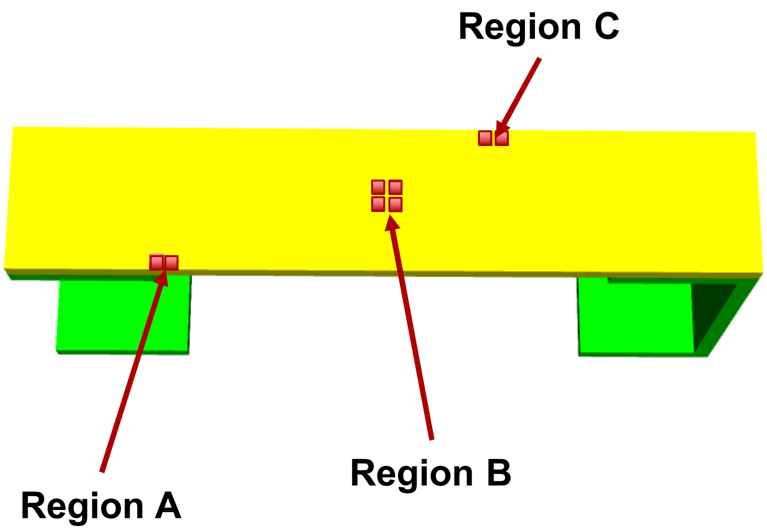


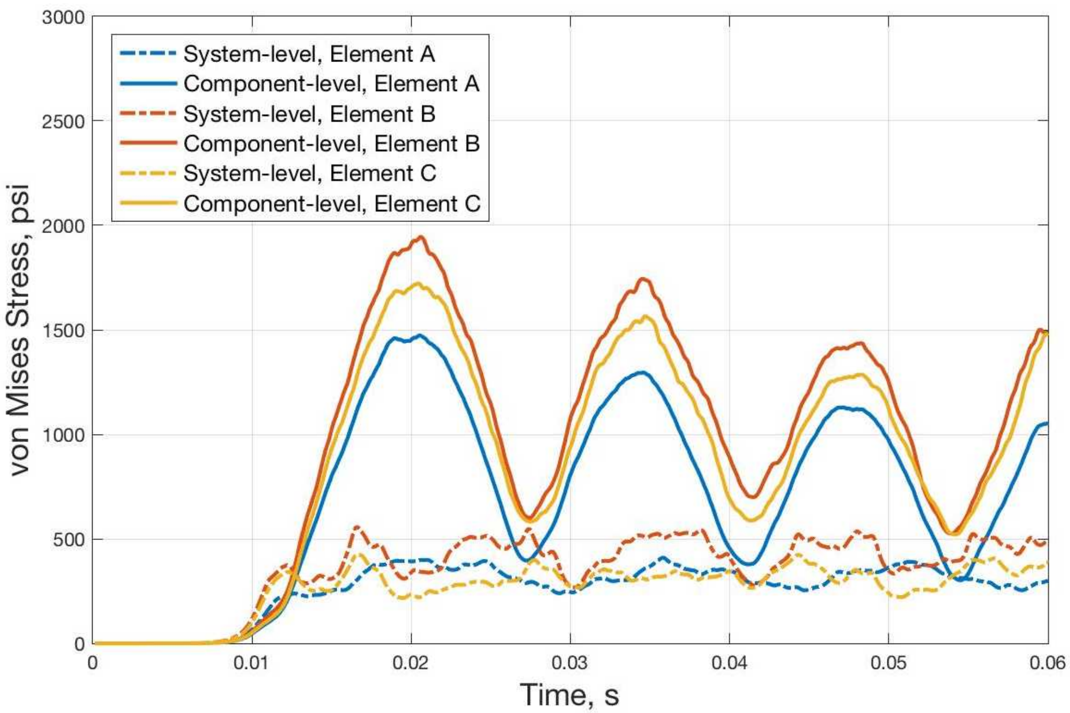
locations of predicted von Mises stress



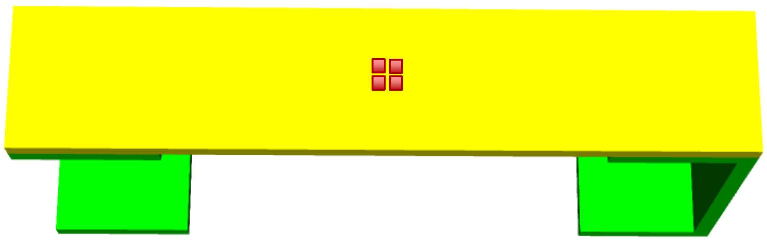
Let's Look at Some Stress Measures

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.

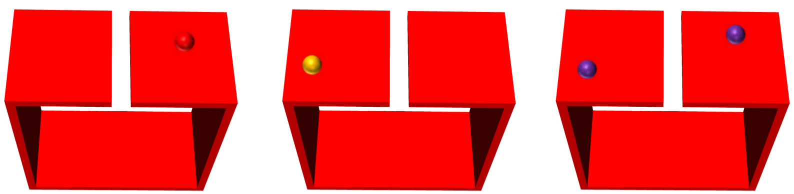




Local Stress States Predicted at Component-Level Differ Significantly from System-Level

