SAND2019-0353C

Flight Environments Demonstrator: Part III – Sensitivity of Expansion to Model Accuracy

PRESENTED BY

Deborah Fowler

Co-Authors: Ryan Schultz, Brandon Zwink, Brian Owens

Motivation/Summary of Parts I and II

It is difficult to develop representative laboratory tests for structures tested in field environments
Many assumptions are utilized to estimate non-instrumented component dynamics, and better tools and techniques are needed to estimate the dynamics of structures in field environments

Flight Environments Demonstrator: Part I – Experiment Design & Test Planning
Considered design of the flight experiment and associated test planning, including hardware design, assessment of hardware under flight environments, instrumentation planning, and data acquisition challenges.

Flight Environments Demonstrator: Part II – Ground Trials of a Sounding Rocket Experiment for Characterization of Flight
Discussed ground test trials of the demonstrator experiment and assessment of the method with flight data.

Flight Environments Demonstrator: Part III – Sensitivity of Expansion to Model Accuracy
Part III will examine full field expansion and sensitivity of methods to model accuracy and acceptable model uncertainties/perturbations.

Theory

SEREP: System Equivalent Reduction Expansion Process

The transformation matrix is calculated using the finite element model's mode shapes

$$[T] = [U_n][U_a]^g$$

It can be used to expand mode shapes and time histories to full field
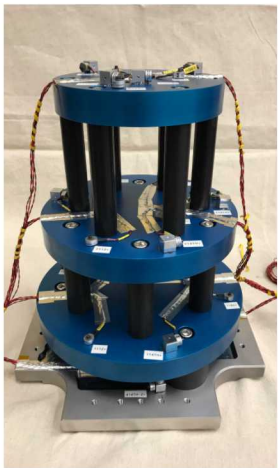
$$[E_n] = [T][E_a]$$

$$[x_n] = [T][x_a]$$

a = active degrees of freedom (measurement points)

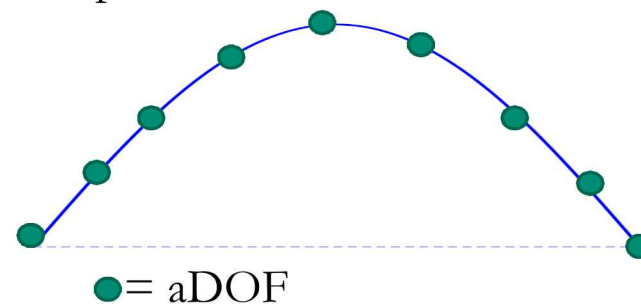n = all degrees of freedom in FE model
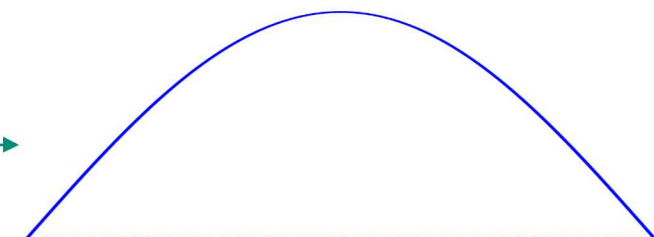
g = generalized inverse

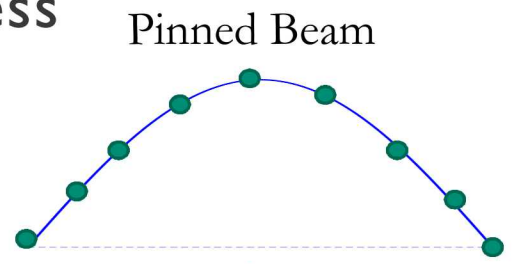U=FE model mode shape matrix

E=experimental mode shape matrix

Sparse Measurement Points

● = aDOF

Full Field Response

SEREP Expansion Process

Pinned Beam

● = aDOF

Physical Space Mode Shape at aDOF

Transformed to modal space of free-free beam using $[U_a]^g$

0.8282 + 0.0058 + 0.5604 + 0.000 + 0.0079

Projection of physical
test mode shape into
free-free beam FE
modal space

Transformed to full physical space using $[U_n]$

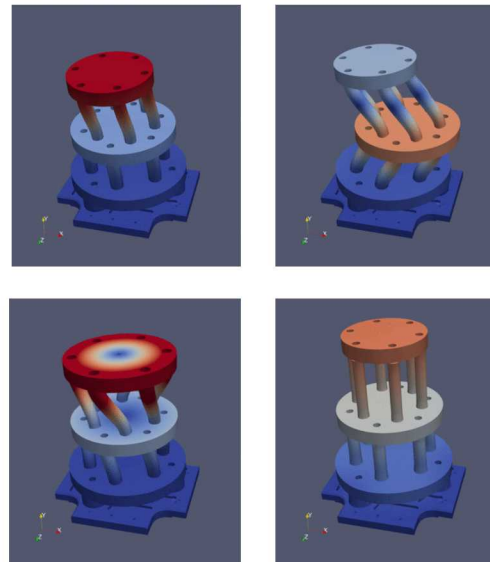Full-field mode shape of pinned beam

Implicit Coordinate Transformation

Test Coordinate system:
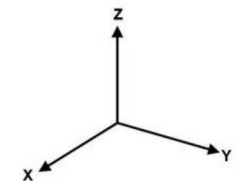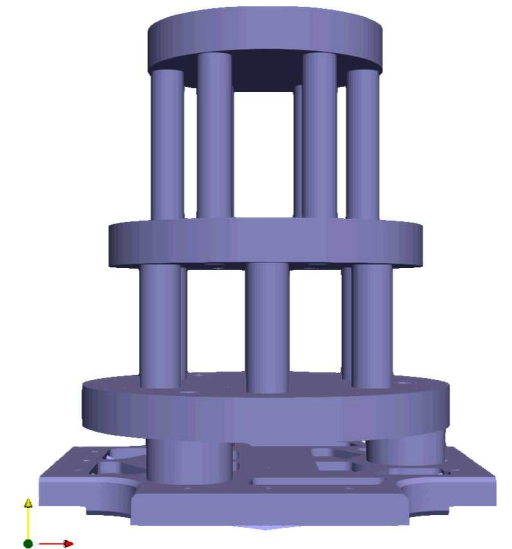Combination of cylindrical and local rectangular points

