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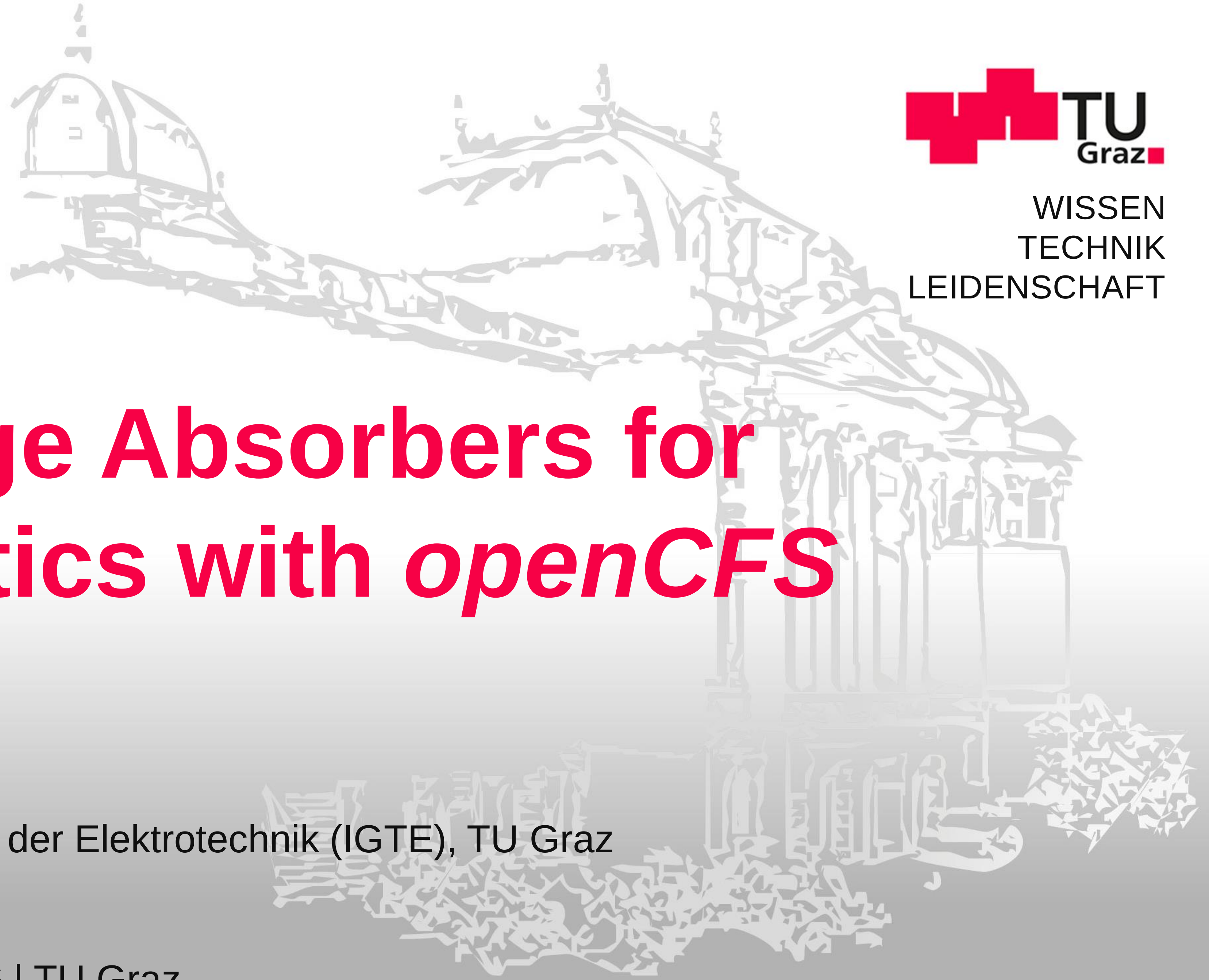

Modeling Edge Absorbers for Room Acoustics with *openCFS*

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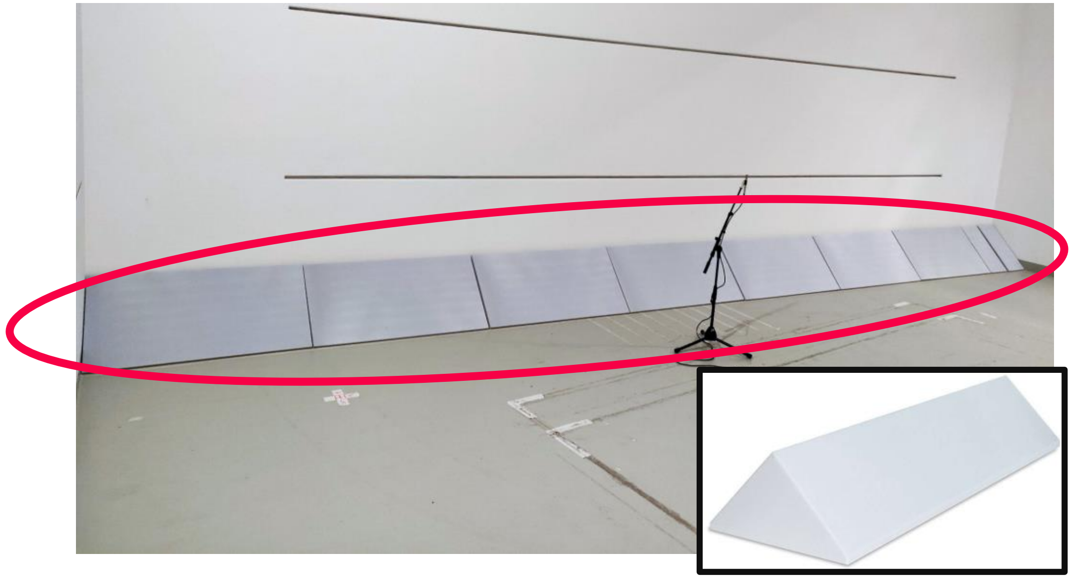
openCFS User Meeting | 09.04.2026 | TU Graz

