



Synthèse de champ pour la mesure de matériaux absorbants

Samuel Dupont, (samuel.dupont@arteac-lab.fr)

Encadrement :

Manuel Melon, (manuel.melon@univ-lemans.fr)

Maryna Sanalatii, Jean-Christophe Le Roux,

Olivier Robin, Alain Berry

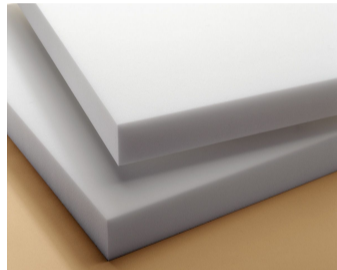
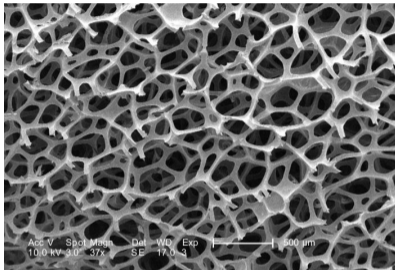
Université du Mans / CTTM / Université de Sherbrooke

ART≡AC 

Content

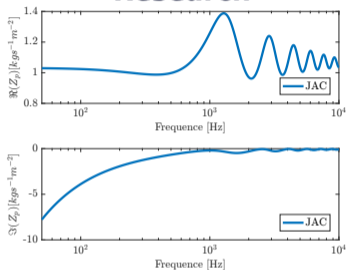
- 1 Contexte
- 2 Strategies
- 3 Method
- 4 Simulations
- 5 Experimental set up
- 6 Diffuse field

Acoustic Material



Targeted characteristics

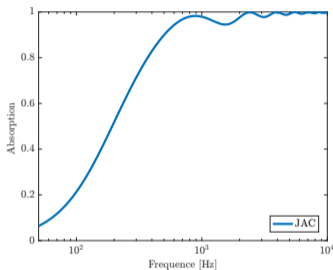
Research



Surface impedance of a melamine foam on a rigid backing

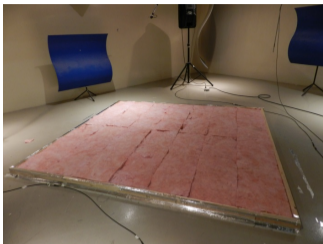


Application

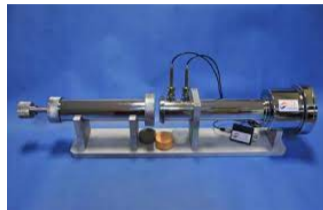


Absorption coefficient of a melamine foam on a rigid backing.

Standardized characterization methods



Reverberant chamber (GAUS).



Impedance tube (©CTTM).

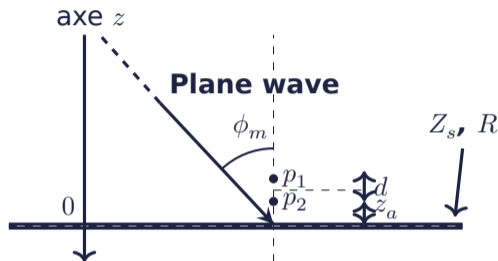
Limites

- Errors in low frequencies,
- Repeatability errors.

Limites

- Small samples,
- Normal incidence.

Historic strategies

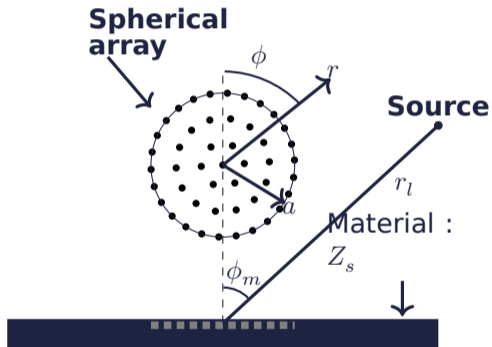


The microphonic doublet technique is used from the ratio $H = \frac{p_1}{p_2}$:

$$R \rightarrow Z_s \text{ \& } \alpha \quad (1)$$

Strategies

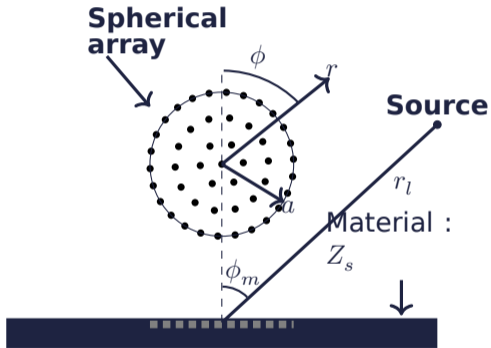
Microphone array [4]