Cylindrical R,θ,Z

FE modal space:
- Only need the FE nodes that correspond to test points to match the test CS to transform data modal space
- Represented by a combination of FE model modes

$$\sum$$

Finite Element Coordinate System:
Global Cartesian
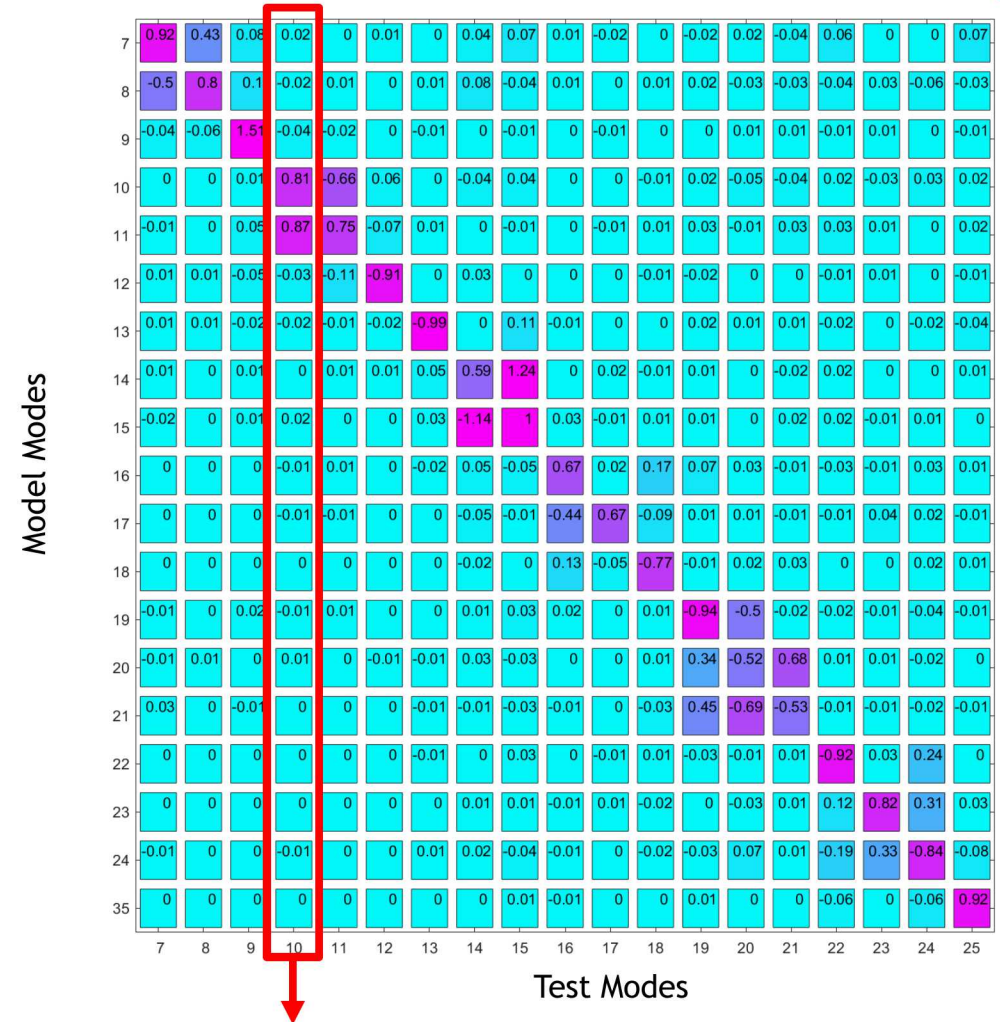Expanded results match the FE

Cartesian X,Y,Z

The U_{12} matrix

From structural dynamic modification, the U_{12} matrix contains the scaling coefficients needed to form the FE model's modes from the experimentally measured modes

$$[U_{12}] = [U_1]^g [U_2]$$

For this application, the U_{12} matrix is the first part of the SEREP process - transformation into modal space using FE mode shapes

$$[U_{12}] = [U_a]^g [E_a]$$

It is used to identify which modes need to be included in the transformation matrix
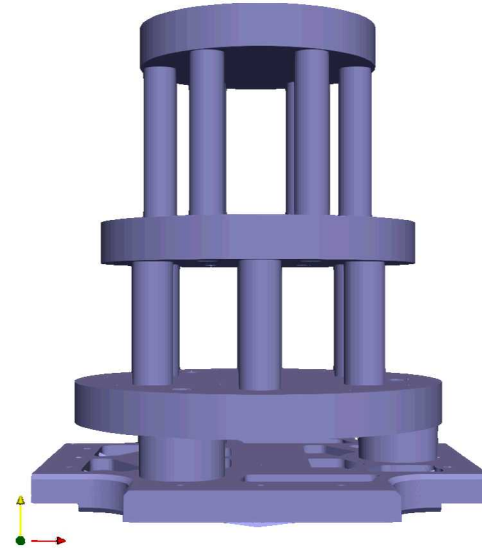

Test Mode 10≈0.81xFE Mode 10+0.87xFE Mode 11…

Wedding cake model and test setup

Three disks of aluminum connected by columns of abs plastic, mounted on a steel base plate

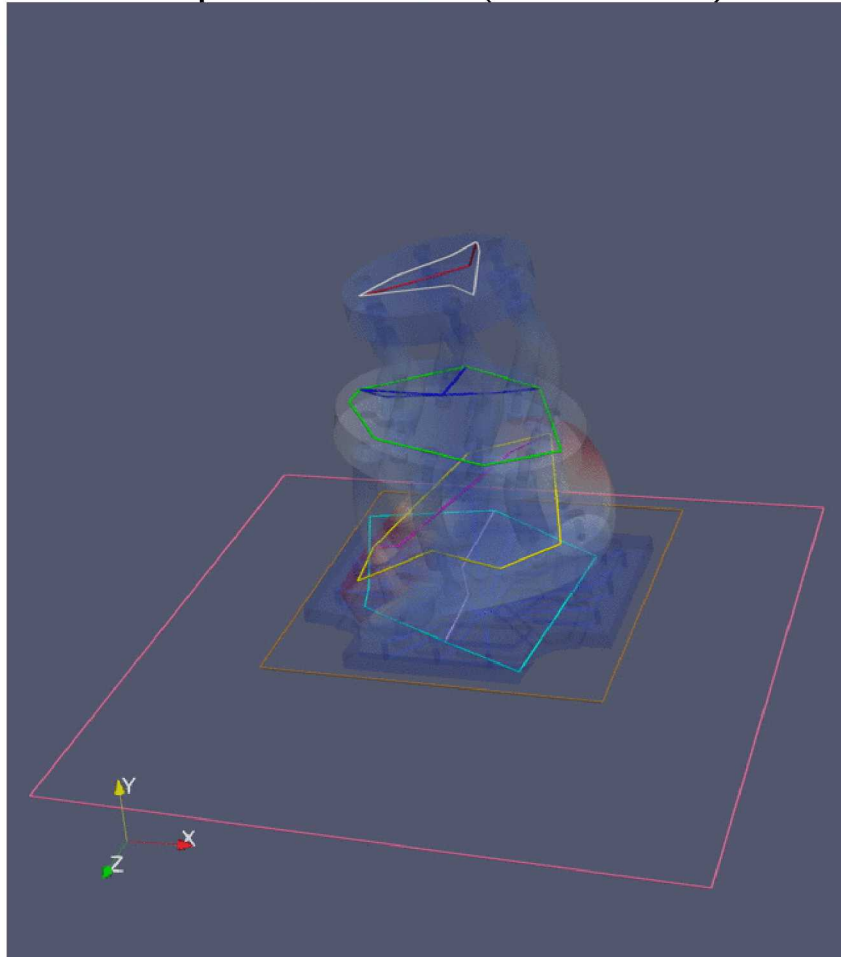Instrumented with accelerometers on the disks and base plate

