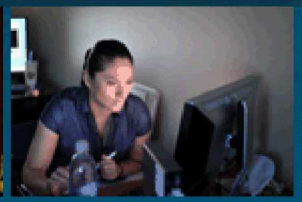
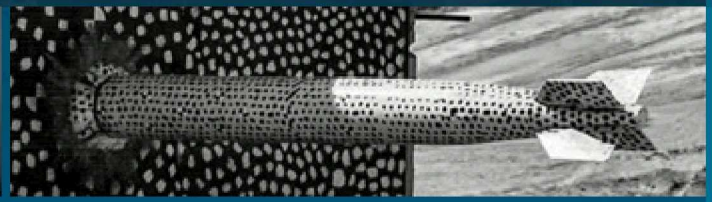
SAND2019-0741C

# Flight Environments Demonstrator: Part II – Ground Trials of a Sounding Rocket Experiment for Characterization of Flight





PRESENTED BY

Brandon Zwink

D. Gregory Tipton, Brian C. Owens, Randy Mayes, Mo Khan

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

# Motivation

What we are trying to do:

- Prediction of flight environment responses at un-instrumented locations

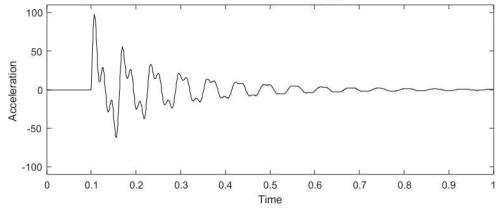
Why is this important?:

- Telemetry data is typically sparse (location and direction)
- Reduce environment uncertainty
- Over/under-designing of components
- Over/under testing of components

# Approach

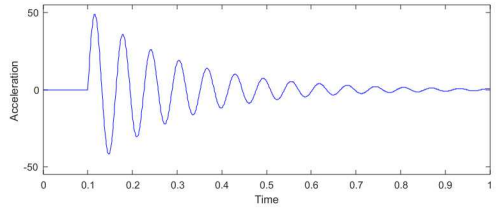
## Modal Superposition

System Response



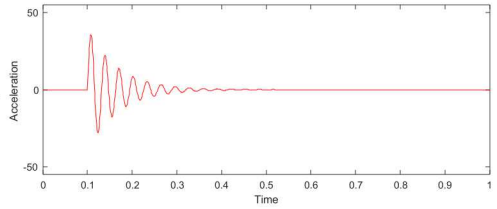

=

Mode 1



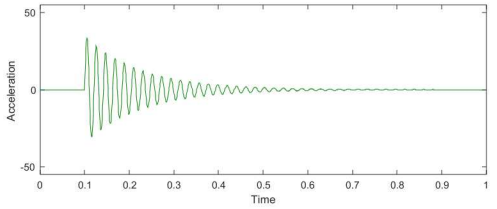

+

Mode 2

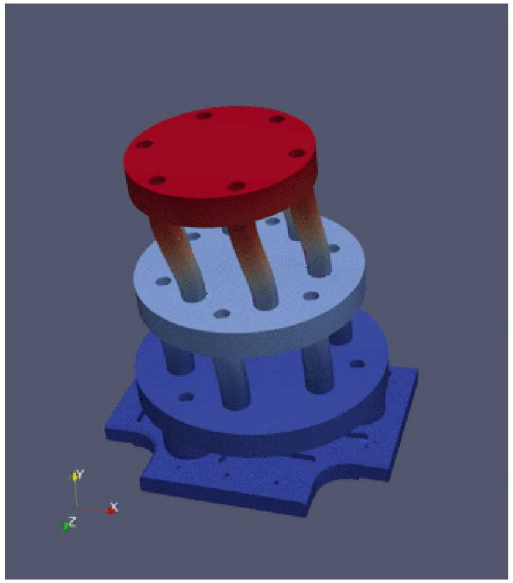


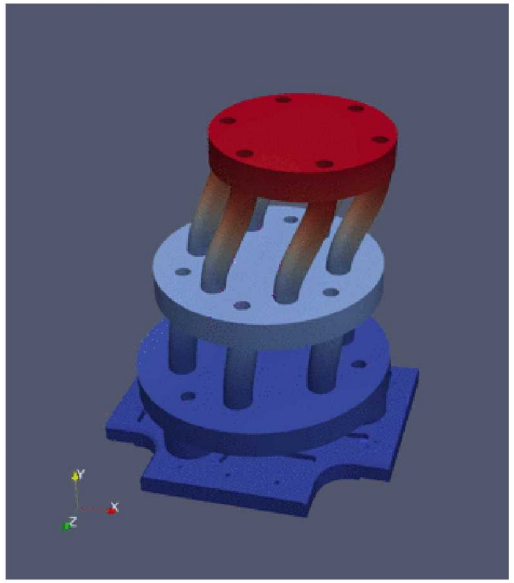

+

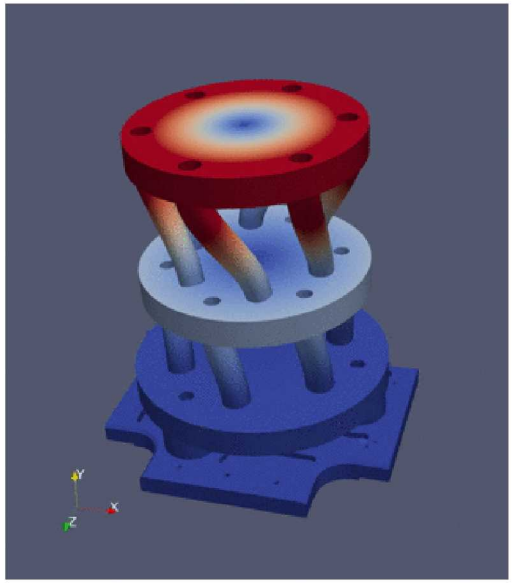
Mode 3




...

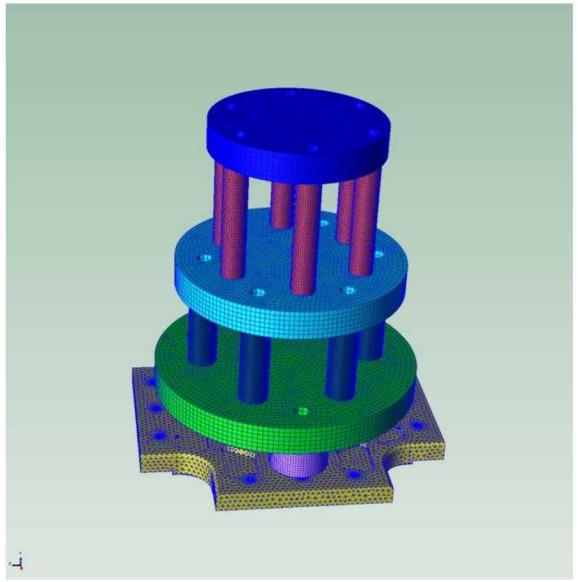


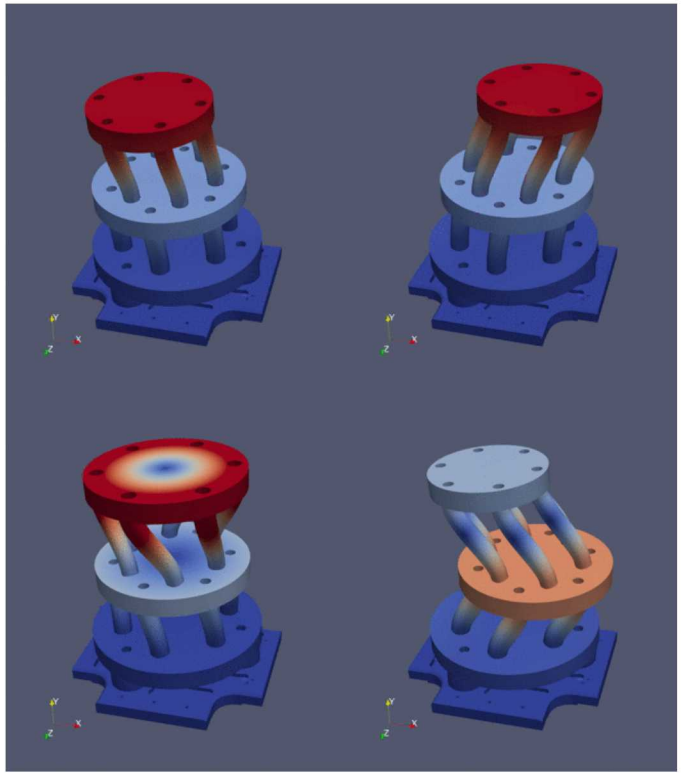


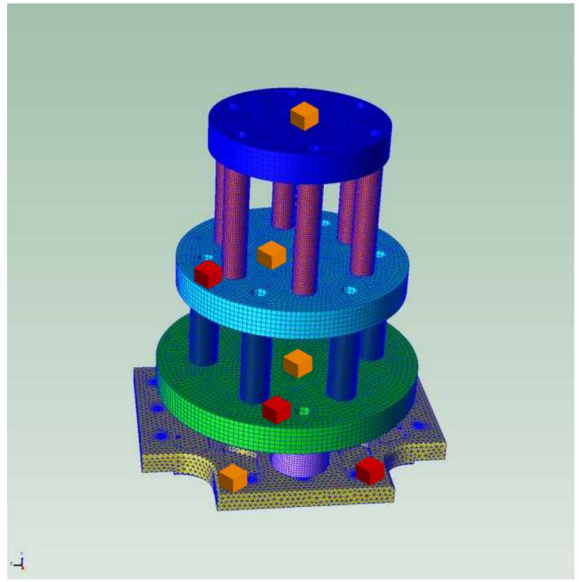


# Approach

Response at Measured Locations → Modal Response (From FEM) → Response at Unmeasured Locations (Virtual Accelerometers)