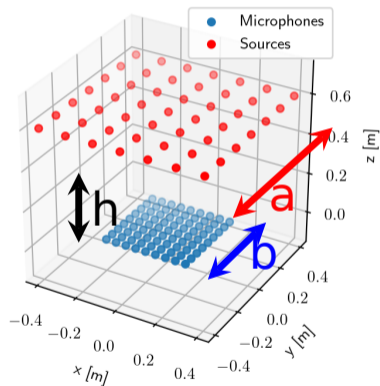
Loudspeaker array [5]

Strategies

Microphone array [4]



Loudspeaker array [5]



Strategies

Microphone array [4]

Pro

- High SNR,
- MEMS are cheap.

Cons

- Calibration process,
- Deal the problem as a consequence,
- Low frequency perturbations,
- Near field effects.

Loudspeaker array [5]

Pro

- High SNR,
- Deal the problem at the cause.
- Plane wave generation

Cons

- Set up can be cumbersome,
- Calibration process,
- Low frequency perturbations,
- Possible invasive set-up.

Content

1 Contexte

2 Strategies

3 Method
■ Inverse problem

4 Simulations

5 Experimental set up

6 Diffuse field

Inverse problem (1)

The pressure measured by the microphone m from the speaker l is defined by :

$$p_m(f) = g_{ml}(f)u_l(f) \quad (2)$$

where $g_{ml}(f)$ is the transfer function between the microphone m and the speaker l . In matrix form :

$$\mathbf{P} = \mathbf{G}\mathbf{u} \quad (3)$$

with :

$$\mathbf{P} = [p_1(f), p_2(f), \dots, p_M(f)]^T \quad (4)$$

$$\mathbf{G} = \begin{bmatrix} g_{11}(f) & \dots & g_{1L}(f) \\ \vdots & \dots & \vdots \\ g_{M1}(f) & \dots & g_{ML}(f) \end{bmatrix} \quad (5)$$

$$\mathbf{u} = [u_1(f), u_2(f), \dots, u_L(f)]^T \quad (6)$$

Inverse problem (2)

For any incidence, the target pressure field is noted :

$$\mathbf{P}_t = [p_{t1}, p_{t2}, \dots, p_{tM}]^T \rightarrow e^{j\omega \vec{k} \vec{r}}. \quad (7)$$

We are looking for the weights \mathbf{u}_{opt} :

$$\min |\mathbf{P}_t - \mathbf{G}\mathbf{u}|_2^2. \quad (8)$$

An approximate solution can be obtained by the least squares method :

$$\mathbf{u}_{opt} = [\mathbf{G}^H \mathbf{G} + \lambda \mathbf{I}]^{-1} \mathbf{G}^H \mathbf{P}_t, \quad (9)$$

Content

1 Contexte

2 Strategies

3 Method

4 Simulations

- Sound pressure fields
 - Parametric study
 - Modeling the porous material
 - Microphone doublet

5 Experimental set up

6 Diffuse field

Strategies

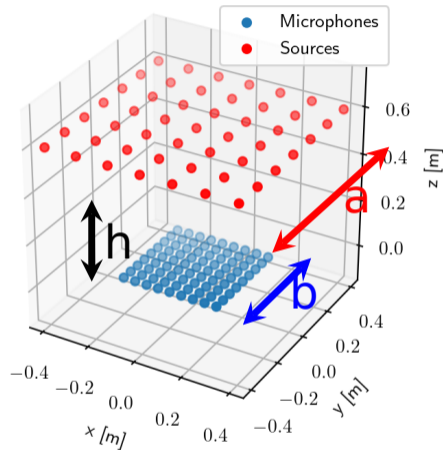


Figure - Example system configuration : 49 sources, $a = 80$ cm and 81 microphones, $b = 40$ cm, $h=60$ cm

