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Random incidence transmission loss of a metamaterial barrier system

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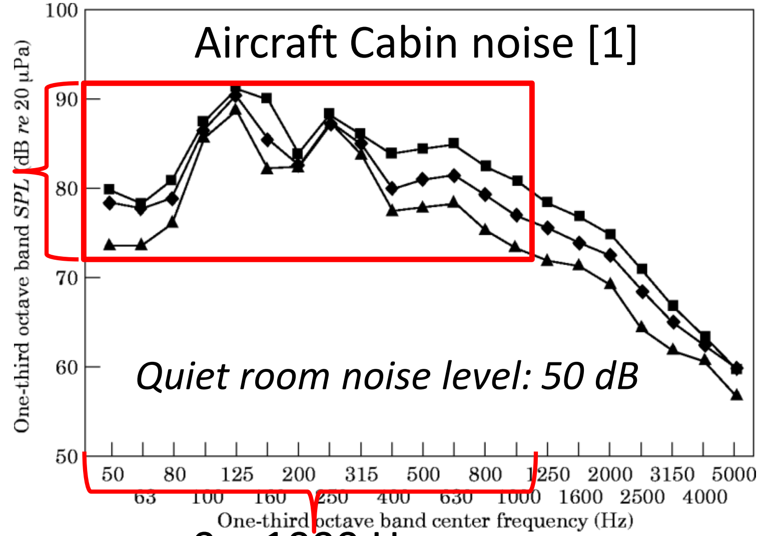
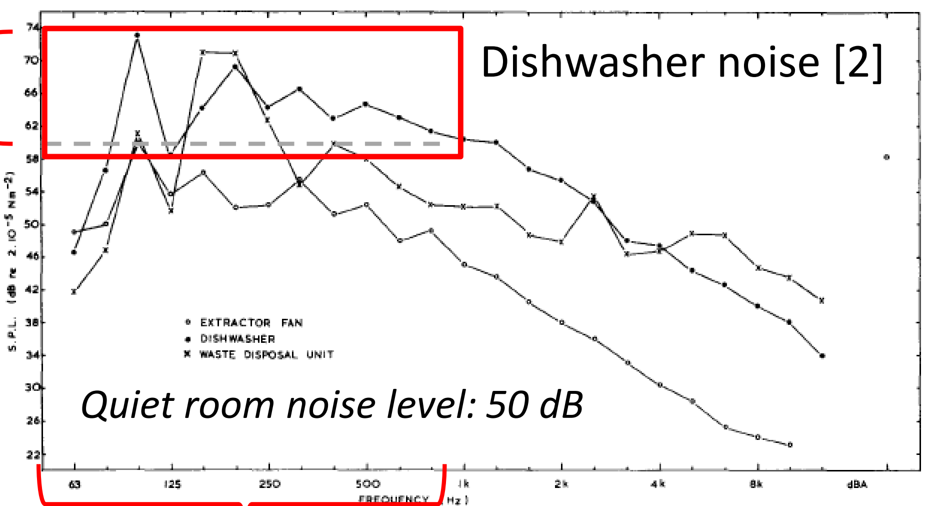
Low Frequency Noise





Sources: [1] Wilby JSV 1996, [2] Jackson and Levinthall, Applied Acoustics, 1975

Barrier Design - Challenges

- ❑ Conventional materials
  - ❑ Perform poorly at low frequencies
  - ❑ Require high mass per unit area for effective noise reduction

