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The Application of Microperforated Panels in Duct Systems

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The Application of Microperforated Panels (MPP) in Duct Systems

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Objective

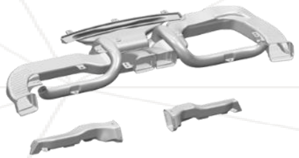
Why do we care?

- ❑ **Industrial Duct Applications**

Building HVAC system

Automotive HVAC

https://grabcad.com/requests/i-am-looking-for-a-hvac-duct-system-of-automobile



Ref: http://exo-s.com/en/products-services/automotive/

- ❑ **HVAC noise is one of the key noise sources in building interiors (office areas, etc.).**

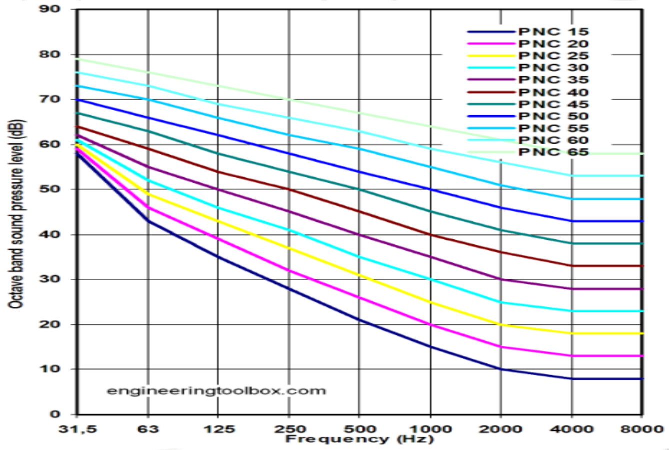
Office space example:

Average SPL = 57 - 60 dBA

Meets the spec but not desirable!!

- ❑ **Room Noise Criterion. (ASHRAE Handbook)**

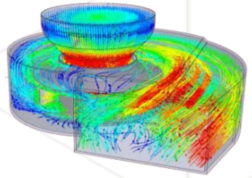
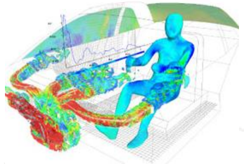
Room Types		Recommended NC or RC
Residences, Apartments, Condominiums	Living areas	30
	Bathrooms, kitchens, utility rooms	35
Hotels/motels	Individual rooms or suites	30
	Meeting/banquet rooms	30
Office buildings	Executive and private offices	30
	Conference rooms	30
	Teleconference rooms	25
	Open-plan offices	**40**
Schools	Classrooms and lecture rooms	25-30



Objective

Efforts to resolve problems.

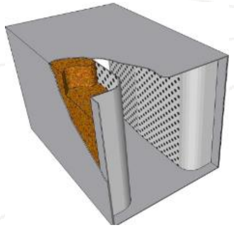
- ✓ ***Modification to the fan***

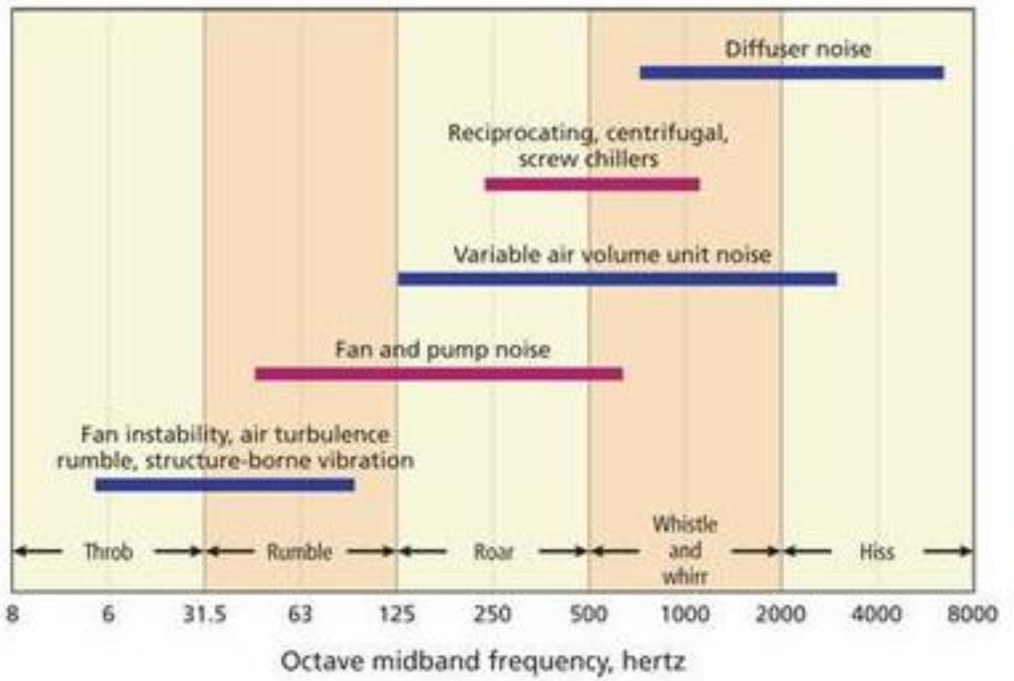

- ✓ ***Diffuser design***


- ✓ ***Duct designs***

silencers



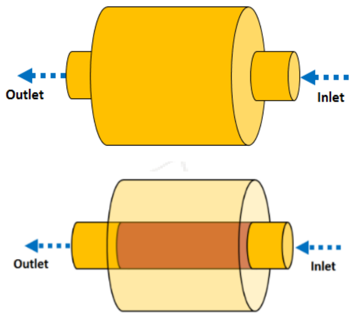
- ❑ **HVAC noise sources for different frequency bands.**



Reference: http://www.csemag.com/single-article/noise-and-vibration-control-in-building-design/d28e9267a7b3f8aa49f83d504d038a9e.html

