Material testing

Realize innovation.

The vehicle manufacturer's acoustics challenge

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Reduce vehicle mass

Reduce interior sound level

Maintain brand comfort image

What is Acoustic Material Testing?

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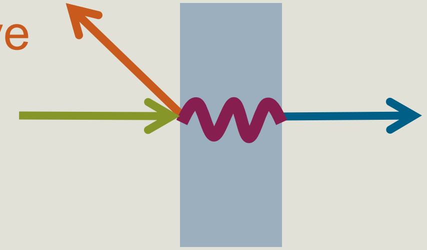
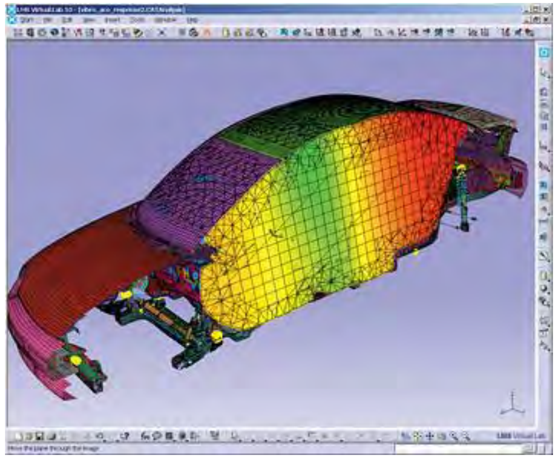
Sound Absorption

determines how much acoustic energy can be absorbed by the material



Sound Transmission Loss

determines the acoustic energy loss when sound passes the material or component



Sound absorption

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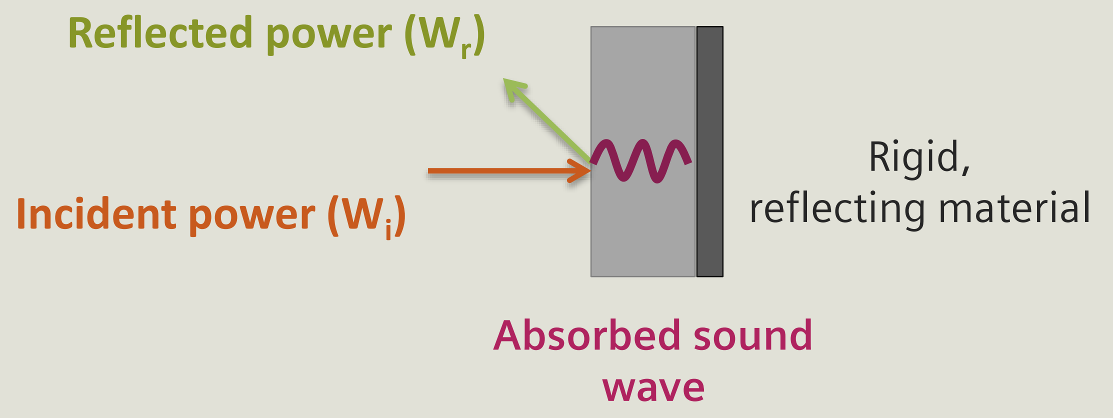
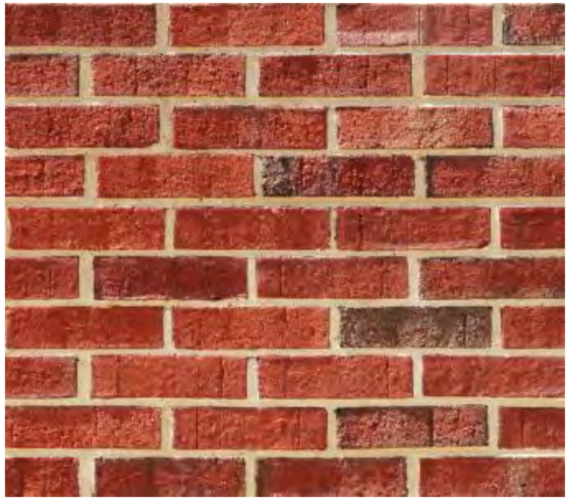
Absorption coefficient α:

$$\alpha = 1 - \frac{W_r}{W_i}$$

α depends on:
- Thickness
- Porosity
- Frequency
- Flow resistance
- Roughness
- …





Material	Absorption (α)
Unpainted brick wall	0.02 – 0.05
Glass pane	0.05 – 0.2
Hardwood	0.3
Acoustic tiles	0.4 – 0.8
Fiber glass	0.8 – 0.9