A conventional panel having 5 kg/m²

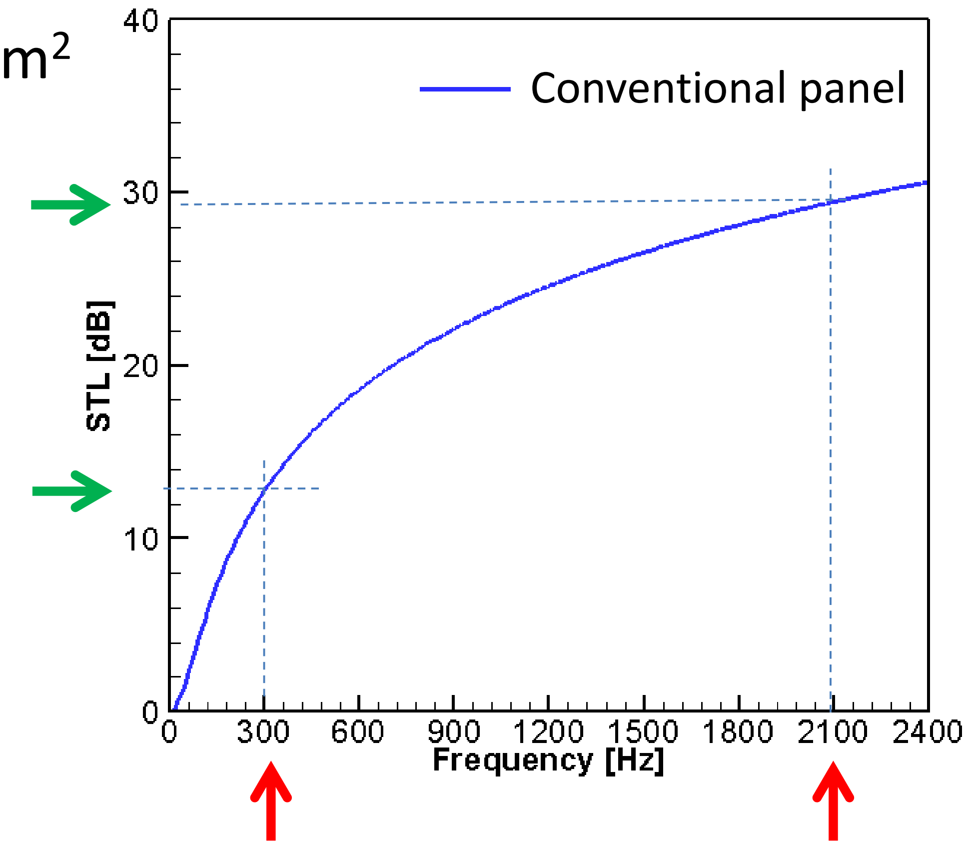
2100 Hz → 30 dB↓ in noise

300 Hz → 12 dB↓ in noise

30 dB ↓ @ 300 Hz, Requires

5×8 =40 kg/m²

STL: Sound Transmission Loss



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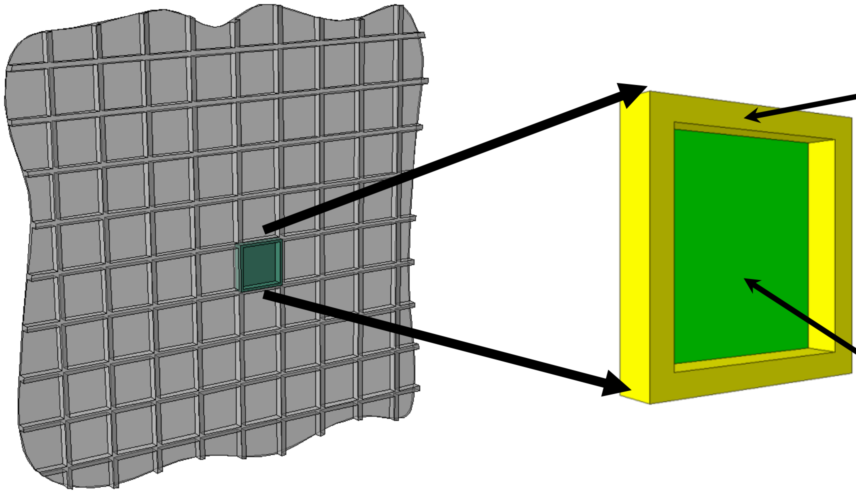
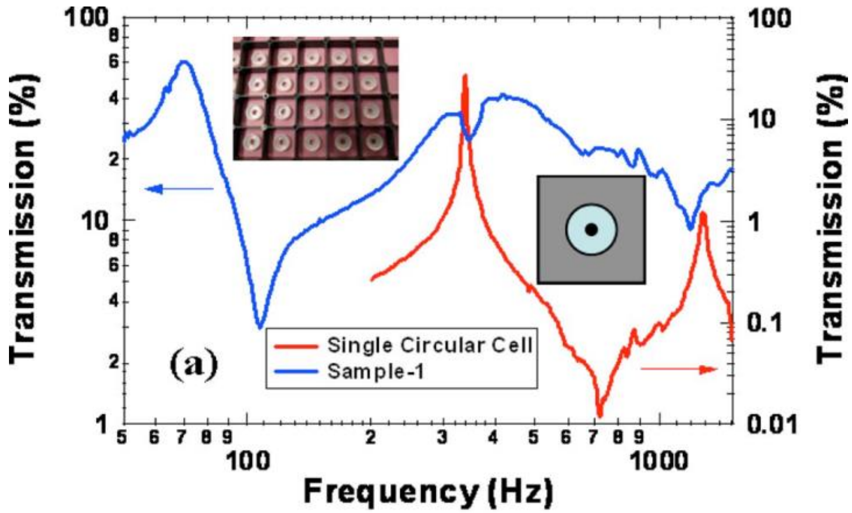
Cellular Meta-Material



- Cellular material[3] with a periodic array of unit cells
- *Unit cell* has components *with contrasting mass and moduli*
- Characteristics of the cellular panel are same as that of a unit cell with periodic BCs for normally incident sound

Source: [3] S. Varanasi et al., Applied Acoustics, 2013

Literature – Sound Barriers

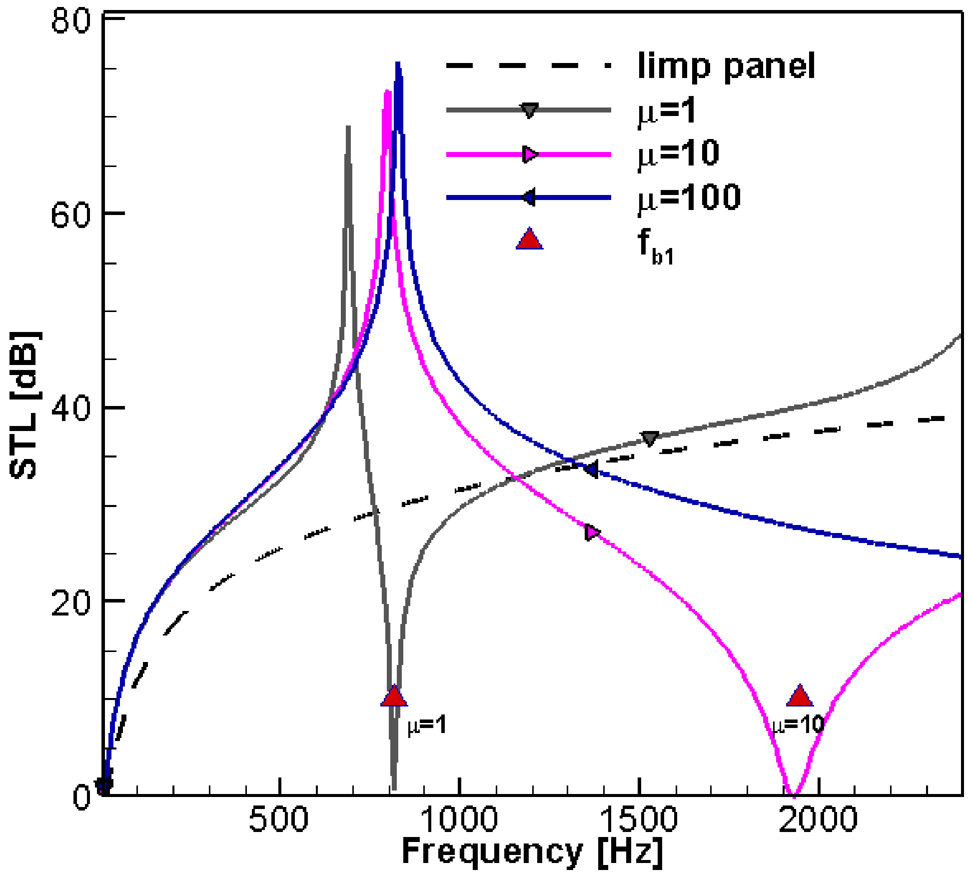


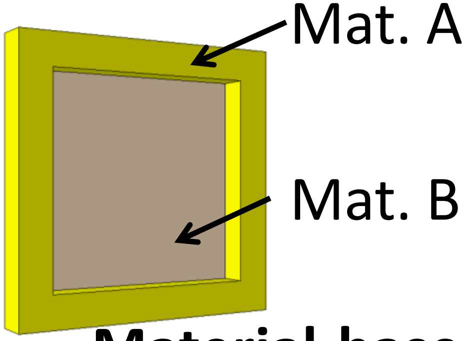
[5] Yang et al., APL2010

Membrane-based metamaterials

- Membrane held by a rigid grid with an attached mass at the center

Cellular Panel Characteristics

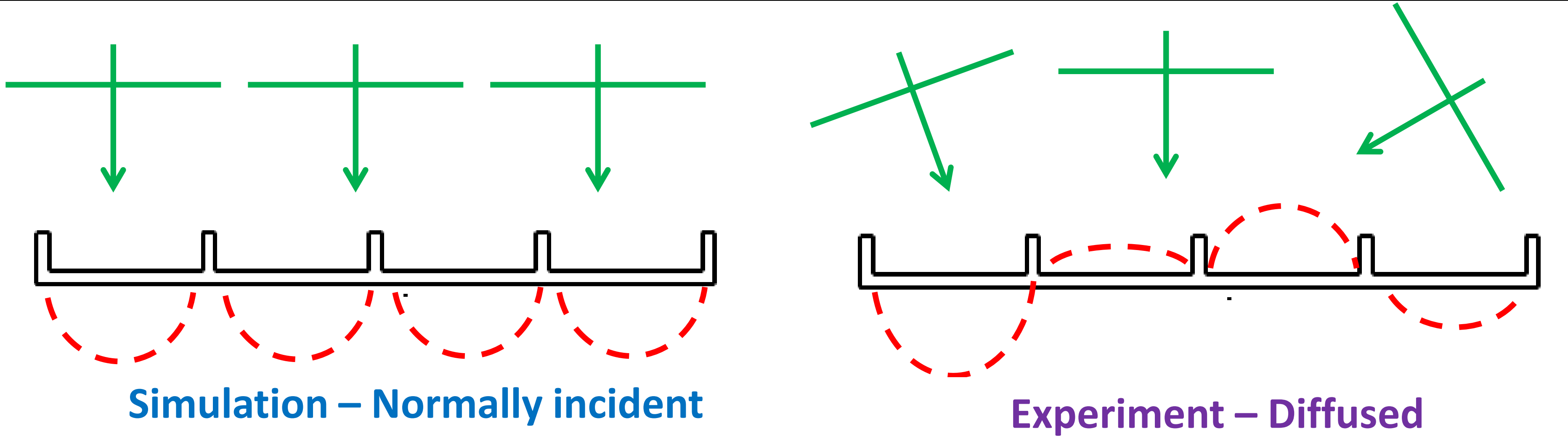




Material-based

All the cases have the same mass per unit area: 5 kg/m²

Sound Fields: Simulation and Experiment



- Analytical expressions for STL of a limp panel in a **normally incident** field and a **diffused** field

