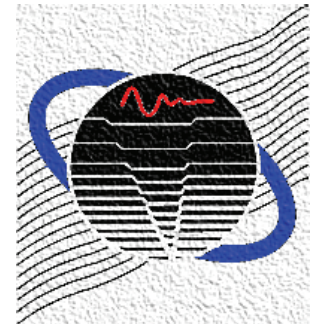


Measurement of Bulk Materials

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University of Kentucky
Department of Mechanical Engineering



Motivation

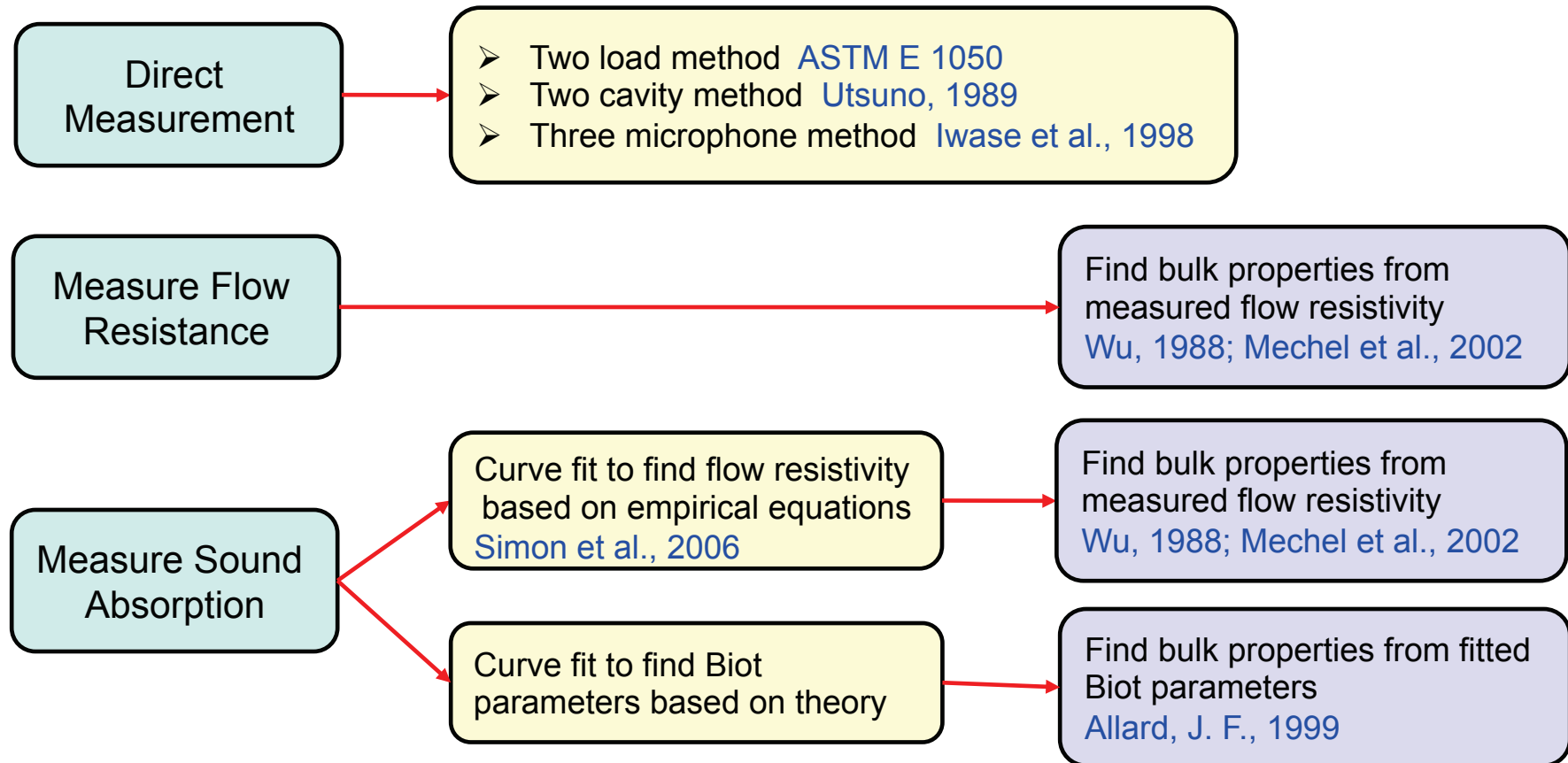
Measurement of Bulk Properties

- Determining the bulk properties
 - ✓ Complex wave number and characteristic impedance
 - ✓ Complex speed of sound and density
- Bulk properties are used
 - ✓ For designing layered absorbers
 - ✓ In FEM and BEM models