Sound absorption
Dependence on material thickness

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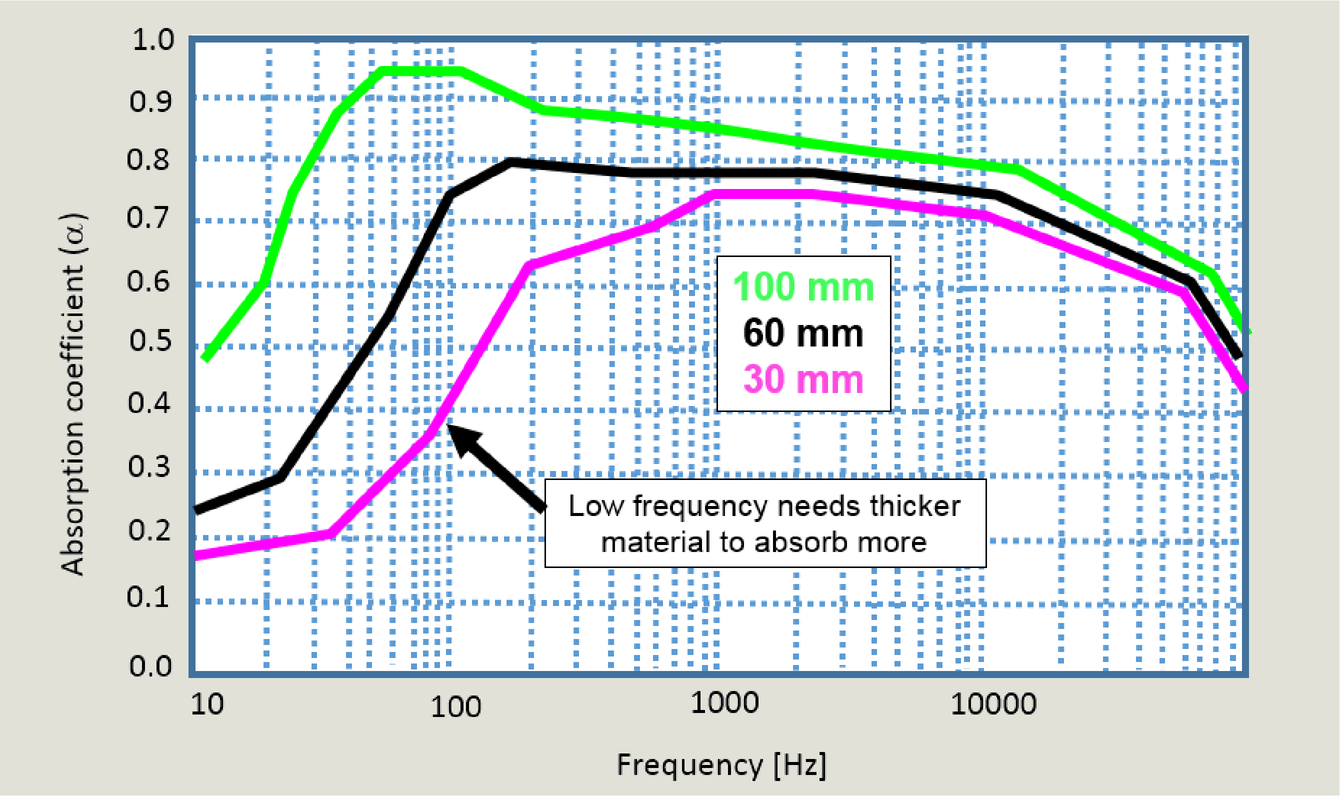
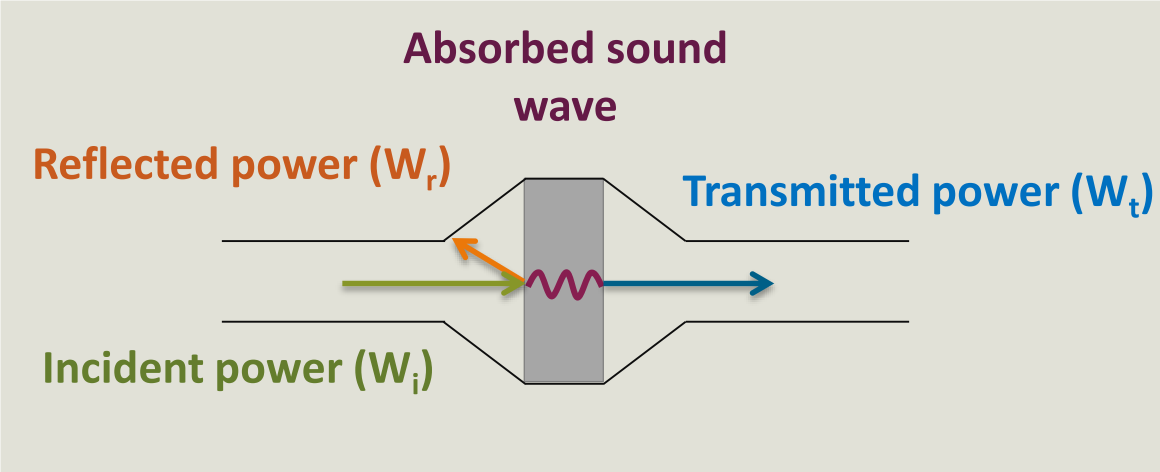


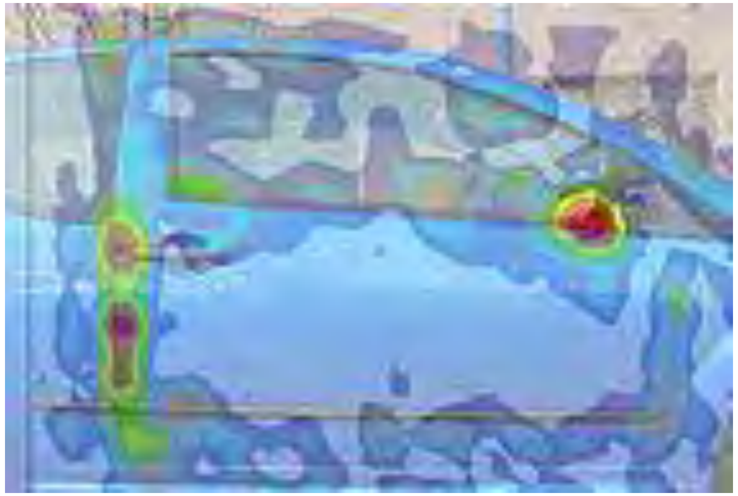
Increased thickness → increased absorption in low frequencies
High frequencies easiest to absorb

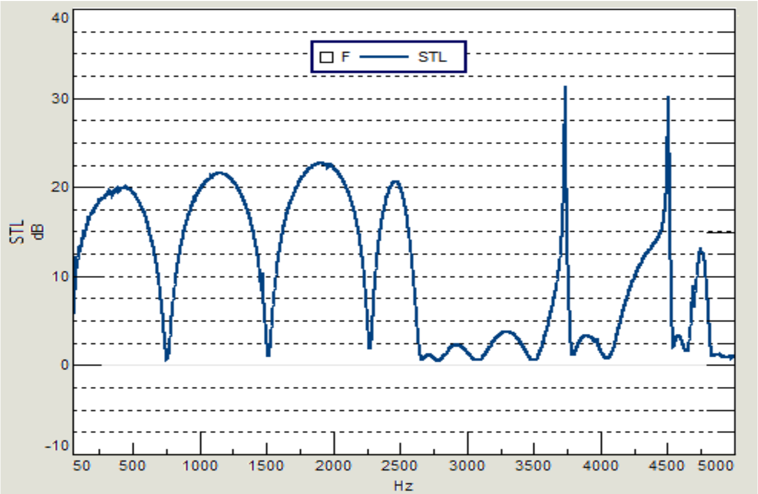
Sound Transmission Loss (STL)

Transmission Loss (TL):

$$TL = 10\log_{10}\frac{W_i}{W_t}$$







Improve cabin and overall acoustic performance

Acoustic Packaging and Trim optimization

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Material Testing
Overview techniques

