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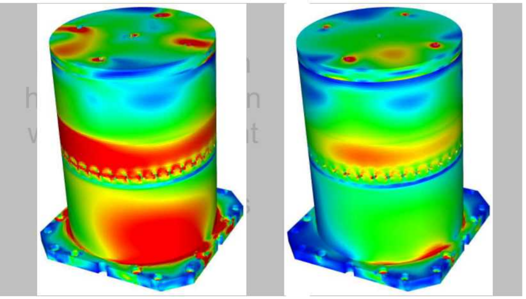

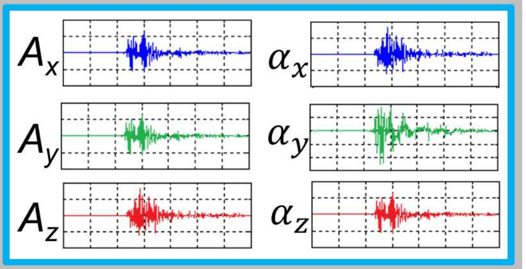

6 DOF Shock and Vibration: Testing and Analysis

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Motivation

- 6 Degree of Freedom (DOF)
  - Inputs applied to a test article/model with 6 DOFs
  - 3 translational DOF, 3 rotational DOF
- Experimental
  - 6 DOF shakers have potential to provide a more representative test of an actual environment than a single-axis test specification
  - Off-axis inputs arise from single-axis testing on single-axis shaker
  - 6 DOF shakers allow off-axis inputs to be controlled/minimized during a single-axis test specification
- Analytical
  - Apply 6 DOF input to models in shock and vibration analysis
  - More accurate post-test analysis and calibration
    - Cross-axis inputs can be significant
  - Investigate unmeasured quantities from testing (i.e. stress)
  - Tool for understanding and developing better 6 DOF testing

Outline

- 6 DOF Analysis Procedure
  - Derivation of 6 DOF inputs
  - Considerations
- Model Configuration
- Vibration
  - 1 DOF vs. 6 DOF Testing
  - Impact on stresses
- Shock
  - Single-axis test spec vs. 6 DOF environment
  - Impact on stresses

Derivation of 6 DOF Inputs

- 6 DOF input is the effective rigid body motion of the structure about seismic mass.
  - Should be relatively non-compliant to avoid capturing deformable effects in the calculation of rigid body motion.
  - Typically use accelerometers on a fixture.
- Consider a measurement by tri-axial accel "i": $\vec{\boldsymbol{a}}^{(\boldsymbol{i})}(\boldsymbol{t})$
- Let the coordinate of this measurement be: $\vec{\boldsymbol{x}}^{(\boldsymbol{i})}$
- Let the reference/ input location coordinate be: $\vec{\boldsymbol{x}}^{(\mathbf{0})}$
- The accel has a position vector: $\vec{\boldsymbol{r}}^{(\boldsymbol{i})} = \vec{\boldsymbol{x}}^{(\boldsymbol{i})} - \vec{\boldsymbol{x}}^{(\mathbf{0})}$

Derivation of 6 DOF Inputs (2)

- Let the effective rigid body acceleration of the structure be:
  - $\vec{A}$(t) for translational acceleration
  - $\vec{\alpha}$(t) for angular acceleration
- The accelerometer acceleration can the be expressed as:
  - $\vec{a}^{(i)}(t) = [I_{3x3}]\vec{A}(\mathrm{t}) + \vec{\alpha}(t) \times \vec{r}^{(i)}$
  - $\vec{a}^{(i)}(t) = [I_{3x3}]\vec{A}(\mathrm{t}) + \left[\widetilde{\vec{r}^{(i)}}\right]^T \vec{\alpha}(t)$

$$[\tilde{\vec{r}}] = \begin{bmatrix} 0 & -r_3 & r_2 \\ r_3 & 0 & -r_1 \\ -r_2 & r_1 & 0 \end{bmatrix}$$

- We can develop a system of equations for multiple measurement points:

$$\begin{bmatrix} \vec{a}^{(1)}(t) \\ \vec{a}^{(2)}(t) \\ \vdots \\ \vec{a}^{(n)}(t) \end{bmatrix} = \begin{bmatrix} [I_{3x3}] & \left[\widetilde{\vec{r}^{(1)}}\right]^T \\ [I_{3x3}] & \left[\widetilde{\vec{r}^{(2)}}\right]^T \\ \vdots & \vdots \\ [I_{3x3}] & \left[\widetilde{\vec{r}^{(3)}}\right]^T \end{bmatrix} \begin{bmatrix} \vec{A}(t) \\ \vec{\alpha}(t) \end{bmatrix}$$