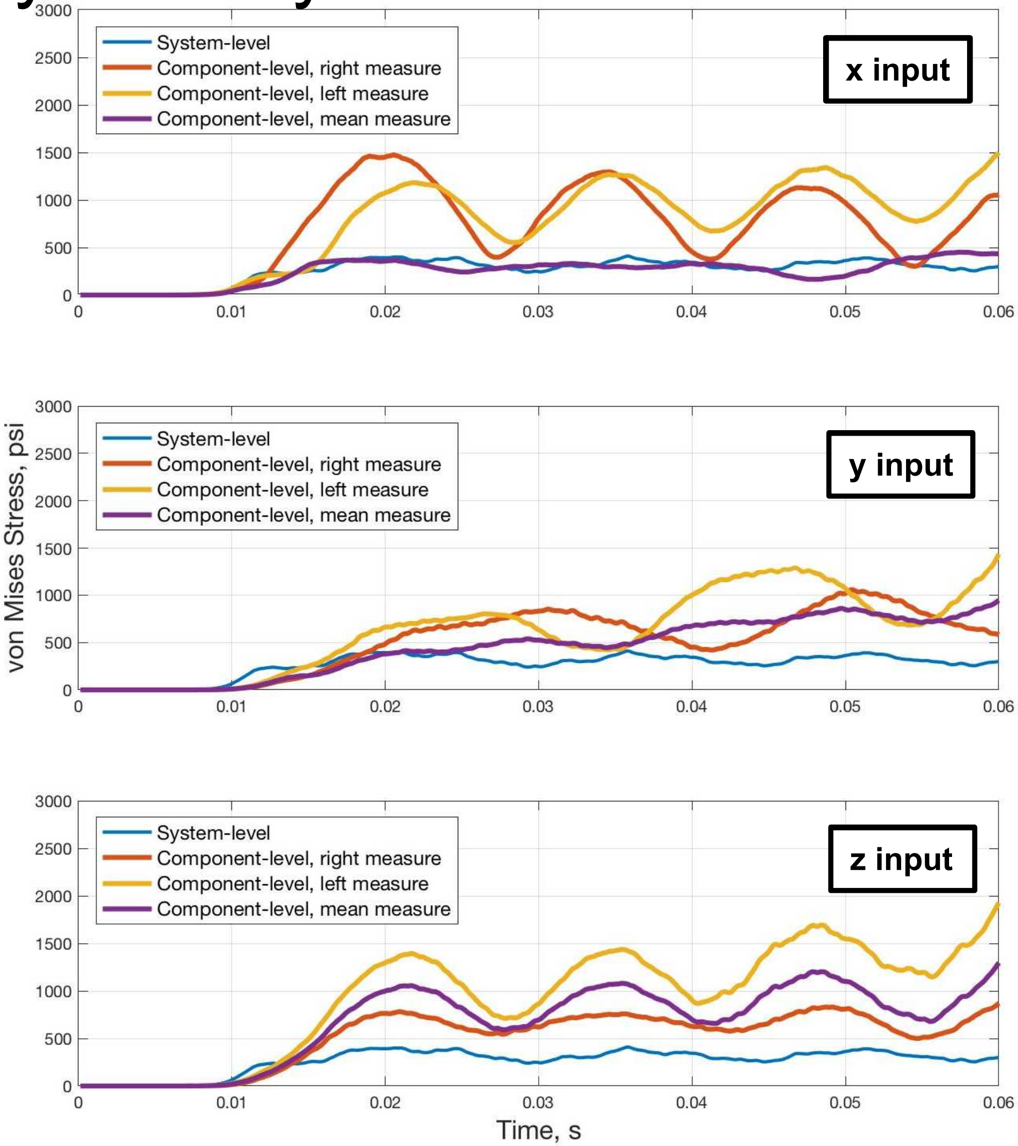


location of predicted von Mises stress



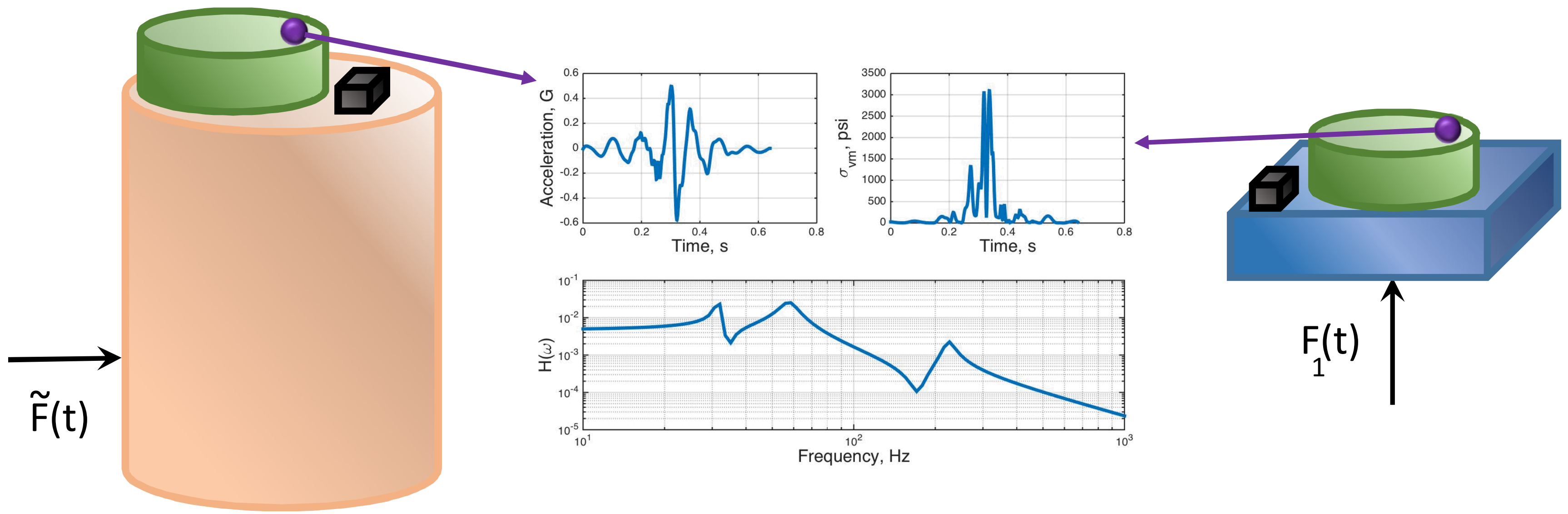
locations of derived component-level inputs

In general, predictions are conservative, but not necessarily guaranteed as such.



