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Influence of Tire Size and Shape on Sound Radiation from a Tire in the Mid-Frequency Region

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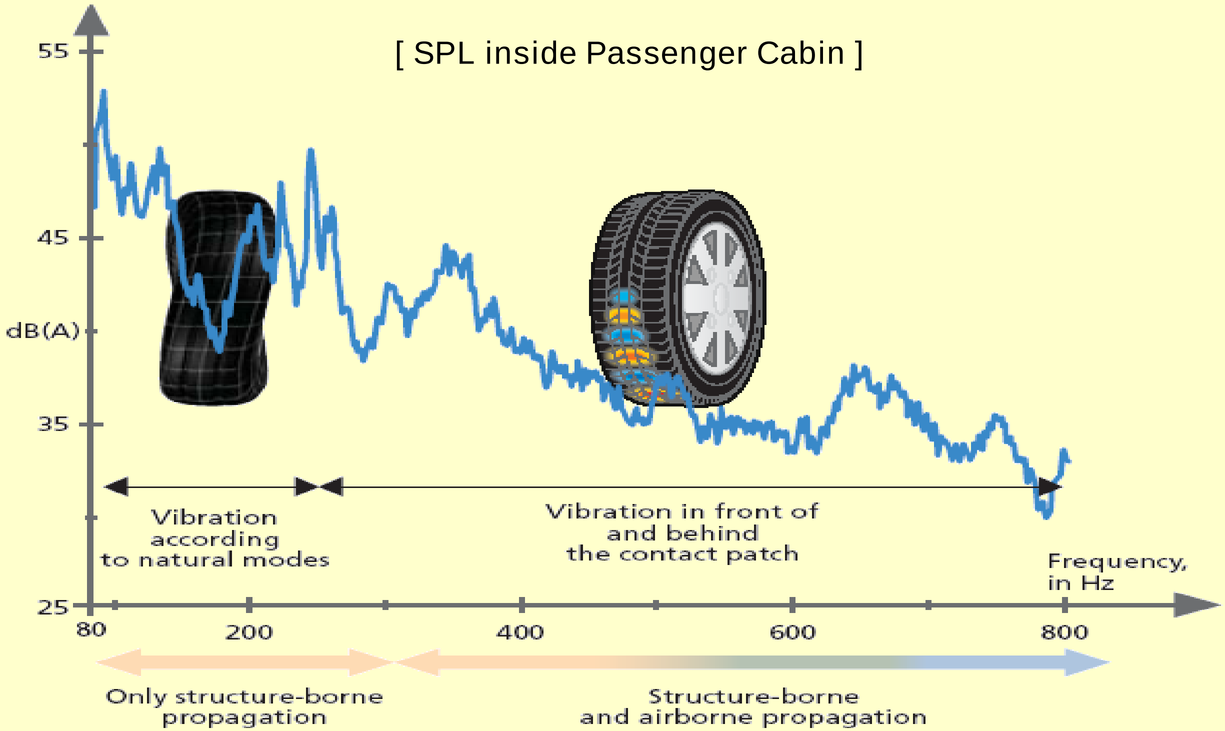
Tire Noise

■ Significance of Tire Noise



Vibration Mode (Structure-borne) Cavity Noise	Vibration ☞ Structure-borne ☞ Air-borne	Pattern (Whine) Air Pumping (Sizzle) Horn Effect

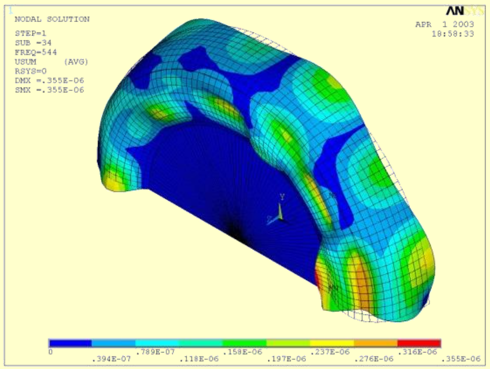
Objectives

- Problem Definition
  - Tire's structural vibration and its sound radiation in a mid-frequency region (300 – 800 Hz)