Solve for RB Accelerations

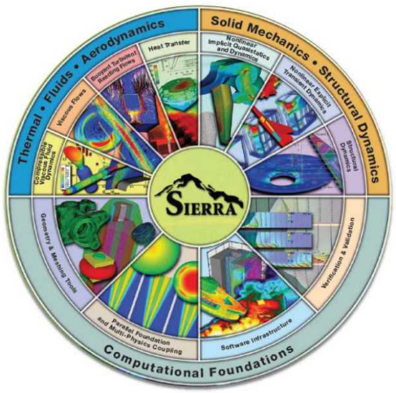
Considerations

- Methodology to derive 6 DOF inputs relies heavily on:
  - Accelerometers mounted to non-compliant points
  - Sufficient measurements to characterize 6 DOF motion
  - Accurate measurement of accelerometer:
    - Position
    - Orientation
    - Polarity (signs do matter)
- Requires measurement of time histories from vibration testing
- Thorough documentation of test setup/instrumentation & accurate channel tables are very helpful
- We've developed some tools to troubleshoot some of these issues

Analysis Work Flow

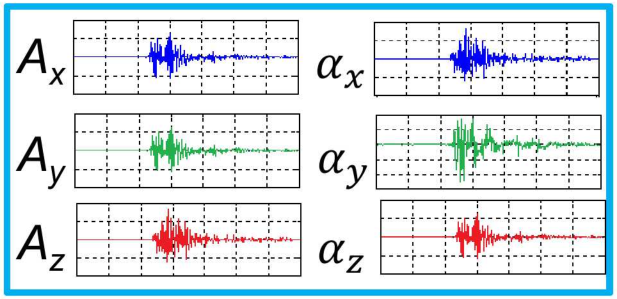
- Toolkit automates deriving 6 DOF inputs from test data
- Written for interface to Sandia's Sierra-SD FEA Software

Inputs:
- Accel coordinates
- Seismic mass coordinate
- Accel time histories



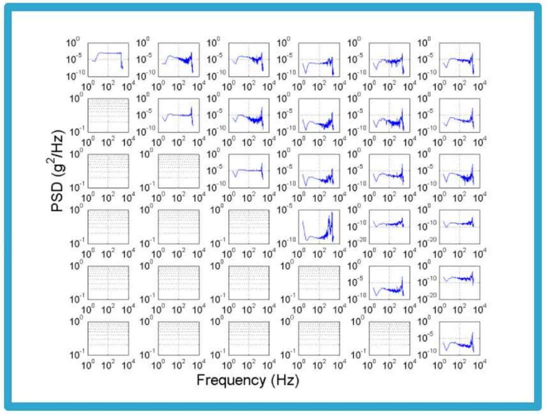
6 DOF Toolkit

Shock



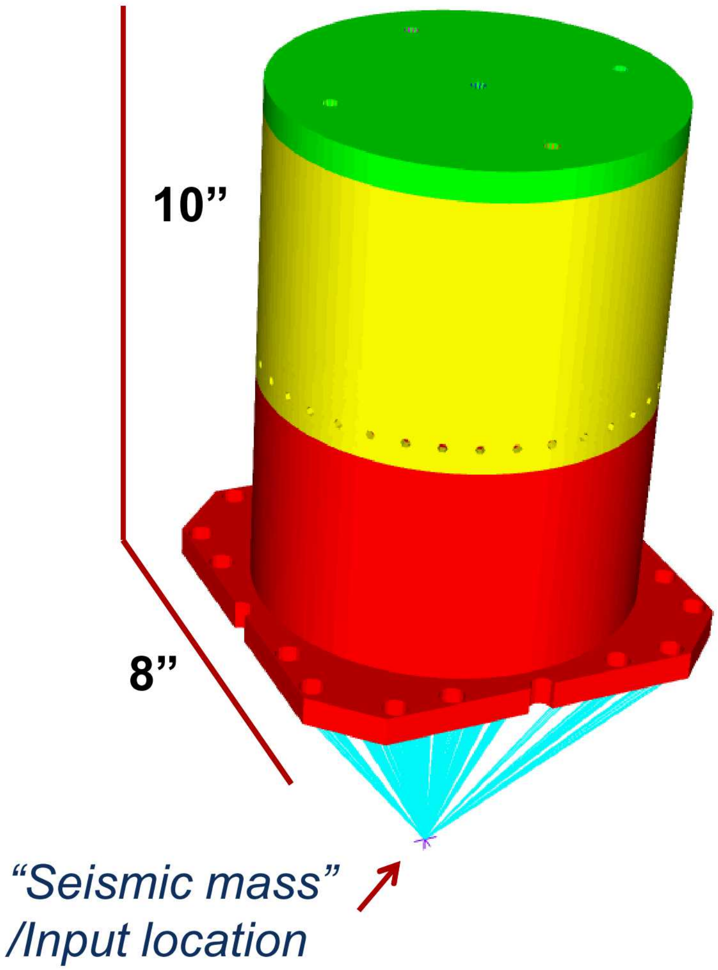
Outputs:
- Sierra function files
- PSD/SRS plots
- Troubleshooting plots