Boundary Conditions in Environmental Testing Challenge Problem

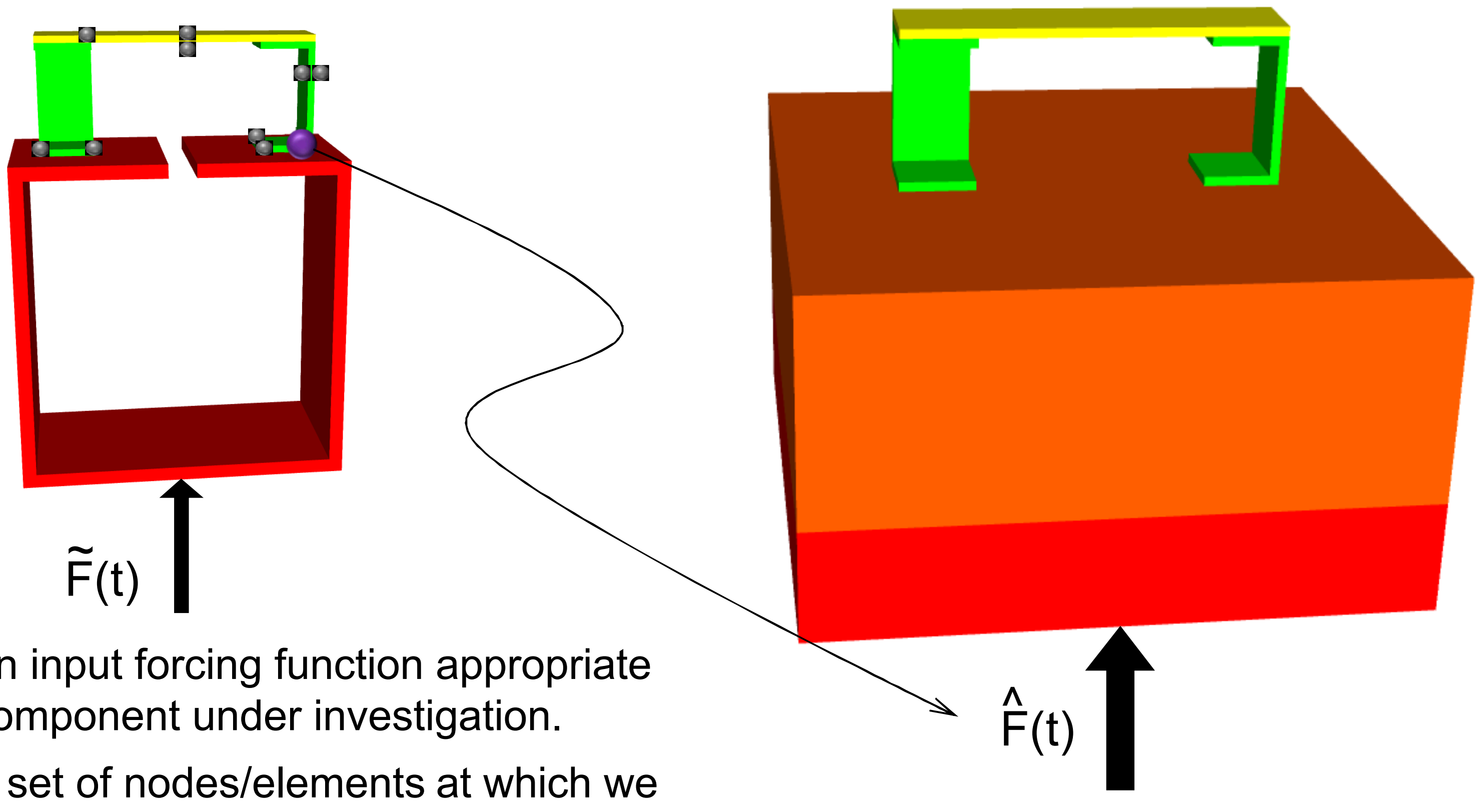
Preserve the "true" environment across all levels of exposure



Would like to try to accomplish this goal with fixed input, *i.e.* only through design/modifications to the component-level fixture.

Boundary Conditions in Environmental Testing Challenge Problem

Create "truth" data from the system-level geometry



- Define an input forcing function appropriate for the component under investigation.
- Define a set of nodes/elements at which we want to preserve the system-level truth state.

This solution approach can be pursued in time- and frequency-domains.

Boundary Conditions in Environmental Testing Challenge Problem

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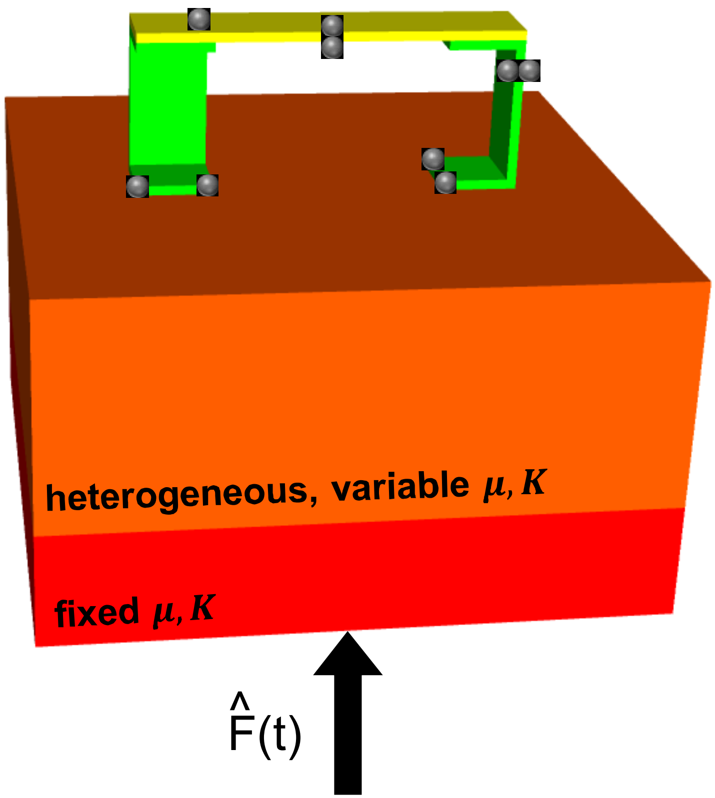
Create a Mechanical Filter By "Optimizing" the Component Fixture



- Build an objective function based on minimizing the difference in state throughout the time of the excitation.
- Given the known forcing function and discrete response set, solve the inverse problem for the mass and stiffness matrices of the discretized fixture (via bulk and shear modulus) that minimizes the objective function.

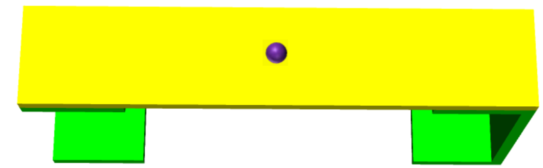
$$J(\{\boldsymbol{a}\},\{\boldsymbol{p}\}) = \frac{\kappa}{2}(\{\boldsymbol{a}\}-\{\boldsymbol{a}_m\})^T[Q](\{\boldsymbol{a}\}-\{\boldsymbol{a}_m\}) - \Re(\{\boldsymbol{p}\})$$

$$\underset{\{\boldsymbol{p}\}}{\text{minimize}}\,\tilde{J}(\{\boldsymbol{p}\}) \text{ subject to } g_i(\{\boldsymbol{p}\}) \le 0, i = 1 \dots n$$