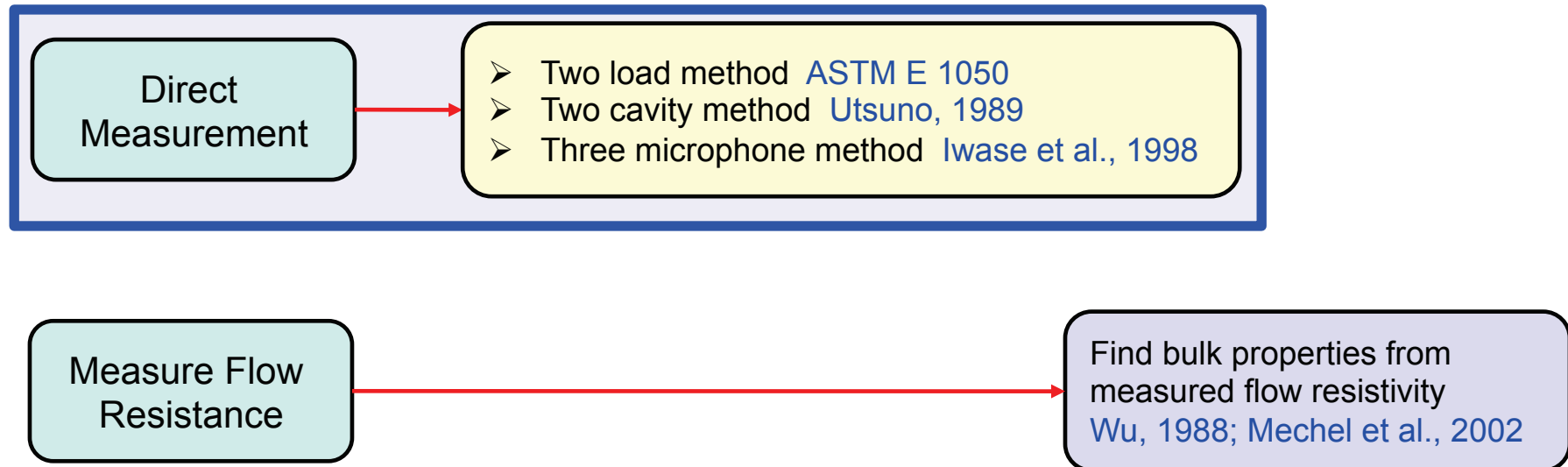
Overview of Approaches

Measurement of Bulk Properties



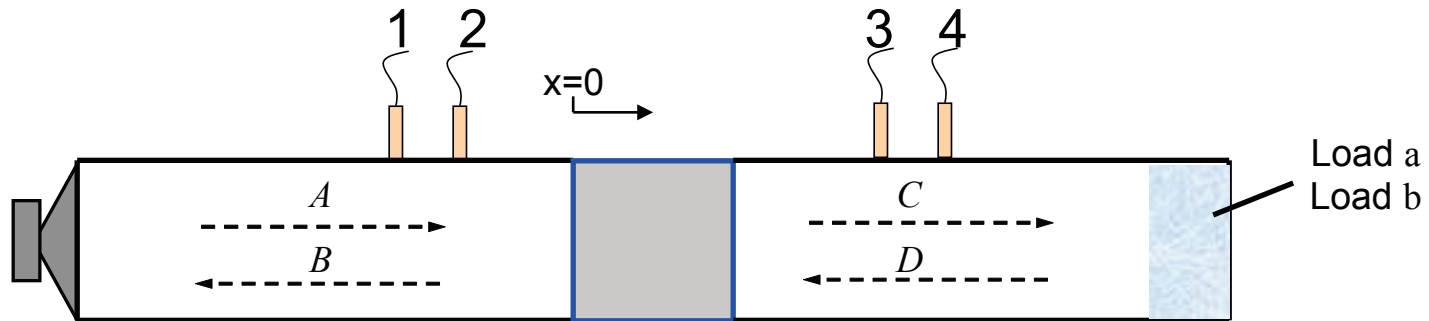
Overview of Approaches

Measurement of Bulk Properties

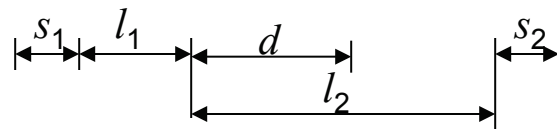


Two-load Method

Measurement of Bulk Properties



For each load:



$$A = j \frac{H_{1,ref} e^{-jkl_1} - H_{2,ref} e^{-jk(l_1+s_1)}}{2 \sin ks_1}$$

$$C = j \frac{H_{3,ref} e^{jk(l_2+s_2)} - H_{4,ref} e^{jkl_2}}{2 \sin ks_2}$$

$$B = j \frac{H_{2,ref} e^{jk(l_1+s_1)} - H_{1,ref} e^{jkl_1}}{2 \sin ks_1}$$

$$D = j \frac{H_{4,ref} e^{-jkl_2} - H_{3,ref} e^{-jk(l_2+s_2)}}{2 \sin ks_2}$$

Transmission Loss Measurement

Measurement of Bulk Properties

Pressures and particle velocities at two ends of the sample:

$$p_0 = A + B$$

$$u_0 = (A - B) / \rho c$$

$$p_d = Ce^{-jkd} + De^{jkd}$$

$$u_d = (Ce^{-jkd} - De^{jkd}) / \rho c$$

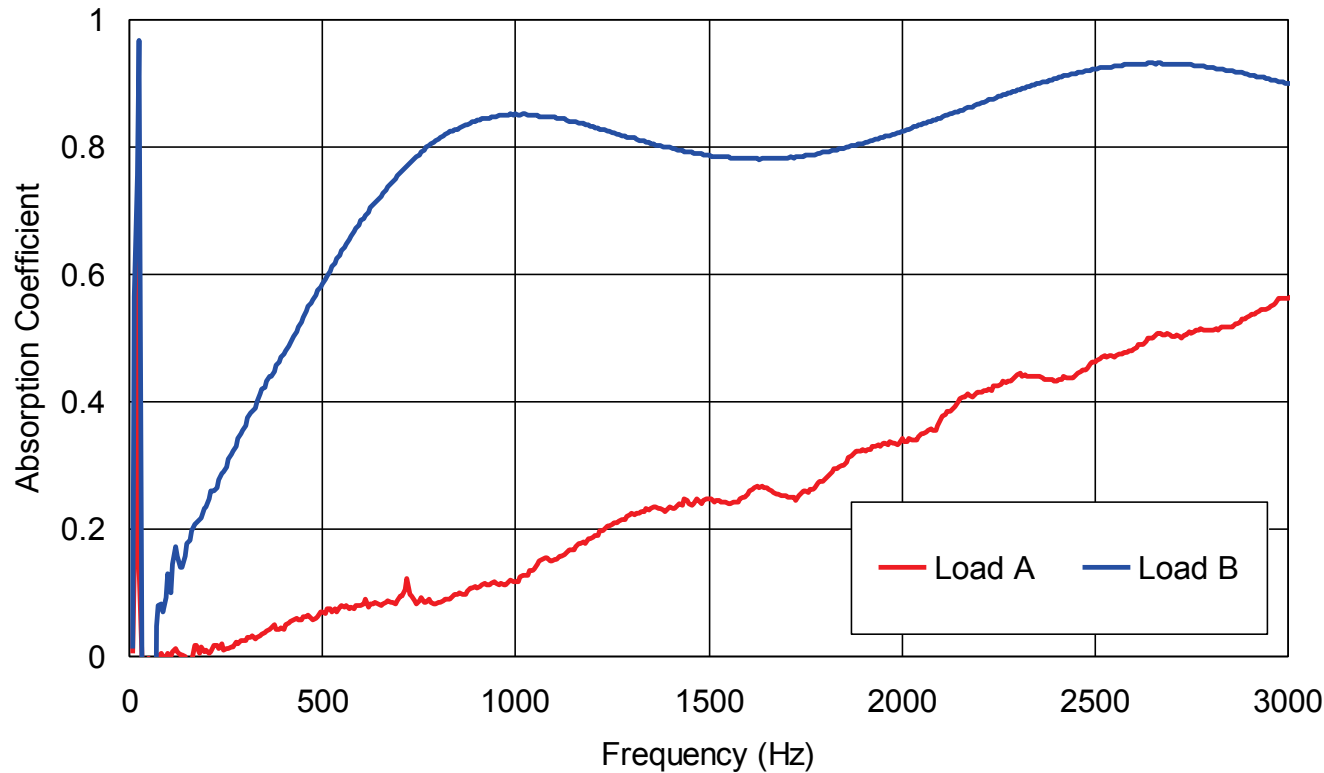
Four-pole matrix

$$T = \begin{bmatrix} \frac{p_{0a}u_{db} - p_{0b}u_{da}}{p_{da}u_{db} - p_{db}u_{da}} & \frac{p_{0b}p_{da} - p_{0a}p_{db}}{p_{da}u_{db} - p_{db}u_{da}} \\ \frac{u_{0a}u_{db} - u_{0b}u_{da}}{p_{da}u_{db} - p_{db}u_{da}} & \frac{p_{da}u_{0b} - p_{db}u_{0a}}{p_{da}u_{db} - p_{db}u_{da}} \end{bmatrix}$$

$$TL = 20 \log_{10} \left| \frac{1}{2} \left(T_{11} + \frac{T_{12}}{\rho c} + \rho c T_{21} + T_{22} \right) \right|$$