Design an acoustic silencer targeting frequency below 4000 Hz

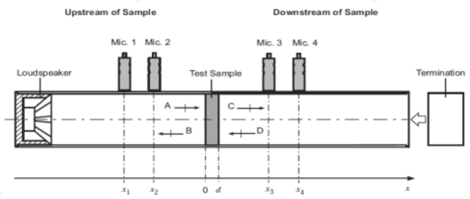
Silencer with MPP liner

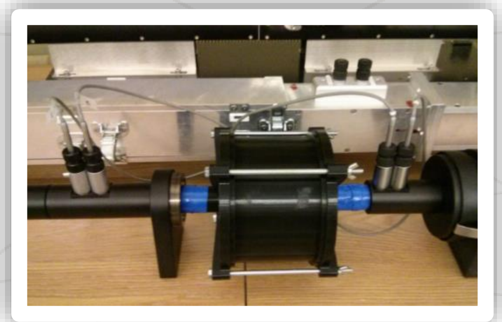


NO MPP

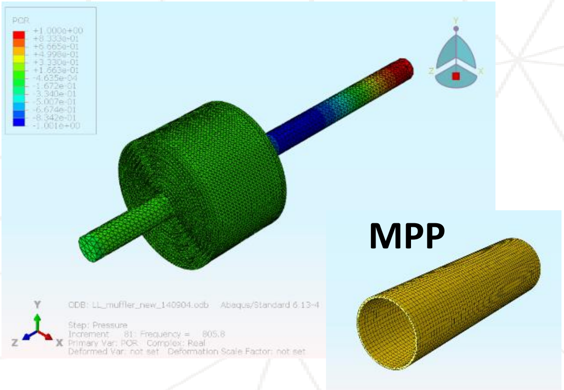
MPP

ASTM E2611 Experiment





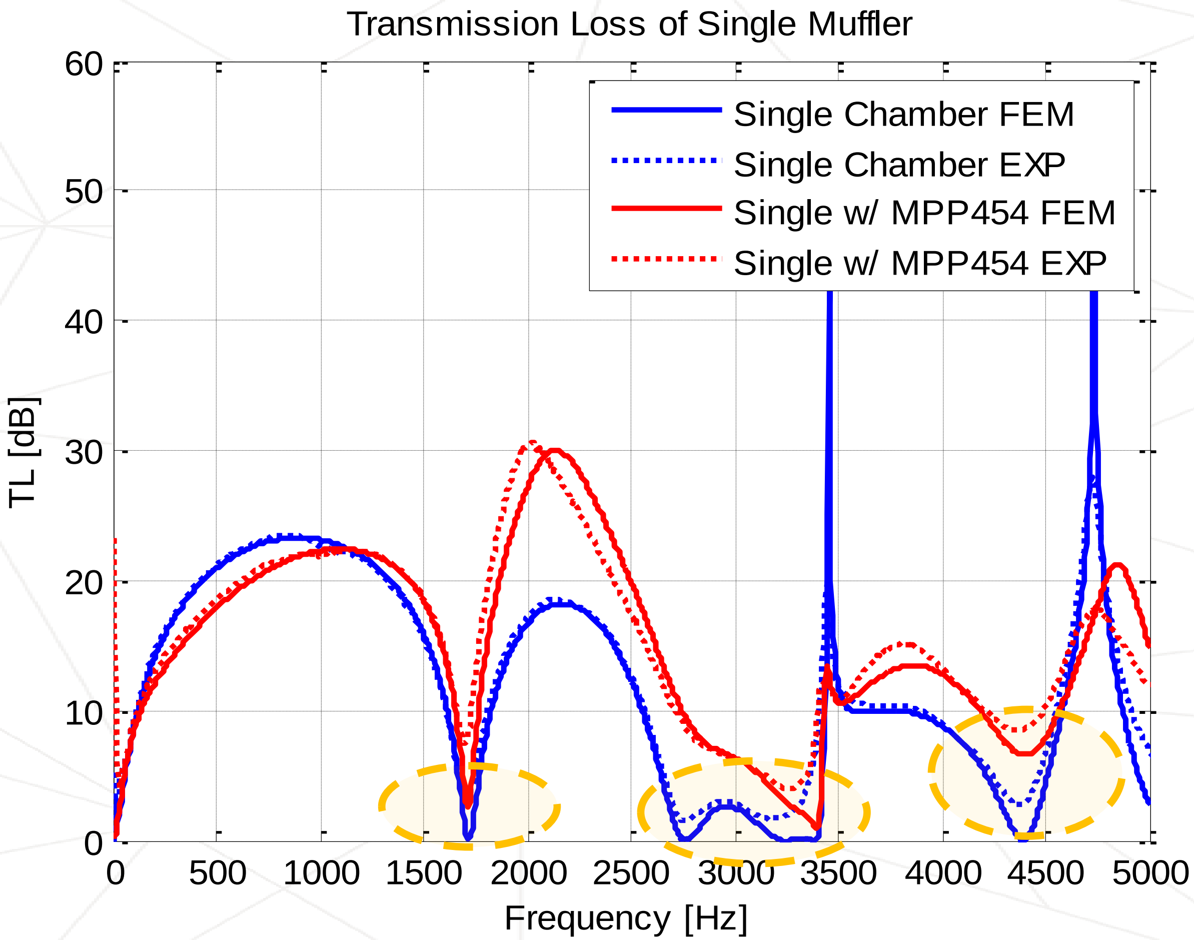
FEM analysis



JCA equivalent fluid model

$$\tilde{\rho}_{cs}(\omega)=\frac{\alpha_\infty\rho_0}{\phi}\left[1-j\frac{\sigma\phi}{\omega\rho_0\alpha_\infty}\sqrt{1+j\frac{4\alpha_\infty^2\eta\rho_0\omega}{\sigma^2\Lambda^2\phi^2}}\right]$$

$$\tilde{K}(\omega)=\frac{\gamma P_0/\phi}{\gamma-(\gamma-1)\left[1-j\frac{8\kappa}{\Lambda'^2C_p\rho_0\omega}\sqrt{1+j\frac{\Lambda'^2C_p\rho_0\omega}{16\kappa}}\right]^{-1}}$$



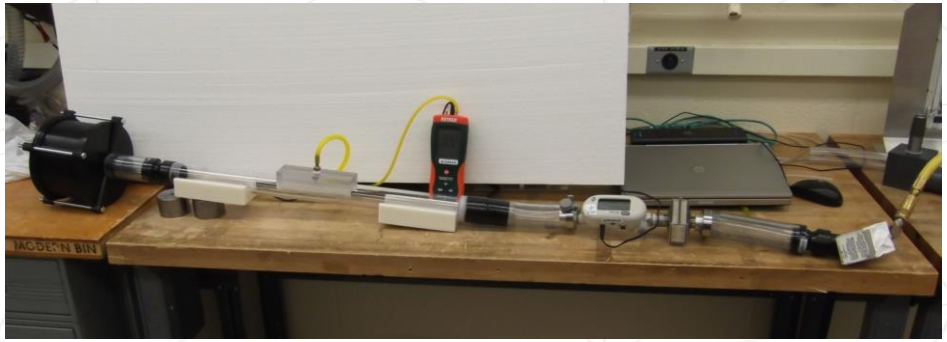
Seungkyu Lee, J. Stuart Bolton and Paul A. Martinson, “Design of multi-chamber cylindrical silencers with microperforated elements,” *Noise Control Engineering Journal,* 64(5), 2016.