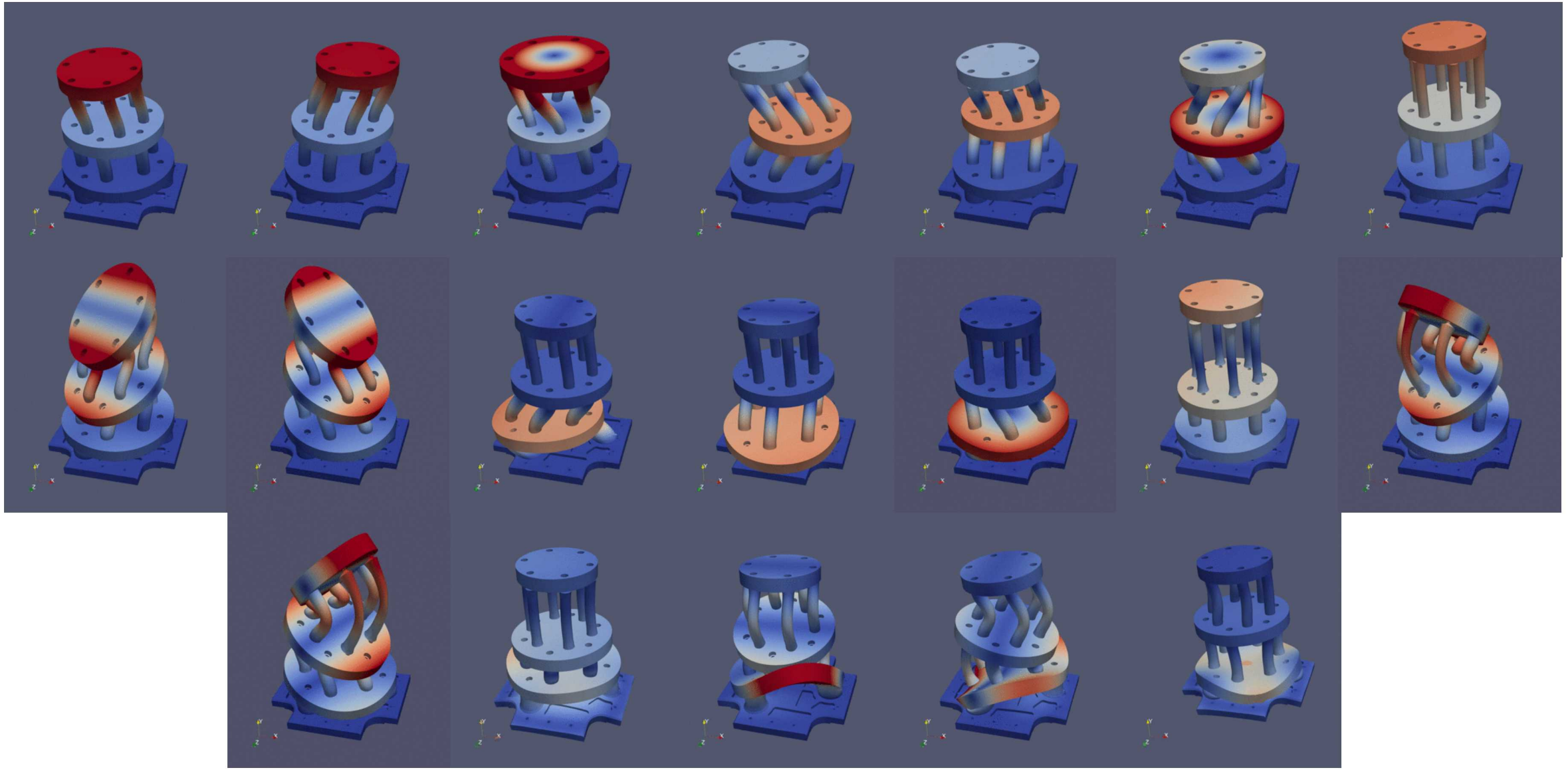




- Measurement Location
- Predicted Response Location

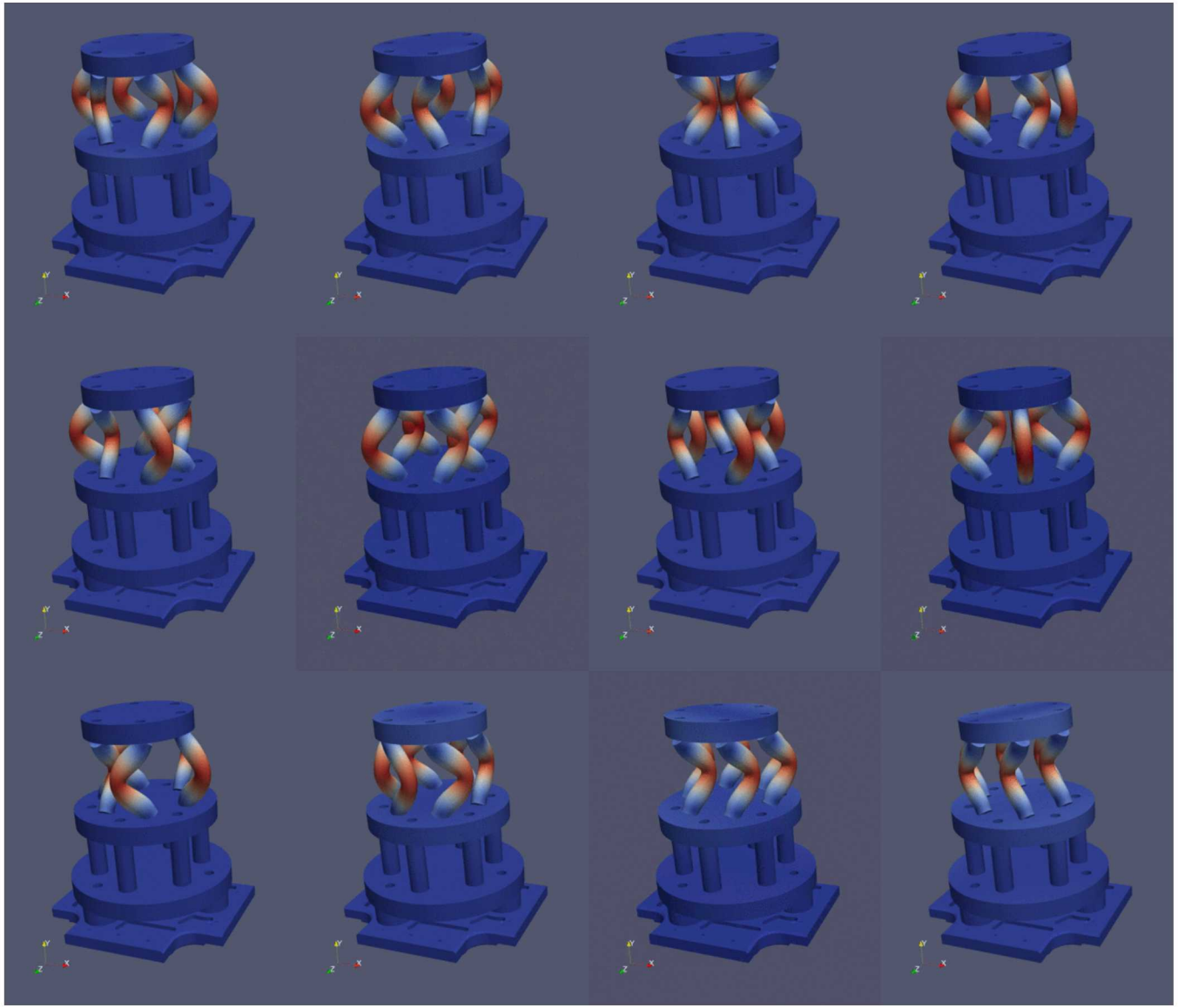
# Finite Element Model Modes

## Selected FEM Modes for Expansion



# Finite Element Model Modes

FEM Modes Not Used in Expansion



# Theory

$$x_n = E_n \; p \qquad \hat{x}_n = U_n \; \hat{p}$$
$$x_b = E_b \; p \qquad \hat{x}_b = U_b \; \hat{p}$$
$$x_a = E_a \; p \qquad \hat{x}_a = U_a \; \hat{p}$$

FEM and Modal Test:
$$\underset{\text{n x time}}{x_n} = \underset{\text{n x FM}}{U_n} \; \underset{\text{FM x b}}{U_b^g} \; \underset{\text{b x EM}}{E_b} \; \underset{\text{EM x a}}{E_a^g} \; \underset{\text{a x time}}{x_a}$$

Modal Test Only:
$$\underset{\text{b x time}}{x_b} = \underset{\text{b x EM}}{E_b} \; \underset{\text{EM x a}}{E_a^g} \; \underset{\text{a x time}}{x_a}$$

FEM Only:
$$\underset{\text{n x time}}{\hat{x}_n} = \underset{\text{n x FM}}{U_n} \; \underset{\text{FM x a}}{U_a^g} \; \underset{\text{a x time}}{x_a}$$

## Nomenclature

x = displacement (time or frequency domain)
E = Experimental Mode Shapes
U = Finite Element Model Mode Shapes

n = 1.2M FEM dofs
b = 99 dofs for modal test
a = 30 dofs to expand from

# Expanding Experimental Modes (SEREP)

## How Expanded Mode Shapes Were Created from FEM Modes

| FEM Mode | Was Used to Make Expanded Experimental Mode | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
| 1 | 6.34 | -14.96 | 19.21 | 1.07 | -1.79 | 3.32 | 3.13 | -1.07 | 0.26 | 2.20 | -0.38 | -0.08 | 2.10 | 0.22 | 0.93 | 0.06 | -0.61 | 0.21 | 0.68 | -1.11 | 0.60 | 3.33 | -1.50 | -4.29 | 8.88 |
| 2 | 5.79 | 15.97 | 8.92 | 1.45 | -5.32 | -8.00 | -1.48 | 1.68 | -0.05 | -1.03 | 1.41 | 0.02 | 0.55 | 2.16 | -1.29 | 0.44 | 0.24 | 0.30 | -1.59 | 1.37 | 2.29 | 3.95 | -5.91 | 5.12 | 7.70 |
| 3 | 23.11 | 5.10 | -4.97 | 6.48 | 15.22 | -1.41 | 2.58 | 3.41 | 0.67 | 1.95 | 2.47 | -0.14 | 0.09 | 1.44 | 0.14 | 1.20 | -1.56 | 0.45 | 0.74 | 0.68 | 1.55 | -2.55 | -3.69 | 1.20 | -1.35 |
| 4 | 3.84 | -3.50 | 5.02 | -4.57 | 4.19 | 7.87 | 2.50 | -0.29 | -0.17 | 1.69 | 0.07 | 0.24 | -0.40 | 0.58 | -0.62 | 0.48 | -1.03 | -0.72 | -3.97 | -0.51 | 0.40 | 9.73 | -2.49 | 2.13 | 6.61 |
| 5 | 7.21 | -3.98 | 0.35 | -5.36 | 4.11 | -4.44 | 0.65 | 0.96 | 0.18 | 0.63 | 0.82 | -0.07 | 0.87 | -0.22 | 1.04 | 0.08 | -0.22 | 0.60 | 3.17 | -0.16 | 0.10 | -6.29 | 0.74 | -3.42 | -2.27 |
| 6 | -5.58 | 13.14 | 14.40 | 1.64 | 0.92 | -10.65 | -1.42 | 1.72 | -0.16 | -1.02 | 1.25 | 0.00 | 0.05 | 0.23 | -1.78 | 3.01 | -1.37 | -0.58 | -3.98 | 0.02 | -0.79 | 9.75 | 0.20 | 3.83 | 6.25 |
| 7 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.85 | -0.54 | -0.10 | -0.02 | -0.01 | -0.01 | 0.00 | -0.05 | -0.07 | -0.02 | 0.02 | 0.01 | 0.04 | -0.01 | 0.04 | -0.06 | -0.01 | 0.00 | 0.00 |
| 8 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.63 | -0.72 | -0.05 | 0.03 | -0.01 | 0.00 | -0.01 | -0.07 | 0.06 | 0.00 | -0.01 | -0.01 | -0.04 | 0.01 | 0.03 | 0.09 | -0.02 | 0.02 | 0.06 |
| 9 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.04 | -0.06 | 1.51 | -0.04 | -0.03 | 0.00 | -0.02 | 0.00 | -0.01 | 0.00 | -0.01 | 0.00 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 | 0.00 | -0.01 |
| 10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | -0.01 | 0.78 | -0.68 | 0.06 | 0.00 | -0.02 | 0.04 | 0.00 | 0.00 | 0.00 | 0.02 | -0.05 | -0.03 | 0.04 | -0.02 | 0.02 | 0.02 |
| 11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | 0.00 | 0.05 | 0.92 | 0.74 | -0.08 | -0.01 | 0.02 | 0.01 | 0.01 | -0.01 | 0.00 | 0.02 | -0.02 | 0.05 | 0.02 | 0.02 | 0.01 | 0.00 |
| 12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | -0.05 | -0.04 | -0.11 | -0.91 | 0.01 | 0.02 | 0.01 | 0.00 | 0.00 | -0.01 | -0.01 | 0.00 | 0.00 | -0.01 | 0.01 | 0.00 | 0.00 |
| 13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | -0.02 | -0.01 | -0.01 | -0.01 | -0.99 | 0.00 | 0.11 | -0.02 | 0.00 | 0.00 | 0.03 | 0.02 | 0.00 | -0.06 | 0.02 | -0.01 | -0.04 |
| 14 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | -0.01 | -0.05 | -0.54 | -1.26 | 0.00 | -0.02 | 0.01 | -0.01 | 0.00 | 0.02 | -0.03 | -0.02 | -0.02 | 0.00 |
| 15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | 0.00 | -0.01 | 0.00 | 0.00 | 0.00 | 0.03 | -1.17 | 0.95 | 0.03 | -0.01 | 0.01 | 0.00 | 0.01 | 0.02 | 0.02 | -0.03 | 0.02 | 0.00 |
| 16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | 0.01 | 0.00 | -0.01 | 0.05 | -0.05 | 0.65 | 0.02 | 0.15 | 0.05 | 0.04 | 0.00 | -0.03 | -0.02 | 0.06 | 0.01 |
| 17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | 0.00 | 0.00 | -0.04 | -0.01 | -0.45 | 0.68 | -0.07 | 0.01 | 0.01 | -0.01 | 0.00 | 0.04 | 0.02 | 0.00 |
| 18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | 0.00 | 0.16 | -0.06 | -0.76 | 0.00 | 0.02 | 0.03 | -0.01 | -0.01 | 0.01 | 0.00 |
| 19 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | -0.01 | 0.00 | 0.00 | -0.01 | 0.01 | 0.01 | -0.04 | -0.02 | 0.00 | -0.01 | 0.94 | 0.49 | 0.02 | 0.09 | 0.00 | 0.02 | 0.00 |
| 20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | -0.03 | 0.01 | 0.00 | -0.01 | -0.01 | -0.37 | 0.57 | -0.63 | -0.03 | -0.07 | -0.04 | 0.00 |
| 21 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | 0.00 | 0.00 | -0.01 | -0.03 | -0.03 | 0.00 | 0.00 | -0.03 | 0.41 | -0.65 | -0.59 | -0.01 | -0.08 | 0.04 | 0.01 |
| 22 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | 0.00 | -0.02 | 0.00 | 0.01 | -0.01 | -0.04 | -0.04 | -0.02 | 0.93 | -0.02 | -0.21 | -0.04 |
| 23 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.01 | 0.00 | 0.01 | 0.01 | 0.02 | 0.00 | 0.10 | -0.10 | -0.86 | -0.21 | -0.03 |
| 24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | 0.01 | -0.03 | -0.02 | 0.00 | 0.02 | -0.04 | 0.02 | 0.01 | 0.16 | -0.23 | 0.88 | 0.08 |
| 37 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.01 | -0.01 | 0.00 | 0.00 | 0.05 | 0.01 | 0.01 | -0.05 | 0.00 | -0.07 | 0.95 |