- Objectives
  - To identify the relationship between structural wave propagation characteristics and its sound radiation
  - To investigate the influence of tire shape and size on a tire's structural vibration and its sound radiation
  - To suggest the optimized tire shape factor with a view to reducing tire noise resulting from tire vibration

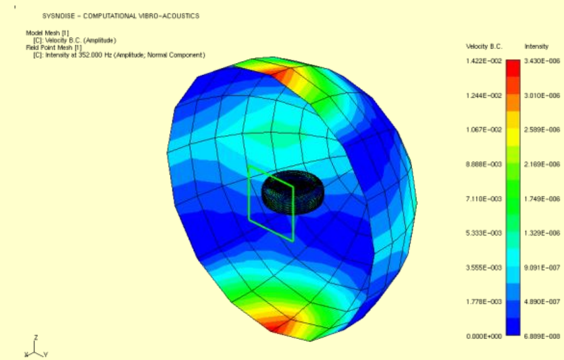
Contents

1. Relationship between Structural Vibration on Tire Surface and its Sound Radiation



[Structural Harmonic FEM]
Structural wave propagation characteristics on tire surface

Relationship



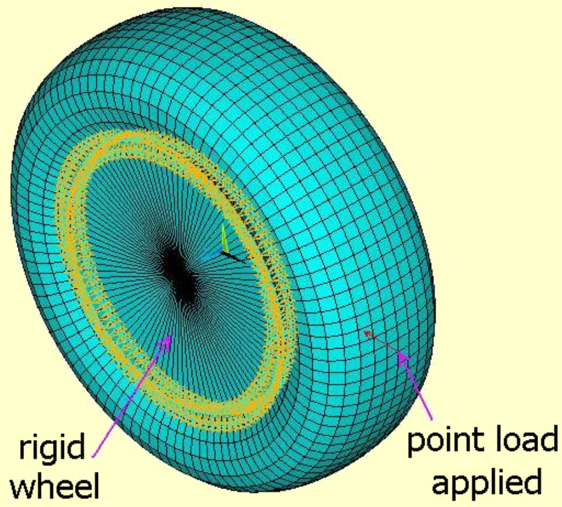
[Direct BEM]
Sound radiation from a tire

2. Influence of Tire Size and Shape (Aspect Ratio, Width, Rim Diameter) on Structural Vibration and Sound Radiation in a Mid-Frequency Region

3. Optimization of Tire Shape factor

Structural FE Analysis

■ Tire FE model



- Based on 205/70R14 Tire
- Shell elements were used.
- **Orthotropic material properties** were applied on treadband and sidewall.

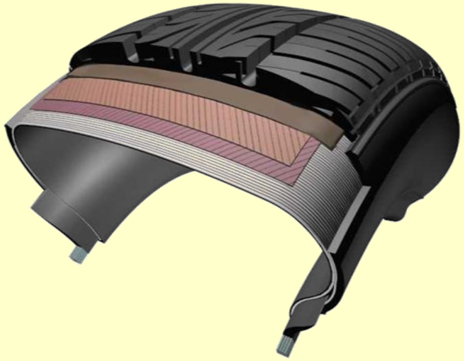
■ Structural Harmonic Analysis

- Full matrix method was performed using ANSYS ver. 7.1.
- Harmonic point source was applied at the point in contact with the ground

Orthotropic Material Properties

tread band	circumferential Young's modulus	750 MPa	side wall	circumferential Young's modulus	7.5 MPa
	cross-sectional Young's modulus	320 MPa		cross-sectional Young's modulus	50 MPa
	shear modulus	50 MPa		shear modulus	1.5 MPa
	Possion's ratio	0.45		Possion's ratio	0.45
	density	1200 kg/m^3		density	800 kg/m^3
inflation pressure		30 psi (207 kPa)			

- adapted from the work of Kropp [1989] and Pinnington and Briscoe [2002], and direct measurement at Continental Tire.