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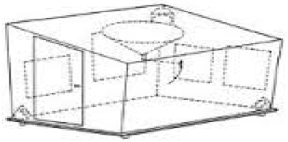
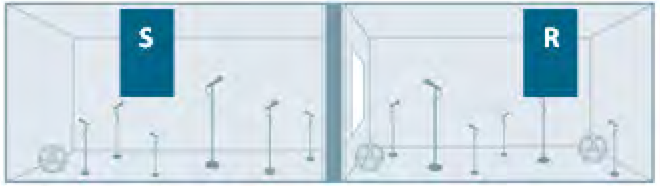
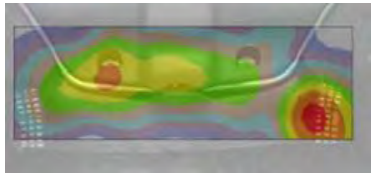
	Absorption	Sound Transmission Loss
Test on small samples or components	2-mic transfer-function method ISO 10534-2 ASTM E1050 	4-mic transfer matrix (mufflers, resonators, materials)  
Test on larger samples or complete objects	ISO 354 ASTM C-423 Alpha cabin  	ISO 140-3/4 ASTM E-90 SAEJ1400 
Other techniques	 **In-situ** Road absorption ISO 13472-2	STL + Intensity or holography 

Sound absorption
Based on Impedance tube

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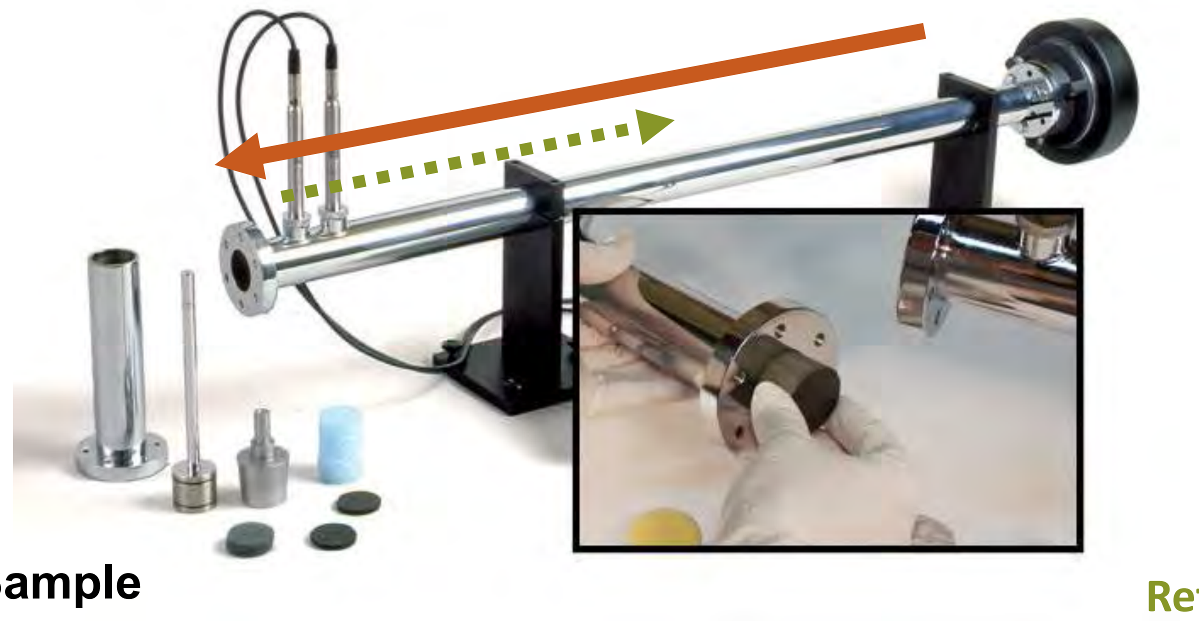

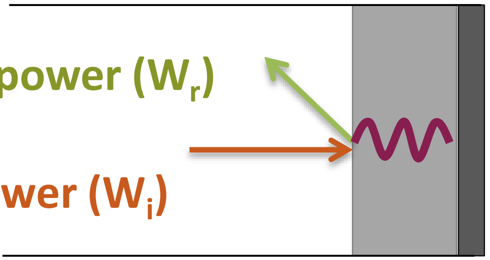

Sound absorption in impedance tube
2-microphone method

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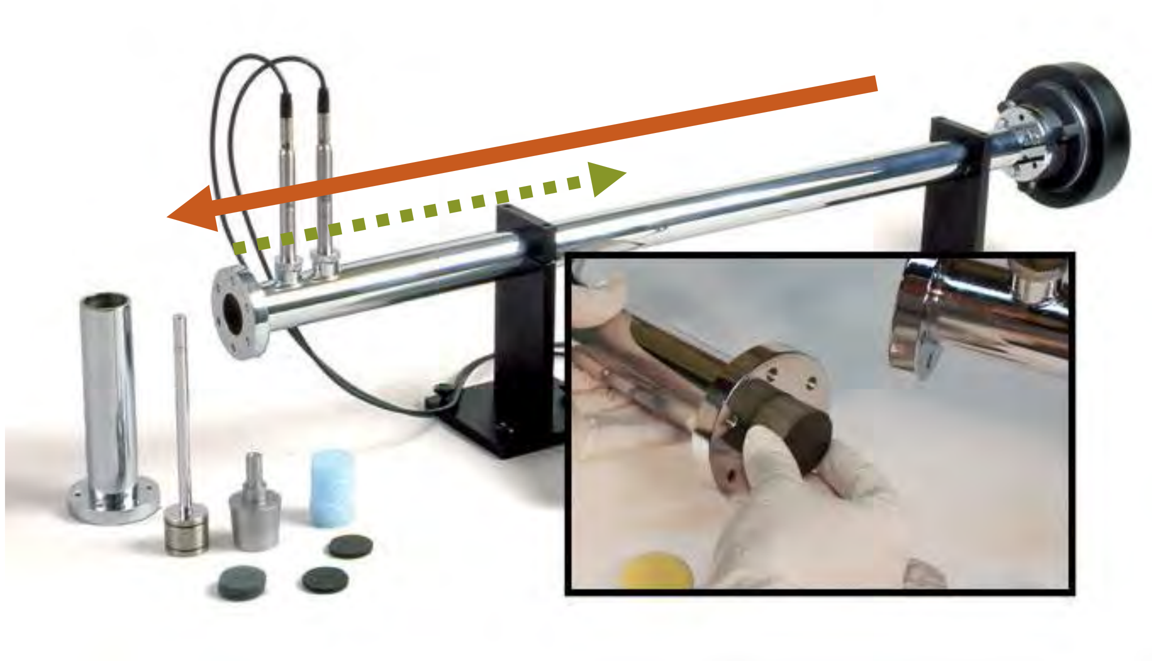


How to measure the incident and reflected energy?