# Expanding Experimental Modes (SEREP)

## How Expanded Mode Shapes Were Created from FEM Modes

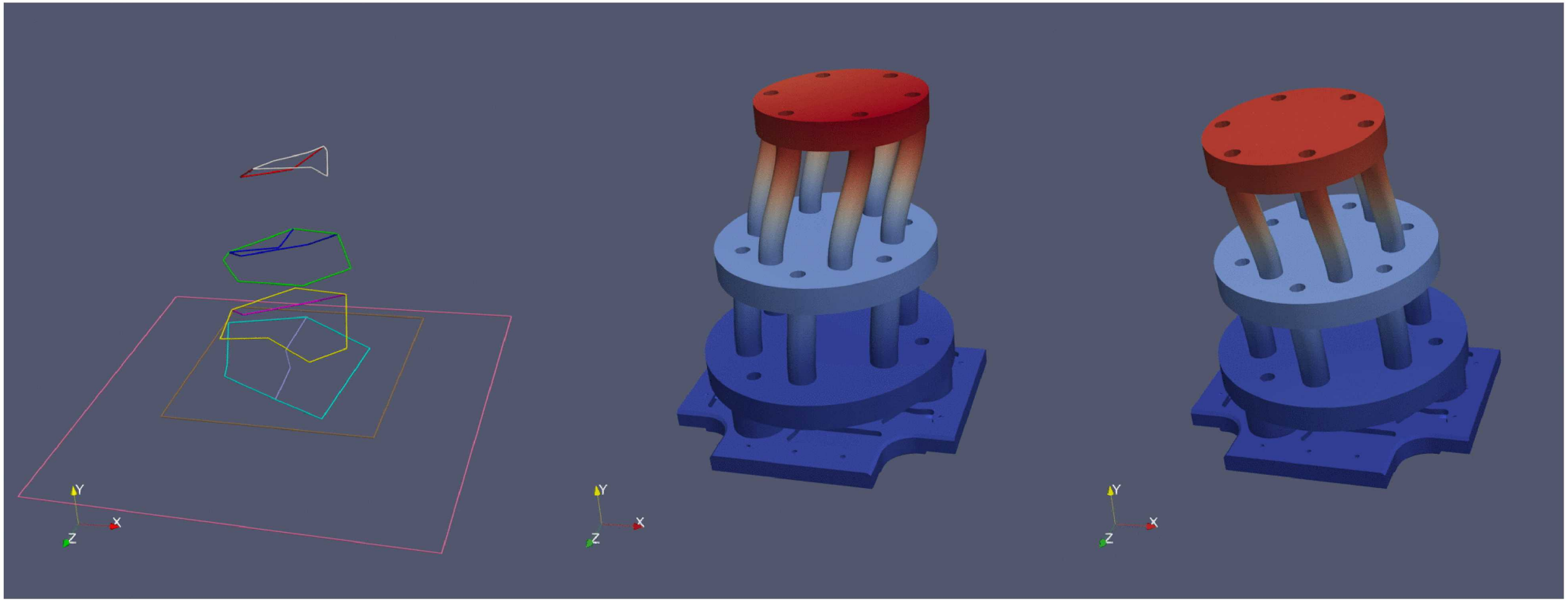
| FEM Mode | Was Used to Make Expanded Experimental Mode | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
| 1 | 6.34 | -14.96 | 19.21 | 1.07 | -1.79 | 3.32 | 3.13 | -1.07 | 0.26 | 2.20 | -0.38 | -0.08 | 2.10 | 0.22 | 0.93 | 0.06 | -0.61 | 0.21 | 0.68 | -1.11 | 0.60 | 3.33 | -1.50 | -4.29 | 8.88 |
| 2 | 5.79 | 15.97 | 8.92 | 1.45 | -5.32 | -8.00 | -1.48 | 1.68 | -0.05 | -1.03 | 1.41 | 0.02 | 0.55 | 2.16 | -1.29 | 0.44 | 0.24 | 0.30 | -1.59 | 1.37 | 2.29 | 3.95 | -5.91 | 5.12 | 7.70 |
| 3 | 23.11 | 5.10 | -4.97 | 6.48 | 15.22 | -1.41 | 2.58 | 3.41 | 0.67 | 1.95 | 2.47 | -0.14 | 0.09 | 1.44 | 0.14 | 1.20 | -1.56 | 0.45 | 0.74 | 0.68 | 1.55 | -2.55 | -3.69 | 1.20 | -1.35 |
| 4 | 3.84 | -3.50 | 5.02 | -4.57 | 4.19 | 7.87 | 2.50 | -0.29 | -0.17 | 1.69 | 0.07 | 0.24 | -0.40 | 0.58 | -0.62 | 0.48 | -1.03 | -0.72 | -3.97 | -0.51 | 0.40 | 9.73 | -2.49 | 2.13 | 6.61 |
| 5 | 7.21 | -3.98 | 0.35 | -5.36 | 4.11 | -4.44 | 0.65 | 0.96 | 0.18 | 0.63 | 0.82 | -0.07 | 0.87 | -0.22 | 1.04 | 0.08 | -0.22 | 0.60 | 3.17 | -0.16 | 0.10 | -6.29 | 0.74 | -3.42 | -2.27 |
| 6 | -5.58 | 13.14 | 14.40 | 1.64 | 0.92 | -10.65 | -1.42 | 1.72 | -0.16 | -1.02 | 1.25 | 0.00 | 0.05 | 0.23 | -1.78 | 3.01 | -1.37 | -0.58 | -3.98 | 0.02 | -0.79 | 9.75 | 0.20 | 3.83 | 6.25 |
| 7 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.85 | -0.54 | -0.10 | -0.02 | -0.01 | -0.01 | 0.00 | -0.05 | -0.07 | -0.02 | 0.02 | 0.01 | 0.04 | -0.01 | 0.04 | -0.06 | -0.01 | 0.00 | 0.00 |
| 8 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.63 | -0.72 | -0.05 | 0.03 | -0.01 | 0.00 | -0.01 | -0.07 | 0.06 | 0.00 | -0.01 | -0.01 | -0.04 | 0.01 | 0.03 | 0.09 | -0.02 | 0.02 | 0.06 |
| 9 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.04 | -0.06 | 1.51 | -0.04 | -0.03 | 0.00 | -0.02 | 0.00 | -0.01 | 0.00 | -0.01 | 0.00 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 | 0.00 | -0.01 |
| 10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | -0.01 | 0.78 | -0.68 | 0.06 | 0.00 | -0.02 | 0.04 | 0.00 | 0.00 | 0.00 | 0.02 | -0.05 | -0.03 | 0.04 | -0.02 | 0.02 | 0.02 |
| 11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | 0.00 | 0.05 | 0.92 | 0.74 | -0.08 | -0.01 | 0.02 | 0.01 | 0.01 | -0.01 | 0.00 | 0.02 | -0.02 | 0.05 | 0.02 | 0.02 | 0.01 | 0.00 |
| 12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | -0.05 | -0.04 | -0.11 | -0.91 | 0.01 | 0.02 | 0.01 | 0.00 | 0.00 | -0.01 | -0.01 | 0.00 | 0.00 | -0.01 | 0.01 | 0.00 | 0.00 |
| 13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | -0.02 | -0.01 | -0.01 | -0.01 | -0.99 | 0.00 | 0.11 | -0.02 | 0.00 | 0.00 | 0.03 | 0.02 | 0.00 | -0.06 | 0.02 | -0.01 | -0.04 |
| 14 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | -0.01 | -0.05 | -0.54 | -1.26 | 0.00 | -0.02 | 0.01 | -0.01 | 0.00 | 0.02 | -0.03 | -0.02 | -0.02 | 0.00 |
| 15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | 0.00 | -0.01 | 0.00 | 0.00 | 0.00 | 0.03 | -1.17 | 0.95 | 0.03 | -0.01 | 0.01 | 0.00 | 0.01 | 0.02 | 0.02 | -0.03 | 0.02 | 0.00 |
| 16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | 0.01 | 0.00 | -0.01 | 0.05 | -0.05 | 0.65 | 0.02 | 0.15 | 0.05 | 0.04 | 0.00 | -0.03 | -0.02 | 0.06 | 0.01 |
| 17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | 0.00 | 0.00 | -0.04 | -0.01 | -0.45 | 0.68 | -0.07 | 0.01 | 0.01 | -0.01 | 0.00 | 0.04 | 0.02 | 0.00 |
| 18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | 0.00 | 0.16 | -0.06 | -0.76 | 0.00 | 0.02 | 0.03 | -0.01 | -0.01 | 0.01 | 0.00 |
| 19 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | -0.01 | 0.00 | 0.00 | -0.01 | 0.01 | 0.01 | -0.04 | -0.02 | 0.00 | -0.01 | 0.94 | 0.49 | 0.02 | 0.09 | 0.00 | 0.02 | 0.00 |
| 20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | -0.03 | 0.01 | 0.00 | -0.01 | -0.01 | -0.37 | 0.57 | -0.63 | -0.03 | -0.07 | -0.04 | 0.00 |
| 21 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | 0.00 | 0.00 | -0.01 | -0.03 | -0.03 | 0.00 | 0.00 | -0.03 | 0.41 | -0.65 | -0.59 | -0.01 | -0.08 | 0.04 | 0.01 |
| 22 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | 0.00 | -0.02 | 0.00 | 0.01 | -0.01 | -0.04 | -0.04 | -0.02 | 0.93 | -0.02 | -0.21 | -0.04 |
| 23 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.01 | 0.00 | 0.01 | 0.01 | 0.02 | 0.00 | 0.10 | -0.10 | -0.86 | -0.21 | -0.03 |
| 24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | 0.01 | -0.03 | -0.02 | 0.00 | 0.02 | -0.04 | 0.02 | 0.01 | 0.16 | -0.23 | 0.88 | 0.08 |
| 37 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.01 | -0.01 | 0.00 | 0.00 | 0.05 | 0.01 | 0.01 | -0.05 | 0.00 | -0.07 | 0.95 |

