June 10, 2021

Sound Absorbing Fabrics

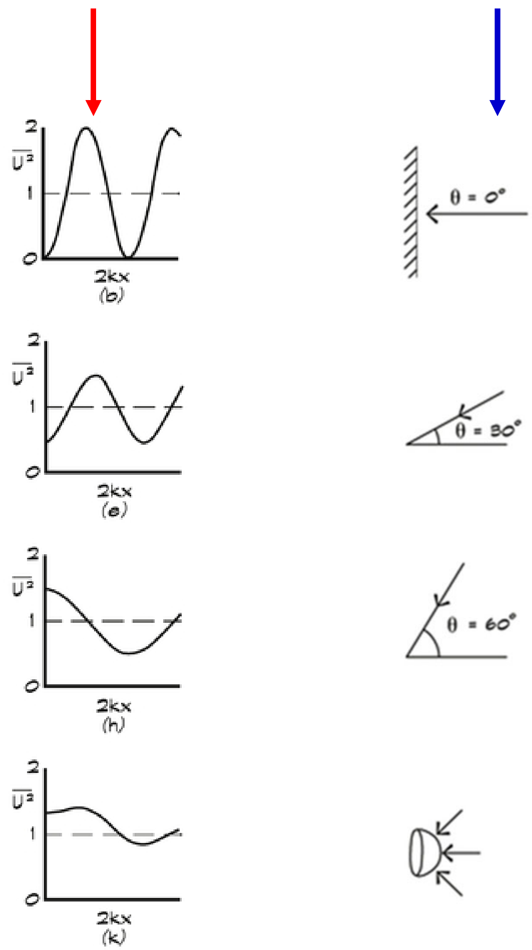
David Herrin
University of Kentucky

Vibro-Acoustics Consortium

Overview

- Fundamentals
- Acoustic Fabrics
- Parameter Study
- Effective Parameters
- Validation Studies

Porous Absorbers Basics for Designers



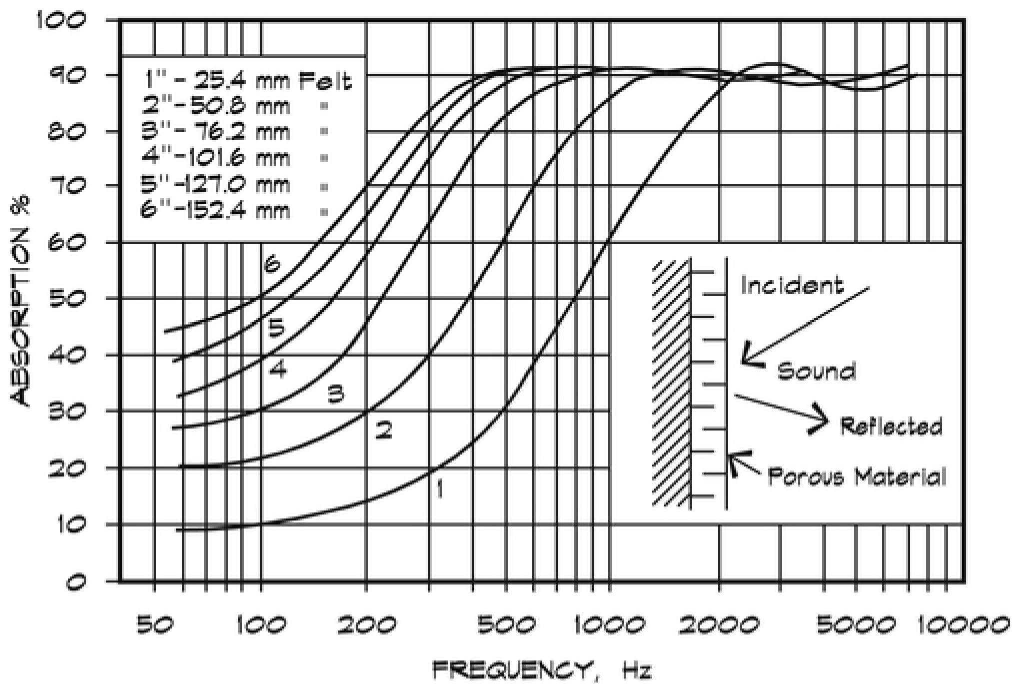
Long, 2014

Takeaways

- Porous sound absorption is less effective at low frequencies because of the long wavelength, small particle velocity, and non-diffuse field.
- Relatively thin sound absorption will have some impact even at lower frequencies if the sound field is diffuse.

Porous Absorbers Basics for Designers

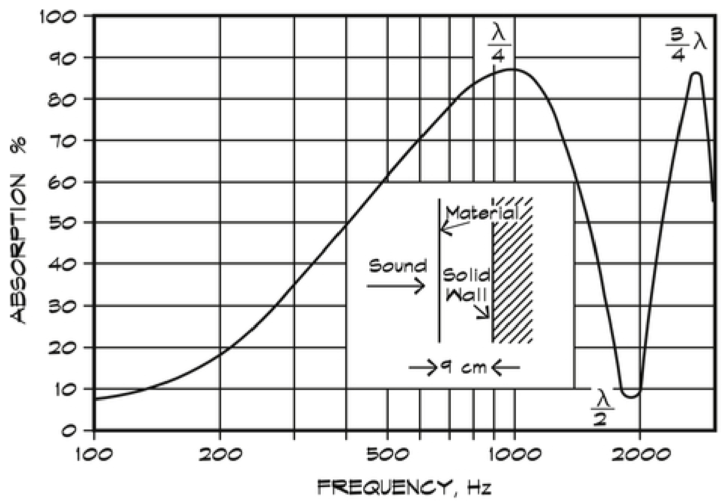
Measured Diffuse Field Sound Absorption



Ginn, 1978 (Reproduced by Long, 2014)

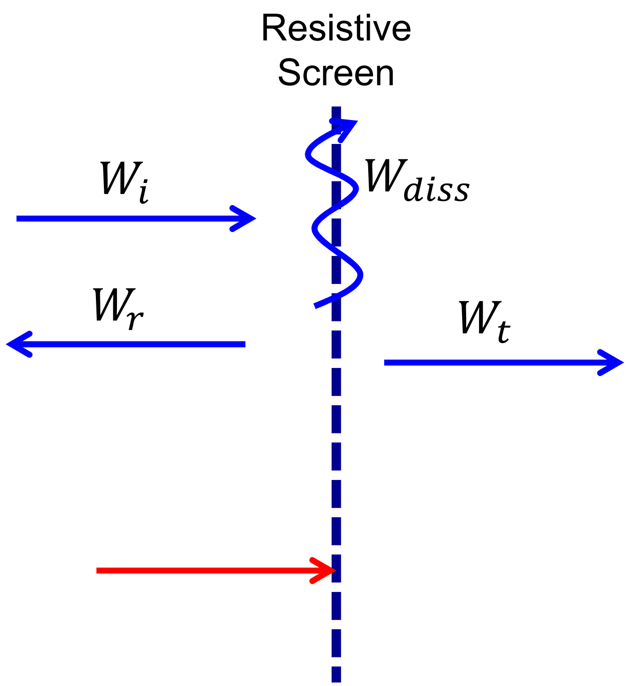
Porous Absorbers Basics for Designers

Thin layer with flow resistance $\sigma_r t$ where σ_r is the flow resistivity and t is the thickness.

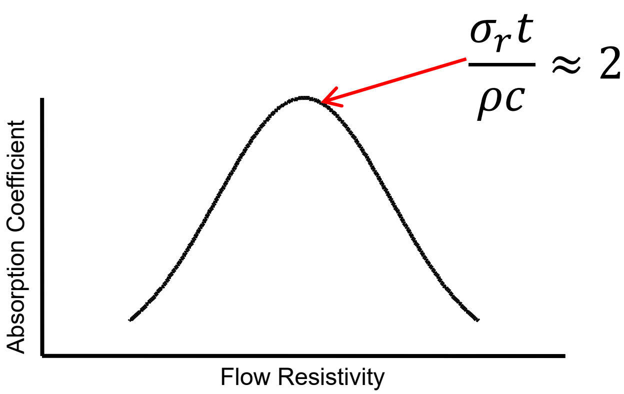


Long, 2014 based on Ginn, 1978

Porous Absorbers Basics for Designers



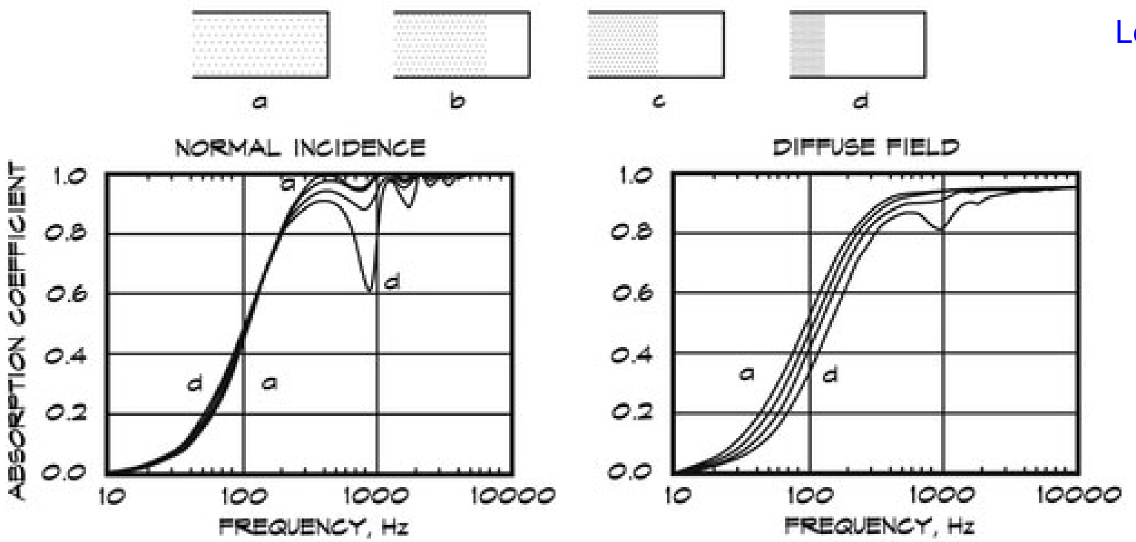
In theory, the dissipated power (W_{diss}) is a maximum when $\sigma_r t = 2\rho c$. A general rule of thumb is that a sound absorber will be effective when $\sigma_r t \approx n\rho c$ where n is on the order of 2. This assumes that the acoustic resistance is equal to the static flow resistance.



Porous Absorbers Basics for Designers

Thin layer with flow resistance $\sigma_r t$ where σ_r is the flow resistivity and t is the thickness.