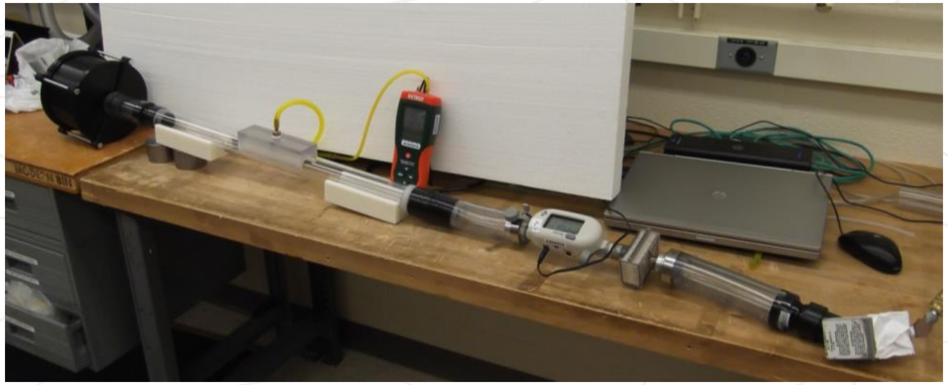
3M RAY W. HERRICK LABORATORIES PURDUE UNIVERSITY

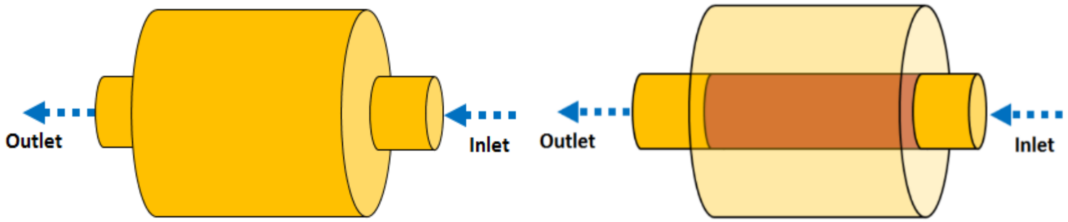
Key design point

Silencer with MPP lining

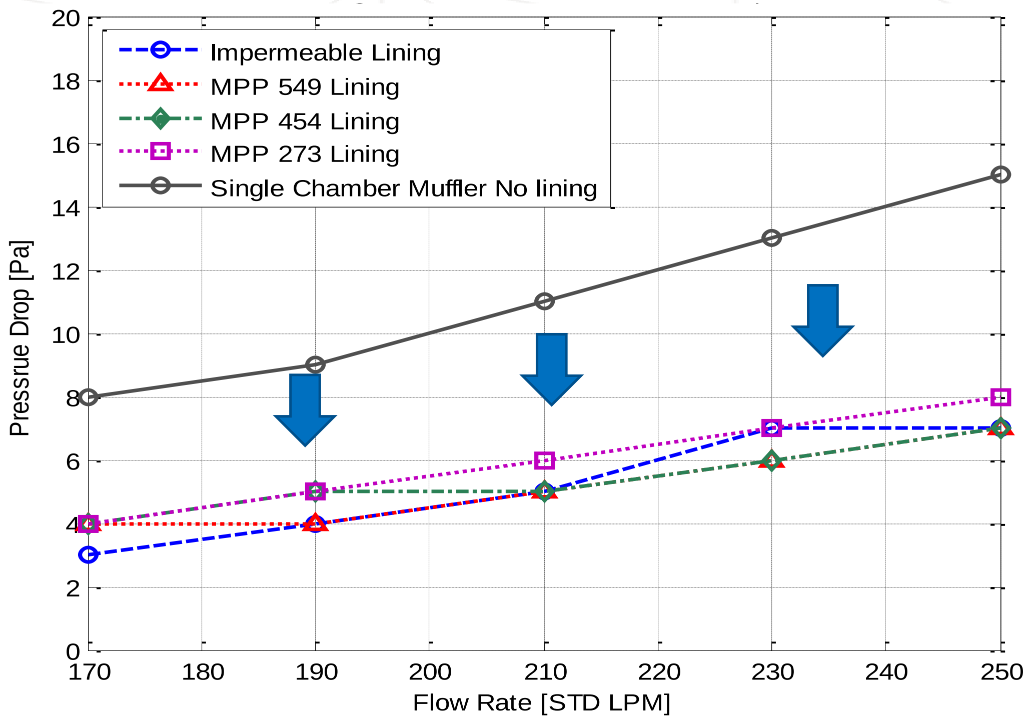
- To reduce undesirable pressure drop from expansion muffler.