# Expanding Experimental Modes (SEREP)

Experimental (Mode 7)

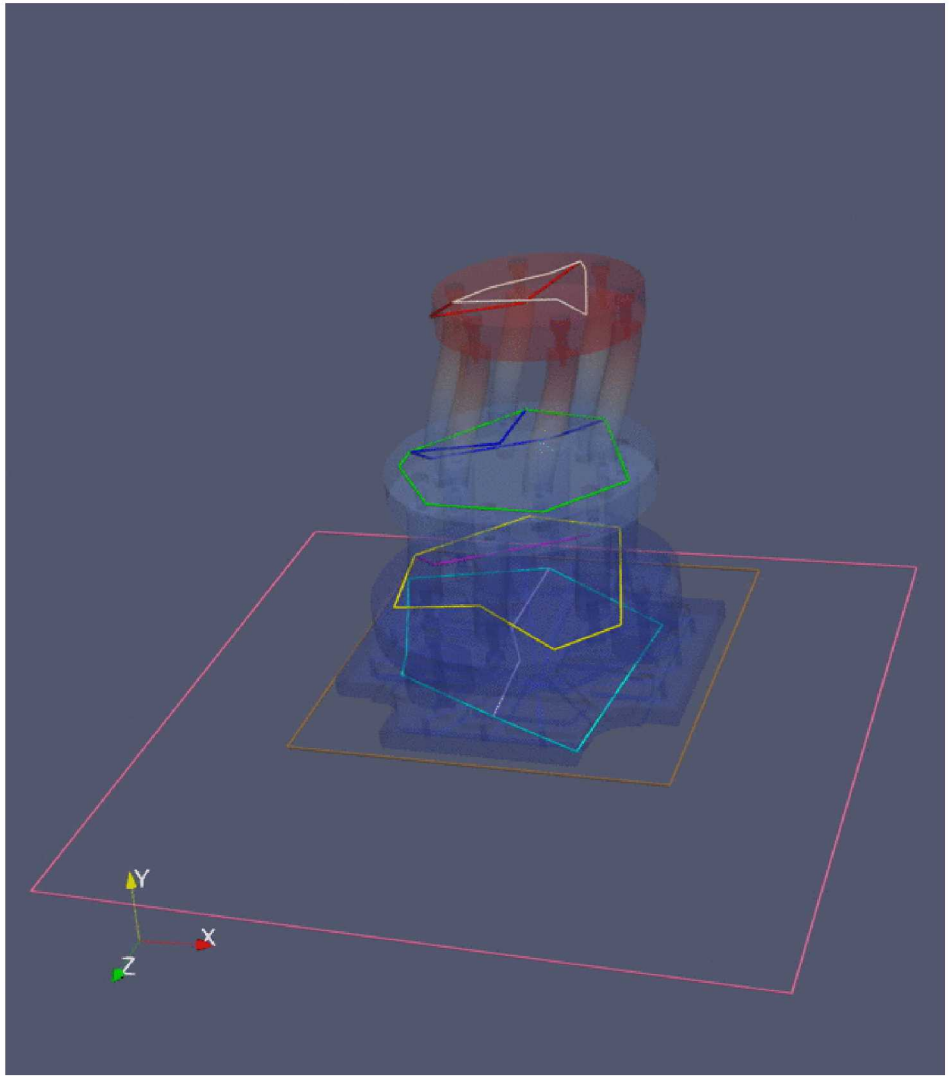
Expanded Experimental (Mode 7)

FEM (Mode 7)



# Expanding Experimental Modes (SEREP)

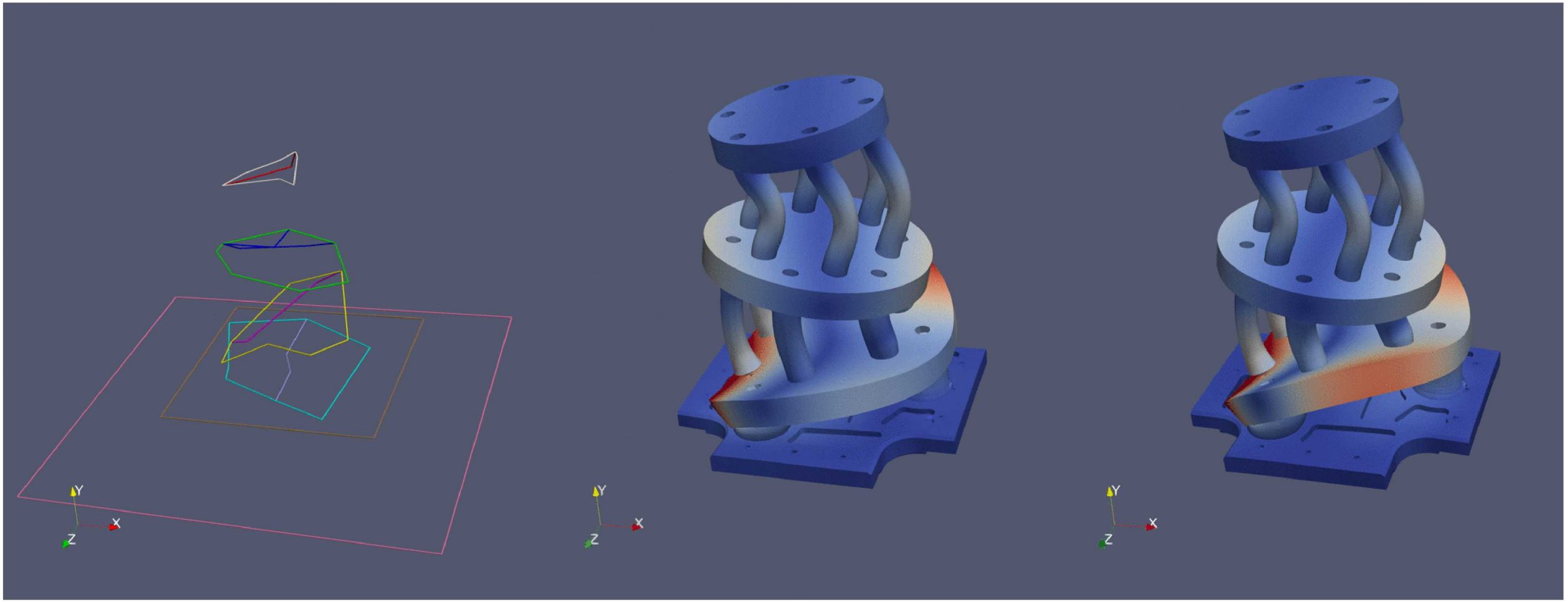
Expanded Experimental and Experimental (Mode 7)



Experimental (Mode 24)

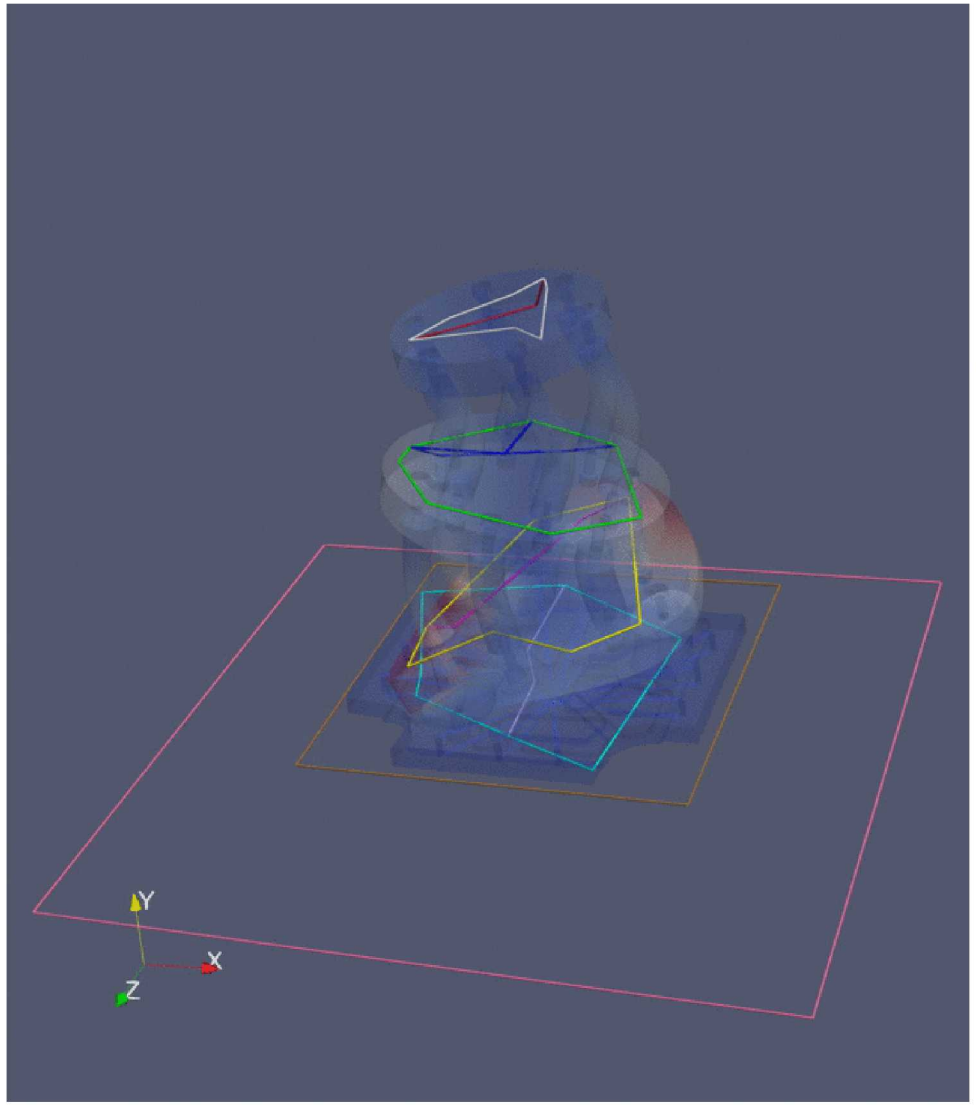
Expanded Experimental (Mode 24)

FEM (Mode 24)