Long, 2014 based on Ingard, 1994



$\sigma_r t = 2\rho c$ for each case

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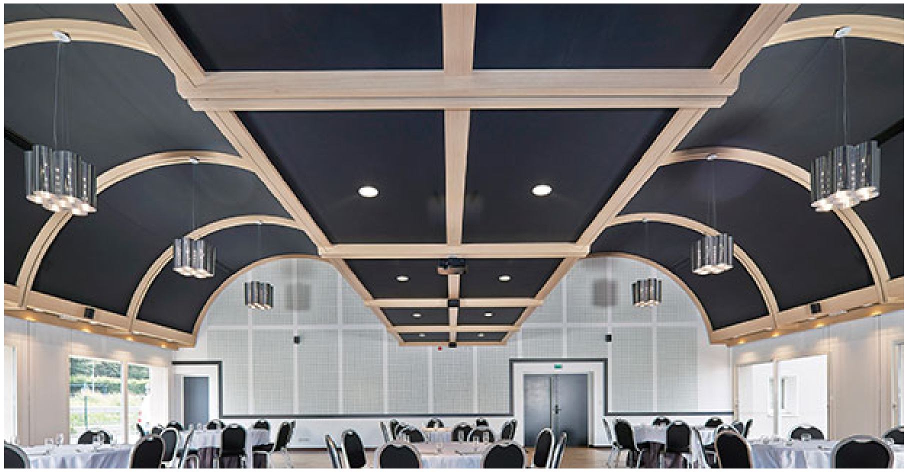
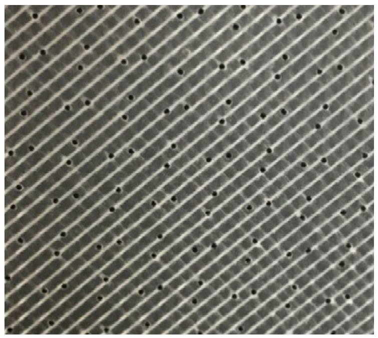
Fabric Applications

Primarily used in architectural spaces.



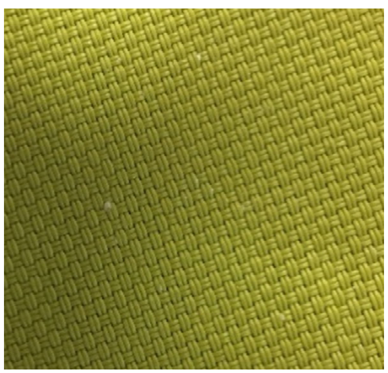
Single Leaf Fabric Samples

Fabric A

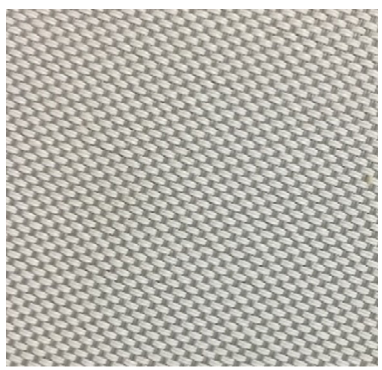


Fabric B

Fabrics A and B are impermeable glass fabrics laminated with a vinyl film on each side. A hot needle process is used to make perforations.



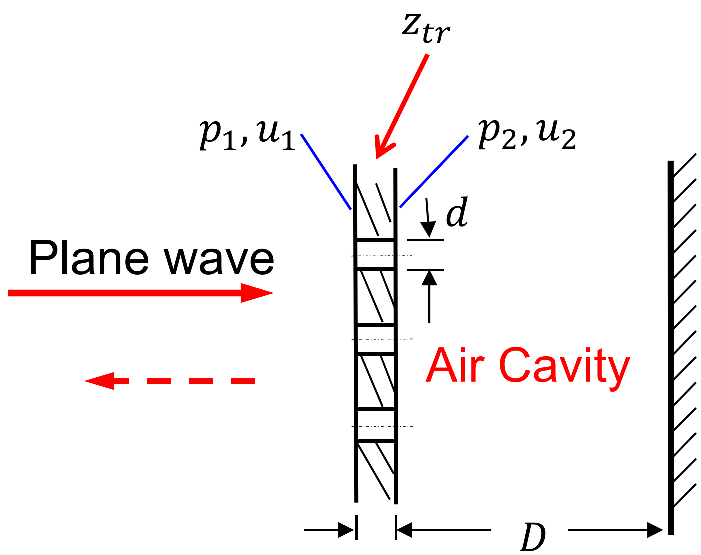
Fabric C



Fabric D

Fabrics C and D are woven.

Highly Resistive Materials



$$z_{tr} = \frac{1}{\rho c}\frac{p_1 - p_2}{u_1}$$

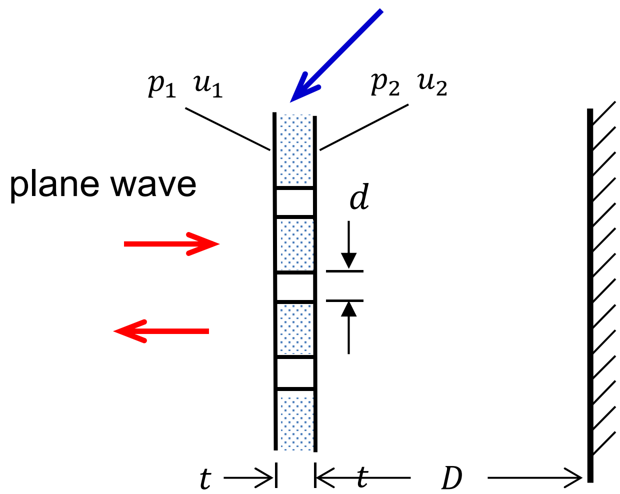
$$z = z_{tr} - j\cot(kD)$$

$$R = \frac{z-1}{z+1}$$

$$\alpha = 1 - |R|^2$$

Maa's Theory

Fabric or MPP



d	hole diameter
σ	perforation rate
t	thickness
D	cavity depth
η	dynamic viscosity

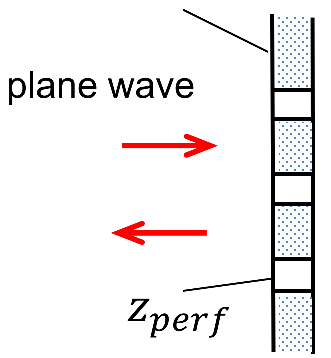
Transfer Impedance

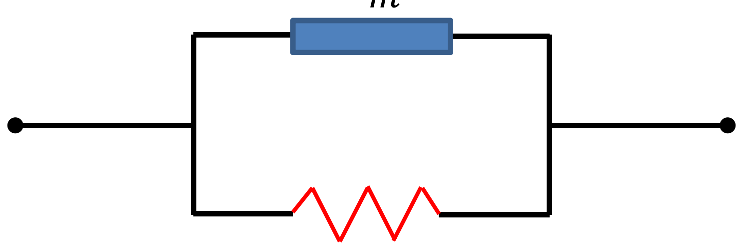
$$z_{perf} = \frac{32\eta t}{\sigma\rho c d^2}\left(\sqrt{1+\frac{\beta^2}{32}}+\frac{\sqrt{2}}{32}\frac{\beta d}{t}\right)+\frac{j\omega t}{\sigma c}\left(1+\frac{1}{\sqrt{9+\frac{\beta^2}{2}}}+\frac{0.85d}{t}\right)$$

$$\beta = d\sqrt{\rho\omega/4\eta}$$

MPP Theory

$$z_m = \frac{j\omega m_s}{\rho c}$$





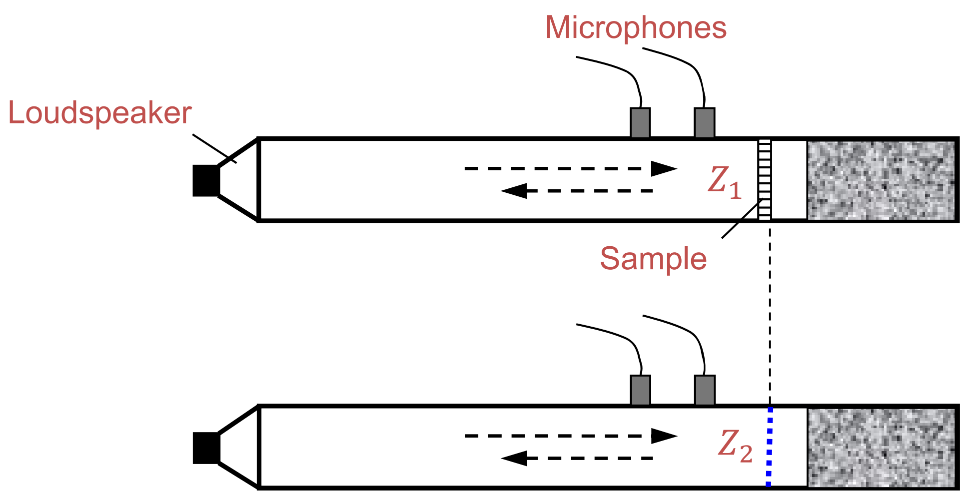
<u>Include Fabric Mass</u>

$$z_{tr} = \frac{z_{perf} z_m}{z_{perf} + z_m}$$

m_s mass per unit area (surface mass density)

