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Random incidence transmission loss of a metamaterial barrier system

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Random Incidence Transmission Loss of a Metamaterial Barrier System

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Low Frequency Noise

- Aircraft Cabin noise [1]: 70 – 90 dB
  - Frequency range: 0 – 1000 Hz

- Dishwasher noise [2]: 60 – 70 dB
  - Frequency range: 0 – 1000 Hz

- Quiet room noise level: 50 dB

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 $\rightarrow$ 30 dB↓ in noise
300 Hz $\rightarrow$ 12 dB↓ in noise
30 dB ↓ @ 300 Hz, Requires 5×8 = 40 kg/m²
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

Membrane-based metamaterials

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

[5] Yang et al., APL2010
All the cases have the same mass per unit area: 5 kg/m²
Simulation – Normally incident

Experiment – Diffused

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

\[
T(\theta) = \frac{2\rho_0 c}{2\rho_0 c + j2\pi f m_s \cos(\theta)}
\]

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

\[
\bar{\tau} = 2 \int_0^{90^\circ} \tau(\theta) \sin(\theta) \cos(\theta) \, d\theta,
\]
Design Specifications

Reference limp panel:
An aluminum sheet of thickness 2.35 mm with mass/area of 6.14 kg/m²

Material: Cast acrylic

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>3.04 GPa</td>
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<tr>
<td>ρ</td>
<td>1100 kg/m³</td>
</tr>
<tr>
<td>ν</td>
<td>0.43</td>
</tr>
</tbody>
</table>
Materials

Metamaterial panel

Ref. Limp panel
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 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
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

(a)  (b)  (c)

1.22 m (4 ft)

25.4 mm (1 in)

16
Effect of Grid
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.
Reference Limp panel

![Graph showing STL vs. Frequency for different panel types](image-url)
Effect of Grid and Mat on Ref. Limp Panel
Ref. Limp Panel system with grid and mat compared to its mass equivalent limp panel
Hybrid Limp Panel system *versus* Hybrid Metamaterial Pane system

Limp panel system – mass per unit area: 6.59 kg/m²
Metamaterial panel system – mass per unit area – 6.18 kg/m²
Cellular Panel Characteristics

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