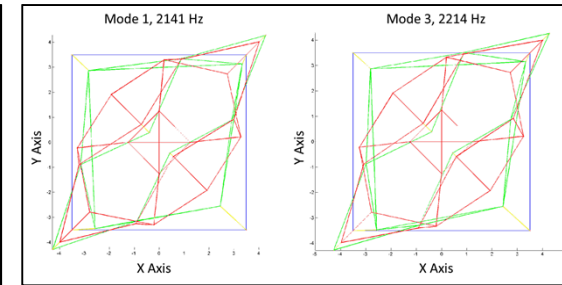
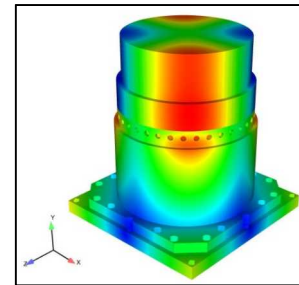
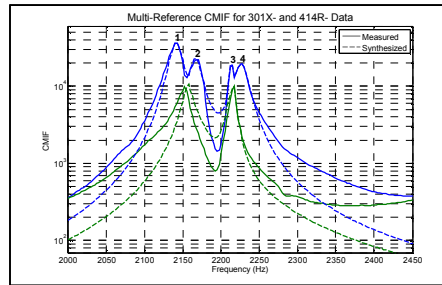
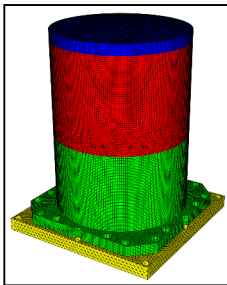
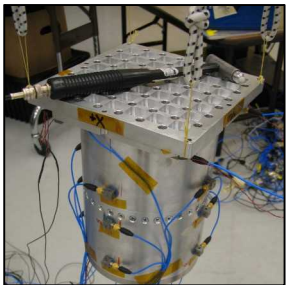


