Tunable Flat-Plate Absorber Design for Active Sound Absorption

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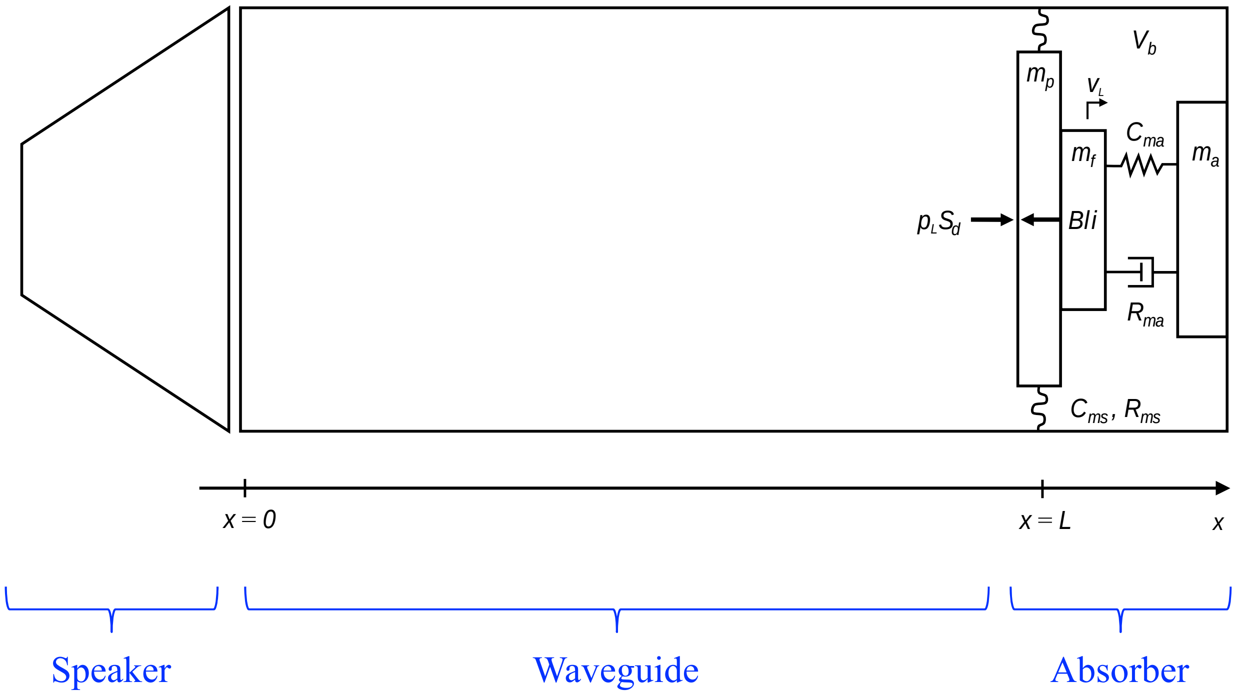
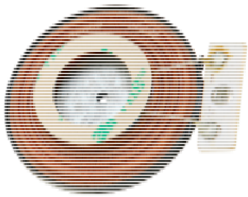
Introduction

- Low frequency noise is an issue in many indoor environments
  - Room resonances
  - Long modal decay times
- There is a need for ways to damp these low frequency modes effectively
- Passive absorbers have limited bandwidth of effective absorption
- Active absorbers (typically in the form of loudspeakers) are tunable and have a wider bandwidth

Objectives

- Design a compact and cost-effective low frequency absorber driven by an inertial actuator
- Effective sound absorption ($\alpha > 0.83$) from 50 to 200 Hz
- Tunable system





Active impedance control

- Absorber is placed at one end of a waveguide
- Absorption coefficient for incident plane waves:

$$\alpha = 1 - \left| \frac{Z_s - \rho c}{Z_s + \rho c} \right|^2$$

- Perfect absorption is achieved when:

$$Z_s = \frac{\hat{p}_L}{\hat{v}_L} = \rho c$$

- With control we can modify the specific acoustic impedance of the system
- In practice, it is impossible to reach ρc, i.e. we cannot completely cancel the effects of the reactive mass and compliance of the system

Active impedance control

- We introduce a target in the form of:

$$Z_{st} = \rho c + j\left(\mu_1 \frac{\omega m_{tot}}{S_d} - \mu_2 \frac{1}{S_d \omega C_{tot}}\right)$$