Absorption coefficient α:

$$\alpha = 1 - \frac{W_r}{W_i}$$

Calculate α from two microphone signals
Brief theory overview

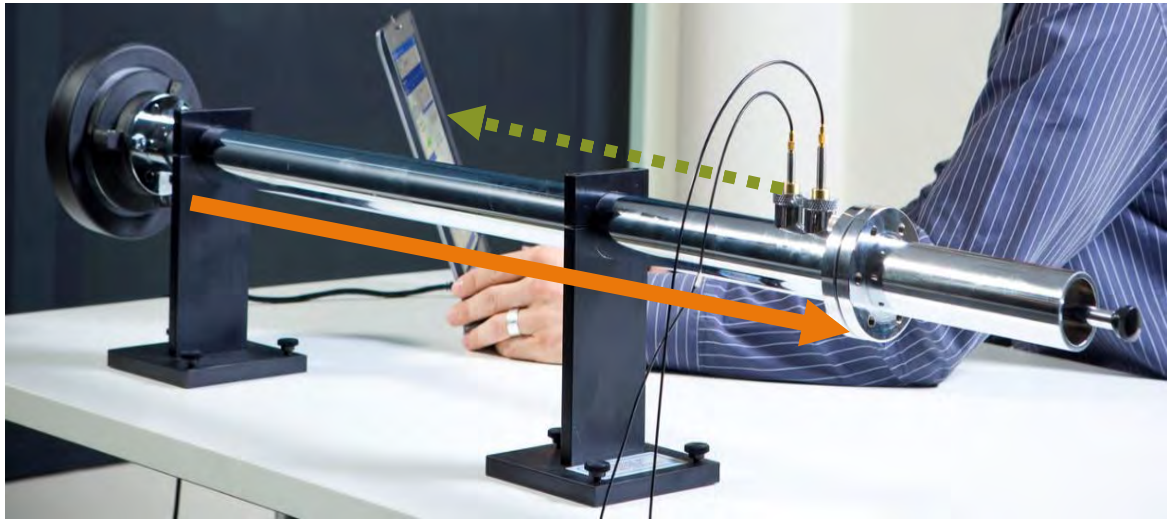
Sound absorption
Based on Impedance tube - principles

Impedance tube based on planar wave sound field:

- Source Excitation by a plane surface
- Tube long enough to have only plane waves (for the frequency range of interest)
- Propagation in one direction only

Sound pressure p and sound particle velocity v depend only on the $\boxed{x}$ coordinate

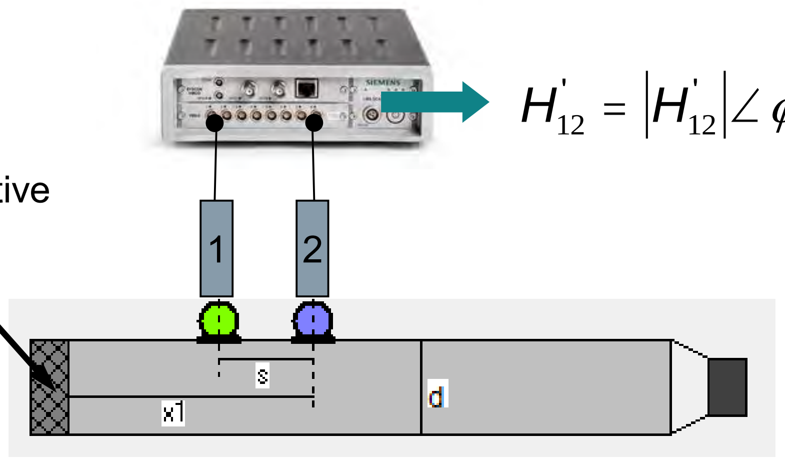
$$\mathbf{p}_i(x,t) = \hat{p}_i e^{i(\omega t - k_1 \boxed{x})}$$



Plane waves – propagation in one direction only

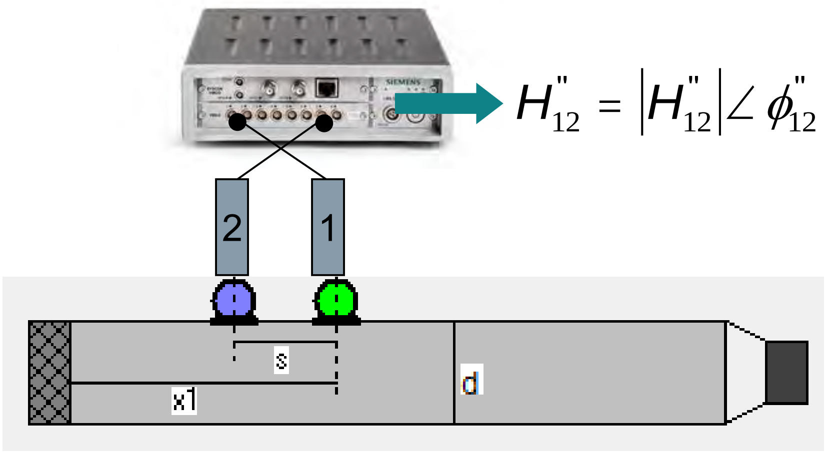
Sound absorption based on Kundt Tube
Amplitude and Phase Corrections