Exceptional service in the national interest



IMAC XXXIV Structural-Acoustic Mode Coupling in a Bolted Aluminum Cylinder

Benjamin Pacini, Gregory Tipton

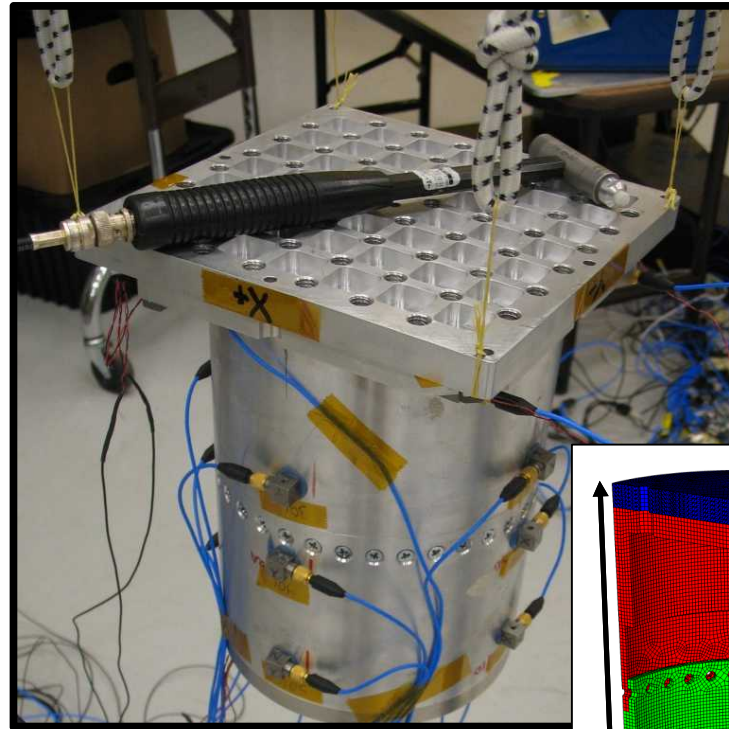
January 25-28, 2016

Introduction

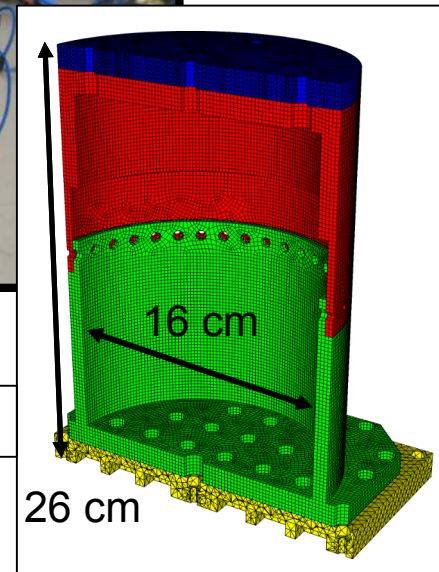
- In typical modal testing, structural-fluid interactions are neglected
- This work details a test where this assumption was not valid
- During a routine modal test, two pairs of (2,0) ovaling modes were discovered at different frequencies but identical shapes
- The repeated shape was initially thought to be the result of an active but uninstrumented component of the structure
- It was later determined that the repeated shapes were the result of the acoustic coupling between the structure and the air contained within

Hardware and Testing

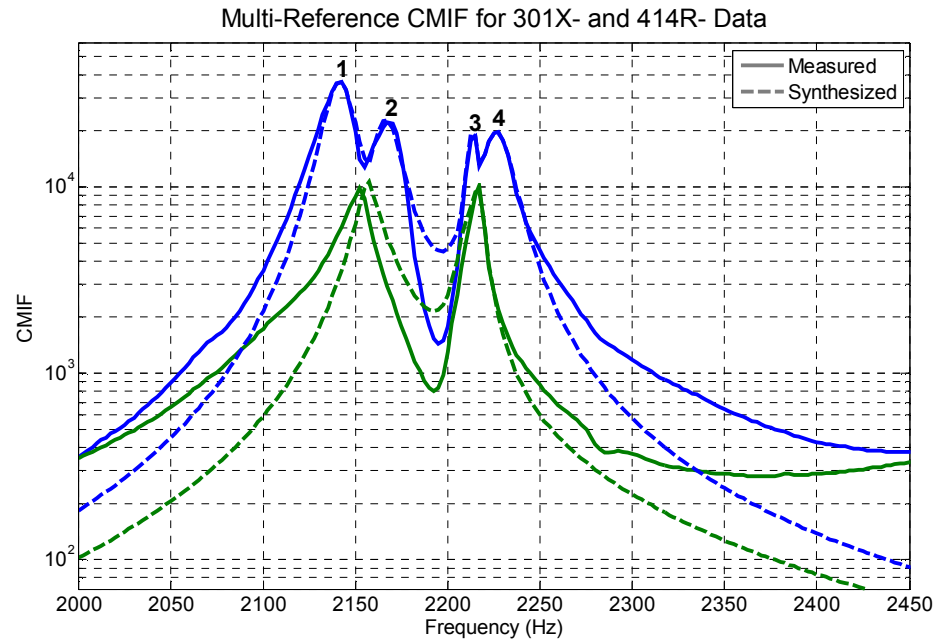
- Softly suspended with bungee cords
- Instrumented with 37 accelerometers
 - 21 uniaxial
 - 16 triaxial
 - Cylinder instrumented every 45°
 - Intermediate instrumentation configuration pictured
- Impact test with 4 excitation points
 - 1 axial
 - 2 radial
 - 1 tangential
- Analyzed data using Synthesize Modes And Correlate (SMAC)