Wu, Cheng, and Tao, 2003

Measure Transfer Impedance



$$Z_{tr} = \rho c z_{tr} = Z_1 - Z_2$$

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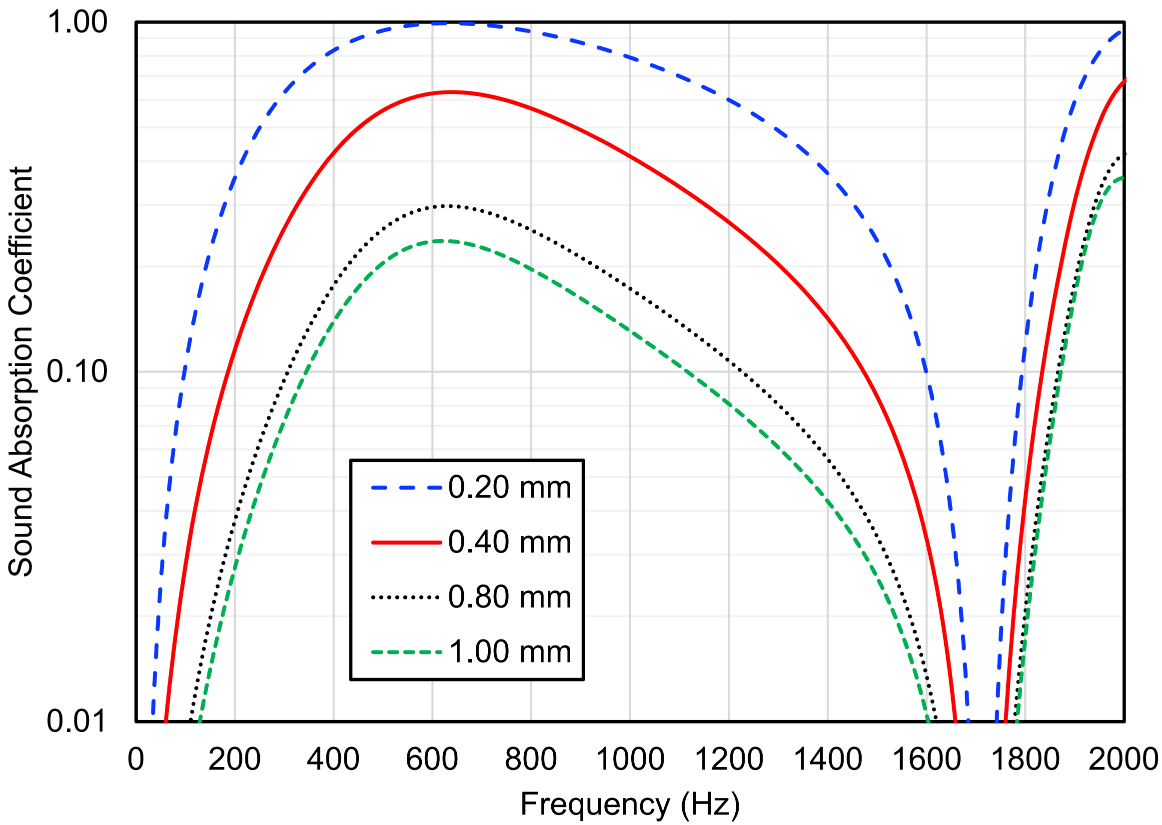
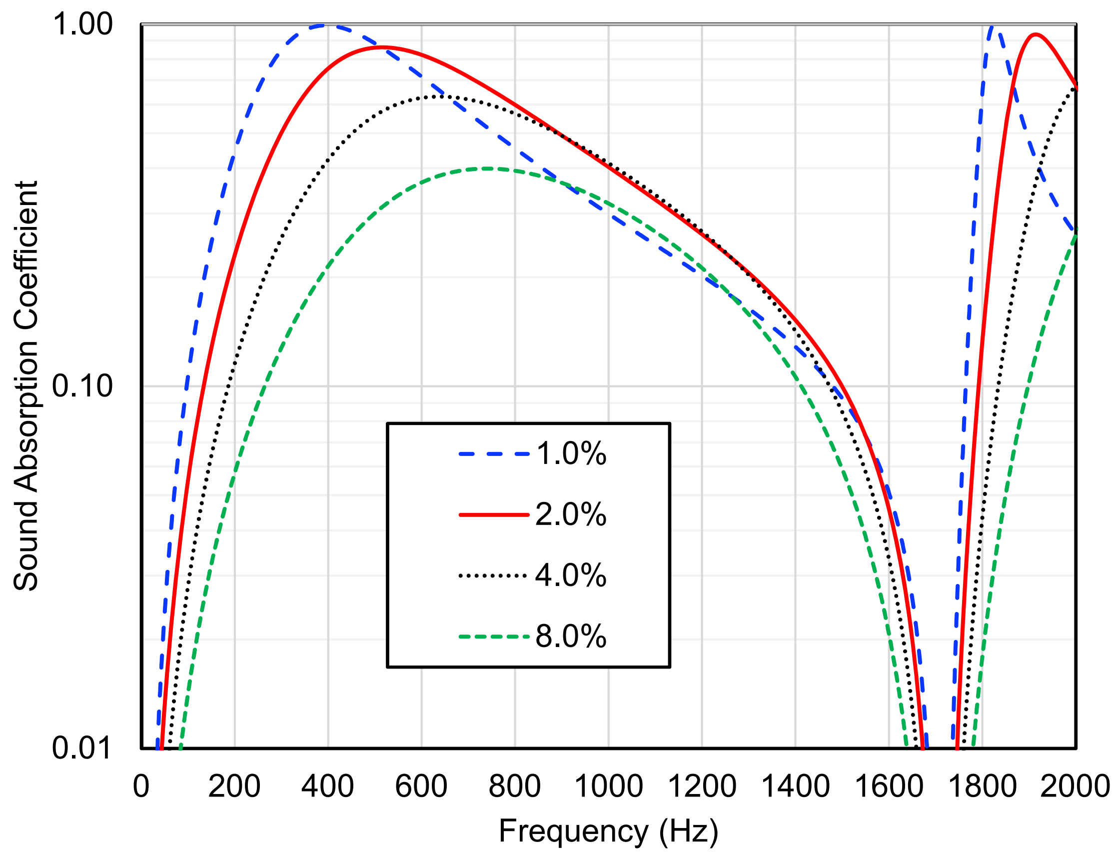
Effect of Hole Diameter



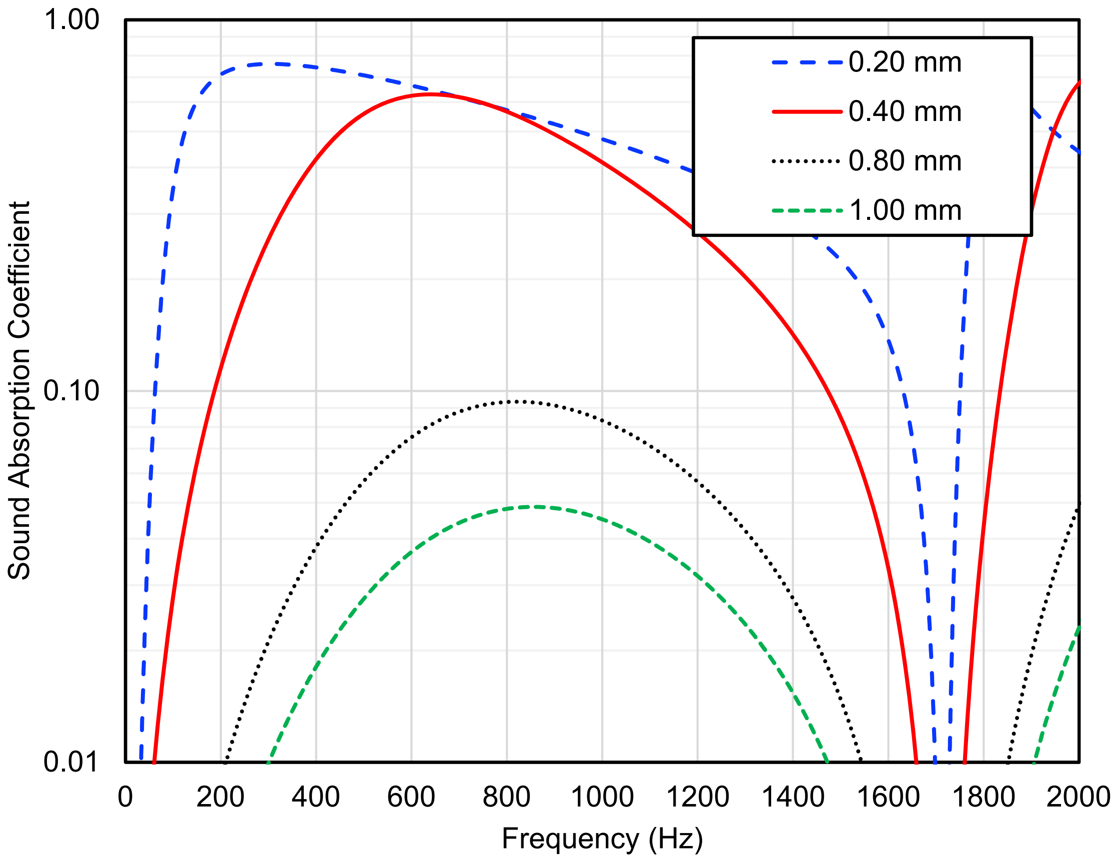
$d = ?$
σ = 0.04
t = 1.0 mm
m_s = 3.20 kg/m^2

Effect of Perforation Rate



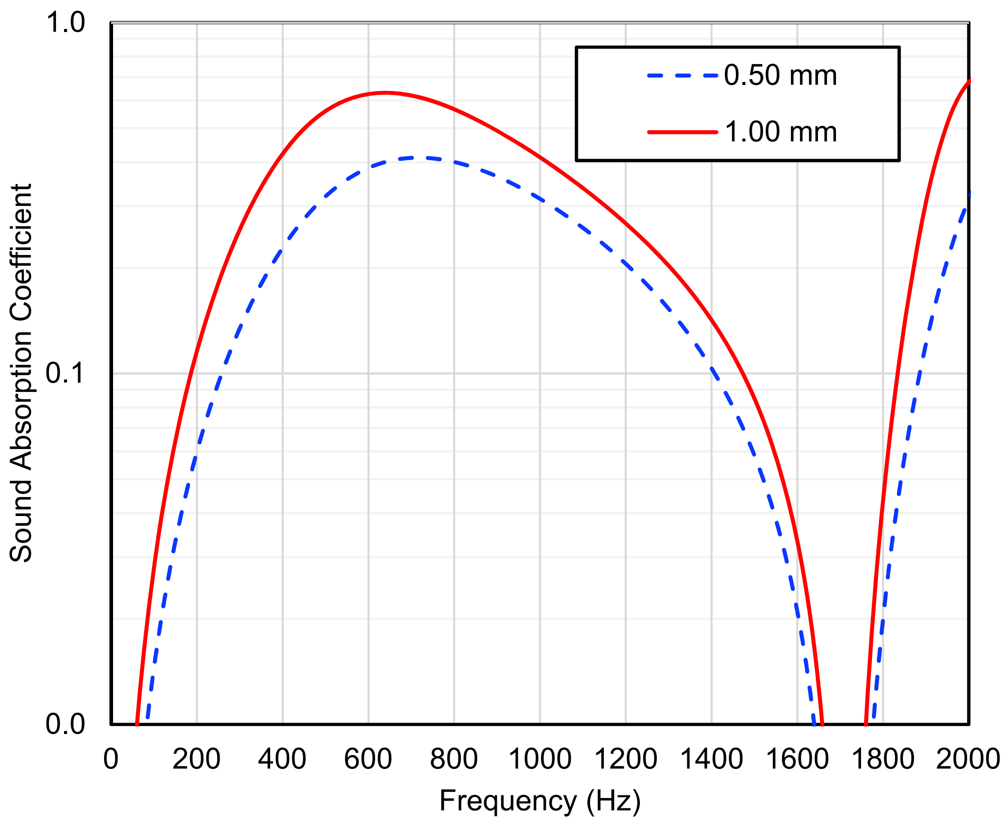
d = 0.40 mm
σ = ?
t = 1.0 mm
m_s = 3.20 kg/m^2

