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Tire Cavity Induced Structure-Borne Noise Study with Experimental Verification

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Tire cavity induced structure-borne noise study with experimental verification

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Herrick Laboratories PURDUE UNIVERSITY

I. Introduction

Traffic noise

Roadside residences

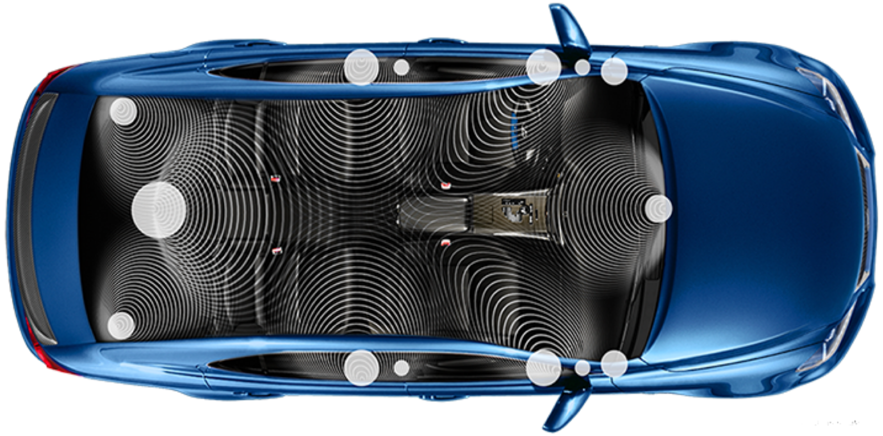
Passengers

Vehicle noise

- Power Unit noise
- Aerodynamic noise
- **Tire/pavement noise**

Transfer paths

Interior noise

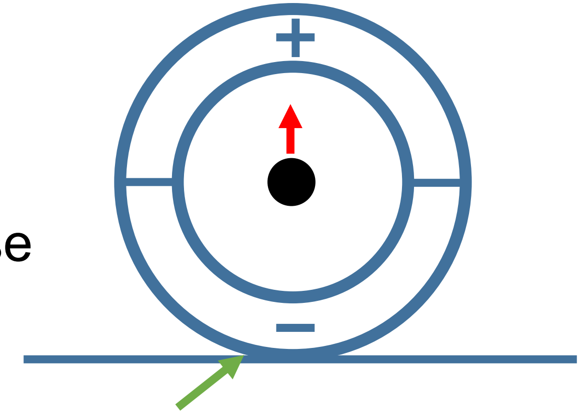


I. Introduction

- High frequency interior noise is mostly airborne and usually is not associated with structural vibration from road excitation. However, low frequency noise, has a strong association with structural vibration and can be perceived by the passengers.
- A major component of structure-borne noise comes from the tire's acoustic cavity mode near 200 Hz

Why do two tires of same size and geometry, from different manufacturers, have very different responses, in terms of cavity noise perception?

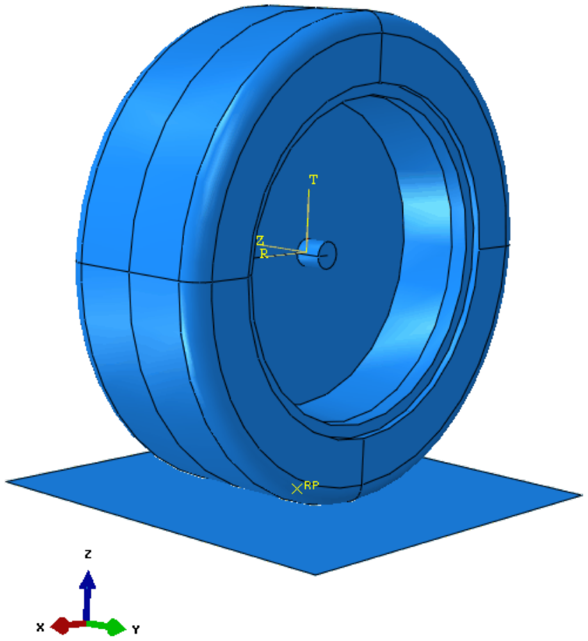
- Study force transmission from contact patch excitation to rim center
- How the cavity resonance may affect force transmission
- Ways of identifying bad tires/good tires, in terms of structure-borne noise



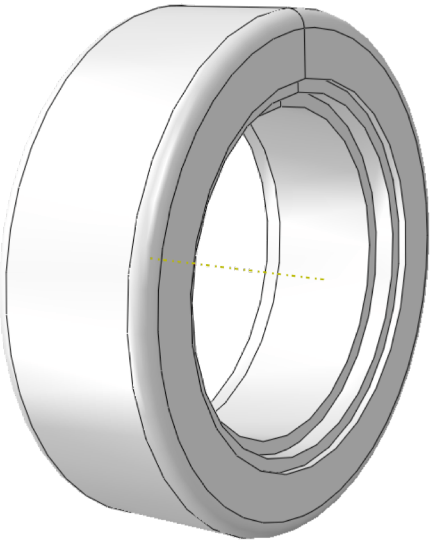
II. A previous finite element tire model

A Finite Element structural-acoustical tire model was created to investigate the tire cavity-induced structure-borne noise

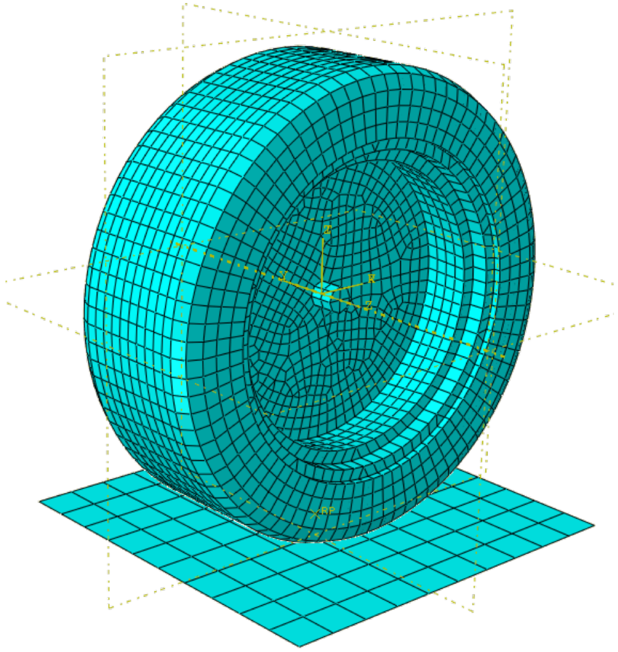
Assembled model



Air cavity model



Meshed assembled model



A 245/40R20 tire was used for dimensions

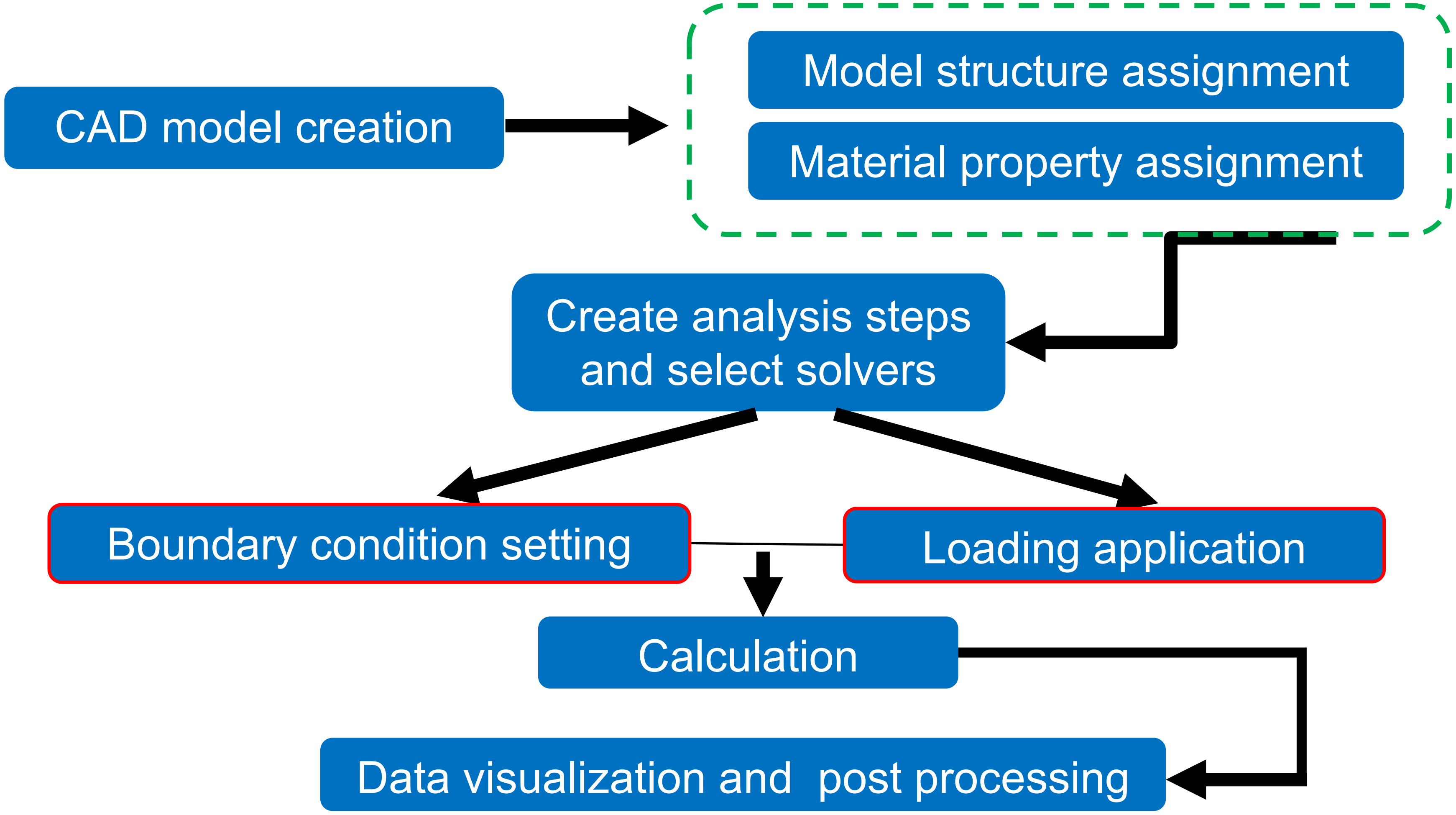
II. A previous finite element tire model

All parts are assumed homogeneous material

Part	Density [kg/m^3]	Modulus [Pa]	Thickness [mm]	Poisson's ratio
Rim	2700	7×10^{12}	10	0.3
Tread	1200	7.5×10^{8}	10	0.45
Sidewall	800	5×10^{7}	8	0.45
Air	1.204	149180	N/A	N/A