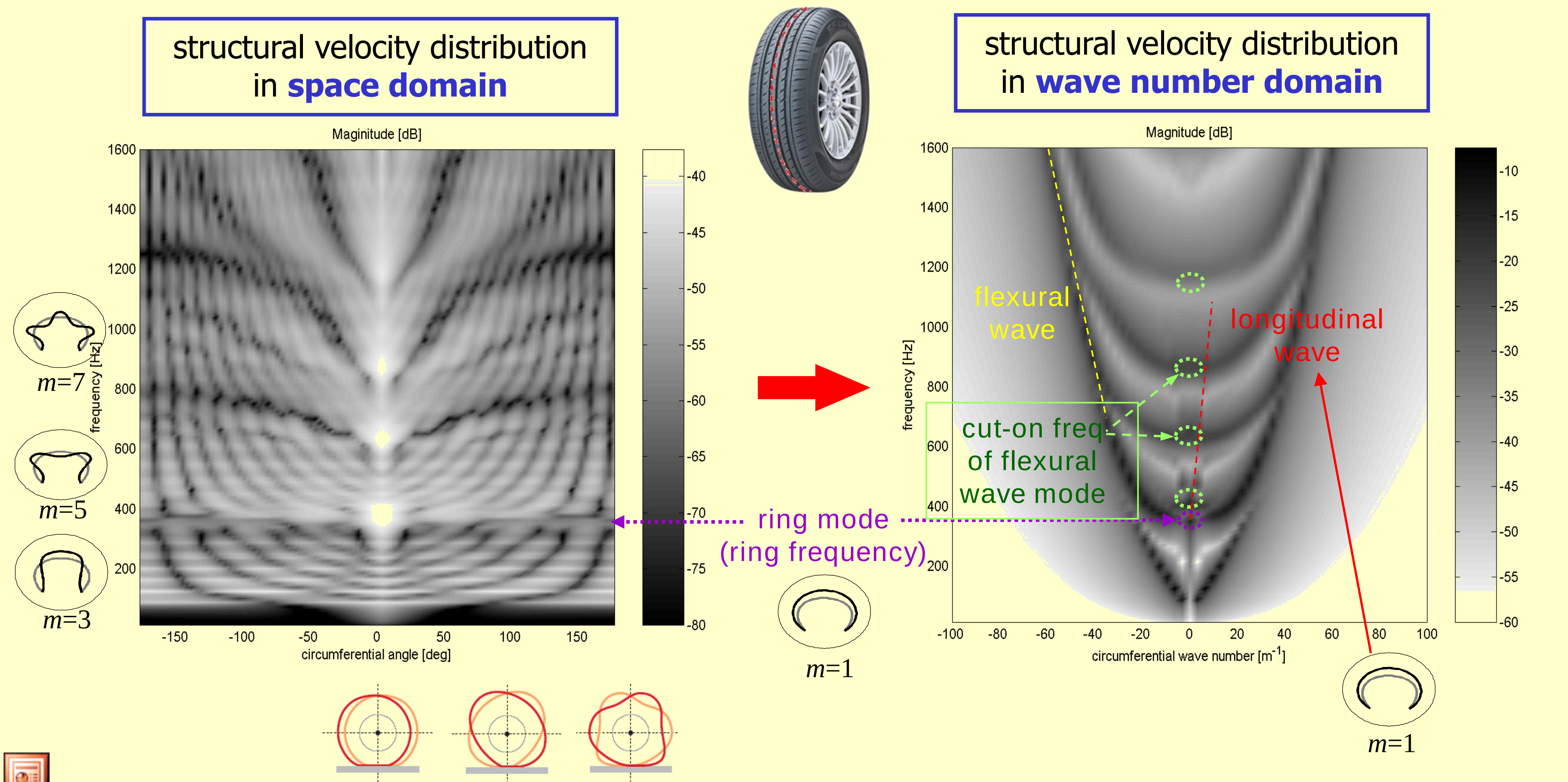


Structural Wave Propagation

■ Circumferential Wave Number Decomposition

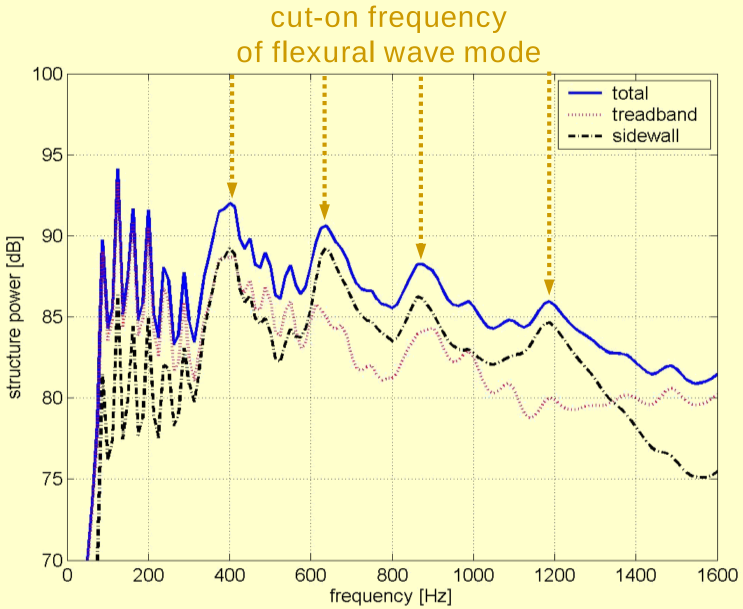
structural velocity distribution
in **space domain**

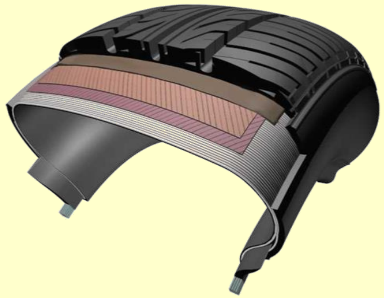
structural velocity distribution
in **wave number domain**



Structural Harmonic Analysis Results

■ Structural input power





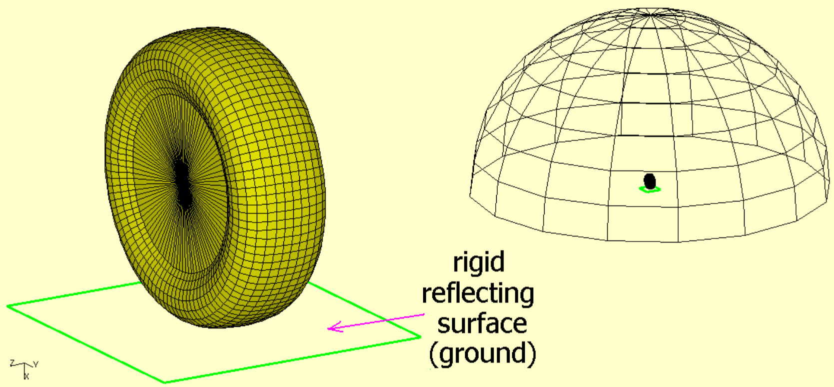