Vibration



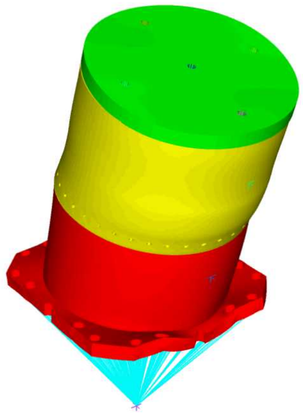
Model Configuration

- 3 piece bolted "can" structure
  - *Bottom can/flange*
  - *Upper can*
  - *Top plate/mass*
  - *Aluminum*
- Test-bed with reasonable complexity
- Rigid elements & concentrated mass model test stand/connection
- Employed in physical 1 DOF and 6 DOF testing
- 6 DOF input will be derived from accelerometers on corners of flange

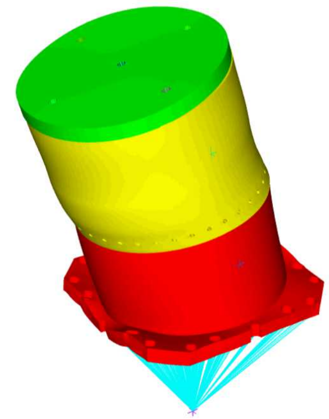


Analytical Modes

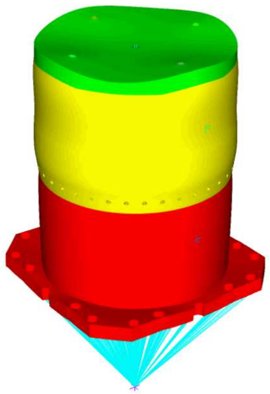
Frequency = 709 Hz