Simulation : sound field synthesis (SFS)

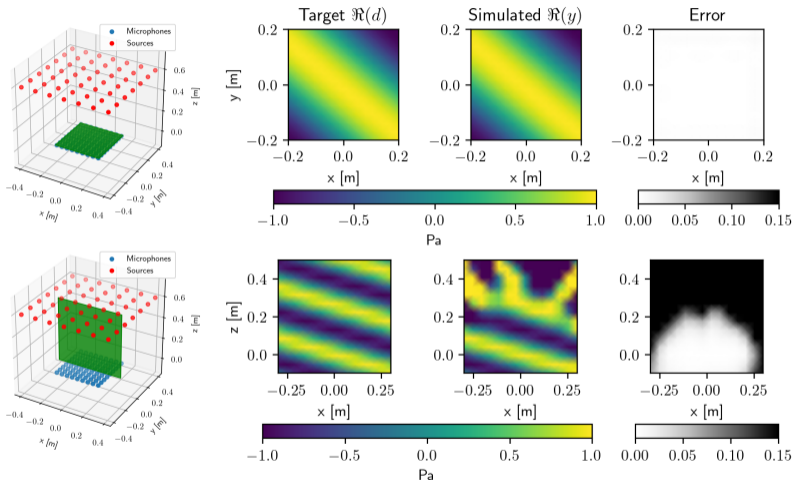


Figure - (xy en $z = 0$ cm) et (xz en $y = 0$ cm) à 1500 Hz. $\phi_m = 10^\circ$, $\theta_m = 45^\circ$, $\lambda = 10^{-5}$.

Parametric study

1. b : the size of the target area
2. ϕ_m : the incidence of the plane wave
3. a : the size of the hp antenna
4. h : the height of the hp plane - microphones
5. the number of hp
6. the number of microphones
7. λ : the regularization parameter

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Parametric study

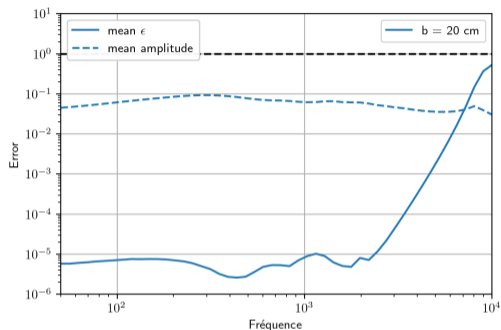


Figure - Error ϵ and average amplitude of the sources by varying b . $a = 100$ cm, $\theta_m = 45^\circ$, $\phi_m = 10^\circ$, $\lambda = 10^{-5}$

Parametric study

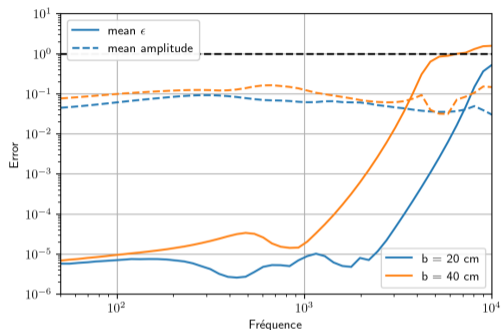


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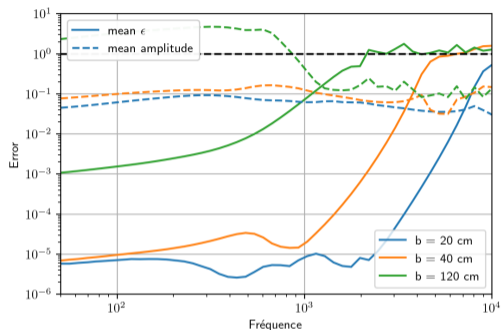


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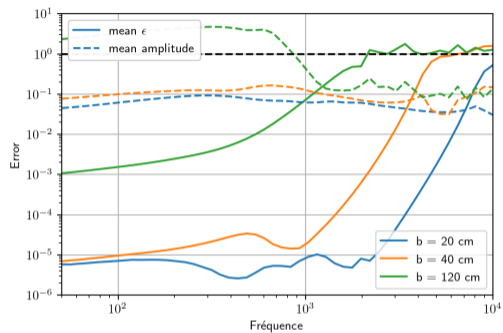