Effect of Hole Diameter ($\sigma = f(d)$)



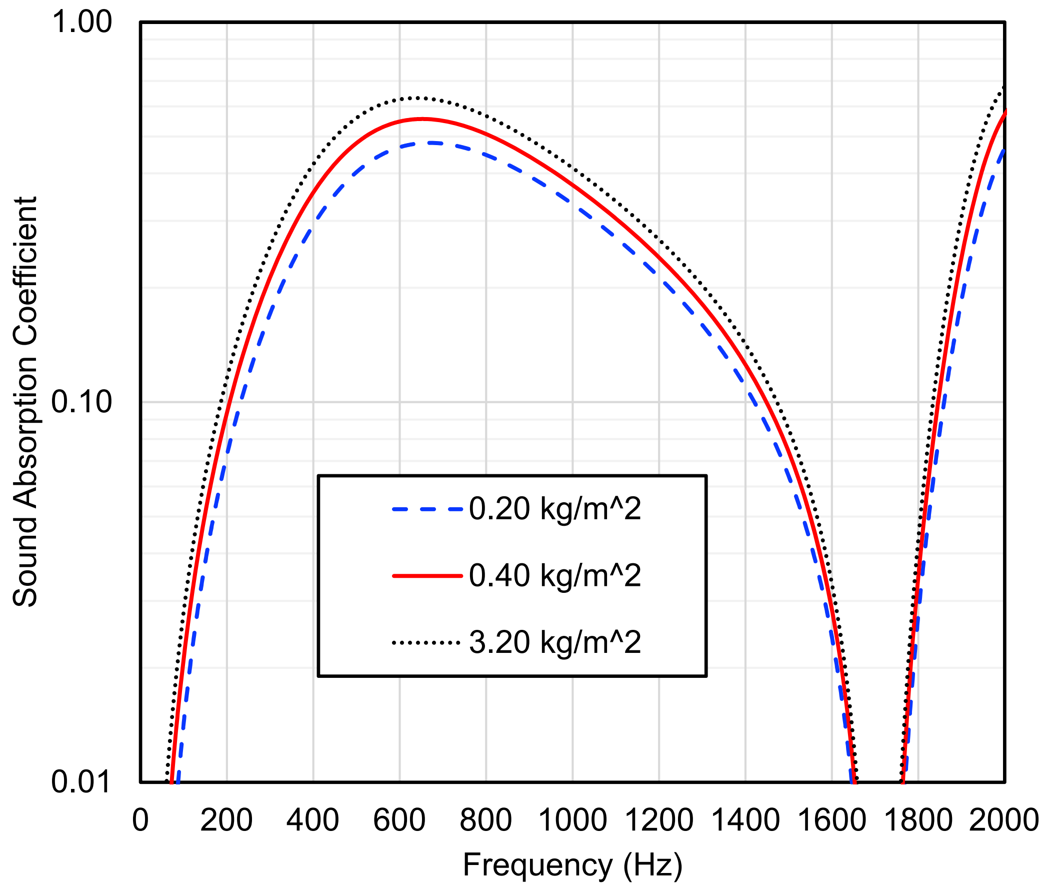
$d = ?$
$\sigma = f(d)$
t = 1.0 mm
m_s = 3.20 kg/m^2

Effect of Thickness



d = 0.40 mm
σ = 0.04
t = ?
m_s = 3.20 kg/m^2

Effect of Surface Mass Density



d = 0.40 mm
σ = 0.04
t = 1.0 mm
m_s = ?

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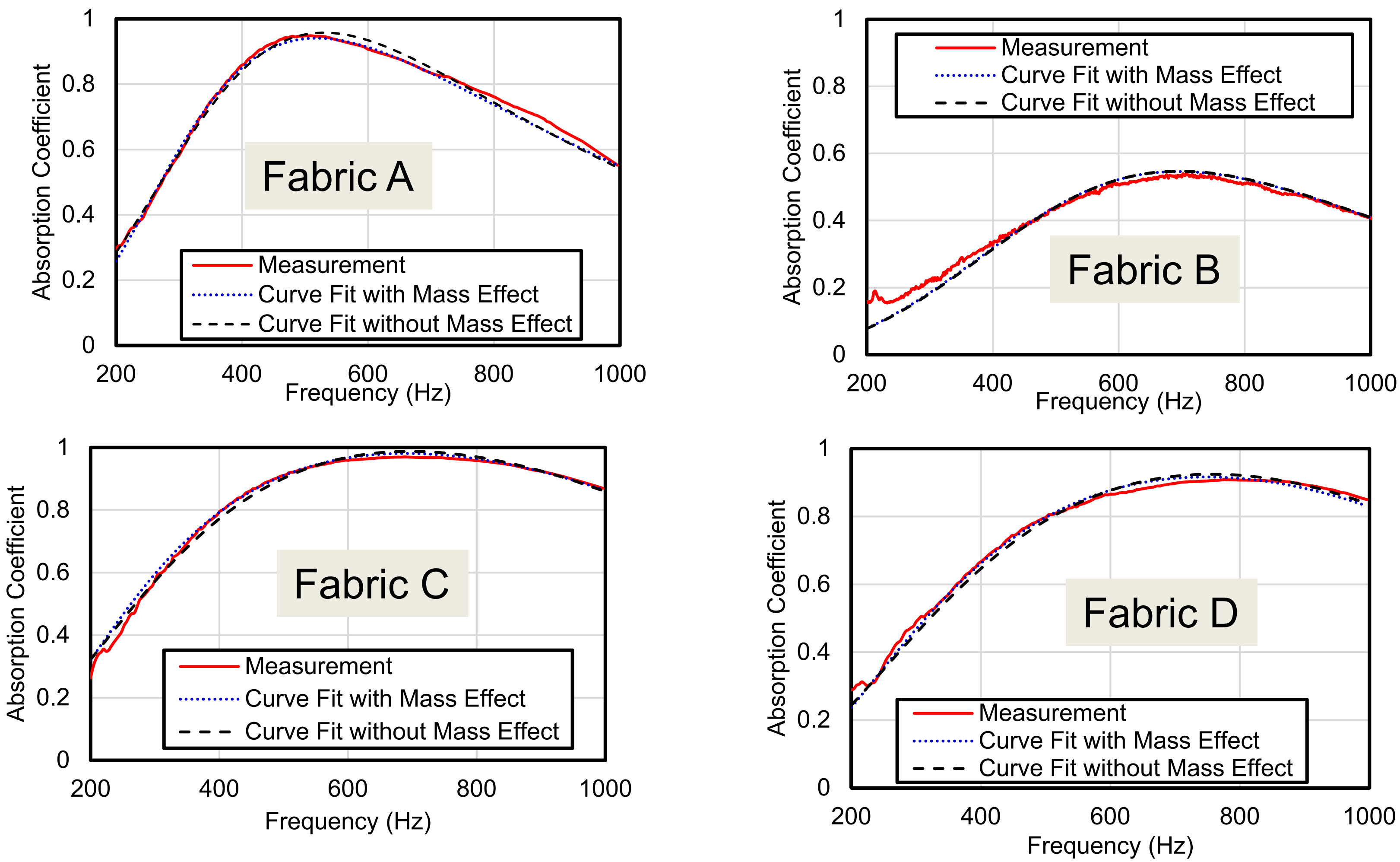
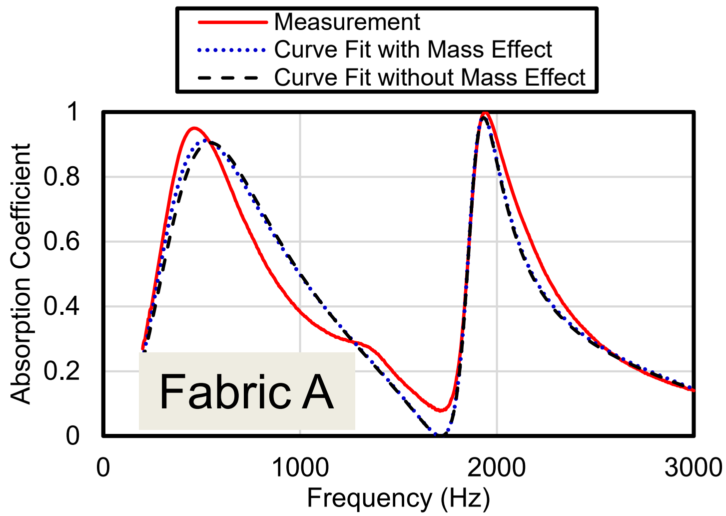
Curve Fitting Procedure

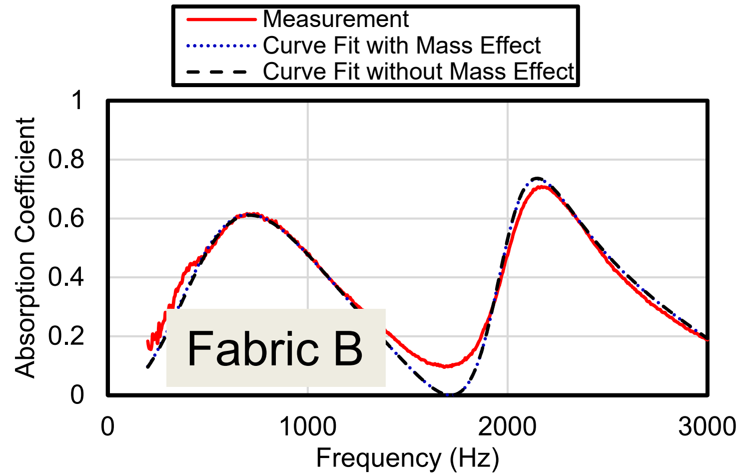
1. Measure sound absorption (10 cm cavity depth behind MPP/fabric).
2. Assume thickness and sometimes mass (based on measurement).
3. Predict sound absorption using Maa's equation with different hole diameters and perforation rates.
4. Determine best fit hole diameter (d) and perforation rate (σ).