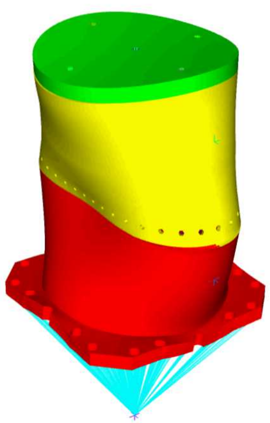
Frequency = 709 Hz



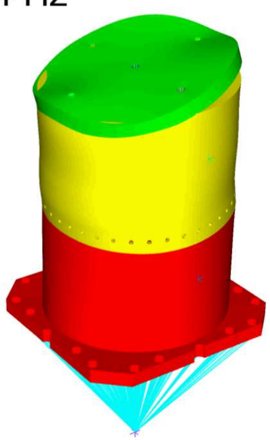
Frequency = 1816 Hz



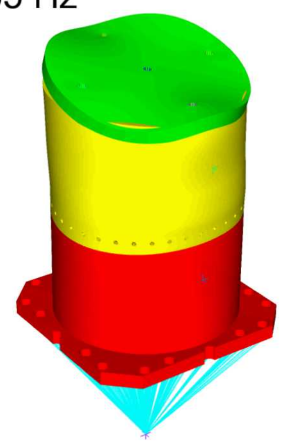
Frequency = 2761 Hz



Frequency = 2764 Hz

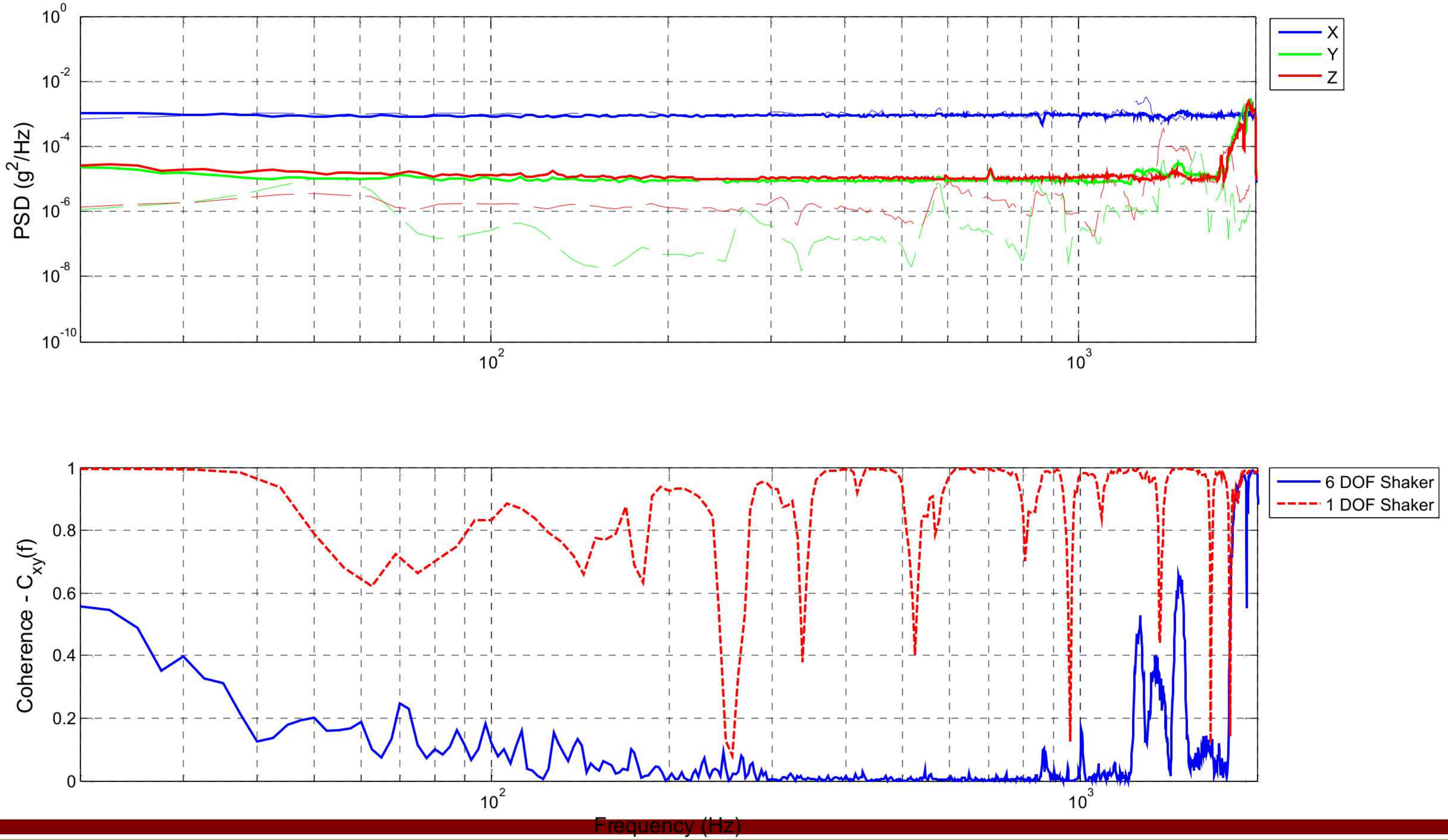


Frequency = 2765 Hz



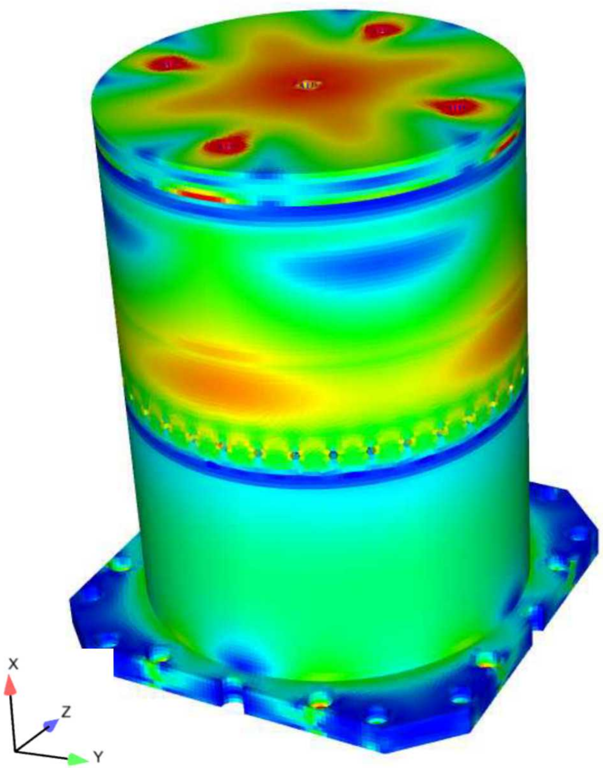
1 DOF vs. 6 DOF Testing

- Single-axis (axial) low level random vibration input on 1 and 6 DOF shakers
  - Off-axis inputs controlled 2 orders of magnitude lower than in-axis
  - Coherence is minimized on 6 DOF shaker