Figure - Error ϵ and average amplitude of the sources by varying b . $a = 100$ cm, $\theta_m = 45^\circ$, $\phi_m = 10^\circ$, $\lambda = 10^{-5}$

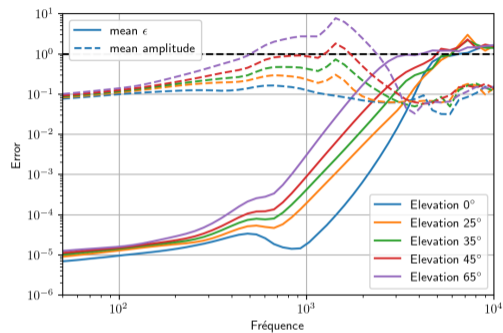


Figure - Error ϵ and average amplitude of the sources by varying the incidence. $a = 100$ cm, $b = 40$ cm, $\theta_m = 45^\circ$, $\lambda = 1 \times 10^{-5}$

SFS : simulation sum up

Good stuff

1. The field is accurately reproduced over a range of frequency (here : 50 - 3000 Hz)
2. One can easily dimension the system by using as a criterion the error of the reproduced field.

Bad stuff

1. The high cut off frequency decreases with the angle of incidence.
2. A bad choice of dimensions implies a high effort of the array.

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- Sound pressure fields
- Parametric study
- **Modeling the porous material**
- Microphone doublet

5 Experimental set up

6 Diffuse field

Simulation of porous material

1. Johnson – Champoux – Allard (JCA) Model [1] :

σ	10000	[N.s.m ⁻⁴] Resistivity
h_p	0.05	[m] Material thickness
ϕ	0.93	Porosity
Λ	60	[μ m] Viscous length
Λ	100	[μ m] Thermal length
α_∞	1.1	Tortuosity

Table – JCA model parameters of a melamine foam characterized by CTTM

2. The sound field of a monopole source above a layer of porous material is calculated by the formulation proposed by Allard *et al.* [2] :

$$p(r, z) = \frac{e^{-ik_0 R_1}}{R_1} - \frac{e^{-ik_0 R_2}}{R_2} - \int_0^\infty \frac{2\rho_m e^{-\nu_0(z_s+z_r)}}{\rho_1\nu_0 + \rho_0\nu_1 \tanh \nu_1 d} k J_0(kr) dk, \quad (10)$$

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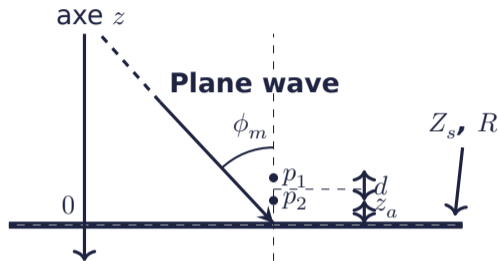
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Measurement with a microphone pair



The microphonic doublet technique is used from the ratio $H = \frac{p_1}{p_2}$:

$$R = \frac{H - e^{jk_0 z_a} \cos \phi_m}{e^{jk_0 z_a} \cos \phi_m - H} e^{2jk_0 h_p \cos \phi_m} \rightarrow Z_s \ \& \ \alpha \quad (11)$$

Measurement simulation with noise

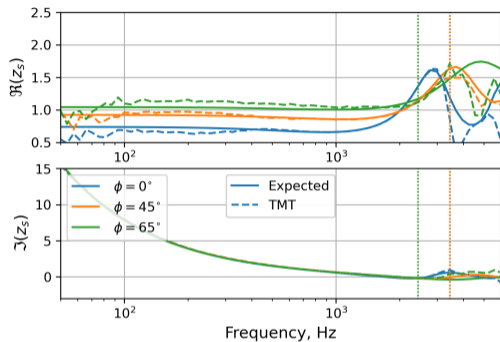


Figure - Normalized surface impedance
 z_s , $a = 105$ cm, $b = 40$ cm, $\theta_m = 45^\circ$,
 $\lambda = 1 \times 10^{-5}$.