0.95 cm wall

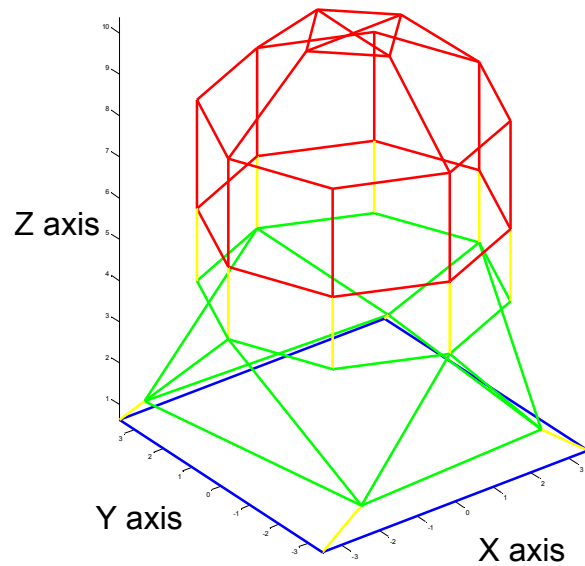


Test Results

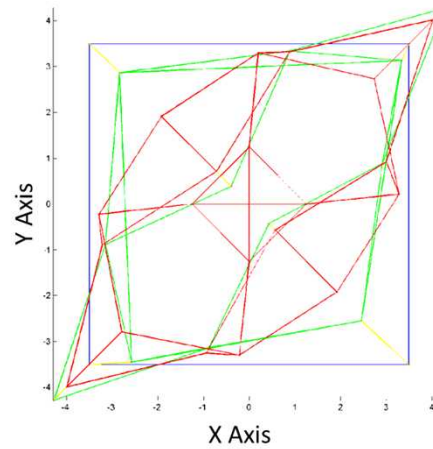


Mode	Frequency (Hz)	Damping (%cr)	Description
1	2141	0.49	(2,0) ovaling of case at 45° from X-Y axes
2	2166	0.46	(2,0) ovaling of case aligned with X-Y axes
3	2214	0.18	(2,0) ovaling of case at 45° from X-Y axes
4	2226	0.49	(2,0) ovaling of case aligned with X-Y axes