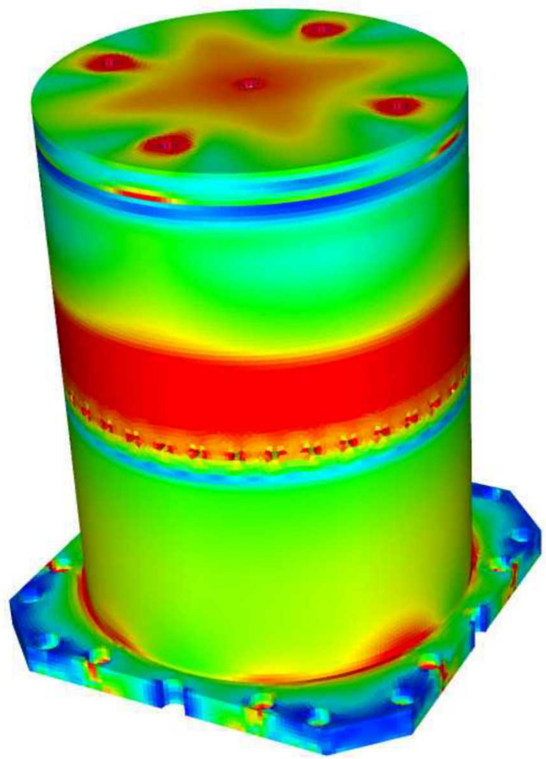


Vibration: Stress Contours

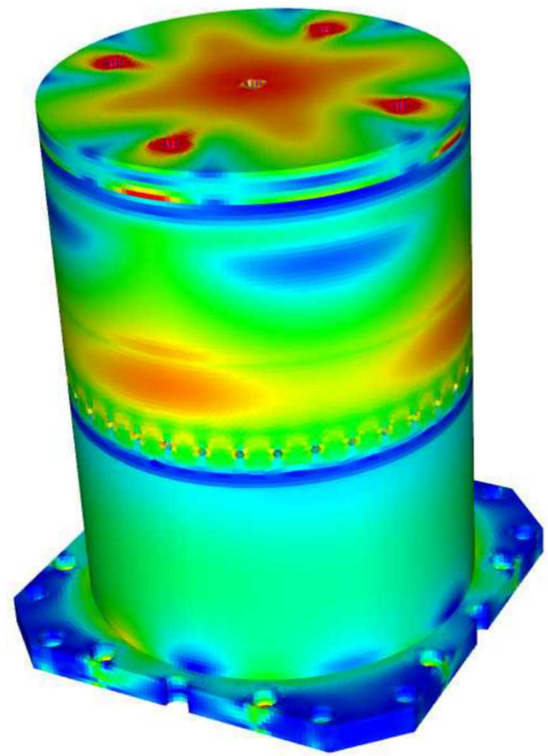
Ideal Single-Axis:



6 DOF Shaker:



1 DOF Shaker:

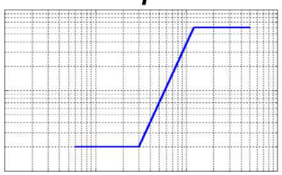


6 DOF Shock Input

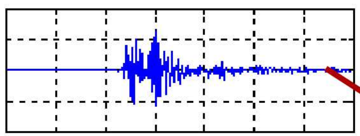
- Comparison of single-axis test spec and 6 DOF input recovered from environment
- Traditionally environmental data is broken out into single-axis test specs
- 6 DOF testing affords new opportunities

Single-Axis Test Spec:

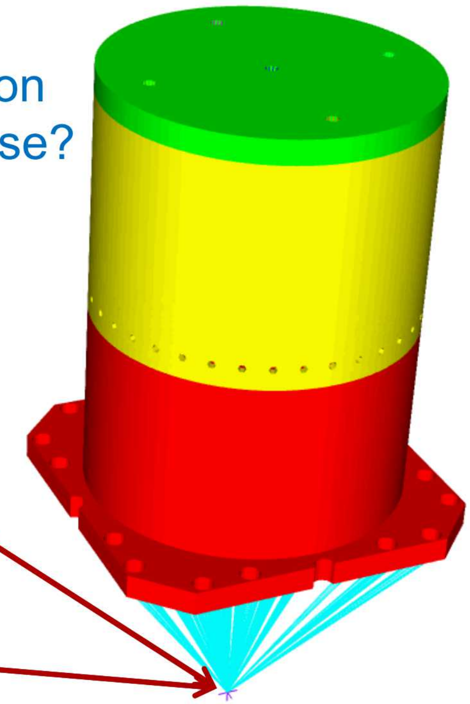
SRS Spec



Decayed Sine Series

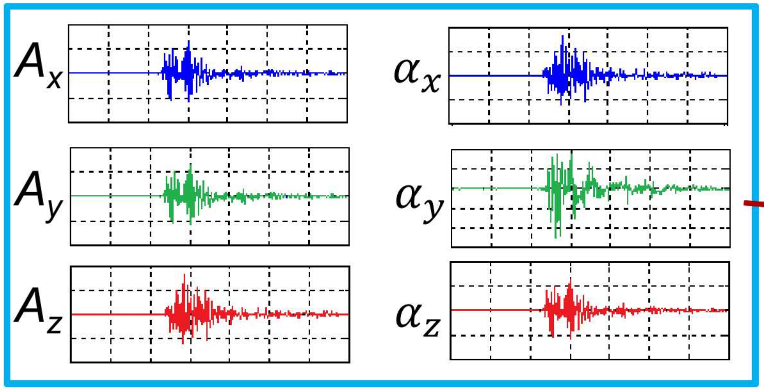


What's the impact on component response? Stresses?



VS.

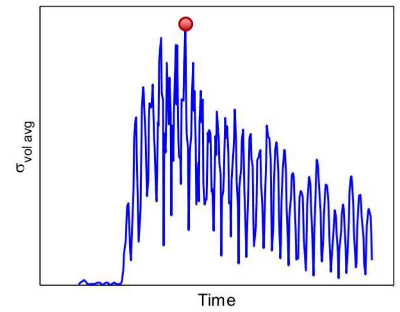
Recovered 6 DOF Input:



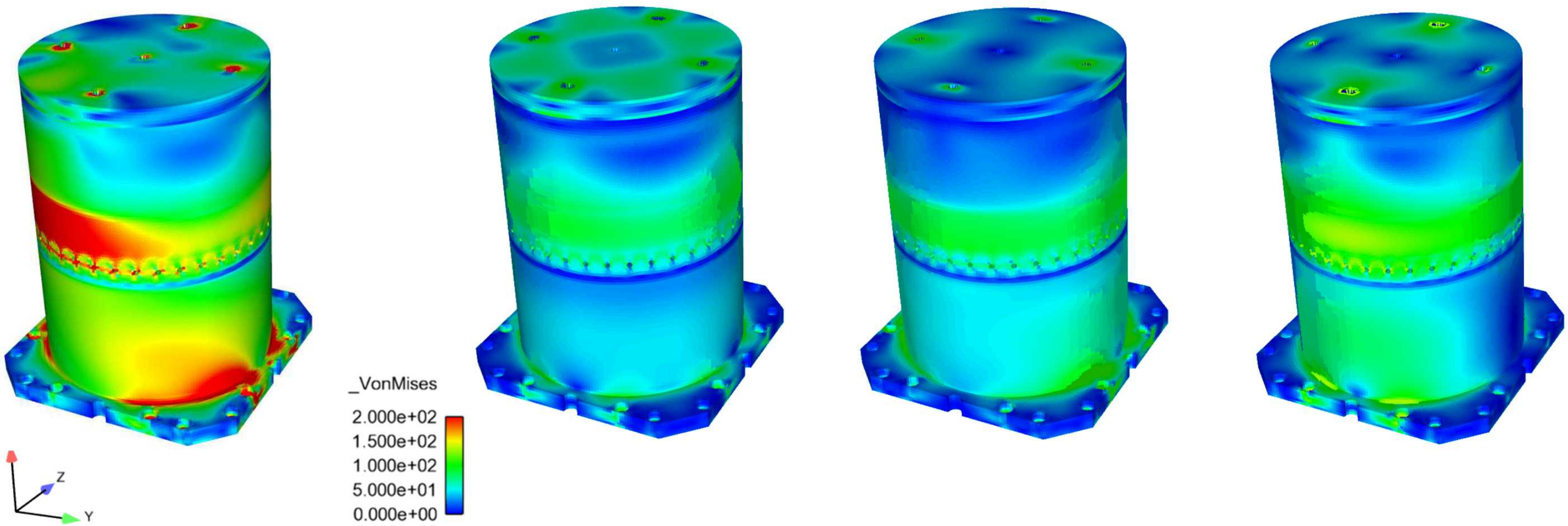
1 & 6 DOF Shock: Stresses

- Compared Von Mises stress distributions at instance of maximum volume averaged stress
- Noticeably different levels and distributions between 6 DOF and 1 DOF inputs

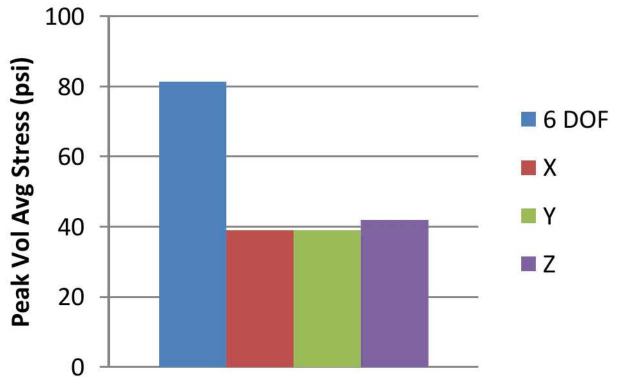
$$\sigma(t)_{vol\ avg} = \frac{\sum_{i=1}^{Nel} \sigma_i(t) v_i}{\sum_{i=1}^{Nel} v_i}$$