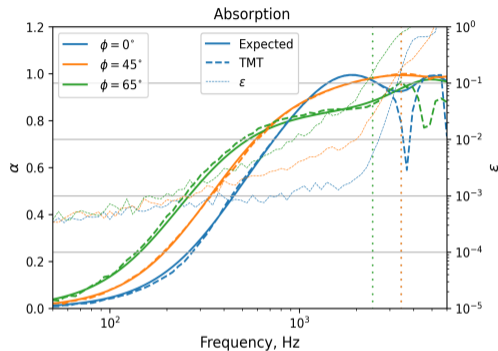


Figure - Absorption coefficient α , px
 $a = 105$ cm, $b = 40$ cm, $\theta_m = 45^\circ$,
 $\lambda = 1 \times 10^{-5}$, $d = 2$ cm, $z_a = 0.5$ cm

Sum up of the simulations

Good stuff

1. Measurement of acoustic parameters at multiple incidences over a wide frequency range that can be adjusted is possible,
2. Confidence criterion related to the error of the predicted field is established.

Bad stuff

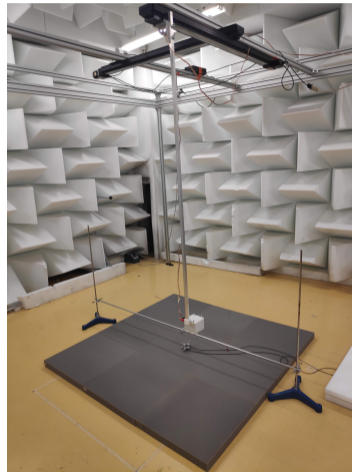
1. The confidence criterion is a prerequisite, not a certainty,
2. Noisy measures are degrade in LF.

Experimental set up

Physical source array



Virtual source array



Experimental set up

Physical source array

Pros

1. Very fast measurement : 30s for an elevation, 20 min for a full measurement.

Cons

1. Slow calibration
2. Invasive set-up

Virtual source array

Pros

1. Fast calibration (microphone pair only)

Cons

1. Slow measurement (40 min-2 h)

Experimental Results (1)

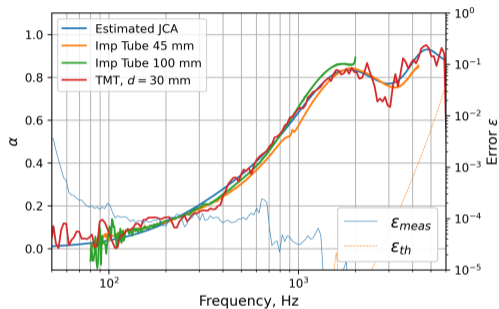


Figure - α , $\phi_m = 0^\circ$. $a = 105$ cm, $b = 60$ cm, $\Delta_m \approx 6.6$ cm, $\theta = 0^\circ$, $z_a = 0.5$ cm, $d = 1.5$ cm. $\epsilon_{th} : \lambda = 10^{-7}$, $\epsilon_{meas} : \lambda = 0$.

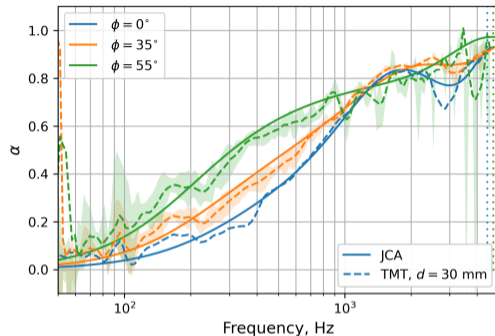


Figure - Mean absorption coefficient α , with $a = 105$ cm, $b = 33$ cm, $\Delta_m \approx 6.6$ cm, $\lambda = 10^{-9}$, $z_a = 0.5$ cm, $d = 3$ cm.