Impact test performed while mounted on a seismic mass to achieve mode shapes

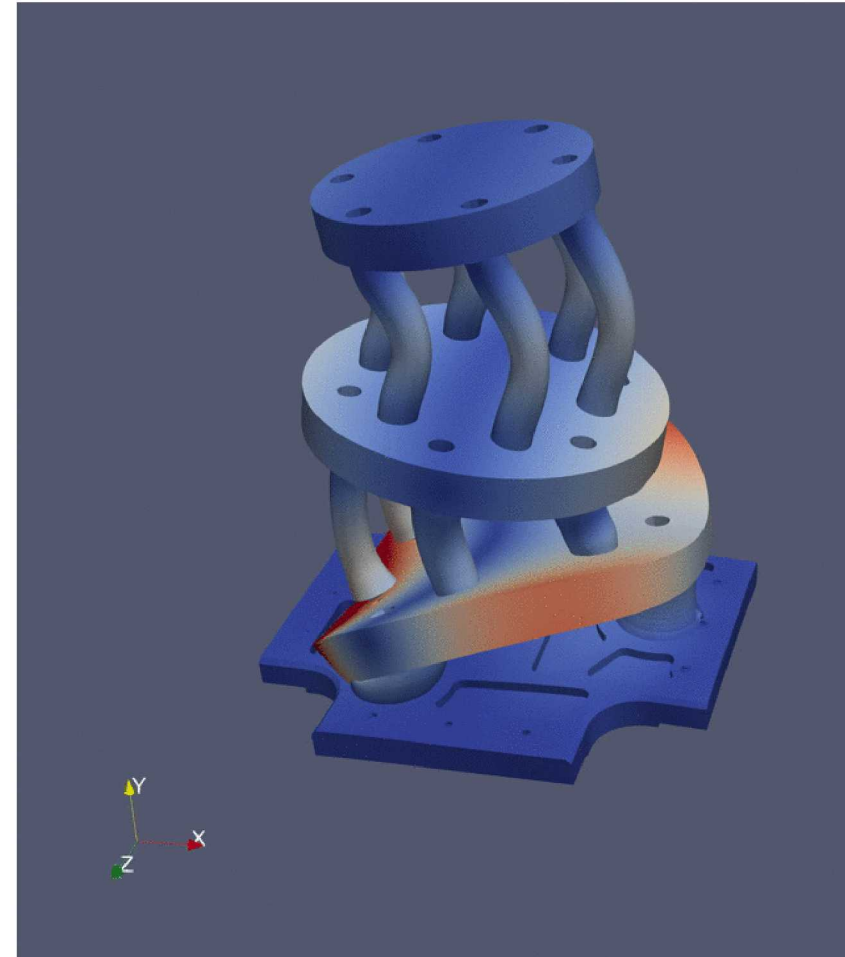Frequency range: 0-1800 Hz, first 25 modes

Mode shape expansion

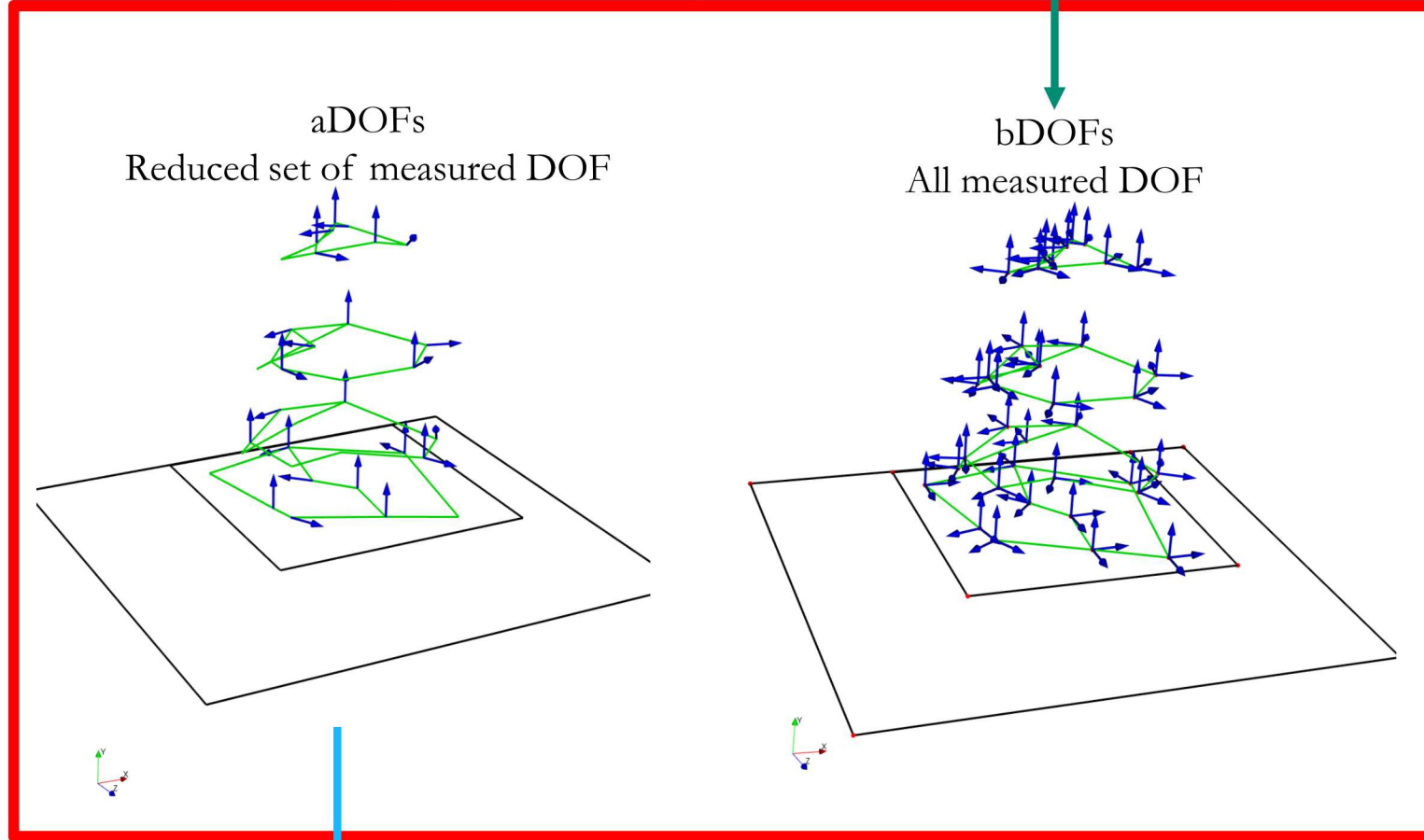Expanded Experimental and
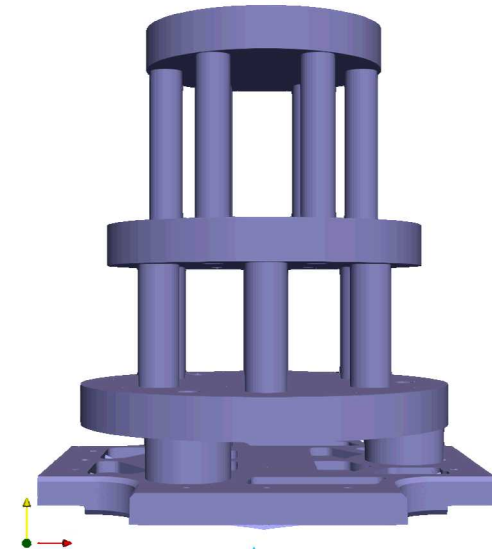Experimental (Mode 24)