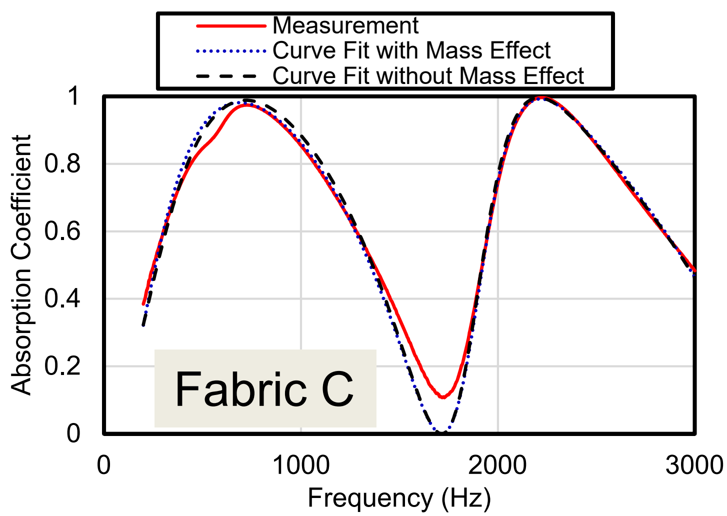
Curve Fit 98.4 mm Diameter Tube

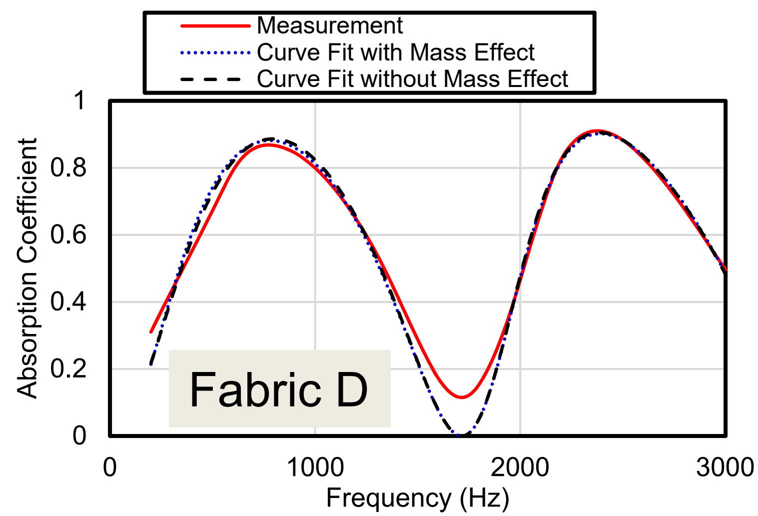


Curve Fit 34.9 mm Diameter Tube









Effective Parameters

Mass effect included

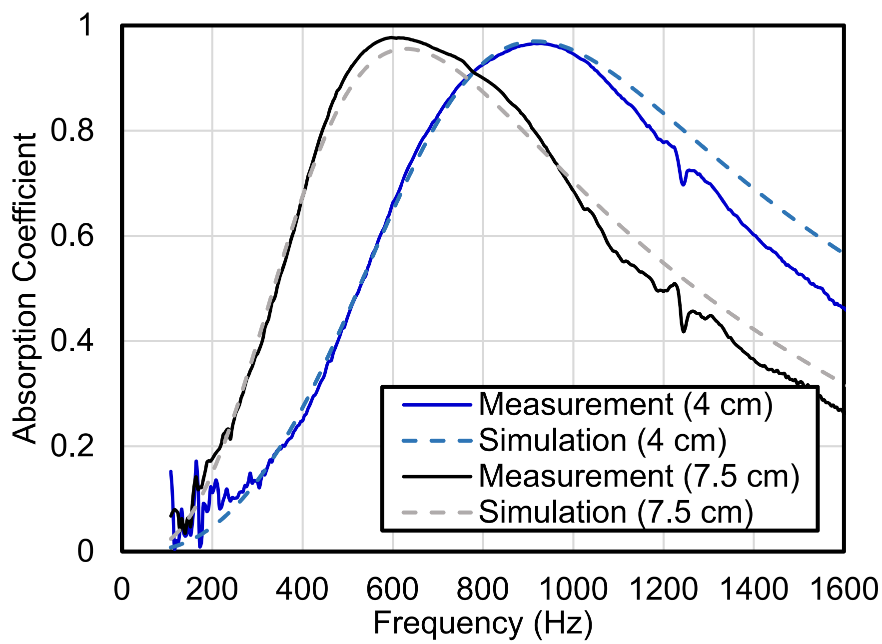
	Thickness (mm)	Effective Hole Diameter (mm)		Effective Perforation Rate (%)		Surface Mass Density (kg/m^2)
		98.4 mm Tube	34.9 mm Tube	98.4 mm Tube	34.9 mm Tube	
Fabric A	0.33	0.26	0.29	0.84	0.79	0.38
Fabric B	0.33	0.38	0.32	2.30	2.45	0.38
Fabric C	0.70	0.15	0.15	5.29	5.54	0.59
Fabric D	0.70	0.14	0.12	8.85	12.78	0.45

Mass effect neglected

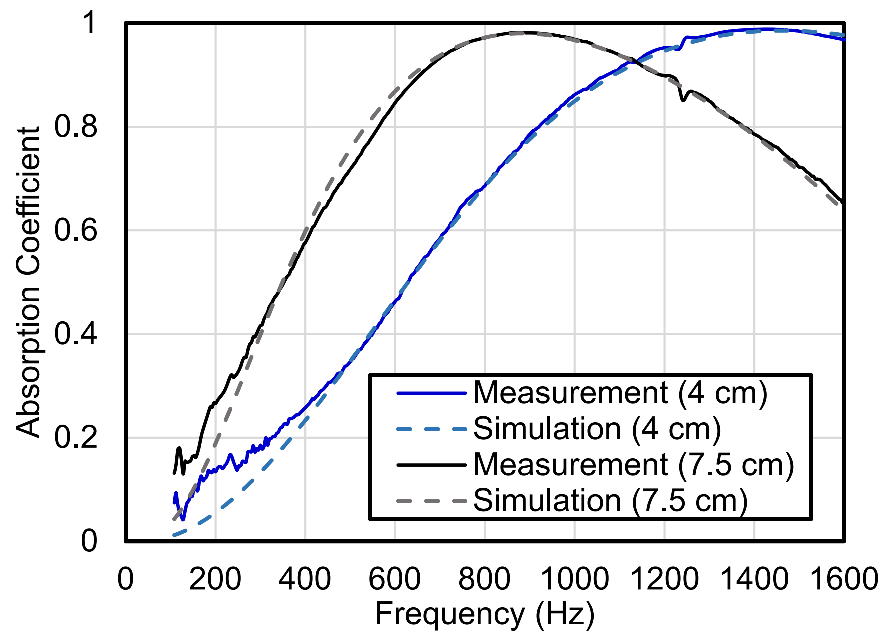
	Thickness (mm)	Effective Hole Diameter (mm)		Effective Perforation Rate (%)	
		98.4 mm Tube	34.9 mm Tube	98.4 mm Tube	34.9 mm Tube
Fabric A	0.33	0.32	0.36	0.96	1.05
Fabric B	0.33	0.42	0.34	2.55	2.70
Fabric C	0.70	0.17	0.15	4.38	5.29
Fabric D	0.70	0.15	0.13	7.41	12.12

Predictions with Effective Parameters

Fabric A



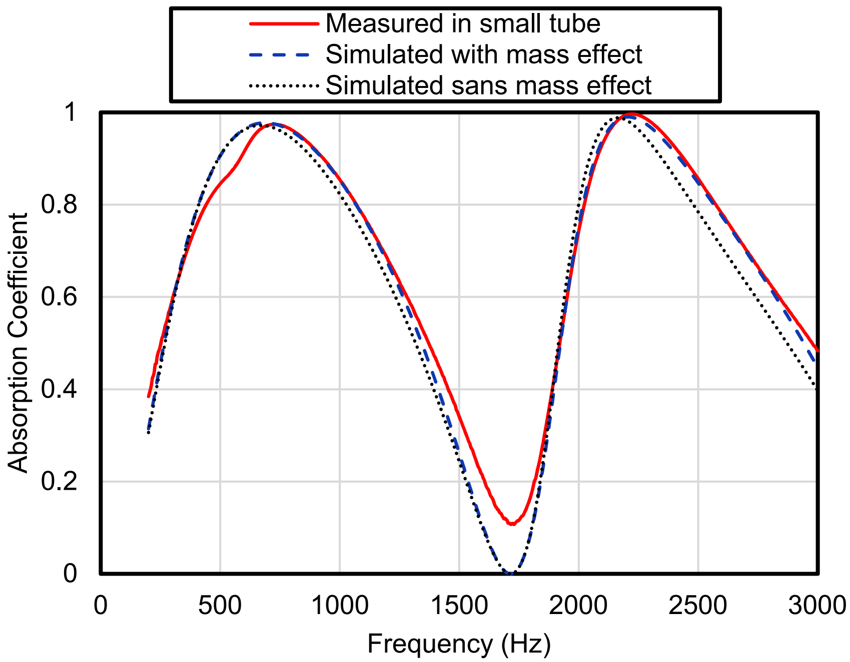
Fabric C



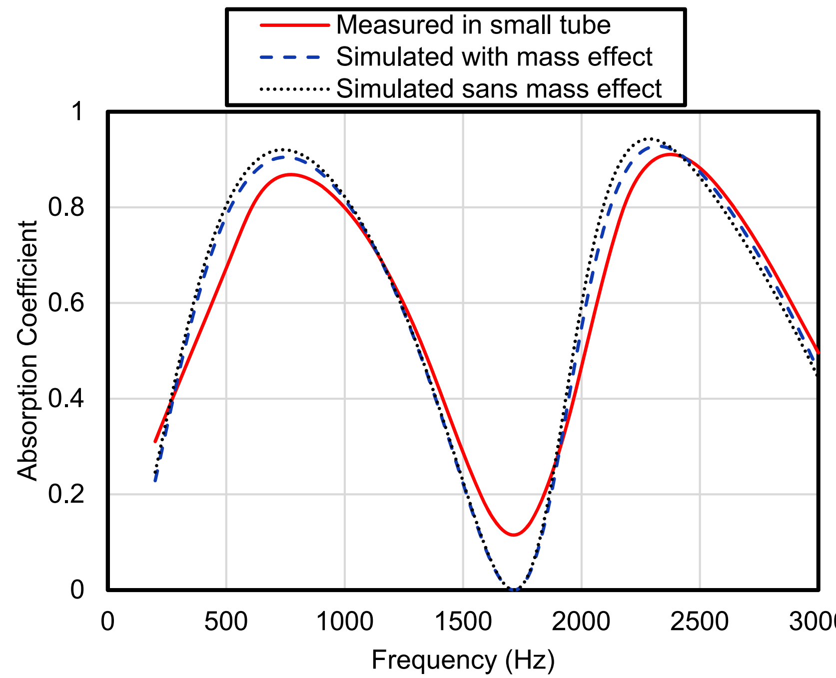
Predictions with Effective Parameters

Effective parameters determined using 98.4 mm tube measurements. Effective parameters then used to predict sound absorption at higher frequencies.