- μ_1 and μ_2 are positive real coefficients that decrease (or increase) the effective mass/stiffness
- Using different μ_1 and μ_2 it is possible to shift the resonance frequency from the resonance of the passive system
- Feedback control is used to achieve the target
- Newton's second law of motion for the moving piston gives the control force:

$$Z_m \hat{v}_L = \hat{p}_L S_d - Bl\hat{\imath} \qquad \Rightarrow \qquad Bl\hat{\imath} = \hat{p}_L \left(S_d - \frac{Z_m}{Z_s}\right)$$

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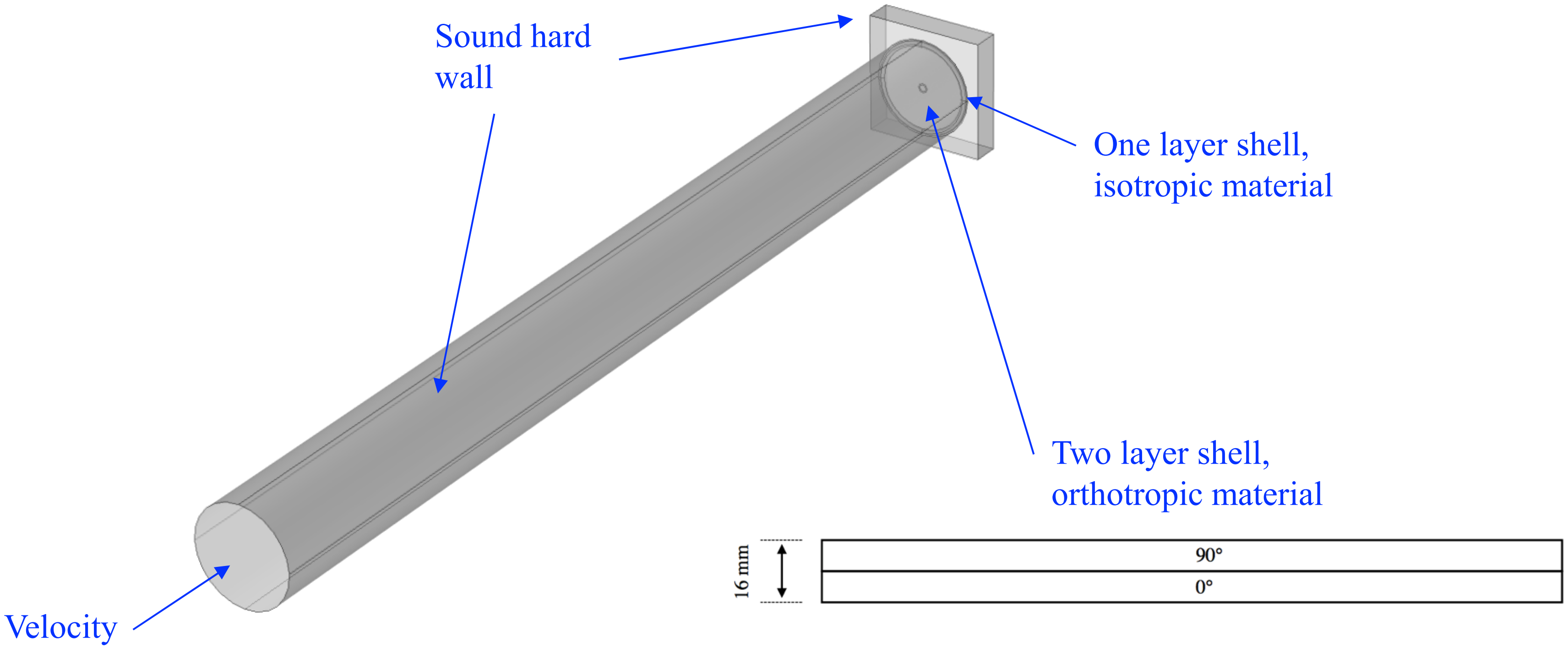
Measure pressure near piston