Single chamber Muffler with a MPP lining

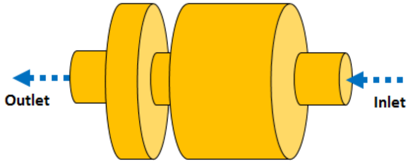


Dual chamber silencer with MPP liner

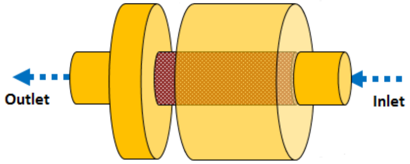
NO MPP

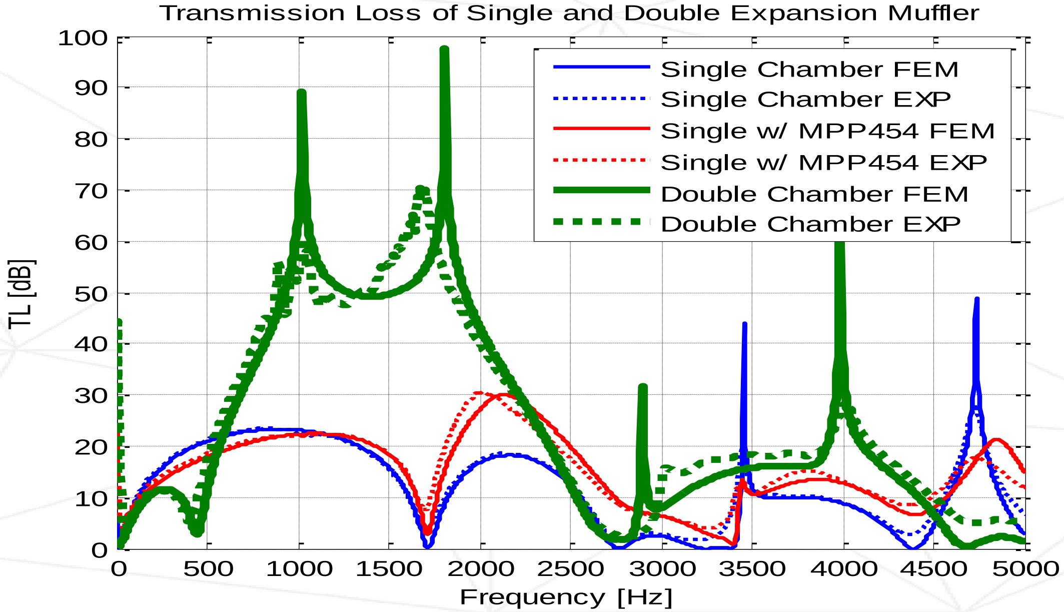
MPP

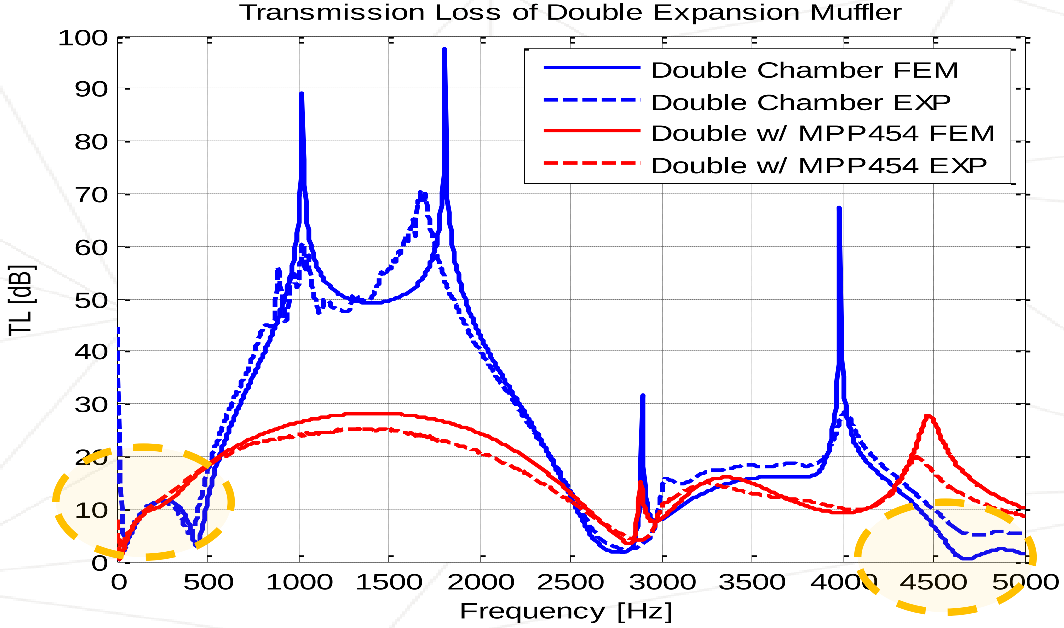
NO MPP



MPP

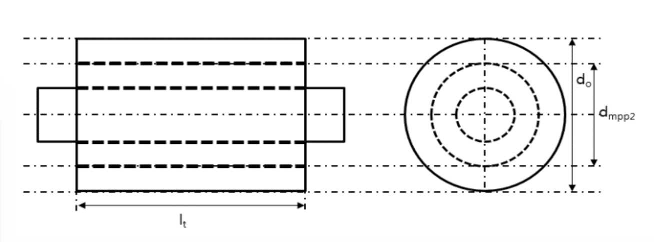


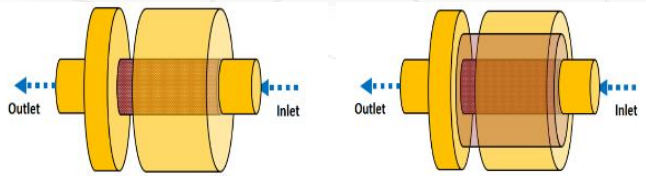


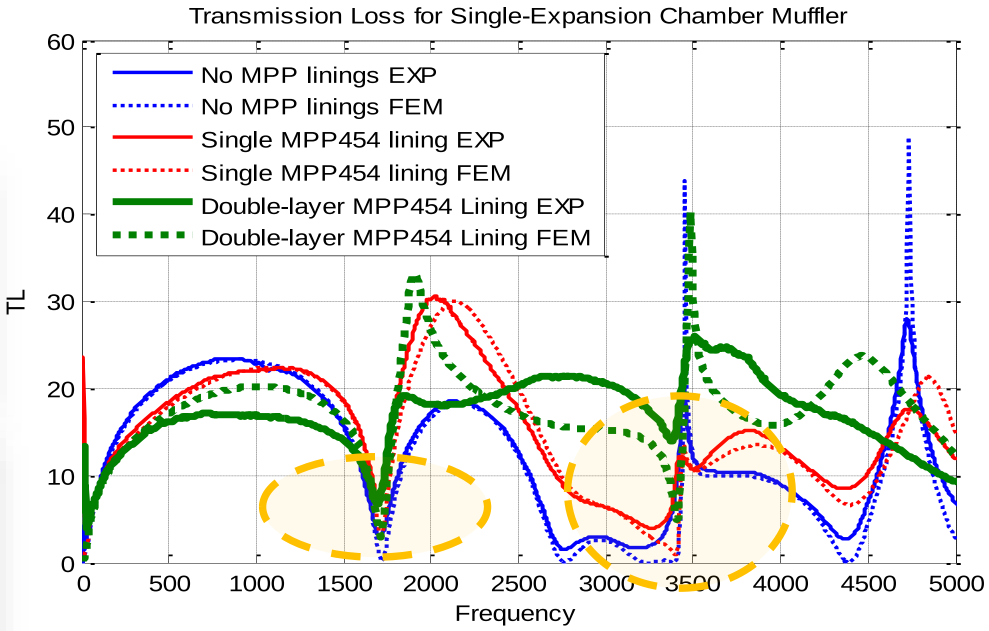


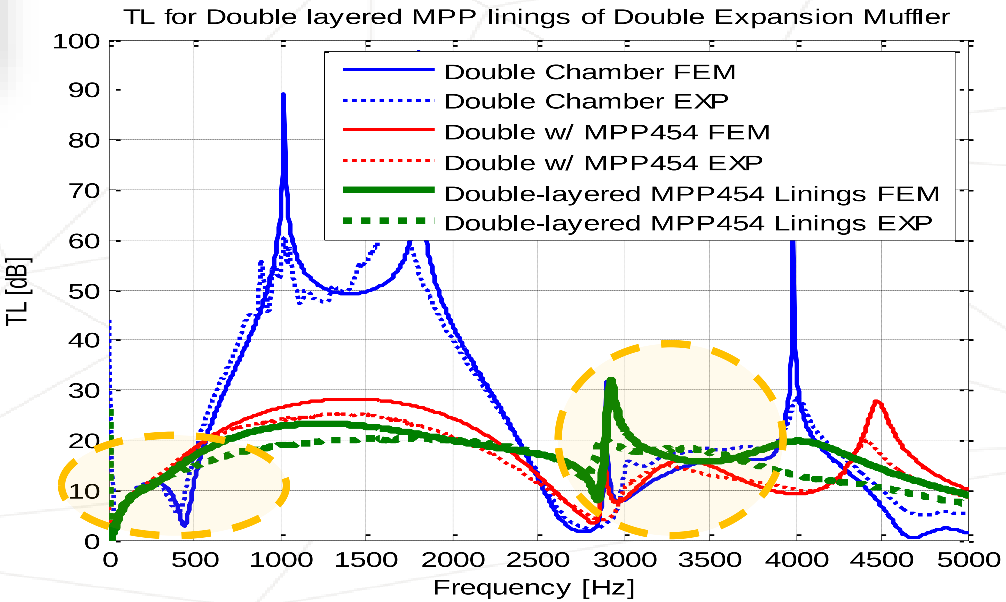
- ❑ Wider TL coverage with dual chamber design
- ❑ Bring up the TL minimum using MPP lining

