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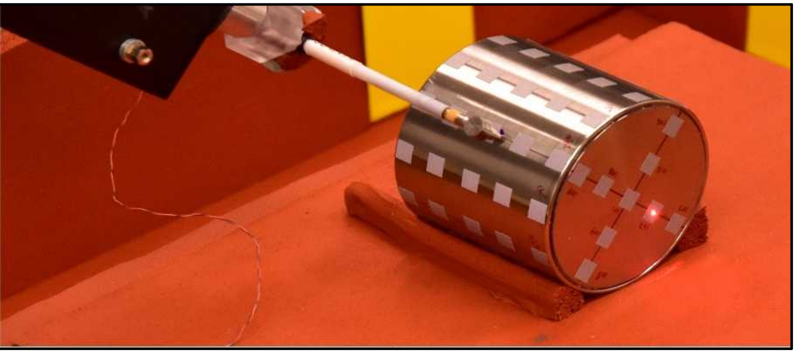

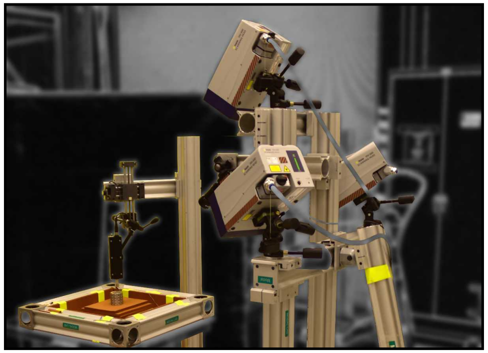

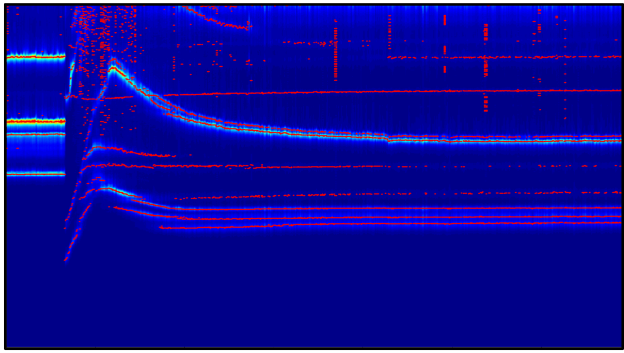

Thermal Battery Modal Testing and Time Varying System Dynamics with 3D SLDV

Bryan Witt & Brandon Zwink

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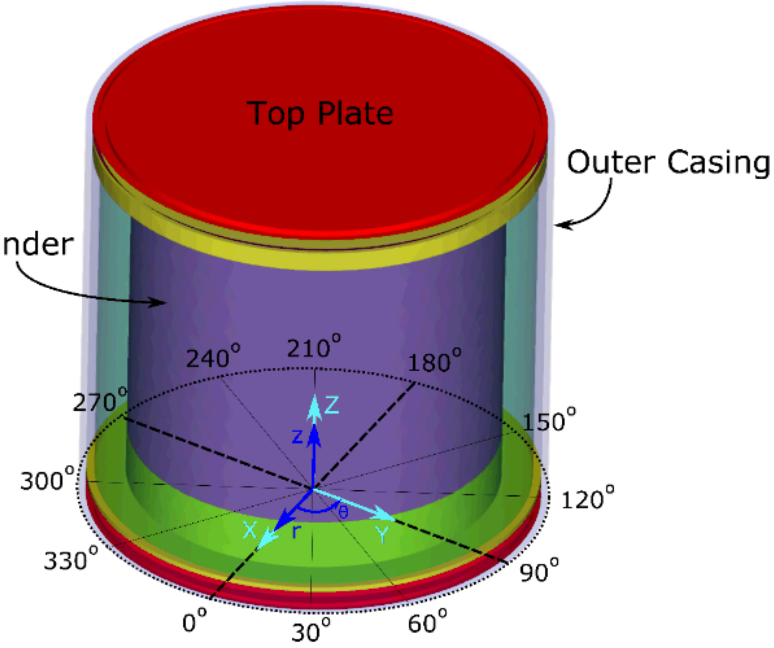
Outline

- Test article
- Motivation
- Preliminary FEM
- Pre-Activation Testing
  - Roving hammer
  - 3D scanning laser Doppler vibrometer
  - Method comparisons
- Activation Testing
  - Setup
  - Data processing/presentation
  - Mode tracking
- Conclusions

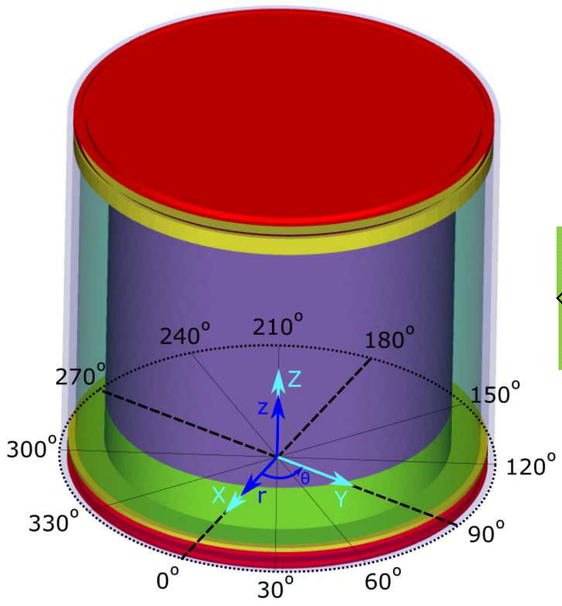
Test Articles

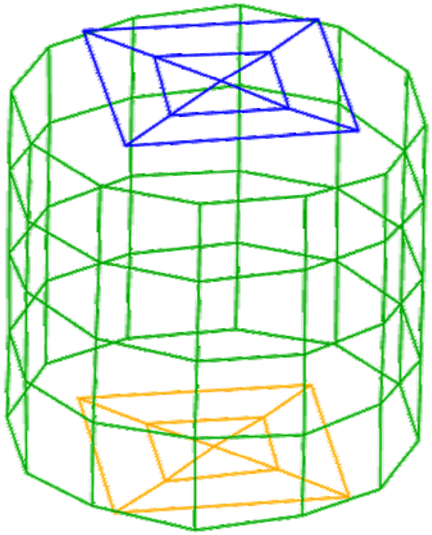


- Thermal Battery
  - Approximate dimensions: height = 6 cm, O.D. = 6 cm, mass = 0.5 kg
  - Six units tested
- Internals under preload, surrounded by insulation material
- Sealed system

Motivation

- Need to develop correlated Finite Element Model (FEM)
- No previous experimental data for model correlation
- Establish baseline modal properties
  - Second phase of testing to investigate variation in modal properties during internal state changes

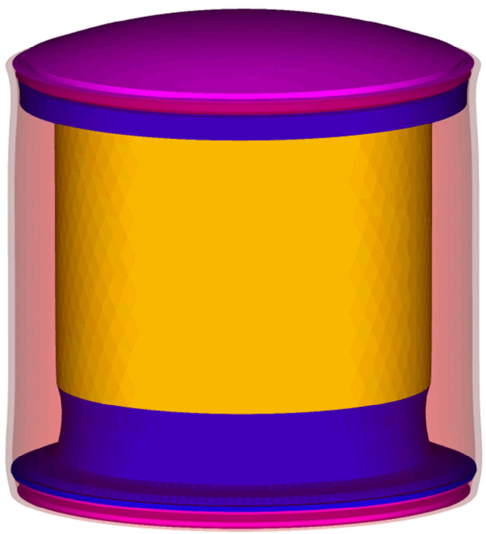




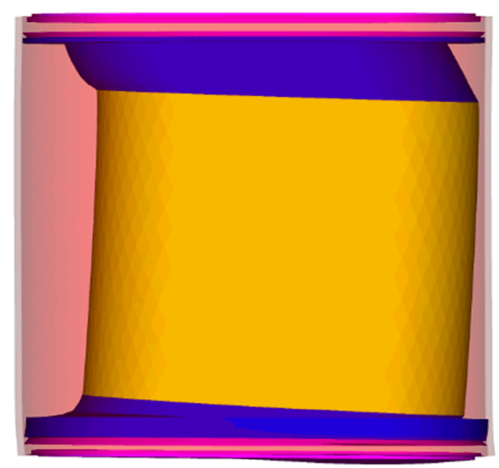
Finite Element Model

- Uncorrelated FEM primary modes of interest:
  - Internal cylinder axial and shear modes
  - Not accessible to measure, no internal instrumentation

Axial Mode

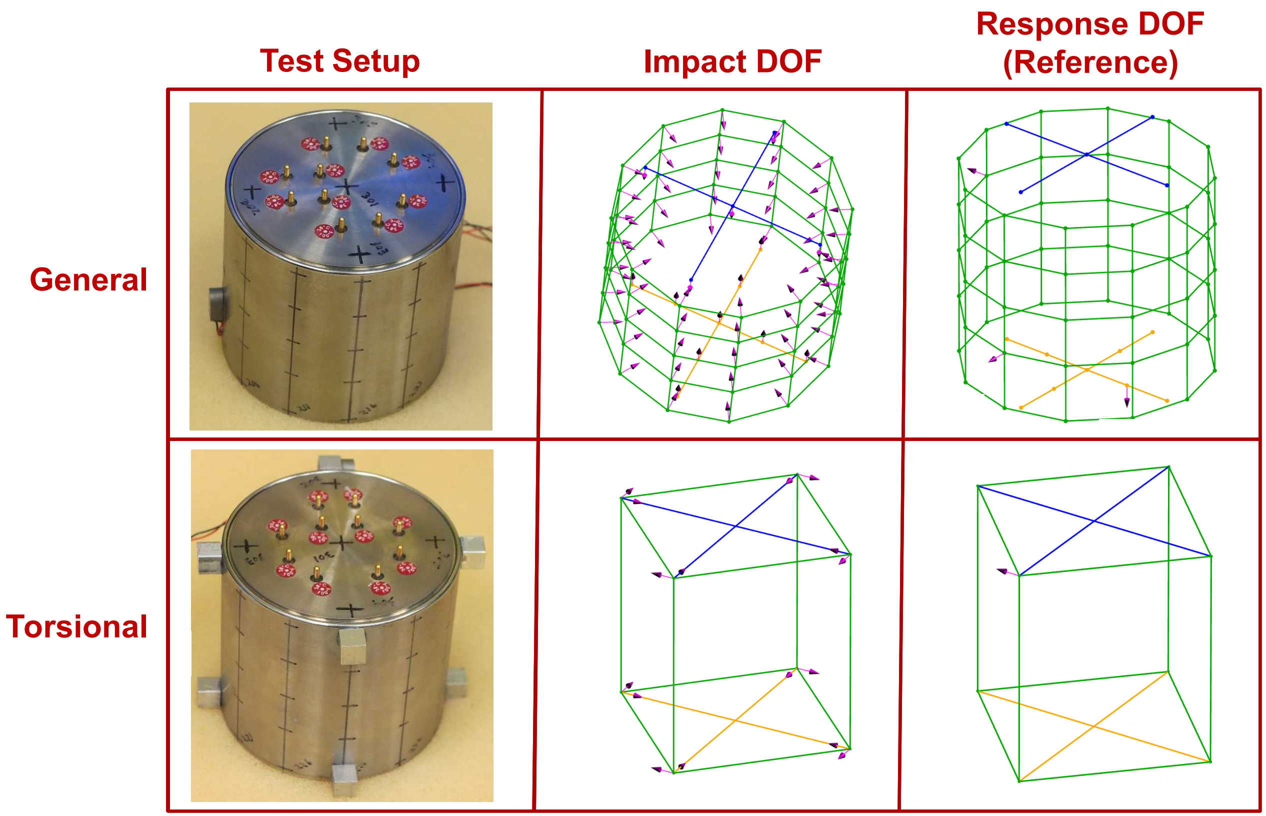


Shear Mode (Pair)