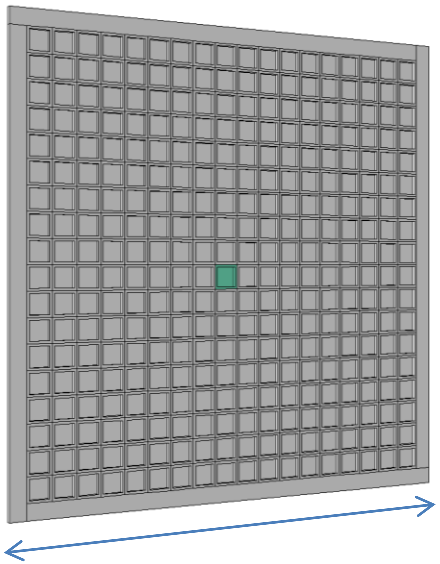
$$T = \frac{2\rho_0 c}{2\rho_0 c + j2\pi f m_s}$$

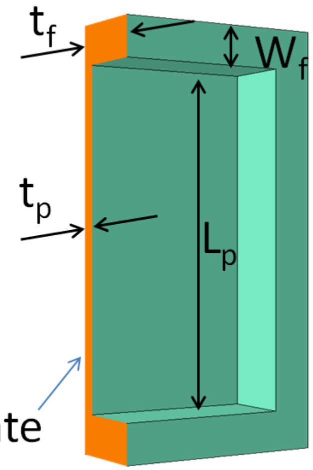
$$T(\theta) = \frac{2\rho_0 c}{2\rho_0 c + j\omega m_s \cos(\theta)},$$

$$\tau(\theta) = \|T(\theta)\|^2 = \frac{4{\rho_0}^2 c^2}{4{\rho_0}^2 c^2 + \omega^2 {m_s}^2 \cos(\theta)^2},$$

$$\bar{\tau} = 2\int_0^{90^\circ} \tau(\theta)\sin(\theta)\cos(\theta)\,\mathrm{d}\theta,$$

Design Specifications





	Design 2
t_p	1.81 mm
t_f	12.03 mm
w_f	6 mm
L_p	51 mm
μ	3.5
Mass/area	5.73 kg/m^2

18×18 cells span the designs

Reference limp panel:

An aluminum sheet of thickness 2.35 mm with mass/area of 6.14 kg/m^2

Material: Cast acrylic	
E	3.04 GPa
ρ	1100 kg/m^3
ν	0.43

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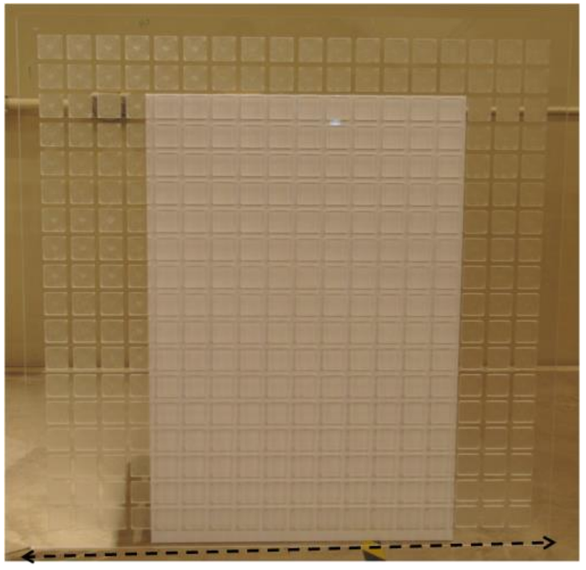
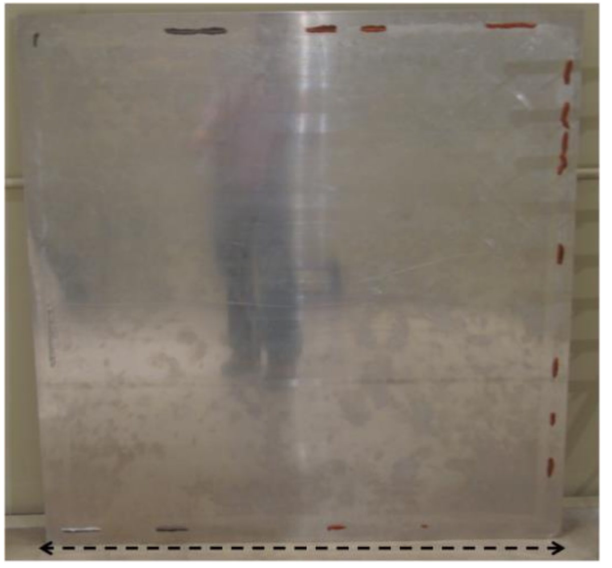
Materials



4 ft

Metamaterial panel



4 ft

Ref. Limp panel

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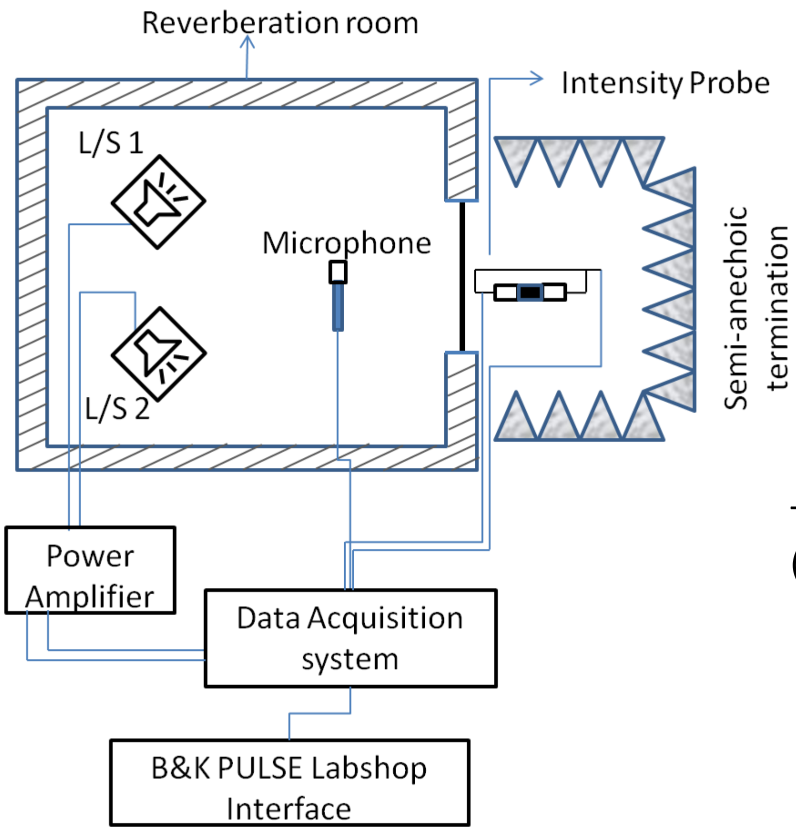
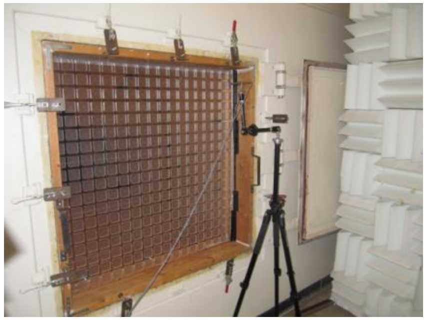
Experimental Setup