Motivation

- Edge Absorbers (EA)
  - Porous material mounted in the edge of a room
  - Good absorption at low frequencies
- But how does the EA work?
  - Literature rather application-centric [4]
  - Preliminary systematic investigations [5]
- Approach:
  - Simulate an empty room
  - Simulate a room with EA
- <u>Goal:</u> Understand the underlying principles of EA by Finite Element simulations

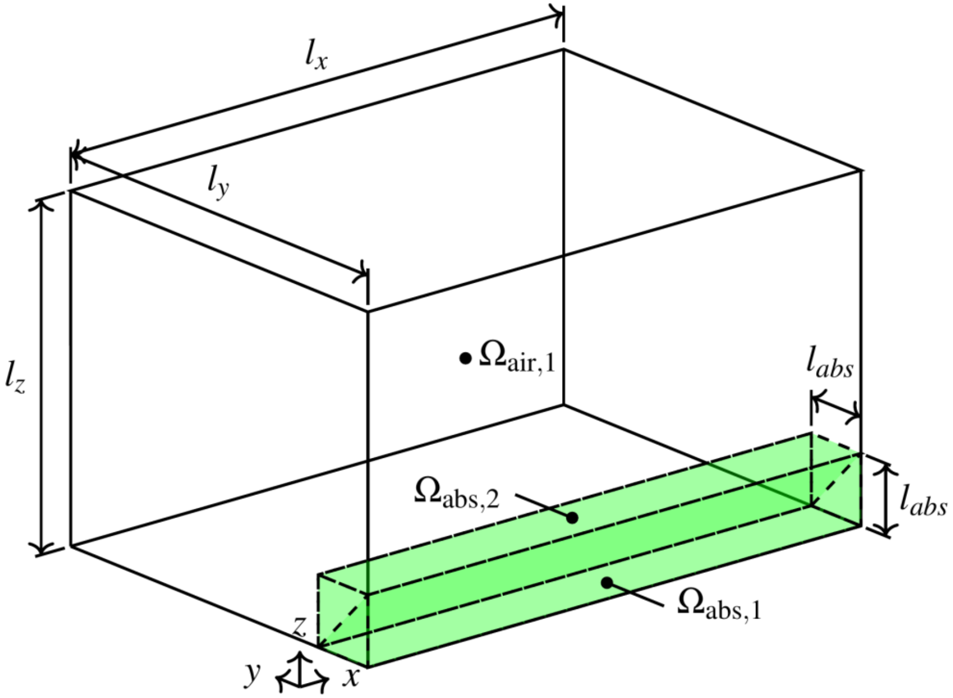


R. Hofer: *Analyse des modalen Schallfeldes zur Untersuchung der Funktionsweise von Kantenabsorbern*, Master‘s thesis, TU Graz, Fig. 3.19

[1] Fuchs et al.: Covered broadband absorbers improving functional acoustics in communication rooms, Applied Acoustics 74.1 (2013), pp. 18–27
[2] Kurz et al.: Systematische Untersuchungen zur Funktionsweise des Kantenabsorbers als “Modenbremse”, Elektrotech. Inf. 138(3):162–170 (2021)

Content

Geometry & Mesh

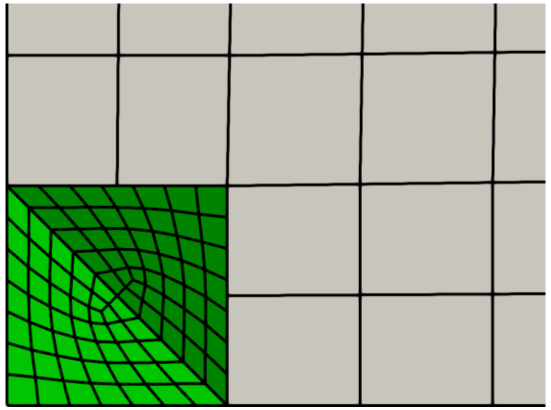


Room Dimensions

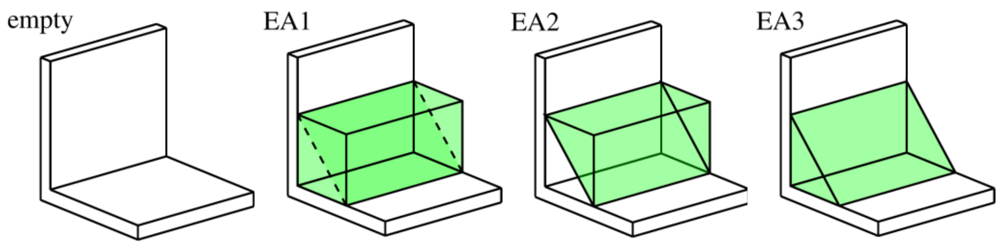
$$l_x = 8.34\,\text{m}$$
$$l_y = 5.99\,\text{m}$$
$$l_z = 4.90\,\text{m}$$
$$V = 244.79\,\text{m}^3$$
$$S = 240.35\,\text{m}^2$$
$$l_\text{abs} = 0.4\,\text{m}$$