- $E = \rho_0 c S_b \left\langle \overline{v}_b^2 \right\rangle$

where S_b : tire surface area

- Structural vibrations related to road noise below 300 Hz appears mainly on treadband.
- Dominant structural power peaks correspond to cut-on frequencies of the flexural waves.

Far-field Radiation Model

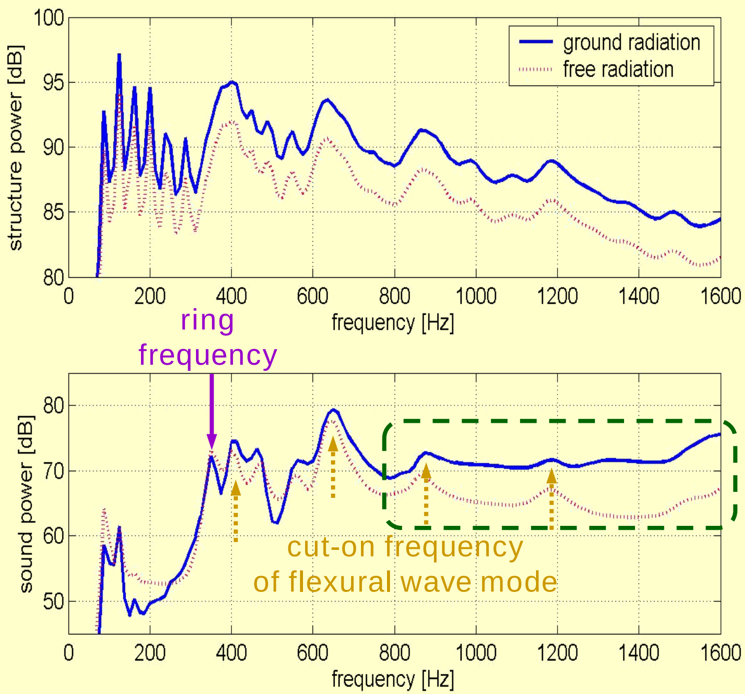
- Boundary Element Model
  - Full tire model used in structural harmonic analysis was imported.