FEM (Mode 24)

Compared to Measured bDOFs

Measured Experimentally

aDOFs
Reduced set of measured DOF

bDOFs
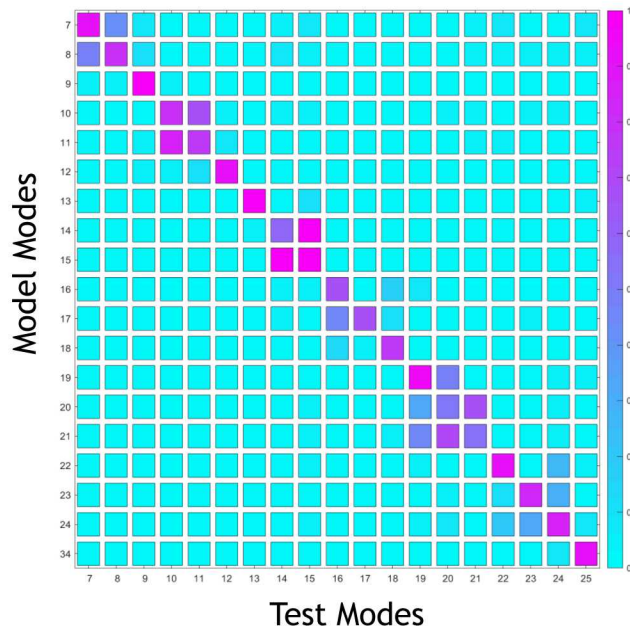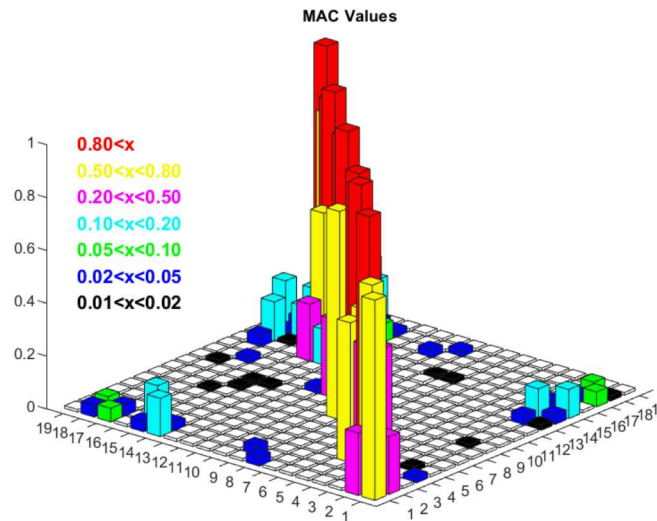All measured DOF

nDOFs
All model DOF

Expanded to nDOFs

How well did this expansion do?

- MAC between model and test shows that model is not perfectly correlated

- U_{12} between model and test indicates that combinations of the FE modes included should be able to combine to approximate the test modes (FE modes span the space of the test modes)

- Expansion results are highly accurate!

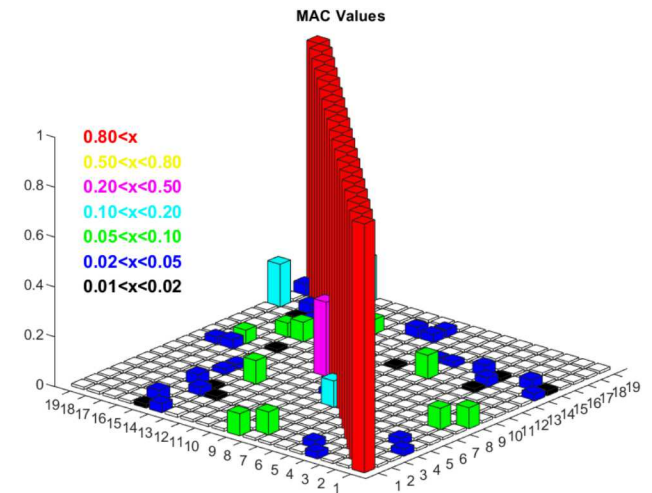- **The model does not need to be perfectly correlated to produce highly accurate expansion results**
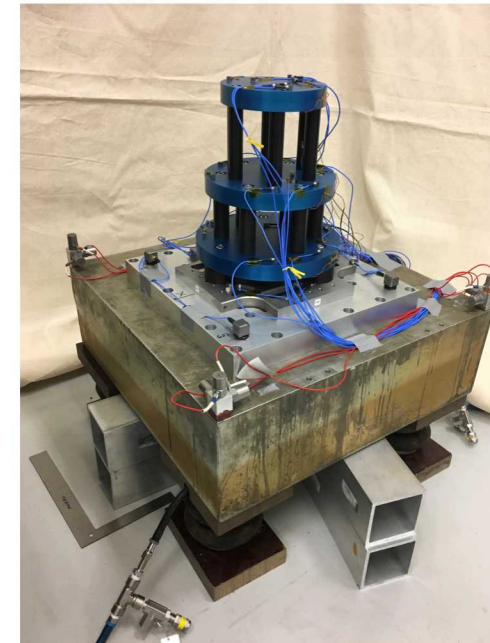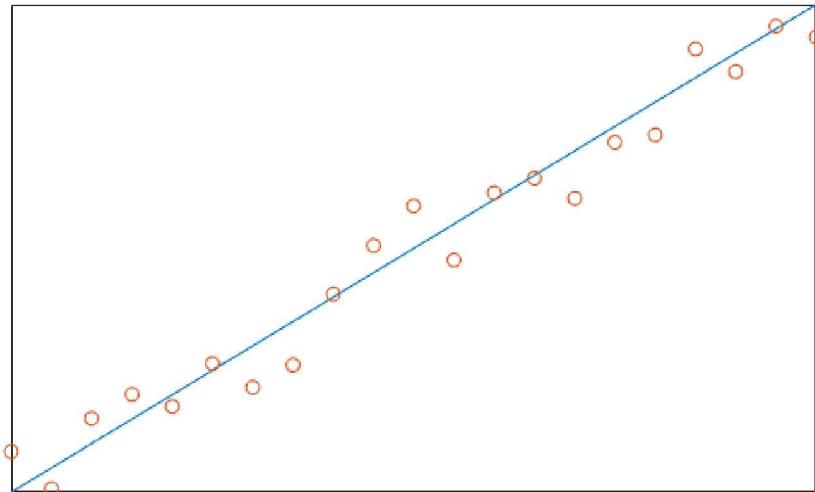
U_{12} at aspace