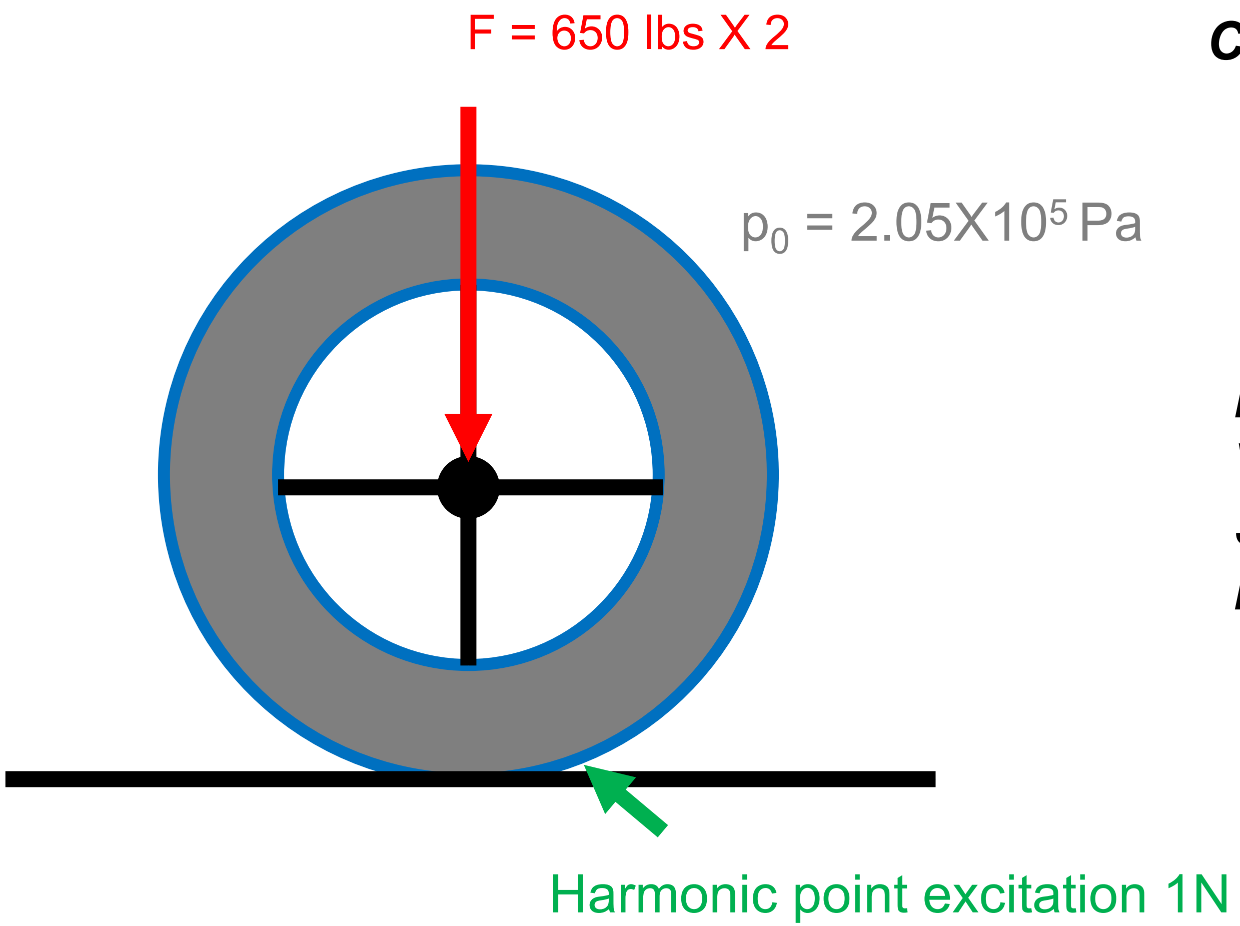
- Material properties were simplified and approximated
- Rim was set to be very stiff, so it's resonances were above the frequency of interest in this study
- Air bulk modulus was given at 97 ˚F

II. A previous finite element tire model



II. A previous finite element tire model

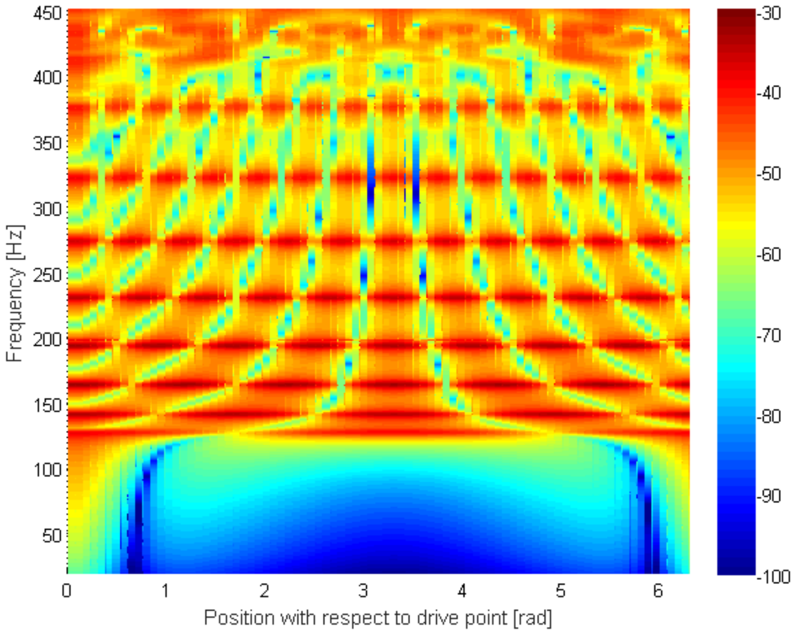
Excitations and boundary conditions

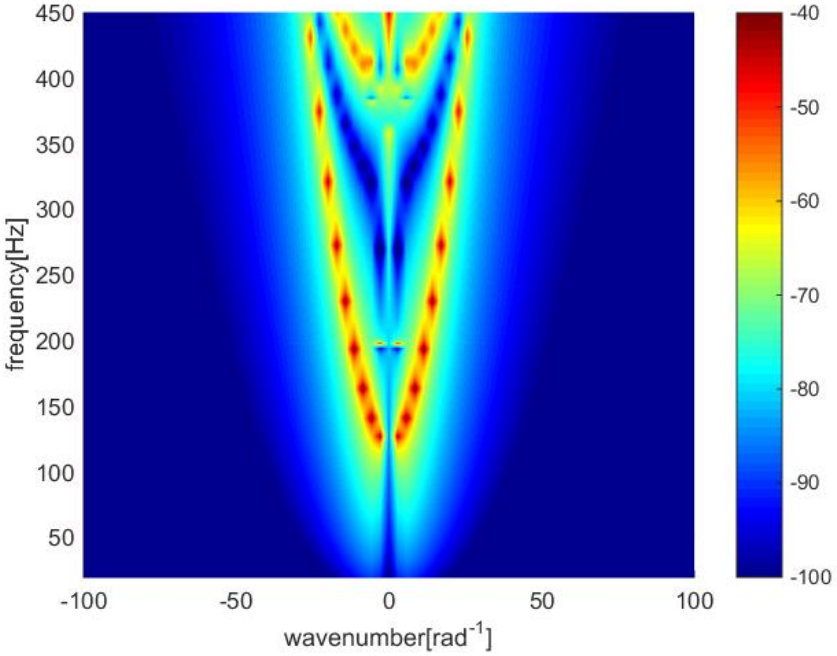


BC -
Continuity boundary
Contact boundary

Load -
Vertical static loads
Static inflation pressure
Point harmonic excitation

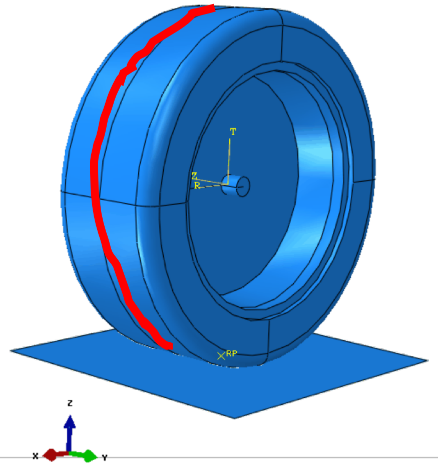
II. A previous finite element tire model





Drive point

Spatial Surface velocity - unloaded tire



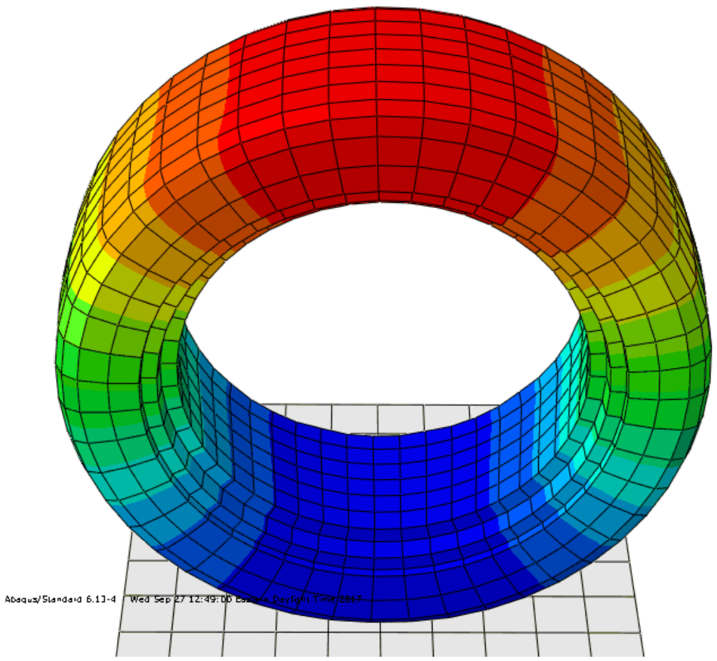
Dispersion relations - unloaded tire

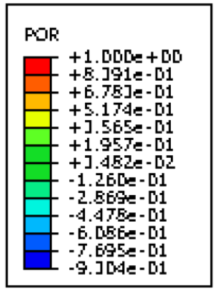
Velocity was measured at points along the tire tread centerline

Dispersion was based on the wavenumber decomposition of the surface mobility data