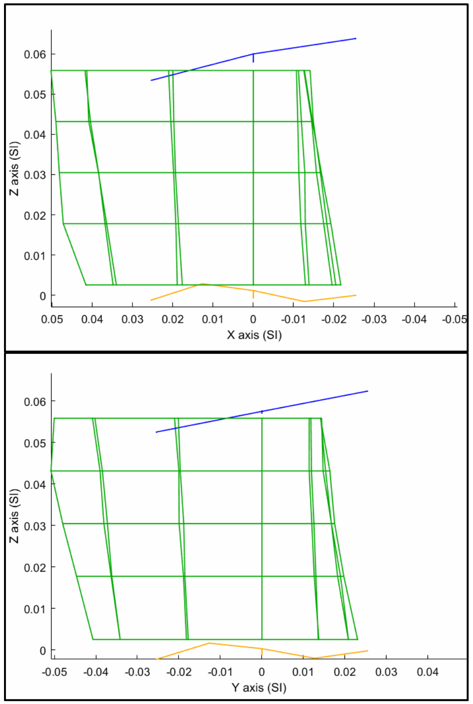


Pre-Activation: Roving Hammer

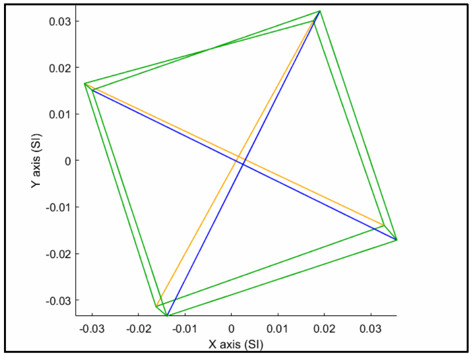
- Attempt to avoid mass loading small test article
  - Including additional reference accelerometers
- Can only collect degrees of freedom (DOF) normal to surfaces
- Torsion degrees of freedom measured with separate configuration
  - Small aluminum blocks added at 90^{o} for mounting/impact surfaces