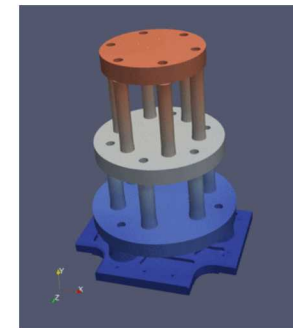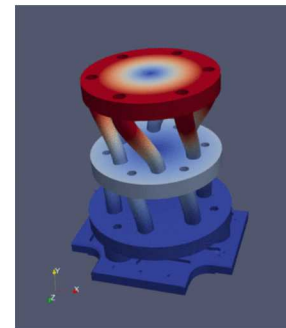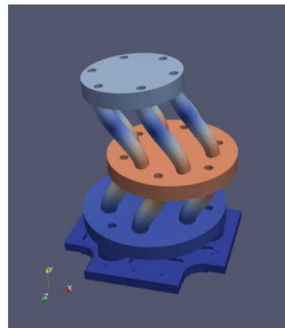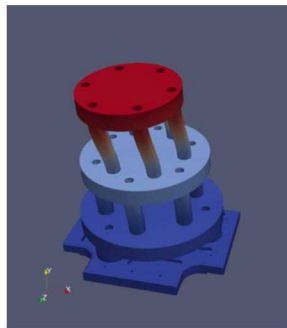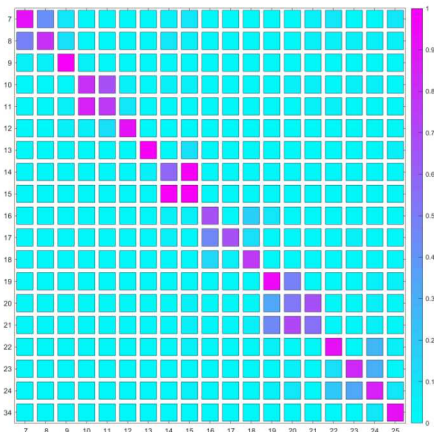MAC Comparing Model and Test

Expansion Results

What are the limitations?

- The SEREP process is mathematically perfect, but applying it to actual measured data is not always easy
- Two big limitations to consider when utilizing SEREP expansion (with actual measured data):
  - Do the DOFs in the a-set fully describe the modes included in the transformation matrix?
  - Do the modes shapes included span the space of the test results?
  - Must always have DOF greater than or equal to the number of modes for SEREP – otherwise an average solution results
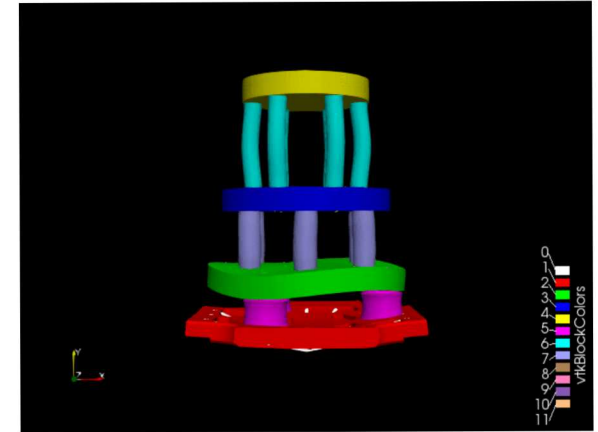
What are the limitations?

- The FE modes do not need to match the test modes, they just need to span the space
- This means the expansion process is NOT highly sensitive to:
  - Incorrect boundary conditions
  - Incorrect joint stiffness values
  - Incorrect material properties
  - Incorrect natural frequencies
- Using the U12 matrix comparing the FE model to the test results will indicate how many modes are needed to span the space of the test modes
- While not strictly necessary for expanding with SEREP, a highly accurate model is valuable and expanded test results can help with the correlation process to improve an existing model.
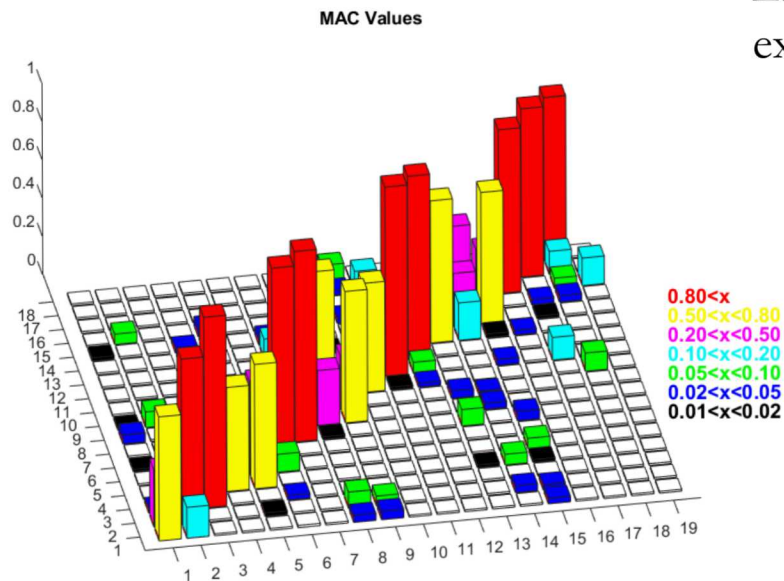
What if the FE modes don't span the space of the test modes?