Load a and Load b

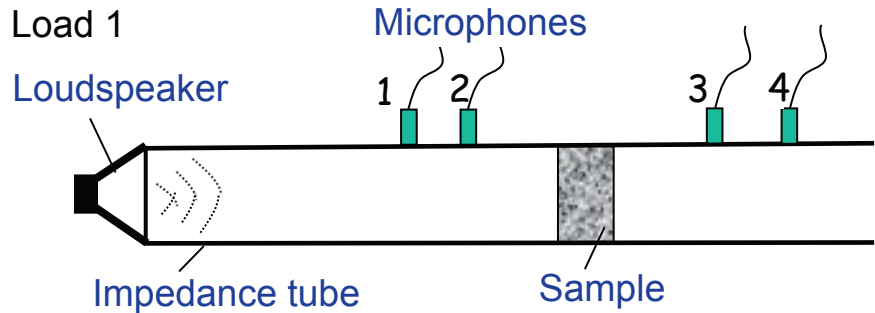
Measurement of Bulk Properties



Load A: Open tube. Load B: Close the tube with 4" absorbing material.

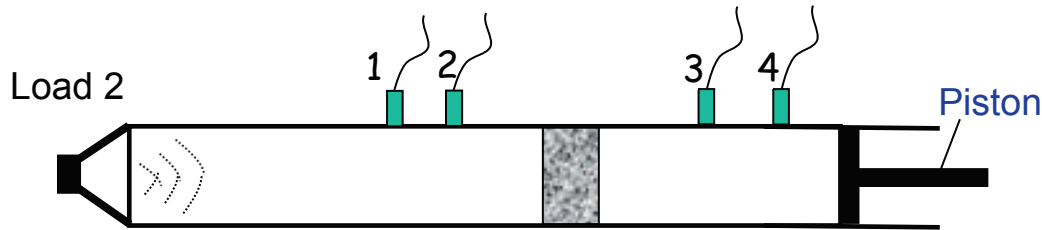
Two Load Method

Measurement of Bulk Properties



$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos(k_c d) & jz_c \sin(k_c d) \\ j \sin(k_c d)/z_c & \cos(k_c d) \end{bmatrix}$$