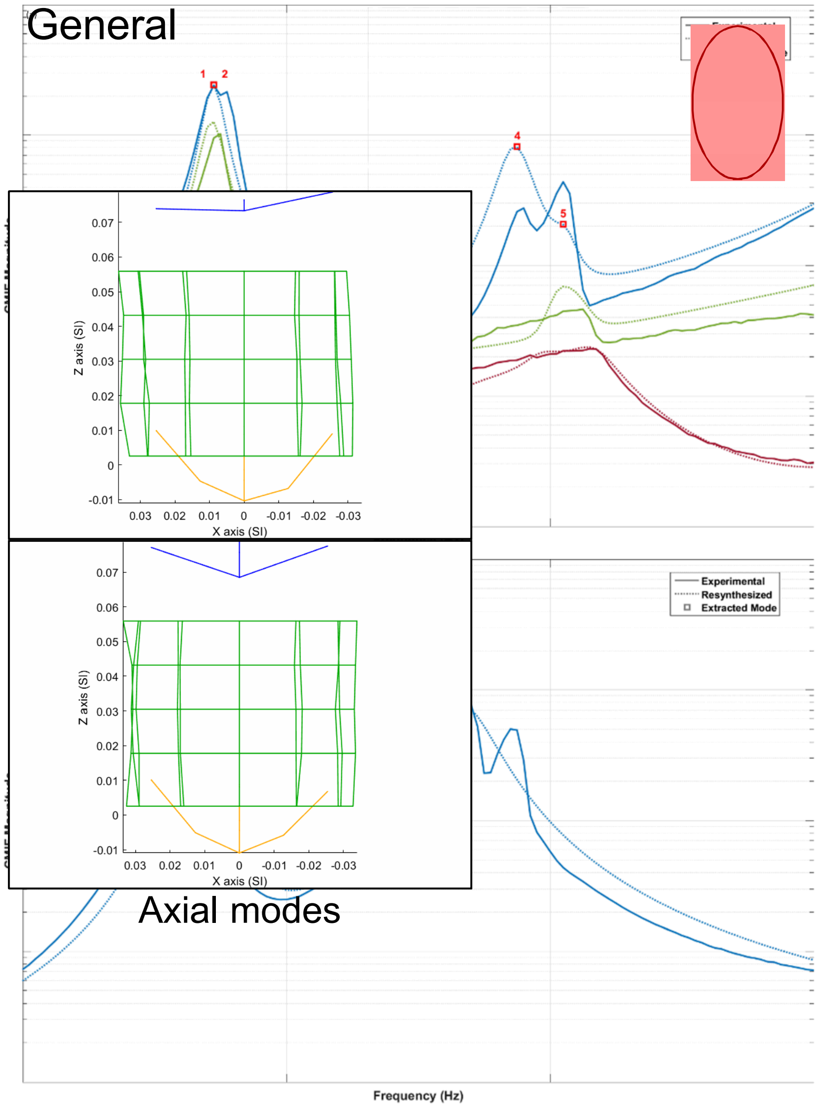
Pre-Activation: Roving Hammer



Internal shear modes

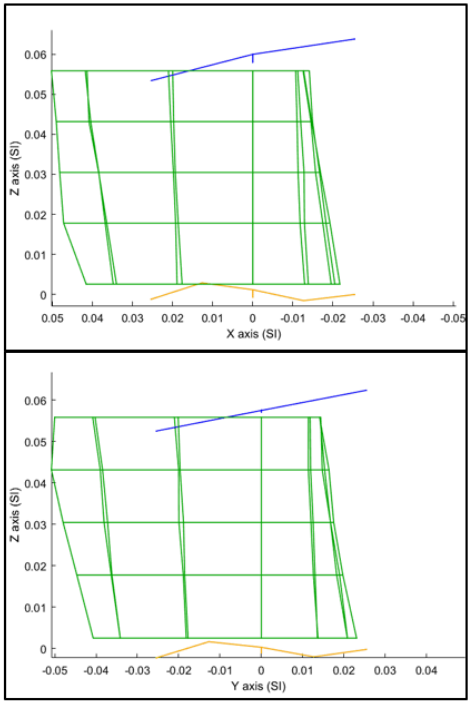


Internal torsion mode

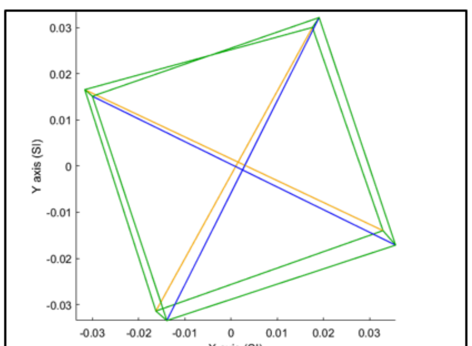


Axial modes

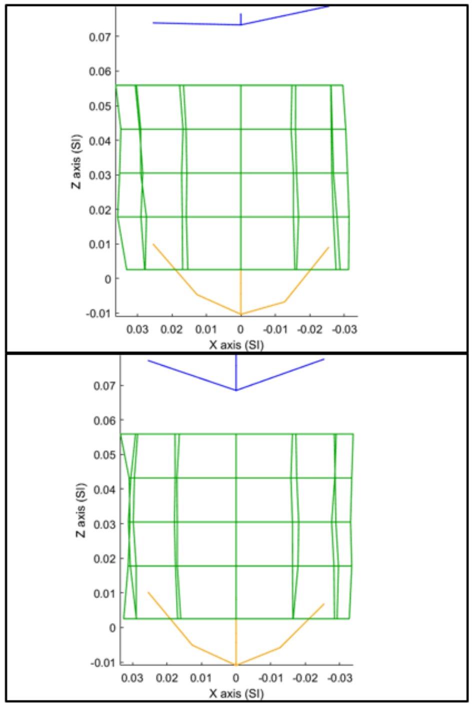
Pre-Activation: Roving Hammer



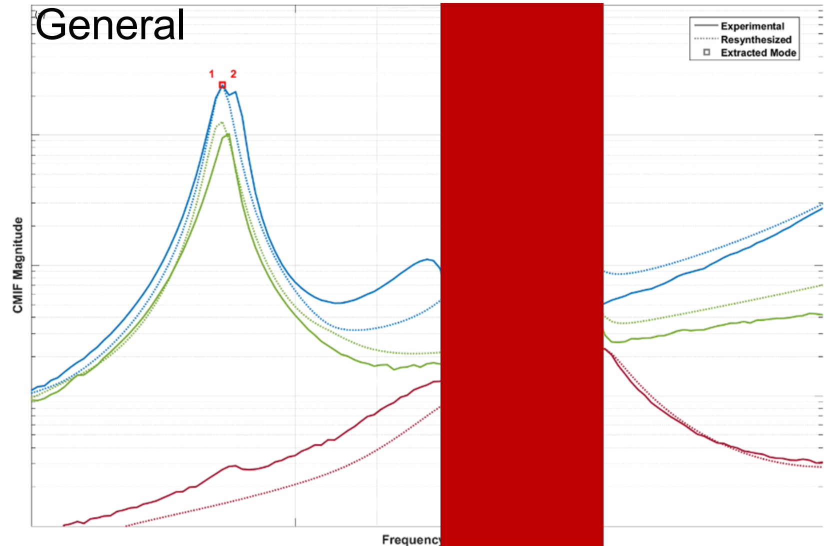
Internal shear modes

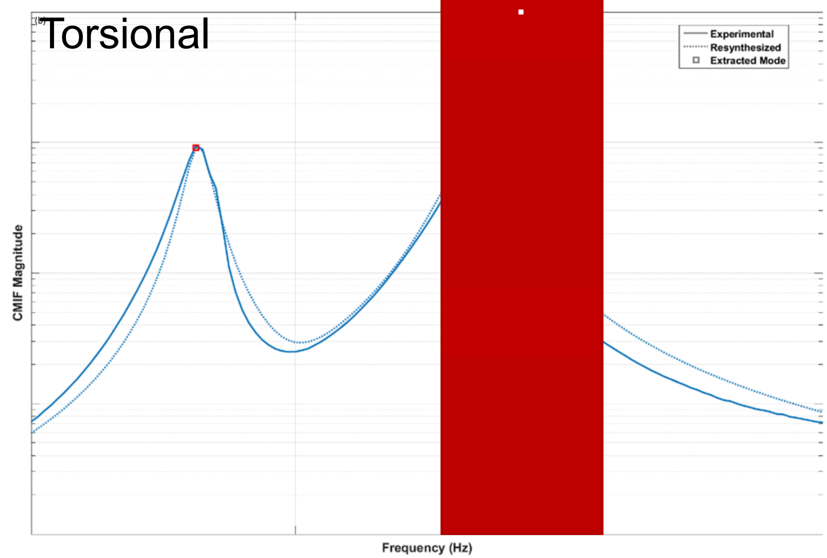


Internal torsion mode

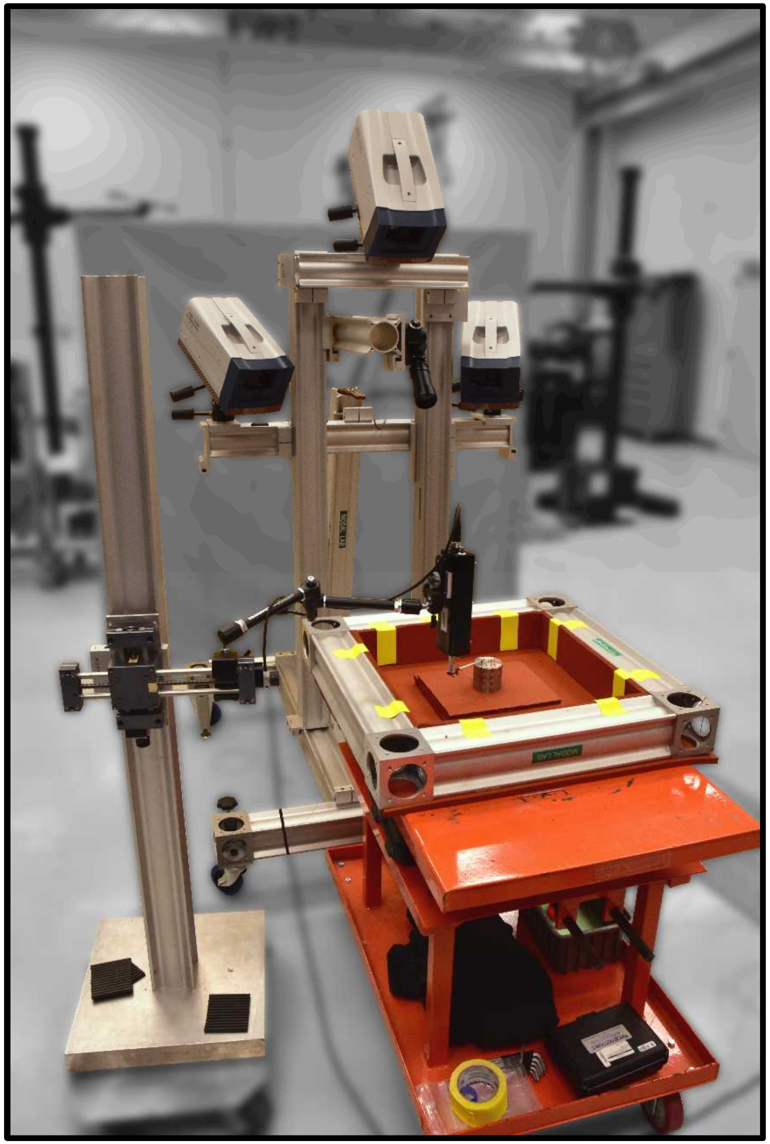


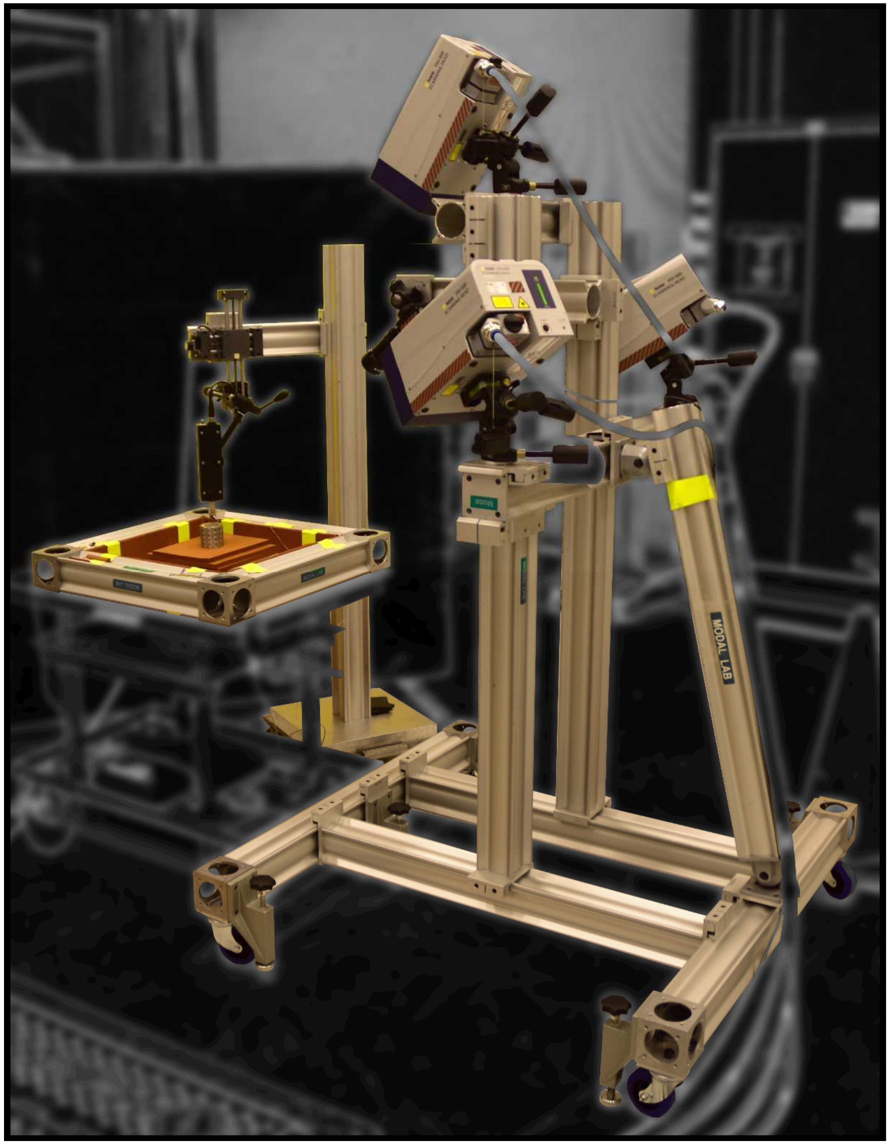
Axial modes



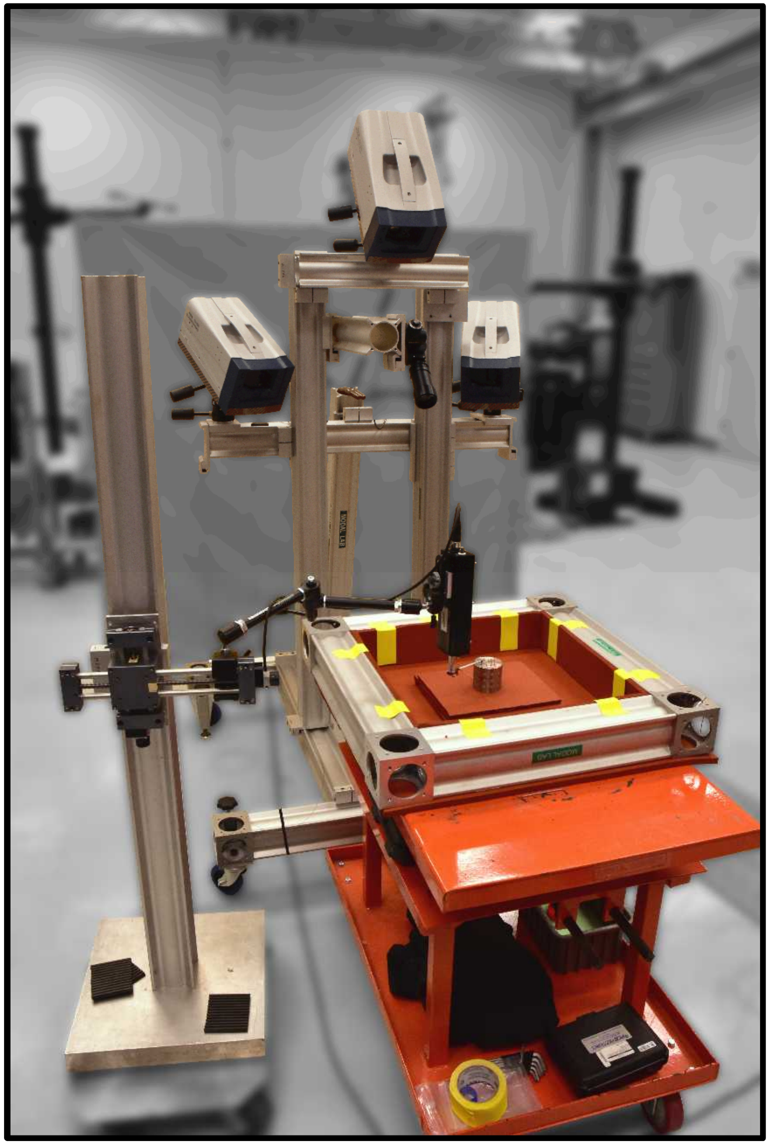


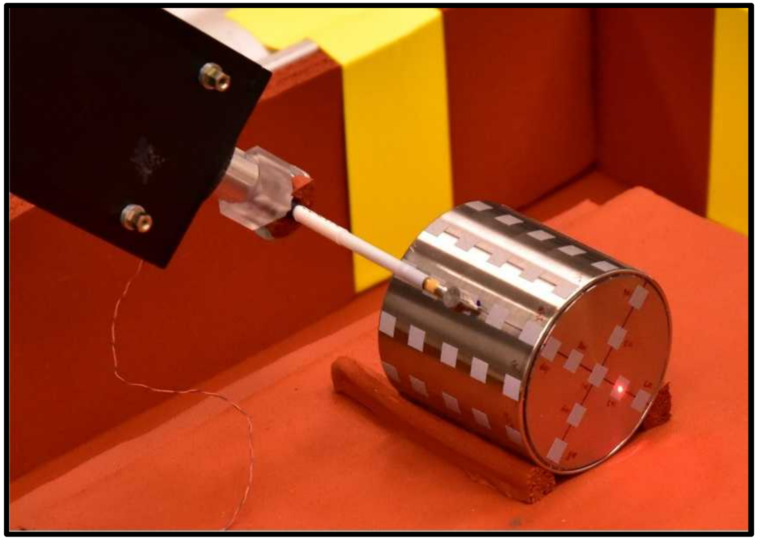
Pre-Activation: 3D SLDV

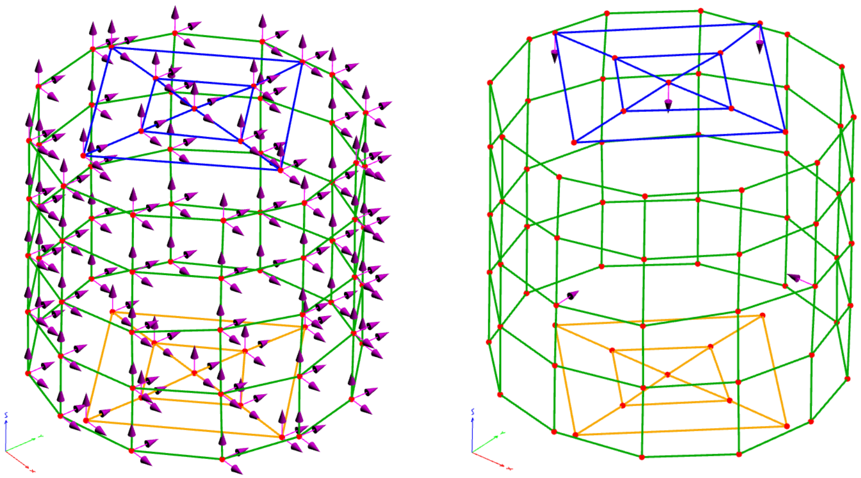




Pre-Activation: 3D SLDV



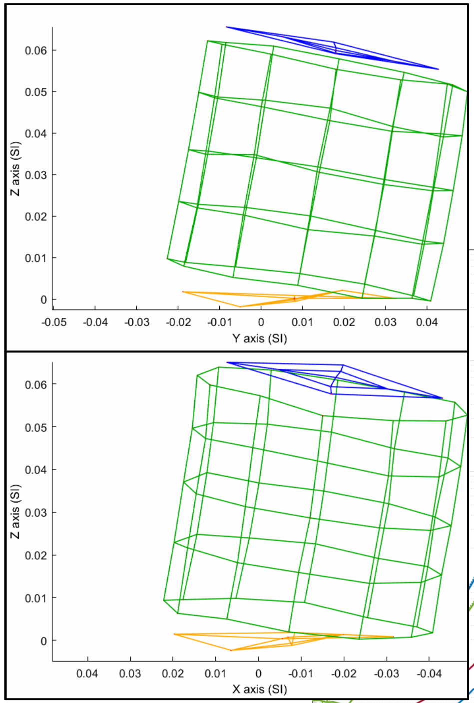