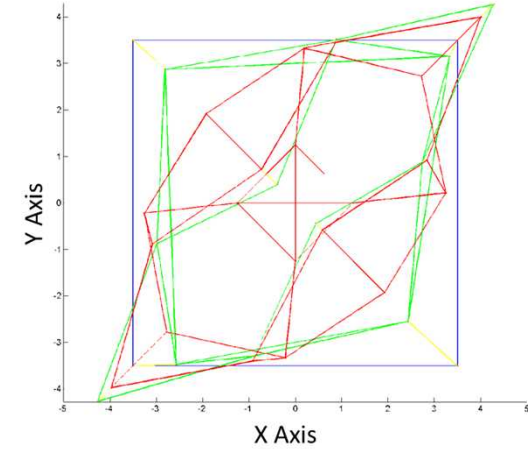
Extracted Mode Shapes



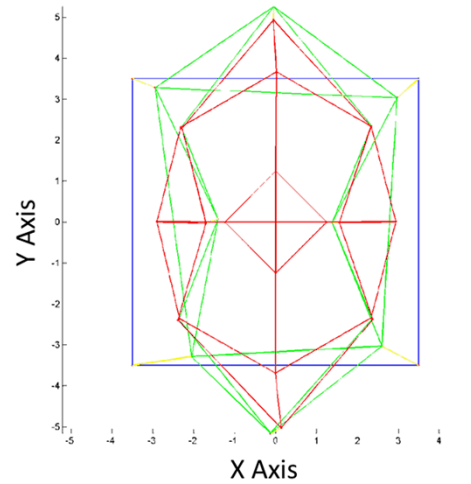
Mode 1, 2141 Hz



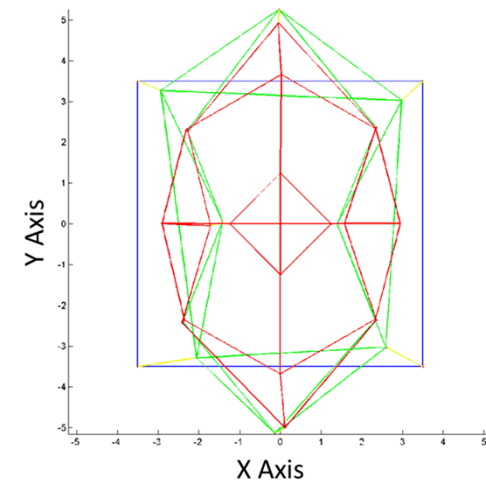
Mode 3, 2214 Hz



Mode 2, 2166 Hz



Mode 4, 2226 Hz

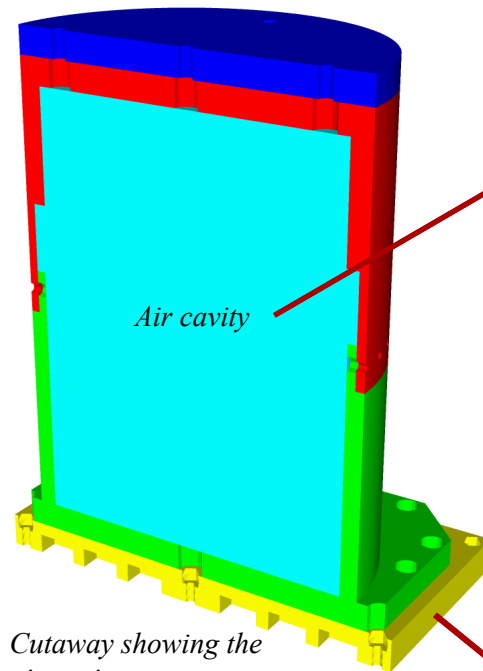
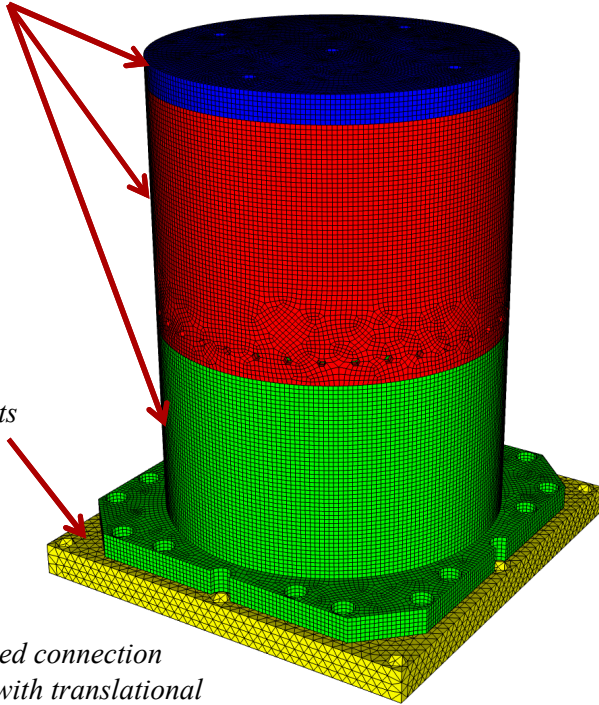


Finite Element Model

*Upper and lower cylinders and top plate
meshed with hex8 elements*

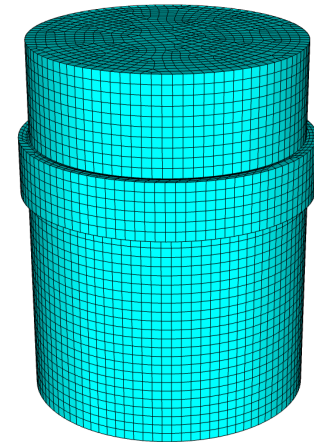
*Lower plate
meshed with
tet10 elements*