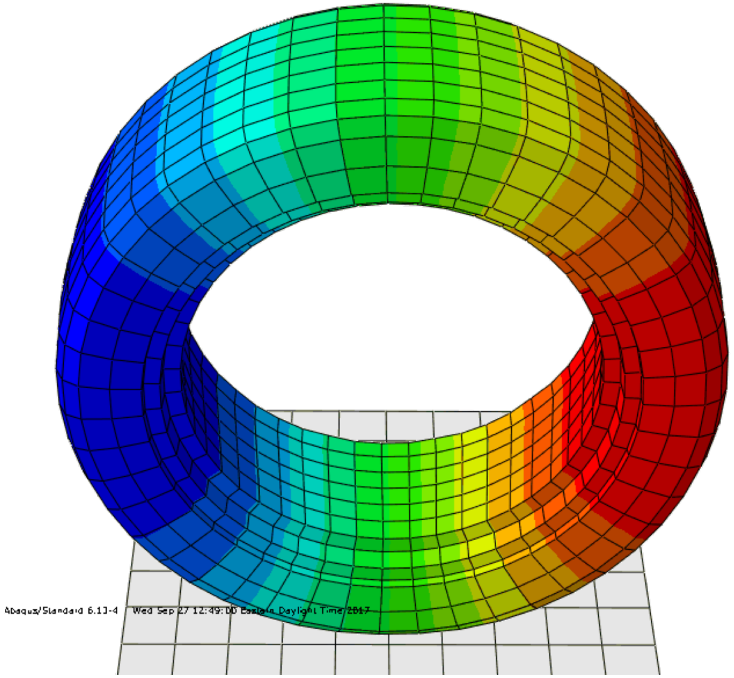
II. A previous finite element tire model

Vertical cavity mode (pressure distribution)

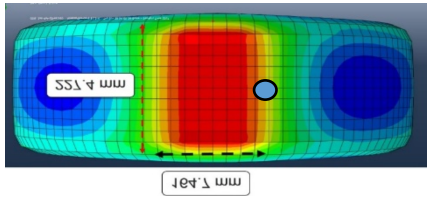




Horizontal cavity mode (pressure distribution)



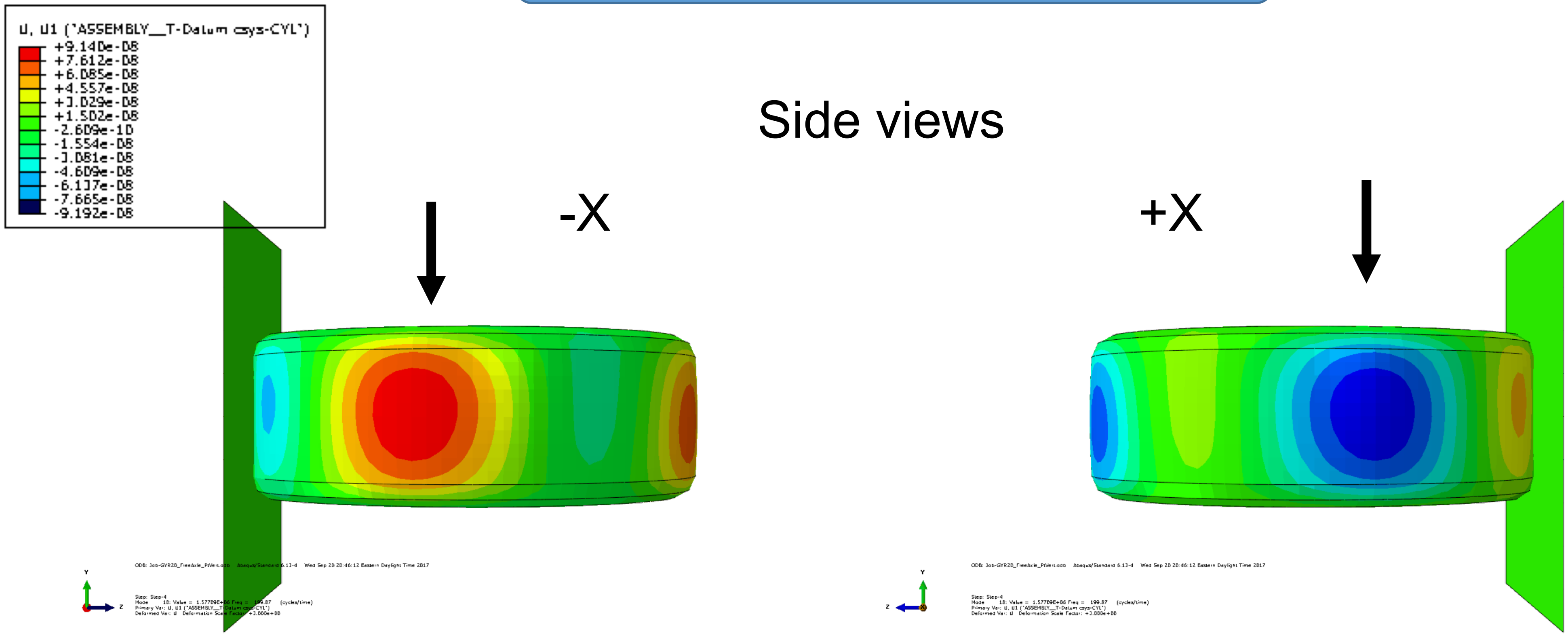
- ❖ Deformation causes cavity resonance split
- ❖ One occurs below undeformed cavity resonance (horizontal)
- ❖ One occurs above undeformed cavity resonance (vertical)



Undeformed resonance: 200.1 Hz; vertical mode: 201.4 Hz; horizontal mode: 199.3 Hz

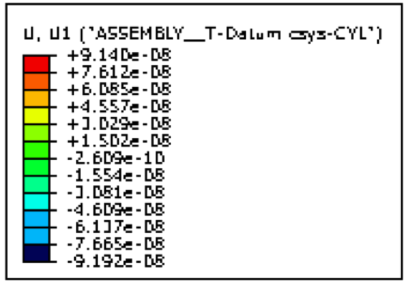
II. A previous finite element tire model