Open

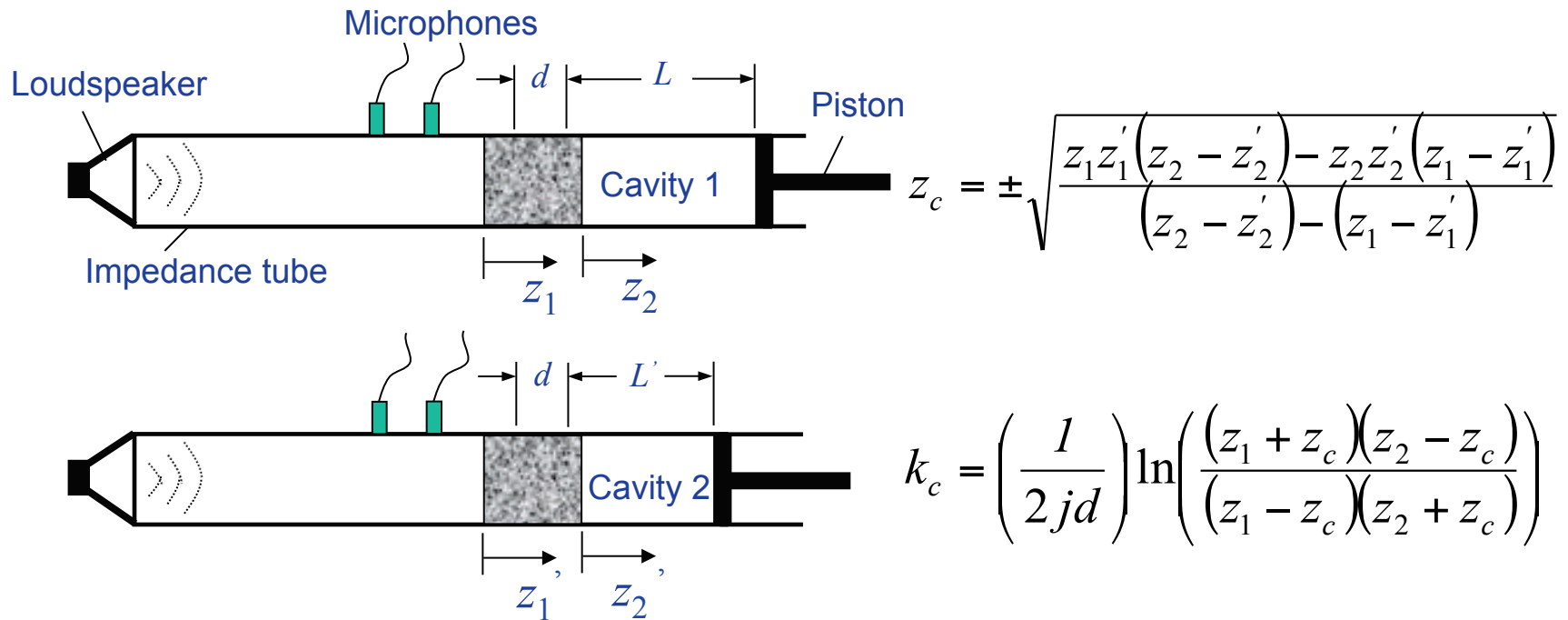


$$z_c = \sqrt{B/C}$$

$$k_c = \arctan\left(\frac{B}{jAz_c}\right) / d$$

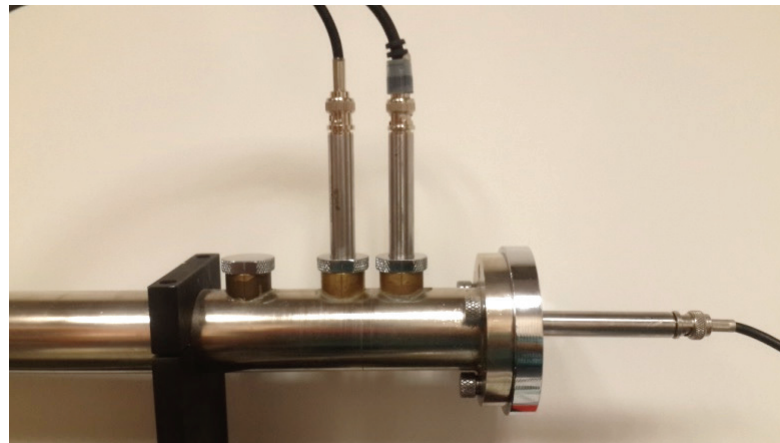
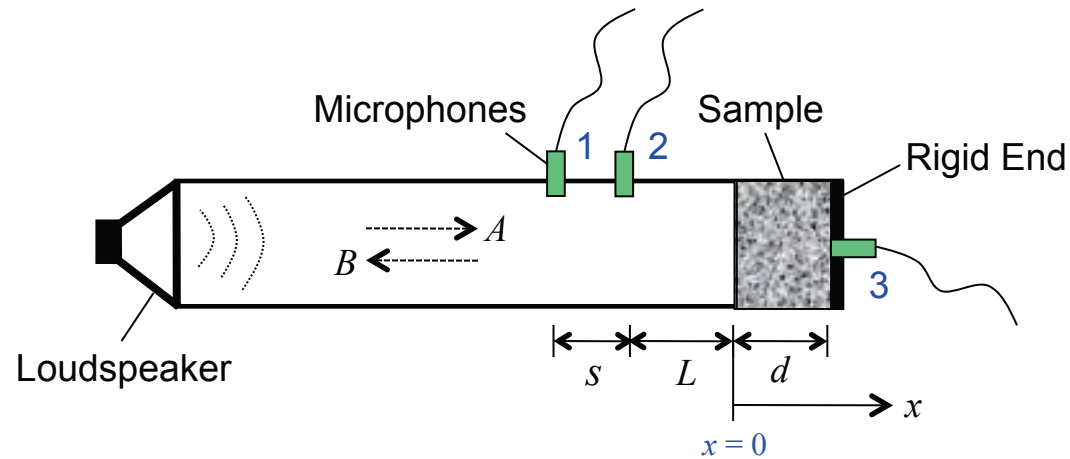
Two Cavity Method

Measurement of Bulk Properties



Three Microphone Method

Measurement of Bulk Properties

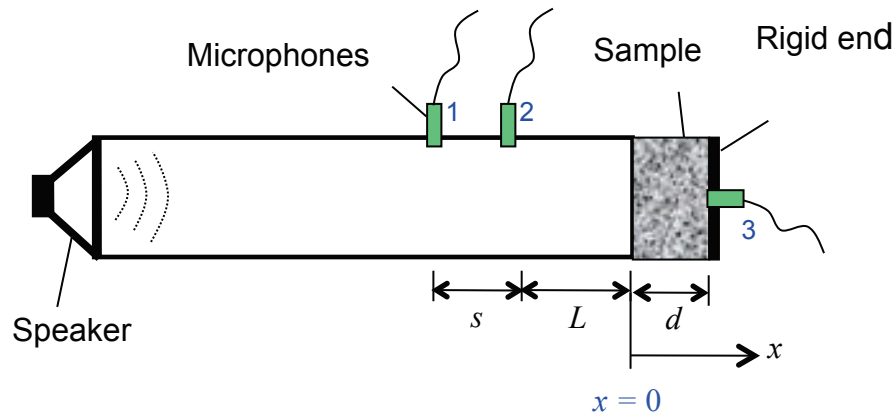


Three Microphone Method

Measurement of Bulk Properties

Reflection coefficient:

$$R = \frac{e^{jks} - H_{12}}{H_{12} - e^{-jks}} e^{2jkL}$$



Three Microphone Method

Measurement of Bulk Properties

The complex wave number of the sample is:

$$k_c = \frac{1}{d} \cos^{-1} \frac{1+R}{e^{jkl} + Re^{-jkl}} H_{23}$$

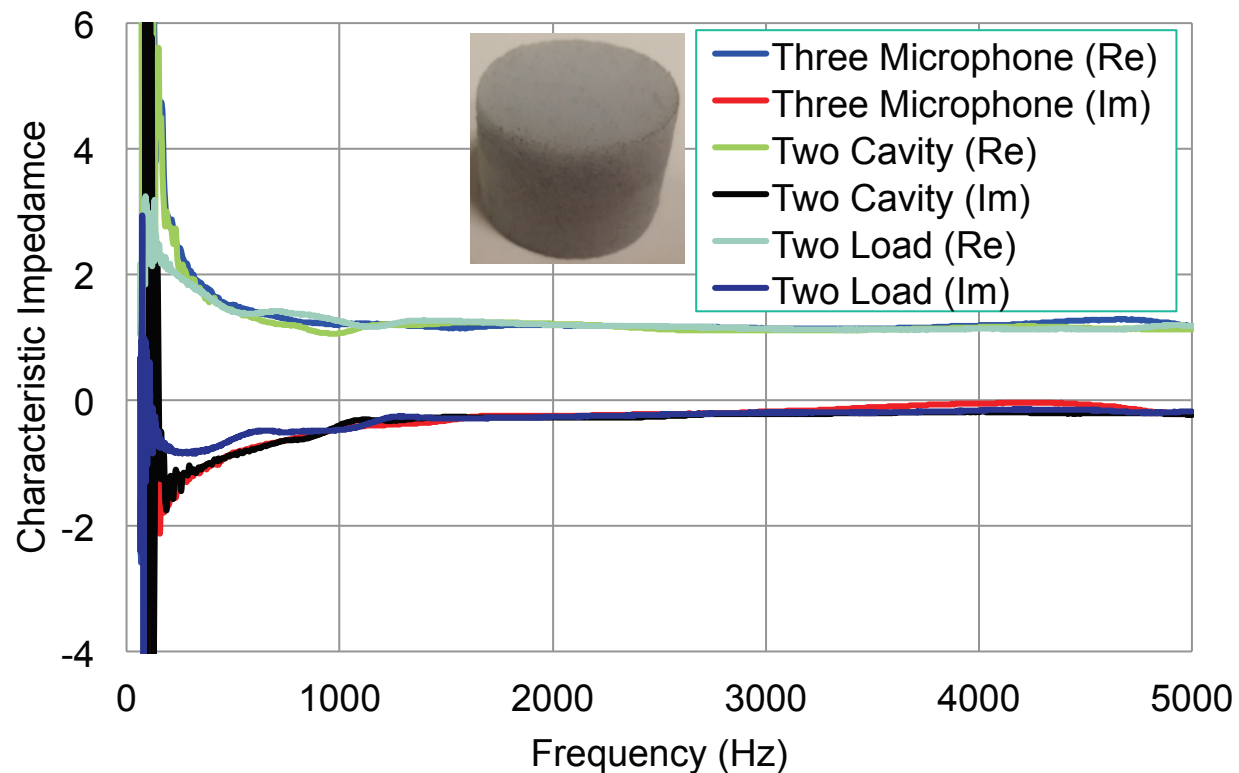
The characteristic impedance of the sample is:

$$z_c = jz_0 \frac{1+R}{1-R} \tan(k_c d)$$

Melamine Characteristic Impedance

Measurement of Bulk Properties

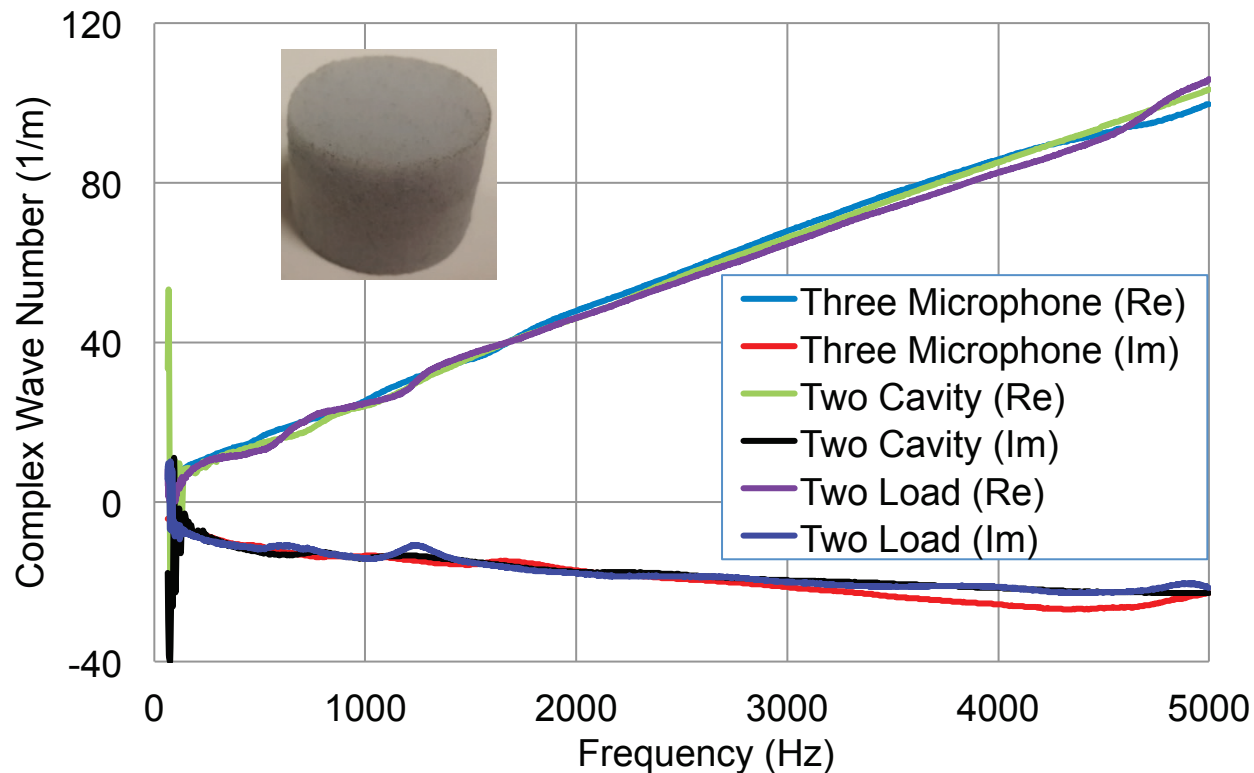
1 inch Melamine Foam



Melamine Complex Wave Number

Measurement of Bulk Properties

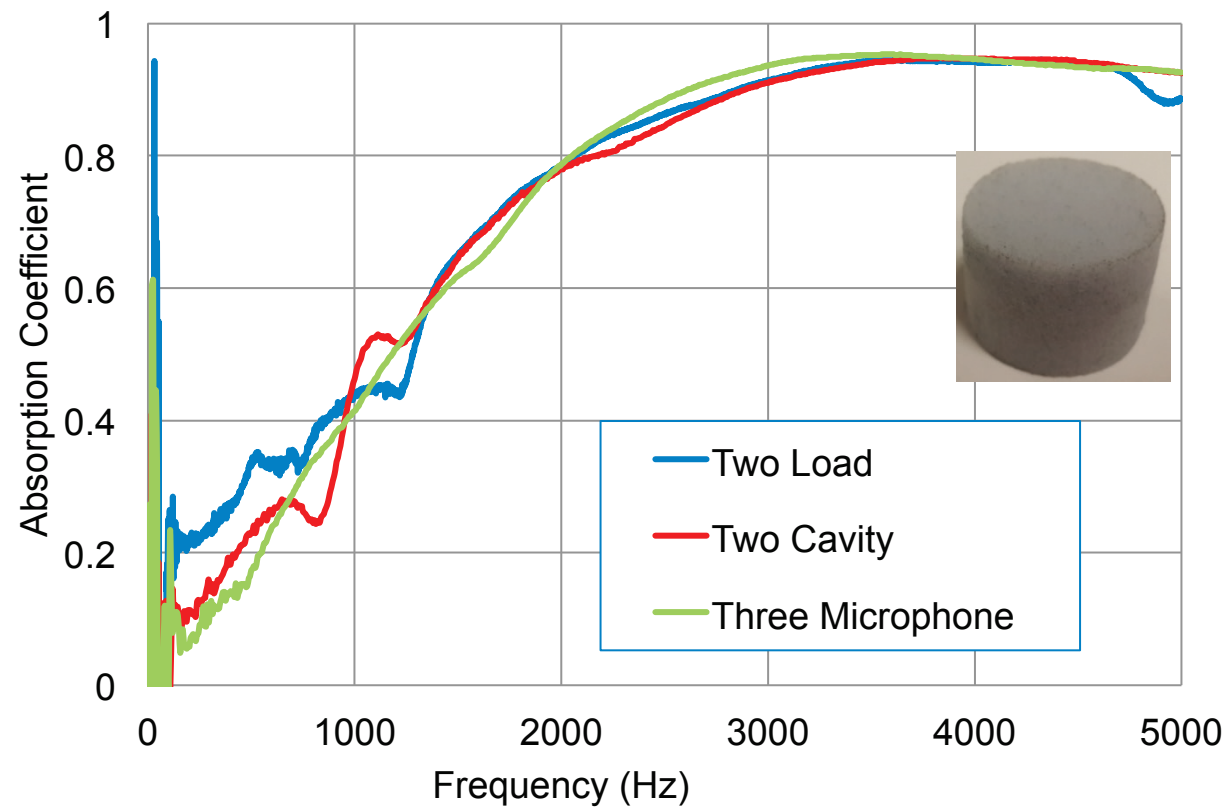
1 inch Melamine Foam