Mesh Specifications

- nonconforming mesh: Nitsche-type mortaring
- elem. size Ω_air : 0.25 m
- elem. size Ω_abs : 0.06 m
- elem. size: $\lambda/6$ at $f = 200$ Hz
- 2nd order Lagrangian elements



4 EA Configurations



[3] M. Kaltenbacher and S. Floss. “Nonconforming Finite Elements Based on Nitsche-Type Mortaring for Inhomogeneous Wave Equation”. In: *Journal of Theoretical and Computational Acoustics* 26.03 (2018), p. 1850028

Simulation Model: Helmholtz Equation with Equivalent Fluid Model

$$\frac{\omega^2}{K(\omega,\vec{x})}p(\omega,\vec{x}) + \nabla\cdot\left(\frac{1}{\rho(\omega,\vec{x})}\nabla p(\omega,\vec{x})\right) = 0 \qquad \text{for} \qquad \vec{x}\in\Omega\,,$$

$$\text{Dirichlet BC:}\quad p = 1\,\text{Pa} \quad \text{for} \quad \vec{x} = \vec{x}_{\text{src}}\,,$$

$$\text{Neumann BC:}\quad \nabla p\cdot\vec{n} = 0 \quad \text{for} \quad \vec{x}\in\partial\Omega$$

$\omega \ldots$ angular frequency

$p \ldots$ acoustic pressure

$K \ldots$ bulk modulus of air/abs.

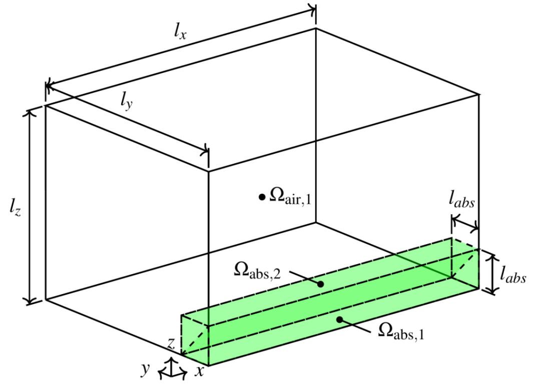
$\rho \ldots$ density of air/absorber

$\vec{x} \ldots$ point in space

- Excitation: Dirichlet boundary condition (point source)
- Sound-hard walls: homogeneous Neumann boundary condition
- Speed of sound $c = \sqrt{K/\rho}$

$$\rho(\vec{x},\omega) = \begin{cases}\rho_0 & \text{for } \vec{x}\in\Omega_{\text{air}}\\ \rho_{\text{abs}}(\omega) & \text{for } \vec{x}\in\Omega_{\text{abs}}\end{cases}; \qquad K(\vec{x},\omega) = \begin{cases}K_0 & \text{for } \vec{x}\in\Omega_{\text{air}}\\ K_{\text{abs}}(\omega) & \text{for } \vec{x}\in\Omega_{\text{abs}}\end{cases}$$

- Material model for $K_{\text{abs}}(\omega)$ and $\rho_{\text{abs}}(\omega)$ → **JCAL-Model**
- Helmholtz-Equation is solved using **Finite Element Method** (openCFS)



$\rho_0 = 1.2305\text{kg/m}^3$

$K_0 = 141855\text{Pa}$

$T_0 = 13.5\text{°C}$

Simulation Model:
JCAL-Model for Porous Materials

Viscous effects: $\rho_{\mathrm{abs}}(\omega) = \dfrac{\alpha_\infty \rho_{\mathrm{air}}}{\phi}\left[1 + \dfrac{\sigma\phi}{\mathrm{j}\omega\rho_{\mathrm{air}}\alpha_\infty}\sqrt{1 + \mathrm{j}\dfrac{4\alpha_\infty^2 \eta_0 \rho_{\mathrm{air}}\omega}{\sigma^2\Lambda^2\phi^2}}\right]$

Thermal effects: $K_{\mathrm{abs}}(\omega) = \dfrac{\gamma p_0/\phi}{\gamma - (\gamma-1)\left[1 - \mathrm{j}\dfrac{\phi\kappa}{k_0' C_{\mathrm{p}}\rho_{\mathrm{air}}\omega}\sqrt{1 + \mathrm{j}\dfrac{4k_0'^2 C_{\mathrm{p}}\rho_{\mathrm{air}}\omega}{\kappa\Lambda'^2\phi^2}}\right]^{-1}}$

- Parameters of air

$\eta_0 = 18.232 \cdot 10^{-6}$ kg/(m · s)…dynamic viscosity
$\kappa = 25.684 \cdot 10^{-3}$ W/(m · K)…thermal conductivity
$\gamma = 1.4$…isentropic exponent
$p_0 = 100325$ Pa…ambient air pressure
$C_{\mathrm{p}} = 1006.825$ J/(kg K)…specific heat of air at constant pressure