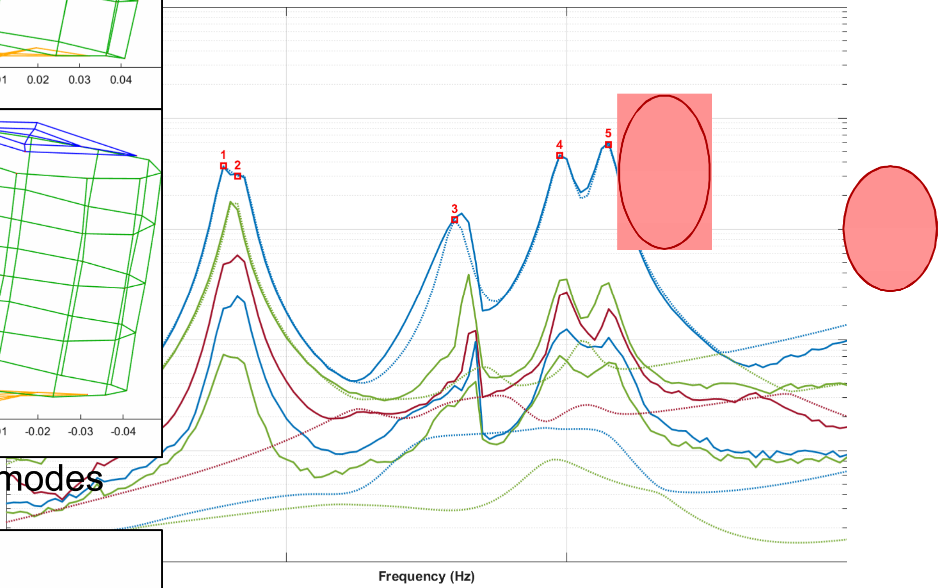


Response DOF

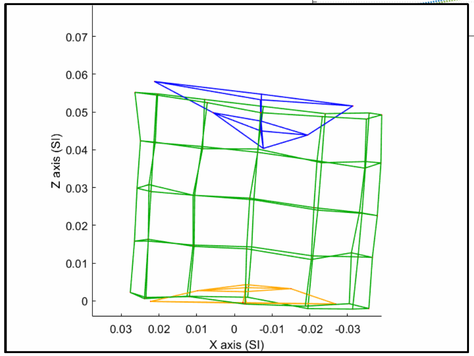
Impact DOF (Reference)

Pre-Activation: 3D SLDV



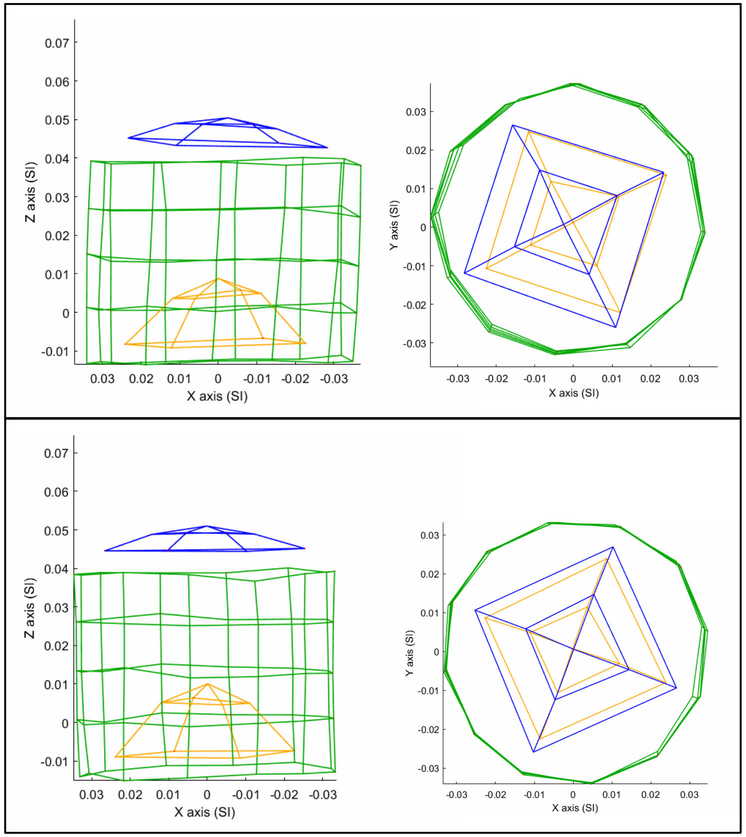


Internal shear modes

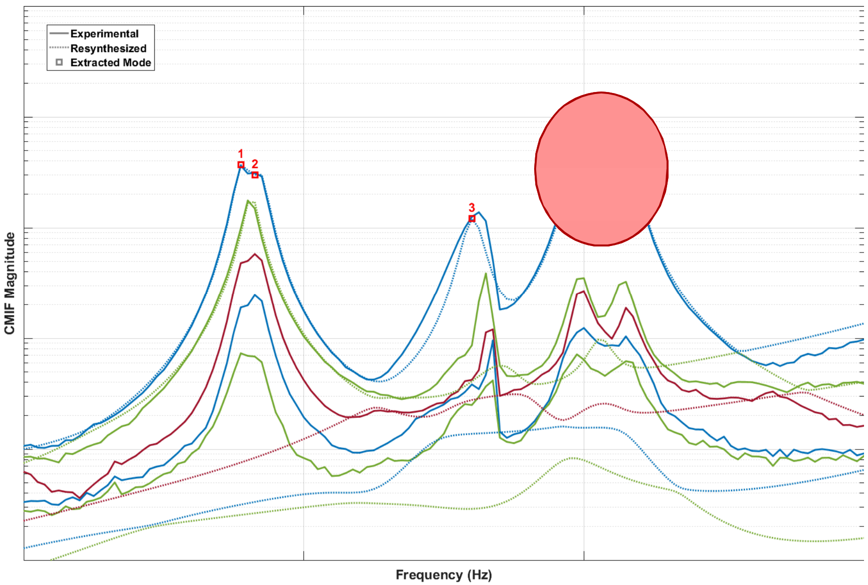


Headers drum mode

Pre-Activation: 3D SLDV

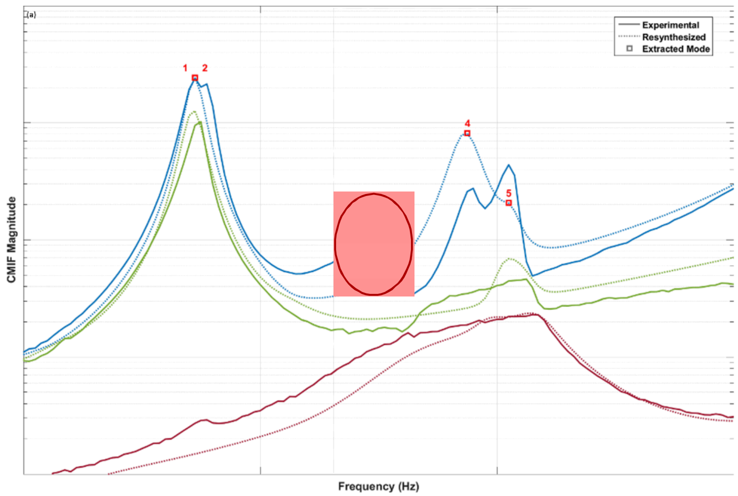


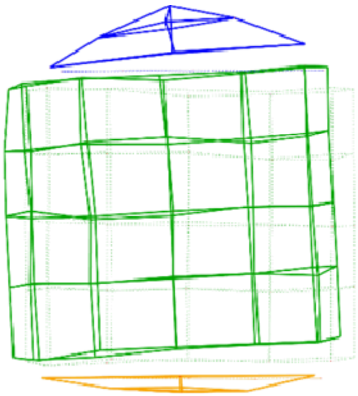
Axial + torsion modes



Pre-Activation: Method Comparison

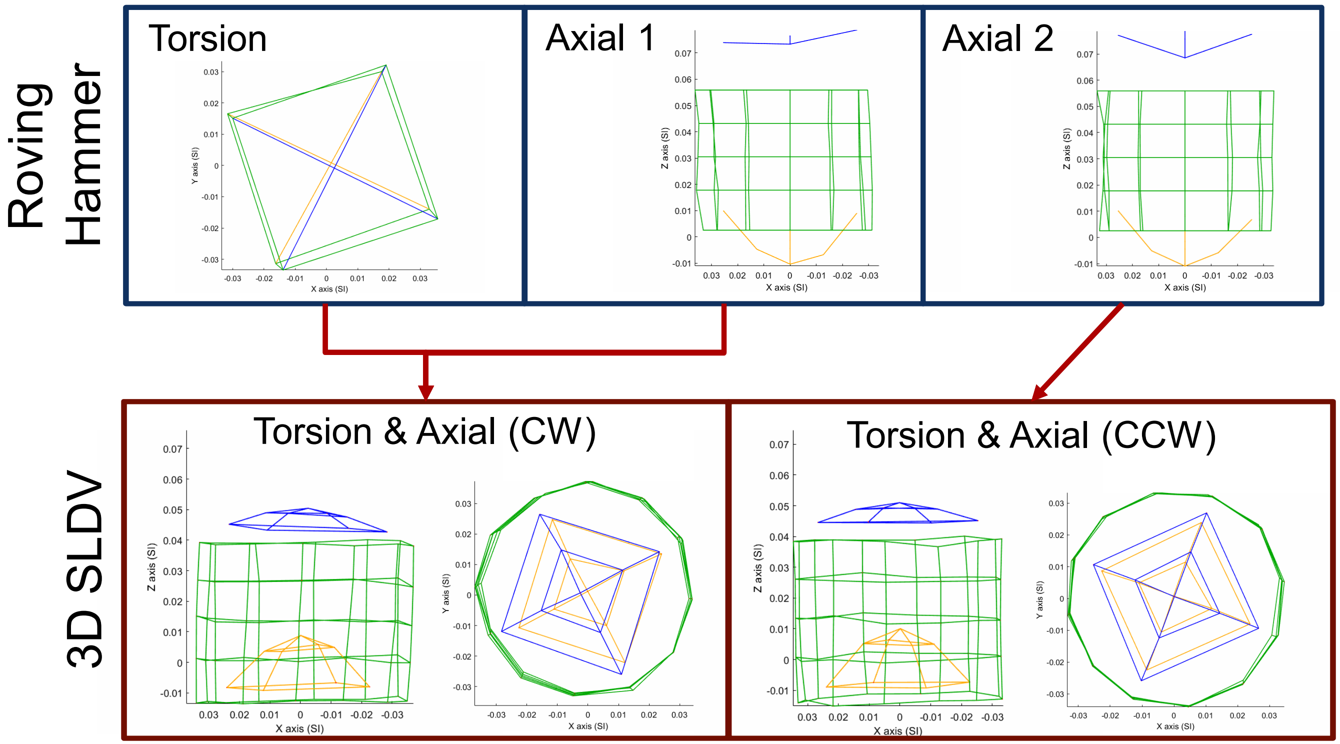
- Roving hammer test results were inadequate in several regards:
  - *Missed header drum mode*
    - Limited reference accelerometers not positioned well
    - With 3D SLDV, easier to increase reference DOF without mass loading