[reflecting surface radiation]

- D-BEM Analysis
  - Using Direct Collocation Boundary Element Method (**D-BEM**) in SYSNOISE ver. 5.6
  - The optimized 18 CHIEF points were applied inside the tire surface to eliminate the singularity effects.

Structural Vibration/Radiation Relationship



[Farfield radiated sound power]

$$W = \sum_{r=1}^{R} \mathrm{Re}[p_r v_r] S_r$$

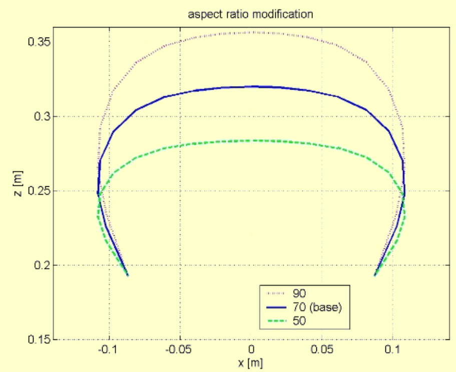
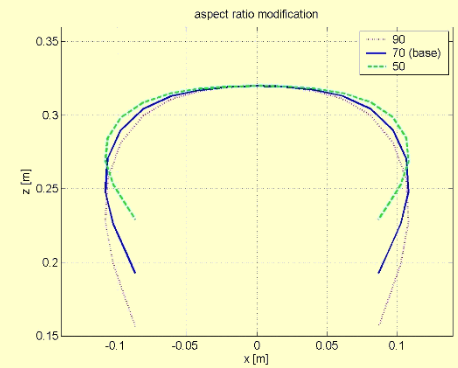
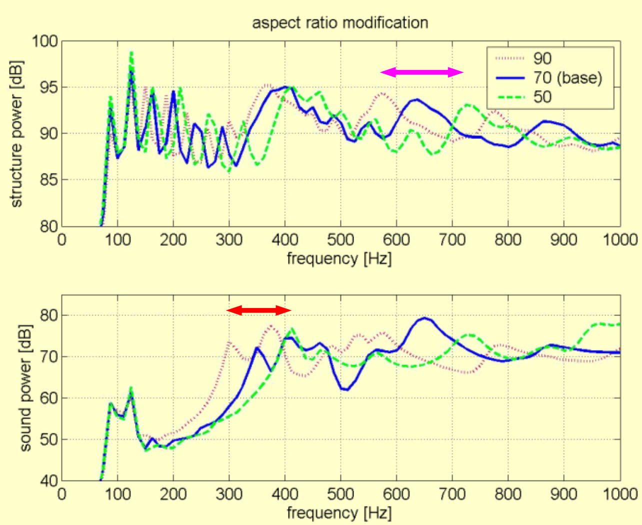
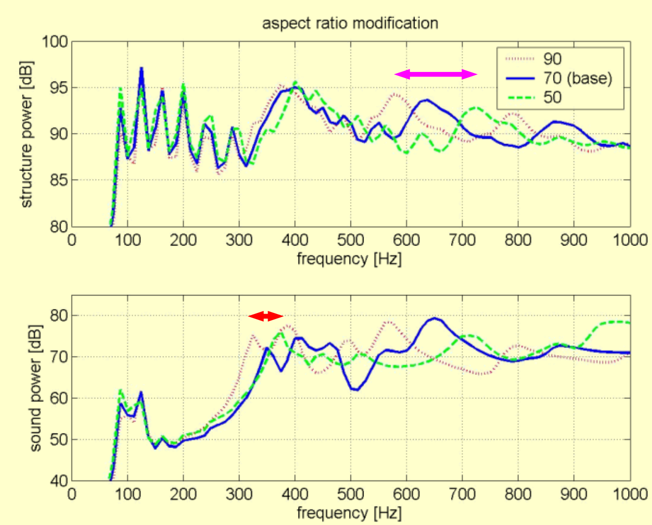
- Relationship between structural wave propagation and its radiation
  - Radiated power peaks don't match with those of structural power.
  - **Flexural wave motion below 400 Hz on the treadband**, which results in structure-bone road noise, does not radiate airborne sound effectively.
  - Radiated power peaks appear **when structural wave has low wave number.**
  - Radiated power for the reflecting surface radiation case is amplified above 800 Hz due to '**horn effect**'.