Melamine Sound Absorption Coefficient

Measurement of Bulk Properties

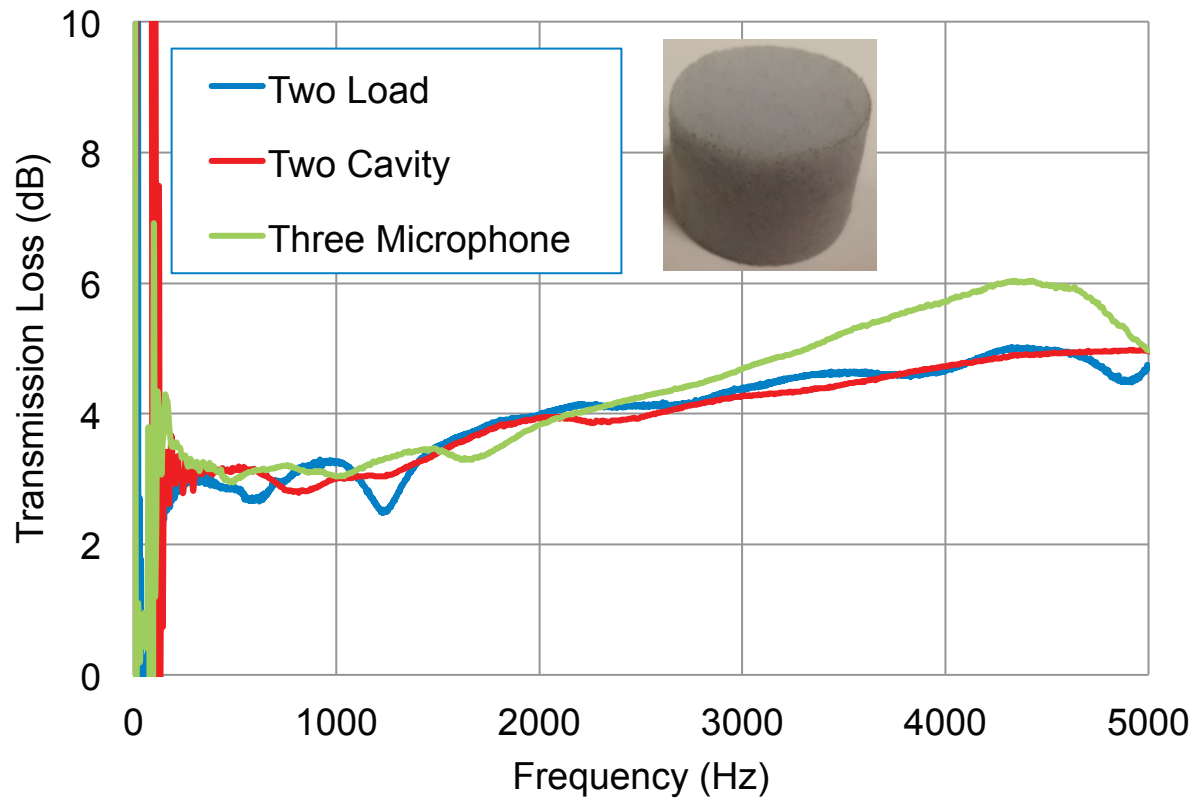
1 inch Melamine Foam



Melamine Transmission Loss

Measurement of Bulk Properties

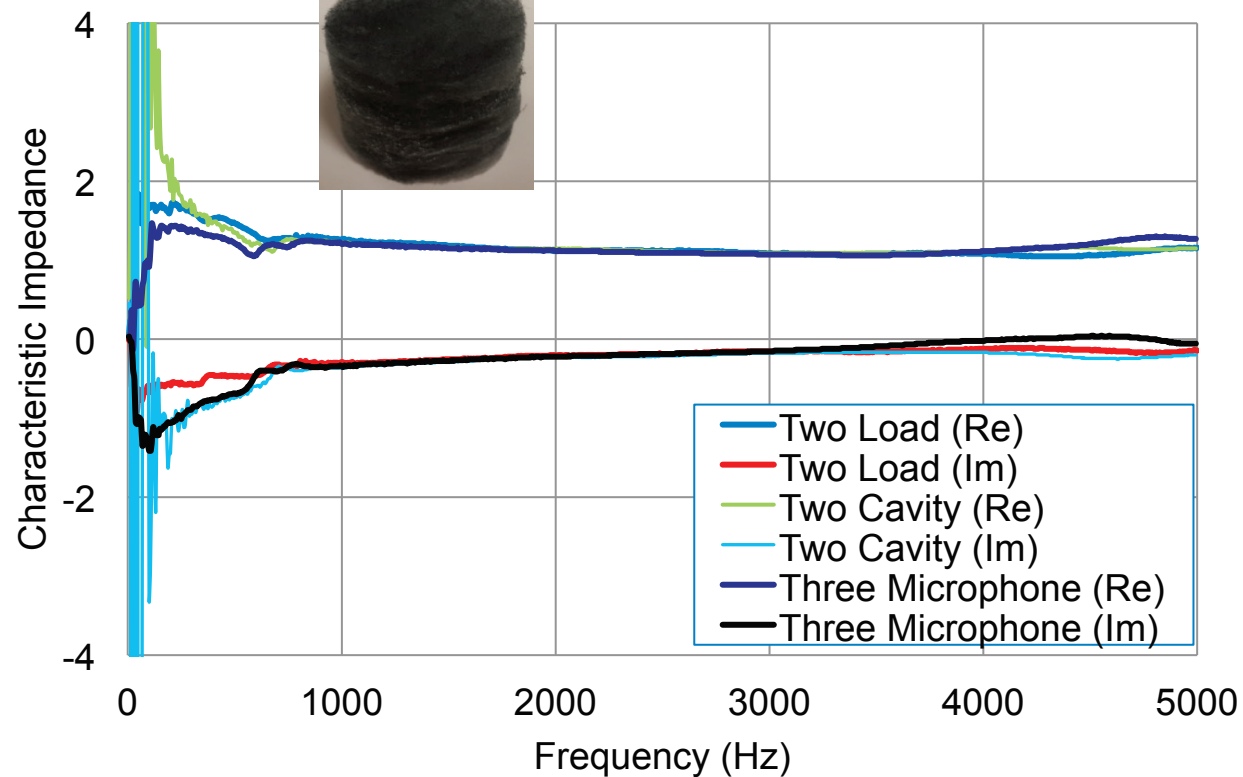
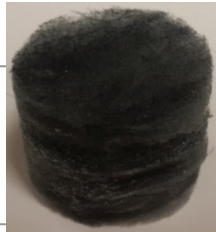
1 inch Melamine Foam