Pre-Activation: Method Comparison

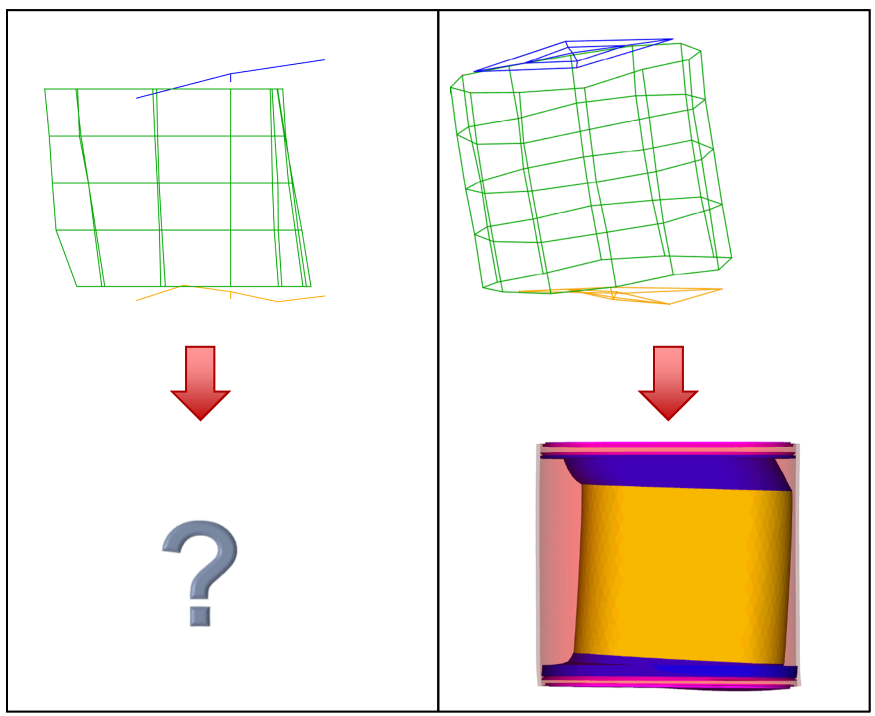
- Roving hammer test results were inadequate in several regards:
  - *No pure internal torsion mode*
    - 3D SLDV measured all necessary DOF in one test article configuration
  - *Axial modes only distinguished by (unmeasured) torsional components*



Pre-Activation: Method Comparison

- Roving hammer test results were inadequate in several regards:
  - *Important internal motion coupling not properly characterized!*
    - *Shear (without rocking)*
    - *Torsion (without axial)*
    - *Axial (without torsion)*

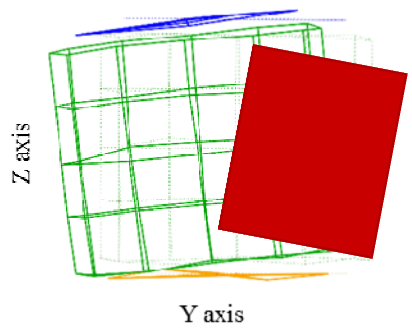
Roving Hammer

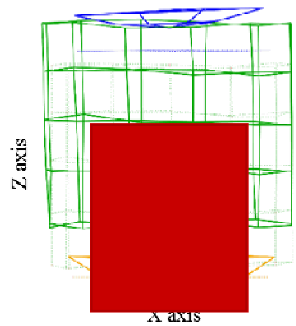


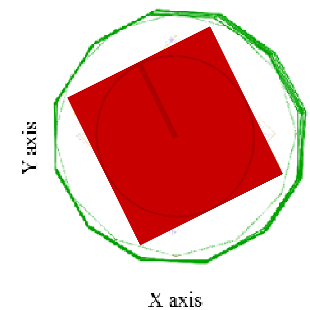
3D SLDV

Pre-Activation: Method Comparison

- **Internal motions deduced from external 3D SLDV measurements**
  - *Additional DOF (especially, in-plane) were critical*
  - *Higher frequency modes that look "rigid" are due to internal feature motion*
    - Conservation of momentum; internals moving opposite external observations
  - *Identifying couplings were essential in model updating*
    - Shear + rocking
    - Torsion + axial
    - Informed model mechanical behavior and material property updates





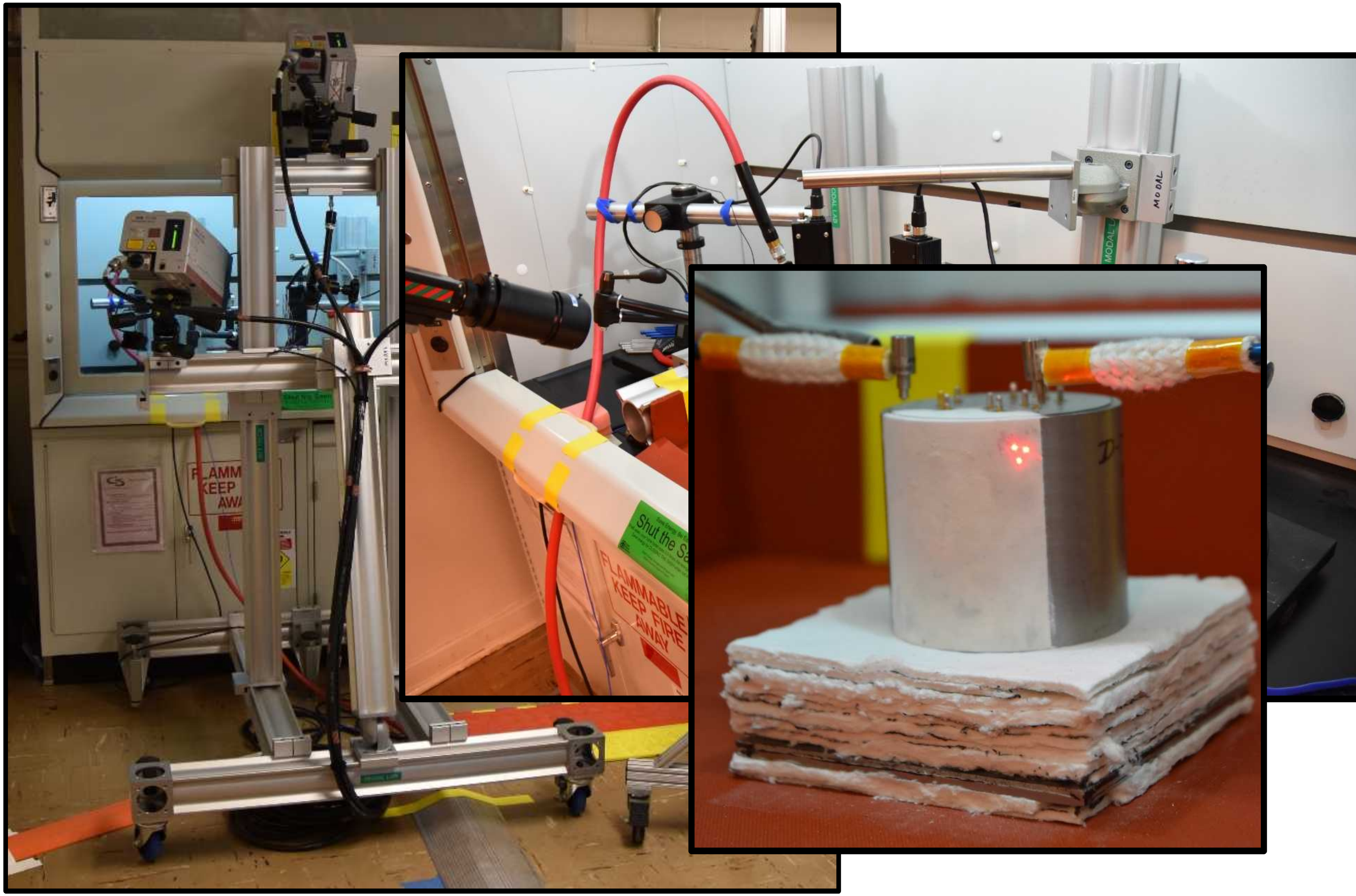


Activated Battery Testing

- Baseline modal characteristics established
  - How do they track with internal state changes?

- FE models want to reflect dynamic characteristics in time following activation
  - Previously, modal testing would be limited to pre-activation or post-activation states (ambient conditions)
  - Expected dynamic characteristics pre/post activation to be different
    - How different?
    - What goes on in between these end points?

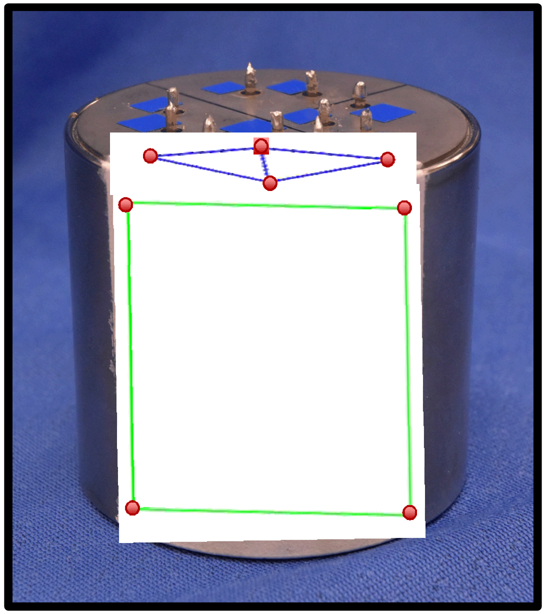
Activated Battery Testing



Activated Battery Testing

- Collected data at reduced set of nodes to speed up acquisition
  - 8 Nodes, 24 DOF
  - Sufficient to visualize modes of interest
  - Collected time histories only