- Last mode excluded from expansion process
- The preceding mode's expansion results were not affected
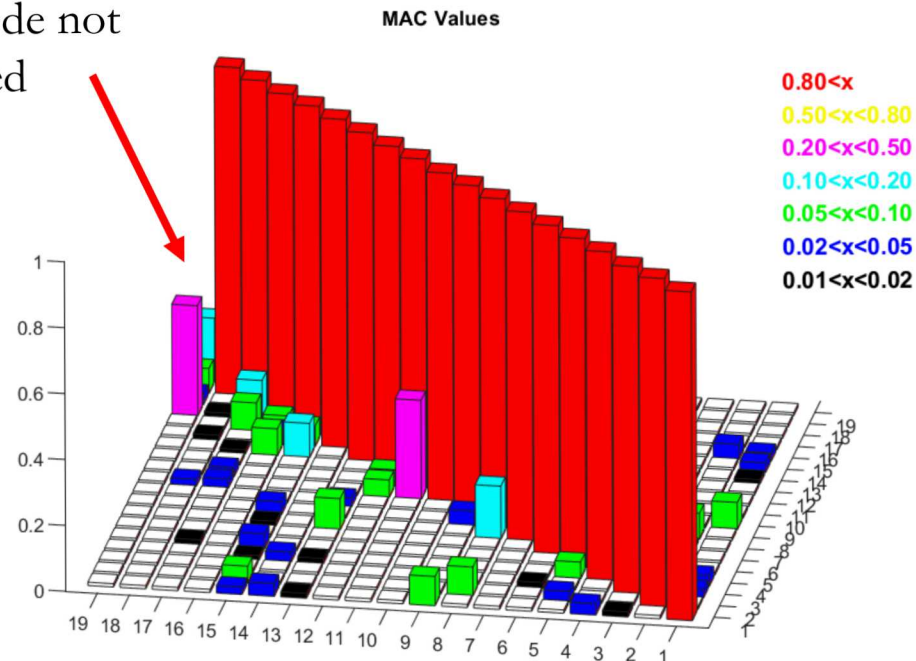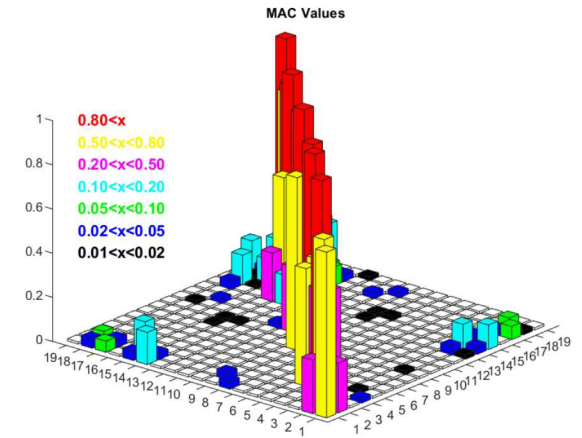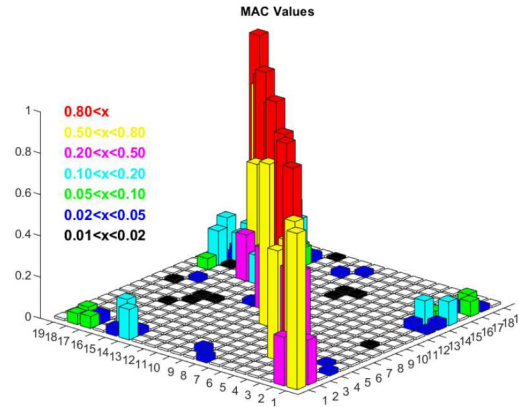- Last mode was not expanded correctly

MAC at aspace

Expansion Results

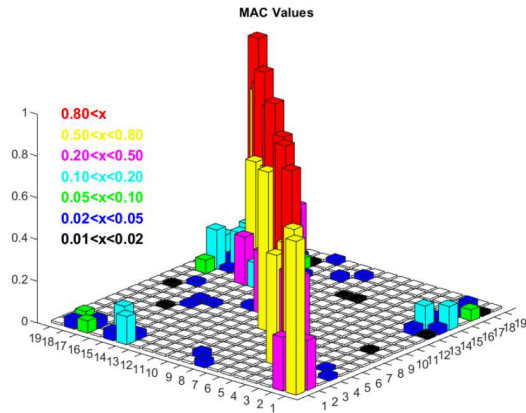Last mode not expanded

What if the model has incorrect properties?
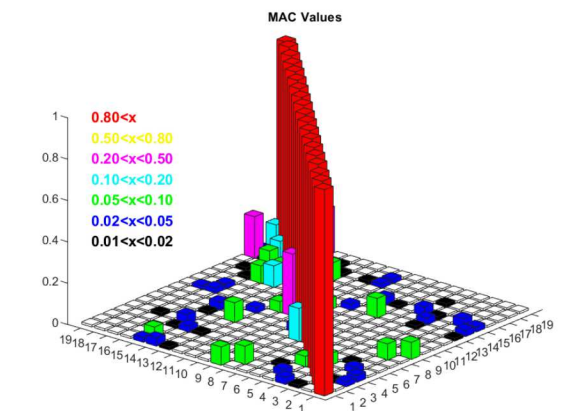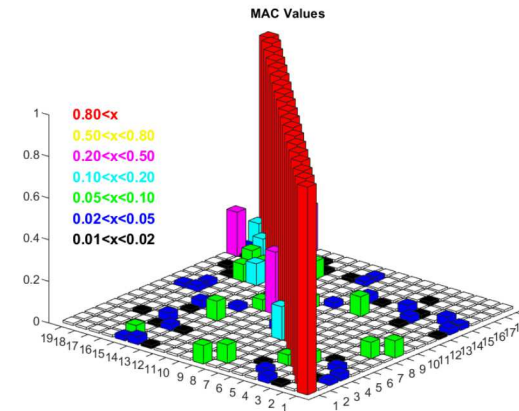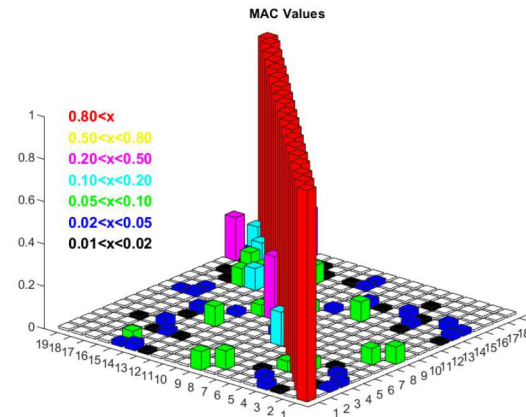
+20% Young's Modulus of Columns   +10% Density of Columns   1000x Joint Stiffness
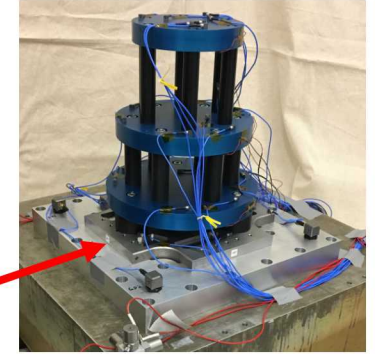
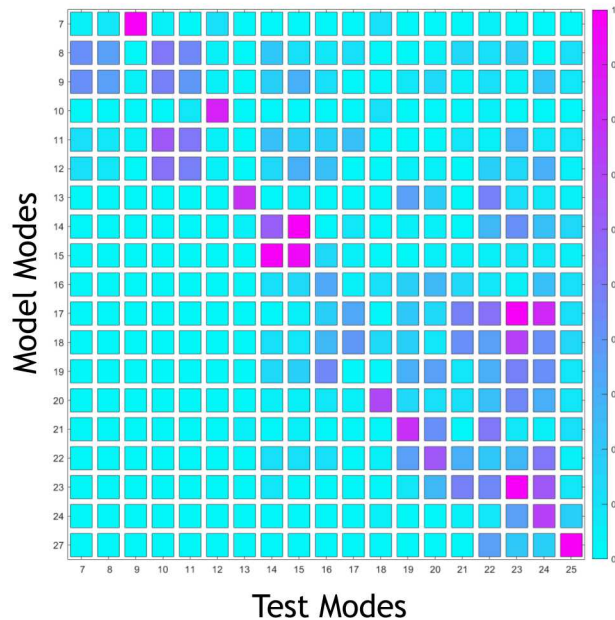aspace FE to Test

