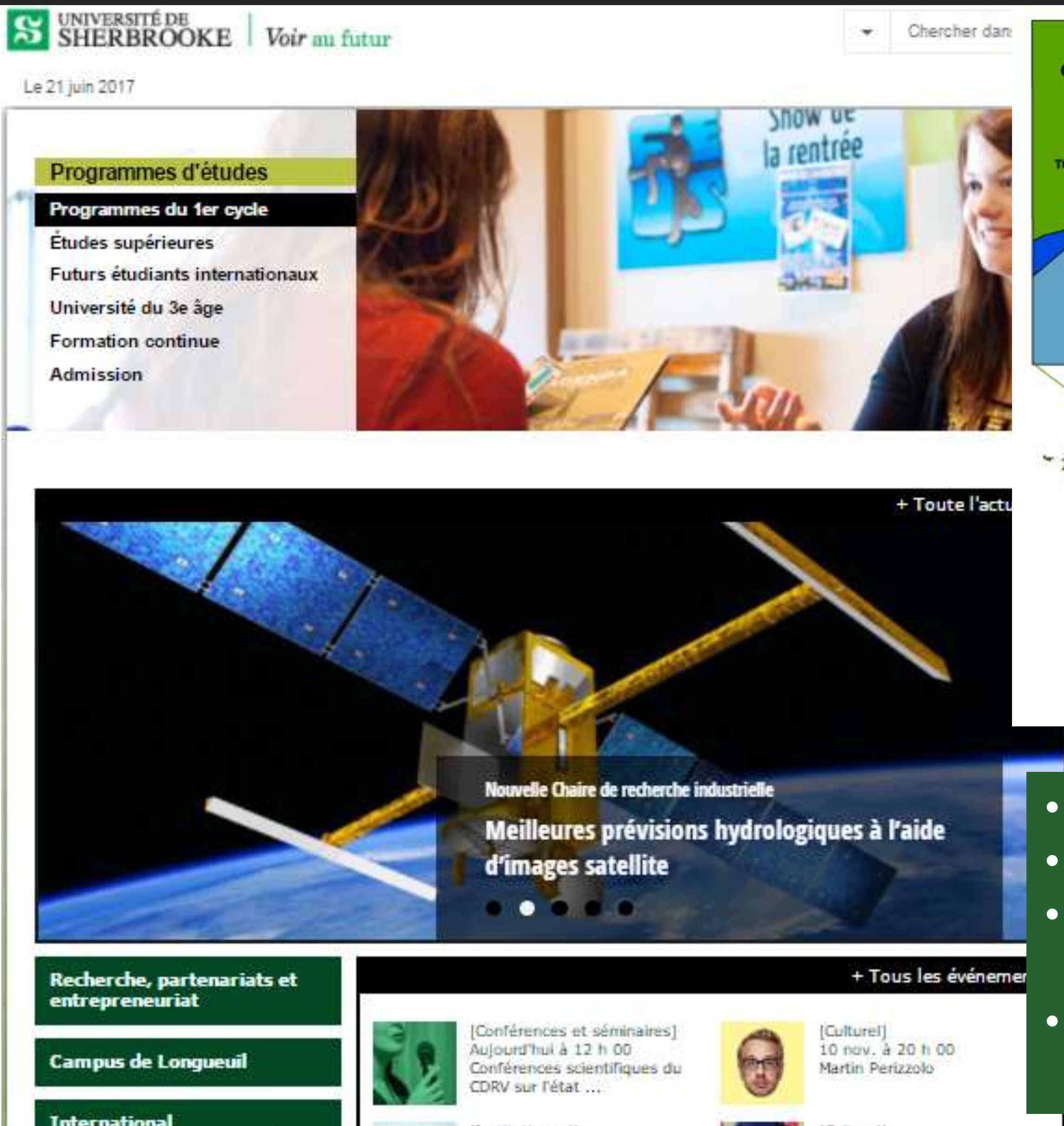
Le Groupe d’Acoustique de l’Université de Sherbrooke

Olivier ROBIN, Ph.D.
National Colloquium on Sustainable Aviation, UTIAS, Toronto, June 21 – 23, 2017

UNIVERSITÉ DE SHERBROOKE

GAUS
GROUPE D'ACOUSTIQUE DE L'UNIVERSITÉ DE SHERBROOKE

L'Université de Sherbrooke



Distancias en Km entre SHERBROOKE y...

Montréal	147
Québec	237
Portland	299
Boston	434
New York	657
Toronto	693
Philadelphie	850
Baltimore	965
Washington	1091

- French-speaking institution
- 40,000 students
- Co-operative program in most faculties
- 1st in Canada in patent licensing
  10th in publication impact

GAUS

- **Established in 1984 by Pr. Jean Nicolas**
- **Part of the Mech. Eng. Dept.**
- **Around 70 people:**

5 professors, 12 research professionals, 22 MSc, 24 PhD, 4 postdocs

GAUS (...)

