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An Improved Model for Microperforated Absorbers

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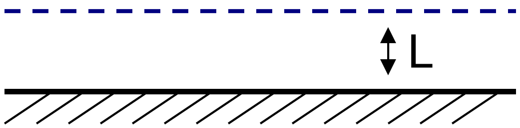
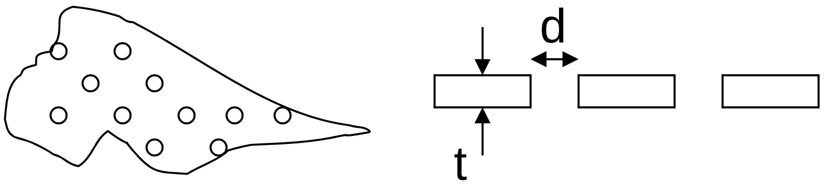
Introduction / Objective

- Microperforated panels work well as sound absorbing materials when backed with finite-depth air space

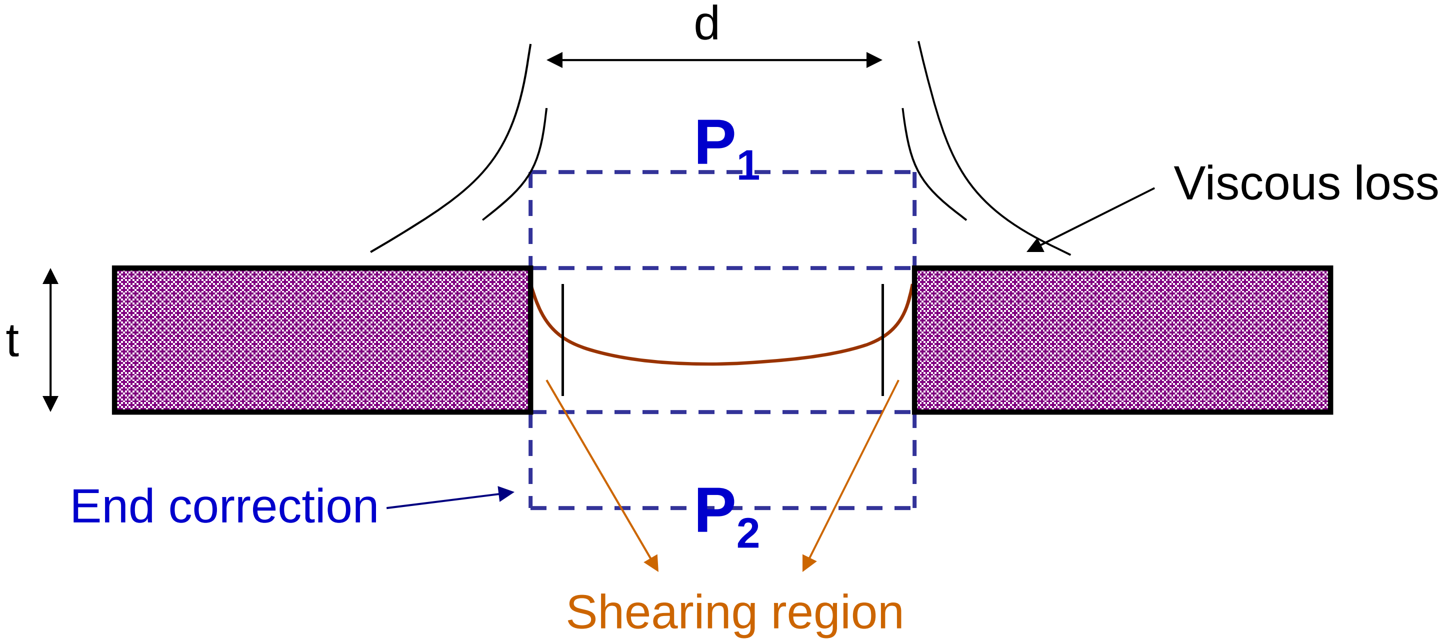


- Controlling parameters: hole diameter, hole depth, number of holes per unit area



- D. Y. Maa models
  - Referred to by many other authors
  - Used as basis for design of microperforated absorbers
  - Various versions (1975, 1987, 1998)
- Objective
  - Perform measurements with precisely manufactured brass samples
  - Find the version of the Maa model that most closely represents the measurements
  - Broaden the range of applicability of the Maa model by modifying the resistive end correction

Maa Model



- Accounts for viscous losses in hole and on flat surface close to hole
- End correction calculated in basis of uniform velocity profile in hole

Maa model (1975)

$$z = \frac{Z_1}{\sigma\rho_0 c} = r + j\omega m$$

Z_1: specific acoustic impedance of single hole
σ: porosity
r: resistance *m*:
effective mass per unit area

- Perforation constant $x = 210 d\sqrt{f}$ Relate to boundary layer

d: hole diameter
f: frequency
t: hole depth
c: speed of sound
μ: kinematic viscosity
v: thermal conductivity
L: backing depth

- Resistance $r = \frac{32(\mu+\nu)}{\sigma c}\frac{t}{d^2}\left(\boxed{\sqrt{1+\frac{x^2}{32}}}+\boxed{\frac{\sqrt{2}}{8}x\frac{d}{t}}\right)$

Contribution from hole

End corrections (effect from flow over outer surface and convergence into and out of holes)

- Reactance $m = \frac{t}{\sigma c}\left(\boxed{1+\frac{1}{\sqrt{9+\frac{x^2}{2}}}}+\boxed{0.85\frac{d}{t}}\right)$
- Absorption Coefficient $\alpha_n = \frac{4r}{(1+r)^2+\left(\omega m-\cot\left(\frac{\omega L}{c}\right)\right)^2}$