1st cavity mode - horizontal

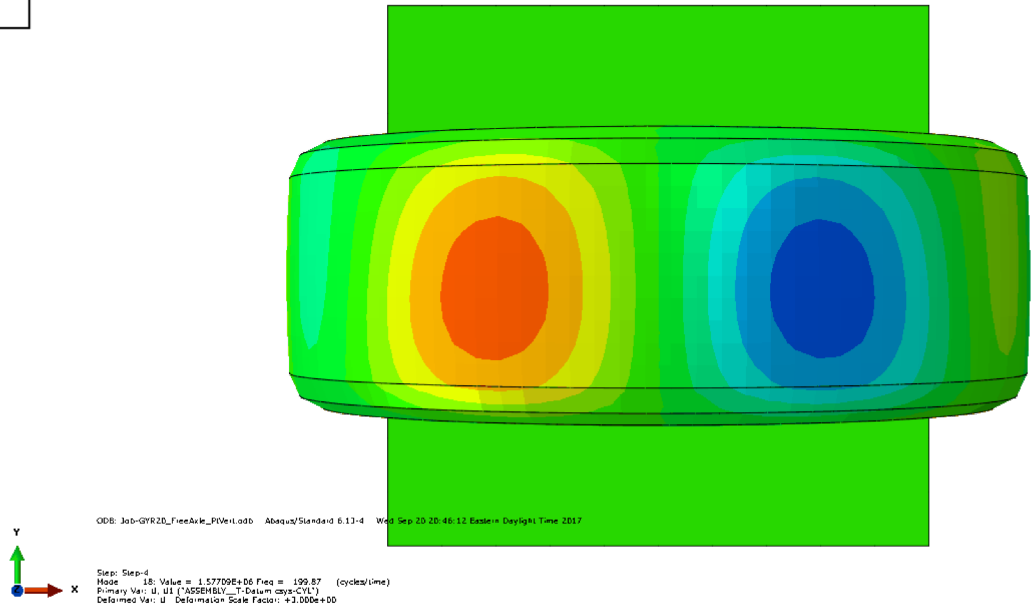


Radial displacement

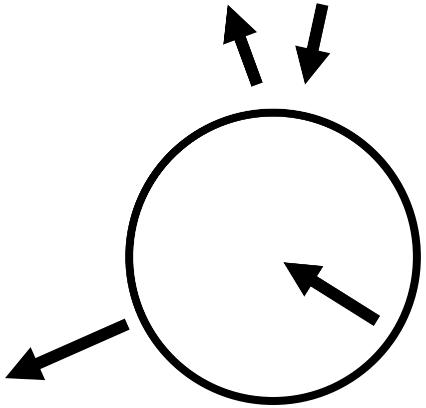
1st cavity mode - horizontal



Top view



Vertical motion components were canceled, leaving only horizontal motions

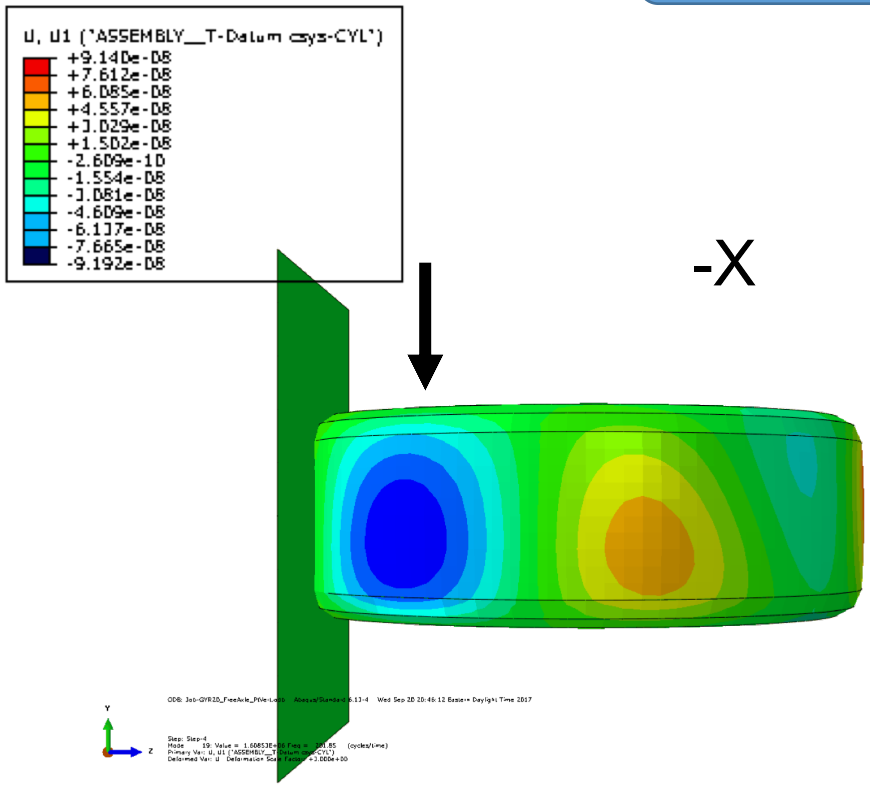


II. A previous finite element tire model

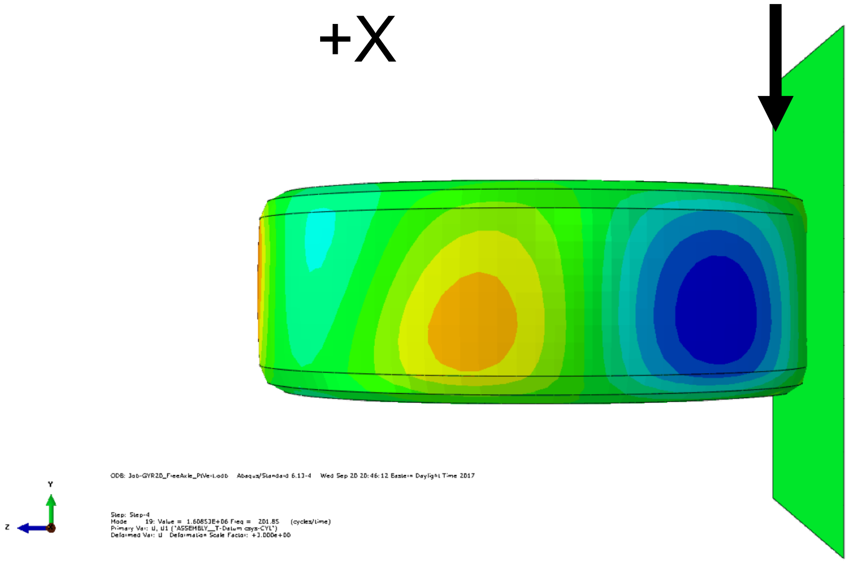
1st cavity mode - vertical

Side views

-X



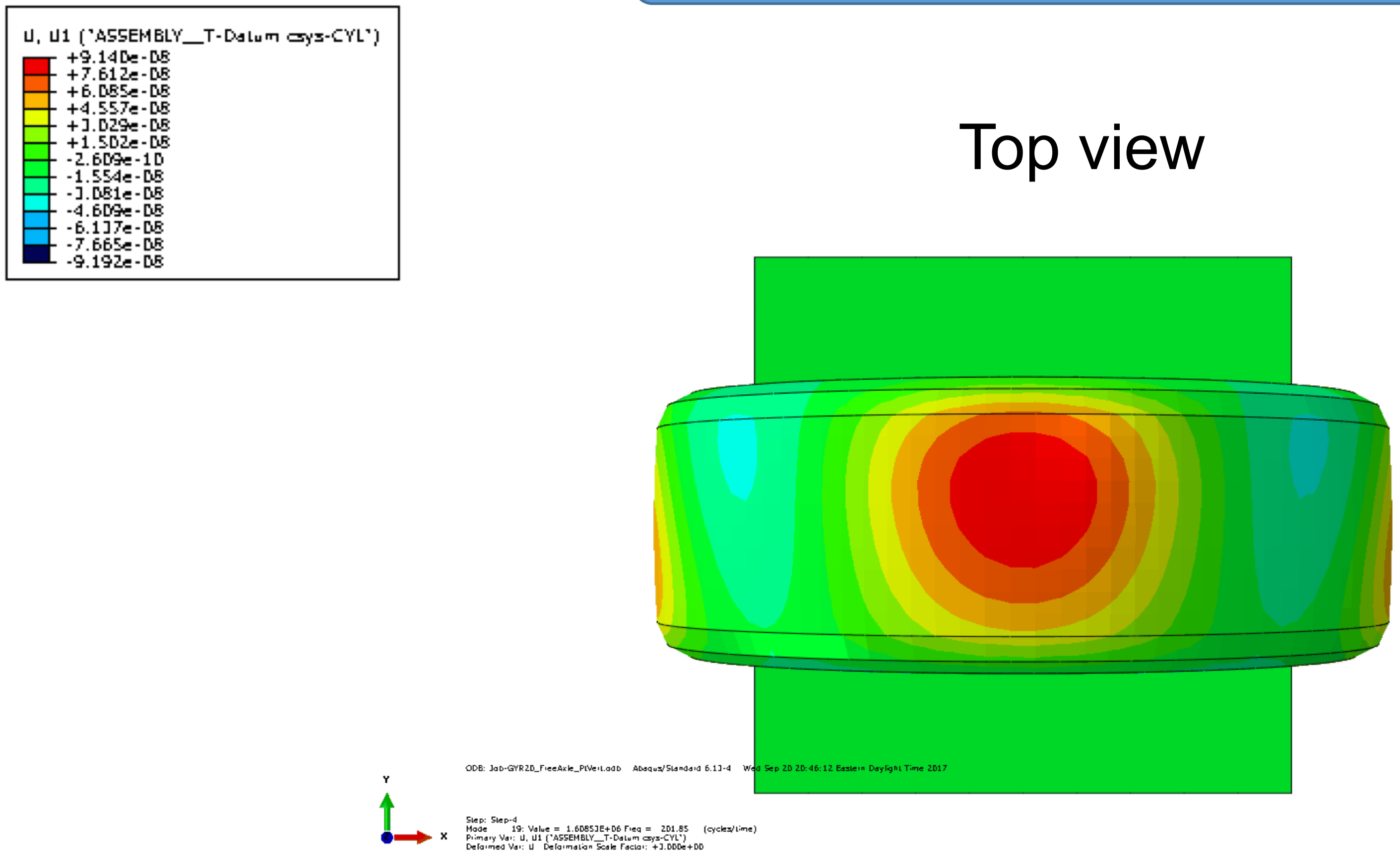
+X



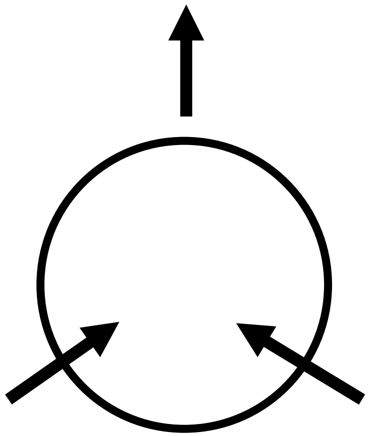
II. A previous finite element tire model

1st cavity mode - vertical

Top view

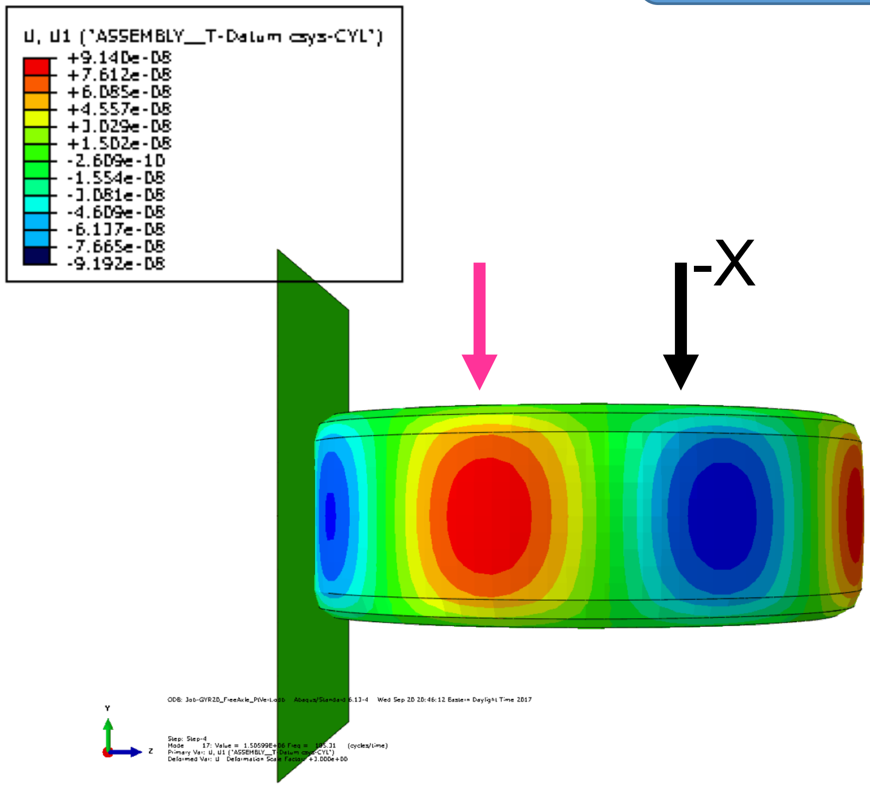


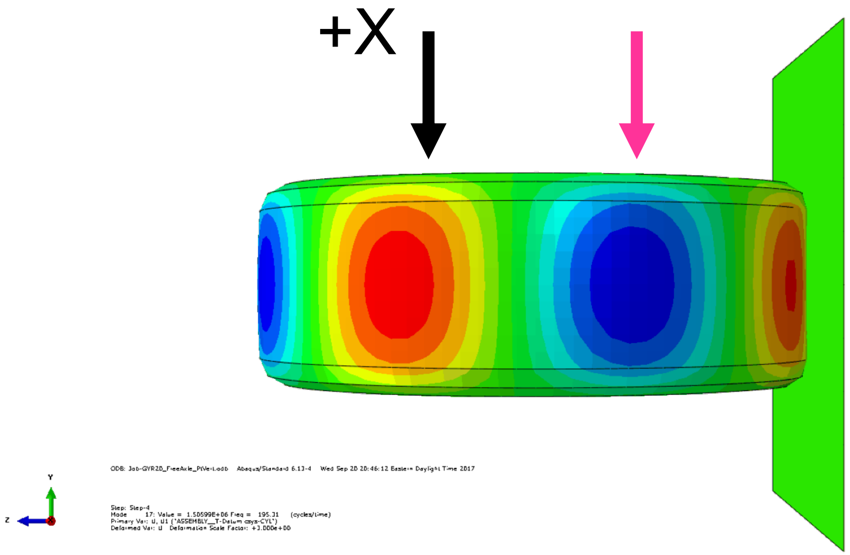
Horizontal motion components were canceled, leaving only vertical motion