- **Noureddine Atalla**: Vibro-acoustics, computational methods, acoustic materials

- **Alain Berry**: vibro-acoustics, active control, acoustic imaging, sound field synthesis

- **Patrice Masson**: active control, mechatronics, ultrasound, structural monitoring

- **Philippe Micheau**: active control, mechatronics, bio-engineering structural monitoring

- **Raymond Panneton**: acoustic materials, eco-materials, computational methods

GAUS (…)

- **Largest Canadian academic research center** in vibration and acoustics
- **NSERC industrial chairs** in aerospace acoustics (Atalla, Berry, 2009-2014)
- **Canada Research Chair in Vibroacoustics applied to the transportation sector** (Berry, 2016-2023)
- «**Center of excellence**» of Université de Sherbrooke since 2001
- **Numerous industrial partners in transport sector** (Airbus, Alstom, BRP, Boeing, Bombardier Aerospace, Bell Helicopter Textron, Daimler-Chrysler, P&W Canada, Valeo, Woodbridge foams, …)
- **Strategic academic collaborations with France**: Lyon (LVA, LFMA, LTDS), Le Mans (LAUM)
- **New international liaison (2017)** : CAV / Penn State University, USA

Bridging vibroacoustics and sustainable aviation

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Facts

- Sustainable aviation mainly implies reducing noise pollution and fuel consumption (and weight gains are efficient to reach this goal)
- From a vibroacoustic point of view

(1) Lighter and stiffer materials (i.e. composite structures) usually result in ‘poorer acoustics’

(2) Standards materials must have large thickness to provide large sound absorption especially at low frequencies (then large dimensions and weight)

(3) The Turbulent Boundary Layer excitation, that develops over the fuselage, is not that well understood but still the main noise source in the cockpit

Facts

(1) Lighter and stiffer materials (i.e. composite structures) usually result in 'poorer acoustics'

-> new tools for characterizing structures and their loadings (A.Berry and P. O'Donoughue, GAUS)

(2) Standards materials that provide large sound absorption especially at low frequencies must have large thickness (then large dimensions and weight)

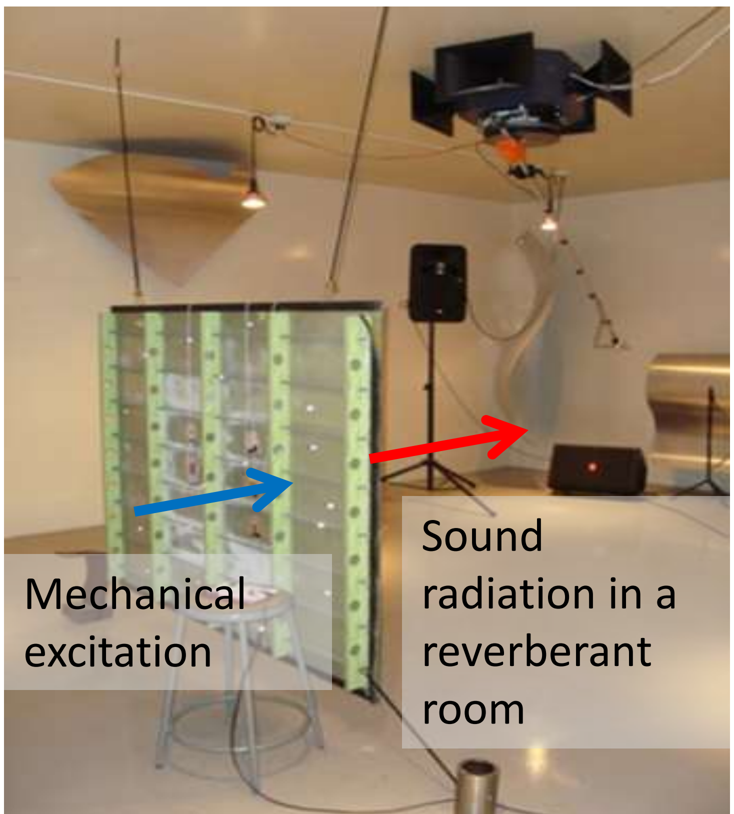
-> new materials designs or arrangements (N. Atalla et al.)

(3) The Turbulent Boundary Layer excitation, that develops over the fuselage, is not that well understood but still the main noise source in the cockpit

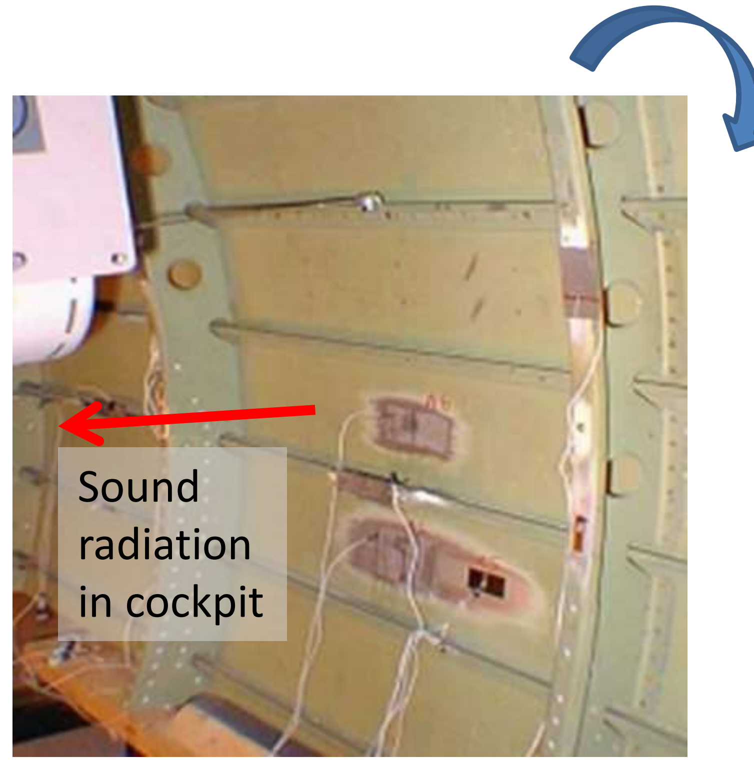
-> new sensors for characterizing this excitation (A.Berry, C.Marchetto, GAUS, P. Bremner, AeroHydroPlus, et al.)

