The Application of Microperforated Panels in Duct Systems

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Objective

- Industrial Duct Applications

Building HVAC system

Automotive HVAC

https://grabcad.com/requests/i-am-looking-for-a-hvac-duct-system-of-automobile


- HVAC noise is one of the key noise sources in building interiors (office areas, etc.).

Office space example:

Average SPL = 57 - 60 dBA

Meets the spec but not desirable!!

Room Noise Criterion. (ASHRAE Handbook)

<table>
<thead>
<tr>
<th>Room Types</th>
<th>Recommended NC or RC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residences, Apartments, Condominiums</td>
<td>Living areas</td>
</tr>
<tr>
<td></td>
<td>Bathrooms, kitchens, utility rooms</td>
</tr>
<tr>
<td>Hotels/motels</td>
<td>Individual rooms or suites</td>
</tr>
<tr>
<td></td>
<td>Meeting/banquet rooms</td>
</tr>
<tr>
<td>Office buildings</td>
<td>Executive and private offices</td>
</tr>
<tr>
<td></td>
<td>Conference rooms</td>
</tr>
<tr>
<td></td>
<td>Teleconference rooms</td>
</tr>
<tr>
<td></td>
<td>Open-plan offices</td>
</tr>
<tr>
<td>Schools</td>
<td>Classrooms and lecture rooms</td>
</tr>
</tbody>
</table>
Objective

- Modification to the fan
- Diffuser design
- Duct designs

Efforts to resolve problems.

- HVAC noise sources for different frequency bands.

Design an acoustic silencer targeting frequency below 4000 Hz

Reference: http://www.csemag.com/single-article/noise-and-vibration-control-in-building-design/d28e9267a7b3f8a49f83d04d038a9e.html
Key design point

Transmission Loss of Single Muffler

- Single Chamber FEM
- Single Chamber EXP
- Single w/ MPP454 FEM
- Single w/ MPP454 EXP

ASTM E2611 Experiment

FEM analysis

JCA equivalent fluid model

\[
\tilde{\rho}(\omega) = \frac{\alpha_p \rho_s}{\phi} \left[ 1 - j \frac{\sigma \phi}{\omega \rho_s \alpha_e} \left( 1 + j \frac{4 \alpha \eta \phi \omega}{\sigma^2 \Lambda^2 \phi^2} \right) \right]
\]

\[
K(\omega) = \frac{\gamma P_i \phi}{1 - j \frac{8 \kappa}{\Lambda^2 C_p \rho_s \alpha_e} \left( 1 + j \frac{2 \Lambda^2 C_p \rho_s \alpha_e}{16 \xi} \right)}
\]

Silencer with MPP liner

Key design point

- To reduce undesirable pressure drop from expansion muffler.

---

Silencer with MPP lining

![Diagram of silencer with MPP lining](image-url)

![Graph showing single chamber muffler pressure drop](graph-url)

- Single Chamber Muffler with a MPP lining
Design modification

- Wider TL coverage with dual chamber design
- Bring up the TL minimum using MPP lining

Dual chamber silencer with MPP liner
Design modification

Silencer with multiple MPP liners

- Improve the minima using double lining treatment
- Achieve TL above 10 dB 5000 Hz with limited space and design of muffler
## Differences in sound?

<table>
<thead>
<tr>
<th>Sound without muffler treatment</th>
<th>Single Chamber</th>
<th>Single Chamber w/ MPP454</th>
<th>Single Chamber w/ Double MPP454</th>
<th>Double Chamber w/ MPP454</th>
<th>Double Chamber w/ Double MPP454</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A-weighted Overall Sound Pressure Level</strong></td>
<td>68.50 dBA</td>
<td>53.98 dBA</td>
<td>52.09 dBA</td>
<td>53.28 dBA</td>
<td>53.24 dBA</td>
</tr>
<tr>
<td><strong>Recordings</strong></td>
<td>![Sound Icon]</td>
<td>![Sound Icon]</td>
<td>![Sound Icon]</td>
<td>![Sound Icon]</td>
<td>![Sound Icon]</td>
</tr>
</tbody>
</table>
4 – Microphone and 2 – load Method