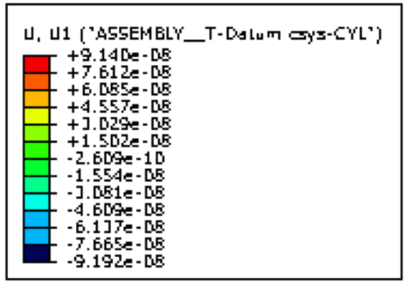
8th structural mode

Side views

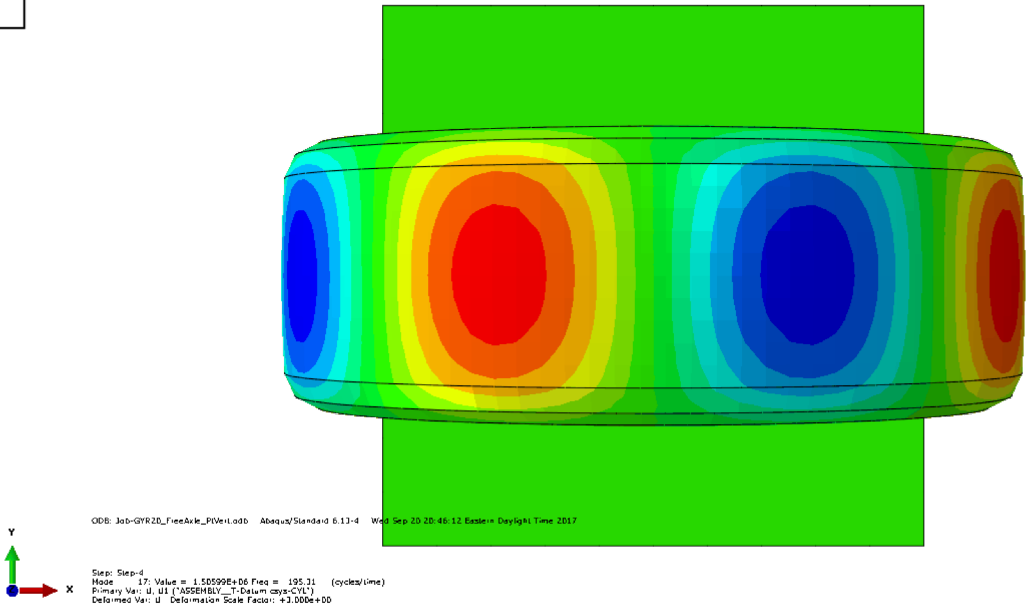




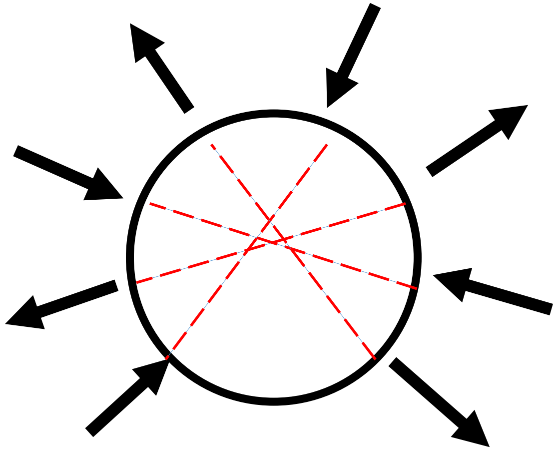
8th structural mode



Top view



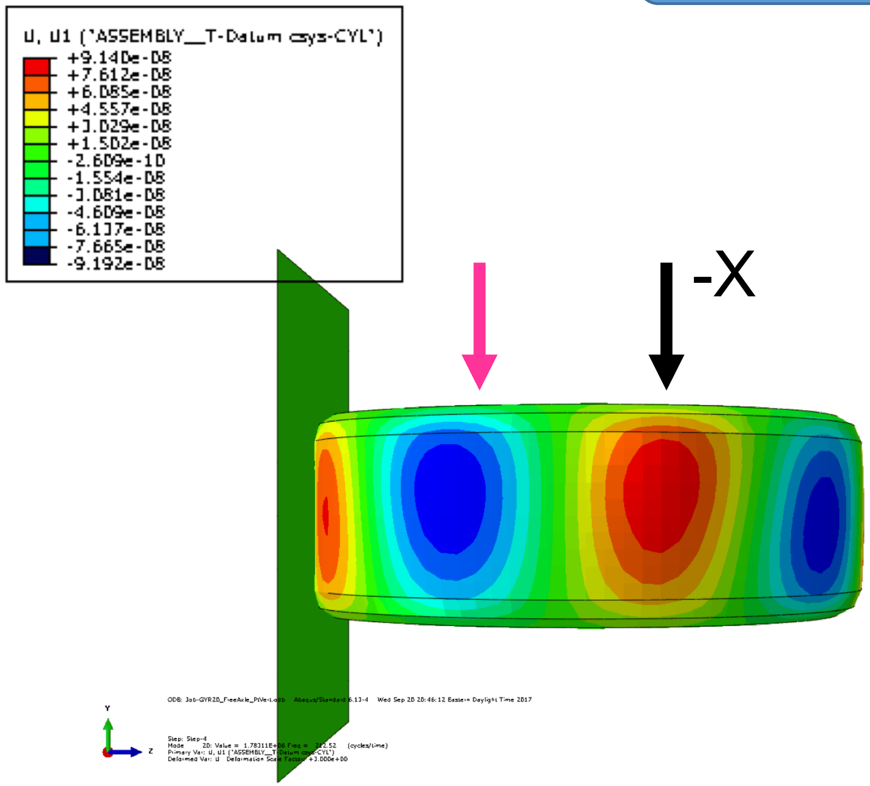
Motion on two sides cancel each other

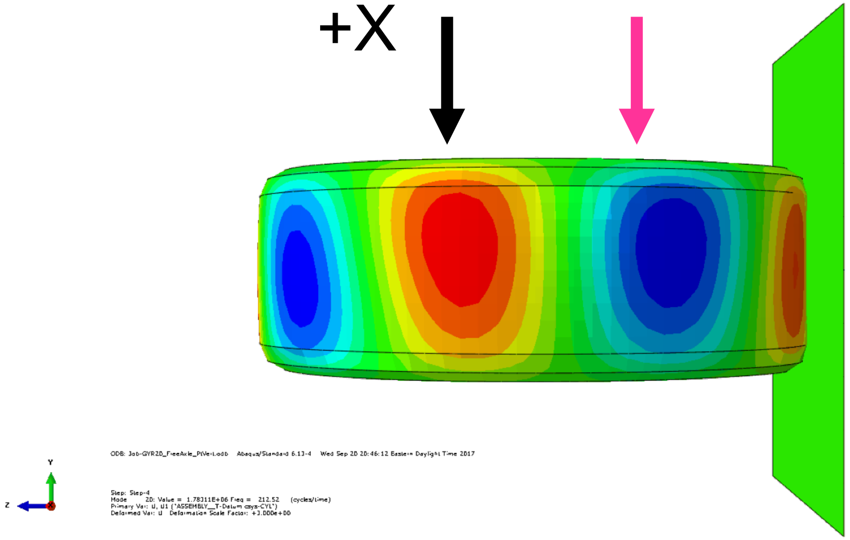


II. A previous finite element tire model

9th structural mode

Side views

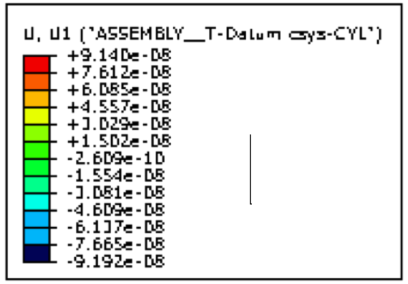


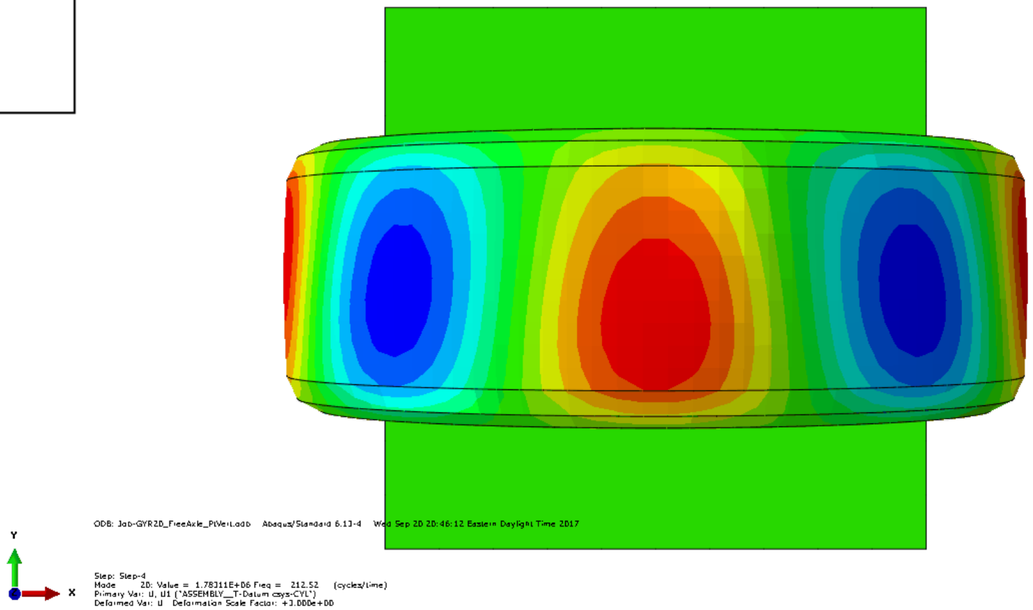


II. A previous finite element tire model

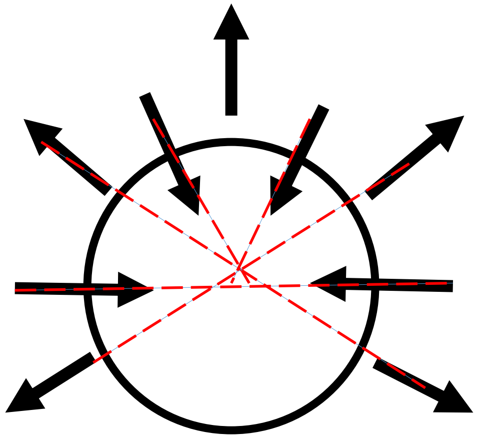
9th structural mode

Top view





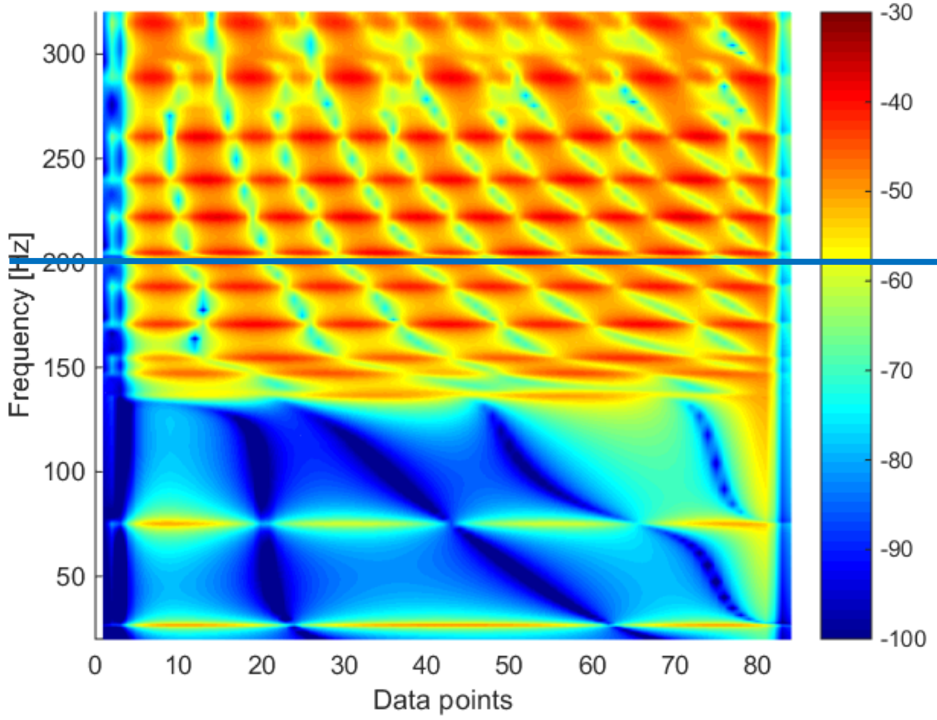
Motion on two sides cancel each other, except for the peak on top