# Expanding Experimental Modes (SEREP)

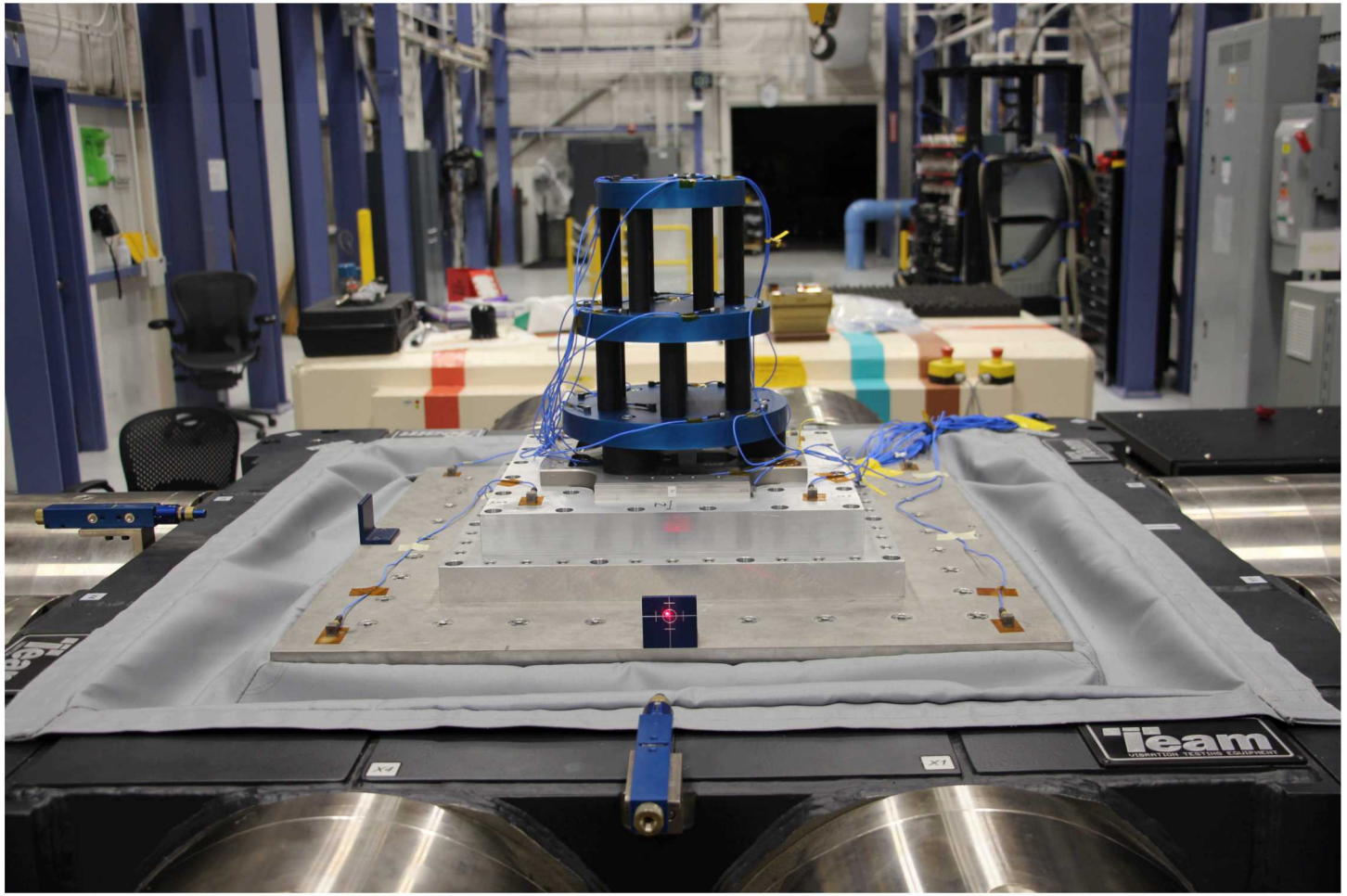
Expanded Experimental and Experimental (Mode 24)



# Trial on 6DOF Shaker

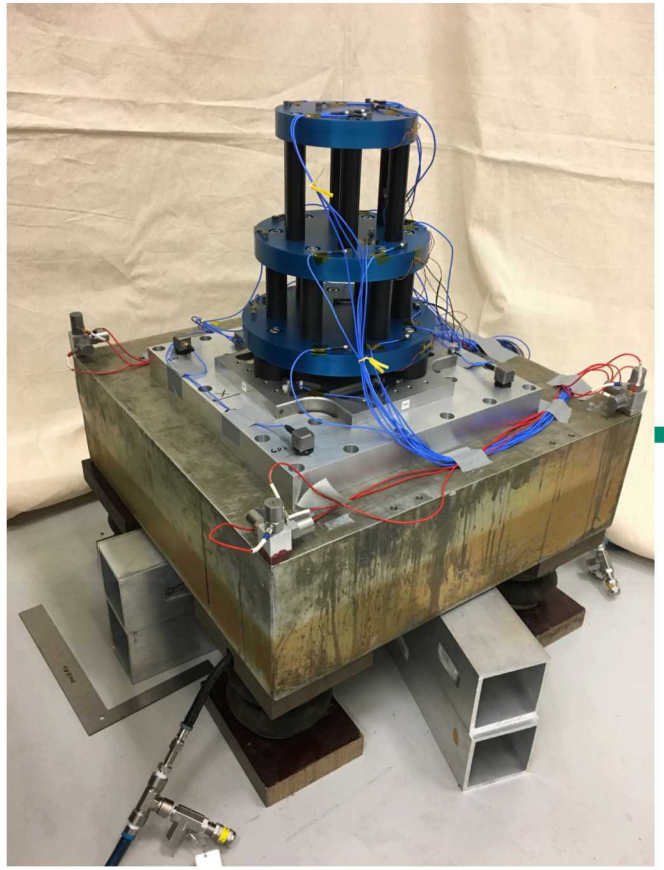
Response Prediction at Unmeasured Locations

- 6DOF Shaker Provides "Environment"



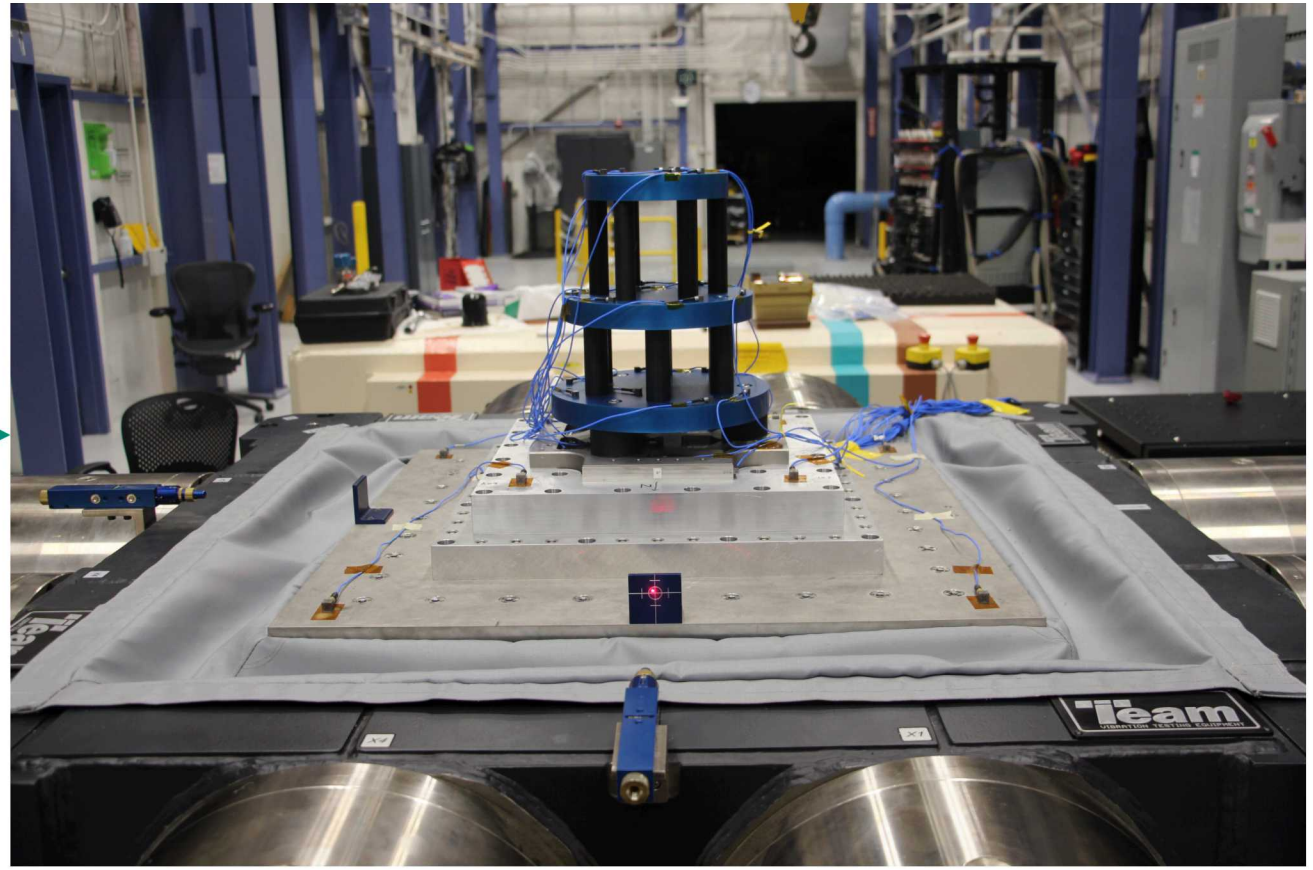
# Results (Experimental to 6DOF)