Experimental Results (2)

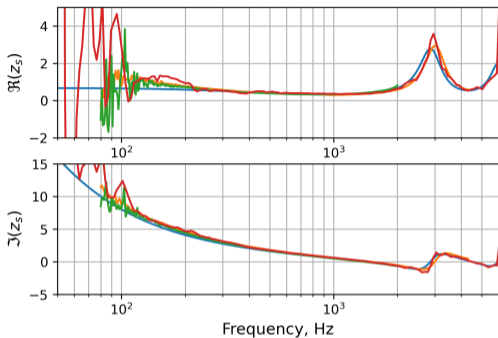


Figure - z_s , $\phi_m = 0^\circ$. $a = 105$ cm,
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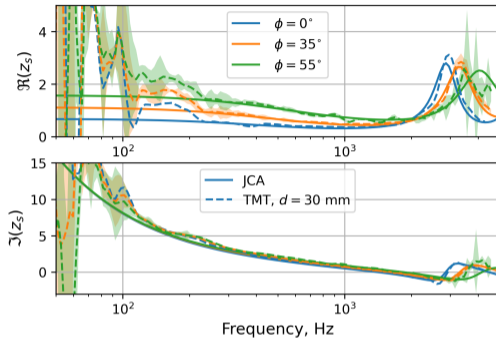


Figure - Mean normalized surface impedance z_s (b), with $a = 105$ cm,
 $b = 33$ cm, $\Delta_m \approx 6.6$ cm, $\lambda = 10^{-9}$,
 $z_a = 0.5$ cm, $d = 3$ cm.

Diffuse field : theoretical Paris formula

$$\alpha_d = \frac{\int_0^{\phi_{lim}} \alpha(\phi) \sin 2\phi \, d\phi}{\int_0^{\phi_{lim}} \sin 2\phi \, d\phi}. \quad (12)$$

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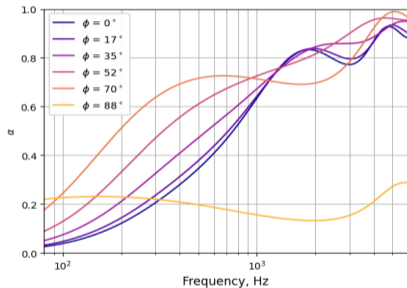


Figure - Theoretical absorption coefficient $\alpha(\phi)$ of a polyurethane foam.

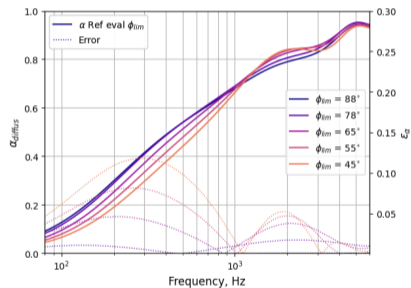


Figure - Diffuse absorption coefficient

Diffuse field : measure with the virtual source array)

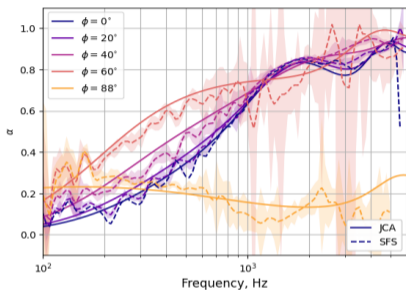


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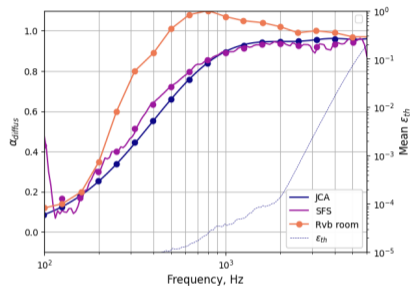


Figure - Diffuse absorption coefficient of a glass wool material.

Conclusion

Pros

Angle dependant absorption coefficient (150 Hz - 3 to 5 kHz).

Diffuse field absorption coefficient (150 Hz - 3 kHz).

Fairly cheap setup (Virtual source array).

Fast measurement (Physical source array).

Small samples (150 cm \times 150 cm).

Limits

Edge effect and room effects (LF).

Speaker directivity and diffraction (HF).

Slow measurement (Virtual array).

Conclusion

Under study

Extending the bandwidth.

Mitigating the edge and room effects.

Reducing the size of the sample (limit around 150 cm in the slide).

In situ studies.

True diffuse field implementation.

Obtain acoustic parameters of the material (ρ_{eff} , K_{eff}).