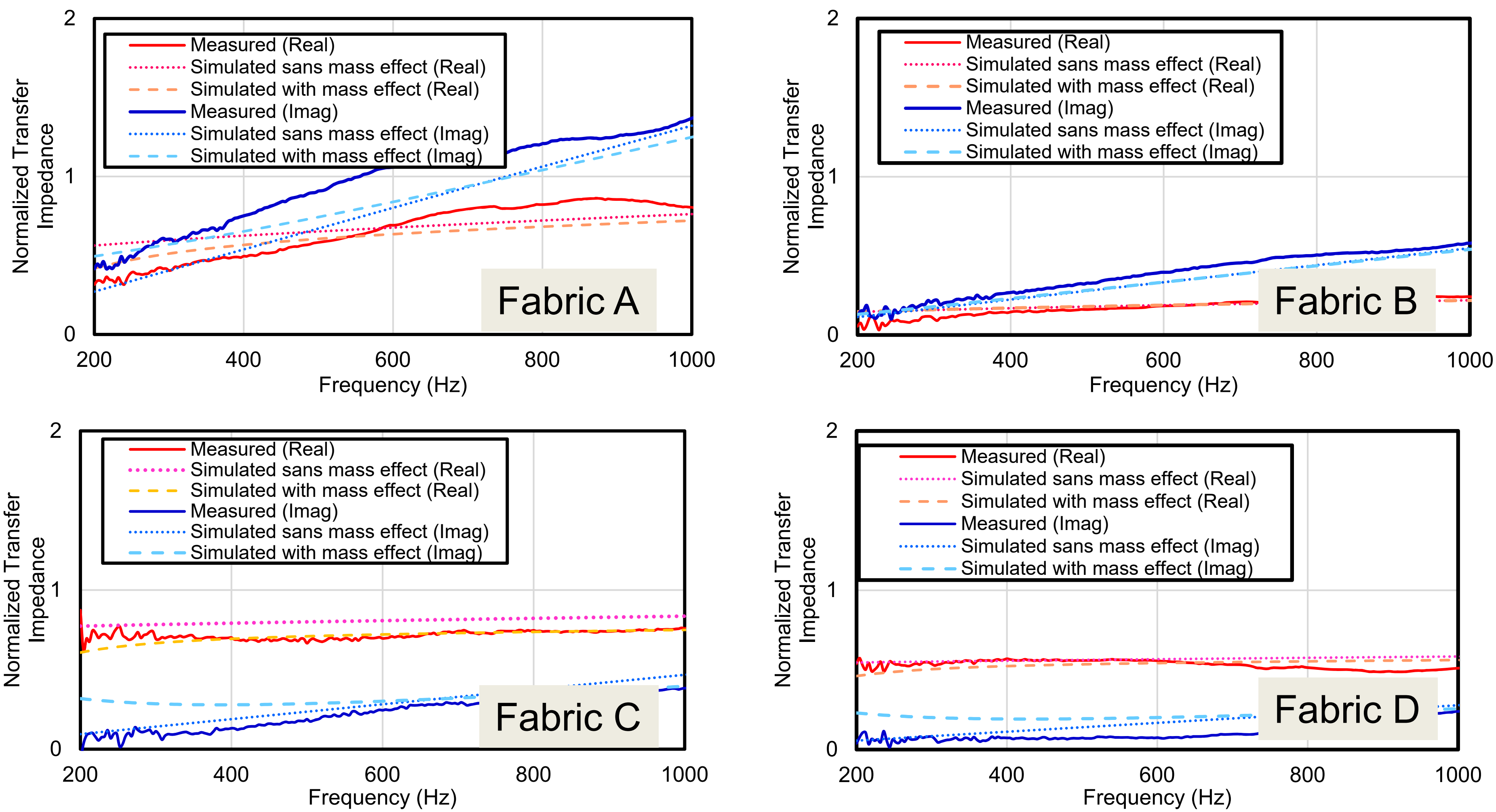
Fabric C



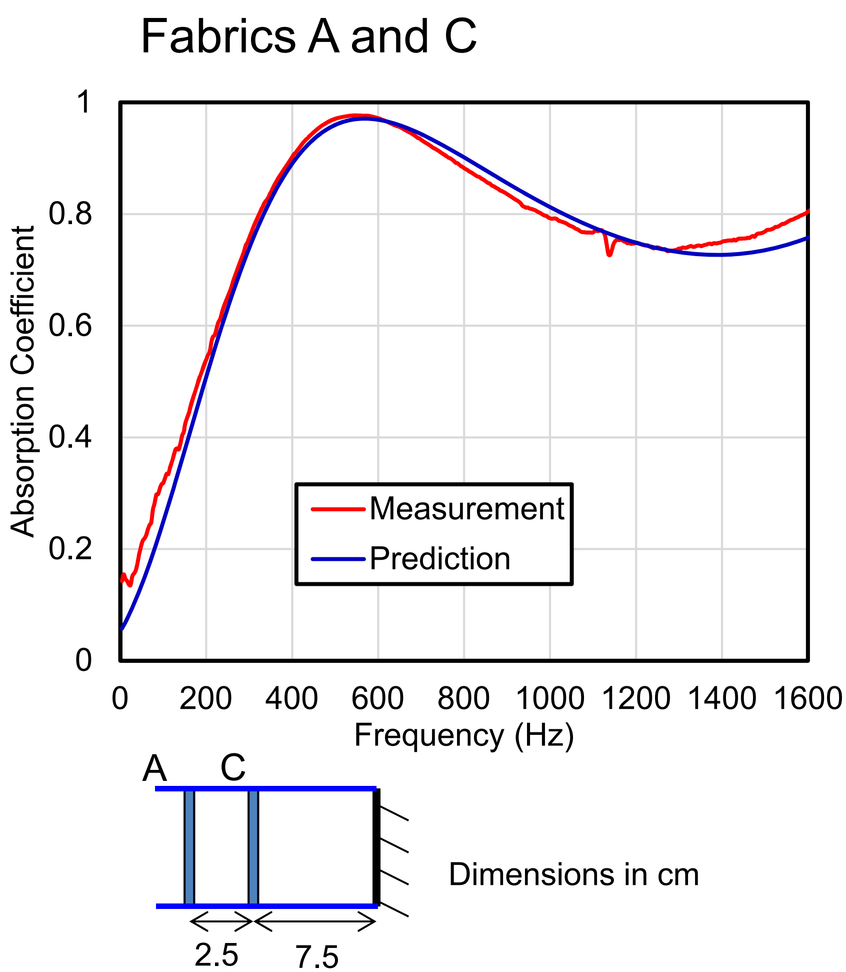
Fabric D

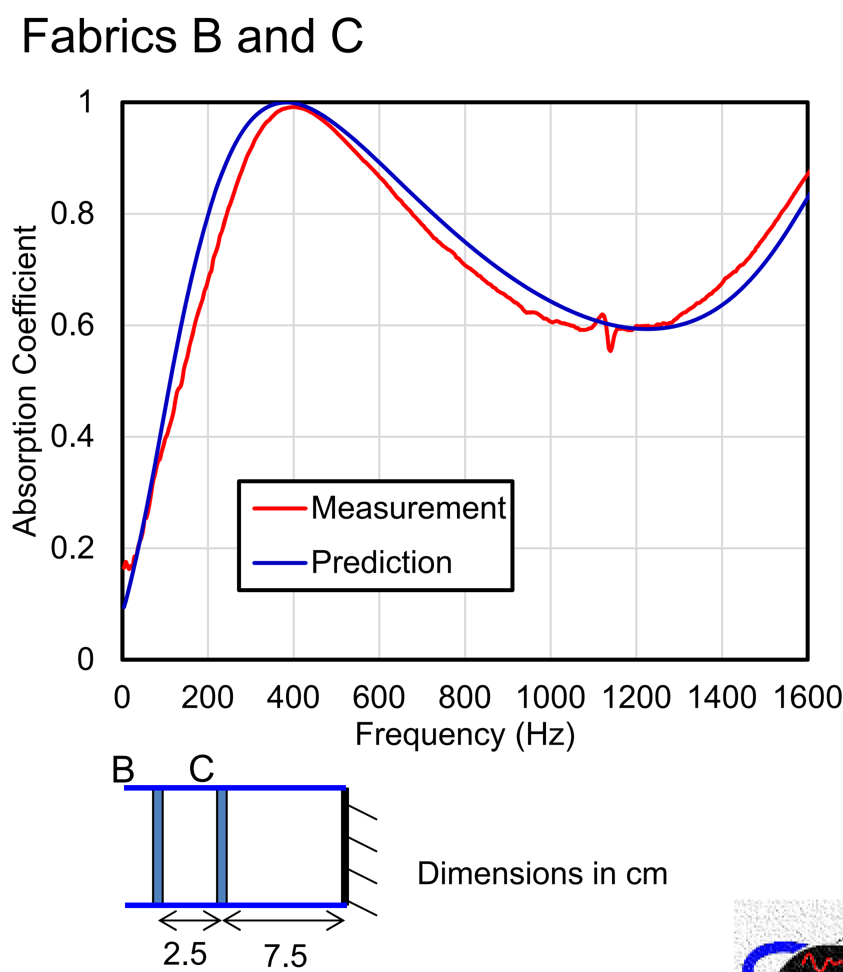


Transfer Impedance Comparison

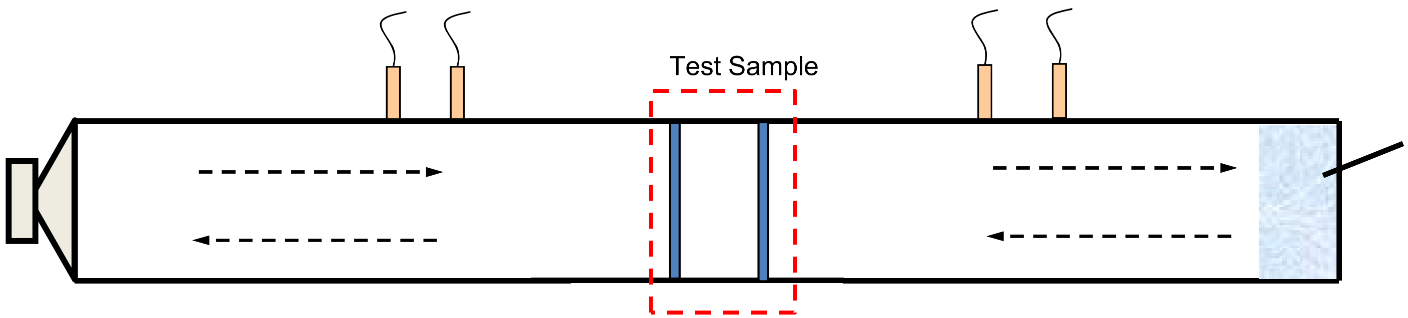


Two Fabric Layers





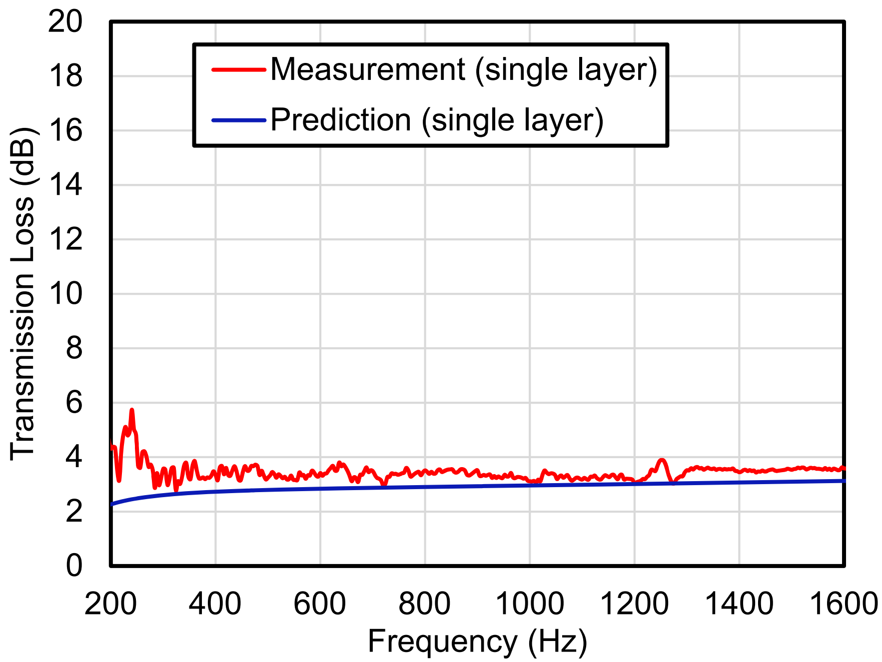
Transmission Loss Measurement



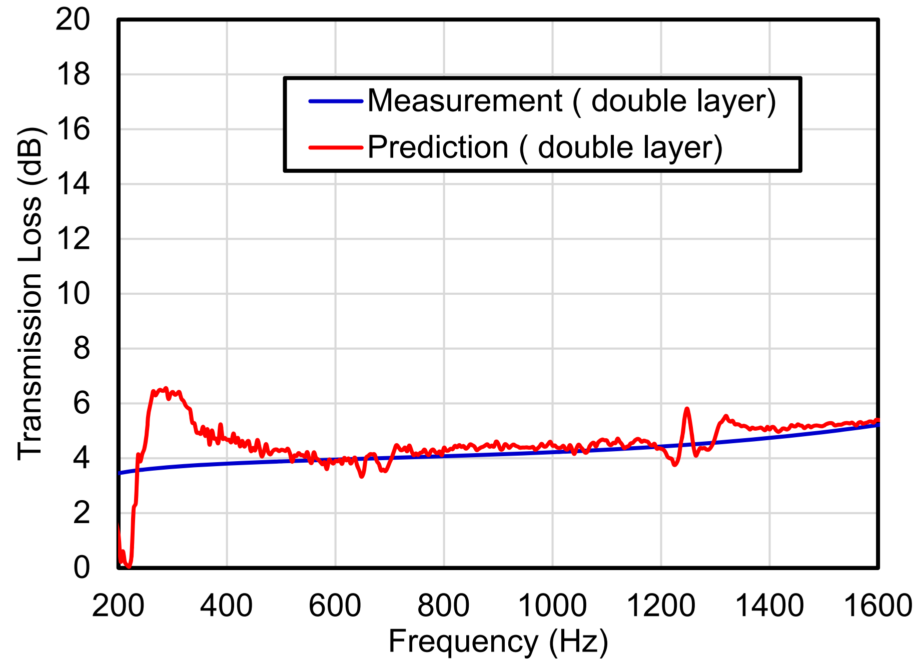