Characterizing structures and their loadings

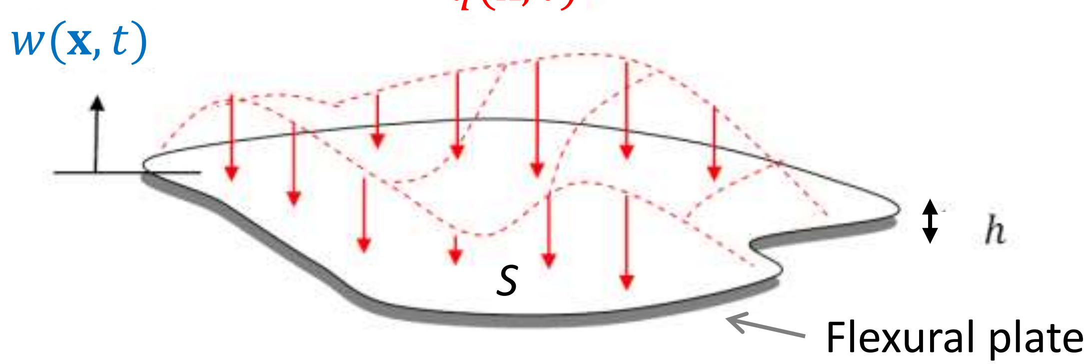
A partition (a fuselage panel) under acoustic or mechanical excitation will then vibrate and radiate noise



TBL excitation



Local equilibrium equation of a plate



- **Local equilibrium** (Love-Kirchhoff plate):

$$\rho h \frac{\partial^2 w(\mathbf{x},t)}{\partial t^2} - \frac{h^3}{12}\{1,1,2\}\begin{bmatrix} \frac{\partial^2}{\partial x^2} & 0 & 0 \\ 0 & \frac{\partial^2}{\partial y^2} & 0 \\ 0 & 0 & \frac{\partial^2}{\partial x \partial y} \end{bmatrix} \mathbf{Q}(\mathbf{x})\mathbf{k}(\mathbf{x},t) = q(\mathbf{x},t)$$

Transverse acceleration field

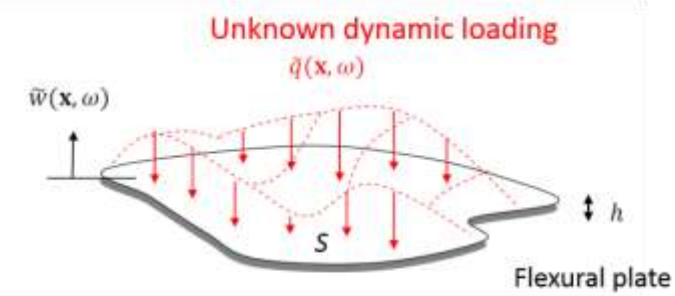
3 x 3 elastic matrix (known a priori)

Bending curvature field

$$\mathbf{k}(\mathbf{x},t) = -\left\{ \frac{\partial^2}{\partial x^2} \quad \frac{\partial^2}{\partial y^2} \quad 2\frac{\partial^2}{\partial x \partial y} \right\} w(\mathbf{x},t)$$

The Virtual Fields Method

- **Virtual Work Principle:**



$$h\int_S \rho w^v(\mathbf{x})\frac{\partial^2 w(\mathbf{x},t)}{\partial t^2}d\mathbf{x} + \frac{h^3}{12}\int_S \mathbf{k}^{v^T}(\mathbf{x})\mathbf{Q}(\mathbf{x})\mathbf{k}(\mathbf{x},t)d\mathbf{x}$$
$$= \int_S w^v(\mathbf{x})q(\mathbf{x},t)d\mathbf{x}$$