Thank you for your attention !

Acknowledgement : The authors would like to thank Nicolas Poulain at CTTM for performing the measurements used to obtain the parameters of the JCA model, James Blondeau and Félix Lebeuf for their help with the measurements.

Material size effect

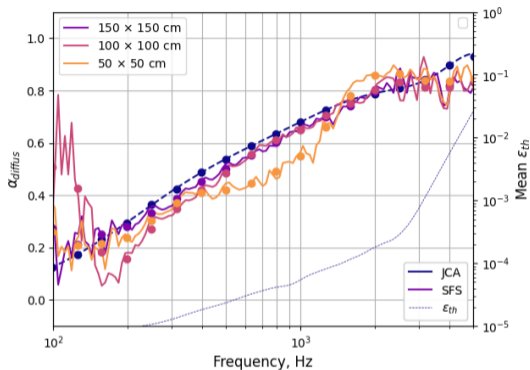


Figure - Theoretical (JCA) versus measured (SFS) diffuse field absorption coefficient α_d of material PU1 with $\phi_{lim} = 88^\circ$ and $\lambda = 10^{-6}$. Measurements have been performed for 3 different material sizes.

Integration average effect

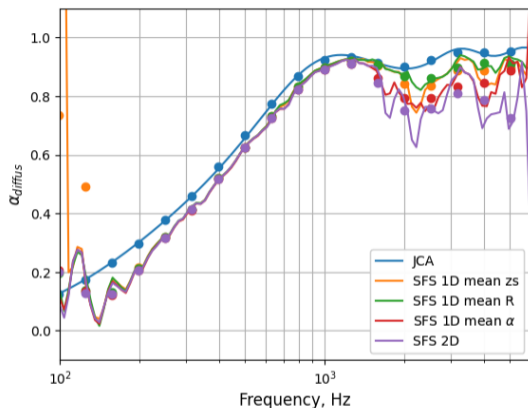


Figure - Theoretical (JCA) versus measured (SFS) diffuse field absorption coefficient α_d , 1D and 2D.

Diffuse field : measure with the virtual vs physical array

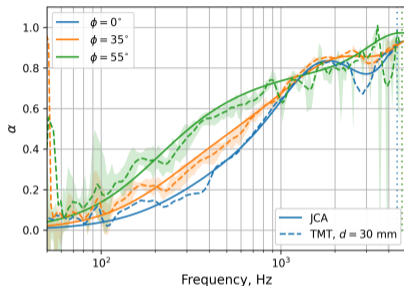


Figure - Absorption coefficient $\alpha(\phi)$ of a polyurethane foam (Physical Array).

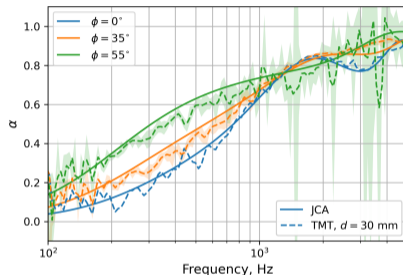







Figure - Diffuse absorption coefficient of a glass wool material (Virtual Array).

-  J. F. Allard et N. Atalla, Propagation of sound in porous media : modelling sound absorbing materials, *Wiley*, 2009,
-  J.F. Allard, W. Lauriks et C. Verhaegen, , The acoustic sound field above a porous layer and the estimation of the acoustic surface impedance from free-field measurements, *The Journal of the Acoustical Society of America*, **91**, 3057-3060 (1992)
-  J.F. Allard et B. Sieben, Measurements of acoustic impedance in a free field with two microphones and a spectrum analyzer, *The Journal of the Acoustical Society of America*, **77**, 1617-1618 (1985)
-  Dupont, S., Melon, M. & Berry, A. Characterization of acoustic material at oblique incidence using a spherical microphone array. *The Journal Of The Acoustical Society Of America*. **147**, 3613-3625 (2020), Publisher : Acoustical Society of America
-  Dupont, S., Sanalattii, M., Melon, M., Robin, O., Berry, A. & Le Roux, J. Characterization of acoustic materials at arbitrary incidence angle using sound field synthesis. *Acta Acustica*. **6** pp. 61 (2022), Publisher : EDP Sciences