Transfer Matrix Calculation*

\[
\begin{bmatrix}
    p_{1a} \\
    v_{1a}
\end{bmatrix}
= \begin{bmatrix}
    A_{12} & B_{12} \\
    C_{12} & D_{12}
\end{bmatrix}
\begin{bmatrix}
    T_{11} & T_{12} \\
    T_{21} & T_{22}
\end{bmatrix}
\begin{bmatrix}
    A_{34} & B_{34} \\
    C_{34} & D_{34}
\end{bmatrix}
\begin{bmatrix}
    p_{4a} \\
    p_{4b}
\end{bmatrix}
\]

\[
\begin{bmatrix}
    p \\
    v
\end{bmatrix}
= e^{-j\alpha l}
\begin{bmatrix}
    \cos kl & jY \sin kl \\
    (j/Y) \sin kl & \cos kl
\end{bmatrix}
\begin{bmatrix}
    p \\
    v
\end{bmatrix}
\]

\[
Y = Y_0 \left(1 - \frac{\alpha(M)}{k_0} + j \frac{\alpha(M)}{k_0} \right)
\]

\[
k_e = \frac{k_0 - j \alpha(M)}{1 - M^2}
\]

\[
T_a = \frac{2e^{j\alpha l}}{T_{11} + T_{12} / \rho_0 c + \rho_0 c T_{21} + T_{22}}
\]

Transmission Loss

\[
TL = 20 \log_{10} \left| \frac{1}{T_a} \right|
\]

Prediction model considering mean flow effect

- Square cross-section standing wave tube model

Sound Pressure along the duct

$$\hat{p} = Ae^{-\frac{jk}{1+M}} + Be^{\frac{jk}{1-M}}$$

Variational form, Helmholtz Equation

$$\int \left[ \frac{1}{\omega \rho_0} \nabla \delta \hat{p} \cdot (I - \nabla \nu) \cdot \nabla \hat{p} - j \frac{1}{\omega \rho_0 c} (\nabla \delta \hat{p} \cdot \nu \hat{p} - \delta \hat{p} \nu \cdot \nabla \hat{p}) - \frac{1}{K} \delta \hat{p} \hat{p} \right] dV$$

$$+ \int \frac{1}{\omega \rho_0} \delta \hat{p} \left[ \mathbf{n} \cdot (I - \nabla \nu) \cdot \nabla \hat{p} - j \omega \frac{c}{c} \mathbf{n} \cdot \nu \hat{p} \right] dS = 0$$

Anechoic Termination

$$\left(1 - M^2\right) \nabla \hat{p} - \frac{j\omega}{c} \hat{p} = p \frac{i\omega}{Z_{\text{anechoic}}} \cdot \mathbf{n} = Z_{\text{anechoic}} = \rho_0 c$$
MPP under flow condition

- **Equivalent fluid – JCA model**
  - Complex Density and Bulk Modulus were modeled using following equations
  - Calculated properties were implemented in the finite element model of the MPP
  - Rigid inclusions to make the MPP locally reacting.

  \[
  \tilde{\rho}_c(\omega) = \frac{\alpha_j \rho_h}{\phi} \left[ 1 - j \frac{\sigma \phi}{\omega \rho_h \alpha_j} \right] + j \frac{4 \alpha_j^2 \eta \rho_h \phi}{\sigma^2 \Lambda^2 \phi^2}
  \]

  \[
  \tilde{K}(\omega) = \frac{\gamma P_0 / \phi}{\gamma - (\gamma - 1) \left[ 1 - j \frac{8 \kappa k}{A^2 C_p \rho_o \phi} \left[ 1 + \frac{\Lambda^2 C_p \rho_o \phi}{16 \kappa} \right] \right]}
  \]

- **MPP Properties**

<table>
<thead>
<tr>
<th>MPP 549</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hole diameter [(\mu m)]</td>
</tr>
<tr>
<td>Thickness [mm]</td>
</tr>
<tr>
<td>Flow resistance [Rayls]</td>
</tr>
</tbody>
</table>

MPP lining with flow effect

- **No MPP lining**
  - P1 P2 P3 P4
  - No Mean Flow
  - 8.5 m/s Mean Flow

- **MPP lining attached**
  - P1 P2 P3 P4
  - No Mean Flow
  - 8.5 m/s Mean Flow

- Low speed flows have very little effect on MPP performance.
- Good prediction results.
Measurements and predictions comparisons.

Different muffler design is possible.

MPP can help to improve TL when there is spatial limitation.
Use of a silencer with Microperforated Panel (MPP) lining in HVAC duct noise control was studied.

Reliable modeling techniques to design a silencer with MPP linings were suggested.

In-line MPP treatment inside a silencer helps in minimizing the pressure-drop as well as improving noise attenuation.

More practical studies will be made in the future.

✓ Building and vehicle applications.
THANK YOU