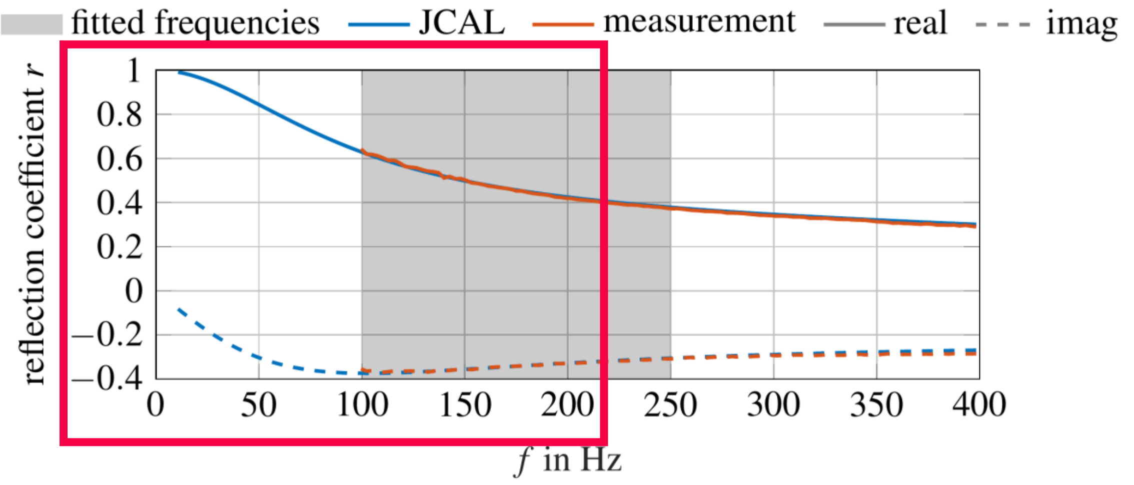
→known

6 JCAL-Parameters:

ϕ…open porosity
σ…static airflow resistance
α_∞…high-frequency limit of the tortuosity
Λ…viscous characteristic length
Λ'…thermal characteristic length
k_0'…static thermal permeability

→unknown

Fitting to impedance tube measurements [4,5]



[4] S. Floss, F. Czwielong, M. Kaltenbacher, and S. Becker. "Design of an in-duct micro-perforated panel absorber for axial fan noise attenuation". In: *Acta Acustica* 5 (2021) 24
[5] F. Kraxberger, E. Kurz, W. Weselak, G. Kubin, M. Kaltenbacher, and S. Schoder. „A validated finite element model for room acoustic treatments with edge absorbers". In: *Acta Acustica* 7 (2023) 48

Material Model in *openCFS*: material.xml (excerpt)

```
<cfsMaterialDataBase>
…
<material name="PorousMaterial">
 <acoustic>
  <density>
   <linear>
    <real> sample1D(‘/path/to/Basotect_JCAL_rho_RE.txt',f,1) </real>
    <imag> sample1D('/path/to/Basotect_JCAL_rho_IM.txt',f,1) </imag>
   </linear>
  </density>
  <compressionModulus>
   <linear>
    <real> sample1D('/path/to/Basotect_JCAL_K_RE.txt',f,1) </real>
    <imag> sample1D('/path/to/Basotect_JCAL_K_IM.txt',f,1) </imag>
   </linear>
  </compressionModulus>
 </acoustic>
</material>
…
</cfsMaterialDataBase>
```