Fiber Characteristic Impedance

Measurement of Bulk Properties

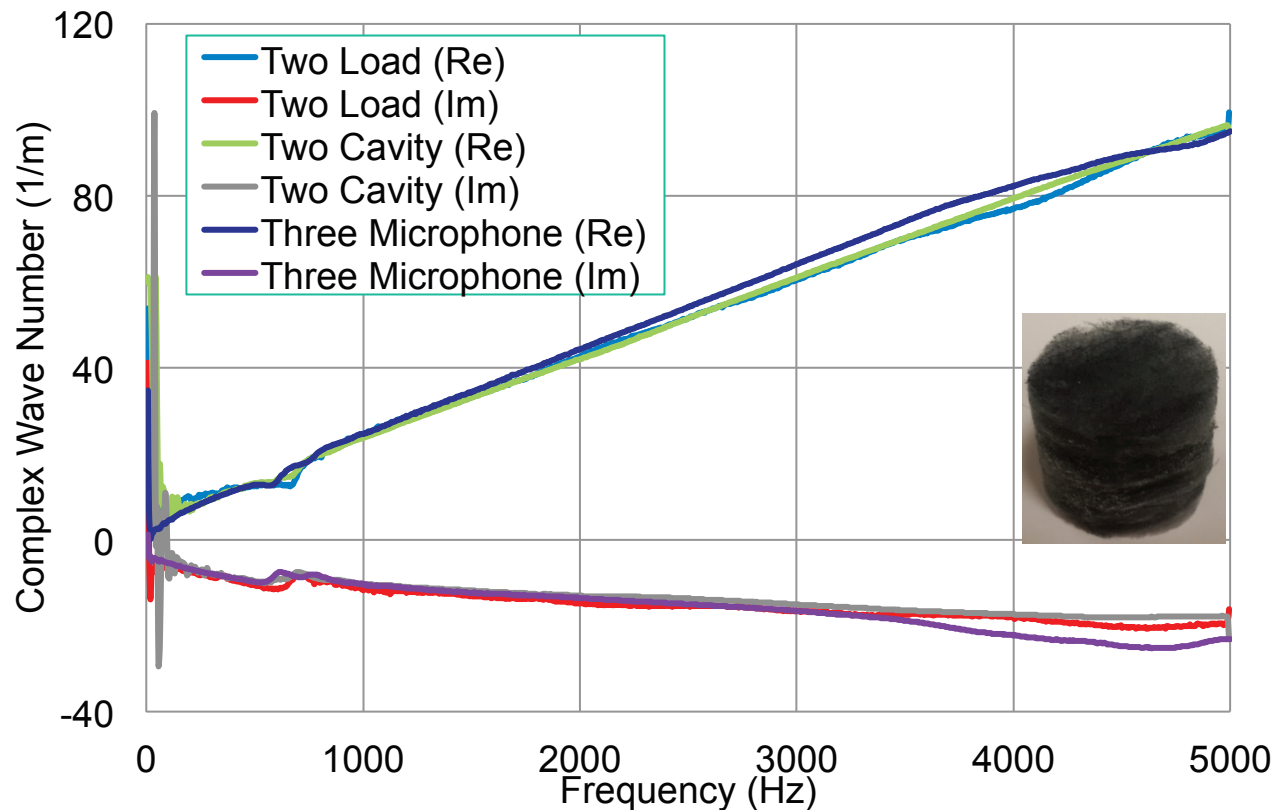
1 inch Glass Fiber



Fiber Complex Wave Number

Measurement of Bulk Properties

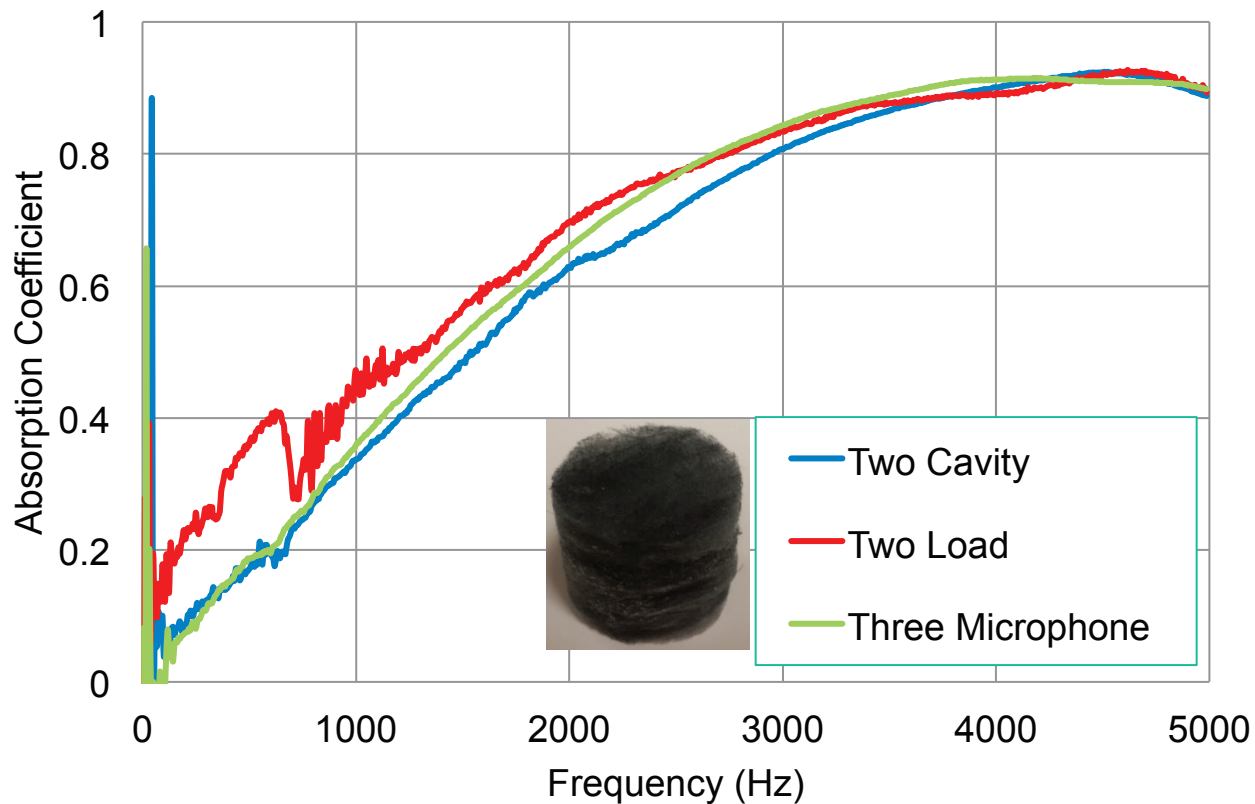
1 inch Glass Fiber



Fiber Sound Absorption Coefficient

Measurement of Bulk Properties

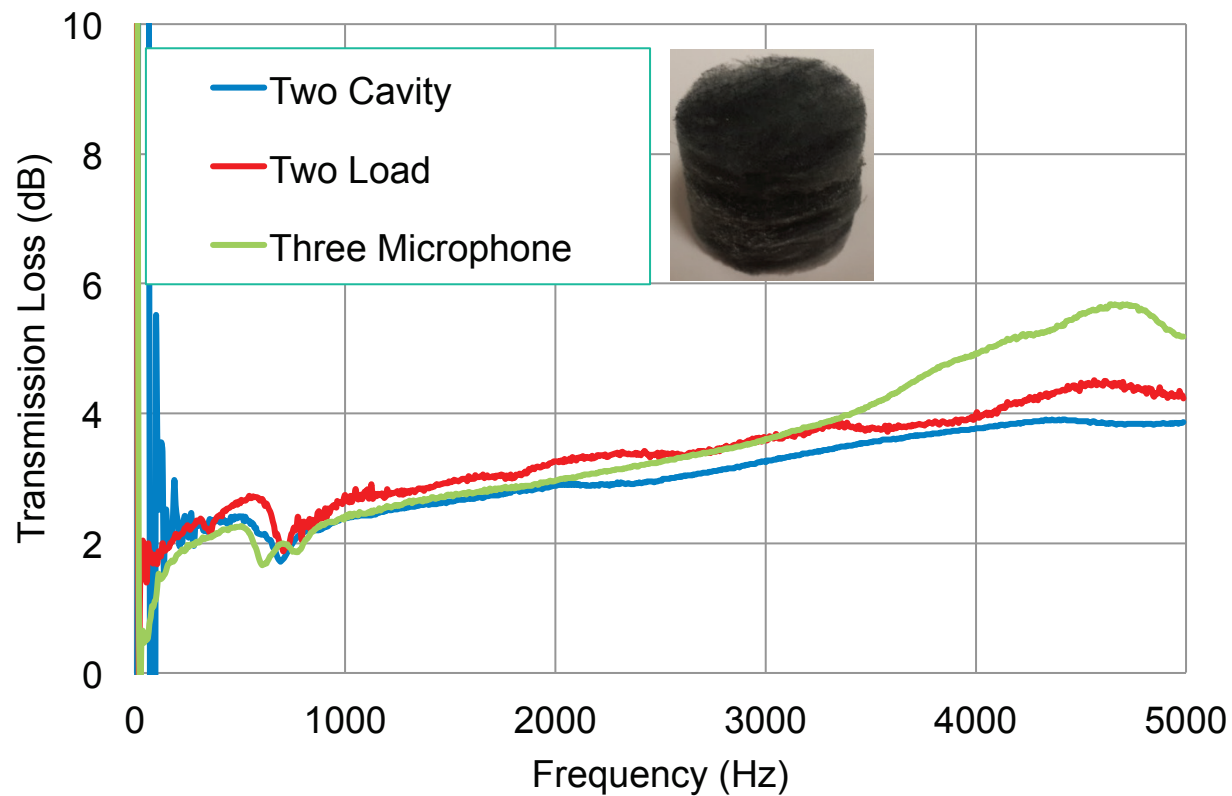
1 inch Glass Fiber



Fiber Transmission Loss

Measurement of Bulk Properties

1 inch Glass Fiber



Comparison

Measurement of Bulk Properties

	Two Load	Two Cavity	Three Microphone
No. of Loads	2	2	1
No. of Calibrations	3	1	2
Smoothness of Curve	Good	Good	Excellent

Overview of Approaches

Measurement of Bulk Properties

Direct
Measurement

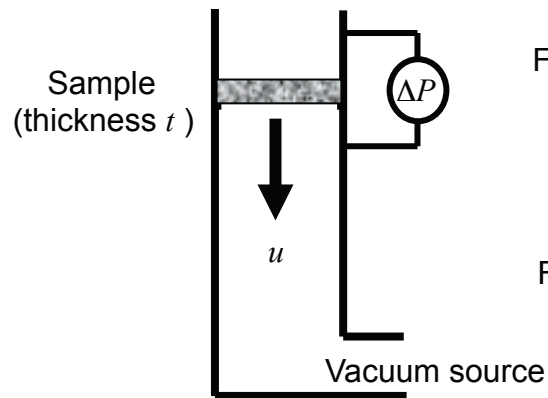