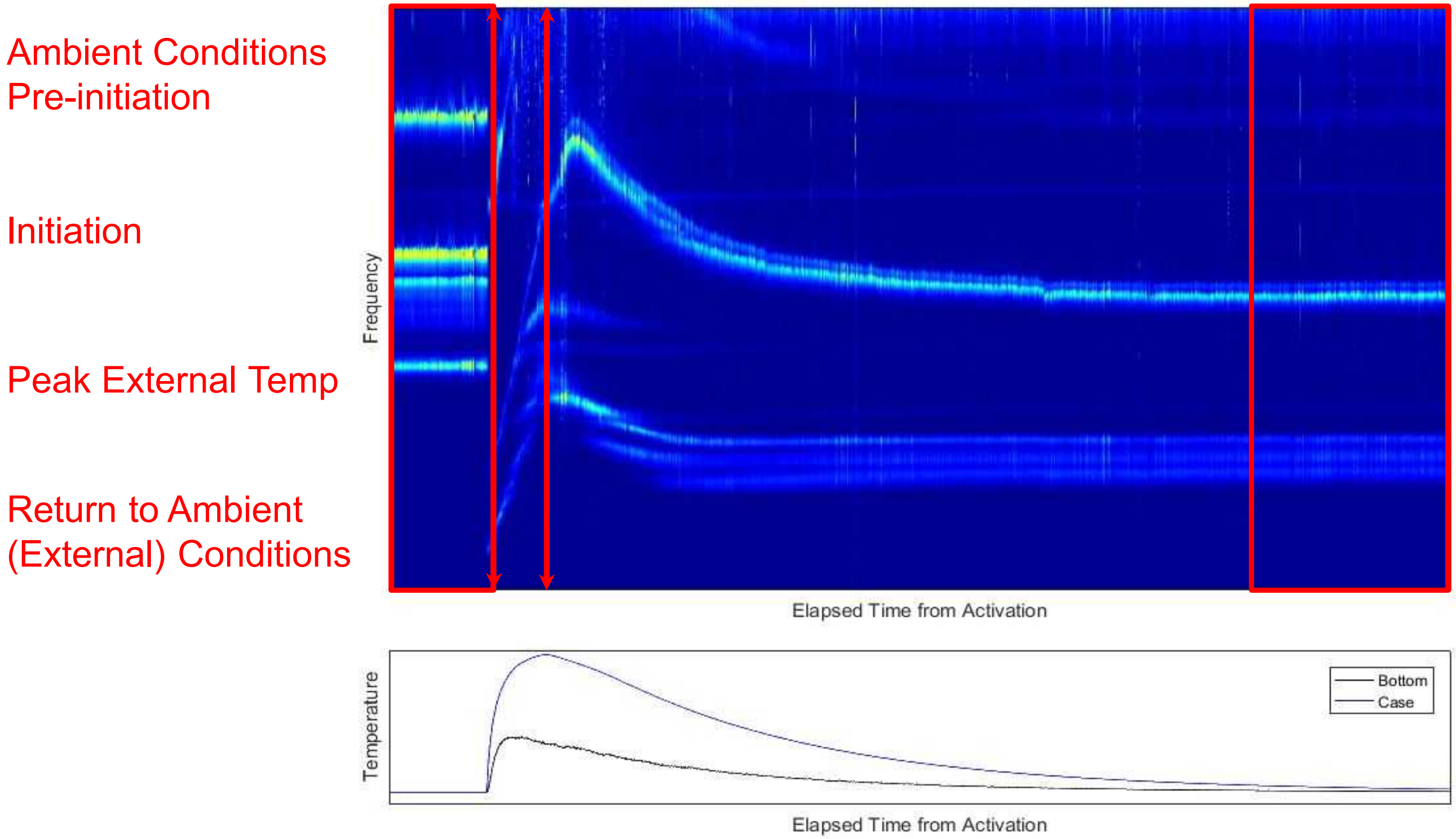
- Fast data acquisition:
  - Used Visual Basic macro to automate Polytec data acquisition
  - Hammer function generators at 0.34 sec
  - Impacts spaced ~100 msec apart
  - One scan per node (no averaging)
  - **~6 seconds to collect all 48 time histories**
  - *File write time was limiting factor*



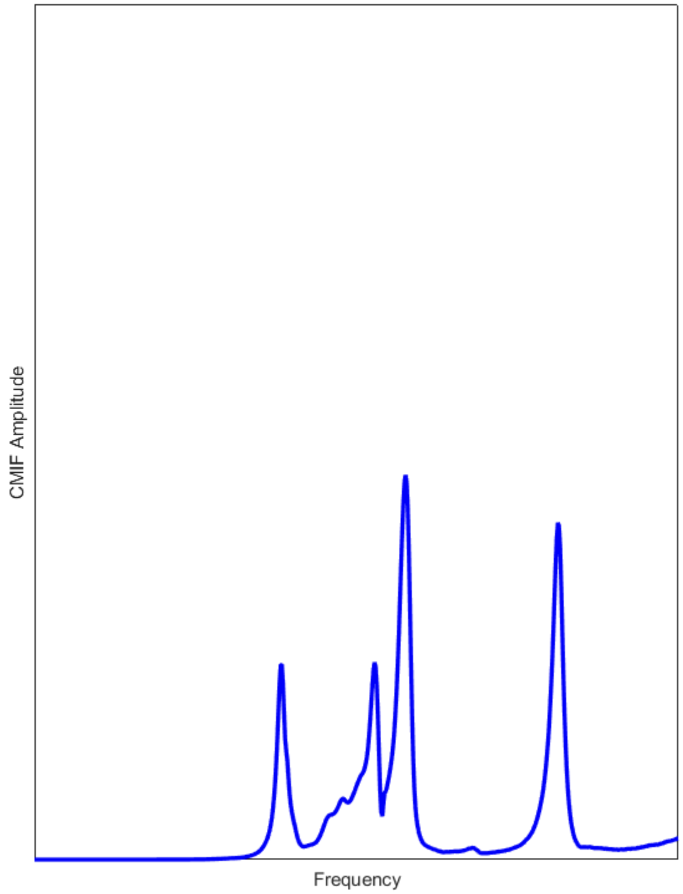
Surface Preparation:
White high-temperature paint covered with retroreflective beads

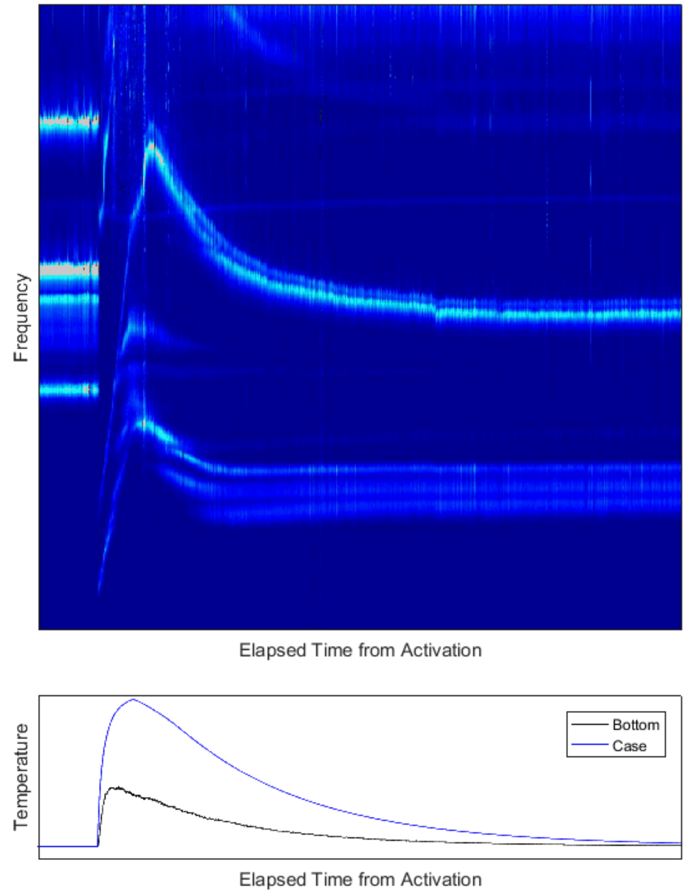
Activated Battery Testing

- CMIF Spectrogram
  - Each time slice is a Complex Mode Indicator Function (CMIF)
  - Each vertical line represents a full set of FRFs