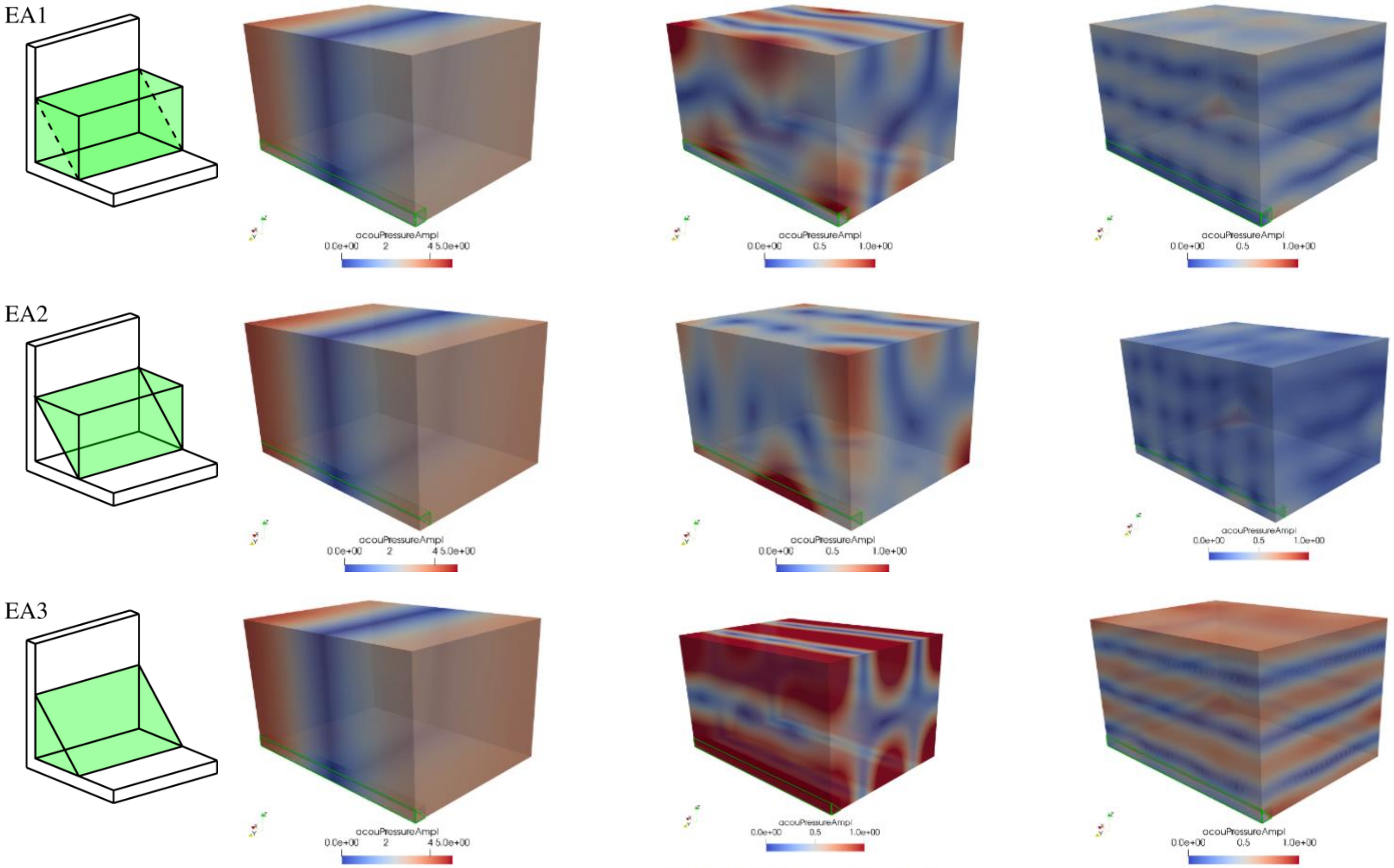
Material Model in *openCFS*: simulation.xml (excerpt)

```xml
<cfsSimulation>
<domain geometryType="3d">
 <regionList>
  <region name="V_mat" material="PorousMaterial" />
  …
 </regionList>
</domain>
…
<sequenceStep index="1">
 <pdeList>
  <acoustic >
   <regionList>
    <region name="V_mat" complexFluid="yes"/>
    …
   </regionList>
   …
  </acoustic>
 </pdeList>
</sequenceStep>
</cfsSimulation>
```

Field Results: Pressure

- EA influences the modal pressure field
  - Mode shape is distorted
  - Modal amplitude is reduced

- EA1 and EA2 distort the modal field
- EA3 can not achieve a similar distortion/damping