Virtual displacement

Virtual curvature

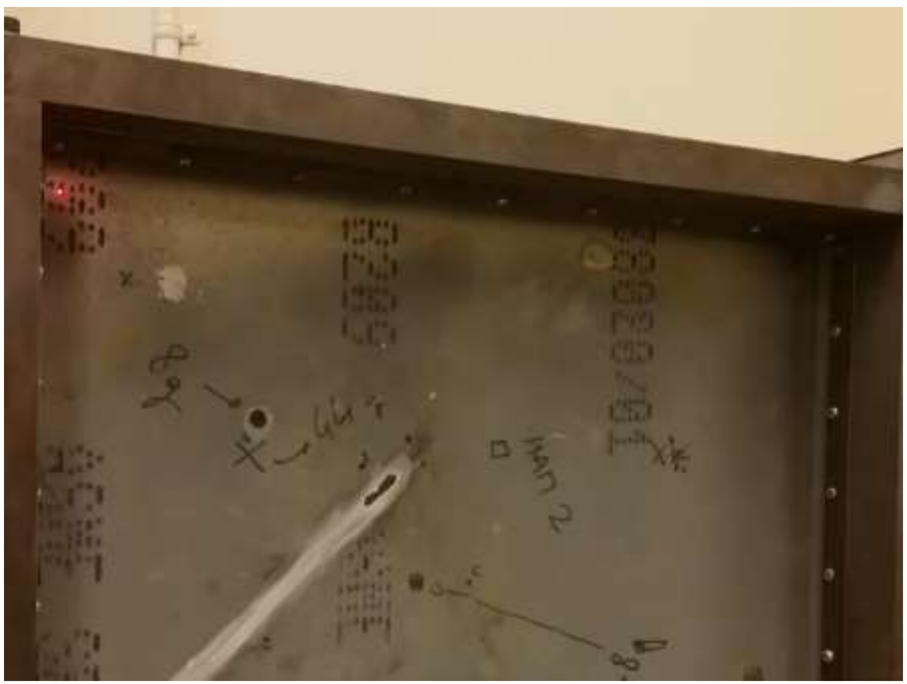
No 4th-order spatial derivatives of $w(\mathrm{x},t)$ involved

- In the frequency domain,

$$-h\omega^2\int_S \rho w^v(\mathbf{x})\tilde{w}(\mathbf{x},\omega)d\mathbf{x} + \frac{h^3}{12}\int_S \mathbf{k}^{v^T}(\mathbf{x})\tilde{\mathbf{Q}}(\mathbf{x})\mathbf{k}(\mathbf{x},\omega)d\mathbf{x} = \int_S w^v(\mathbf{x})\tilde{q}(\mathbf{x},\omega)d\mathbf{x}$$

Full field measurements

- Scanning Doppler laser vibrometry (stationary loading)