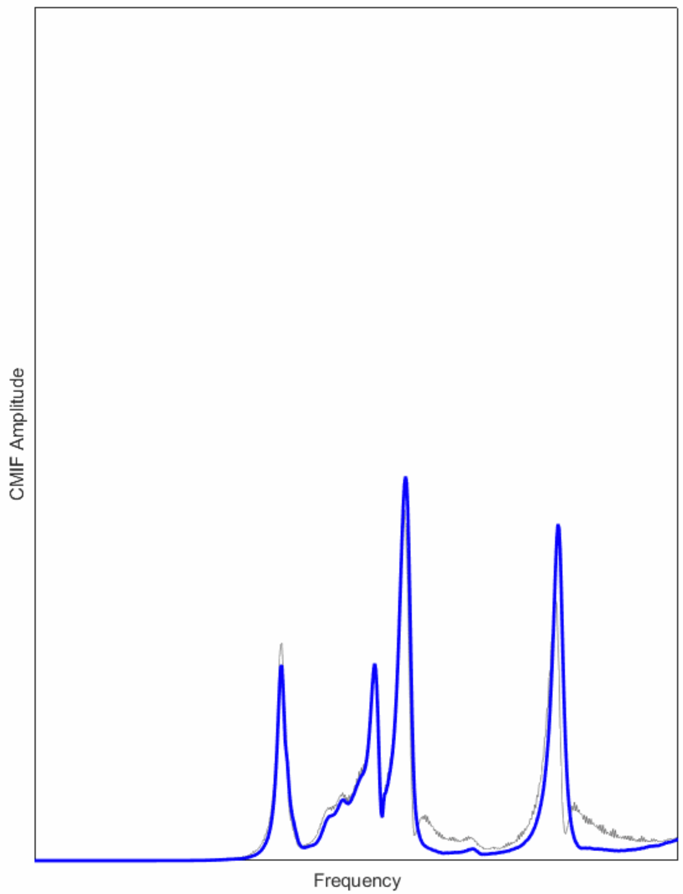


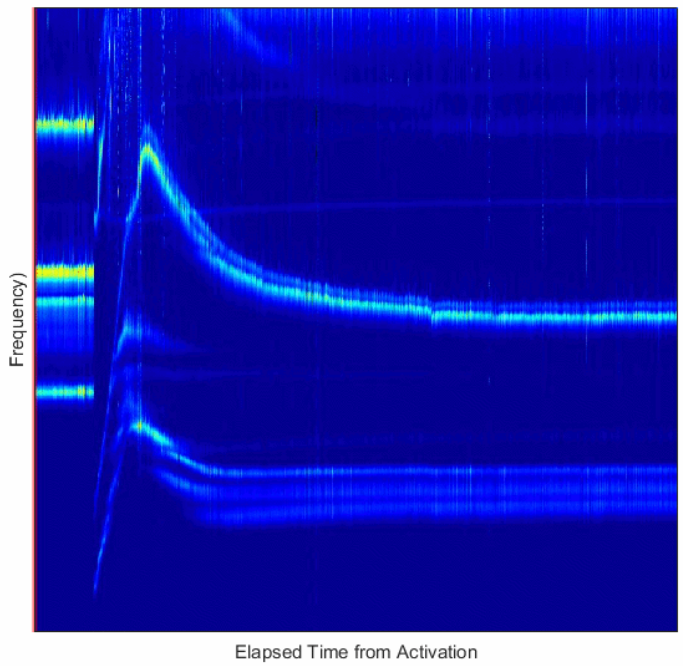
Activated Battery Testing

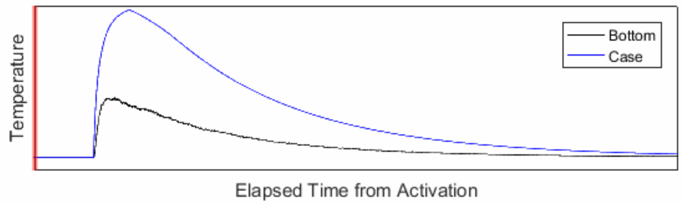




Activated Battery Testing

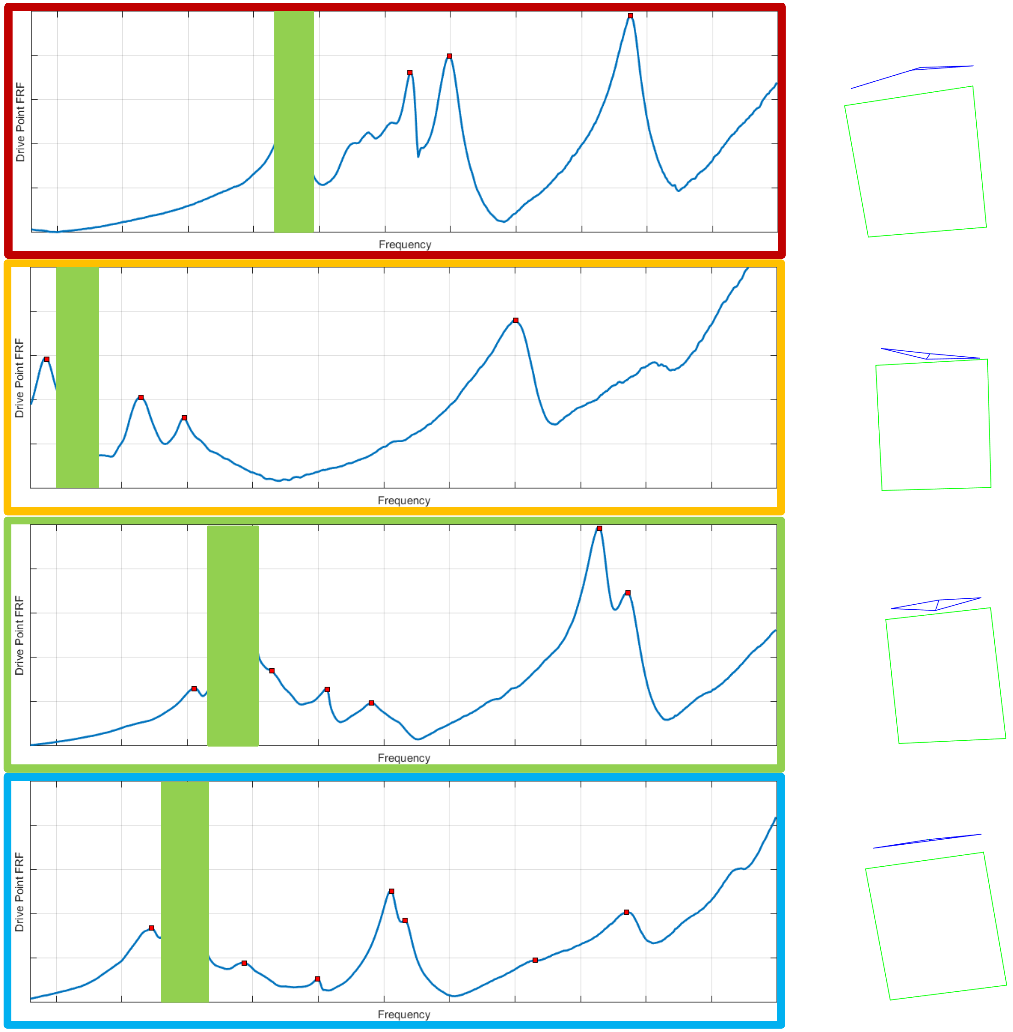




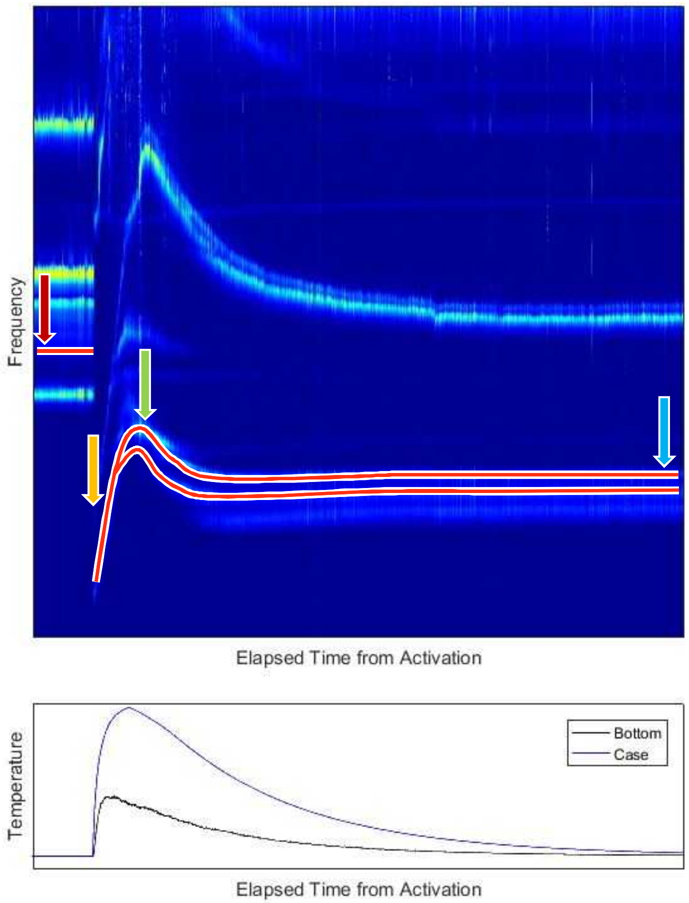


Activated Battery Testing

Internal Shear Modes



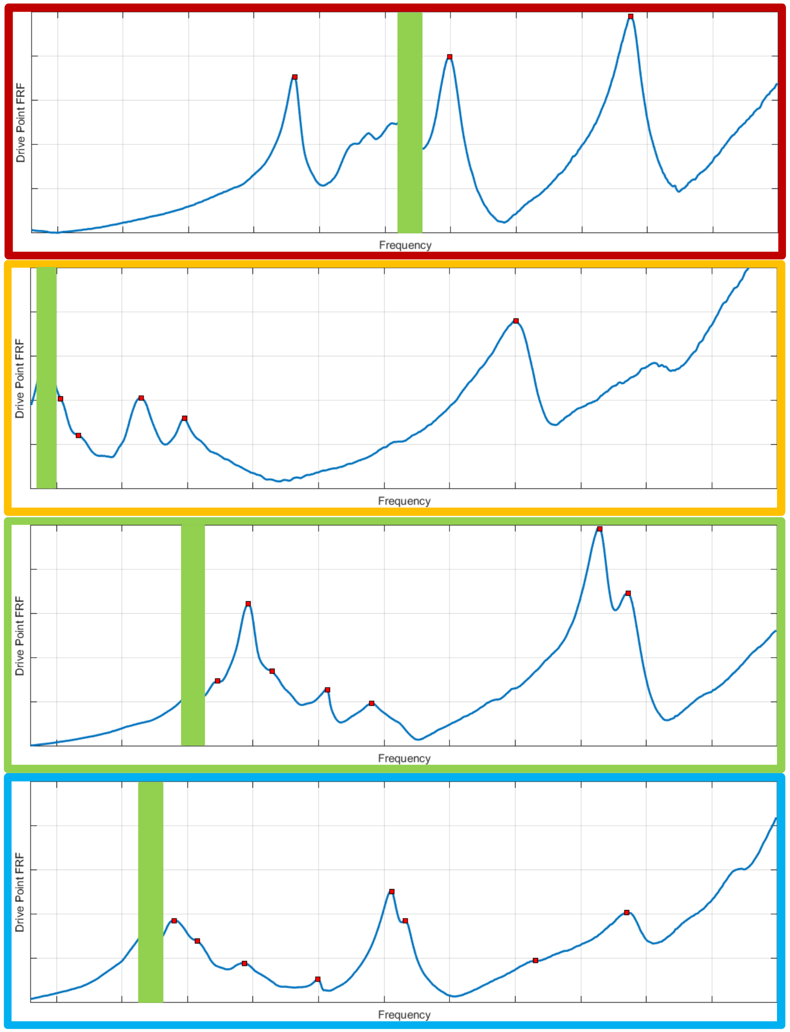
Operational Deflection Shape (ODS)