bspace Expansion to Test

What if the boundary conditions are radically different from the test setup?

- Used mode shapes from a free-free model to expand modes from a fixed base test

- U_{12} shows that many more FE modes are needed to approximate each test mode

- Expansion results still good for the first 21 modes

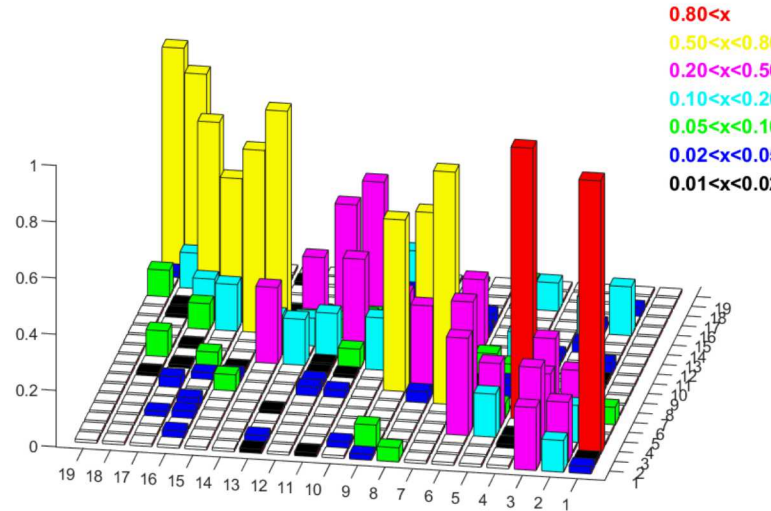- Not enough free-free modes included to describe the last four modes
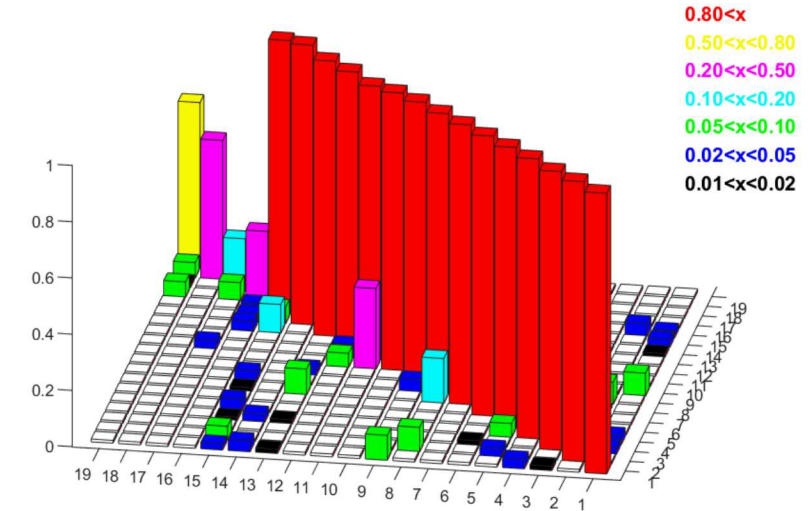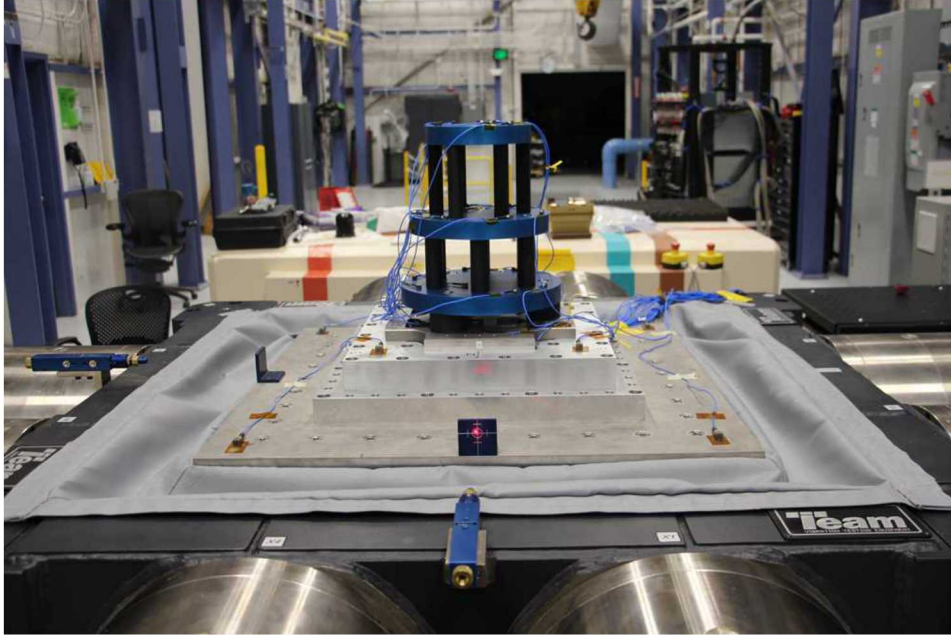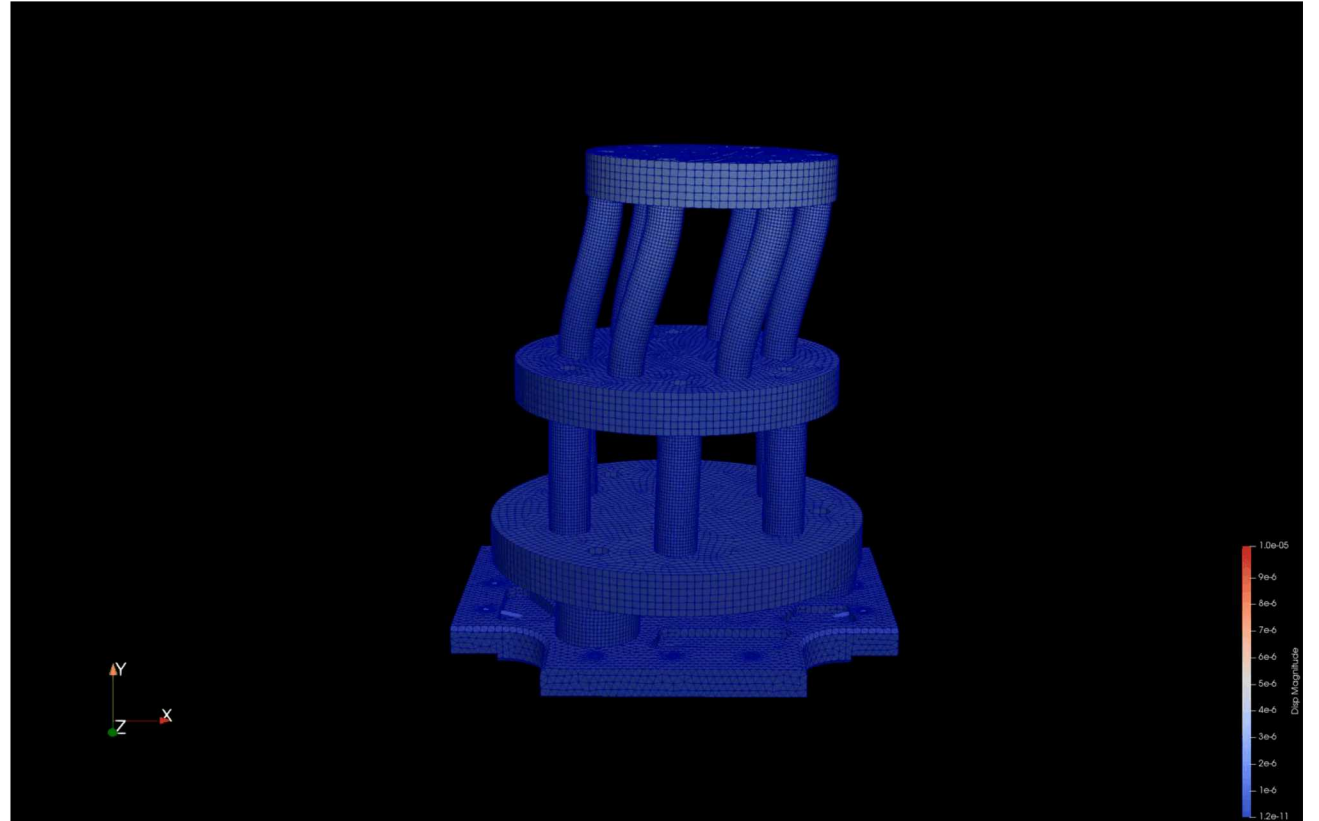
Fixed Base