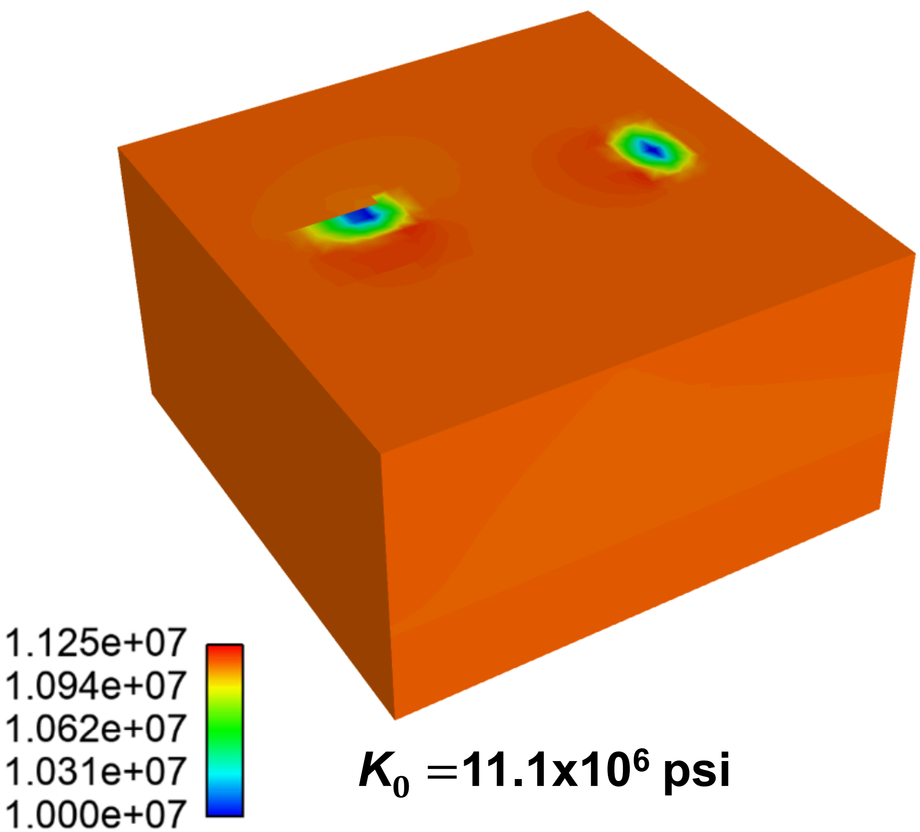
$$[M(\{\boldsymbol{p}\})]\boldsymbol{a}_{k+1} + [C(\{\boldsymbol{p}\})]\boldsymbol{v}_{k+1} + [K(\{\boldsymbol{p}\})]\boldsymbol{u}_{k+1} = f_{k+1}$$

Explore the sensitivity (and admissibility) of solution to changes in the objective function.