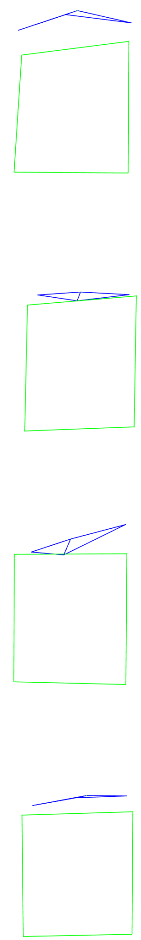


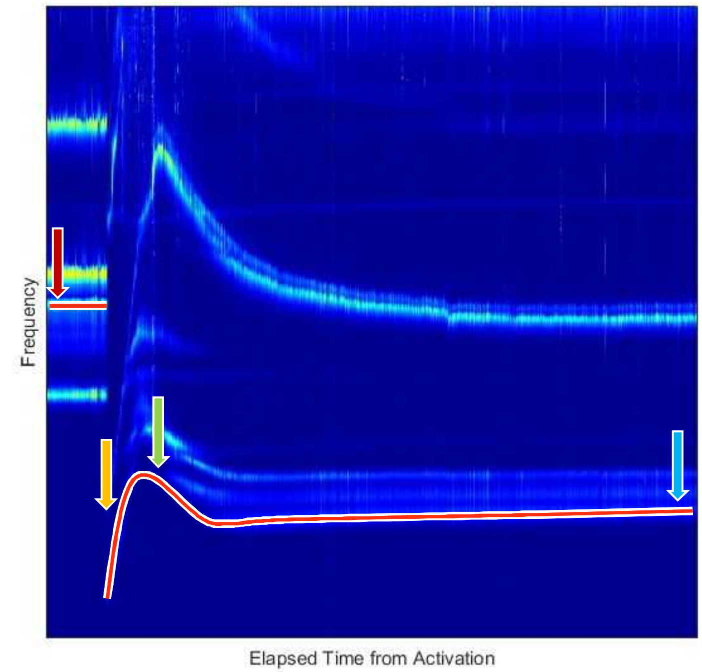
Activated Battery Testing

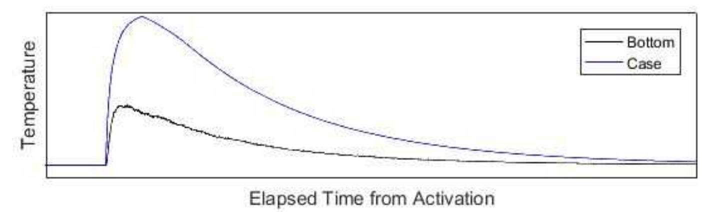
Internal Axial Mode

ODS









Activated Battery Testing

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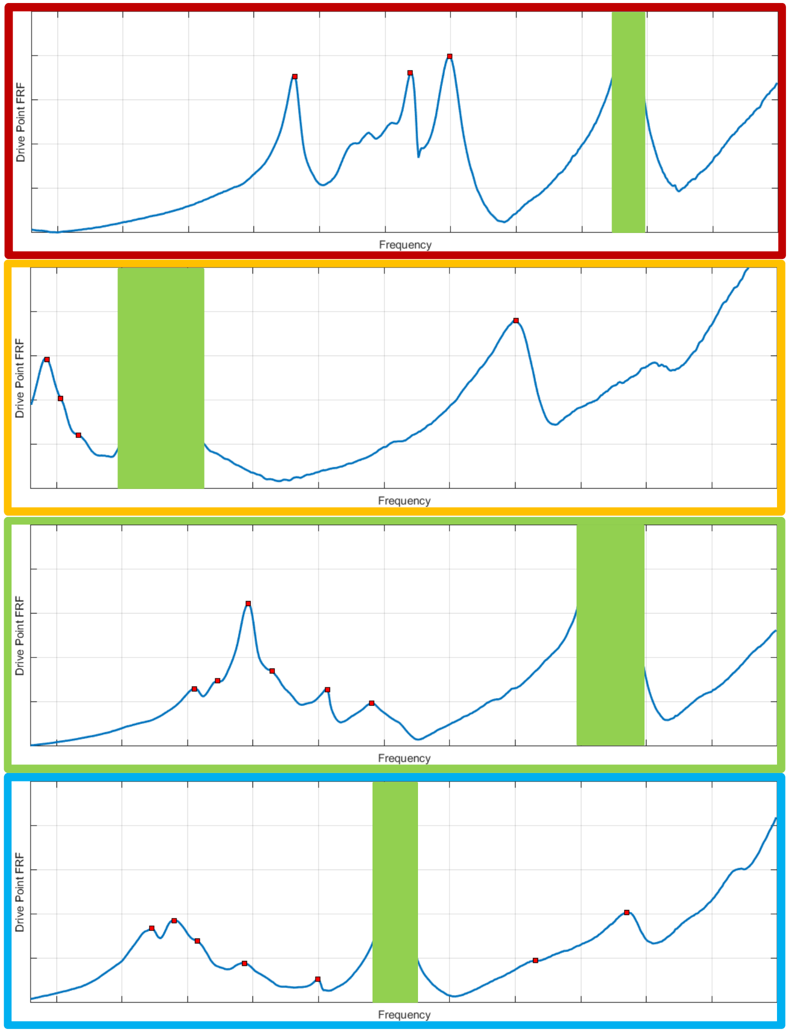
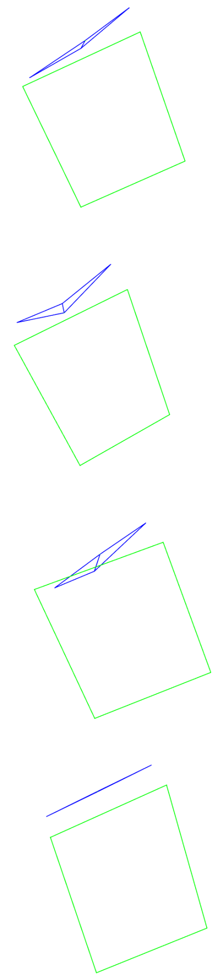
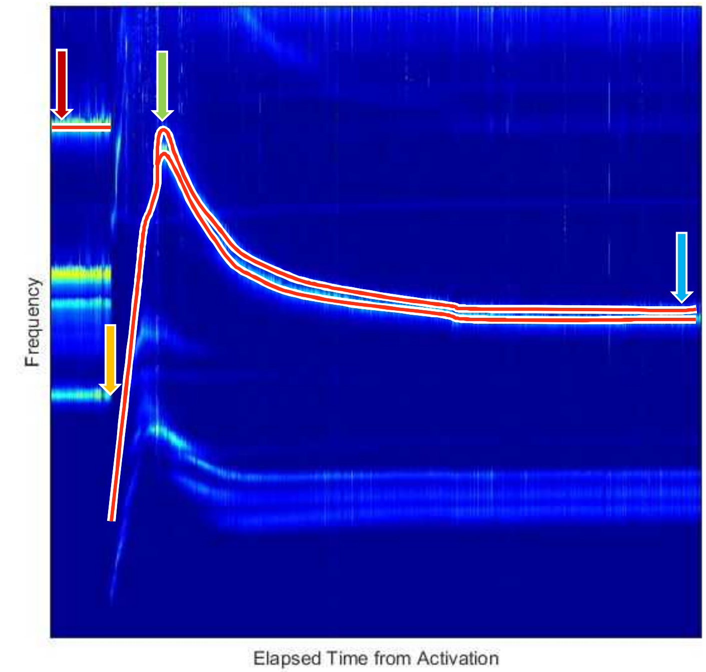
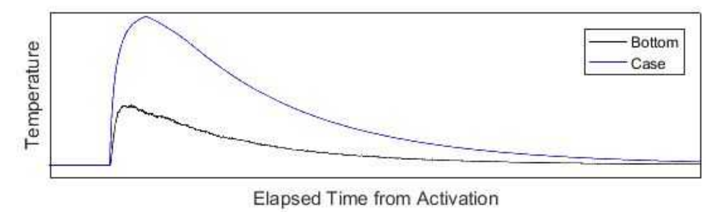
Internal Rocking Modes



ODS

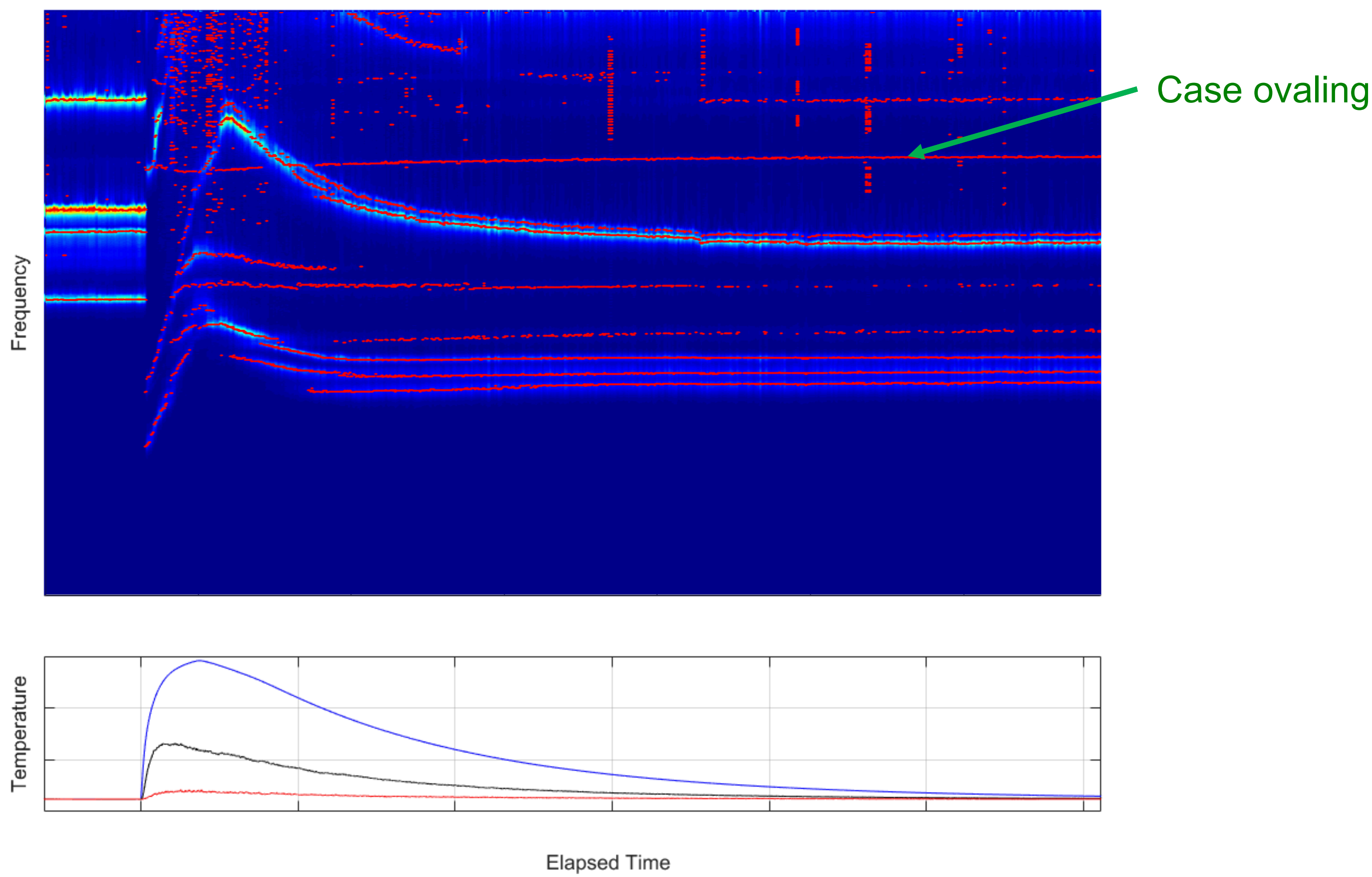






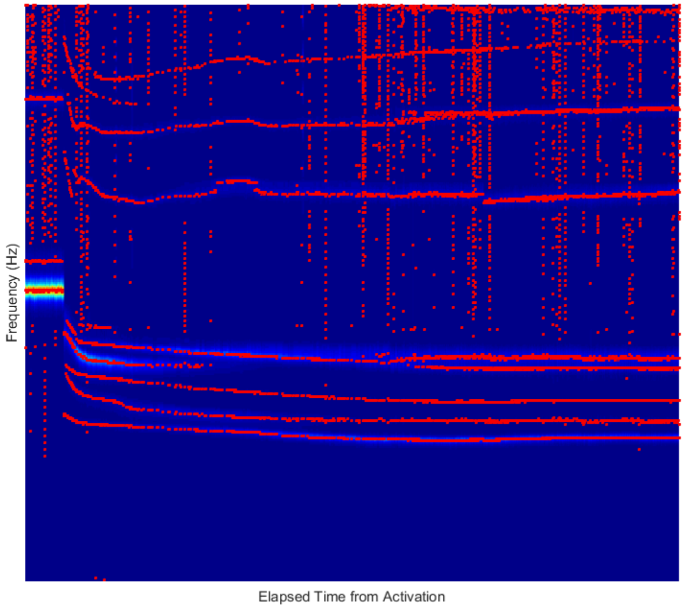
Activated Battery Testing

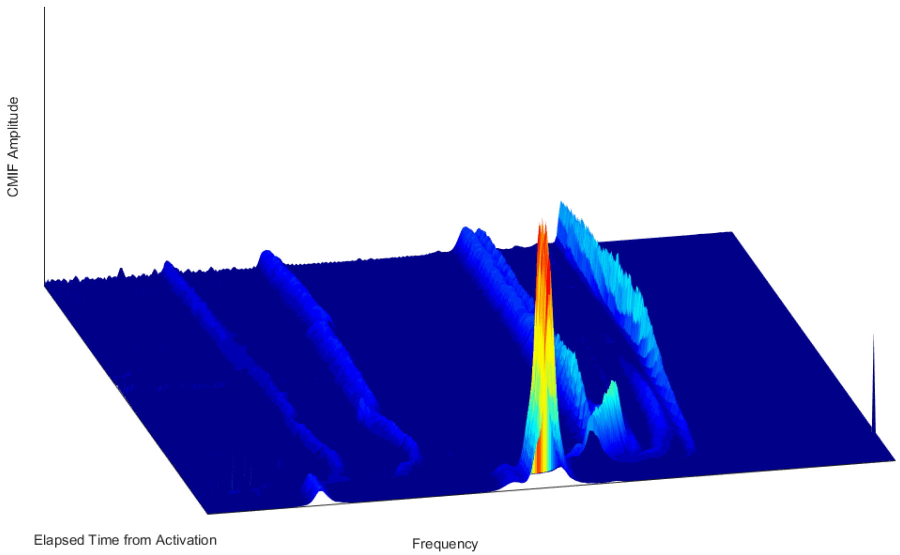
- Case ovaling modes less affected by internal changes



Activated Battery Testing

- Second type of thermal battery was also tested
  - Similar but different designs
  - Different trends altogether





Conclusions

- **3D SLDV benefits:**
  - Higher point density without mass loading
  - Out of plane measurements & high fidelity shape spatial resolution
  - Non-contact for test articles at extreme temperatures
  - Essentially: allowed us to do a test we couldn't before
- **3D SLDV drawbacks/issues:**
  - Typical deficiencies: Line of sight only, small displacements only
  - LDV affected by thermal gradients around test article at extreme temperatures
    - Changes in refractive index around part caused appreciable speckle noise (hypothesis)
    - Indications that this can be mitigated in some circumstances
  - Surface preparation can be a challenge for high temperatures
    - Mitigated with new PSV-500 Xtra (IR) system
  - High-temp sponge has a high coefficient of thermal expansion
    - Caused first test articles to displace upwards, causing hammer contact/double impacts
    - Had to change base material, stiffer but rigid body modes still well below elastic
  - It worked, but...SLDV not optimal for this application!
    - Changes too quickly for averaging and induces FRF inconsistencies during scans
    - Multipoint 1D/3D LDV, possibly DIC?