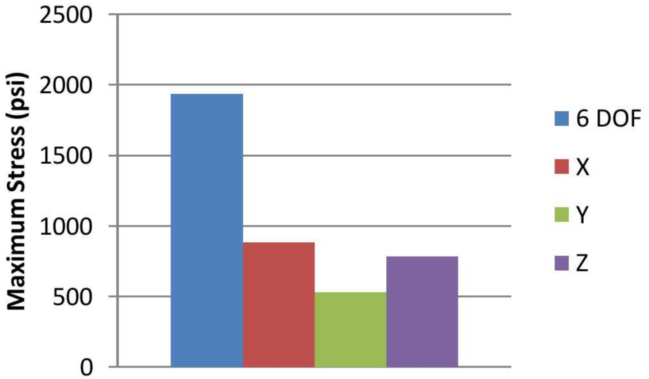


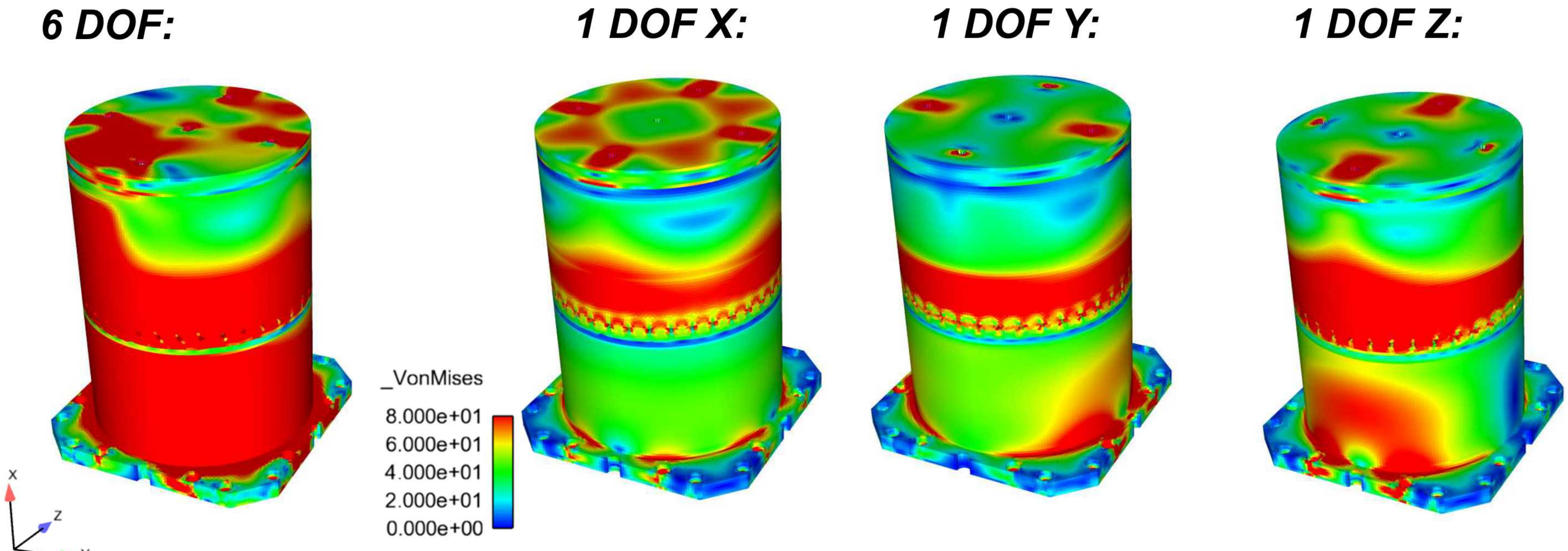
6 DOF: **1 DOF X:** **1 DOF Y:** **1 DOF Z:**



1 & 6 DOF Shock: Stresses (2)