Silencer with multiple MPP liners



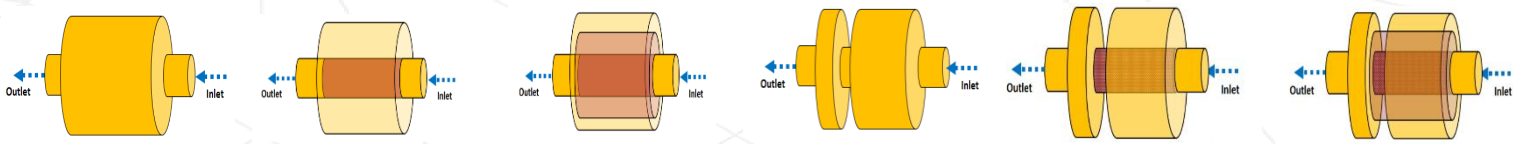






- ❑ Improve the minima using double lining treatment
- ❑ Achieve TL above 10 dB 5000 Hz with limited space and design of muffler

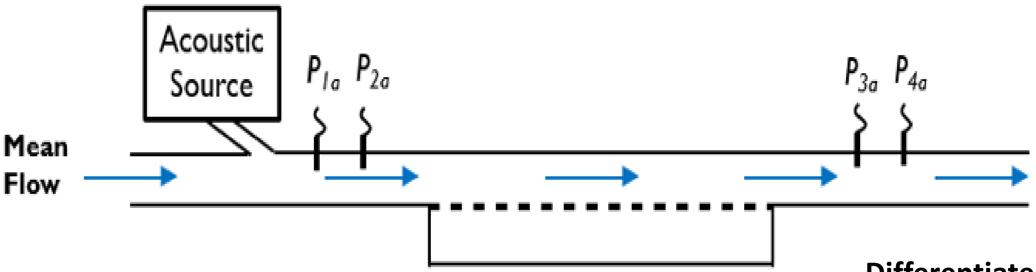
Differences in sound?



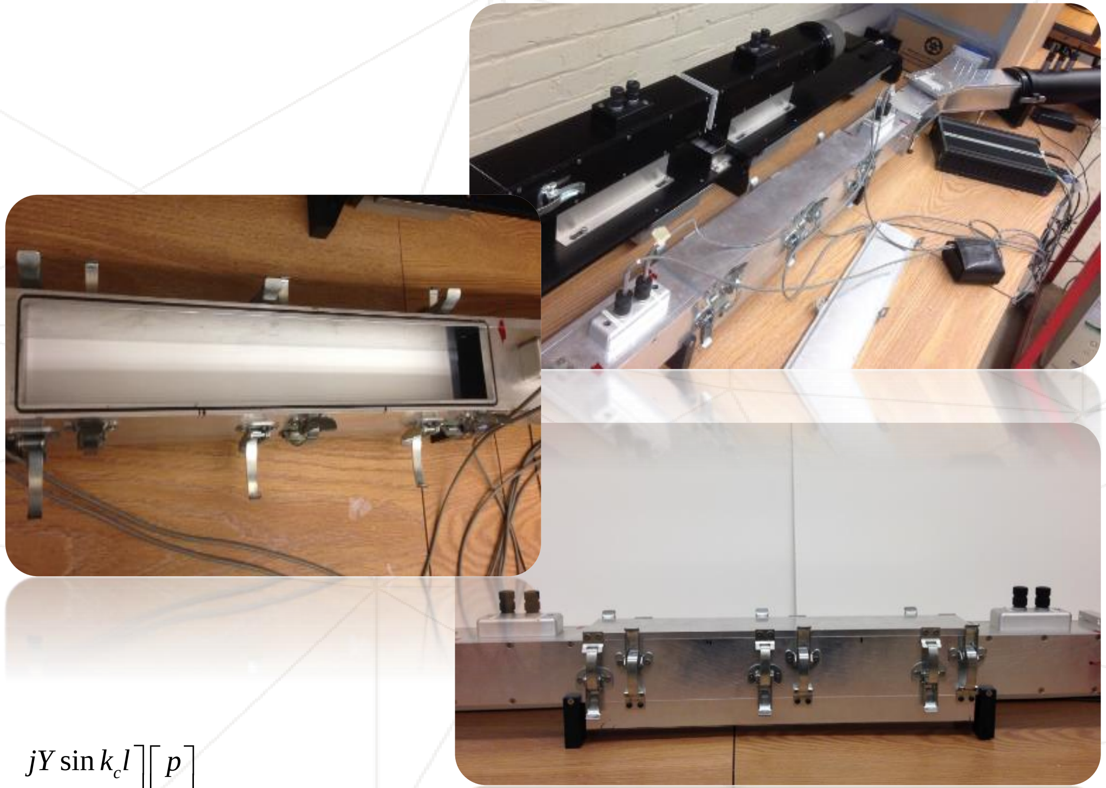
	Sound without muffler treatment	Single Chamber	Single Chamber w/ MPP454	Single Chamber w/ Double MPP454	Double Chamber	Double Chamber w/ MPP454	Double Chamber w/ Double MPP454
A-weighted Overall Sound Pressure Level	68.50 dBA	53.98 dBA	52.09 dBA	53.28 dBA	53.24 dBA	50.49 dBA	51.28 dBA
Recordings							