*Each bolted connection
modeled with translational
and rotational springs*

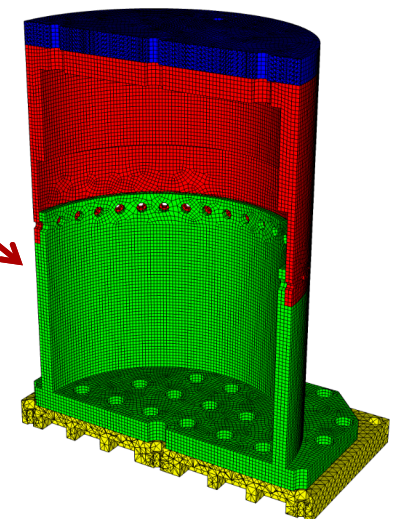


*Cutaway showing the
air cavity*

Air cavity meshed with hex8 elements



*The air and structure meshes were
connected with tied-contact*



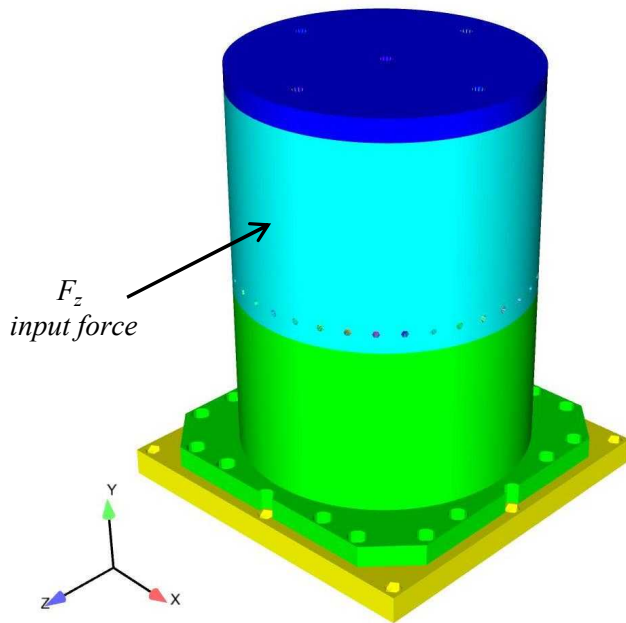
Structure

- Analysis performed with Sierra Mechanics software suite developed at SNL
- Both quadratic eigenvalue analysis and direct frequency response analyses were performed on the coupled system of equations

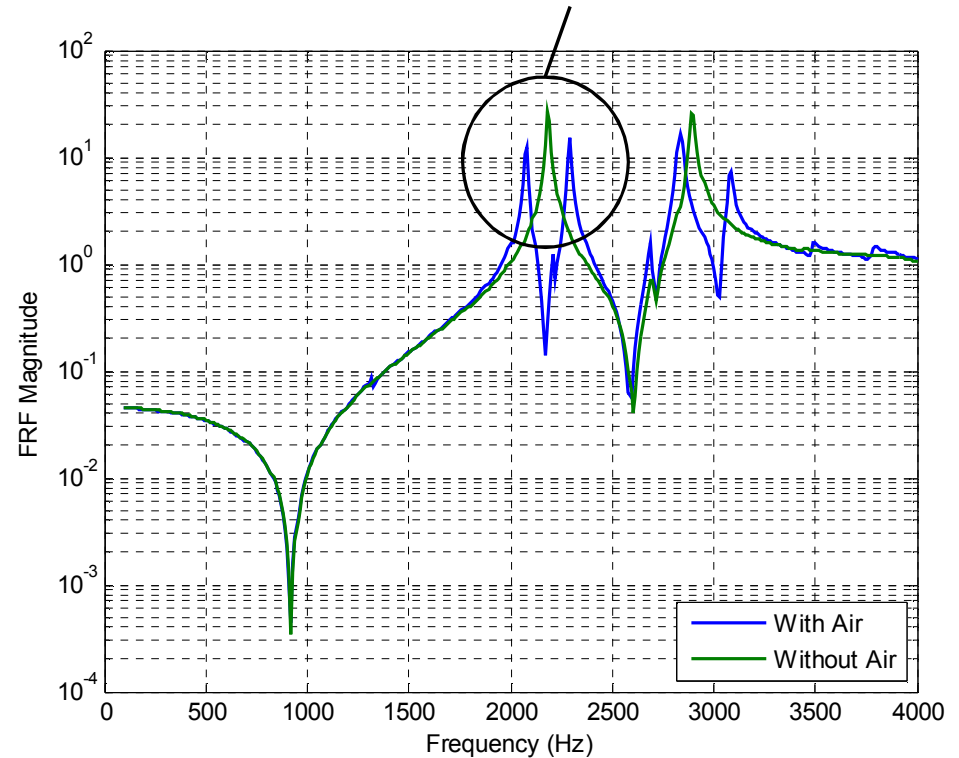
Direct Frequency Response Calculations

A typical hit with a modal hammer was simulated with the model.

Driving point FRF's were computed and compared with and without the air included in the model.



With the air included inside the cavity, the (2,0) ovaling mode (assuming vacuum inside) split into two pairs

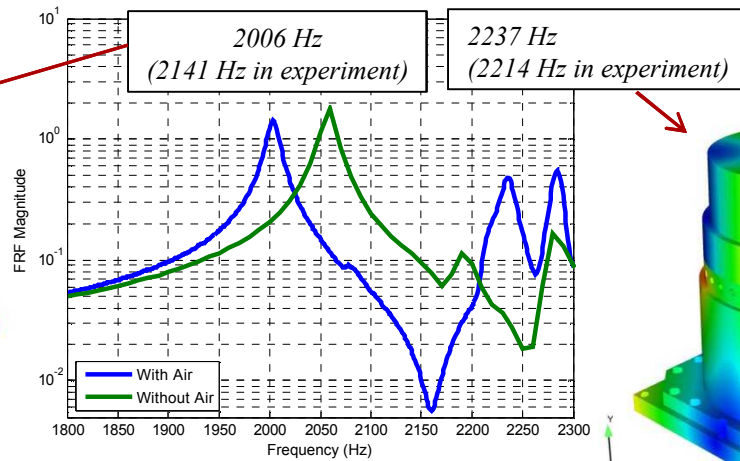
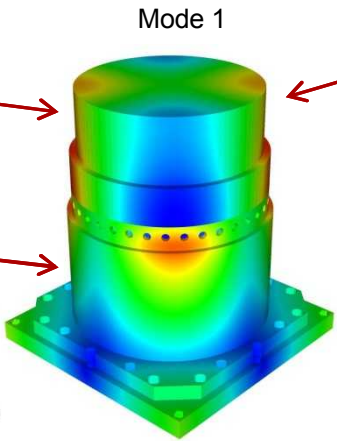