Panel is assumed RIGID in Maa models: no flexural motion is considered

Maa models

Substantial change in Resistance

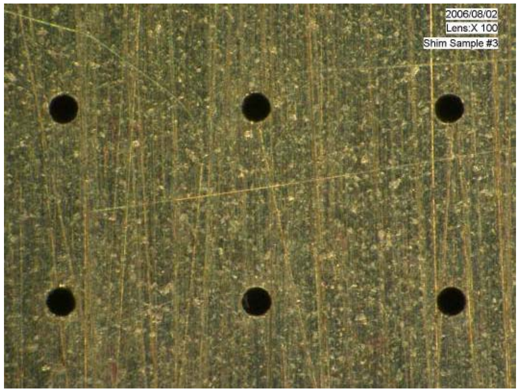
Not much change in Reactance

Models	Perforation constant	Resistance	Reactance
1975 High thermal conductivity model- Scientia Sinica	$x = 210d\sqrt{f}$	$r = \frac{32(\mu+\nu)}{\sigma c}\frac{t}{d^2}\left(\boxed{\sqrt{1+\frac{x^2}{32}}}+\boxed{\frac{\sqrt{2}}{8}x\frac{d}{t}}\right)$	$m = \frac{t}{\sigma c}\left(\boxed{1+\frac{1}{\sqrt{9+\frac{x^2}{2}}}}+\boxed{0.85\frac{d}{t}}\right)$
1975 Low thermal conductivity model- Scientia Sinica	$x = 316d\sqrt{f}$	$r = \frac{32\mu}{\sigma c}\frac{t}{d^2}\left(\boxed{\sqrt{1+\frac{x^2}{32}}}+\boxed{\frac{\sqrt{2}}{8}x\frac{d}{t}}\right)$	$m = \frac{t}{\sigma c}\left(\boxed{1+\frac{1}{\sqrt{9+\frac{x^2}{2}}}}+\boxed{0.85\frac{d}{t}}\right)$
1987 Noise Control Engineering Journal	$x = d\sqrt{\frac{\omega\rho_0}{4\eta}}$	$r = \frac{32\eta}{\sigma\rho_0 c}\frac{t}{d^2}\left(\boxed{\sqrt{1+\frac{x^2}{32}}}+\boxed{\sqrt{\frac{2xd}{8t}}}\right)$	$m = \frac{t}{\sigma c}\left(\boxed{1+\frac{1}{\sqrt{9+\frac{x^2}{2}}}}+\boxed{0.85\frac{d}{t}}\right)$
1998 Journal of Acoustical Society of America	$x = d\sqrt{\frac{\omega\rho_0}{4\eta}}$	$r = \frac{32\eta}{\sigma\rho_0 c}\frac{t}{d^2}\left(\boxed{\sqrt{1+\frac{x^2}{32}}}+\boxed{\frac{\sqrt{2}}{32}x\frac{d}{t}}\right)$	$m = \frac{t}{\sigma c}\left(\boxed{1+\frac{1}{\sqrt{1+\frac{x^2}{2}}}}+\boxed{0.85\frac{d}{t}}\right)$

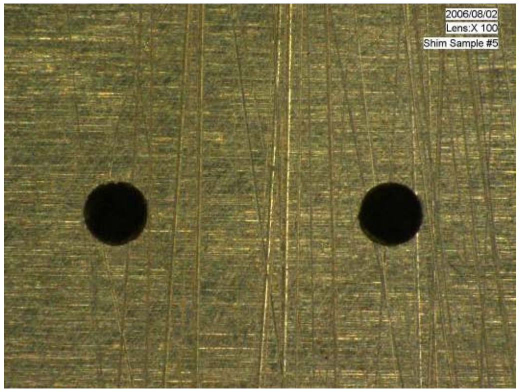
d: hole diameter, f: frequency, t: hole depth, c: speed of sound, μ: kinematic viscosity, ν: thermal conductivity, η: viscosity coefficient ($=\mu\rho_0$)

Brass samples

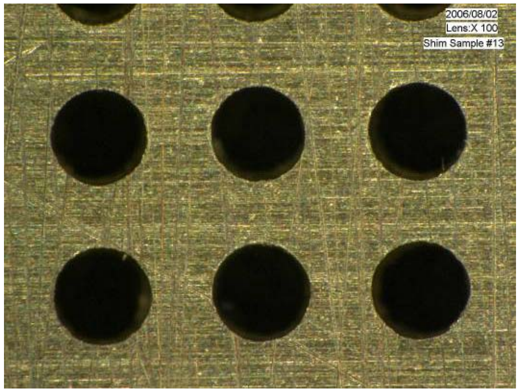
Sample number	Hole diameter *d* [mm]	Hole depth *t* [mm]	Number of holes per m^2	*t/d*	Mass/area [kg/m^2]	Porosity [%]
1	0.197	0.813	3.06 x 10^5	4.1	6.5	0.9
2	0.185	1.27	6.20 x 10^5	6.8	9.8	1.7
3	0.41	0.406	3.03 x 10^5	1	3.2	4
4	0.413	0.813	6.07 x 10^5	2	5.9	8.1
5	0.41	0.432	9.47 x 10^5	1.1	2.9	12.5
6	0.419	1.27	9.11 x 10^5	3	8.9	12.6
7	0.622	0.813	3.11 x 10^5	1.3	5.9	9.5
8	0.645	0.432	6.11 x 10^5	0.7	2.6	20
9	0.625	1.27	6.26 x 10^5	2	8.1	19.2
10	0.625	0.813	9.22 x 10^5	1.3	4.7	28.3



Sample 2 (x100)