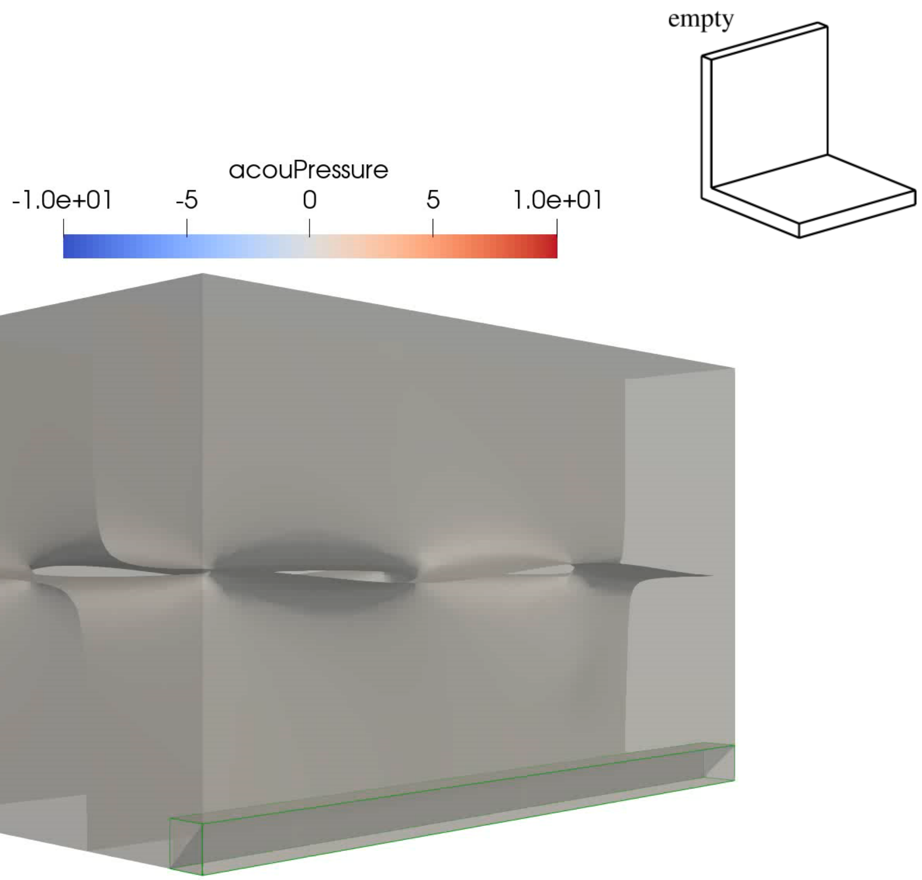
(a) (1, 0, 0)-mode at $f =$ 21.5 Hz

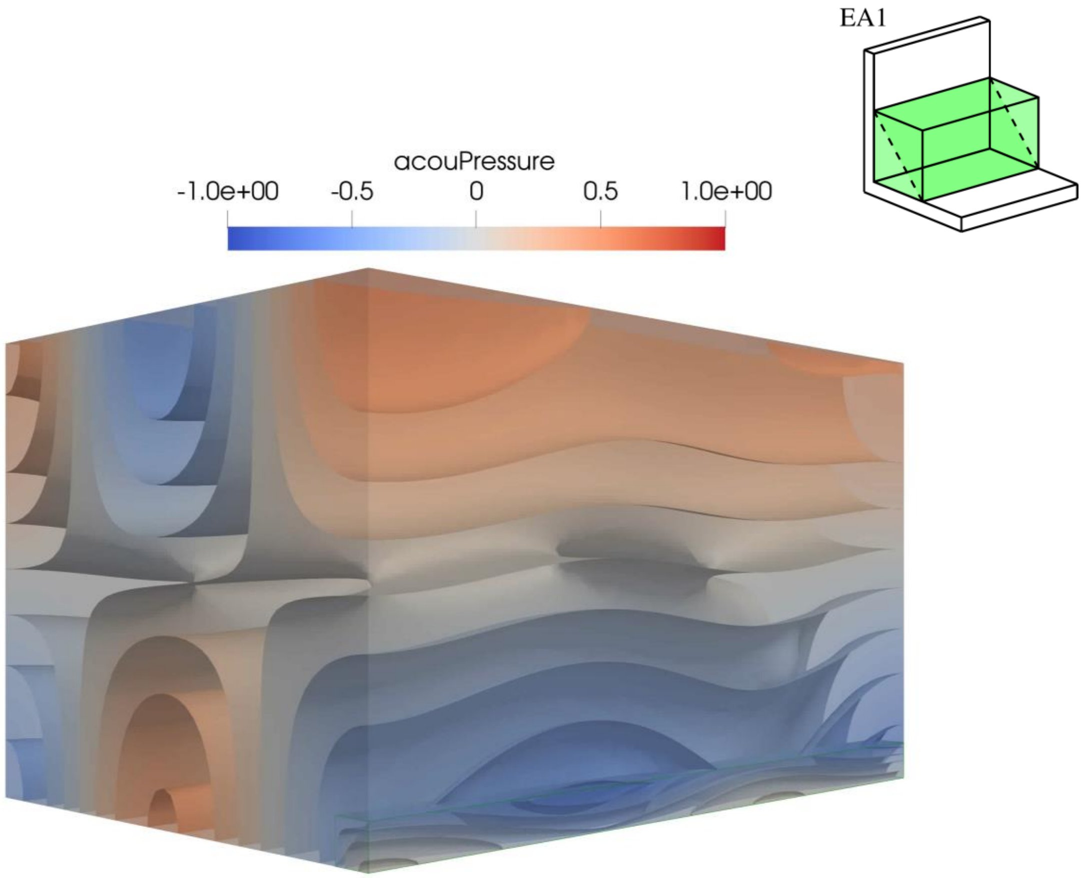
(b) (0, 2, 1)-mode at $f =$ 66.5 Hz

(c) (0, 0, 3)-mode at $f =$ 104.0 Hz

Field Results: Pressure at 66.5 Hz

Animation of isosurfaces of acoustic pressure (modal result)