A schematic of the reverberation room test setup

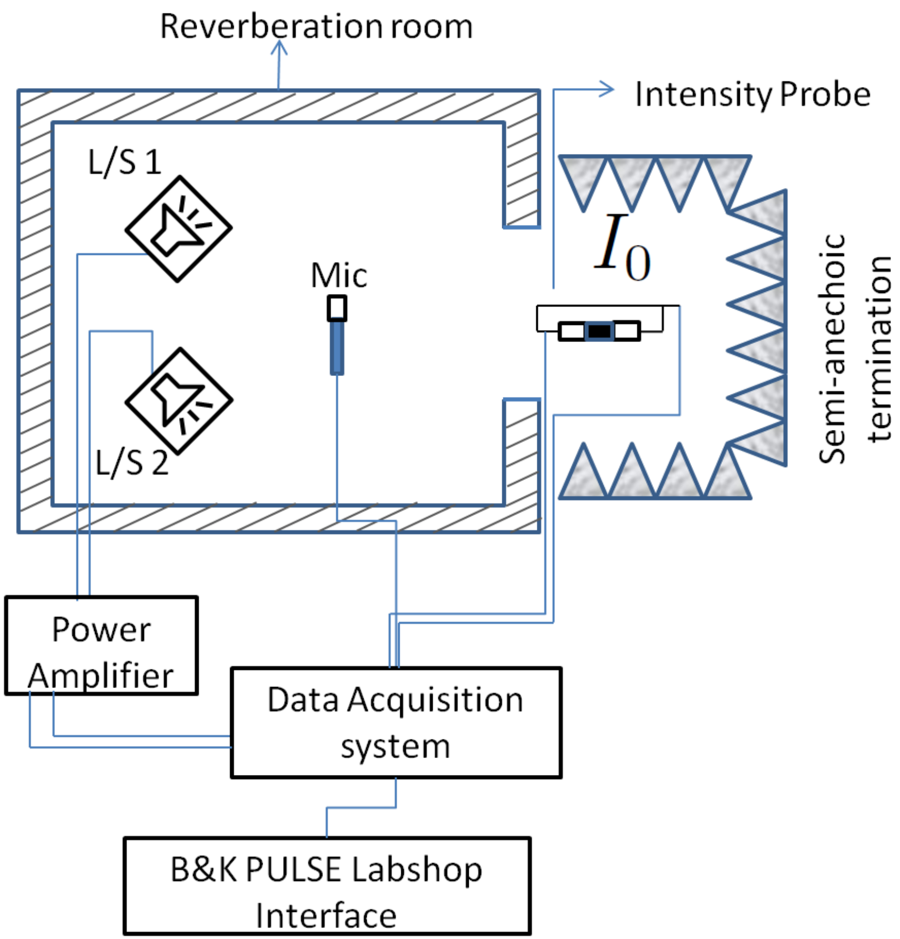
Test panel in the window
(from inside of reverb. room)



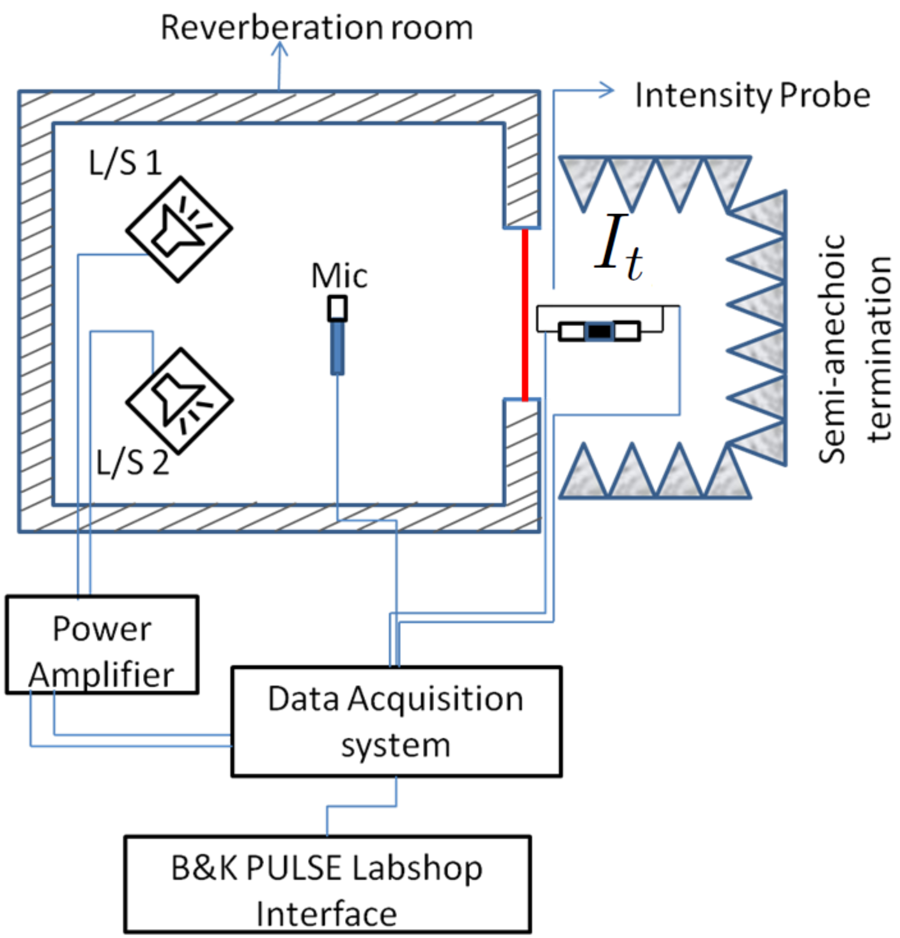
Test panel in the window
(from outside of reverb. room)

