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Use of CFD to Calculate the Transfer Impedance of Microperforated Materials Having Round-Edged Holes

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Use of CFD to calculate the transfer impedance of microperforated materials having round-edged holes

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**Introduction**

- **Microperforated material**
- **Dissipation**
  - In hole
  - Along outer surface
  - Within shearing fluid
- **Analytical models**
  - Maa (1975) and Guo *et al.* (2008) account for first two
Objective

By using computational fluid dynamics approach, calculate dynamic flow resistance for microperforated panel considering flow through one hole and compare with existing formulation, especially in round-edged case.

\[ R_f = \frac{P_1 - P_2}{v_{in}} \]
Guo’s Model

**Guo Model**

\[ R = \left( \text{Re} \left\{ \frac{\omega t}{\sigma c} \left[ 1 - \frac{2}{k \sqrt{-j} J_1(k \sqrt{-j})} \right]^{-1} \right\} + \frac{\alpha 2 R_s}{\sigma c} \right) \times \rho c \]

\[ k = \sqrt{\frac{\omega \rho_0}{4 \eta}} \]

\[ R_s = \frac{\sqrt{2 \omega \rho_0 \eta}}{2} \]

- \( \alpha = 2 \) when smooth end
- \( \alpha = 4 \) when sharp end

**Flow resistance (R) is function of \( t, d, \sigma \)**

**Note that \( R_s \rightarrow 0 \) as \( \omega \rightarrow 0 \)**
Previous work (sharp-edged hole)

$\alpha$ vs. frequency

In these graphs, it is shown that $\alpha$ is a function of frequency, thickness, hole diameter, and porosity.
Definition of $\beta$

$\alpha$, end correction coefficient in Guo model, is dependent variable on frequency.

$$\alpha = \beta f^{-0.5}$$

$\beta$ is function of thickness, hole diameter, and porosity.

$$\beta = 16.3 \frac{t}{d} + 146.7$$

Flow resistance vs. frequency

( $t = 0.4064$ mm, $d = 0.2032$ mm, $\sigma = 0.02$)
Geometry of CFD model

Mesh Interval : 0.005 mm

Pressure outlet

Velocity inlet

Axis

1 mm

t

1 mm

r

d/2
Definition of *roundness* $\gamma$

$$\gamma = \frac{2r}{t}$$

$t$ is thickness of the panel,

$r$ is radius of hole edge

Three different sets $(0 < \gamma < 1)$

<table>
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<th>Set 1. Thickness</th>
<th>Set 2. Diameter</th>
<th>Set 3. Porosity</th>
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Inlet velocity and Pressure

Inlet velocity was chosen to be a Hann windowed, 5 kHz half-sine wave having a maximum value of 1 mm/s in order to cover the frequency range up to 10 kHz.
Pressure derivation in simulation

\[ t = 0.4064 \text{ mm}, \quad d = 0.2032 \text{ mm}, \quad \sigma = 0.02 \]
Dynamic flow resistance and reactance

Changing by roundness
($t = 0.4064 \text{ mm}, d = 0.2032 \text{ mm}, \sigma = 0.02$)

Make $\alpha$, which is defined by Guo et al., function of roundness $\gamma$ to fit with CFD results.
Set 1. (different thicknesses)

As the panel goes thicker, the slope of $\beta$ is steeper.
Set 2. (different hole diameters)

As the diameter of hole goes smaller, the slope of $\beta$ is steeper.
Set 3. (different porosities)

The slope of $\beta$ is not affected by the porosity.
Dynamic flow resistance and reactance

Slope \(a\)

\[ \beta = \left( 16.3 \frac{t}{d} + 146.7 \right)(1 + a\gamma) \]
Dynamic flow resistance and reactance

Slope $a$

$$a = 0.0444 \left( \frac{t}{d} \right)^2 - 0.9624 \frac{t}{d} + 0.046$$

End correction coefficient $\alpha$

$$\alpha = \left[ 1 + \left\{ 0.04 \left( \frac{t}{d} \right)^2 - 0.96 \frac{t}{d} + 0.05 \right\} \gamma \right] \left[ 16.3 \frac{t}{d} + 146.7 \right] f^{-0.5}$$
Compared CFD Result with new formula

\[(t = 0.4064 \text{ mm}, \ p = 0.2032 \text{ mm}, \ \sigma = 0.02)\]

\[\gamma = 0.125 \ (\text{top left}), \ \gamma = 0.375 \ (\text{top right}), \ \gamma = 0.625 \ (\text{bottom left}), \ \gamma = 0.875 \ (\text{bottom right})\]
Compared CFD Result with new formula

\( t = 0.4064 \text{ mm}, \ d = 0.2032 \text{ mm}, \ \sigma = 0.01 \)

\( \gamma = 0.125 \) (top left), \( \gamma = 0.375 \) (top right),
\( \gamma = 0.625 \) (bottom left), \( \gamma = 0.875 \) (bottom right)
Compared CFD Result with new formula

\[(t = 0.4064 \text{ mm}, d = 0.4064 \text{ mm}, \sigma = 0.02)\]

\[\gamma = 0.125 \text{ (top left)}, \ \gamma = 0.375 \text{ (top right)}, \ \gamma = 0.625 \text{ (bottom left)}, \ \gamma = 0.875 \text{ (bottom right)}\]
By change the definition of $\alpha$, which is defined by Guo et al., accuracy can be improved in low frequencies.

By making $\alpha$ a function of roundness, thickness, hole diameter, and frequency (as below), we can define dynamic flow resistance for any cylindrical hole.

$$\alpha = \left[ 1 + \left\{ 0.04 \left( \frac{t}{d} \right)^2 - 0.96 \frac{t}{d} + 0.05 \right\} \gamma \right] \left[ 16.3 \frac{t}{d} + 146.7 \right] f^{-0.5}$$

Future: Make complete definition of $\alpha$ and an examination of the effect of tapered hole geometry.
Acknowledgements

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