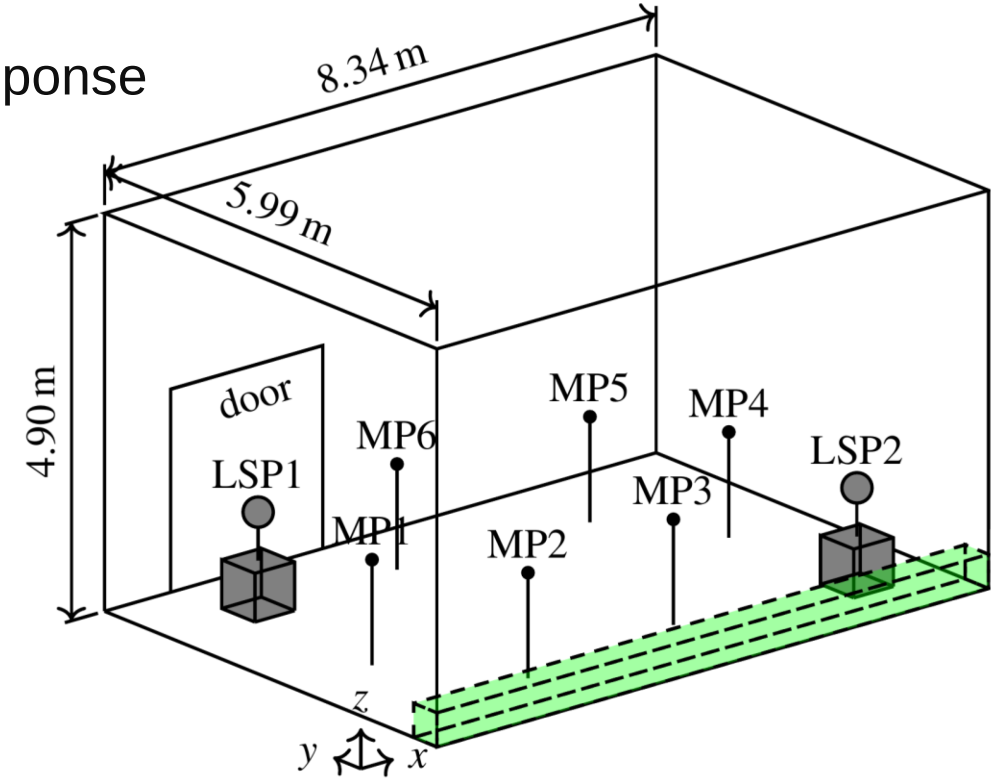




Validation with Impulse Response Measurements [5]

- Measurement: 12 impulse responses
  - 6 microphone positions (MP1 – MP6)
  - 2 loudspeaker positions (LSP1, LSP2)
  - → for each EA configuration
  - Equalization with inverse of loudspeaker frequency response
  - Level correction (median alignment)

- FE Simulation:
  - Source position at LSP1/LSP2
  - Evaluation points at the microphone positions
  - Amplitude normalisation of transfer functions



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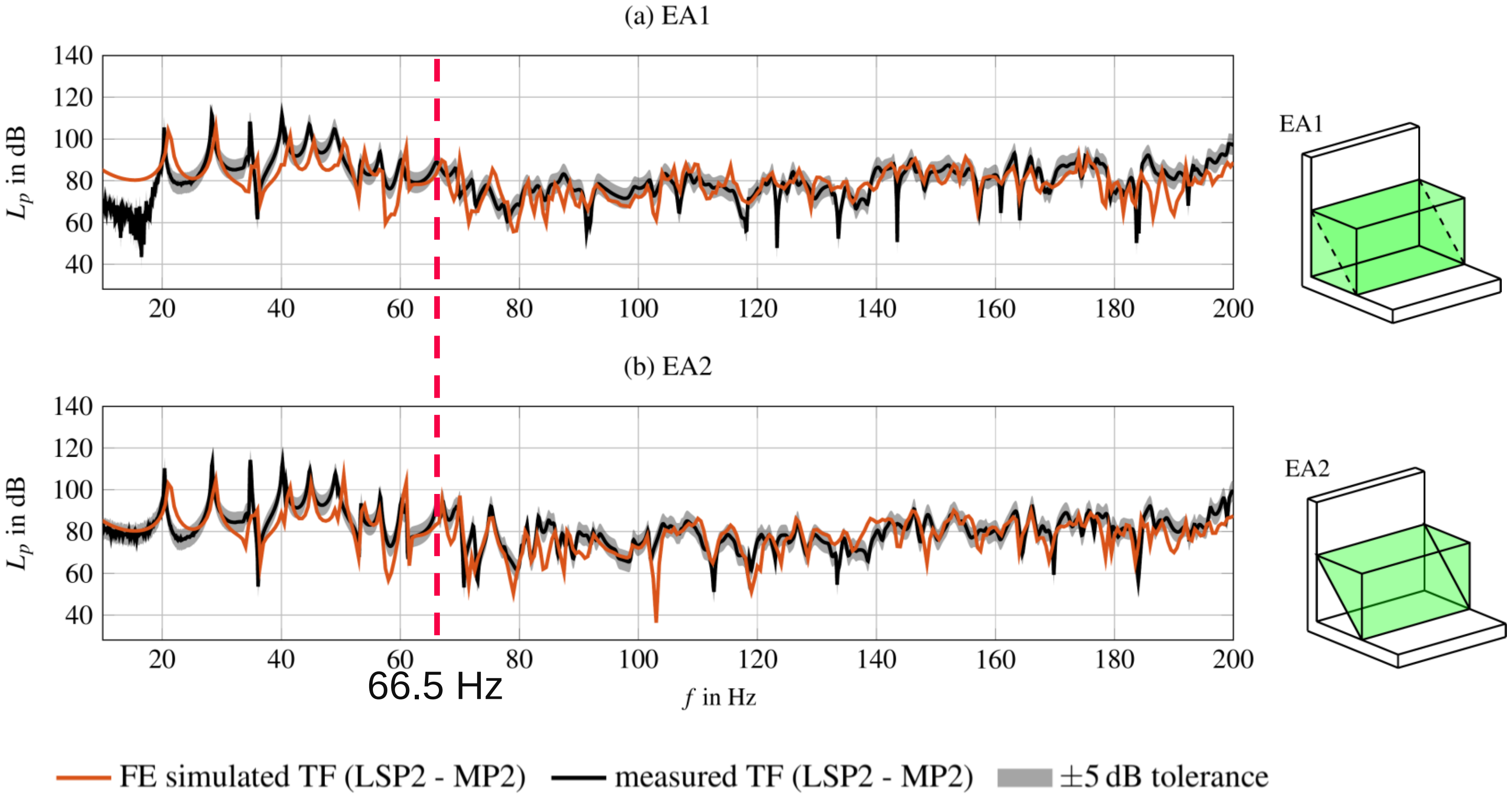