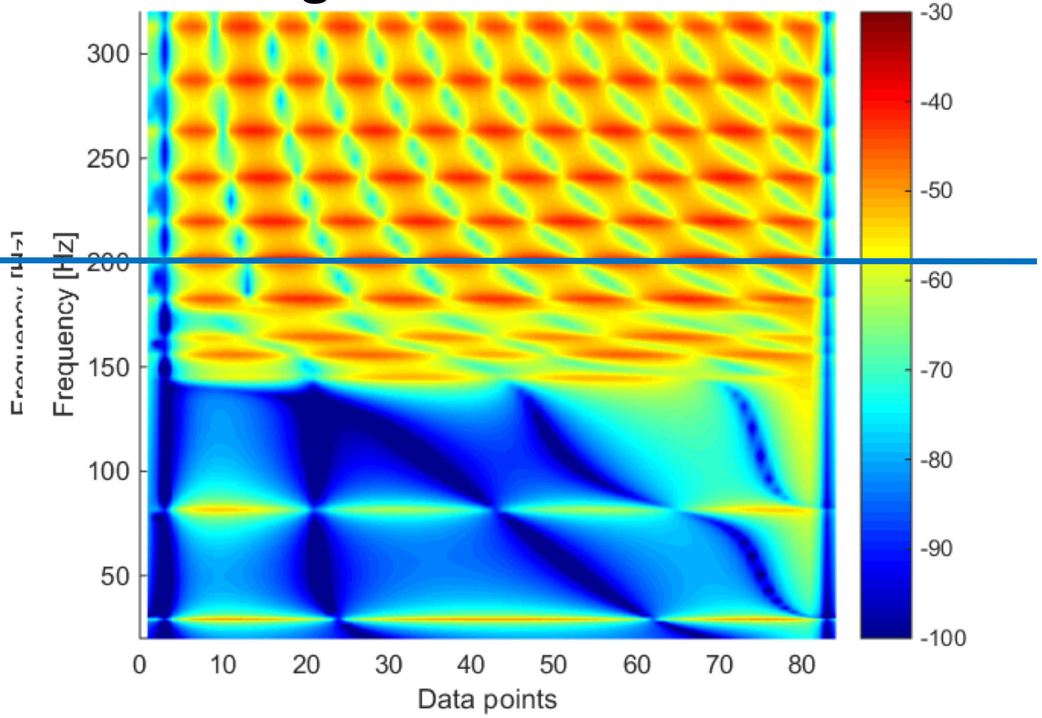
When 9th circumferential structural mode has same frequency as the vertical cavity mode, large response is observed

Align the structural resonance with cavity resonance

Low stiffness material



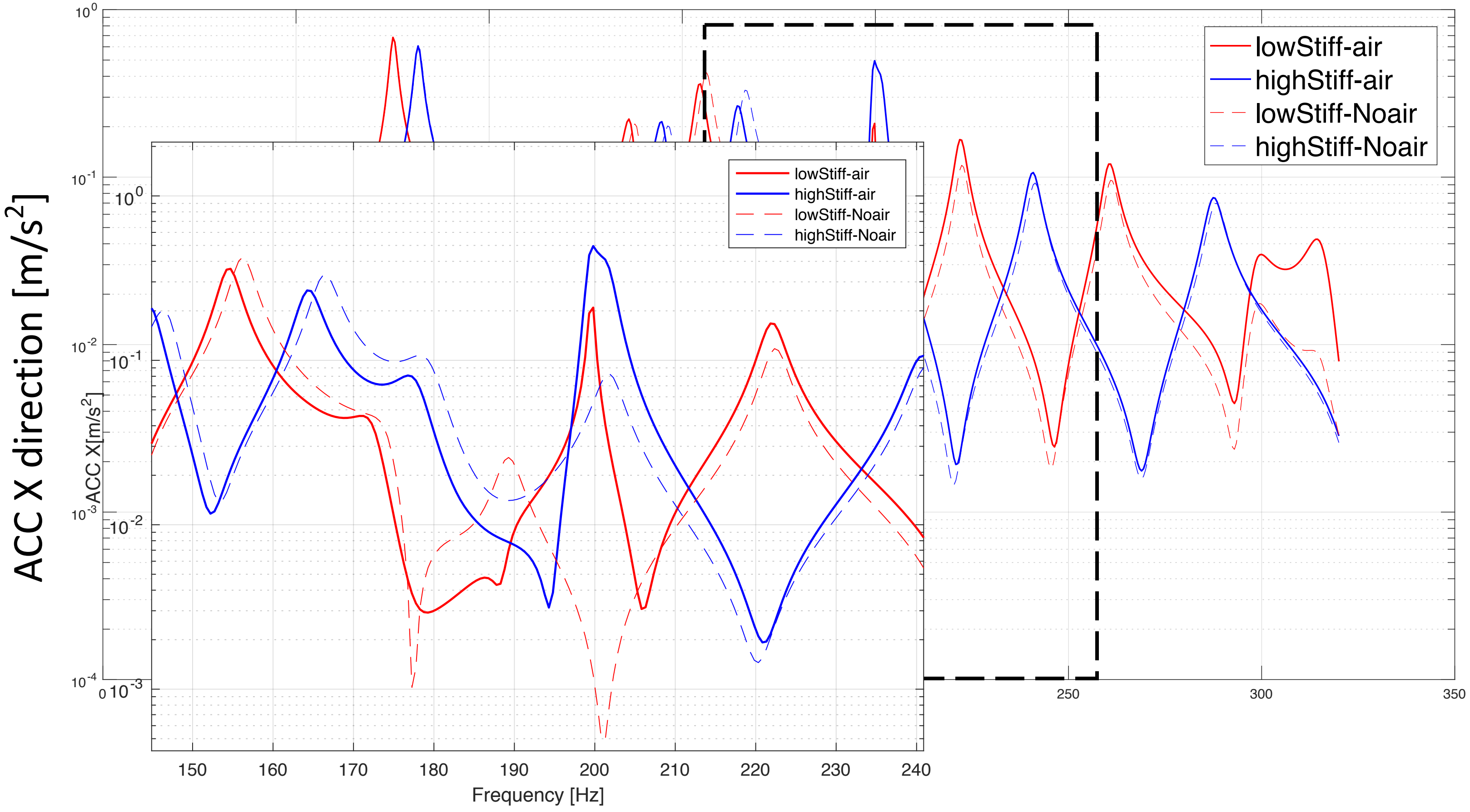
High stiffness material



Compare with a model without air cavity

Low Stiffness
Vertical cavity mode
= 9th structural mode

High Stiffness
Vertical cavity mode
= 8th structural mode



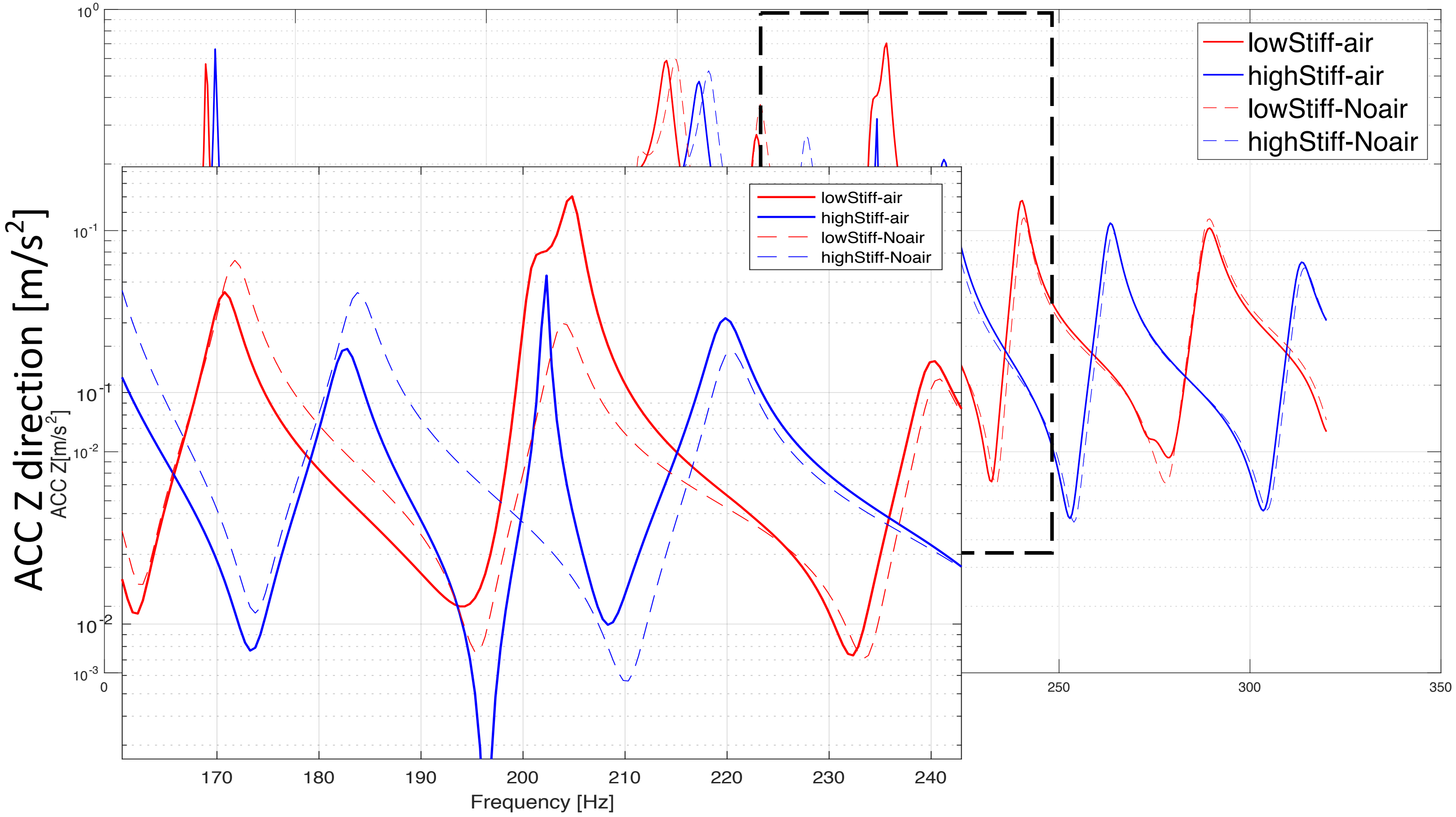
Without air – fore-aft motion is substantially reduced near 200 Hz for high stiffness case