Transverse velocity field $v(\mathbf{x}, \omega)$

$\frac{1}{j\omega}$

Transverse displacement field $w(\mathbf{x}, \omega)$

Low wavenumber filtering

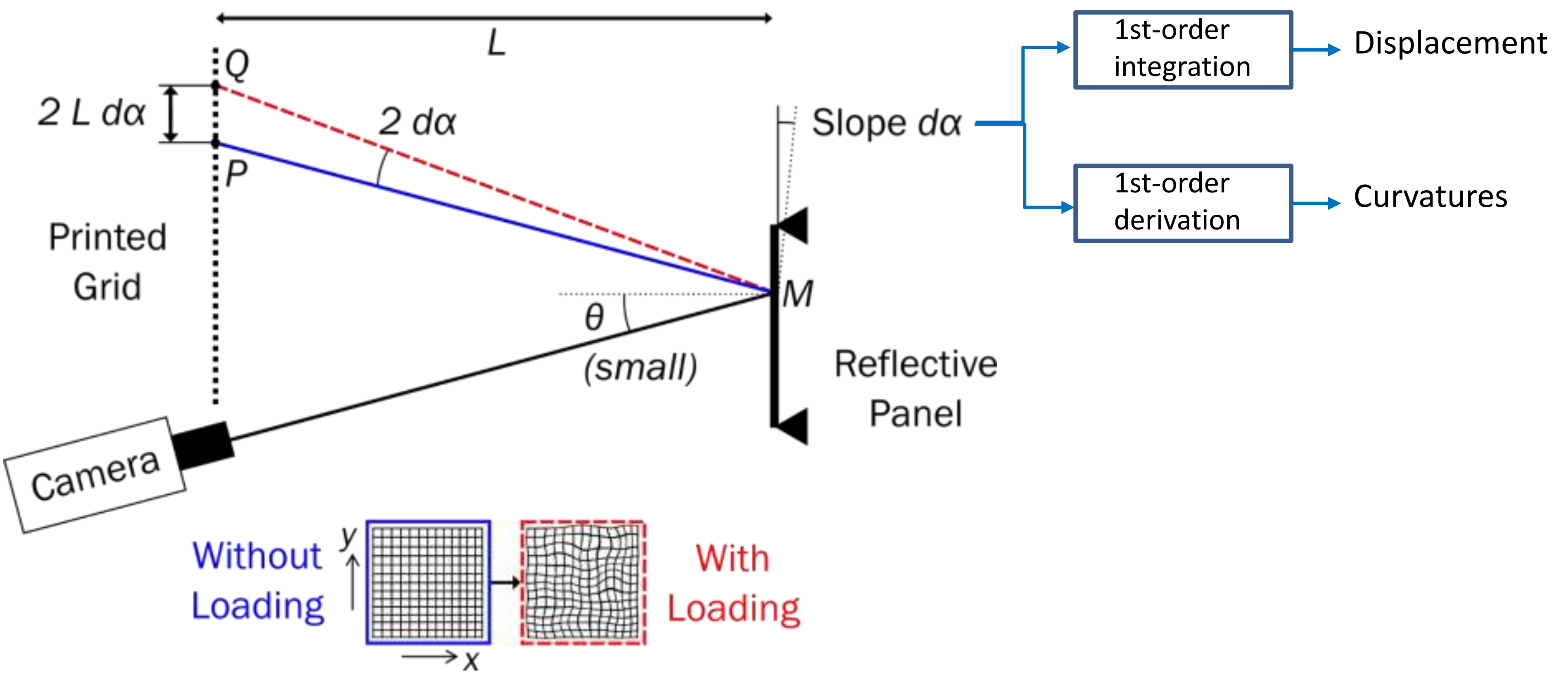
$w_{filt}(\mathbf{x}, \omega)$

Finite difference

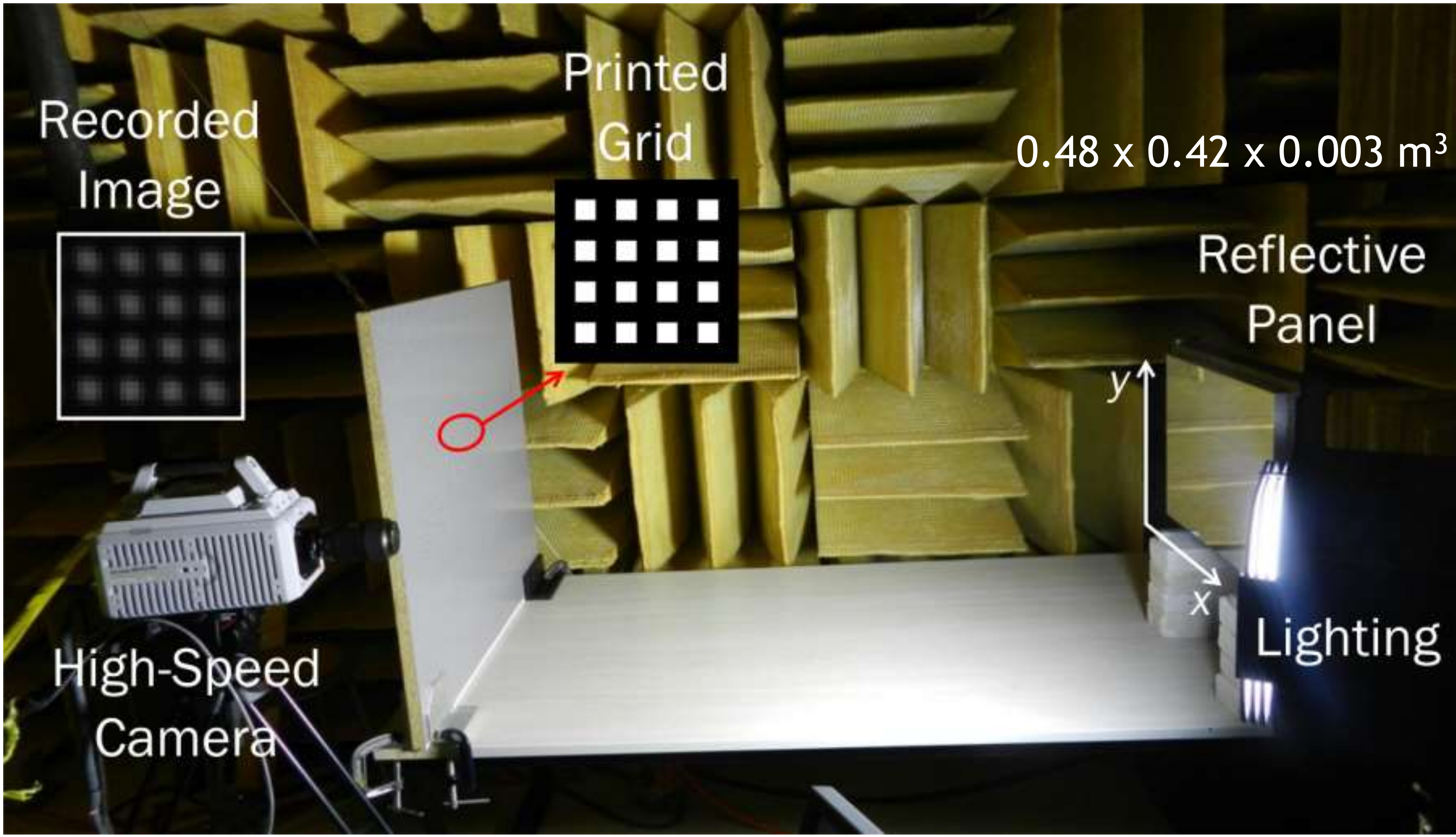
Curvature field $\mathbf{k}(\mathbf{x}, \omega)$

Full field measurements (…)