Impose target impedance

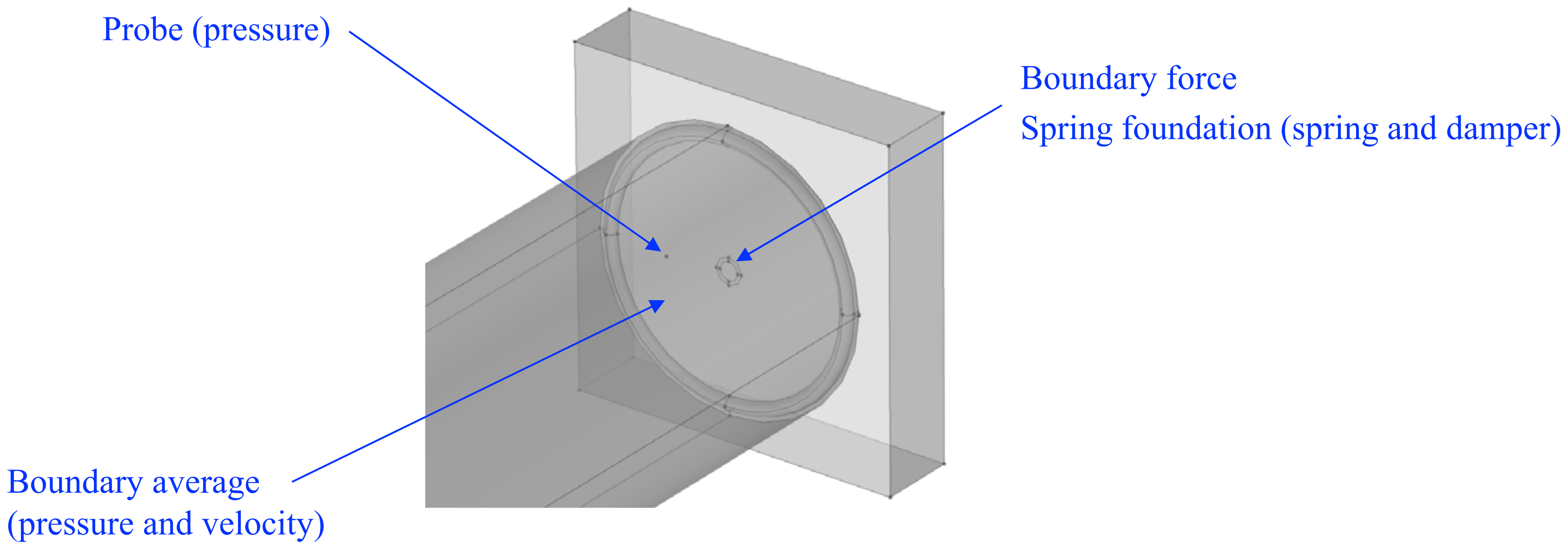
Use of COMSOL Multiphysics

- The control law assumes the plate is perfectly rigid
- Effects of bending modes investigated in COMSOL
- Two acoustical domains coupled with a structural domain (shell)
- We consider a cross-plied balsa plate and model it as a two layer shell with orthotropic material properties