1. Measure Transfer function (TF)



$$H'_{12} = |H'_{12}| \angle \phi'_{12}$$

2. Switch microphones, measure TF



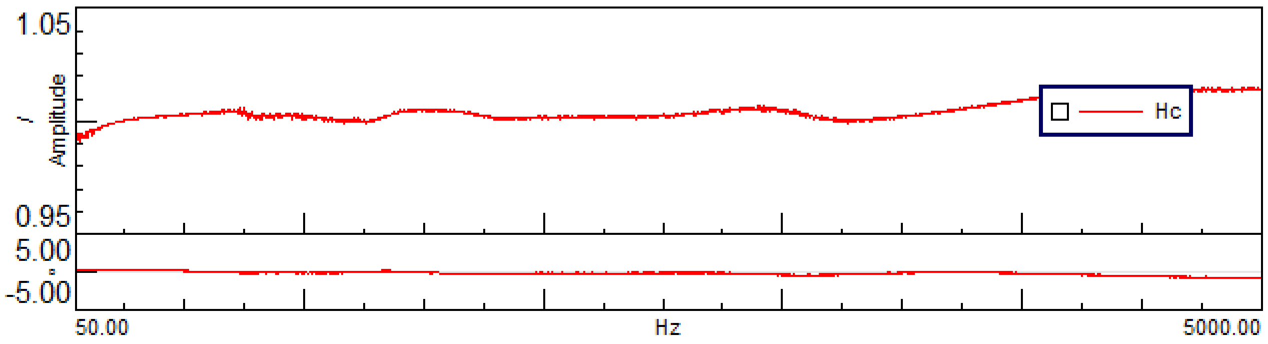
$$H''_{12} = |H''_{12}| \angle \phi''_{12}$$

3. Calculate correction FRF

$$H_c = \sqrt{H'_{12} H''_{12}}$$

Ideally, amplitude =1, phase = 0º

Hc in practical measurement:



Sound absorption based on Kundt Tube
Amplitude and Phase Corrections

4. Correct every acquired FRF using Hc

$$H_{12}^{c} = H_{12} / H_{c}$$

H_c: Correction FRF
$H^c{}_{12}$: Corrected FRF

5. Use corrected FRF's to calculate absorption coefficient α

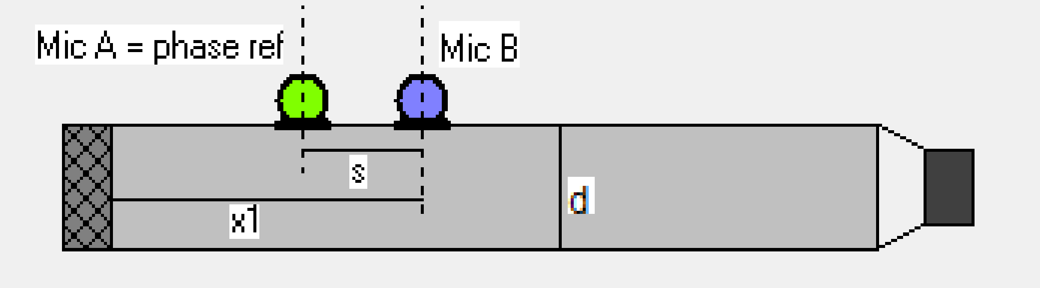
$$\widetilde{R} = \frac{e^{-jkx_2} - \boxed{H_{12}^{c}} e^{-jkx_1}}{\boxed{H_{12}^{c}} e^{jkx_1} - e^{jkx_2}}$$

$$\alpha_o = 1 - \left|\widetilde{R}\right|^2$$

Sound absorption based on Impedance tube
Frequency limits

Lower frequency limit f_{min}:
Limited by spacing between microphones “s”

$$s > 0.01 \cdot \lambda_{max} \rightarrow f_{min} > \frac{0.01 \cdot c}{s} = 117\ Hz.$$



Upper frequency limit f_{max}
Depends on spacing between microphones “s” and tube diameter “d”.

Based on diameter d: $f_{max} = 0.586 \cdot \frac{c_0}{d} = 0.586 \cdot \frac{343}{0.0348} = 5776\ Hz$

Based on spacing s: $f_{max} = 0.5 \cdot \frac{c_0}{s} = 0.5 \cdot \frac{343}{0.02921} = 5871\ Hz$

c: speed of sound [m/s]
λ: wavelength [m]
s: spacing between microphones [m]
d: diameter of the tube [m]

Demonstration of Absorption in Tube measurements

Agenda:

Simulation of intake and exhaust systems

End-to-end process
Air intake Transmission Loss

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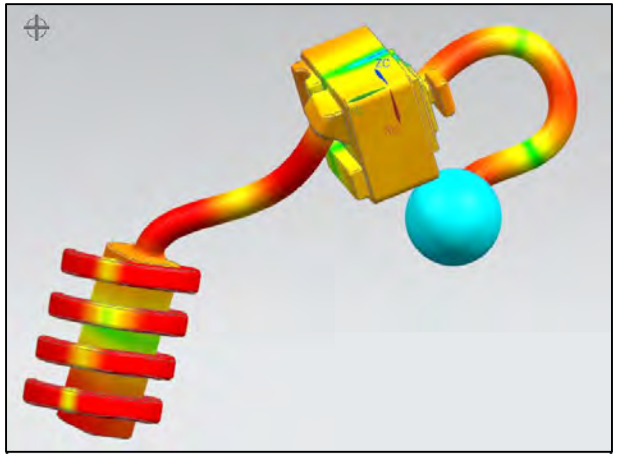
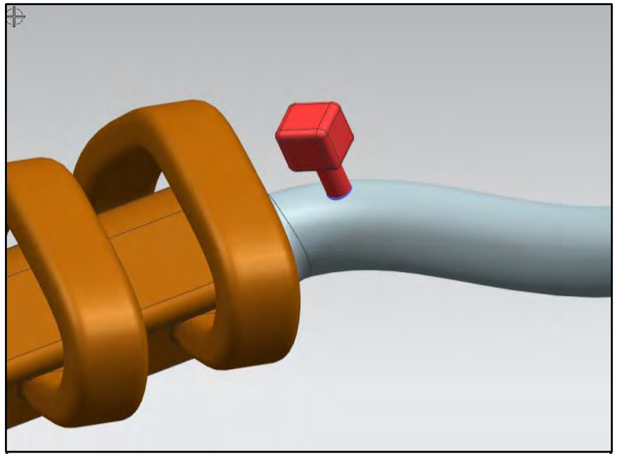
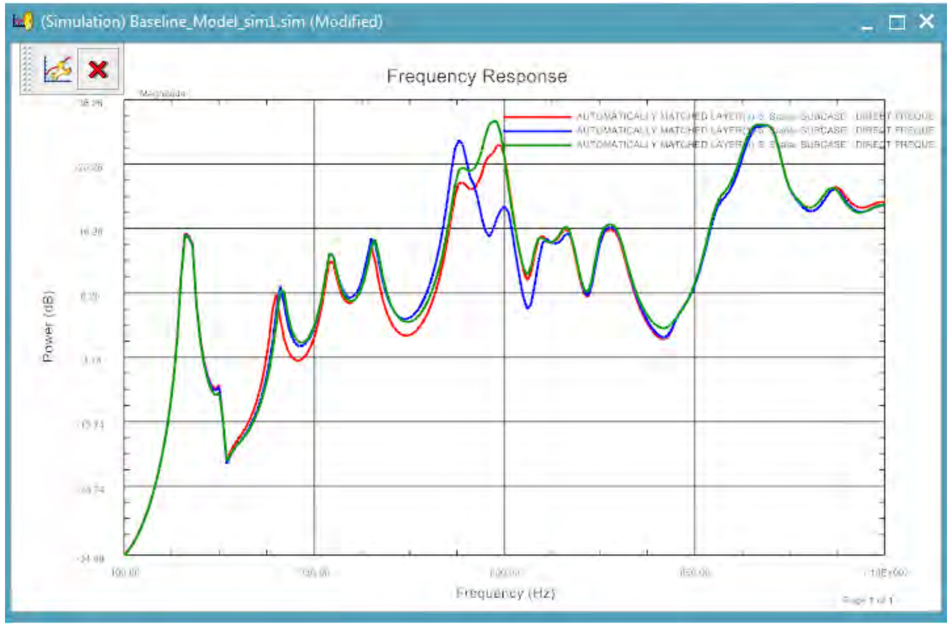