Influence of Tire Shape and Size

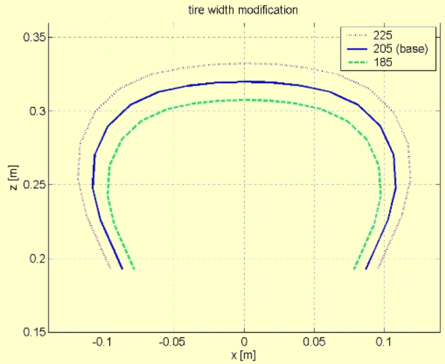
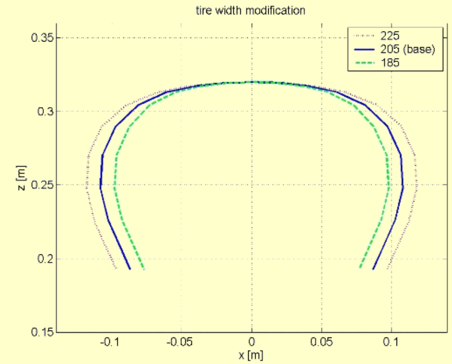
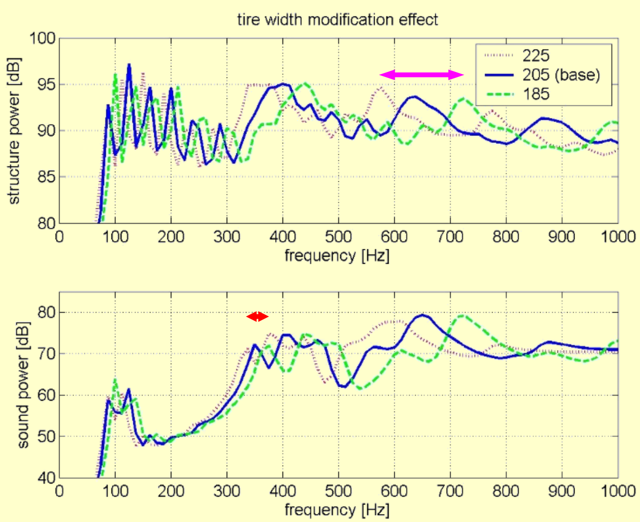
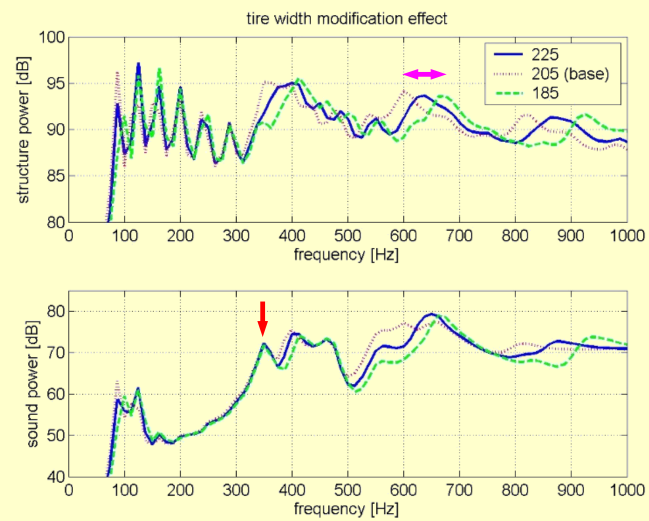
- Procedure
  - Performing structural harmonic analysis and sound radiation calculation by modifying each tire shape factor
  - Applying same material properties as the base set

	base	high	Low
tire width (w) [mm]	205	225	185
aspect ratio (h/w*100)	70	90	50
rim diameter (d) ["]	14	16	12