- Optical deflectometry

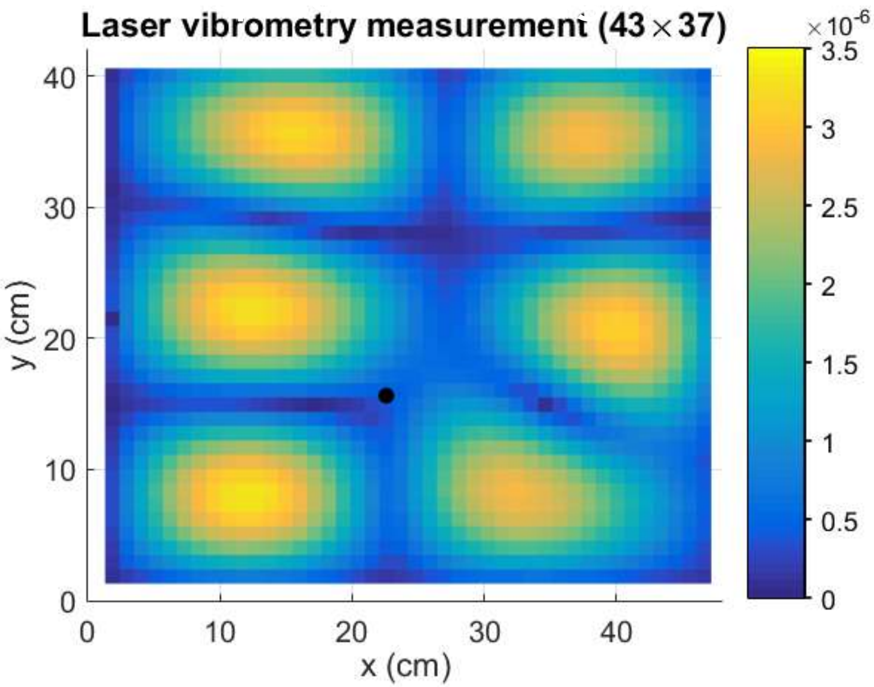


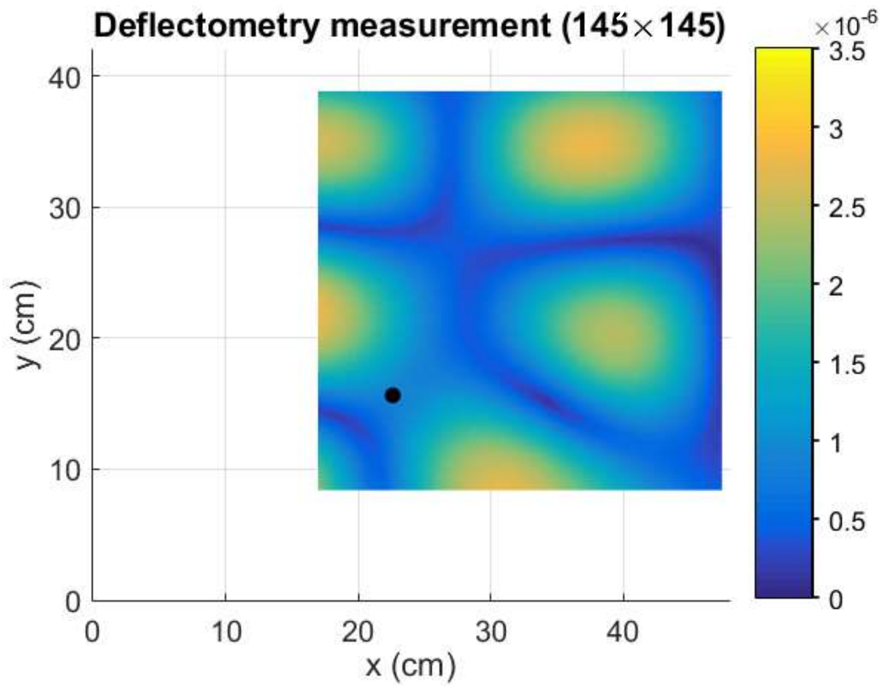
Full field measurements (...)



Full field measurements (...)

- LDV vs deflectometry
  - Displacement magnitude (in m) under shaker excitation, f = 525Hz