$$TL = 10\log\left(\frac{W_{inc}}{W_{tr}}\right)$$ assuming anechoic termination

Transmission Loss

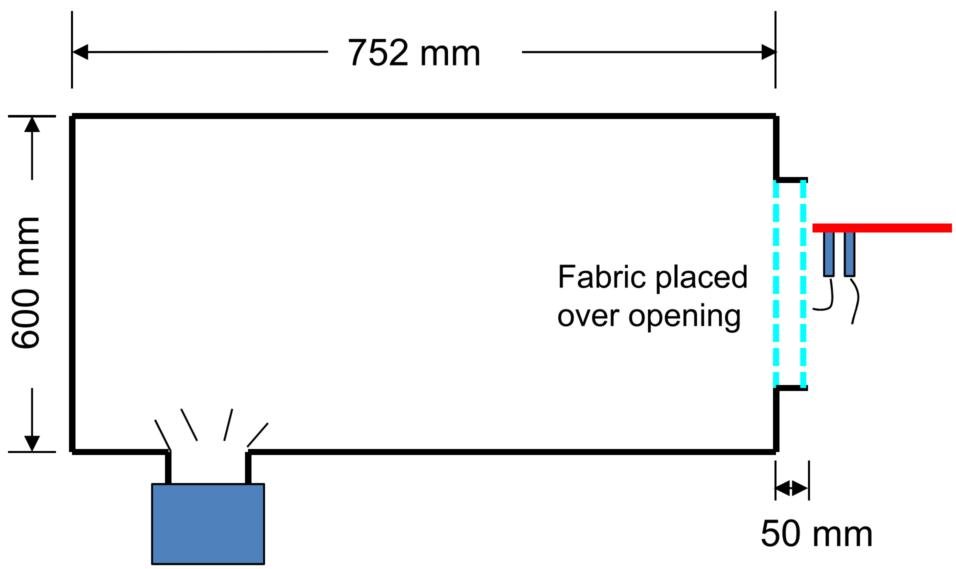
Fabric C

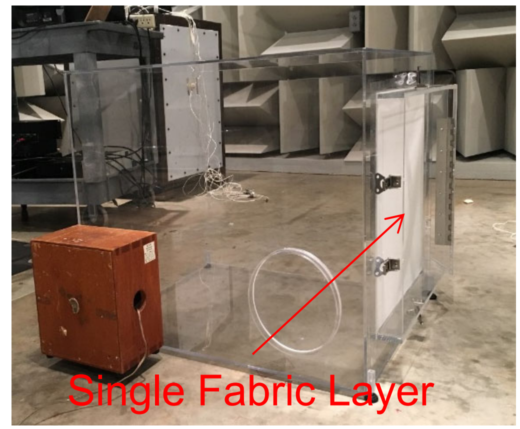


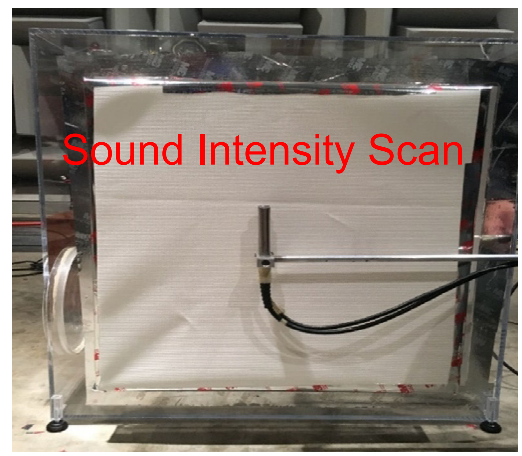
Fabrics A and C



Test 1 Enclosure Insertion Loss







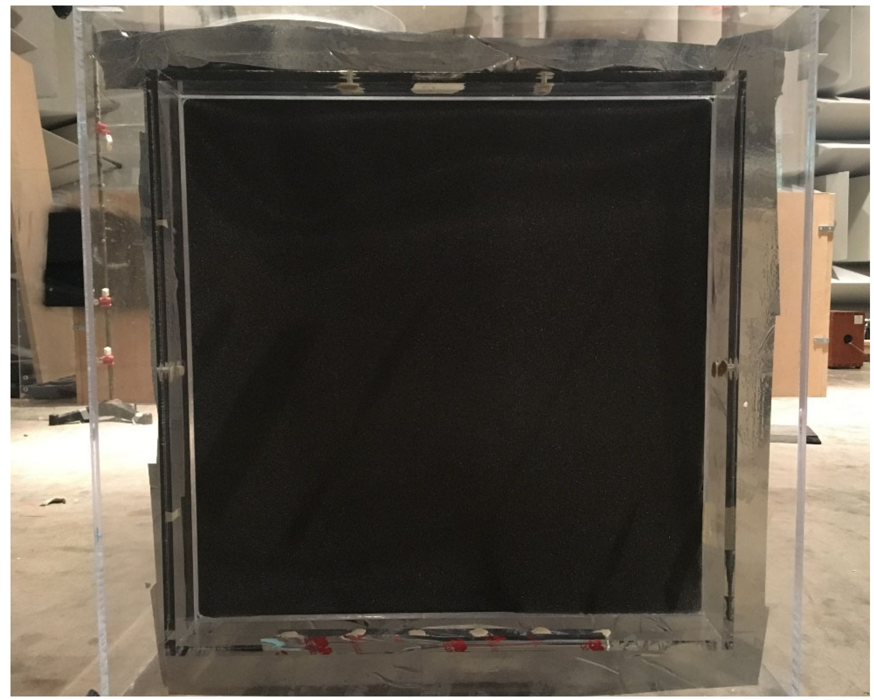
$$IL = L_{W,untreated} - L_{w,treated}$$