Experimental Mode Shapes

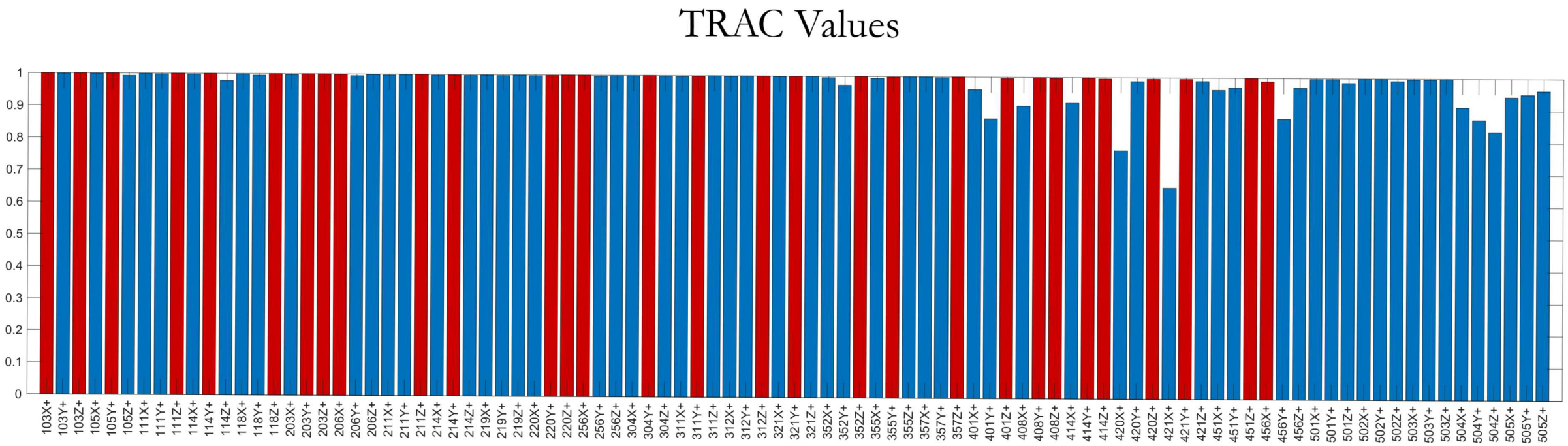


Used to Predict

6 DOF Shaker Environment



# Results (Experimental to 6DOF)

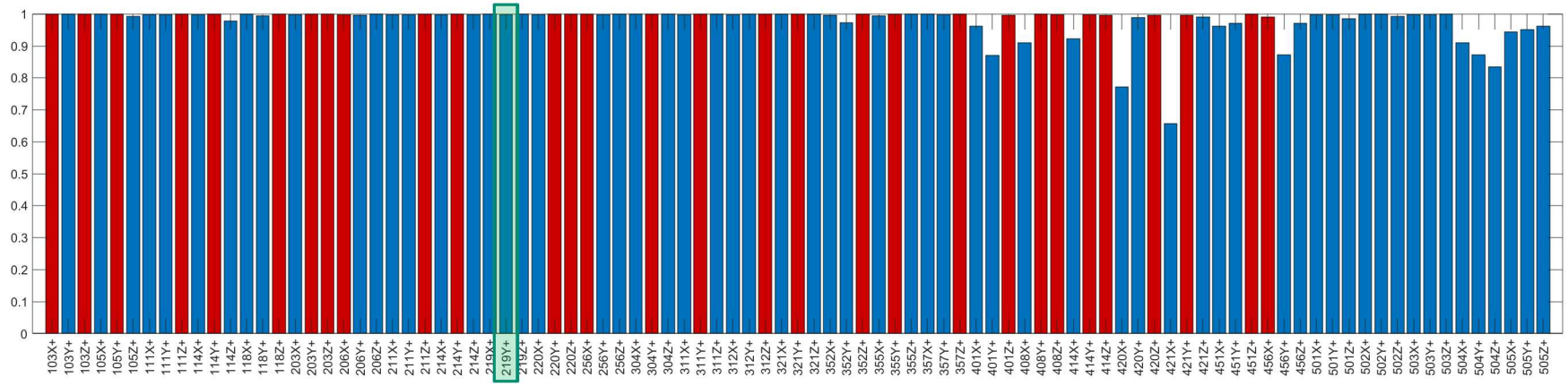



30 DOFs used to expand from

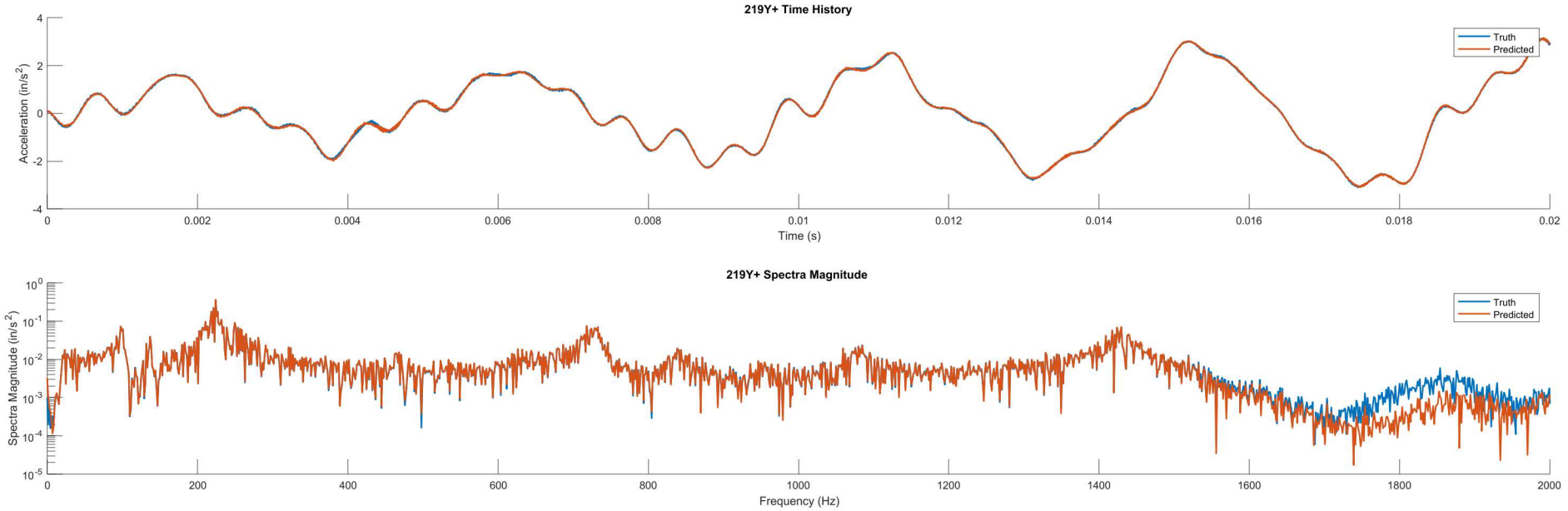
Predicted DOFs

# Results (Experimental to 6DOF)

TRAC Values

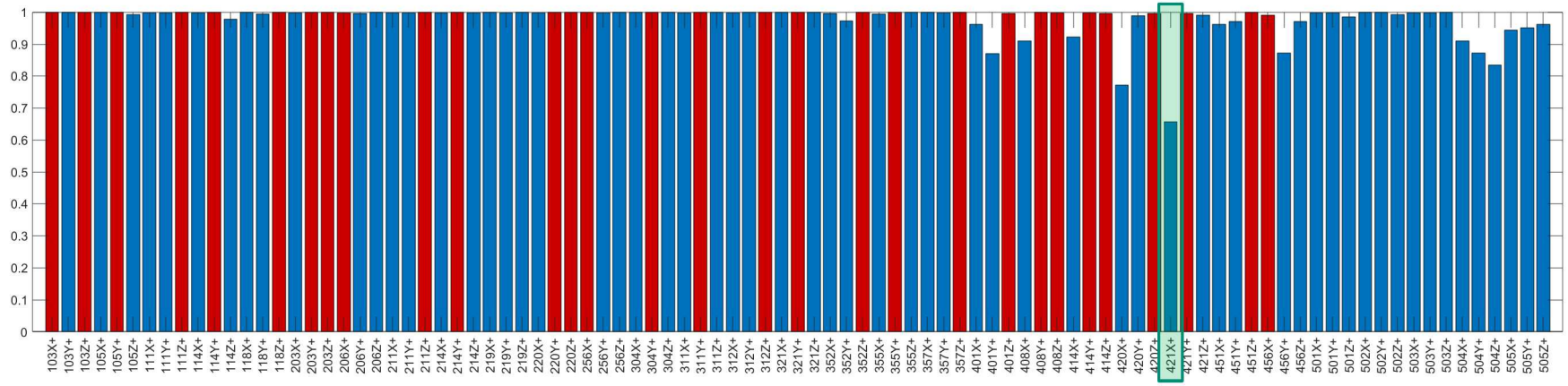



Time History (Well Predicted DOF)

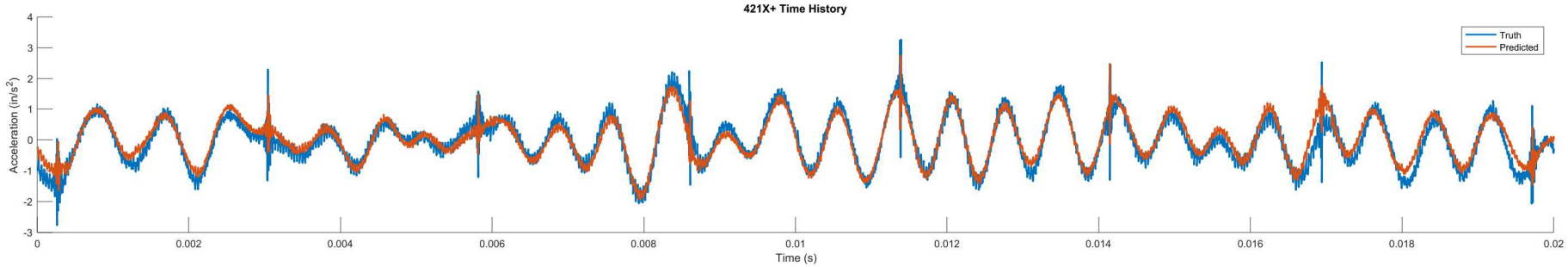


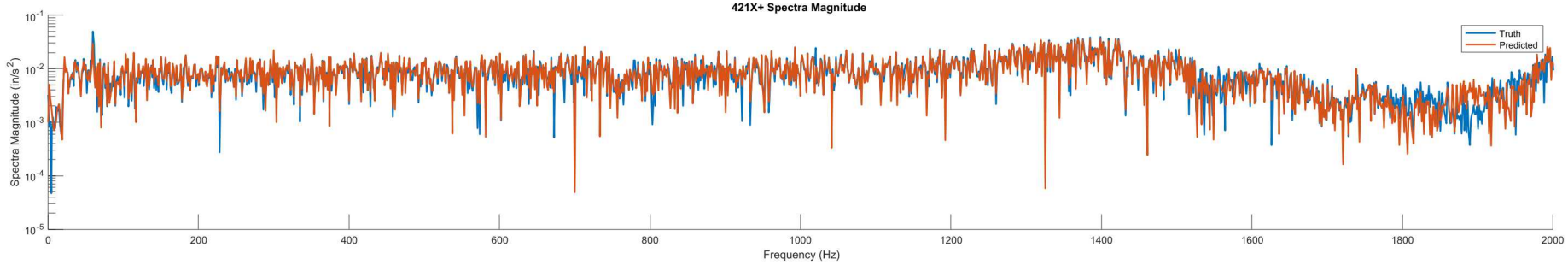
# Results (Experimental to 6DOF)

TRAC Values



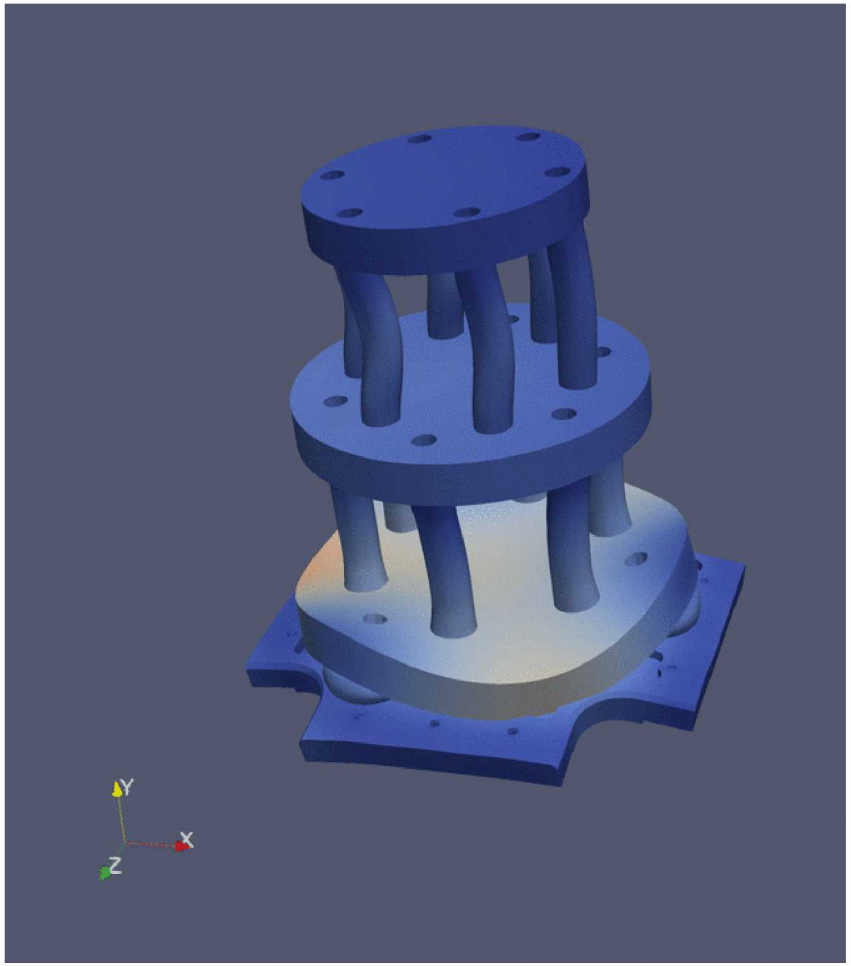

Time History (Worst Predicted DOF)