II. A previous finite element tire model

Low Stiffness
Vertical cavity mode
= 9th structural mode

High Stiffness
Vertical cavity mode
= 8th structural mode

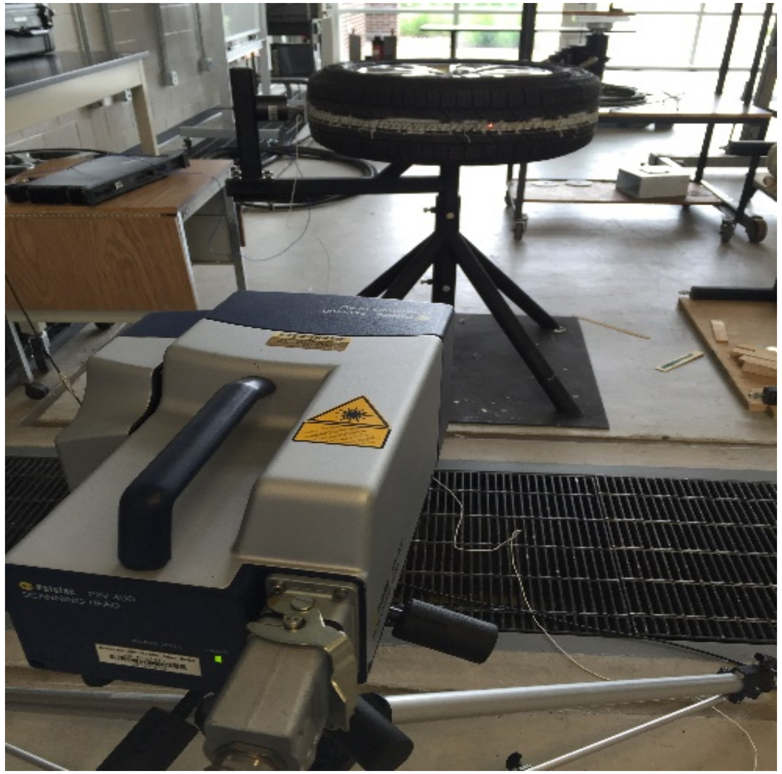
Compare with a model without air cavity



Without air - vertical motion is substantially reduced near 200 Hz

III. Experiment verification

Laser Doppler Vibrometry



- Measure tire surface velocity

Tire set up

- Static tire mounted on a rig
- driven by a mini-shaker

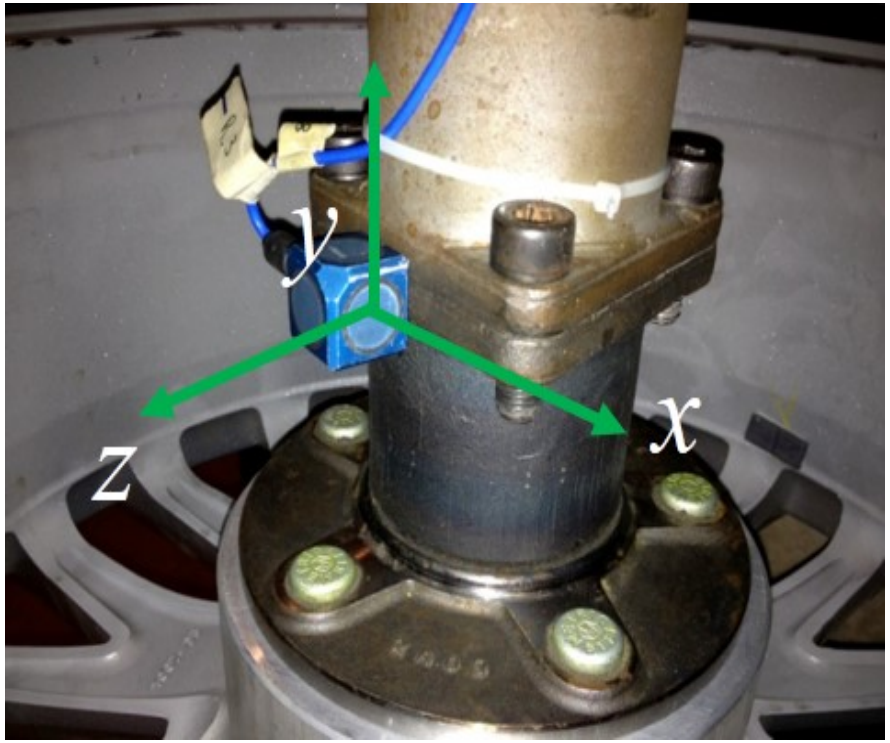
III. Experiment verification

Test facility

Tire Pavement Testing Apparatus (TPTA)
at Ray W. Herrick Laboratories, Purdue University, West Lafayette, IN

- ❖ Tires run at 50 km/hr
- ❖ Loaded up to 6000 N, inflation set at 33 psi
- ❖ Tests run with and without fibrous lining in the cavity

Sensors



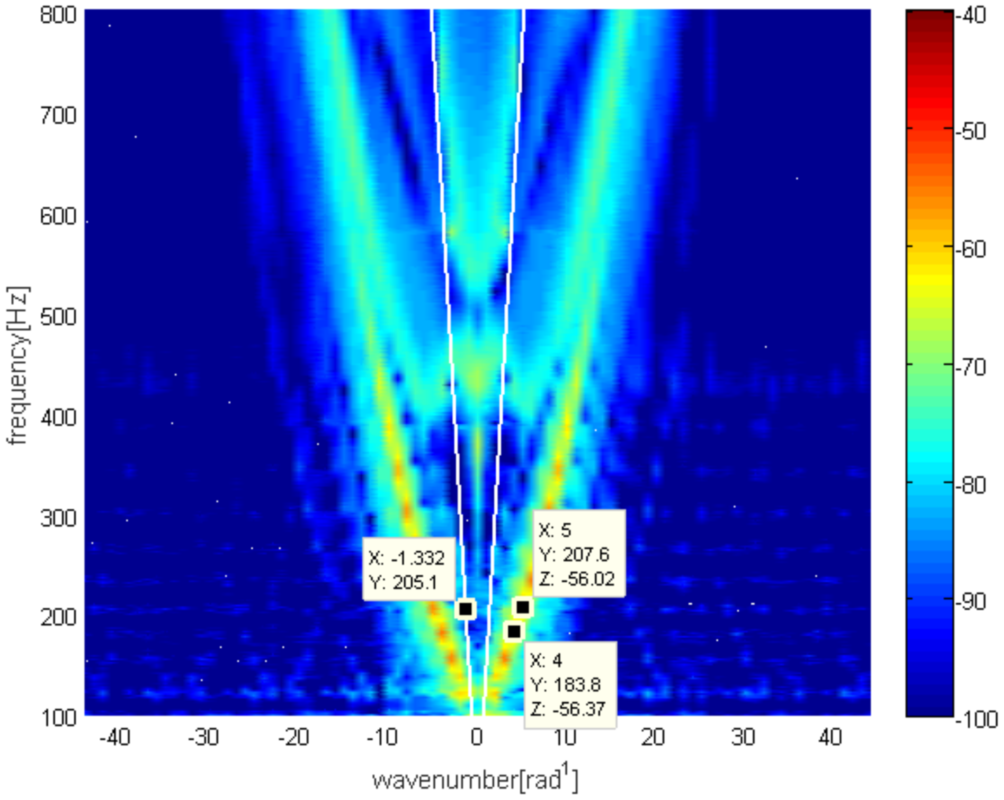
Tri-axial accelerometer mounted on the rigid hub

- ❖ *Z*-direction – normal to the pavement surface
- ❖ *Y*-direction – axial direction
- ❖ *X*-direction – tire travel direction