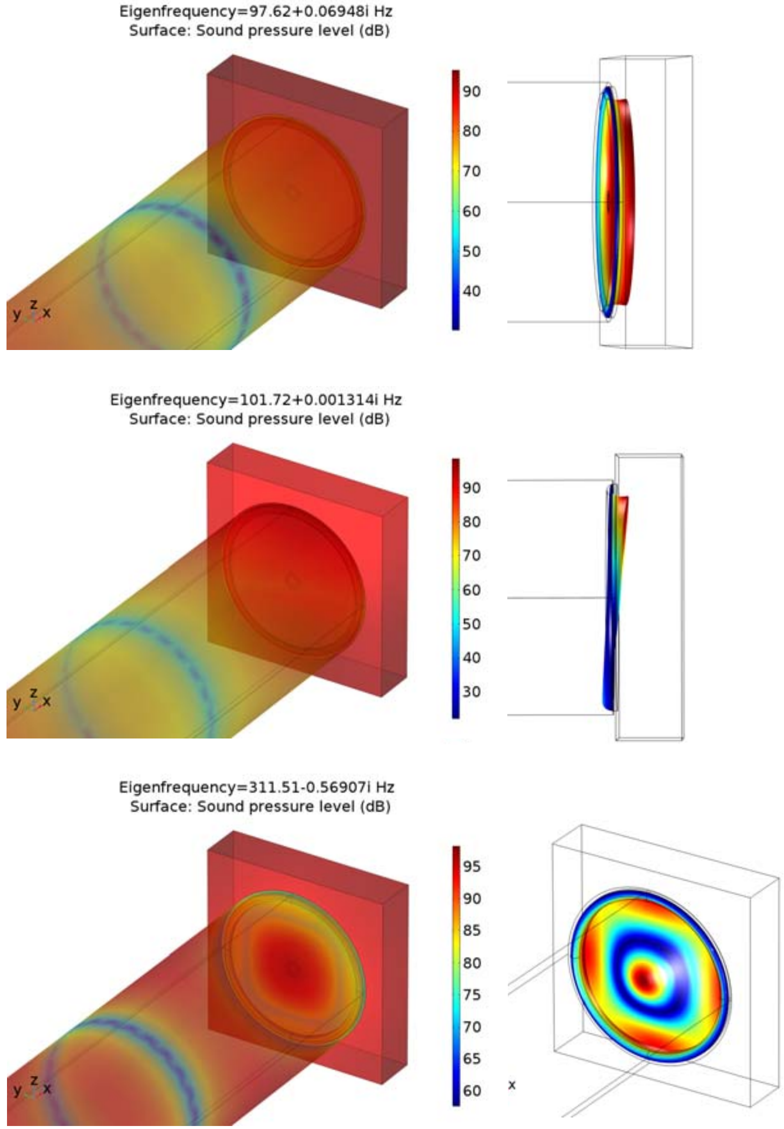
Implementation of the control

- Pressure is measured in the proximity of the plate and defined as a variable
- Control force is calculate via the control law: $Bl\hat{\imath} = \hat{p}_m(S_d - Z_m/Z_{st})$
- The mechanical parameters (m_{tot} , R_{tot} , C_{tot}) are curve fitted from the response of the passive system allowing for calculation of Z_m and Z_{st}
- Pressure and velocity are averaged over the plate area allowing for calculation of its specific acoustic impedance and absorption coefficient

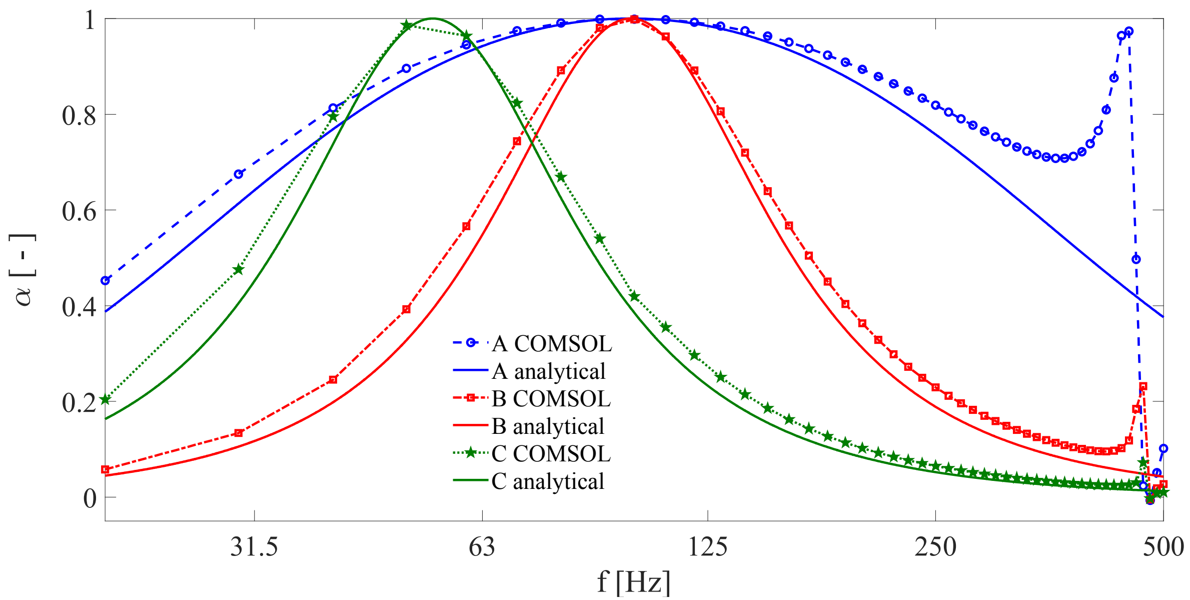


Eigenfrequency analysis

- Piston mode at approx. 98 Hz
- Rocking modes of the surround suspension at low frequencies
  - Expected as no countermeasures for rocking motion are applied
- First bending mode of the plate at approx. 312 Hz
- Strong acoustic-structure coupling
  - Bending modes occur at lower frequencies than for the uncoupled system