Predictions of Optimized Fixture For Single-Node Objective Function: X-input

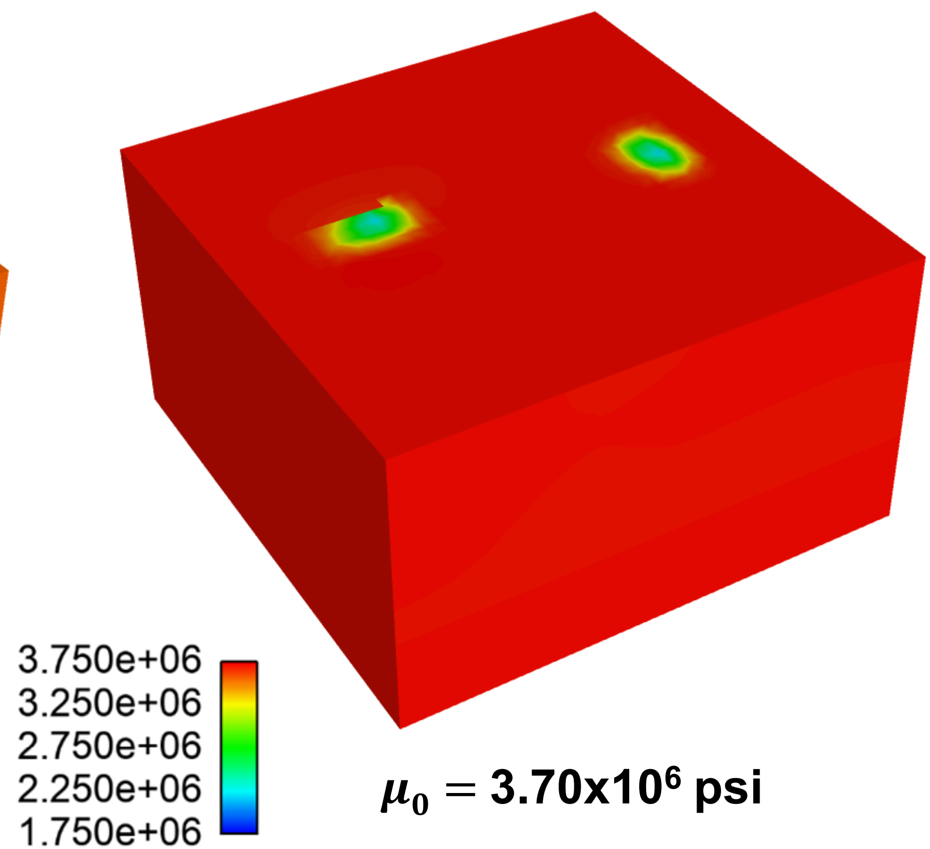


Bulk Modulus



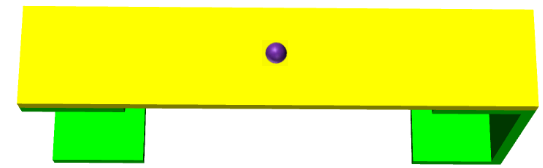
$K_0 = 11.1 \times 10^6$ psi

Shear Modulus

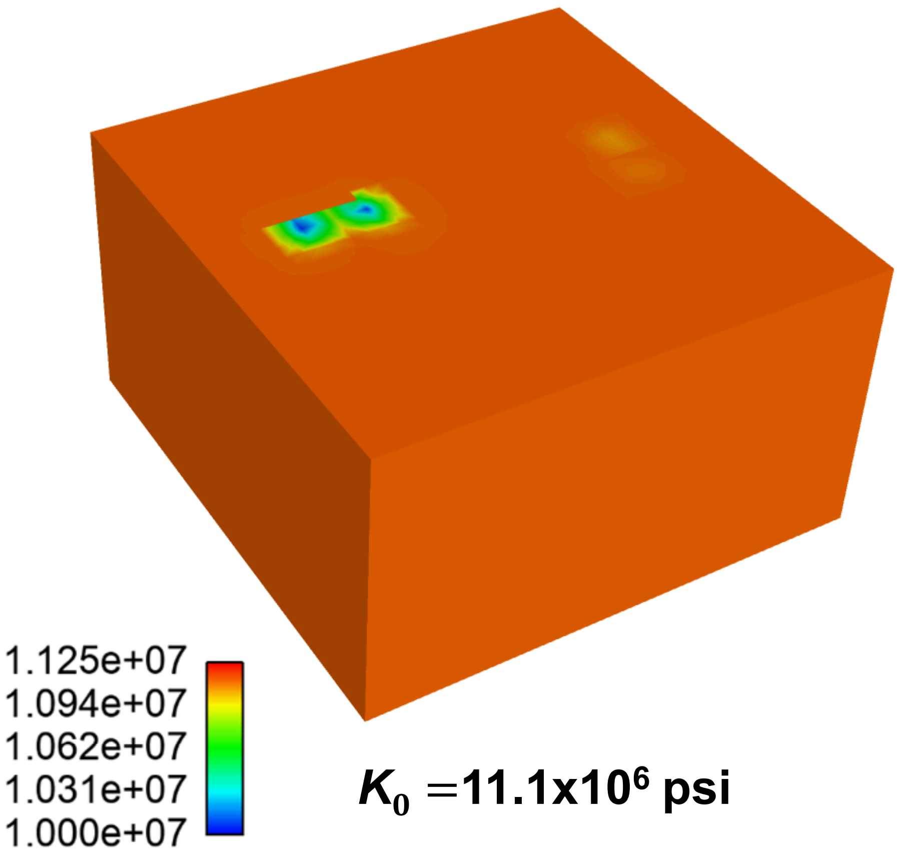


$\mu_0 = 3.70 \times 10^6$ psi

Predictions of Optimized Fixture For Single-Node Objective Function: Y-input

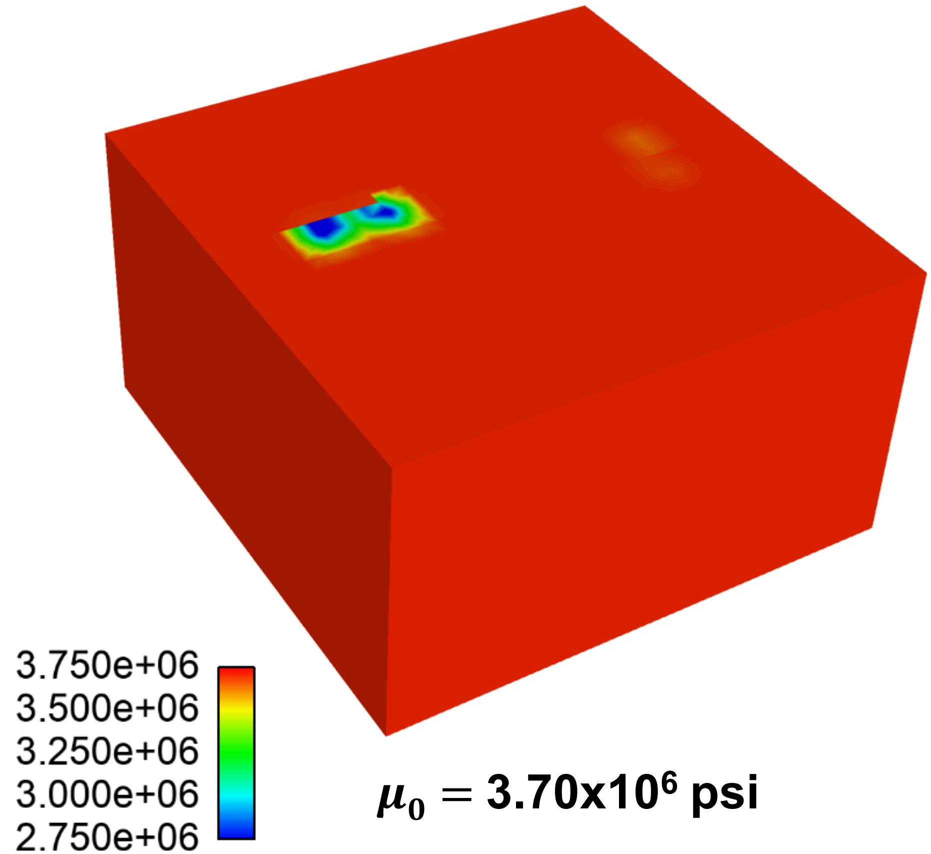


Bulk Modulus



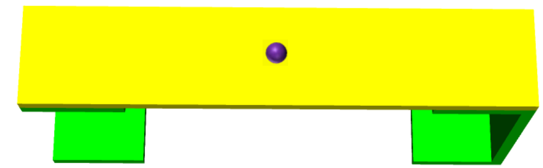