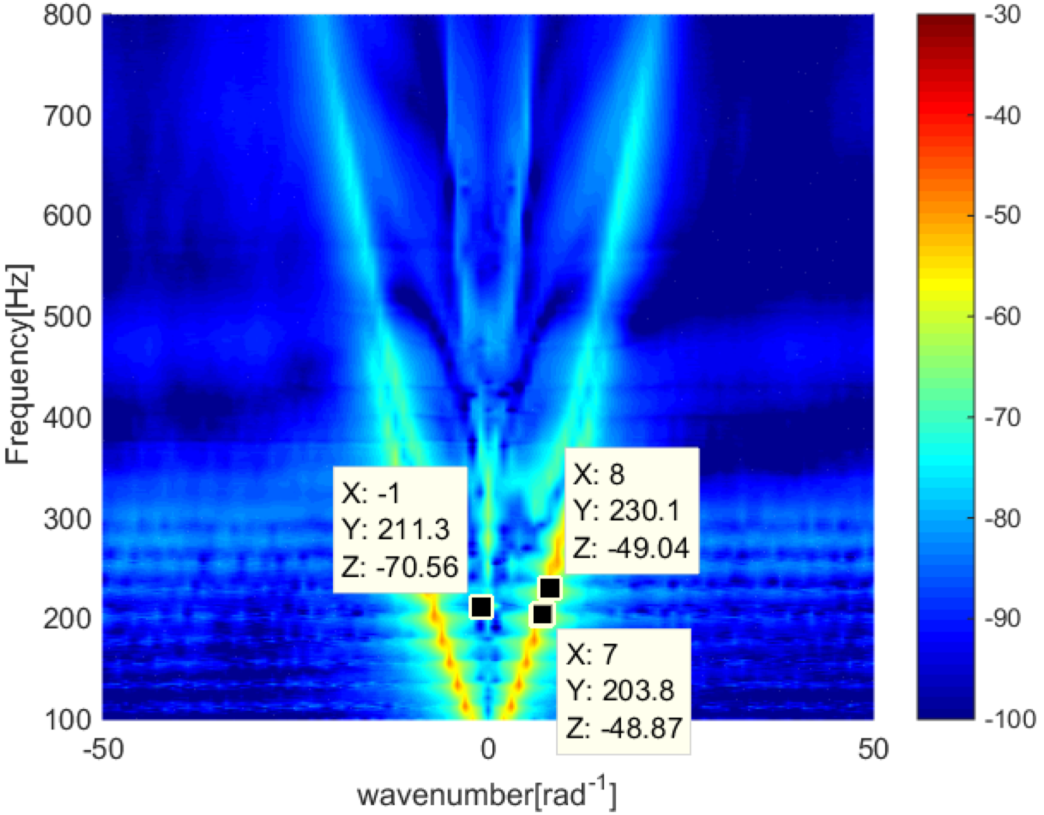
III. Experimental result

Static dispersion results

Tire 1



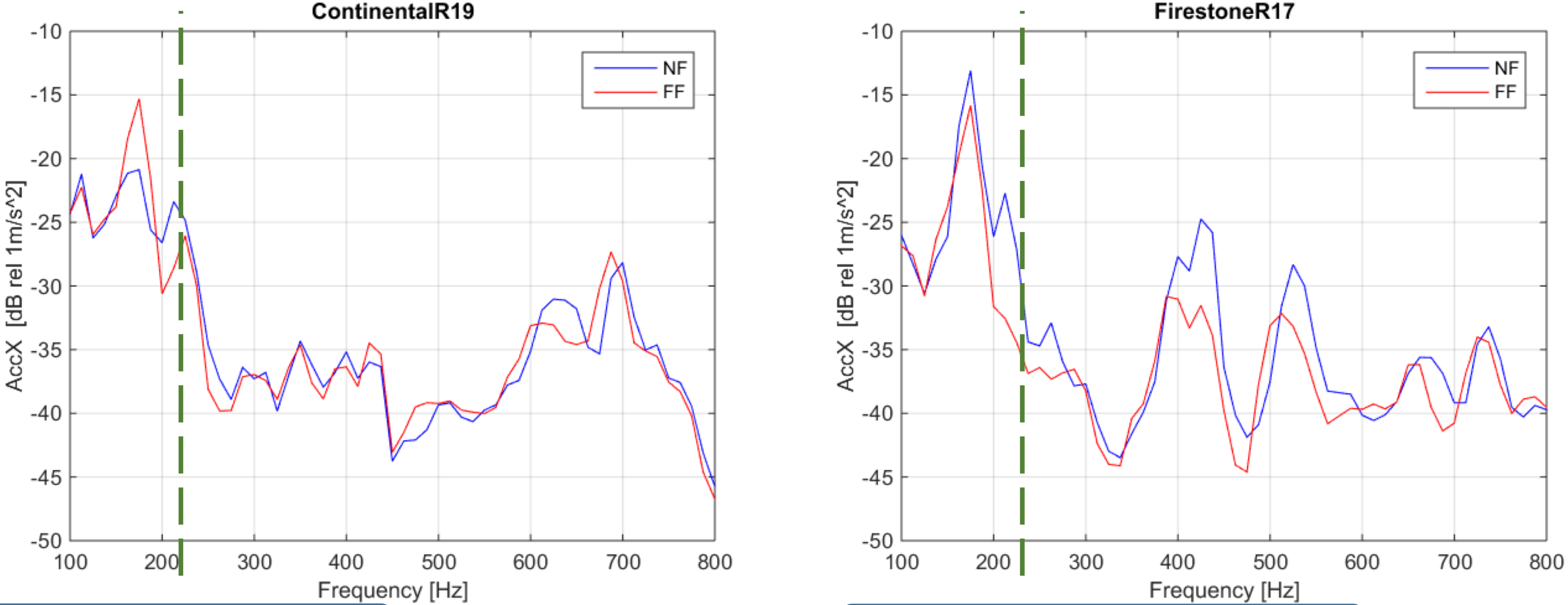
Tire 2



- ❑ Static cavity resonance is close to an odd structural mode for Tire 1
- ❑ Static cavity resonance is close to an even structural mode for Tire 2

III. Experimental result

Rim center accelerations – X-direction (fore-aft)



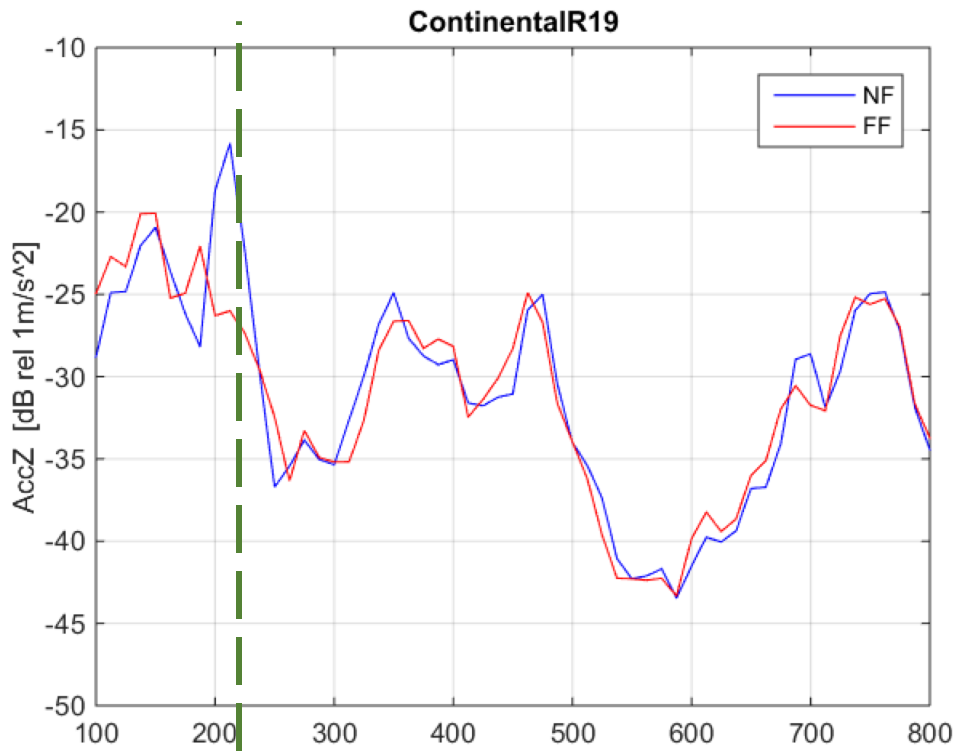
Static cavity resonance: 205 Hz

Static cavity resonance: 211 Hz

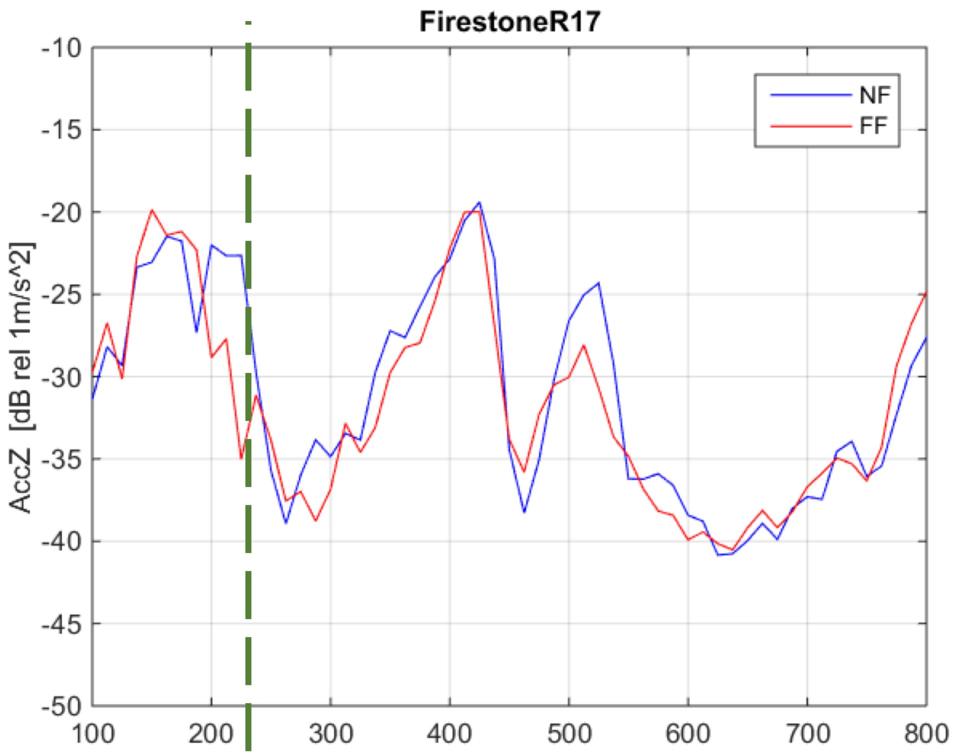
- ❑ 5-10 dB reduction seen at resonance frequencies
- ❑ Larger reduction seen in Tire 2

III. Experimental result

Rim center accelerations – Z-direction (vertical)



Static cavity resonance: 205 Hz



Static cavity resonance: 211 Hz

- ❑ Higher response compared to the *x*-direction
- ❑ Larger reduction seen in Tire 1

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Conclusion

- Both the finite element model and the tests confirmed that, if the **vertical cavity mode** couples with an **odd-number structural mode**, the rim center acceleration will be increased, especially in vertical directions
- If the **horizontal cavity mode** couples with an **even-number structural mode**, the rim center acceleration will be increased, especially in fore-aft directions
- The **acoustic material** was found to effectively **decouple** the cavity resonance from the structural resonance by absorbing the cavity resonance, thus substantially reducing the resultant narrow-band vibration levels around 200 Hz, in both fore-aft and vertical directions

Appendix

Reference

Rui Cao, J. Stuart Bolton and Matt Black, Force transmission characteristics for a loaded structural-acoustic tire model, *SAE International Journal of Passenger Cars-Mechanical Systems*, 2018 (In Press)

Rui Cao, J. Stuart Bolton, Tire cavity induced structure-borne noise study with experimental verification, *INTER-NOISE and NOISE-CON Congress and Conference Proceedings*, 2018 (Conference submission)

Acknowledgement

Financial support provided by Ford Motor Company, Matt Black, contract monitor.