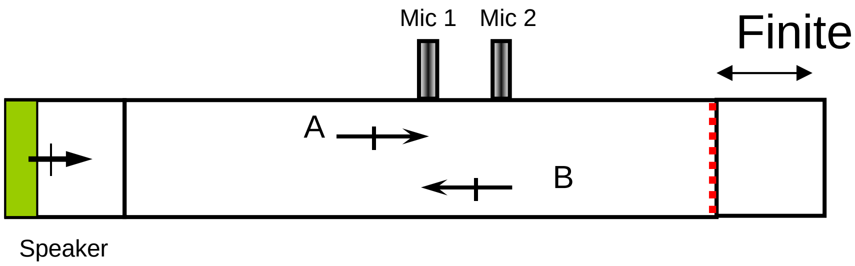


Sample 3 (x100)



Sample 10 (x100)

Measurement of normal incidence absorption coefficient



Finite depth air space

Normal Incidence
Absorption coefficient

1. Sound pressures

$$P_1 = \left(Ae^{-jkx_1} + Be^{jkx_1}\right)e^{j\omega t}$$

$$P_2 = \left(Ae^{-jkx_2} + Be^{jkx_2}\right)e^{j\omega t}$$

2. Measuring transfer function

$$H_{21} = \frac{Ae^{-jkx_2} + Be^{jkx_2}}{Ae^{-jkx_1} + Be^{jkx_1}}$$

$$H_{21} = \frac{e^{-jkx_2} + \mathrm{R}e^{jkx_2}}{e^{-jkx_1} + \mathrm{R}e^{jkx_1}}$$

3. Solve for R

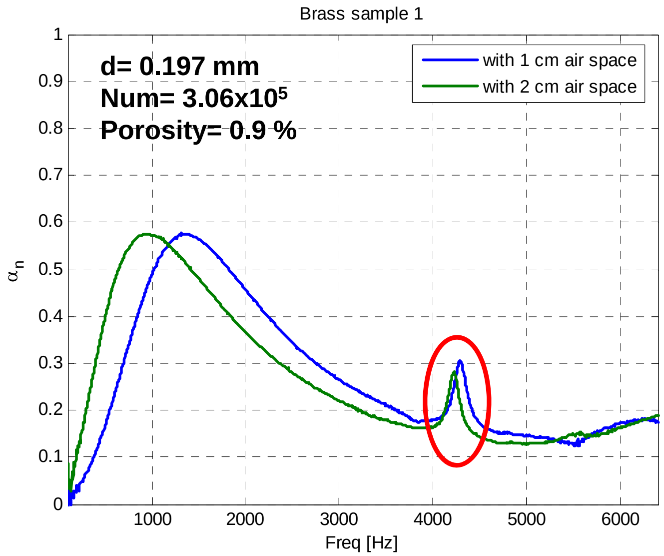
$$R = \frac{-H_{21}e^{-jkx_1} + e^{-jkx_2}}{H_{21}e^{jkx_1} - \mathrm{R}e^{jkx_2}}$$