$K_0 =$ **11.1x10^6 psi**

Shear Modulus

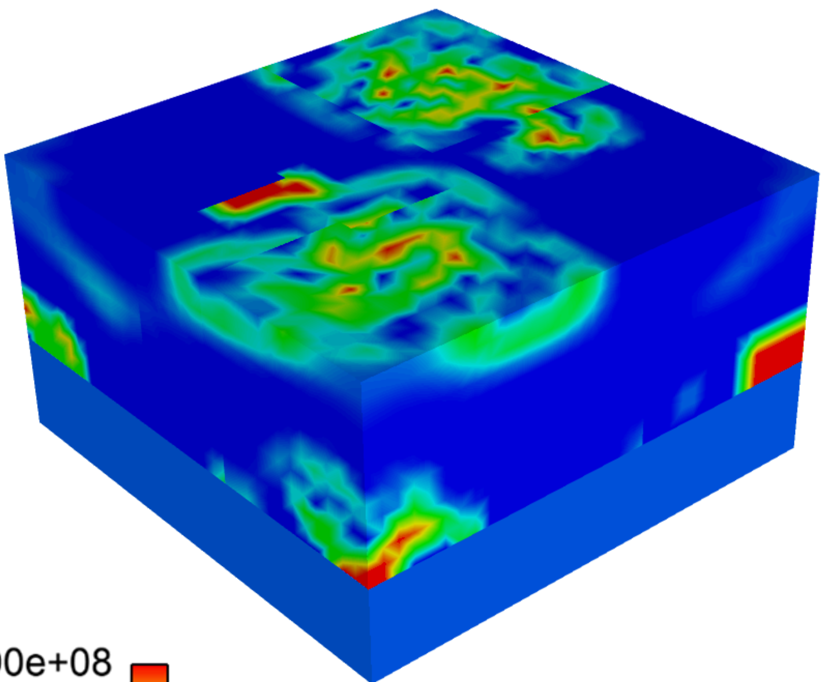


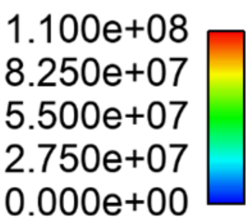
$\mu_0 =$ **3.70x10^6 psi**

Predictions of Optimized Fixture For Single-Node Objective Function: Z-input



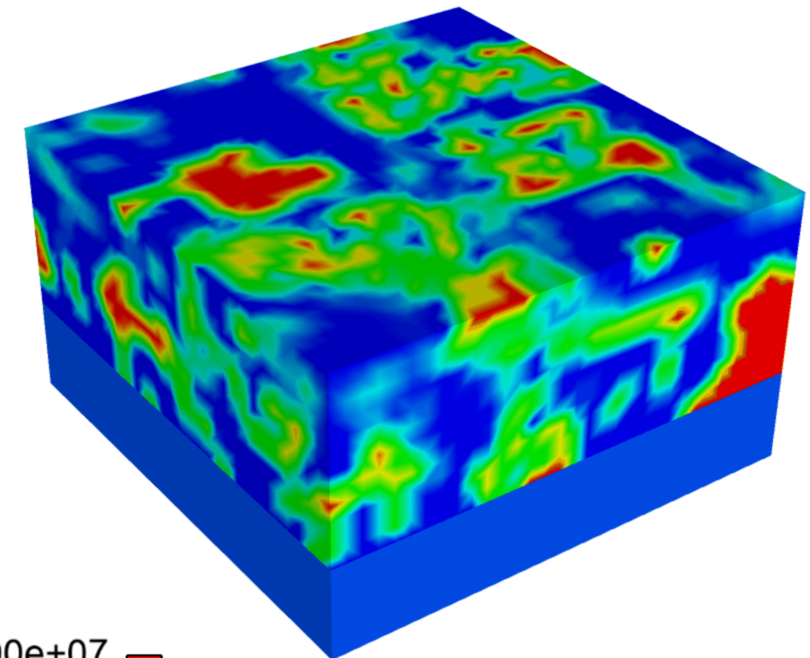
Bulk Modulus

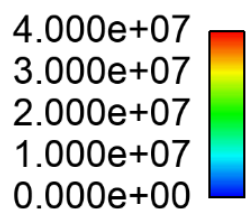




K_0 = **11.1x10^6 psi**

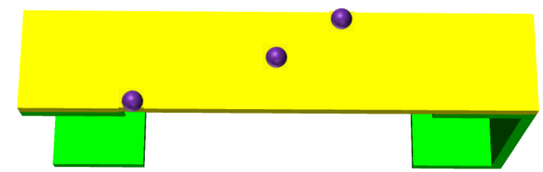
Shear Modulus



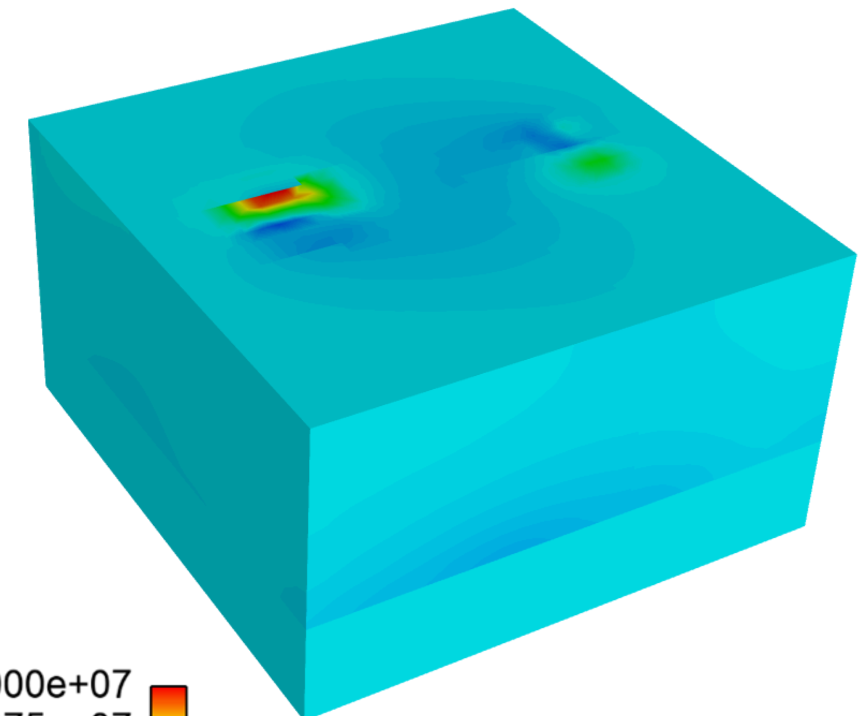


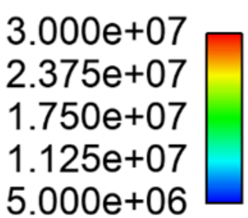