# Results (Experimental to 6DOF)

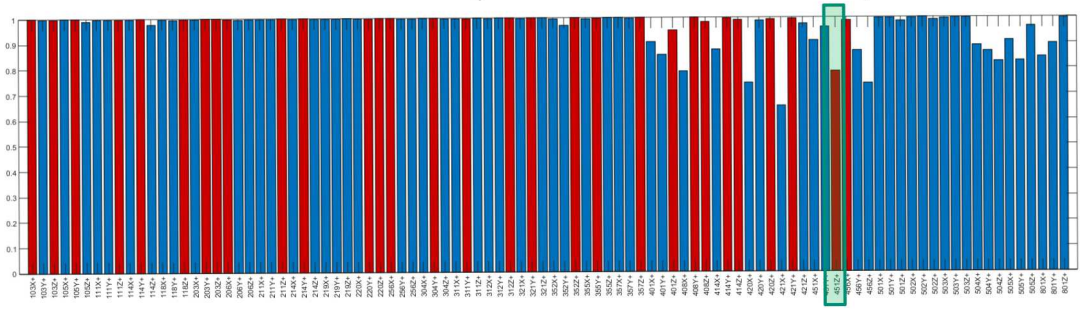
Case Study: Missing Dynamics - Base Plate Mode (FEM:37 at 1861.63 Hz)



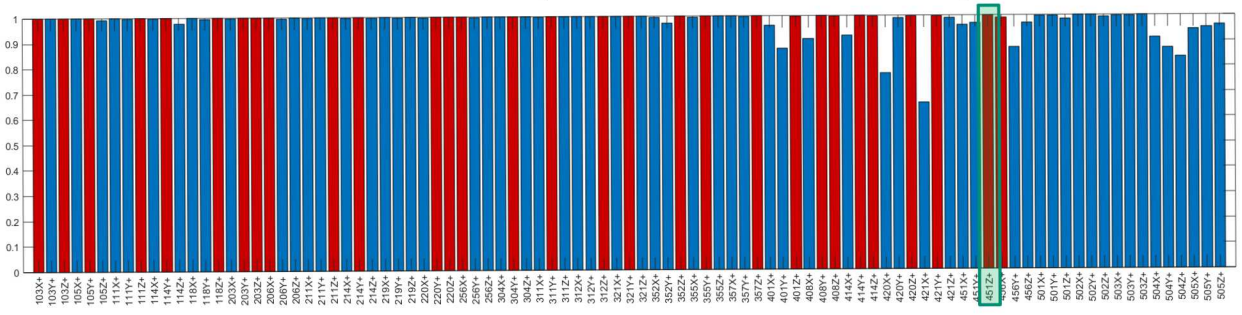
# Results (Experimental to 6DOF)

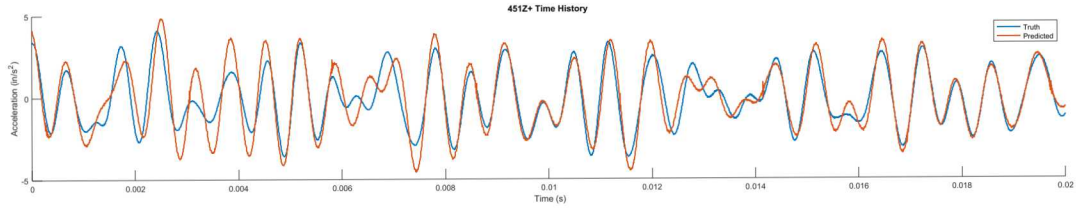
## Case Study: Missing Dynamics - Base Plate Mode (FEM:37 at 1861.63 Hz)

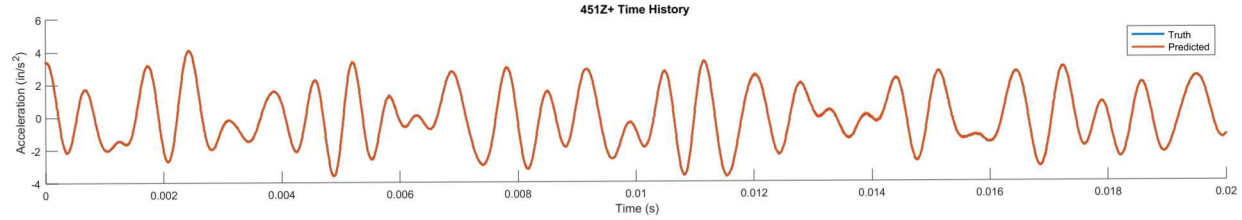
### TRAC Values (No Base Plate Mode)

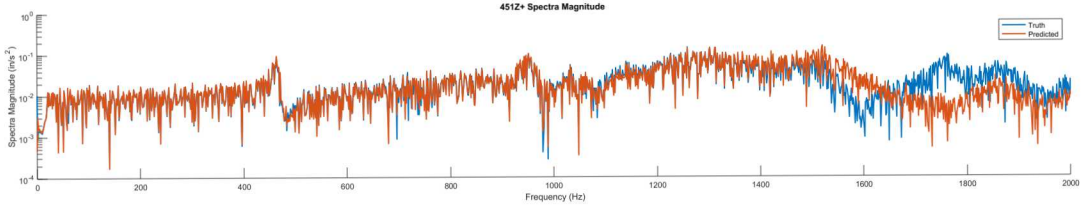


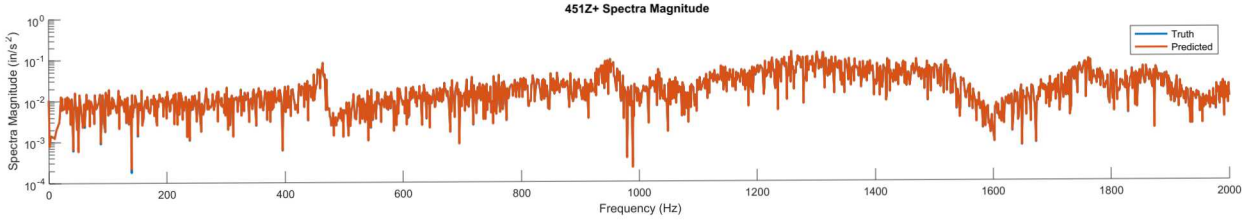
### TRAC Values (With Base Plate Mode)





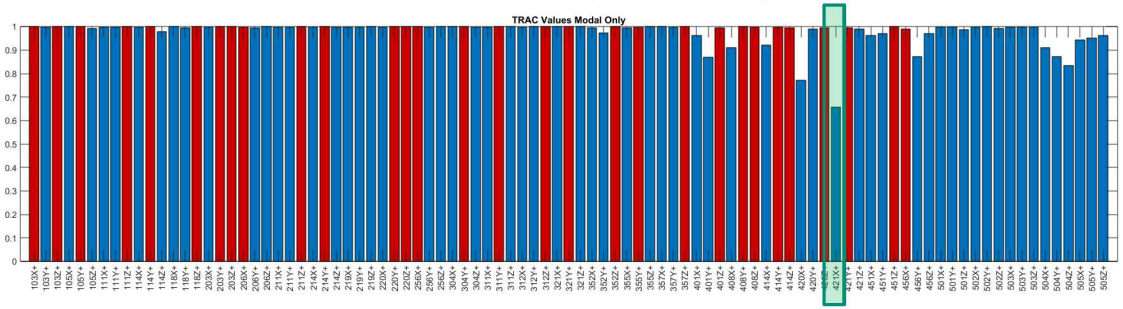



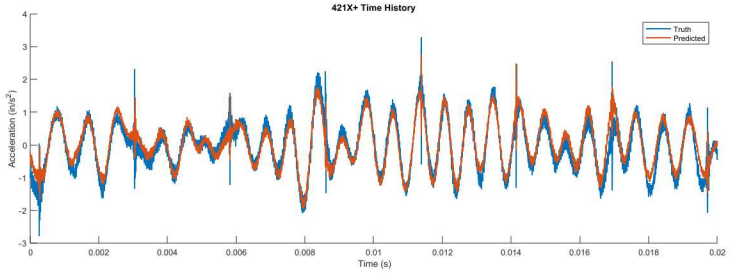



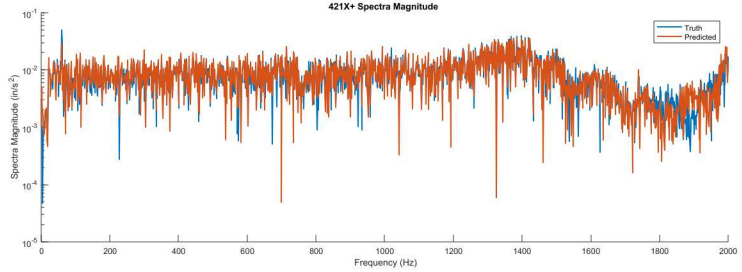
# Results (Experimental to 6DOF)

## Case Study: 1800 Hz Low Pass Filter

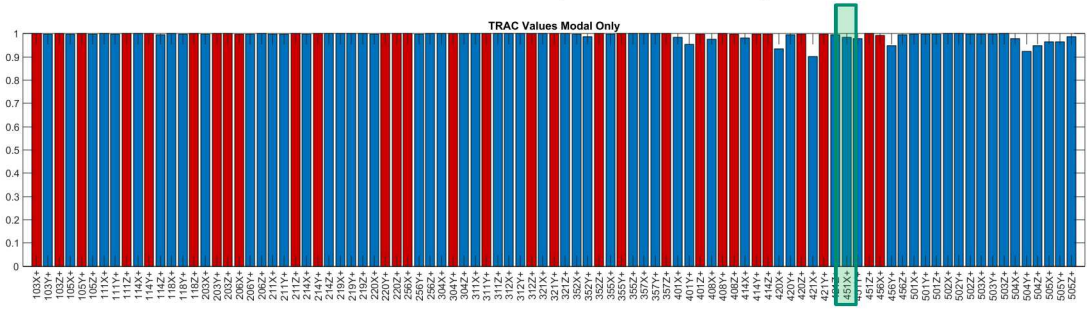
### TRAC Values (No Filter)