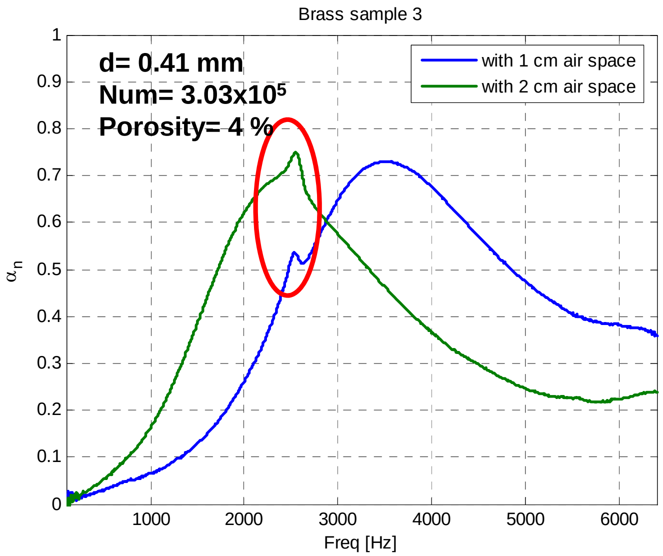
4. Absorption coefficient

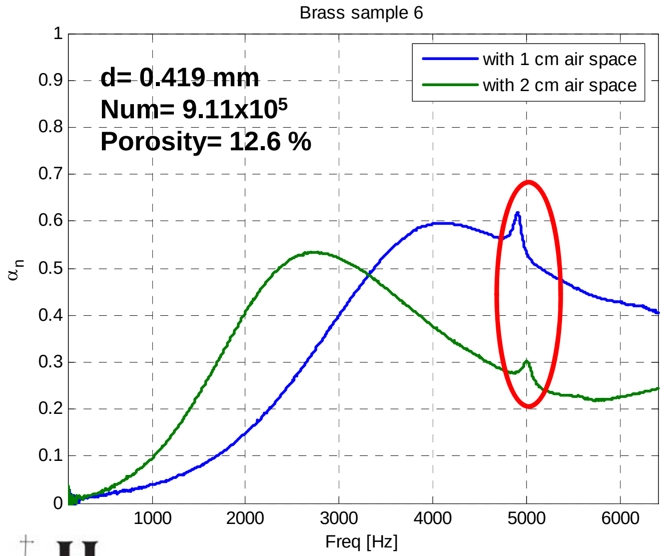
$$\alpha = 1 - |R|^2$$

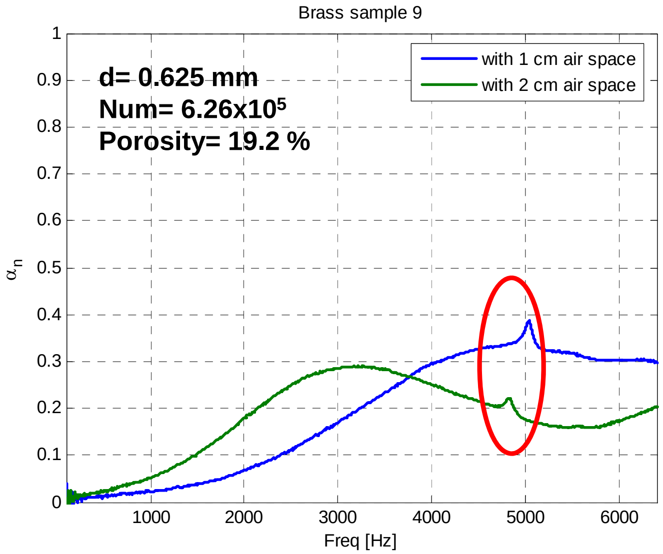
- Two backing depths: 1 cm and 2 cm
- B&K small impedance tube (d=2.9 cm) was used with Pulse 10
- Rubber O-ring was used to avoid the leakage from the contact between sample and tube surface

Absorption coefficients measured results









- As the backing space increases, the peak shifts to lower frequency
- Flexural resonance features due to finite size of the sample are shown
- High absorption at low frequency can be achieved with smaller hole size
- When the porosity is large, the absorption performance is significantly reduced

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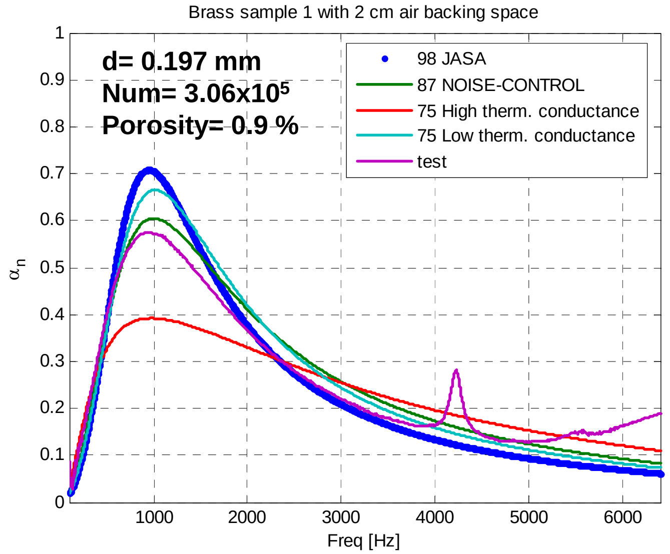
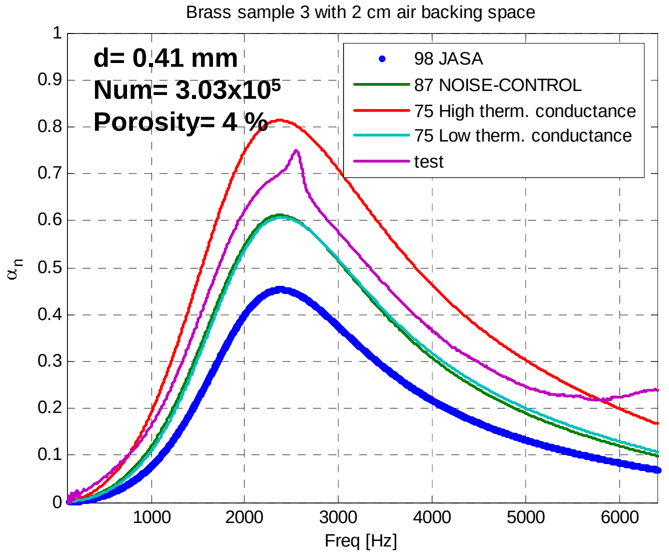
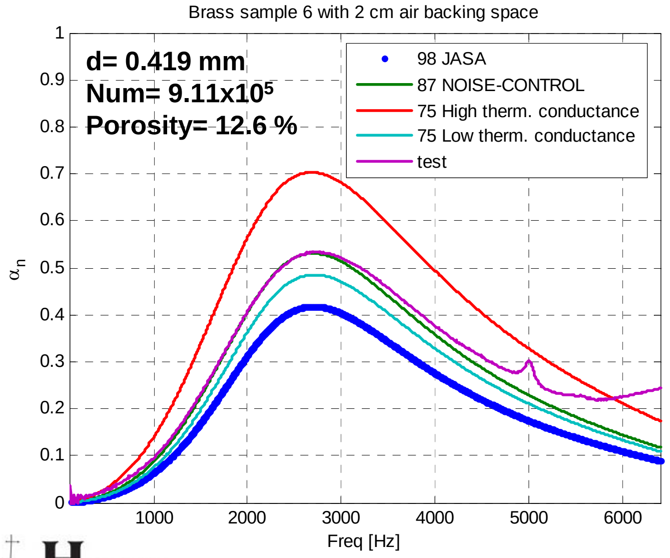
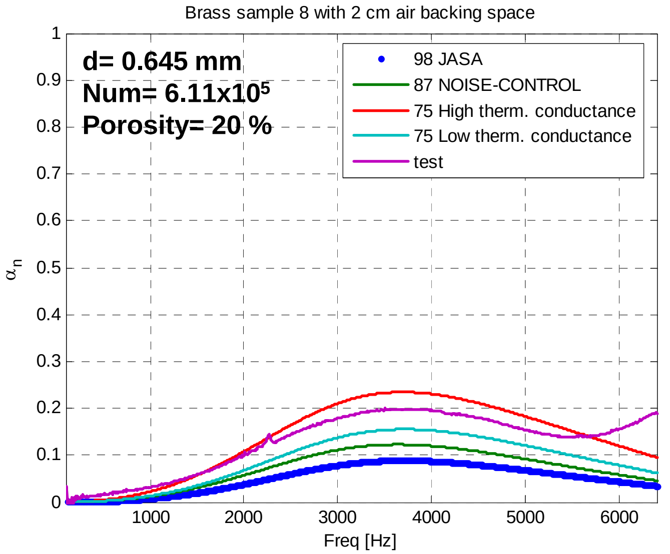
Measurements and predictions from various Maa models