μ_0 = **3.70x10^6 psi**

Predictions of Optimized Fixture For Multi-Node Objective Function: X-input



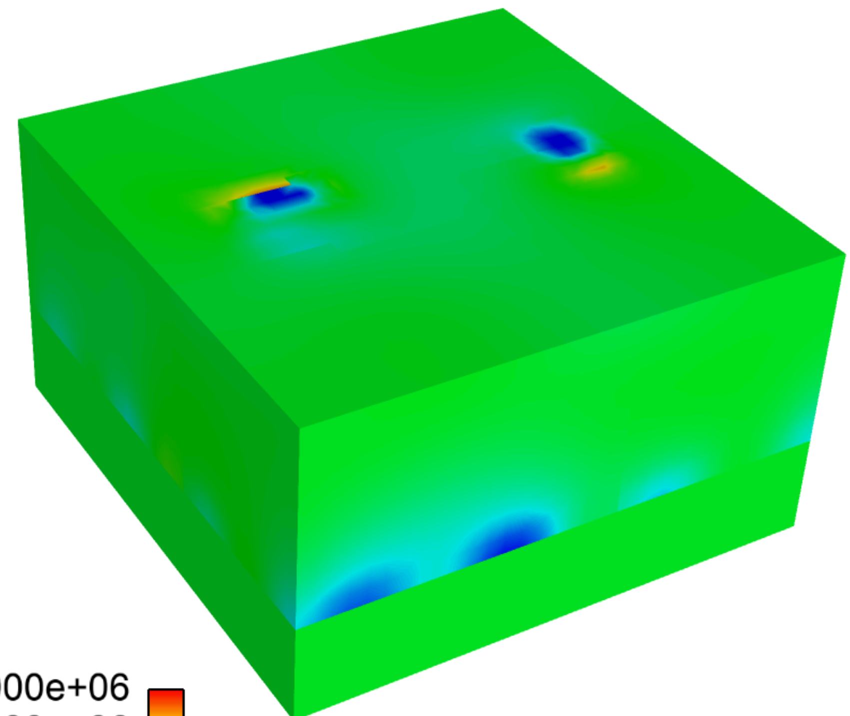
Bulk Modulus

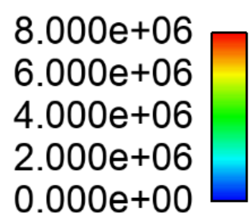




$K_0 = 11.1\text{x}10^6$ **psi**

Shear Modulus

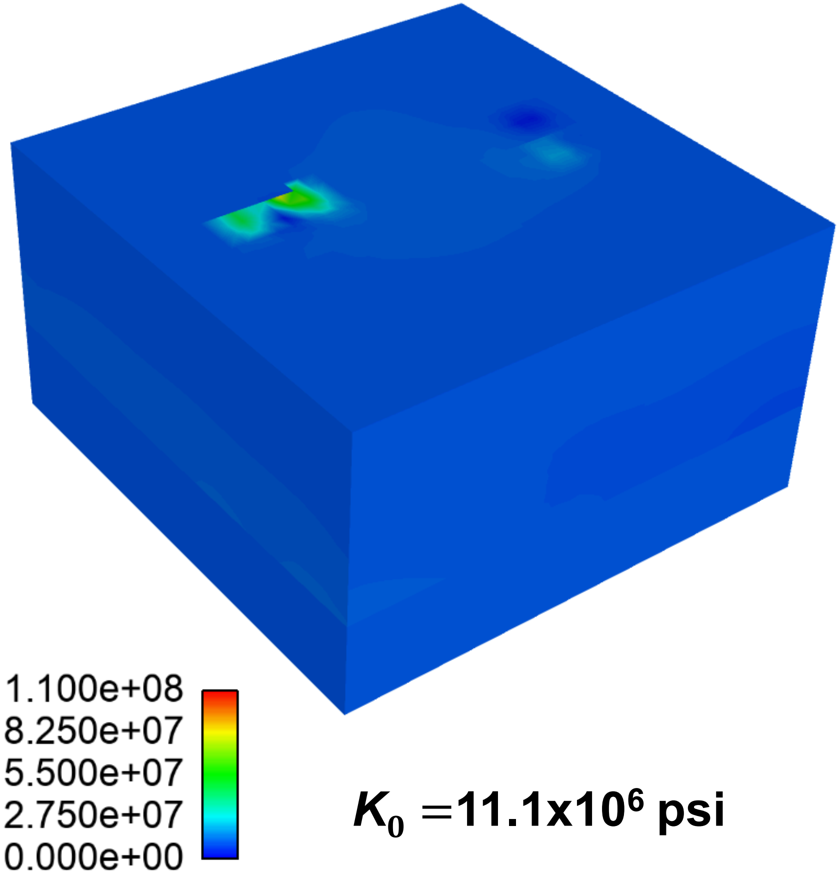




$\mu_0 = 3.70\text{x}10^6$ **psi**

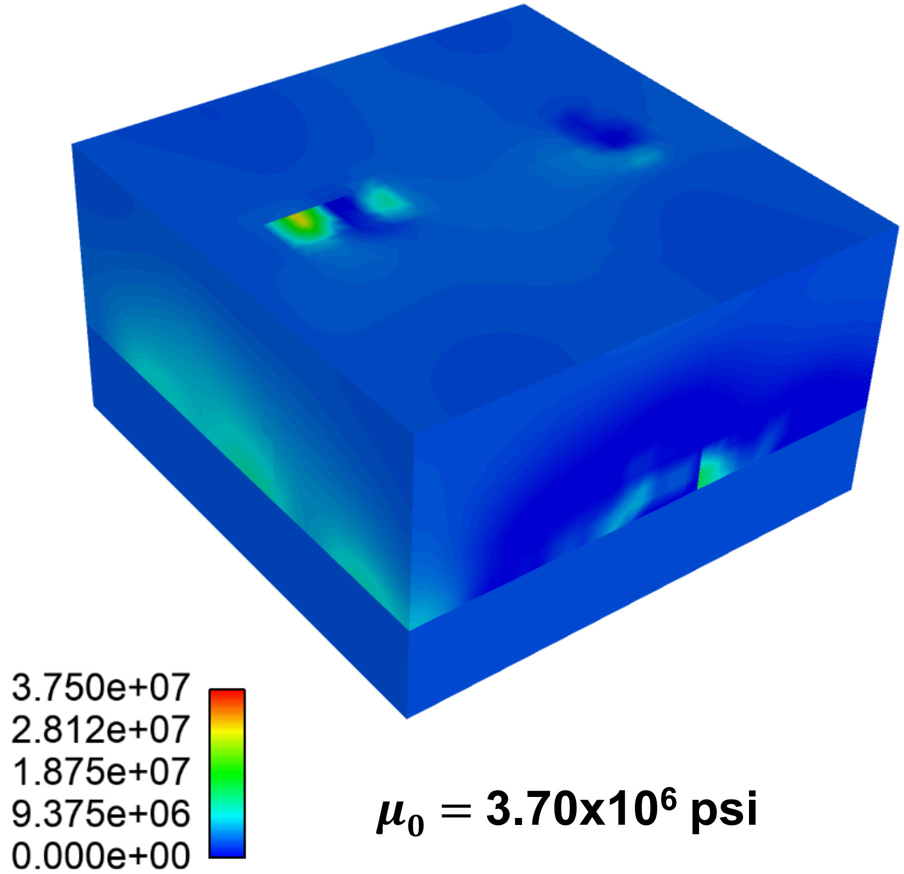
Predictions of Optimized Fixture For Single-Node, Multi-DOF Objective: All axis input