Intensity probe setup

Measurement Procedure

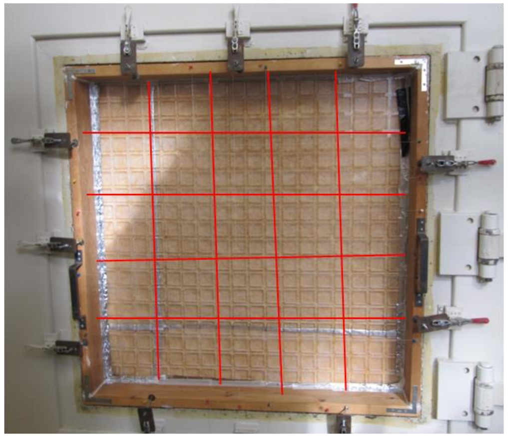


Measurement Procedure



$$STL = -10\log_{10}(\|I_t/I_0\|)$$

Measurement Procedure

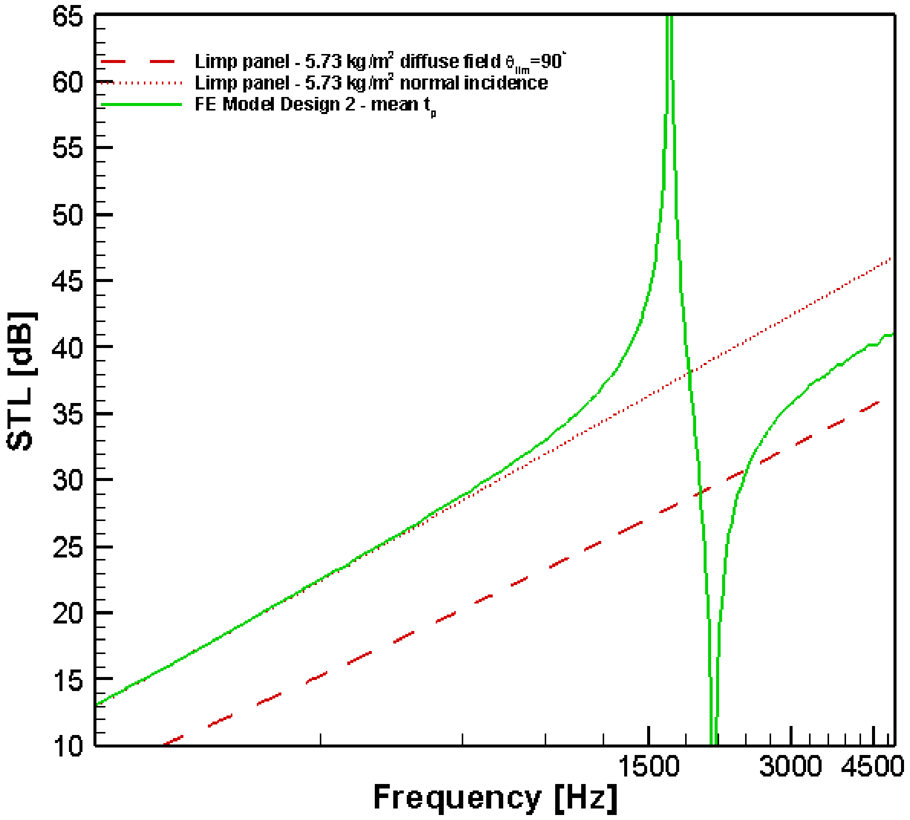


Indexing of the window space (seen from outside the reverb room)

Intensity probe setup

- Intensity measurement made in each of the 25 cells
- Ref. sound field and the sound emanating from the panel are determined by averaging the 25 intensity measurements without/with the panel
- Probe placed normal to the panel at a distance of 12 cm from the panel on the transmission side

Numerical Prediction for Design 2



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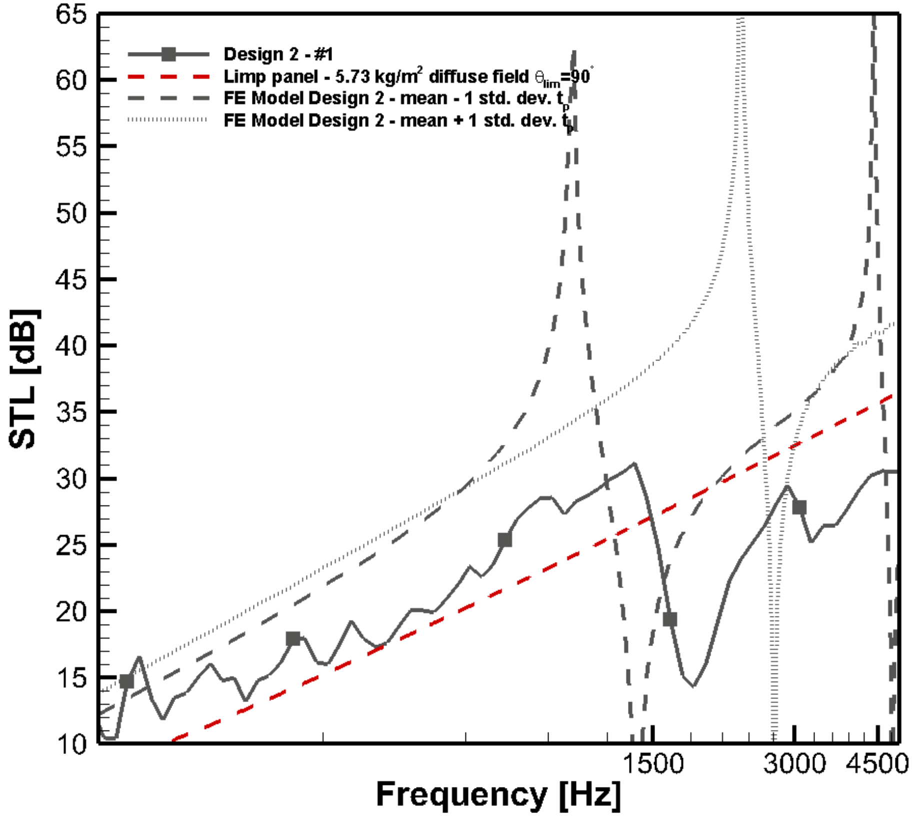
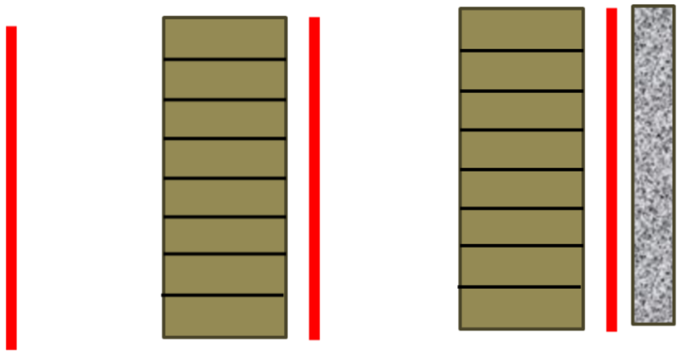
Experiment *versus* Numerical Prediction



- The STL peak when subjected to a diffused sound field is reduced compared to the numerically predicted value