June 8, 2021

Test 1 Enclosure Insertion Loss

Double Layer Fabrics

Single Layer Foam



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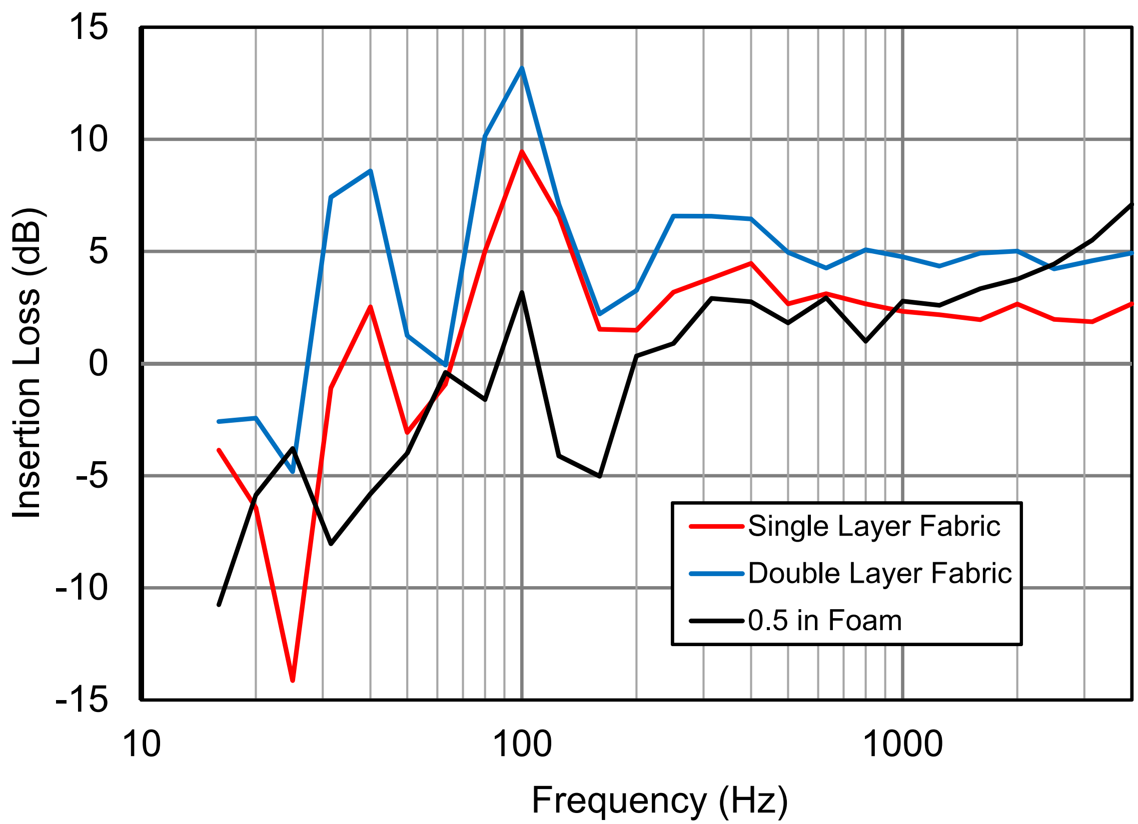
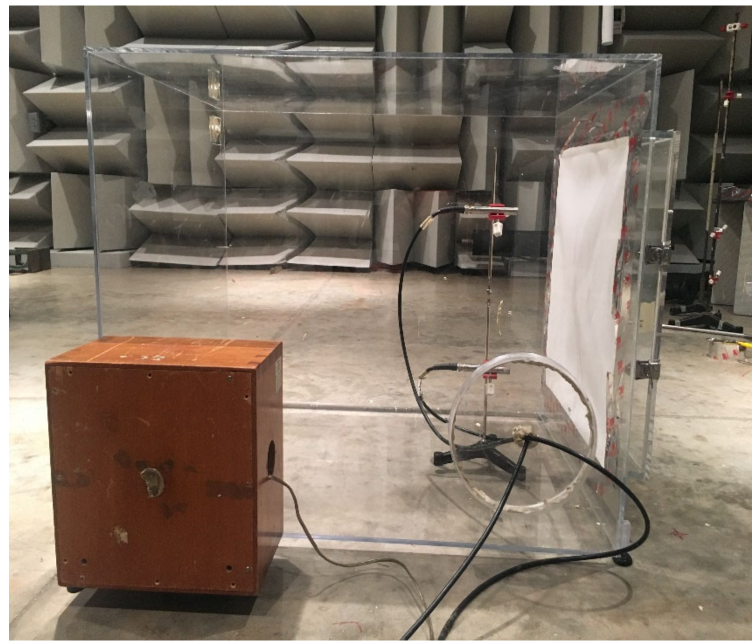


Sample	Flow Resistance (Rayls)
Single Layer Fabric	180
Double Layer Fabric	360
1.25 cm Foam	160

Test 2 Enclosure Attenuation

Empty Box

Single Layer Fabrics



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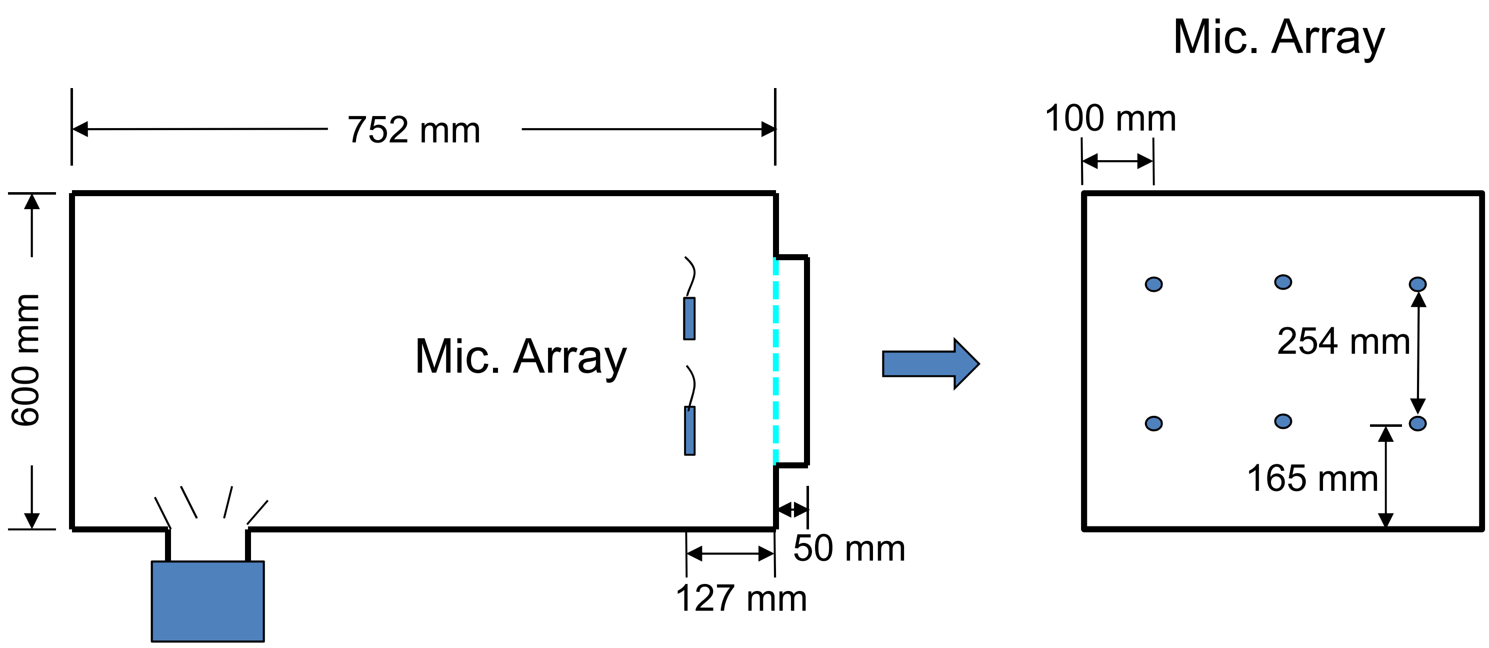

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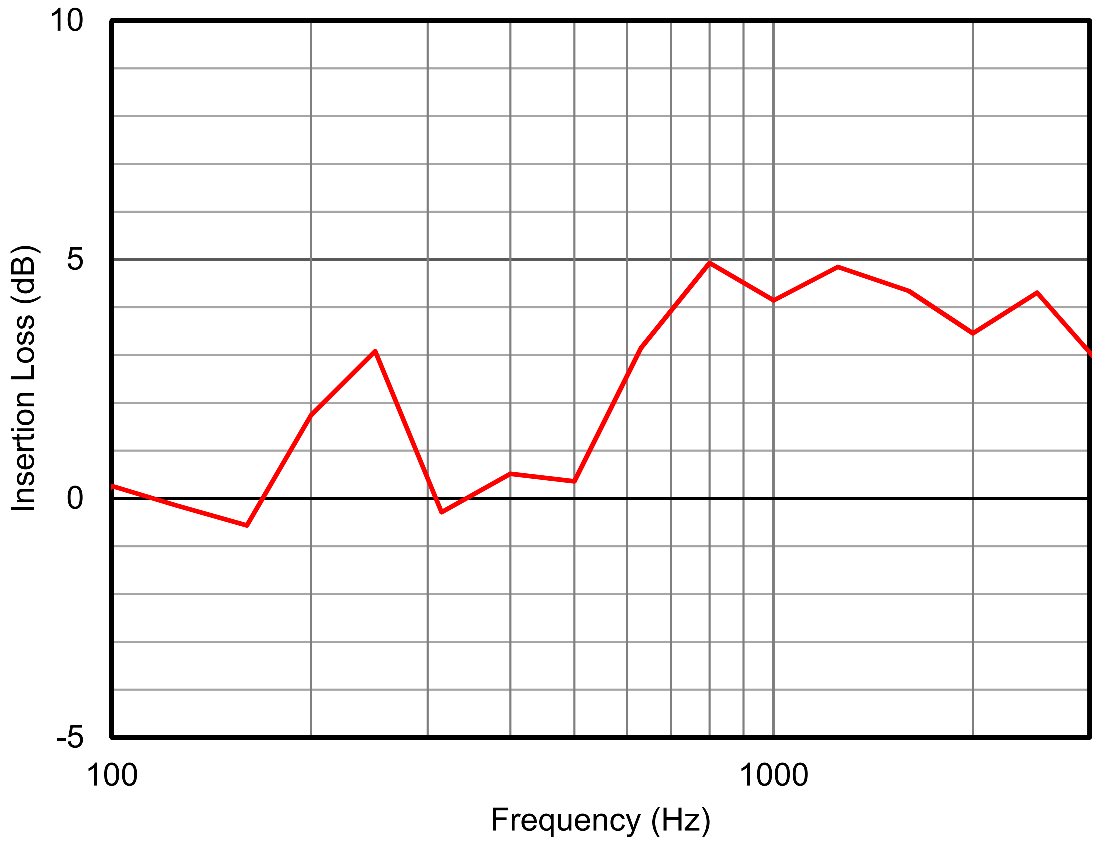

Summary

- Fabric sound absorption and transmission loss is similar to that of MPP sound absorbers.
- Potential uses include deployable enclosures and architectural applications.