Brass sample 1 with 2 cm air backing space

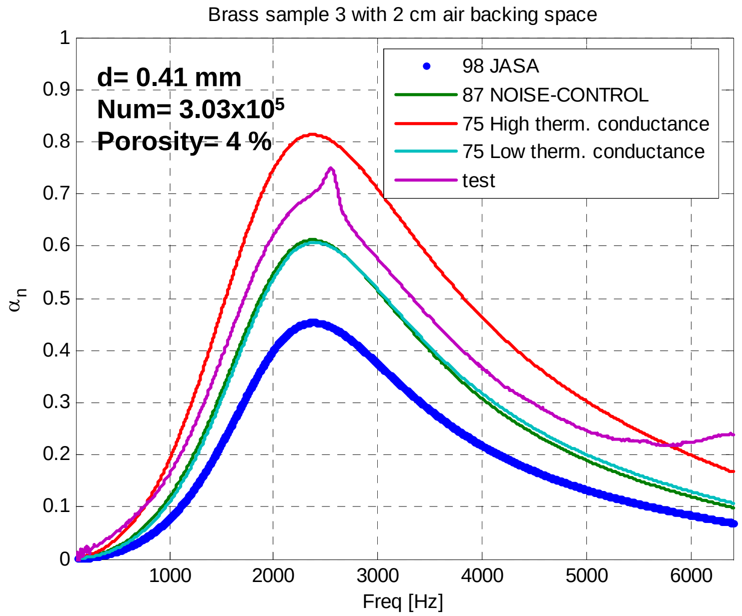

Brass sample 3 with 2 cm air backing space


Brass sample 6 with 2 cm air backing space


Brass sample 8 with 2 cm air backing space

- There are significant differences on absorption predictions depending on model used
- Which one gives the most accurate prediction?
- Error calculation

Model performance



- Observations
  - Absorption peak locations accurately predicted in all cases- reactive part of model impedance is assumed to be accurate
  - Absorption peaks heights are not predicted accurately consistently by any of the models- resistive end correction is assumed to be inaccurate

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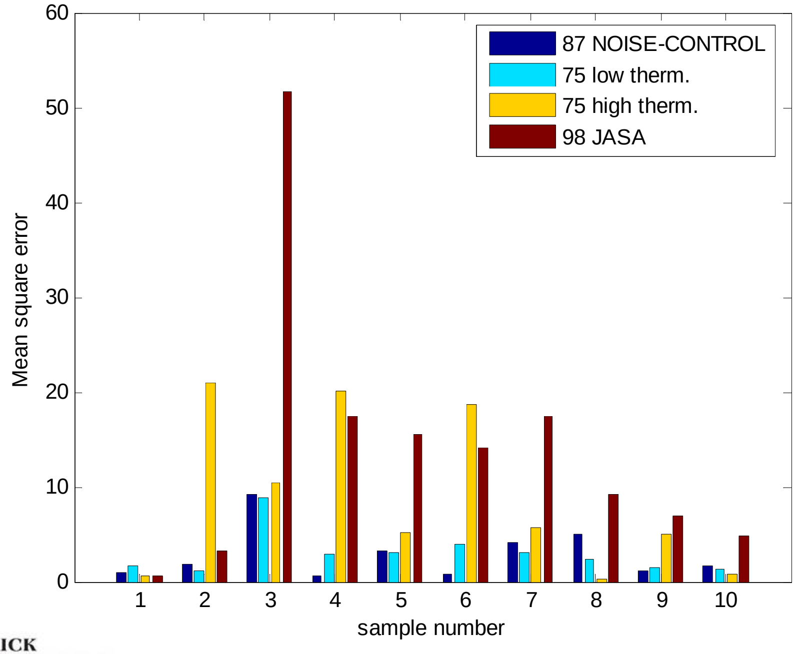
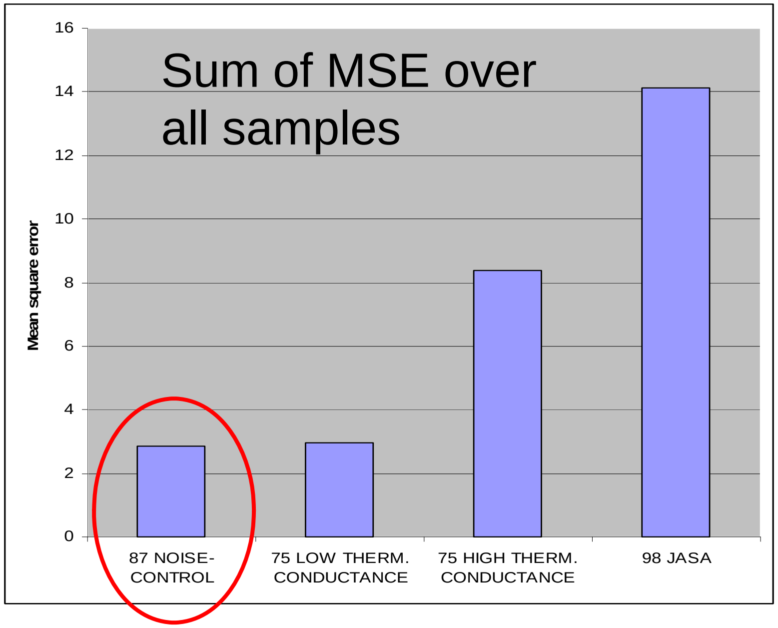
Error calculation