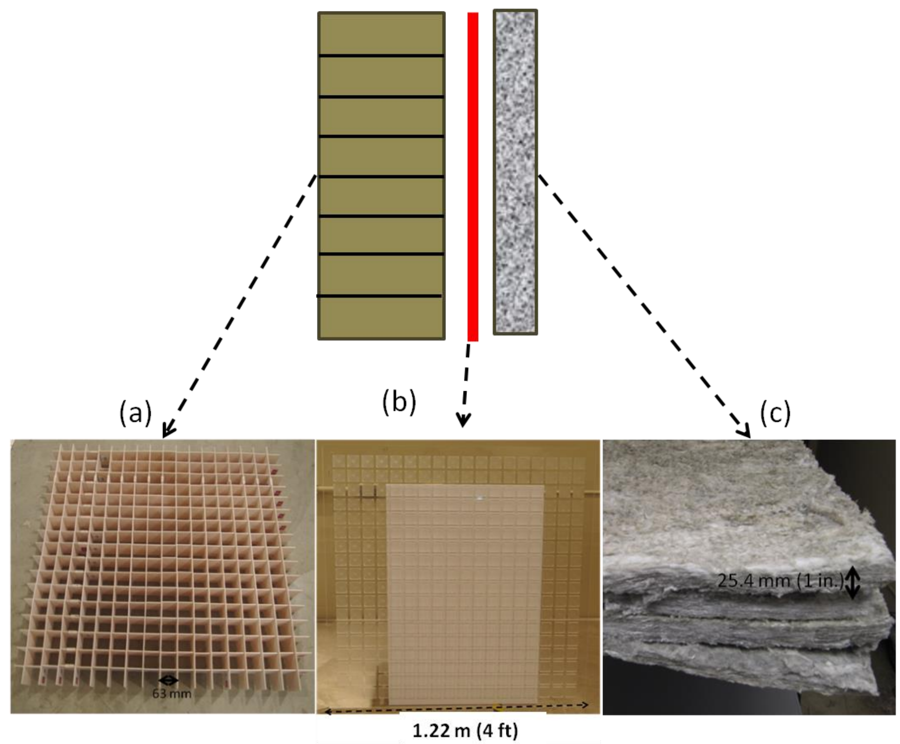
Hybrid Metamaterial Panel System



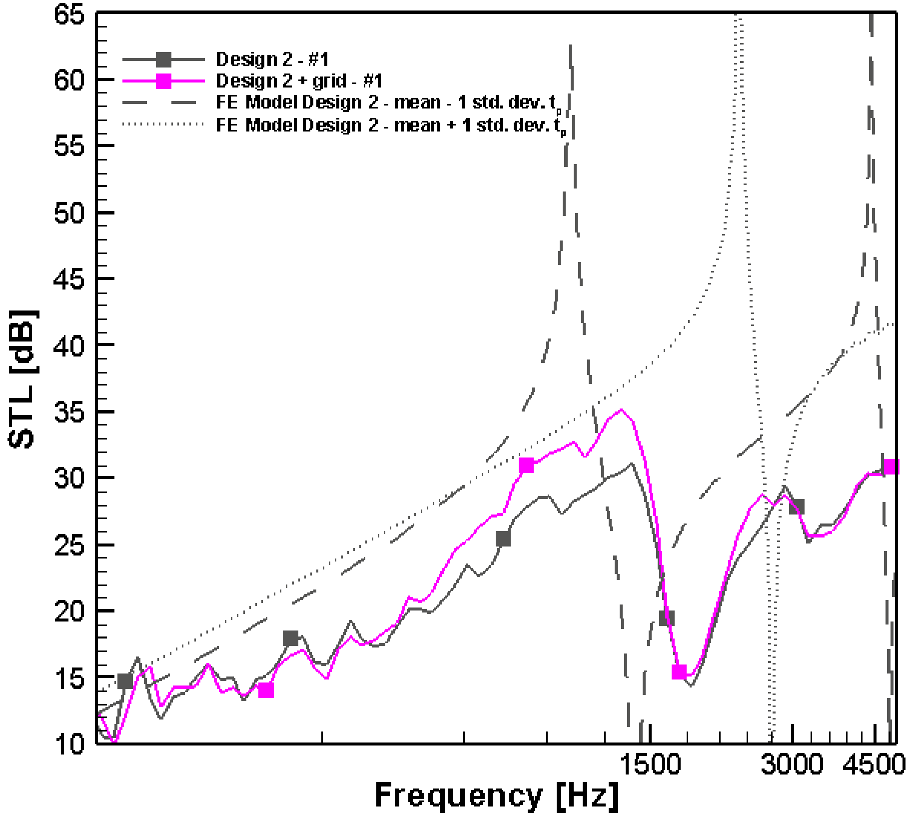
Cellular Panel

Grid + Cellular Panel

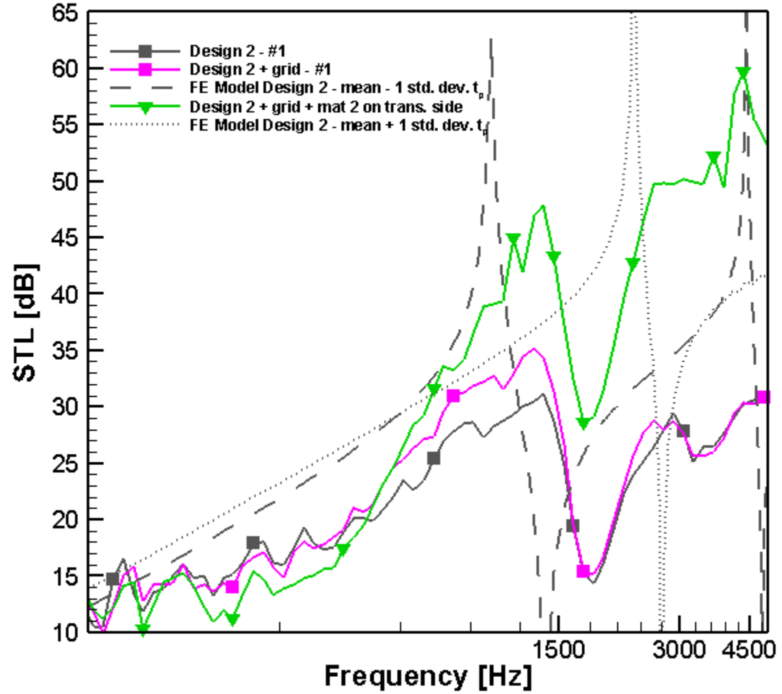
Grid + Cellular Panel + Mat



Effect of Grid

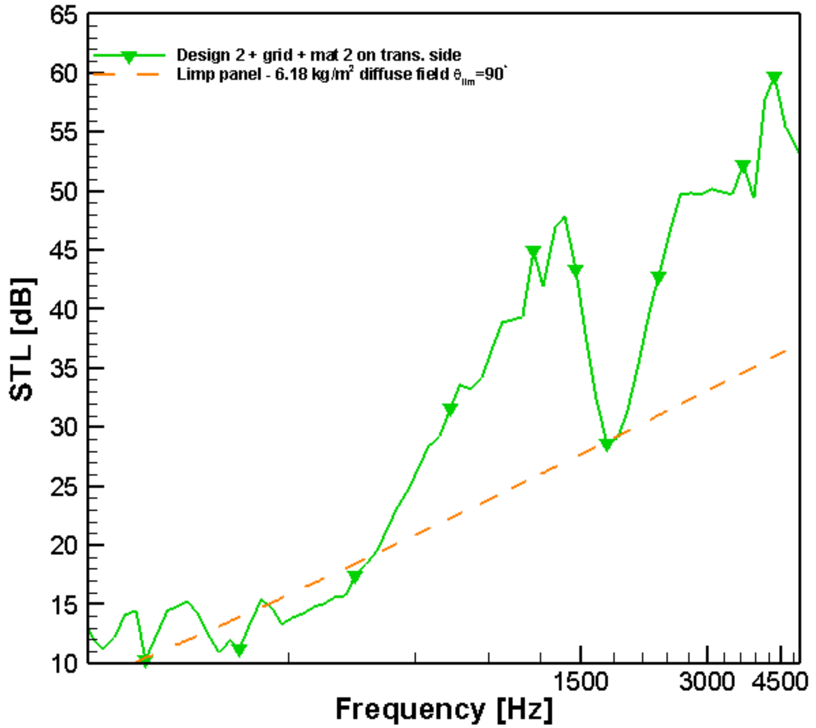


Effect of Grid + Absorbing Mat



- The peak STL is accentuated with addition of grid
- The addition of mat lifts the peak and dip