Computed driving-point FRF's

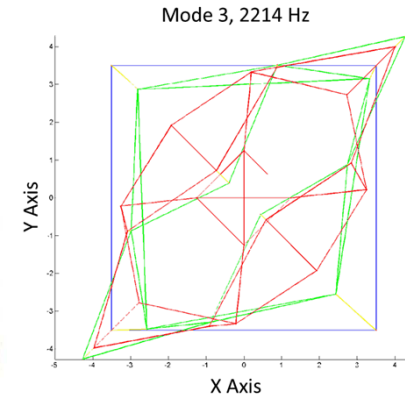
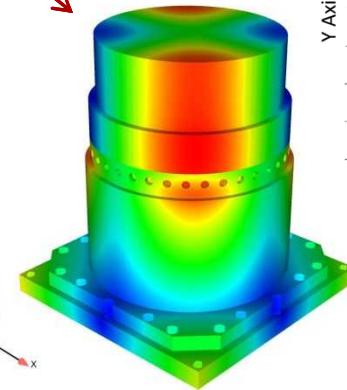
Computed (2,0) Modal Response

Air cavity with acoustic pressure plotted

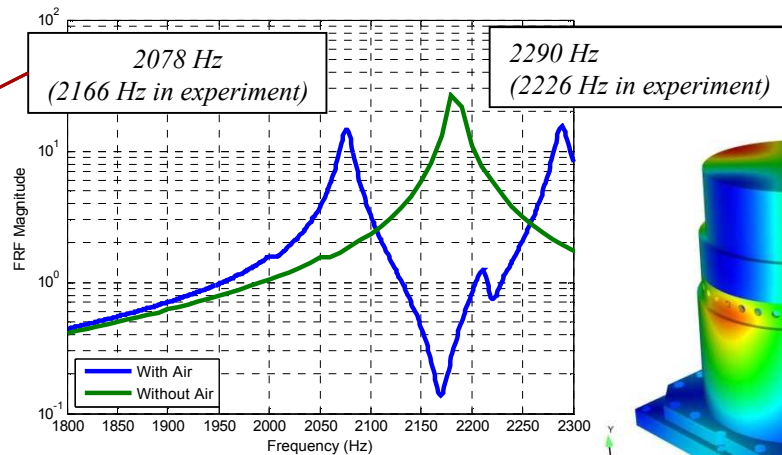
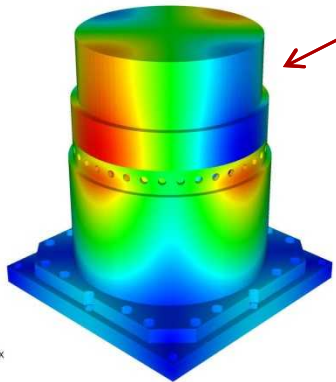
Bottom portion of the structure with displacement magnitude plotted



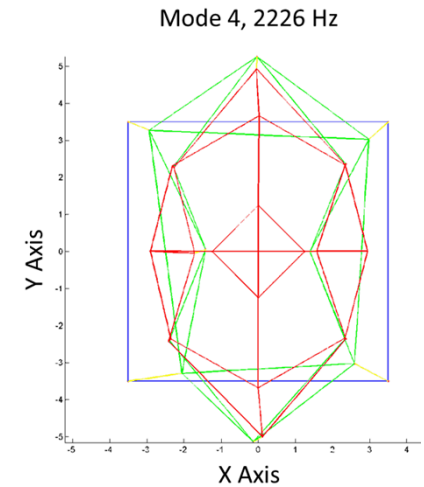
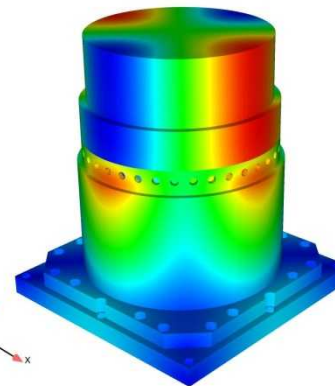
Mode 3