Identify hot spots for location of resonator



Develop and add 'resonator'

Radius	0.008
Surface	0.000201
Sound Speed	340
Frequency	590
Tube Length	0.03
Eq length	0.038
Volume	4.31E-05
Side length	0.03505

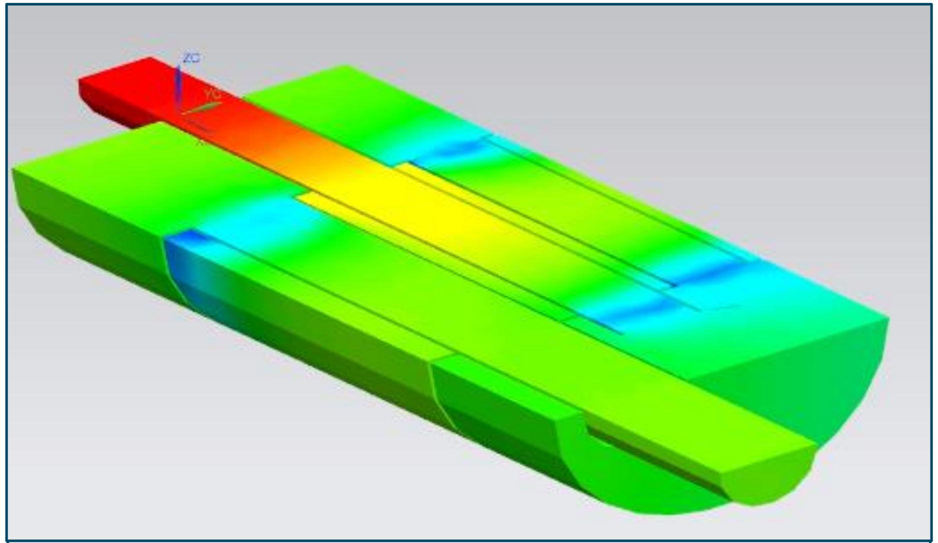


No resonator

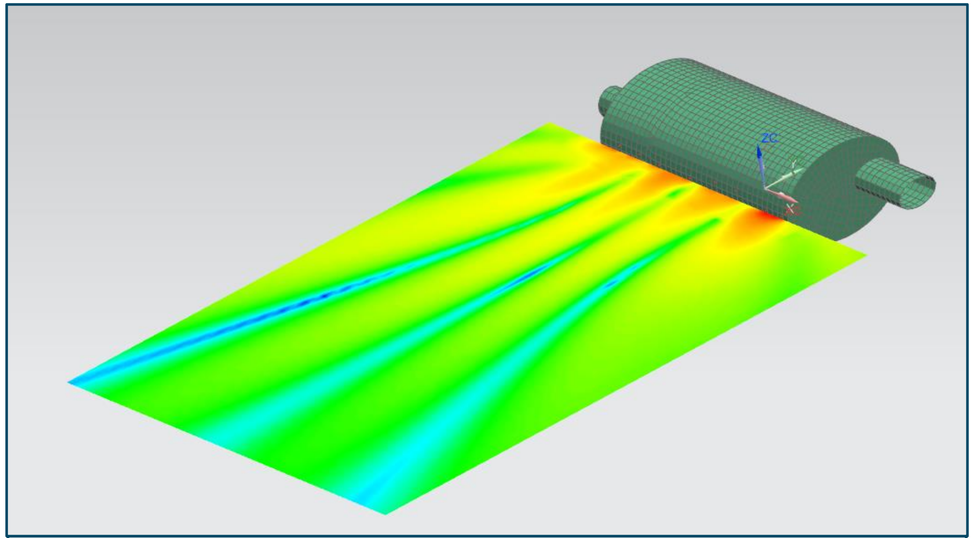
Effective location

Not effective location

Exhaust Systems
Prime Applications concerning Acoustics



Airborne Transmission Loss through mufflers + **Tailpipe radiation into environment** (Pass-By Noise)