Simulated absorption coefficient

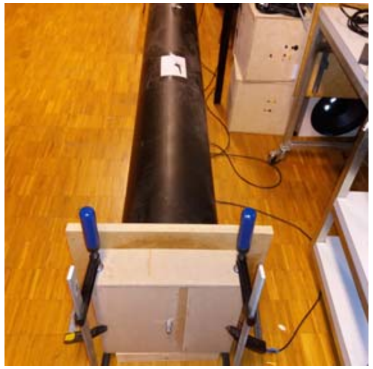


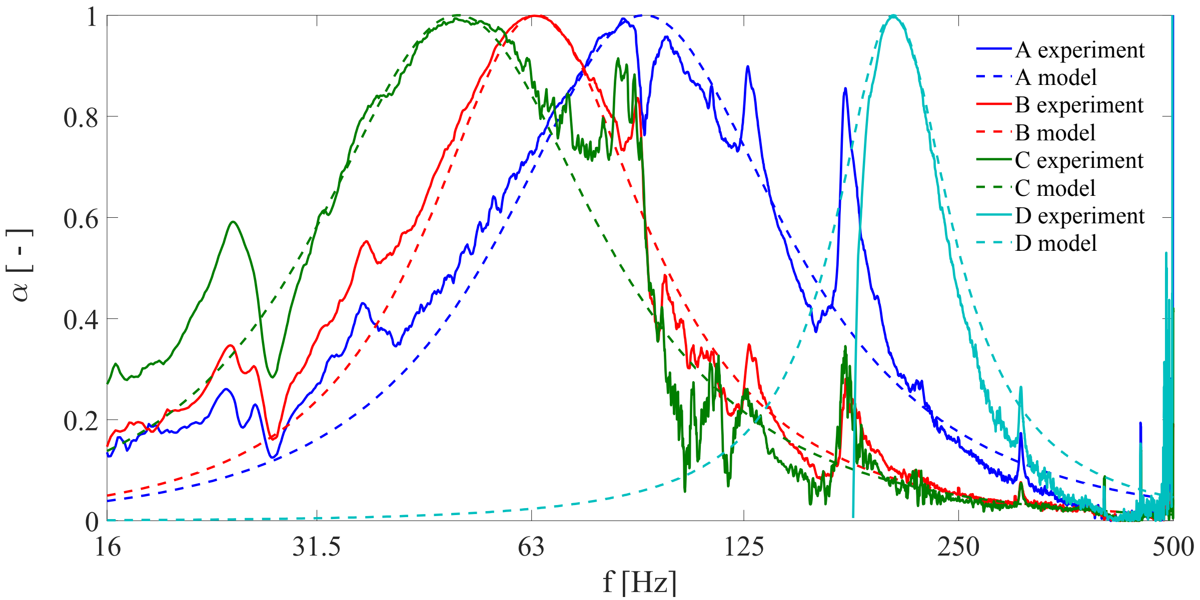
$$Z_{st} = R_{st} + j\left(\mu_1 \frac{\omega m_{tot}}{S_d} - \mu_2 \frac{1}{S_d \omega C_{tot}}\right)$$

	R_{st}	μ_1	μ_2
A	ρc	0.15	0.15
B	ρc	0.55	0.55
C	ρc	1.00	0.30

- COMSOL model consistent with the lumped model
- Significant deviation from the lumped near the first bending mode
- Rocking modes are not excited due to symmetry of geometry and boundary conditions

Assessment of a prototype





- A prototype has been built and tested to validate the concept
- Made of different material which renders it somewhat incomparable with the numerical model
- Overall, good agreement with prediction from the lumped model
- Largest deviations are likely due to rocking modes

Conclusion

- A compact and tunable electroacoustic absorber driven by an inertial actuator has been designed
- The system could be further improved by countermeasures for rocking motion
- The modeling of the system could be improved by including non-symmetries in the geometry and boundary conditions

Thank you for your attention

References

Rivet E, Karkar S, Lissek H. Broadband low-frequency electroacoustic absorbers through hybrid sensor-/shunt-based impedance control. IEEE Transactions on Control Systems Technology. 2017 Jan;25(1):63-72.