Mode 2



Mode 4



Structural-Acoustic Coupling

- Assuming the coupled mode shapes can be partitioned into structural and acoustic degrees-of-freedom as

$$\{\phi\} = \begin{Bmatrix} \phi_s \\ \phi_a \end{Bmatrix}$$

- The relative structural and acoustic contributions can be computed as

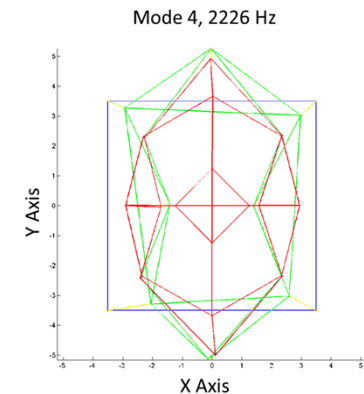
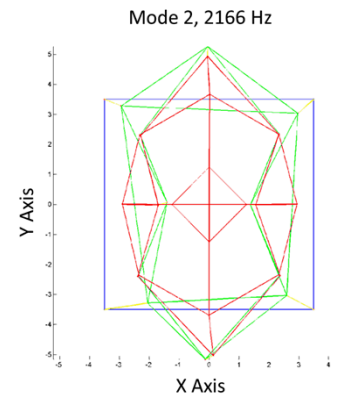
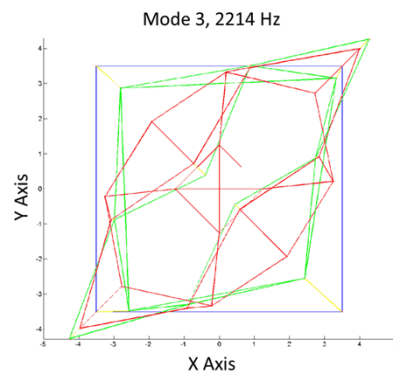
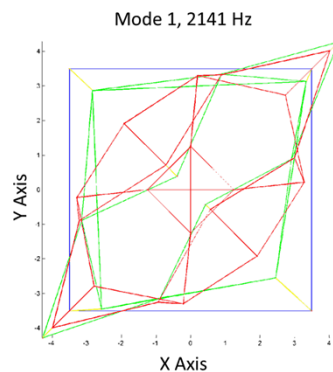
$$F_s = \frac{\phi_s^* \cdot \phi_s}{\phi_s^* \cdot \phi_s + \phi_a^* \cdot \phi_a}$$

$$F_a = \frac{\phi_a^* \cdot \phi_a}{\phi_s^* \cdot \phi_s + \phi_a^* \cdot \phi_a}$$

Mode	Analysis Frequency (Hz)	Experimental Frequency (Hz)	Description	Structural Fraction	Acoustic Fraction
1	2006	2141	(2,0) ovaling at 45° – air in phase	0.81	0.19
2	2078	2166	(2,0) ovaling – air in phase	0.50	0.50
3	2237	2214	(2,0) ovaling at 45° – air out of phase	0.21	0.79
4	2290	2226	(2,0) ovaling – air out of phase	0.49	0.51

Modes 1 and 3 – Predominantly driven by the structure and the air respectively

Modes 2 and 4 – Equal participation



Summary

- Atypical for most structures, the air inside the cylinder's cavity had a measureable influence on the modes of the structure
- The close proximity in frequency of the structural (2,0) ovaling modes with those of the air cavity caused the modes to split into two separate pairs at different frequencies but with nearly identical mode shapes
- Coupled structural-acoustic finite element analyses of the hardware demonstrated the mode splitting behavior and allowed interpretation of the mode shapes that were determined experimentally
 - Even though the modes in each pair had identical structural deformations, the air was in phase for one and out of phase for the other
- One mode pair demonstrated reciprocal structural and acoustic participation while the other mode pair had near equal structural and acoustic participation