ASTM E2611 Measurement preparation

- 4 – Microphone and 2 – load Method



Differentiate end terminations



- Transfer Matrix Calculation*

$$\begin{bmatrix} p_{1a} \\ v_{1a}\end{bmatrix} = \begin{bmatrix}A_{12} & B_{12}\\ C_{12} & D_{12}\end{bmatrix}\begin{bmatrix}T_{11}&T_{12}\\T_{21}&T_{22}\end{bmatrix}\begin{bmatrix}A_{34}&B_{34}\\C_{34}&D_{34}\end{bmatrix}\begin{bmatrix}p_{4a}\\p_{4a}/Z_a\end{bmatrix}, \quad \begin{bmatrix}p\\v\end{bmatrix}_{z=0} = e^{-jMk_c l}\begin{bmatrix}\cos k_c l & jY\sin k_c l\\ (j/Y)\sin k_c l & \cos k_c l\end{bmatrix}\begin{bmatrix}p\\v\end{bmatrix}_{z=l}$$

$$Y = Y_0\left\{1-\frac{\alpha(M)}{k_0}+j\frac{\alpha(M)}{k_0}\right\} \qquad k_c = \frac{k_0 - j\alpha(M)}{1-M^2}$$

$$T_a = \frac{2e^{jkd}}{T_{11}+T_{12}/\rho_0 c+\rho_0 c T_{21}+T_{22}}$$

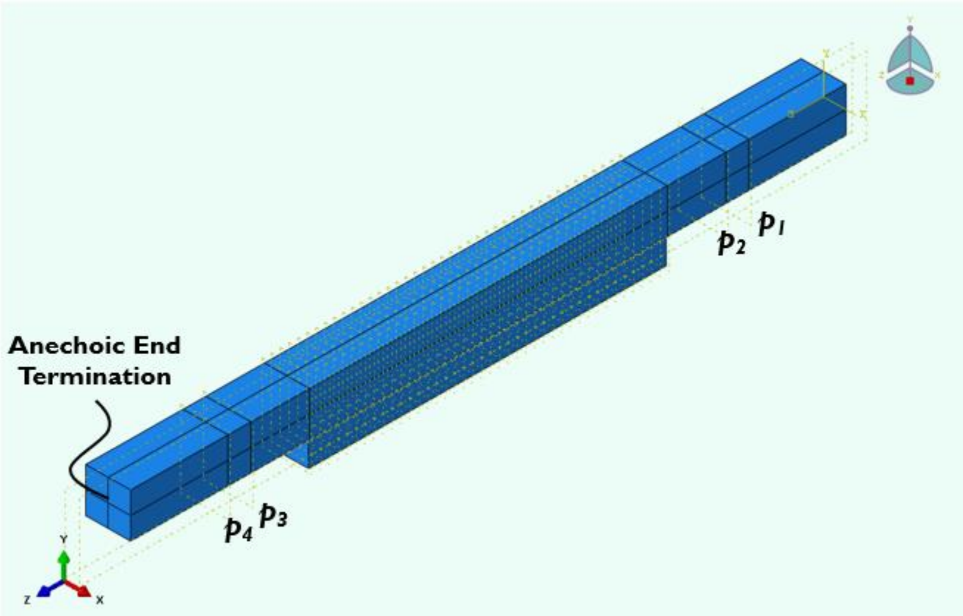
- Transmission Loss

$$TL = 20\log_{10}\left|\frac{1}{T_a}\right|$$

* M. L. Munjal, *Acoustics of Ducts and Mufflers*, WILEY (2014)

Prediction model considering mean flow effect

- Square cross-section standing wave tube model



- Sound Pressure along the duct

$$\tilde{p} = Ae^{-\frac{jkx}{1+M}} + Be^{\frac{jkx}{1-M}}$$

- Variational form, Helmholtz Equation

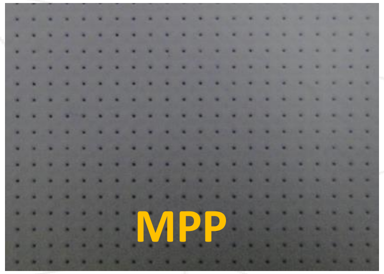
$$\int_V \left[\frac{1}{\omega^2\rho_0}\nabla\delta\tilde{p}\cdot(I-\tilde{\mathbf{v}}\tilde{\mathbf{v}})\cdot\nabla\tilde{p} - \frac{j}{\omega\rho_0 c}(\nabla\delta\tilde{p}\cdot\tilde{\mathbf{v}}\tilde{p} - \delta\tilde{p}\tilde{\mathbf{v}}\cdot\nabla\tilde{p}) - \frac{1}{K}\delta\tilde{p}\tilde{p}\right]dV$$
$$+\int_S \frac{1}{\omega^2\rho_0}\delta\tilde{p}\left[\mathbf{n}^-\cdot(I-\tilde{\mathbf{v}}\tilde{\mathbf{v}})\cdot\nabla\tilde{p} - \frac{j\omega}{c}\mathbf{n}^-\cdot\tilde{\mathbf{v}}\tilde{p}\right]dS = 0$$

- Anechoic Termination

$$\left((1-M^2)\nabla\tilde{p} - \frac{j\omega}{c}M\tilde{p}\right)\cdot\mathbf{n} = p\frac{i\omega}{Z_{anechoic}} \qquad Z_{anechoic} = \rho_0 c$$

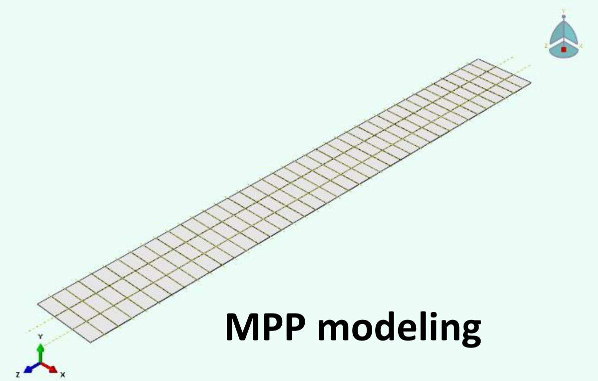
MPP under flow condition

MPP modeling



Equivalent fluid – JCA model [1,2]

- Complex Density and Bulk Modulus were modeled using following equations
- Calculated properties were implemented in the finite element model of the MPP
- Rigid inclusions to make the MPP locally reacting. *



Complex Density :

$$\tilde{\rho}_{cs}(\omega) = \frac{\alpha_\infty \rho_0}{\phi}\left[1 - j\frac{\sigma\phi}{\omega\rho_0\alpha_\infty}\sqrt{1 + j\frac{4\alpha_\infty^2\eta\rho_0\omega}{\sigma^2\Lambda^2\phi^2}}\right]$$

Complex Bulk Modulus :

$$\tilde{K}(\omega) = \frac{\gamma P_0/\phi}{\gamma - (\gamma-1)\left[1 - j\frac{8\kappa}{\Lambda'^2 C_p\rho_0\omega}\sqrt{1+j\frac{\Lambda'^2 C_p\rho_0\omega}{16\kappa}}\right]^{-1}}$$

ϕ: Perforation rate
α: Dynamic Tortuosity
σ: Flow resistivity
η: Dynamic viscosity of air
Λ: Viscous characteristic length
Λ': Thermal characteristic length
$\Lambda = \Lambda' = r$ (radius of perforation)

k: Thermal conductivity
γ: Specific heat ratio of air
P_o: Atmospheric pressure
C_p: Specific heat of air at const. pressure