Influence of Tire Aspect Ratio

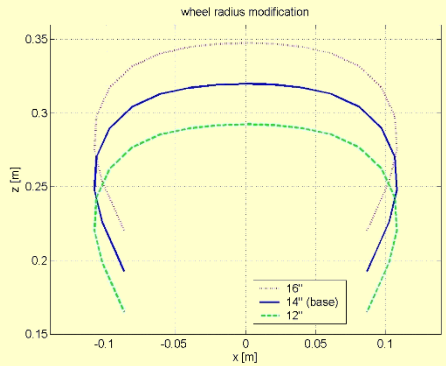
tire width & rim diameter fixed	overall diameter (OD) & tire width fixed
 	
	

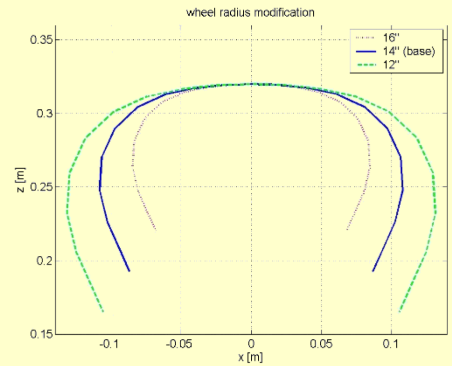
Influence of Tire Width

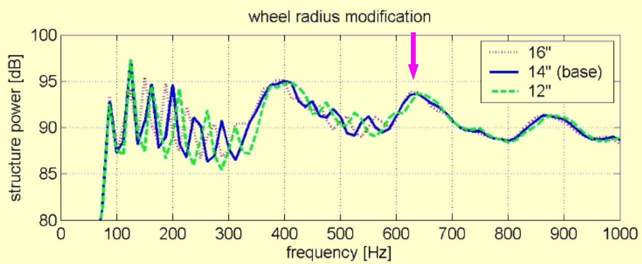
aspect ratio & rim diameter fixed	overall diameter (OD) & rim diameter fixed
 	
	

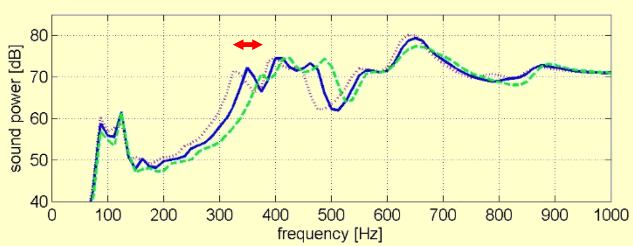
Influence of Rim Diameter

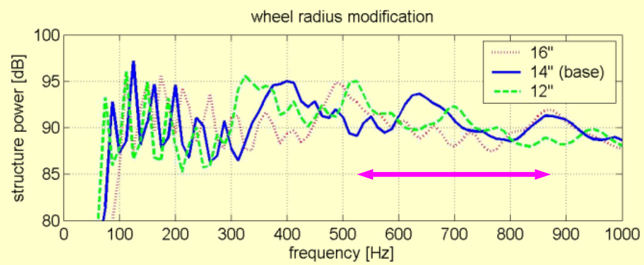
tire width & aspect ratio fixed	overall diameter (OD) & aspect ratio fixed