U_{12} at aspace

MAC at aspace

Expansion Results
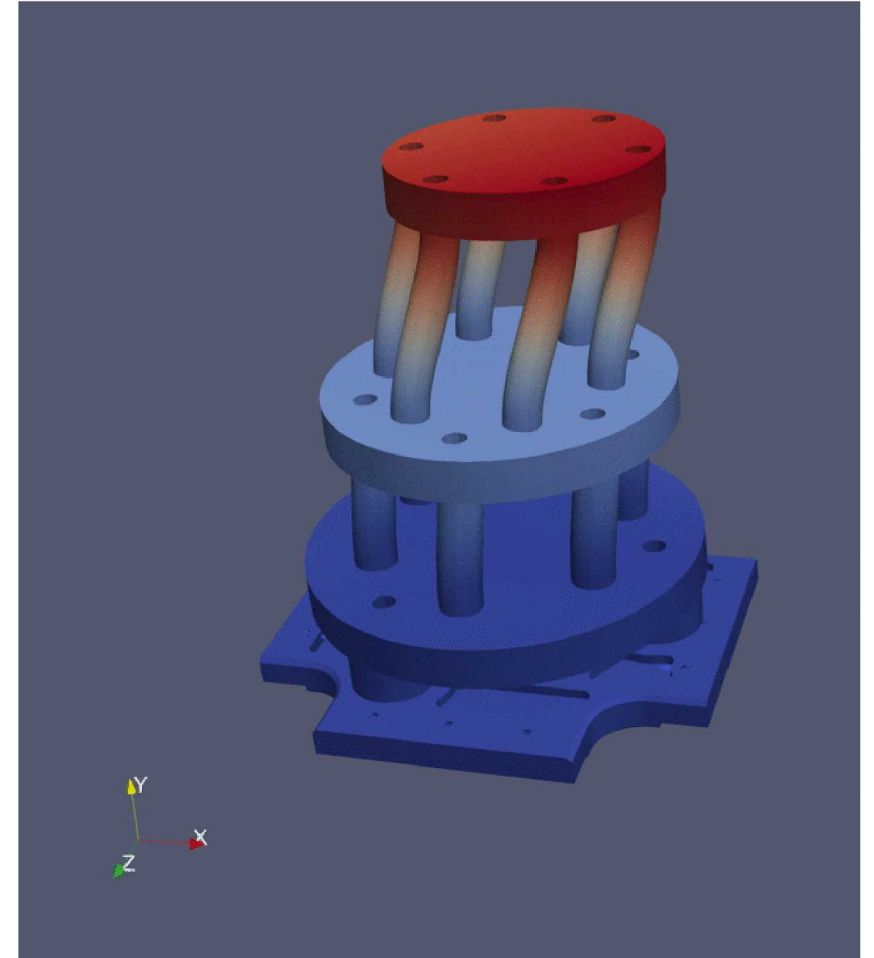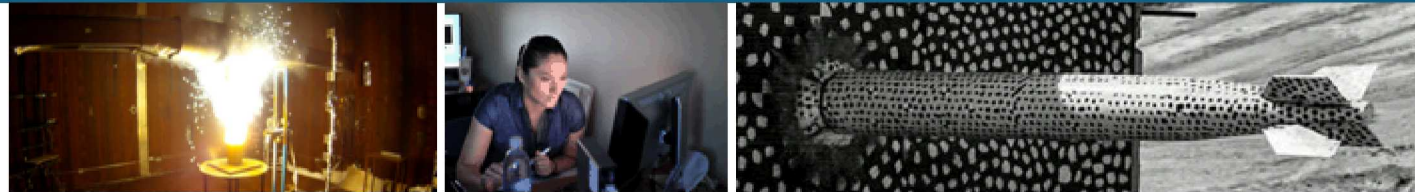
Expansion of time response

$$[x_n] = [U_n][U_a]^g[x_a]$$

Conclusions

- SEREP expands test data to full field using the model's mode shapes to fit the data

- The FE model does not need to be well correlated to the test to get good expansion results

- The FE model mode shapes used to expand the data need to span the space of the data

- The DOF used to expand need to sufficiently describe the mode shapes included in the expansion process

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