MPP Properties

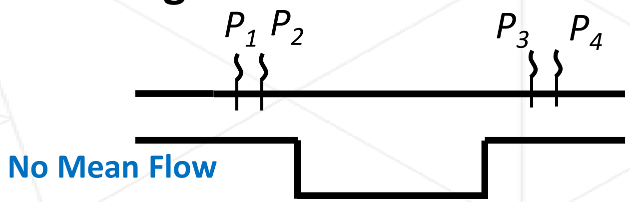
	MPP 549
Hole diameter [µm]	126.6
Thickness [mm]	0.35
Flow resistance [Rayls]	549

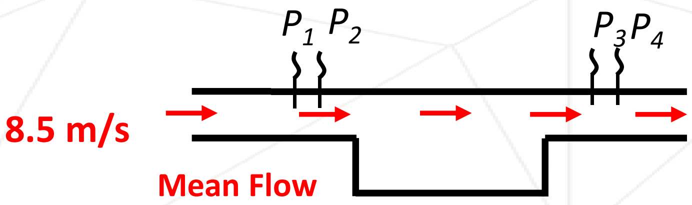
1) Champoux Y. and Allard J.-F., *Dynamic tortuosity and bulk modulus in air-saturated porous media*, J. Appl. Phys. 70, 1991, pp. 1975-1979
2) L. Jaouen and F.-X. Be´cot, “Acoustical characterization of perforated facings”, J. Acoust. Soc. Am. 129 (3), March 2011
* S. Lee, J. S. Bolton and P. A. Martinson, “Design of multi-chamber silencers with microperforated elements,” NoiseCon 14 Conference Proceedings, Fort Lauderdale, Florida, USA (2014)

MPP design - Modeling

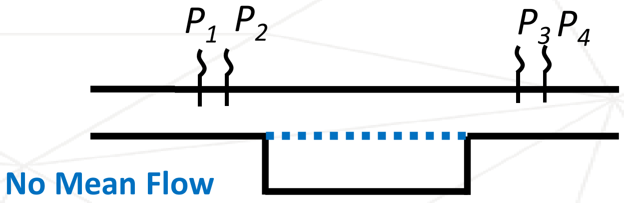
MPP lining with flow effect

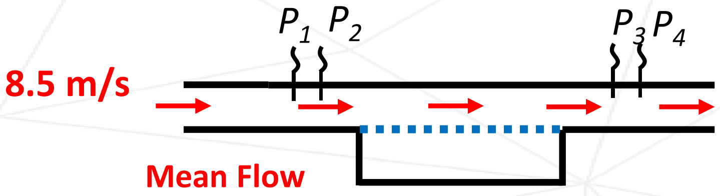
- ❑ **No MPP lining**

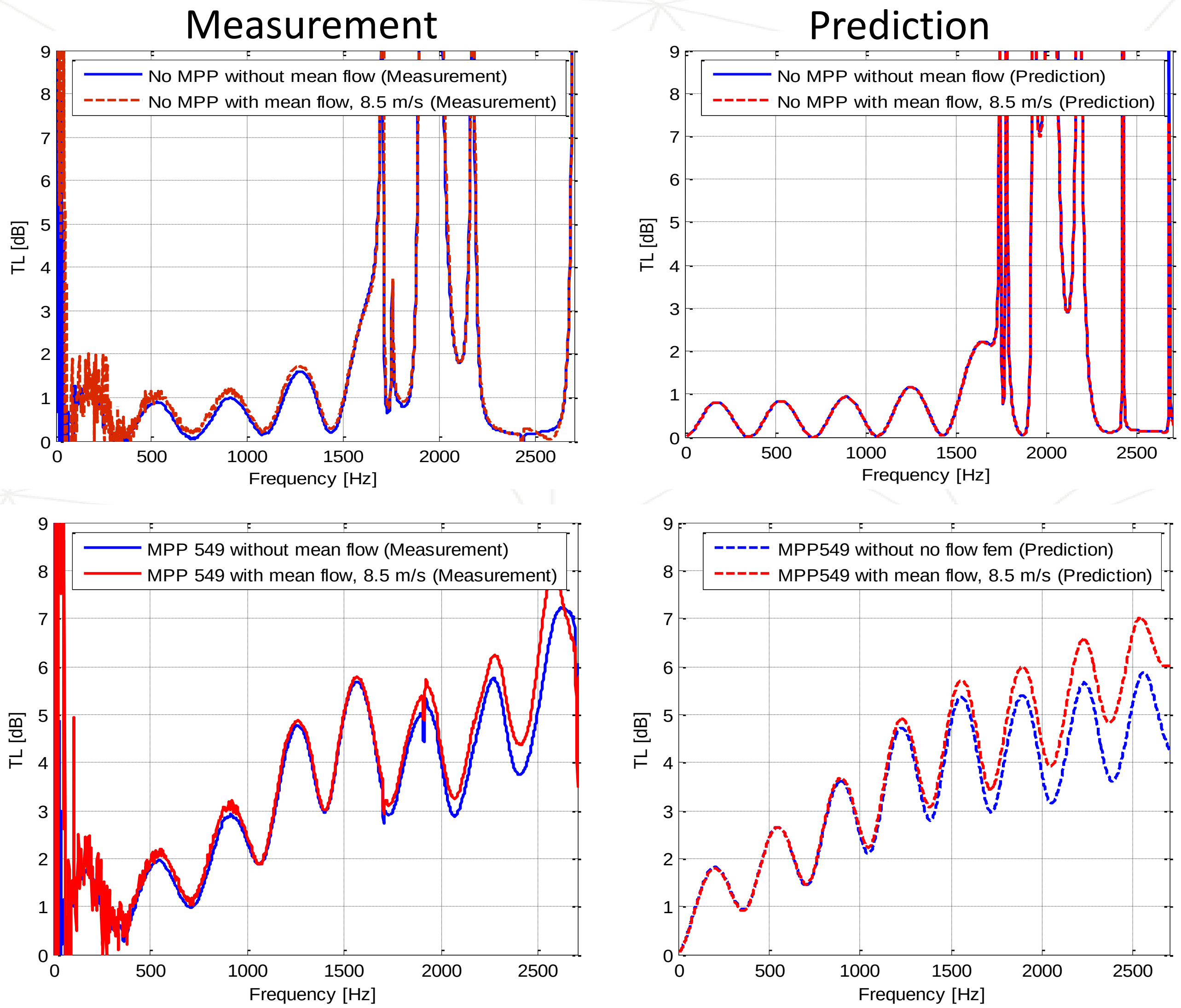




- ❑ **MPP lining attached**



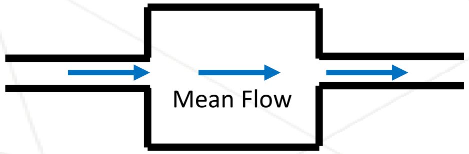


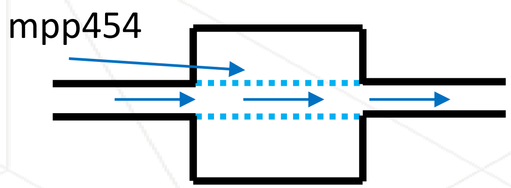


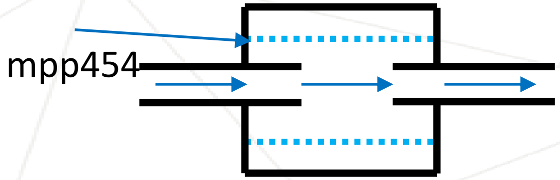
- ❑ Low speed flows have very little effect on MPP performance.
- ❑ Good prediction results.