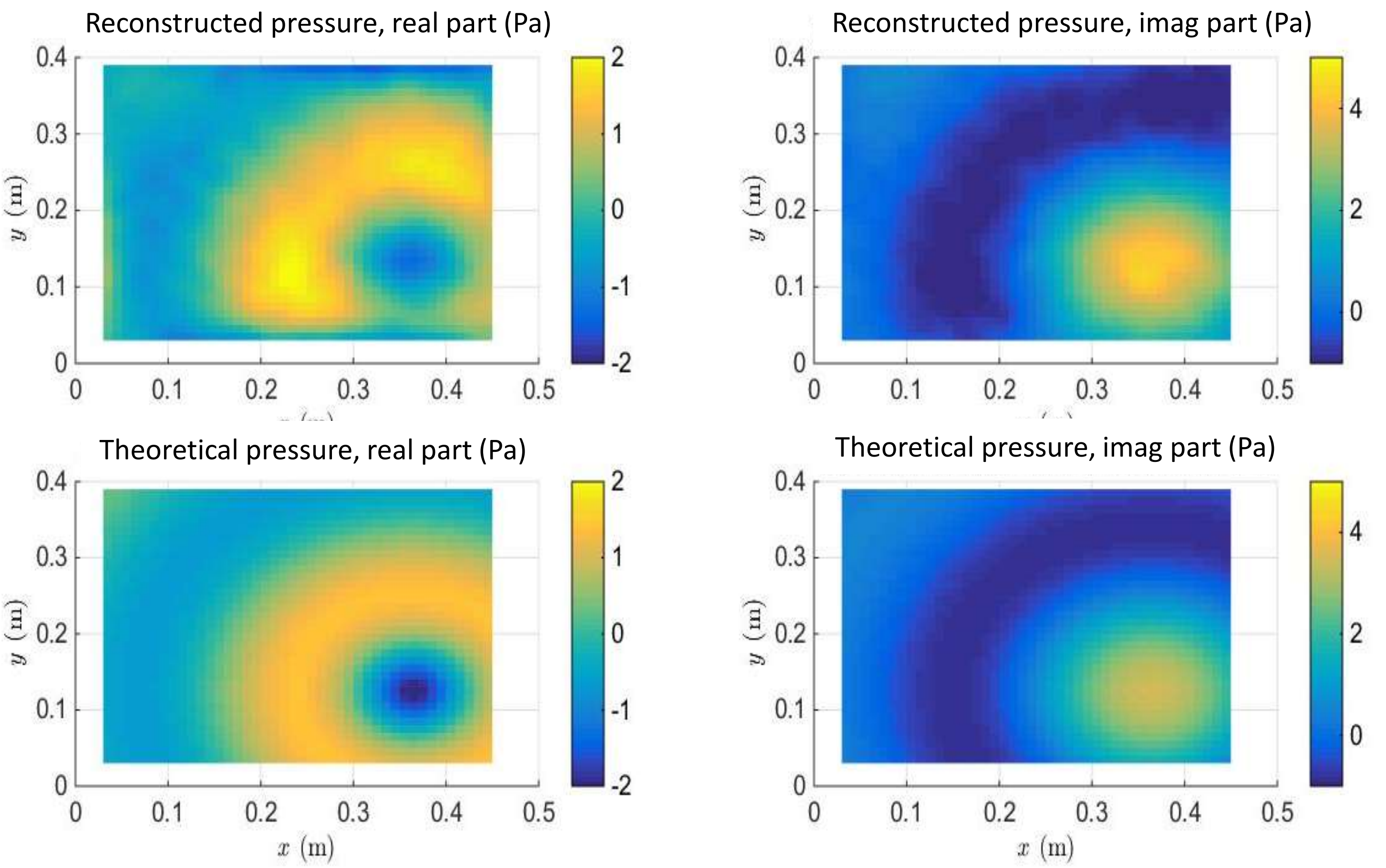




Number of points:	**1,591 pts**	**21,025 pts**
Spatial sampling:	**1 cm**	**2.1 mm**
Acquisition time:	**15 mins** (fastscan)	**1 s**

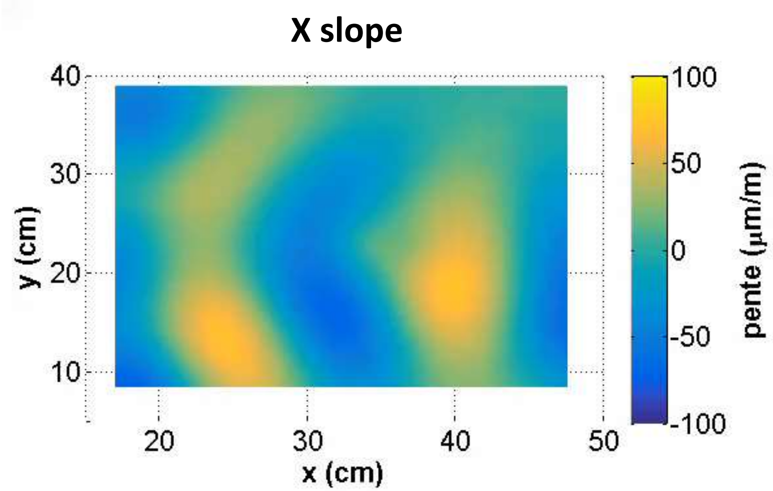
Loading identification

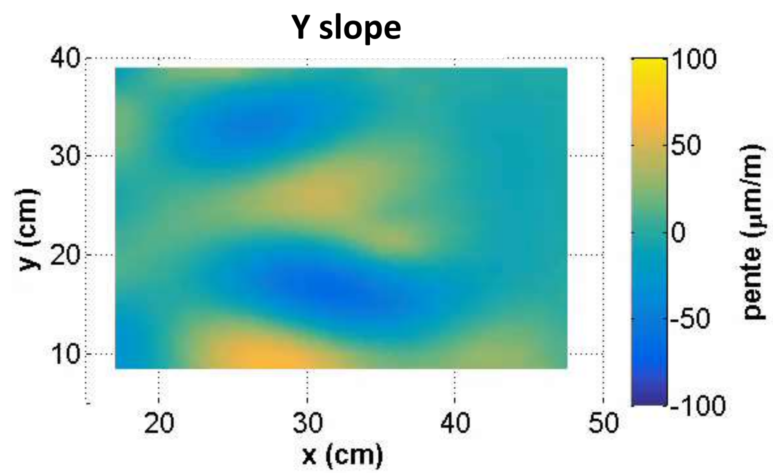
- Acoustic excitation: near-field monopole f=1.1kHz
  - LDV measurement 37 x 27 pts, virtual window 7 x 7 pts