Shell noise radiation from e.g. exhaust

Intake and exhaust acoustics
many phenomena to account for …

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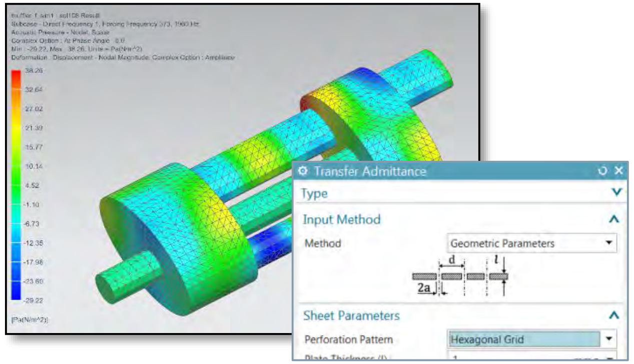
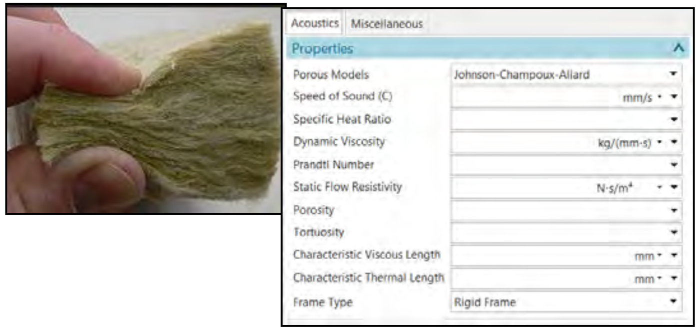
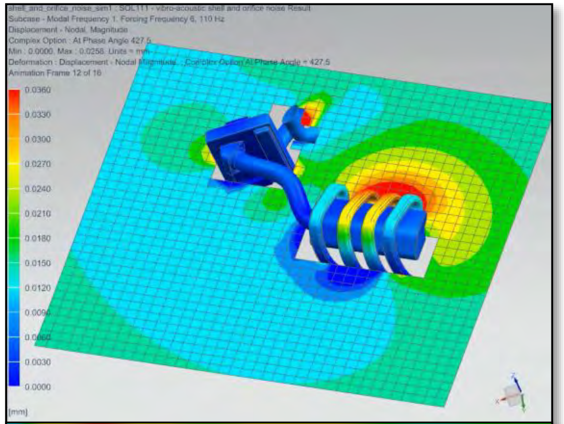
Perforated ducts

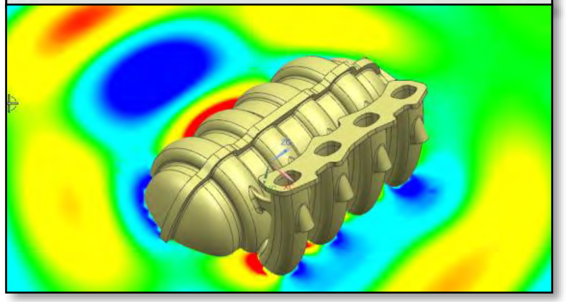


Porous materials



Shell Noise
Coupled FEM vibro-acoustics in NX Nastran



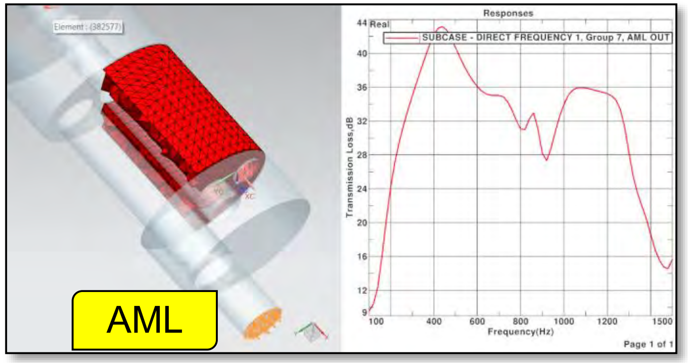


$$\begin{bmatrix} \mathbf{K}-\omega^2\mathbf{M}+i\omega\mathbf{D} & -\mathbf{C}^T \\ -\omega^2\mathbf{C} & \mathbf{H}-\omega^2\mathbf{Q}+i\omega\mathbf{A} \end{bmatrix} \begin{Bmatrix} \mathbf{x} \\ \mathbf{p} \end{Bmatrix} = \begin{Bmatrix} \mathbf{f} \\ \mathbf{s} \end{Bmatrix}$$

Transfer Admittance to represent DPF, CC, ..

$$\begin{pmatrix} p_1 \\ q_1 \end{pmatrix} = \begin{bmatrix} t_{11} & t_{12} \\ t_{21} & t_{22} \end{bmatrix} \begin{pmatrix} p_2 \\ q_2 \end{pmatrix} = T \begin{pmatrix} p_2 \\ q_2 \end{pmatrix}$$

non-reflective boundary condition for Duct-acoustic transmission loss



Perforated Ducts
Transfer Admittance

- Capture acoustic cross-talk between two fluids separated by a perforated wall/sheet, using transfer admittance
- Typical use case: mufflers

