Effect of flow on the acoustic behavior of a vibrating cantilever beam liner

Y. Auregan, M. E. D'Elia, T. Humbert

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Everything that was said in the previous talk is interesting but ...

1) it corresponds to a normal incidence and not a grazing incidence
2) it does not take into account the effect of the flow
Introduction

Normal vs. grazing incidence

“Perfect” Helmholtz resonator

\[ R(Z) \]

\[ S(Z) \]

Frequency (Hz)

Optimal impedance

$L = 120 \text{ mm}$

$H = 40 \text{ mm}$

Cremer
Introduction

\[ Z = 1 \]

\[ Z = 1 + i(\hat{f} - 1/\hat{f})/C \]

\[ Z_{\text{opt}} \]
Effect of flow

Aurégan, Y., Farooqui, M., & Groby, J. P.  
Low frequency sound attenuation in a flow duct using a thin slow sound material.  
*JASA, 139*(5), EL149 (2016).
Introduction

How respond a cantilever beam material in a duct wall with a grazing flow?
Micro-slit systems

⇒ 2D model

Titanium plate of thickness 0.1 mm

Micro-slit by laser-cutting opening 30 µm

⇒ 2D model

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Multi-Modal Method

First Step: Numerical investigation of 1 beam + cavity

Propagation without flow

\[ k^2 P - \omega^2 P - d_y^2 P = 0 \]

Beam

\[ k^4 \delta - k_M^2 \delta = -C[p]_{y=1} \]
\[ i\omega \delta = V(y = 1) \]

Resistance

\[ [p]_{y=1} = R V \]

Propagation in a shear flow

\[ \begin{aligned}
    i(\omega - M k)V &= -d_y P \\
    (1 - M^2) k^2 P + 2\omega M k P - \omega^2 P - d_y^2 P &= -2i d_y M k V
\end{aligned} \]

Pressure

\[ p = P(y)e^{i(\omega t - kx)} \]

Vertical velocity

\[ v = V(y)e^{i(\omega t - kx)} \]

Beam displacement

\[ d = \delta e^{i(\omega t - kx)} \]
Multi-Modal Method

First Step: Numerical investigation of 1 beam + cavity

Computed by MultiModal method:
1) Discretized by Finite difference method in the transverse direction.
2) The wavenumbers and the mode shapes are computed in each zone (I, II, III and IV).
3) The unknown amplitudes of modes are computed as a function of the amplitude of the incident modes by matching the fields between the different zones.

⇒ Scattering matrix and fields
Multi-Modal Method Modelling

![Graph showing multi-modal method modelling results.](Image)

- $|T^+|$
- $|T^-|$
- $|T^+, M=0.3|
- $|T^-, M=0.3|

Frequency (Hz)
Then, to go from one beam to a 5 by 3 beams configurations, we can compose the final scattering matrix, due to the inner linearity of the system

\[
\begin{bmatrix}
A_6 \\
B_1
\end{bmatrix} = [S_{tot}] \begin{bmatrix}
A_1 \\
B_6
\end{bmatrix} = [S_1] \otimes \cdots \otimes [S_5] \begin{bmatrix}
A_1 \\
B_6
\end{bmatrix}
\]
Global Transmission curves are therefore obtained by the composition of 5 sequences of beam and resistive zones, preceded and followed by a rigid tube.
Acoustic measurements Setup

- Sources (Up/Downstream)
- Piezoelectric Microphones
- T-R Microphones
- LDV

FLOW

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Acoustic Measurements

Source in Upstream position

![Graph showing frequency response](image-url)
Acoustic Measurements

Source in Downstream position

![Graph showing acoustic measurements with frequency on the x-axis and amplitude on the y-axis, with different lines representing different Mach numbers.](image)
Acoustic Measurements vs MM Method

![Graph showing acoustic measurements vs MM method](image)

- $|T^{-}|$, $M = 0.27$, Exp.
- $|T^{+}|$, $M = 0.27$, Exp.
- $|T^{+}|$, $M = 0.27$, 5 beams
- $|T^{+}|$, $M = 0.27$, 5 beams

$Frequency [Hz]$

$|T|$

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MM Method

Velocity Fields

@ 405 Hz

@ 1480 Hz
Conclusions

Analysis on vibrating beams shows that the behaviour of these elements changes drastically in a grazing configuration.

The modelling with a Multi-Modal Method seems to correctly describe the aeroacoustic behaviour of the cantilever beams both from a qualitatively and quantitatively point of view.

Both Resonance frequencies and Transmission values are well predicted.

Future works will focus on an optical investigation by the means of the Laser Doppler Velocimetry (LDV) technique.