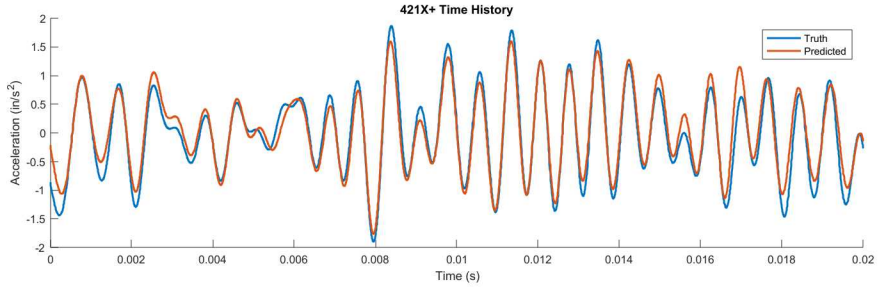


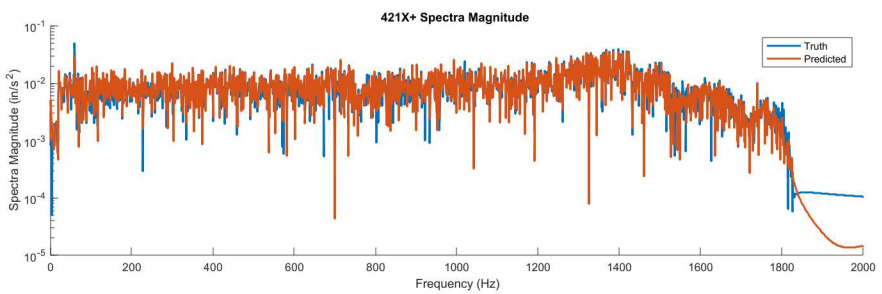




### TRAC Values (With Filter)



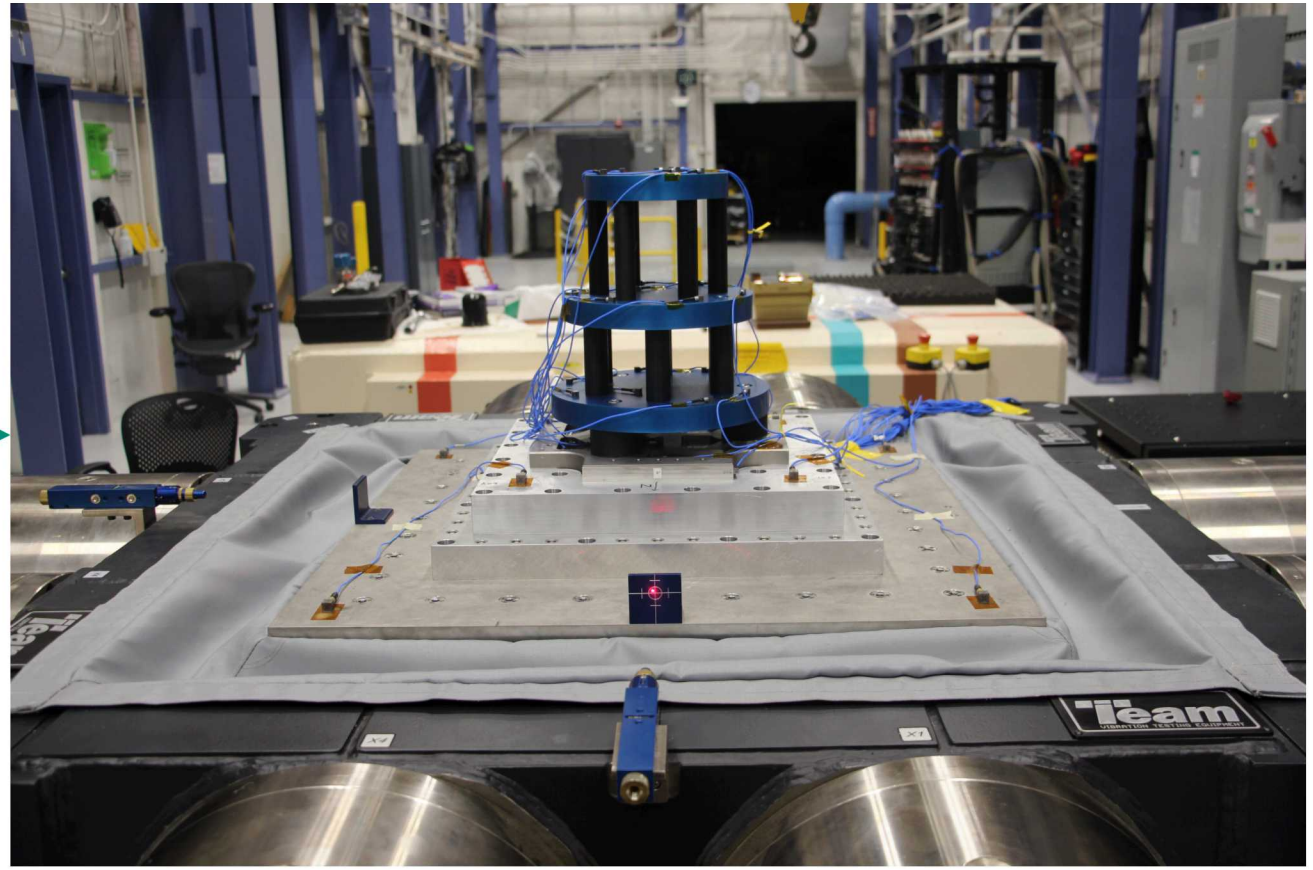



# Results (Experimental to 6DOF)

FEM Mode Shapes

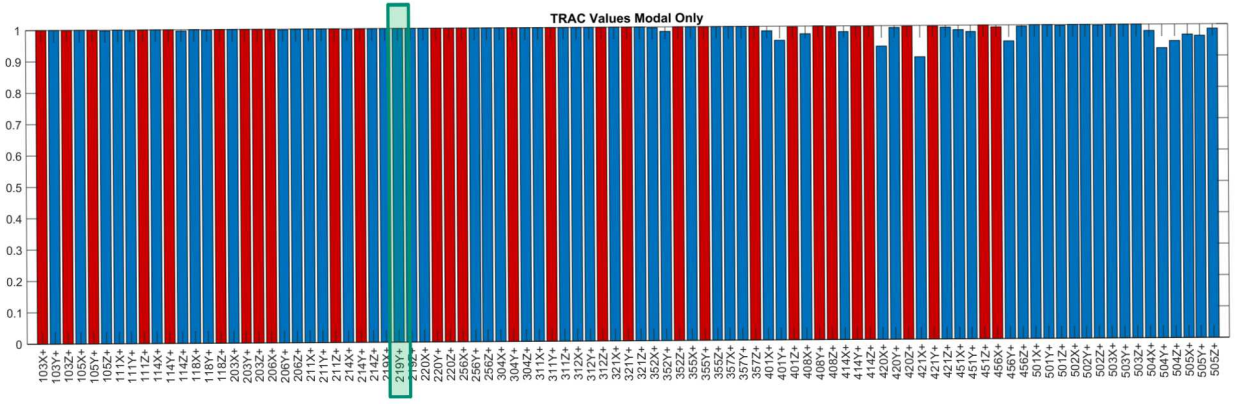
Used to Predict

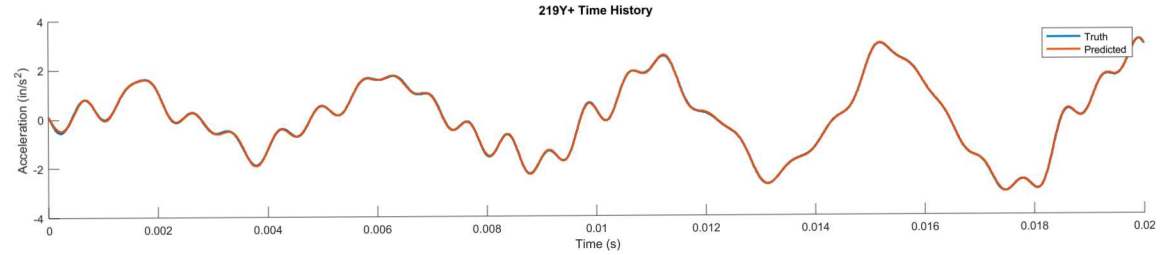
6 DOF Shaker Environment

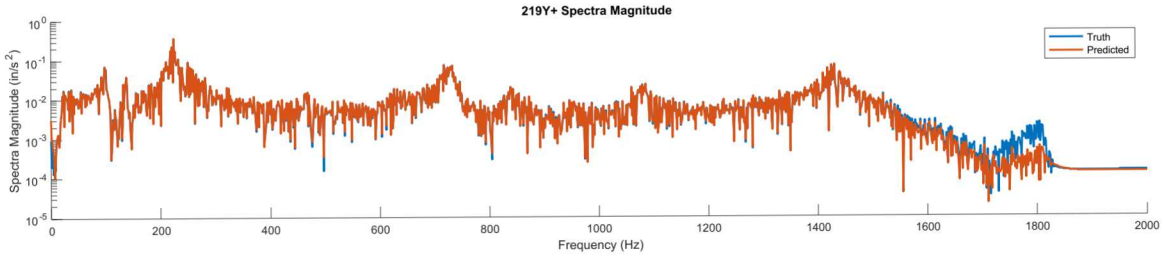


# Results (FEM to 6DOF)

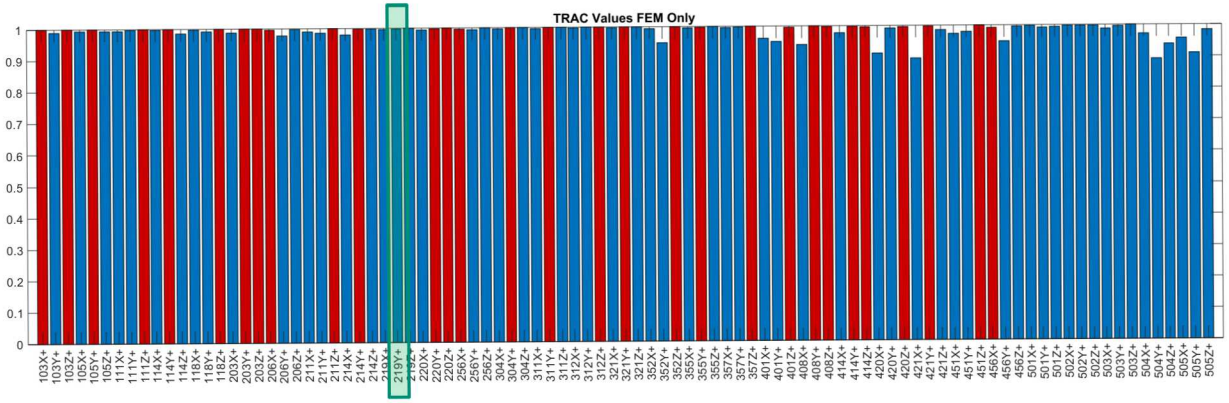
## Experimental to 6DOF

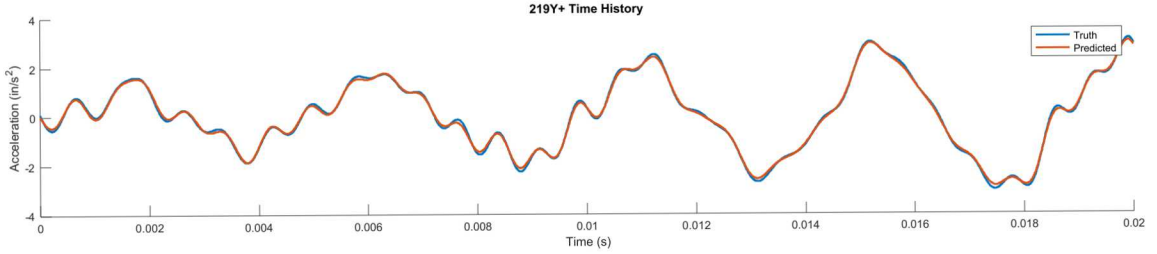


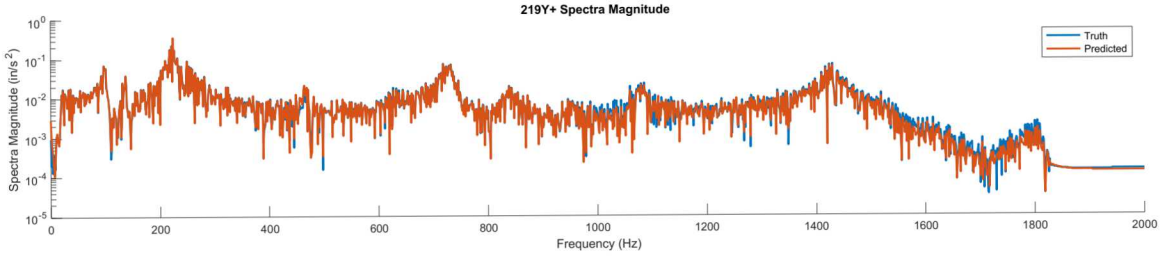




## FEM to 6DOF



# Conclusions

- Response prediction of 6DOF environment was accurate
- Responses can be predicted using either experimental or FEM modes (well correlated FEM)
- Careful selection of measurement DOFs is imperative

# Future Work

- Expand method to more of the rocket structure
- Develop rocket component specifications from expanded results
- Re-create flight dynamics in laboratory test
- Investigate uncertainty of expanded results

# Acknowledgements

Sandia National Laboratories

Pete Avitabile

Greg Tipton

Brian Owens

Randy Mayes

Mo Kahn

# Questions