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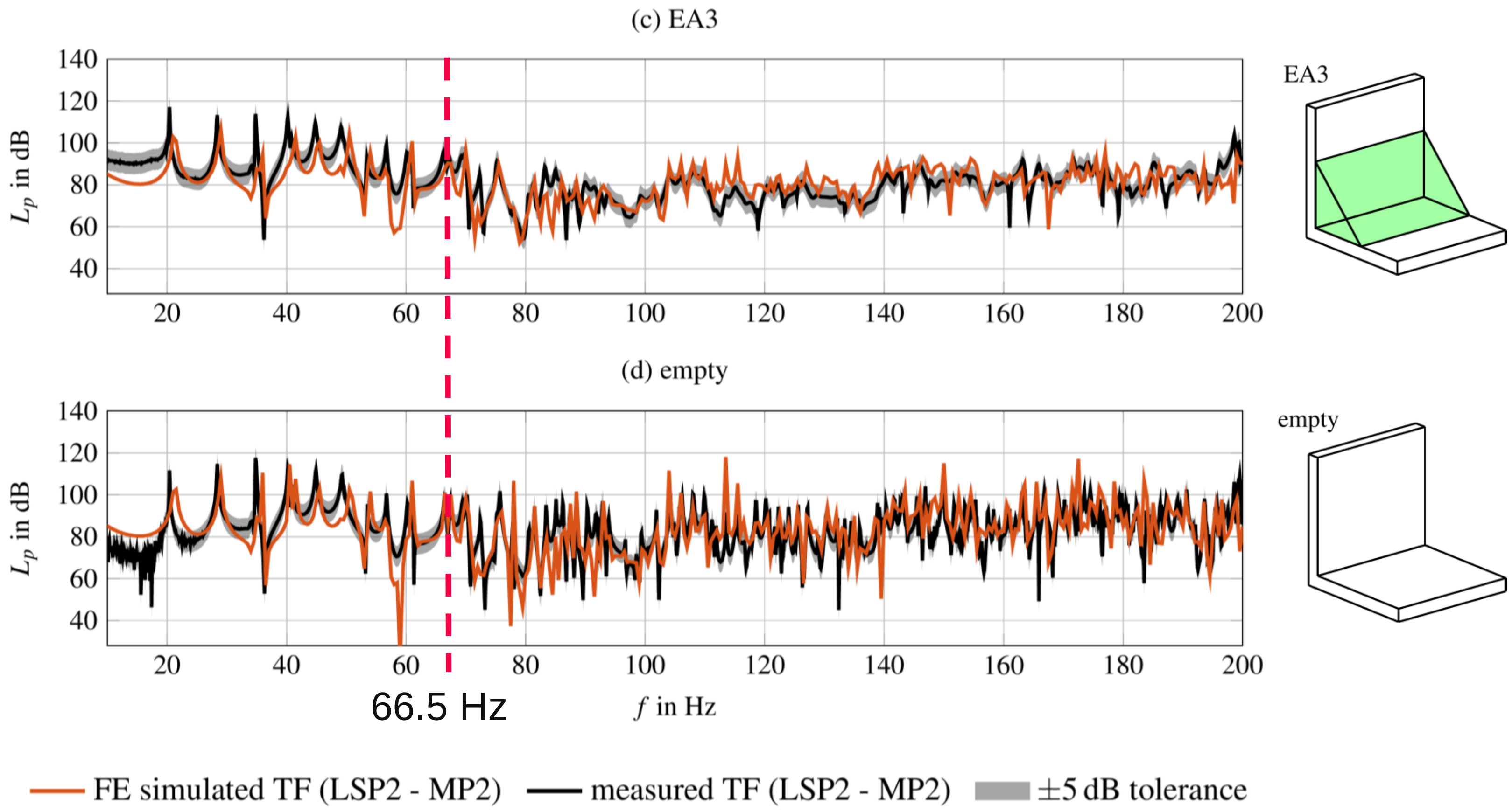

EA Config.	**3rd-Oct.-Avg.-Error [5]**
EA1	**3.44 dB**
EA1	**3.55 dB**
EA3	**4.11 dB**
Empty	**3.25 dB**

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[5] F. Kraxberger, E. Kurz, W. Weselak, G. Kubin, M. Kaltenbacher, and S. Schoder. „A validated finite element model for room acoustic treatments with edge absorbers“. In: *Acta Acustica* 7 (2023) 48

Conclusion

- FE model for different EA configurations in a reverberation chamber
- 3rd-Octave-band average error between 3.25 dB (empty) and 4.11 dB (EA3)
- EA distorts the modal field
- Wave propagation is dampened significantly in the absorber
- Validation shows good agreement between simulation and measurement
  - Reasons for minor deviations at low frequencies:
    - Influence of door
    - Concrete walls not purely sound hard for very low frequencies
- Journal paper [5]

[5] F. Kraxberger, E. Kurz, W. Weselak, G. Kubin, M. Kaltenbacher, and S. Schoder. „A validated finite element model for room acoustic treatments with edge absorbers“. In: *Acta Acustica* 7 (2023) 48

Thank you!
Questions?

Bibliography

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