Metamaterial panel system *versus* the mass equivalent Limp Panel



- ❑ The dip STL is above the mass equivalent STL for a diffused field
- ❑ Significant benefit in STL at the peak compared to the limp panel

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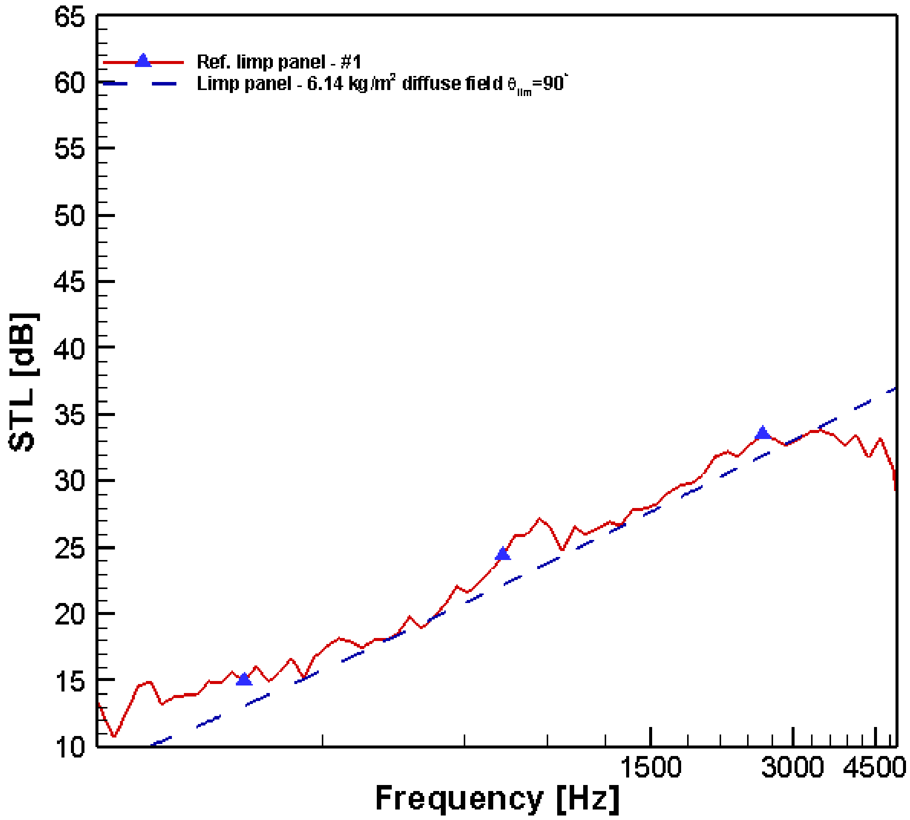
Reference Limp panel



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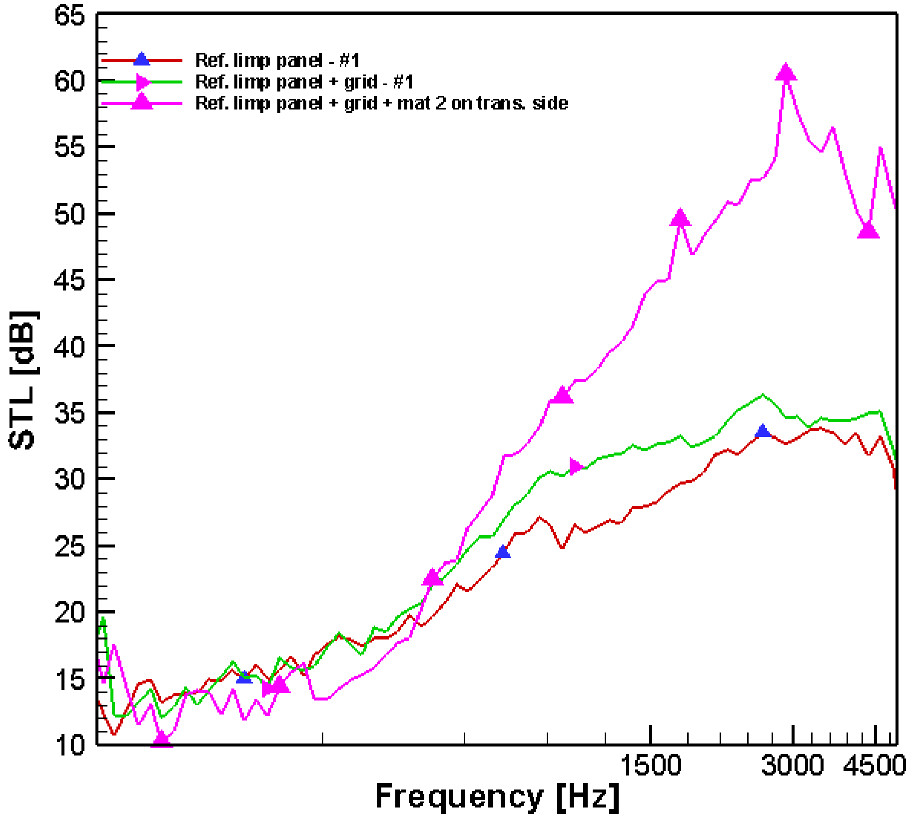
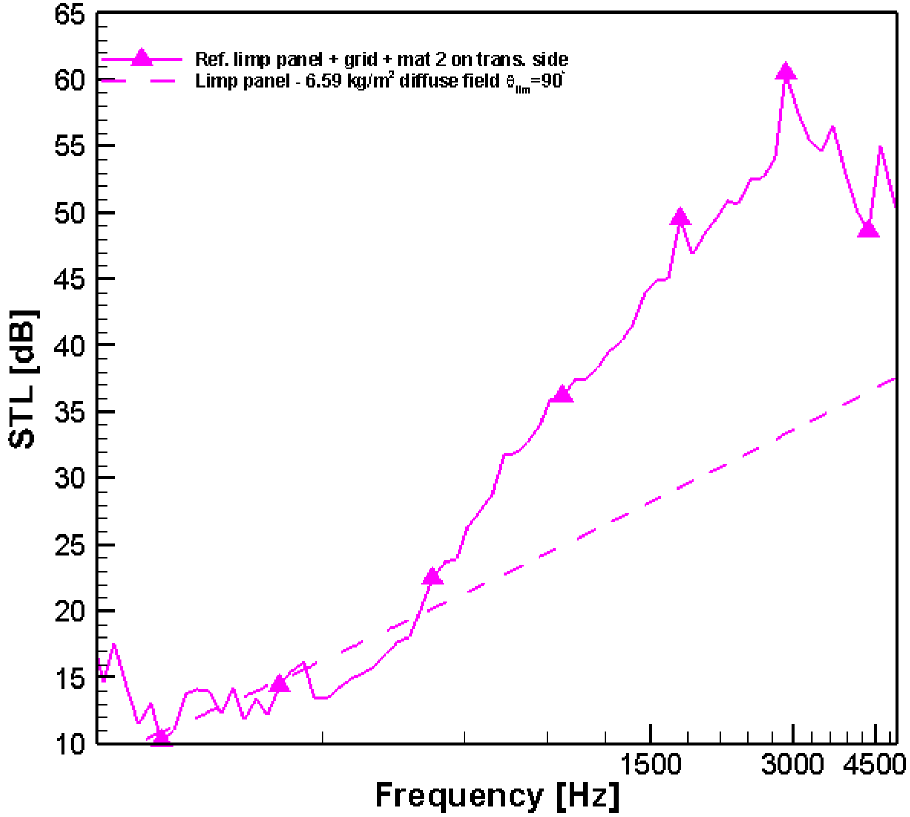
Effect of Grid and Mat on Ref. Limp Panel