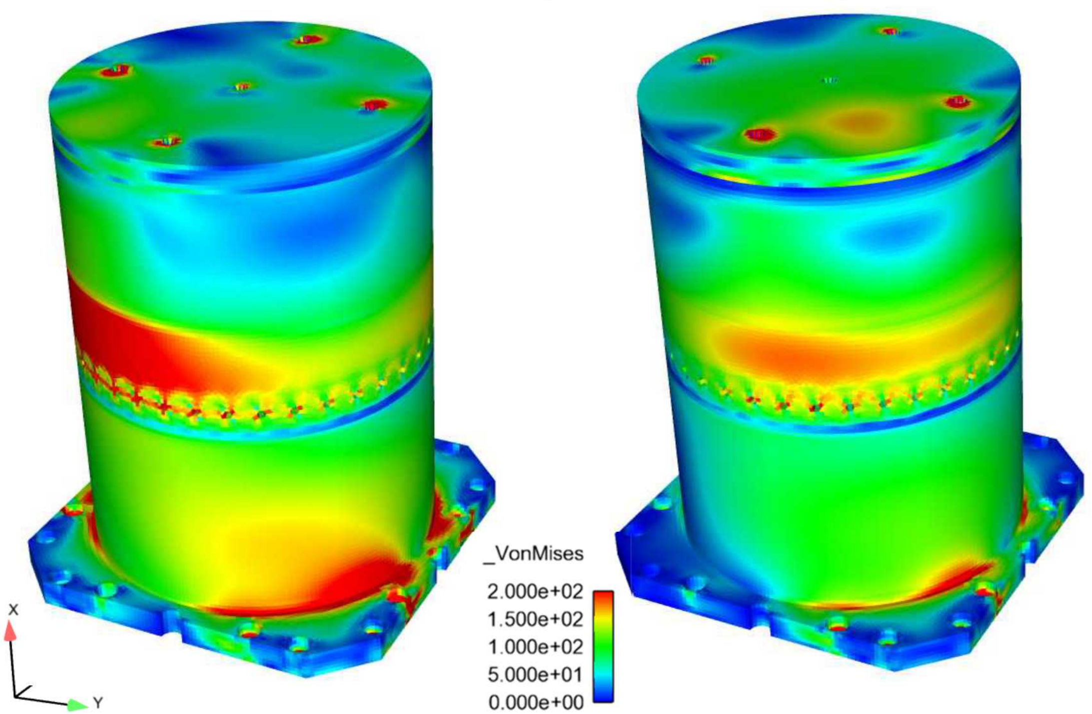
(same as last slide, contours rescaled to lower stress value)

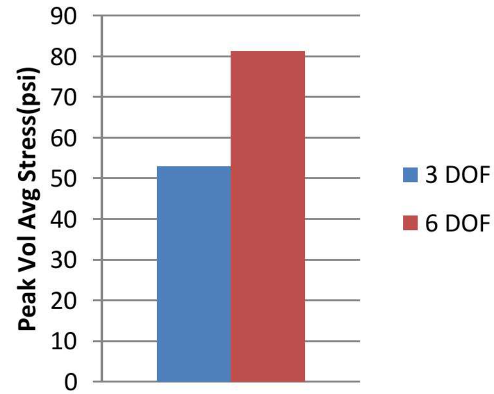
3 & 6 DOF Shock: Stresses

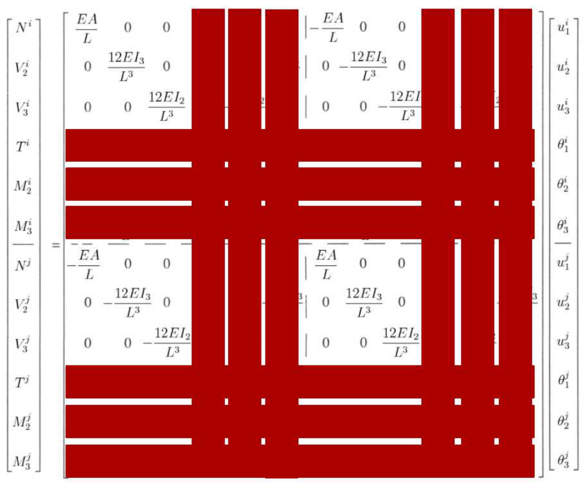
- Can we capture the fundamental input & response with 3 DOF inputs?
- How important are rotations? … <u>They can be very important</u>

6 DOF:

3 DOF: (translational)







Conclusions

- 6 DOF testing affords new opportunities for testing
  - More representative, multi-axis test environments
  - More control over single-axis test inputs and associated cross-axis inputs
- 6 DOF analysis allows for greater insight to be obtained
  - Designing better 6 DOF tests, understanding relationships of input and stress
  - Better model validation through accurate characterization of inputs
  - Development of tools to integrate 6 DOF into analysis workflow
- Vibration
  - Compared cross-axis input levels and coherence of tests on 1 & 6 DOF shakers
  - Ongoing work to understand impact of off-axis control levels and coherence
- Shock
  - Compared a 6 DOF test spec to single-axis test specs
  - Examined impact of testing on stresses in a component
  - Rotational input can be very important