- Mean square error was calculated by

$$MSE = \frac{1}{n}\sum_{freq=f_1}^{f_n}\left(\alpha_{prediction}-\alpha_{test}\right)^2$$

  - Data at flexural resonance peaks were not considered
  - Data at the frequencies from 100 Hz to 5000 Hz were used
    - Leakage is suspected above 5500 Hz




Sum of MSE over all samples

Optimization of Maa model (1)

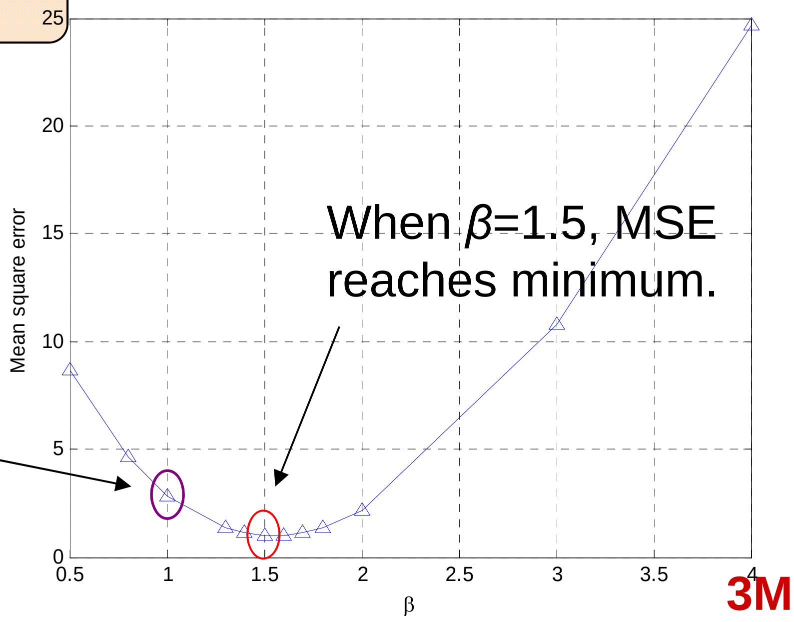
- Using the most accurate, 87 N.C.E.J. model
- Modify the resistive end correction by introducing constant factor β

$$r = \frac{32\eta}{\sigma\rho_0 c}\frac{t}{d^2}\left(\boxed{\sqrt{1+\frac{x^2}{32}}}+\boxed{\beta\sqrt{\frac{2xd}{8t}}}\right)$$

Effect from hole

End correction (effect from surface)

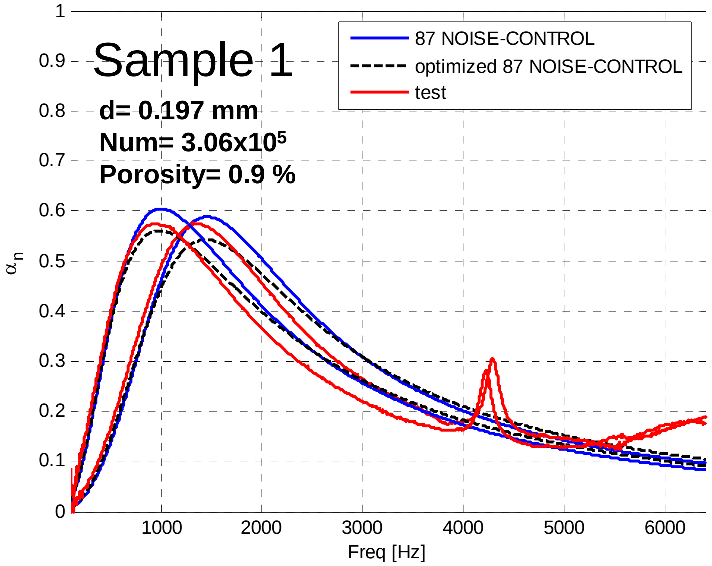
•Sum of mean square error was calculated with varying β