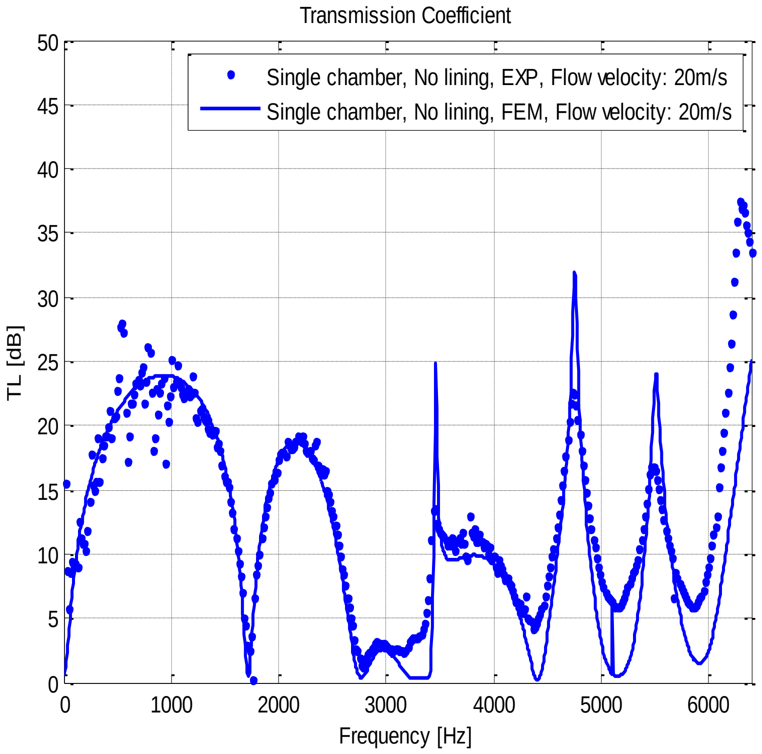
MPP design - Modeling

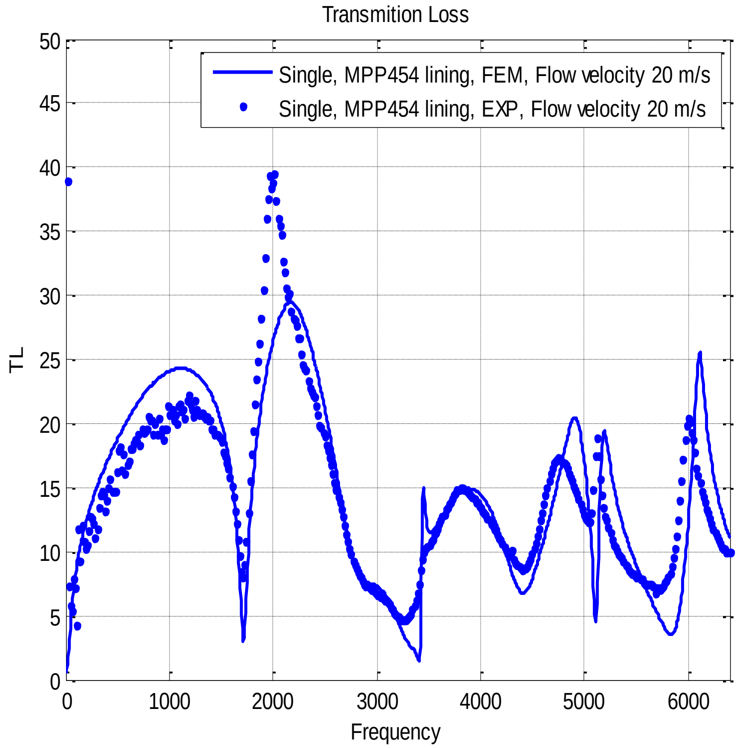
Measurements and predictions comparisons.

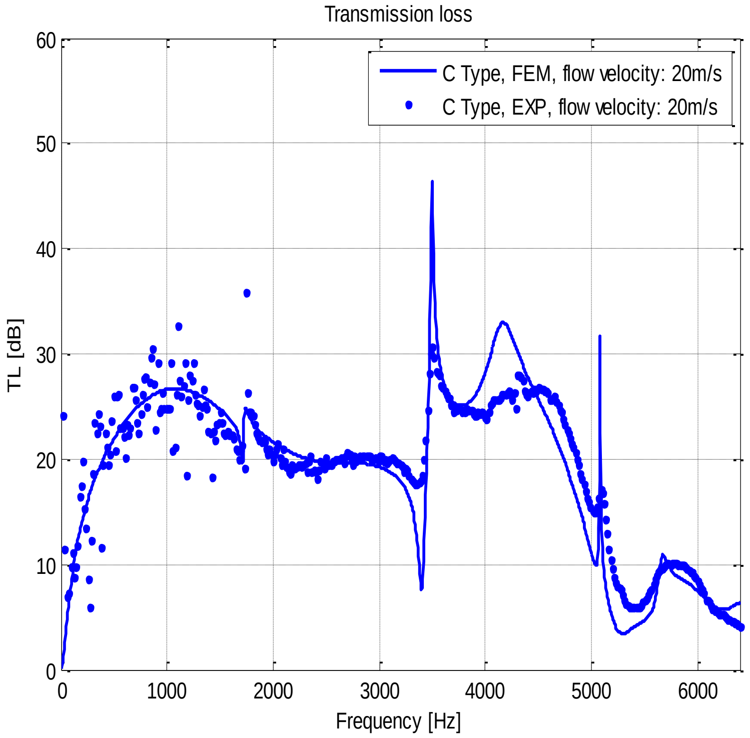












- ❑ Different muffler design is possible.
- ❑ MPP can help to improve TL when there is spatial limitation.

Conclusion and Plans

- Use of a silencer with Microperforated Panel (MPP) lining in HVAC duct noise control was studied
- Reliable modeling techniques to design a silencer with MPP linings were suggested
- In-line MPP treatment inside a silencer helps in minimizing the pressure-drop as well as improving noise attenuation
- More practical studies will be made in the future.
  - ✓ *Building and vehicle applications.*

THANK YOU