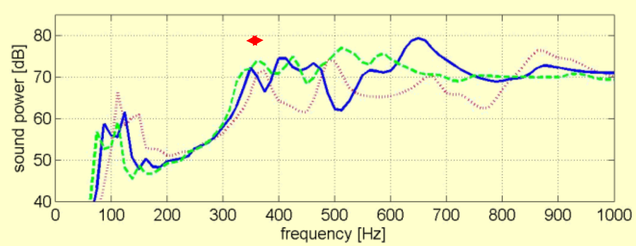










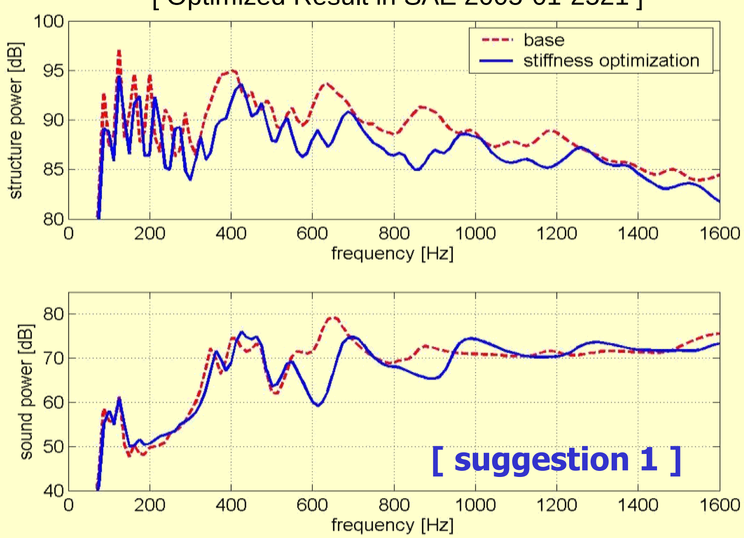


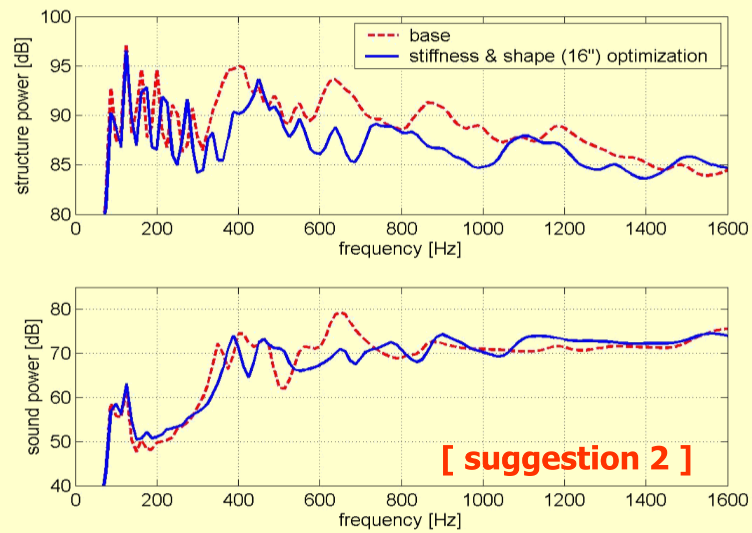
Tire Shape and Stiffness Optimization

■ Structural and tire shape optimization

	Treadband Stiffness		Tire Size and Shape			
	circumferential stiffness [MPa]	**cross-sectional stiffness** [MPa]	**width** [mm]	**aspect ratio**	**rim diameter** ["]	**Overall Diameter** [mm]
base	750	320	205	70	14	320
suggestion 1	**938**	**240**	205	70	14	320
suggestion 2	938	240	**205**	**55**	**16**	320

[Optimized Result in SAE 2005-01-2521]





Summary and Conclusions

Summary

- The **relationship** between structural wave propagation on the tire surface and its sound radiation was identified analytically.
- Influence of **tire size and shape** on structural vibration and sound radiation was investigated.
- **Optimization of tire shape and tire structure** was suggested.

Conclusions

- Radiated power peaks appear **when structural wave has low wave number.**
- The **flexural wave** motion was controlled primarily by the **tire cross-section length** while the **longitudinal wave** motion was mainly affected by the **treadband centerline diameter** (OD).
- **Decrease of aspect ratio** and **increase of treadband circumferential stiffness** moves the structural vibration characteristics into a higher frequency region.

Q & A

~ Thank you ~