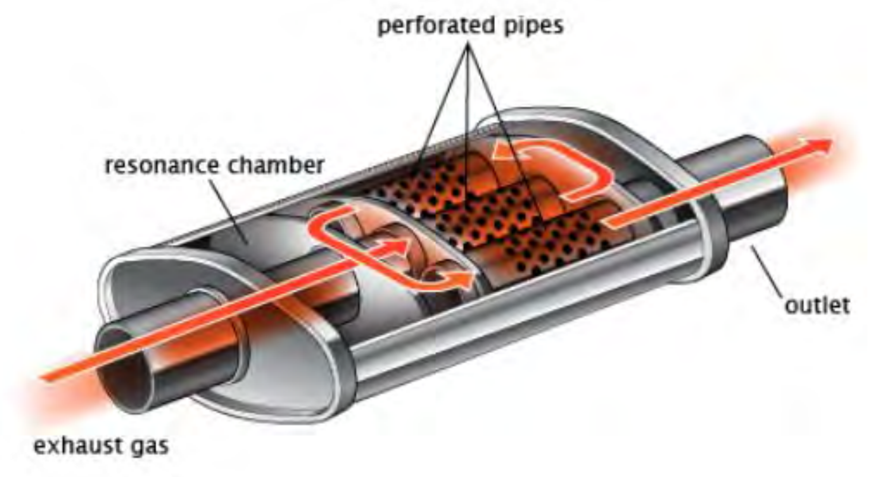
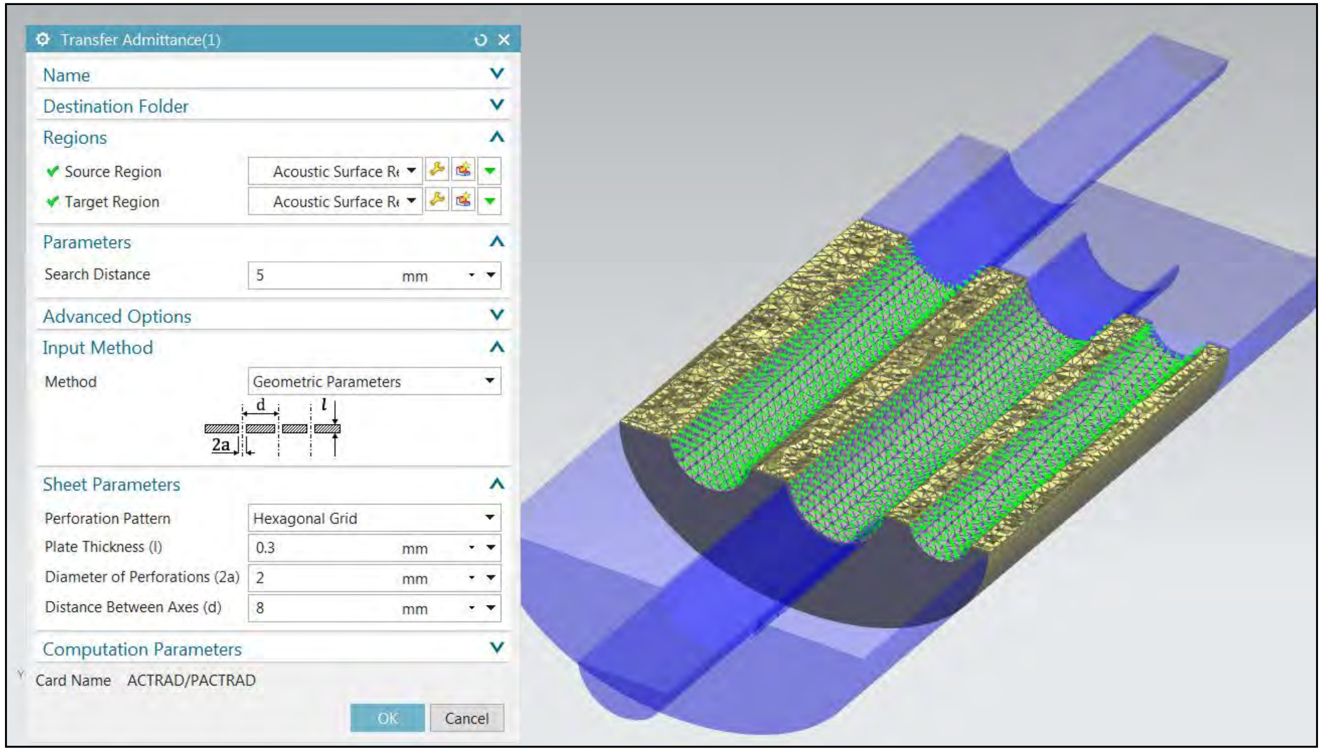


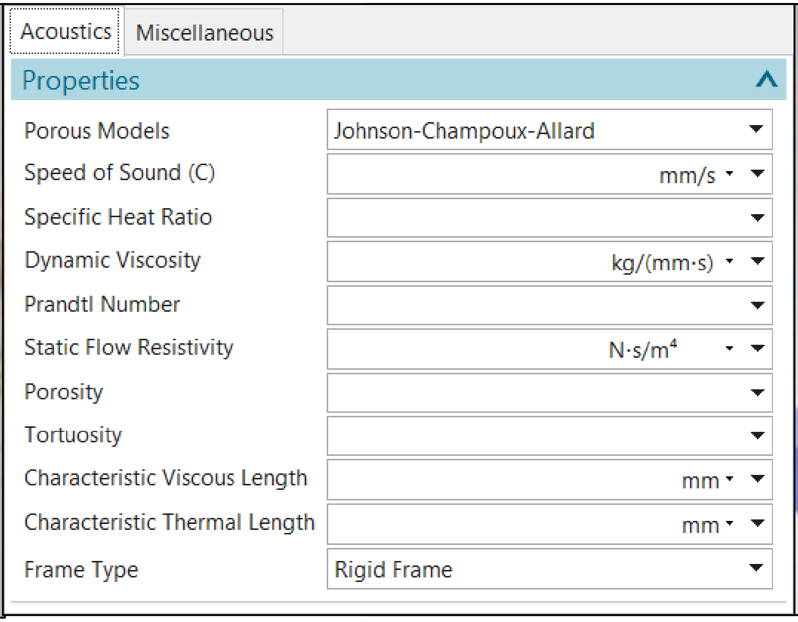
image courtesy of ClearMechanic.com

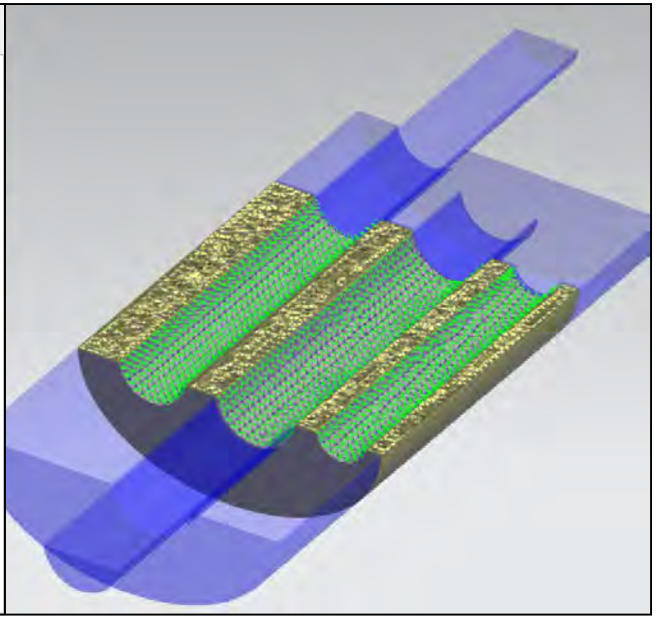


Porous Materials

Porous material models: equivalent fluid models, rigid or limp frame

- Craggs
- Delany-Bazley- Miki,
- Johnson-Champoux-Allard (FEM)





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