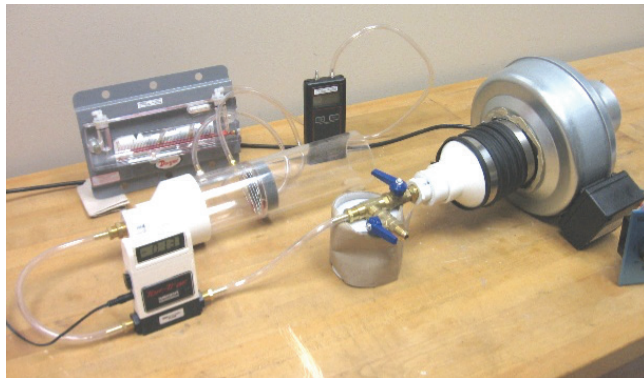
- Two load method [ASTM E 1050](#)
- Two cavity method [Utsuno, 1989](#)
- Three microphone method [Iwase et.al., 1998](#)

Measure Flow
Resistance

Find bulk properties from
measured flow resistivity
[Wu, 1988](#); [Mechel et al., 2002](#)

Measure Flow Resistance

Measurement of Bulk Properties



Flow resistance:

$$r_s = \frac{\Delta P}{u}$$

Flow resistivity:

$$\sigma = \frac{r_s}{t}$$

Measure
Flow Resistivity Using
ASTM C522



Plug into Empirical Models
Wu (1988) or Mechel et al. (2002)

Summary

Measurement of Bulk Properties

- Compared the various methods for determining the bulk properties of sound absorbers.
- Curve fitting approaches are adequate for common sound absorbing materials.