Ref. Limp Panel system with grid and mat compared to its mass equivalent limp panel



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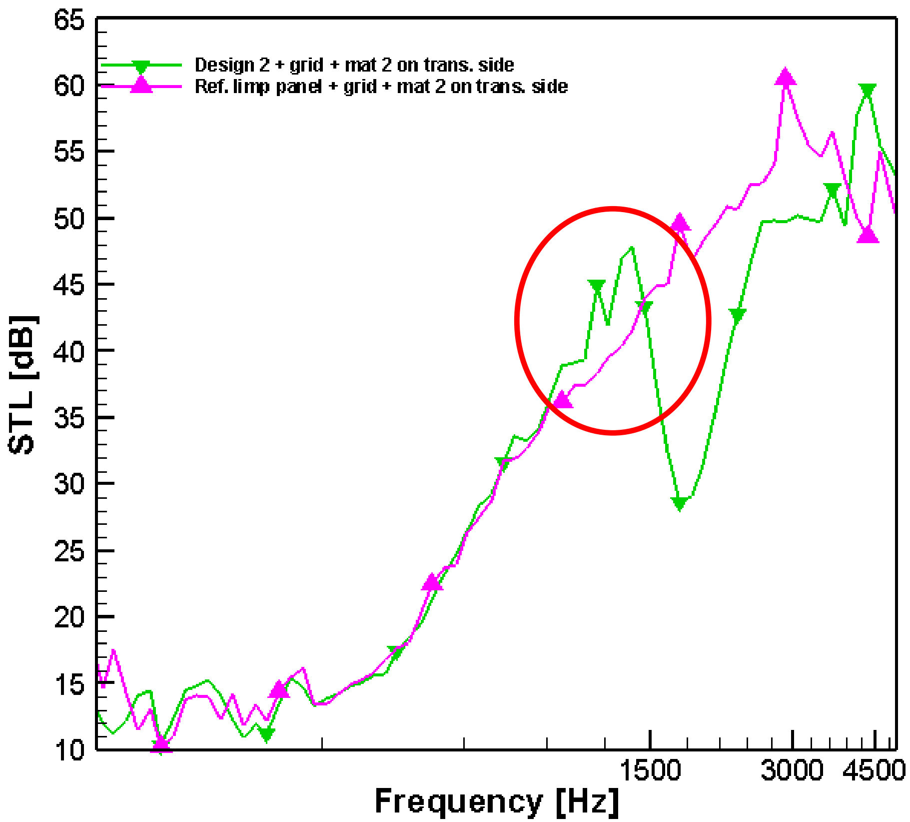
Hybrid Limp Panel system *versus* Hybrid Metamaterial Pane system



Limp panel system – mass per unit area: 6.59 kg/m^2

Metamaterial panel system – mass per unit area – 6.18 kg/m^2

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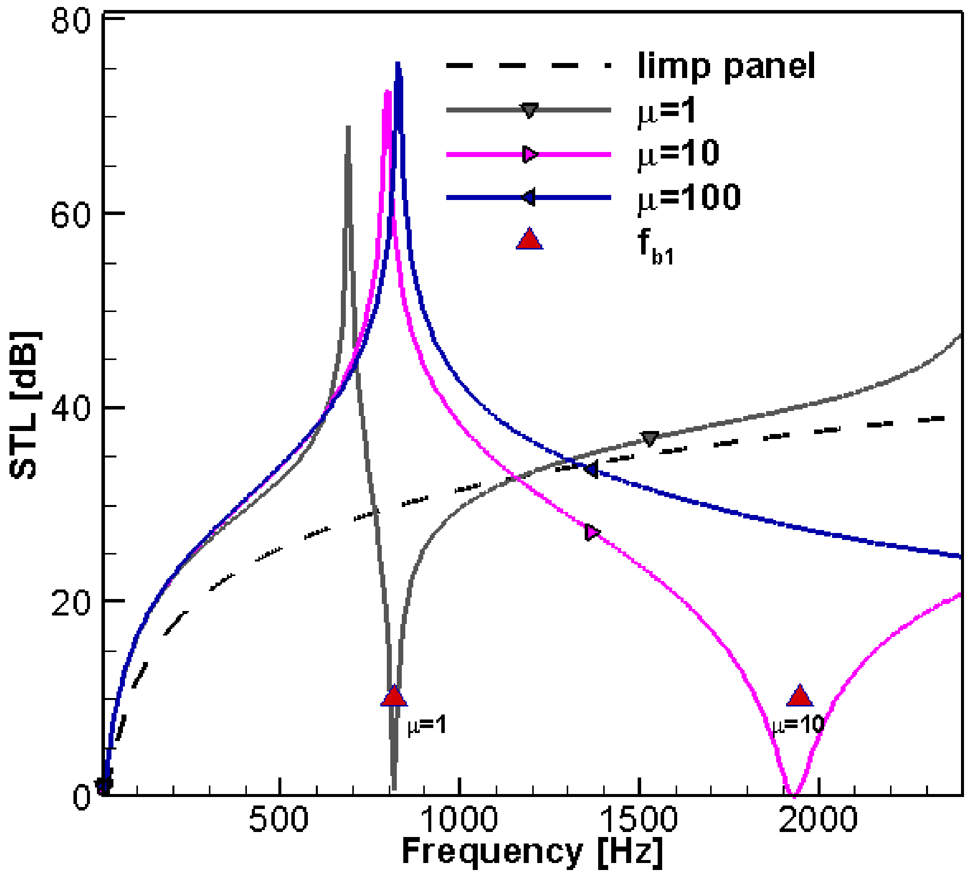
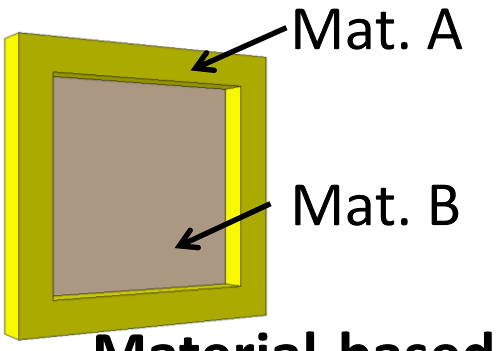
Cellular Panel Characteristics





Material-based

All the cases have the same mass per unit area: 5 kg/m^2

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Conclusions

- Have measured the Transmission Loss of a prototype metamaterial barrier system at **random incidence**
- **Two additional elements** (grid and absorbing mat) are required to approach the Transmission Loss benefit predicted at normal incidence
- There was some **observed benefit** compared with a reference limp panel, although the benefit for this particular panel was small when the hybrid elements were added to the reference limp panel
- It is suggested that the benefit could be increased substantially by creating a metamaterial barrier having a **higher mass ratio** closer to the ideal value