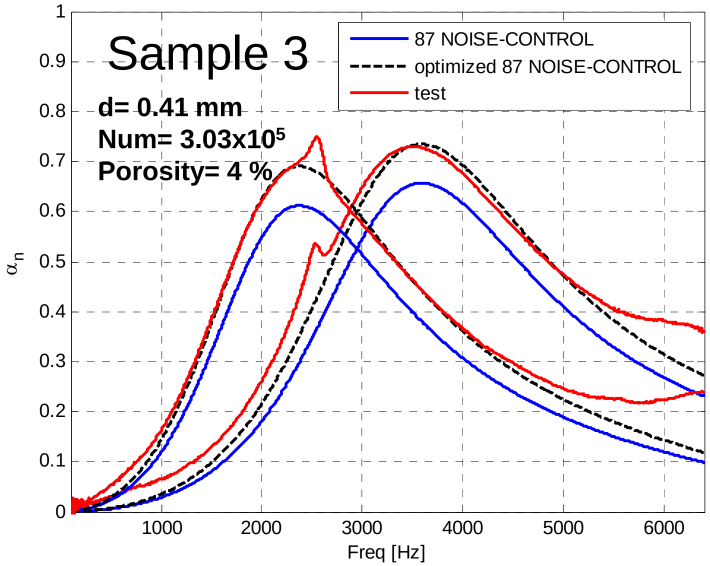


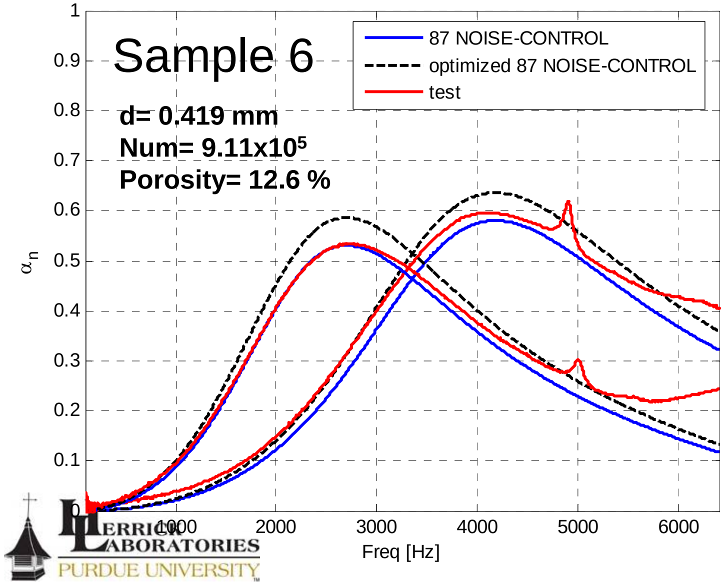
When β=1.5, MSE reaches minimum.

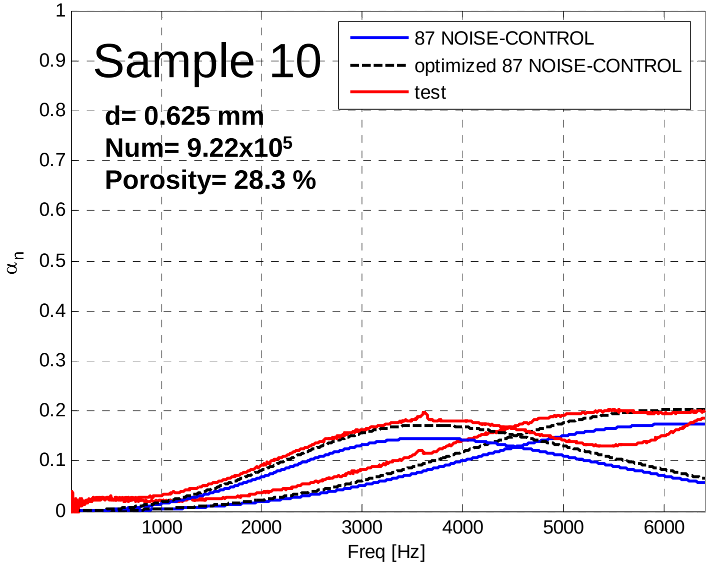
87 NOISE CONTRL model

Improved model results









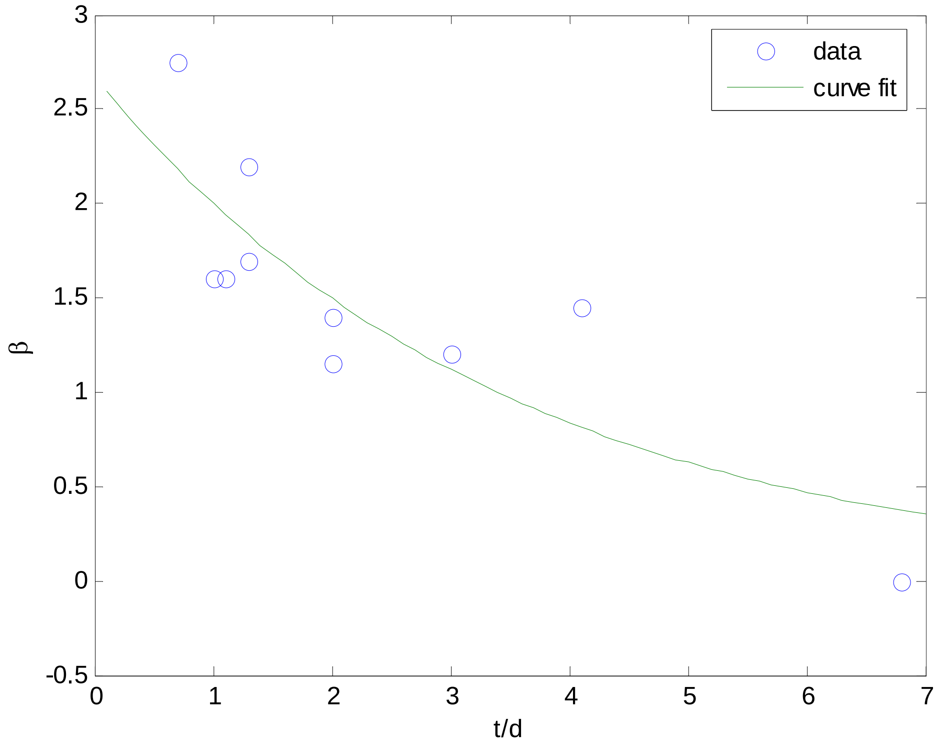
- Modified model can predict the absorption performance more accurately for large porosity cases
- It covers wide range of porosity
- Discrepancy remains for in some cases

Optimization of Maa model (2)

- Assume that resistive end correction is a function of hole aspect ratio (t/d)
- Determine optimal β for each sample
- Plot as function of hole aspect ratio (t/d)

Optimization of Maa model (2)

- Resistive end correction factor versus hole aspect ratio (t/d)



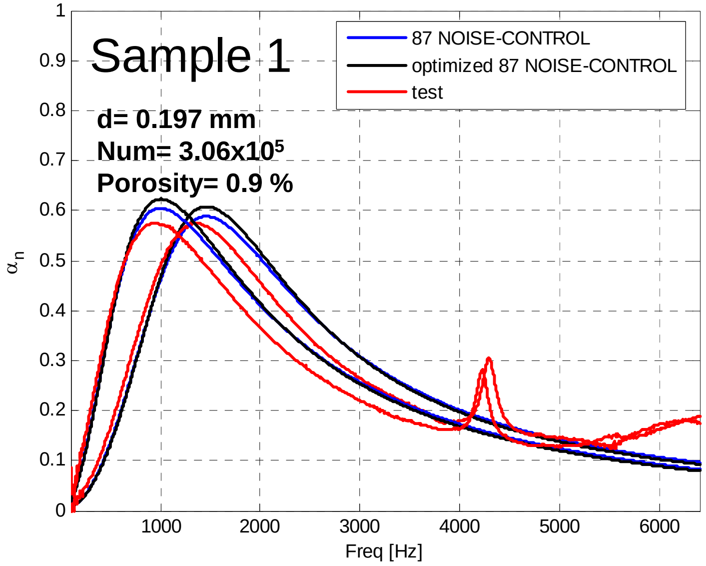
Using least square method with exponential curve fit