Bulk Modulus



$K_0 = 11.1 \times 10^6$ **psi**

Shear Modulus



$\mu_0 = 3.70 \times 10^6$ **psi**

Manner of Convergence Depends Sensitively on Objective Function

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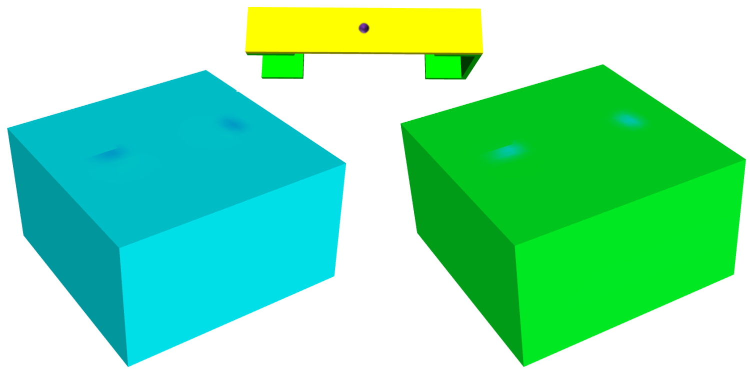
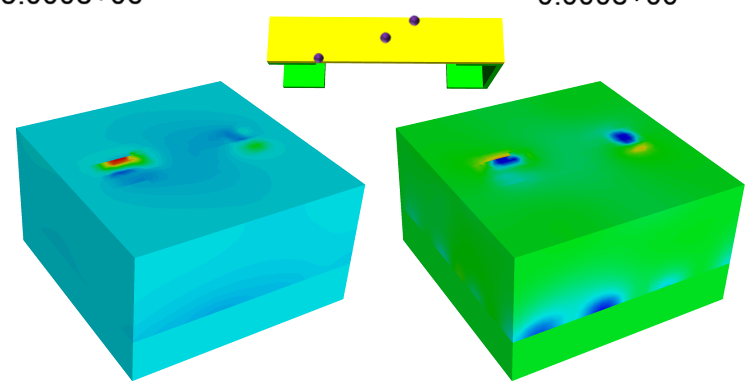
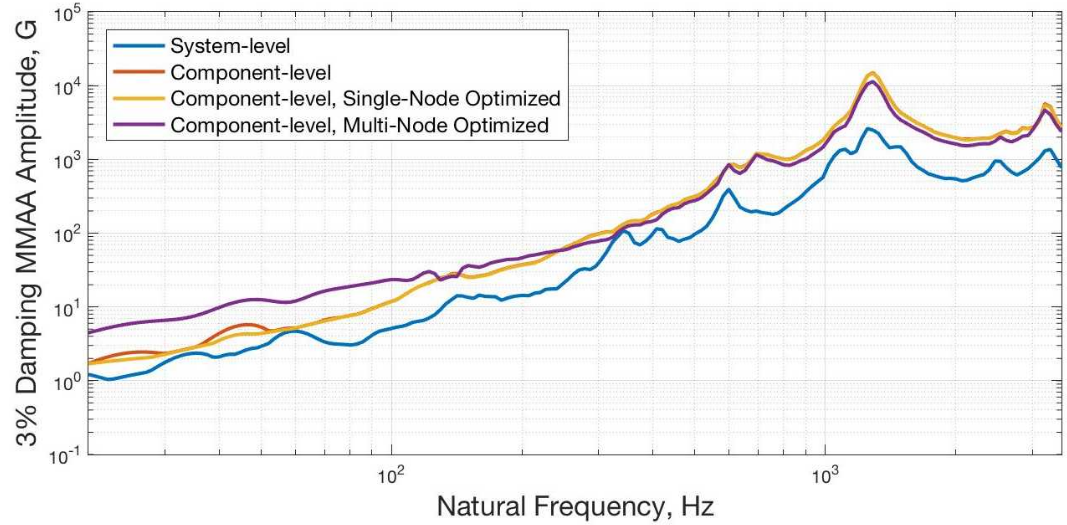
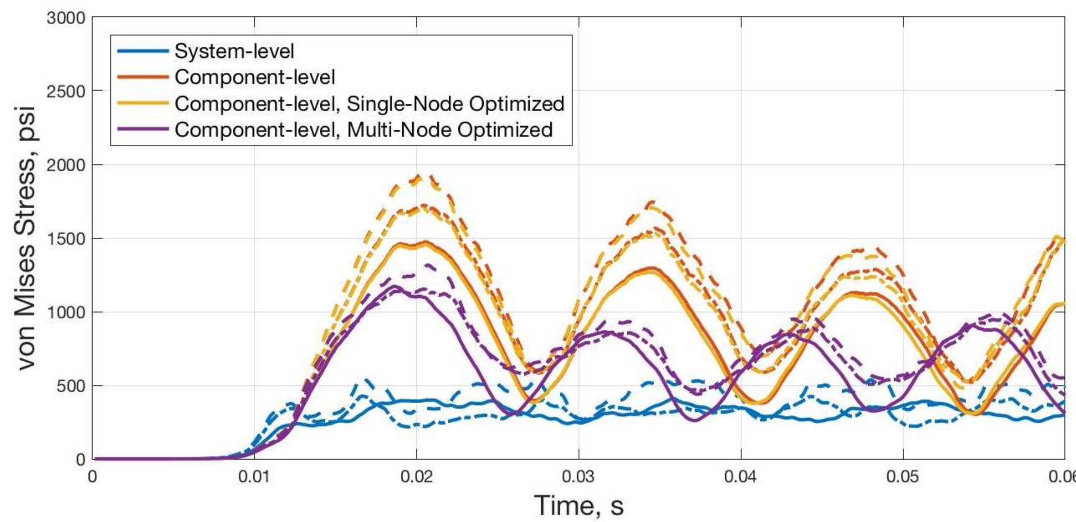


single-node optimization



multi-node optimization





Discussion

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- The solution set, ***p***, is likely to have sensitive dependence on the input environments, so a unique fixture will be required for each unique input environment.
- Since the solution converges only in the least squares minimization sense, there can be no expectation that the complicated field state can be reproduced closely enough to exercise the correct fatigue and damage mechanisms.
- The practical matters of actually developing a test fixture that matches the theoretical distribution of material parameters have been ignored. Even if it were possible to do so using additive manufacturing or some other technique, a single fixture might not be adequate.
    - More on this next

Discussion

- Although acceleration is a common variable of interest for comparisons of environments and responses, stress is a more natural variable when attempting to quantify fatigue, damage, consumed lifetime, or margin.
  - The use of a stress-based objective function could be more appropriate for this type of optimization exercise.
  - Such an objective function could also alleviate some of the concerns of matching the full-field kinematics.
  - If certain regions are known, *a priori*, to be the primary locations of first failure, then satisfying the stress-state locally in those areas without regard to matching globally might be adequate (provided no induced stress states elsewhere shift where first failure occurs.)