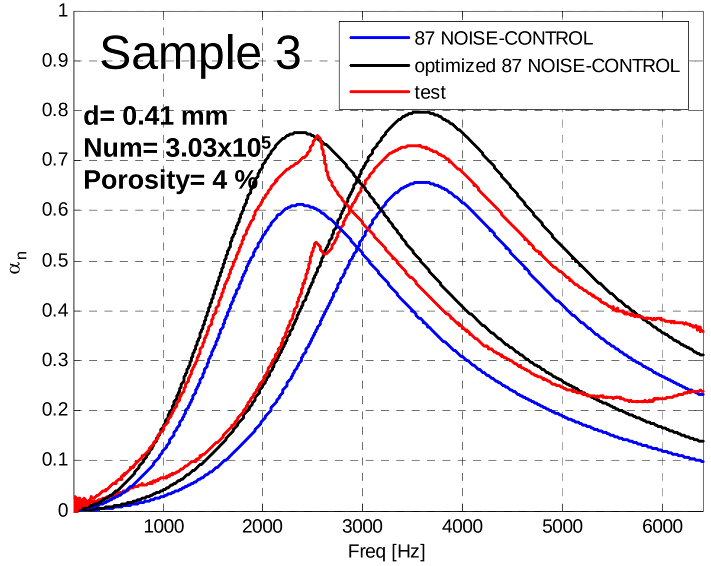
$$\beta = 2.672 \times e^{-0.2897(t/d)}$$

Substitute β to resistive calculation

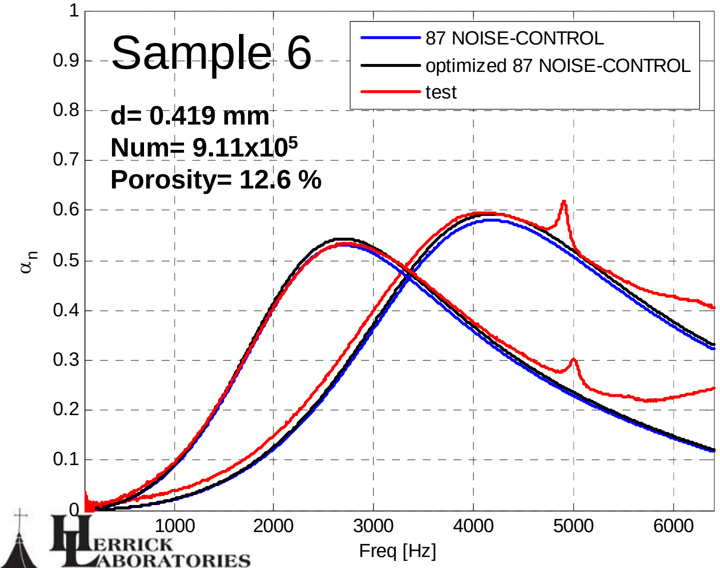
$$r = \frac{32\eta}{\sigma\rho_0 c}\frac{t}{d^2}\left(\sqrt{1+\frac{x^2}{32}} + \beta\sqrt{\frac{2xd}{8t}}\right)$$

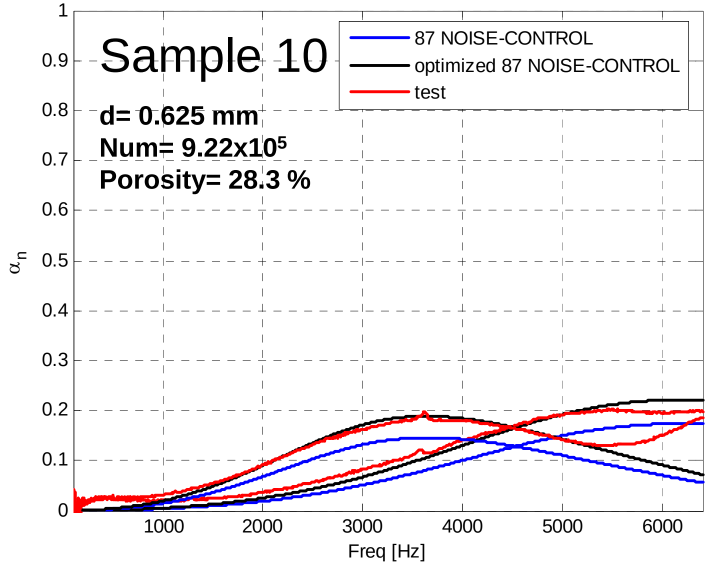
Optimization of Maa model (2)





$$\beta = 2.672 \times e^{-0.2897(t/d)}$$





Conclusions

- Microperforated panel works well an absorber
  - Depending on hole geometries, the absorption capability changes
  - Deeper air space gives better absorption at low frequencies
  - Flexural resonances affect absorption performance in narrow frequency ranges
- Among Maa models, 1987 NCEJ model predicts the absorption performance most accurately
- By modifying the resistive end correction in the 1987 model, the accuracy of the predictions was improved over a very wide range of surface porosity
- Measurements will be repeated with non-metallic material to establish effect of thermal conduction