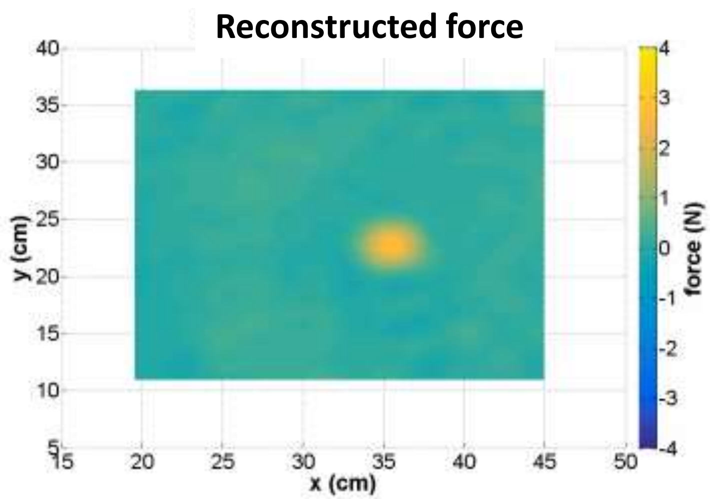


Loading identification (…)

- Mechanical excitation: Shaker f = 1.3 kHz, F = 3.63N
  - Deflectometry, 145 x 145 pts, virtual window 25 x 25 pts

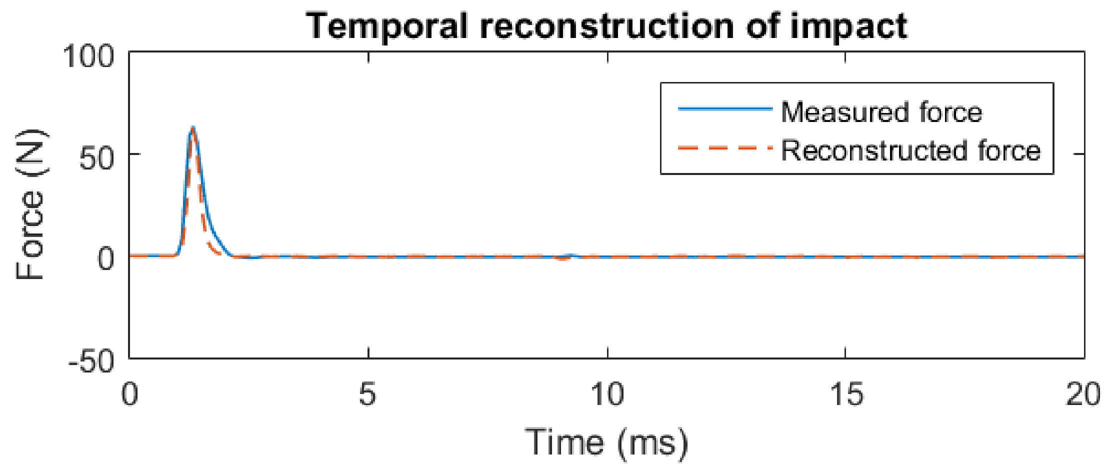


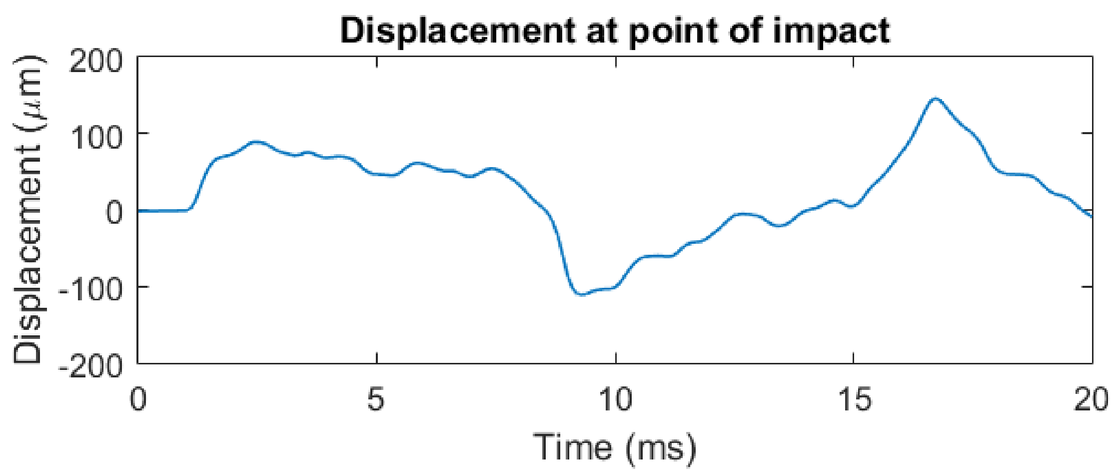




Loading identification (...)

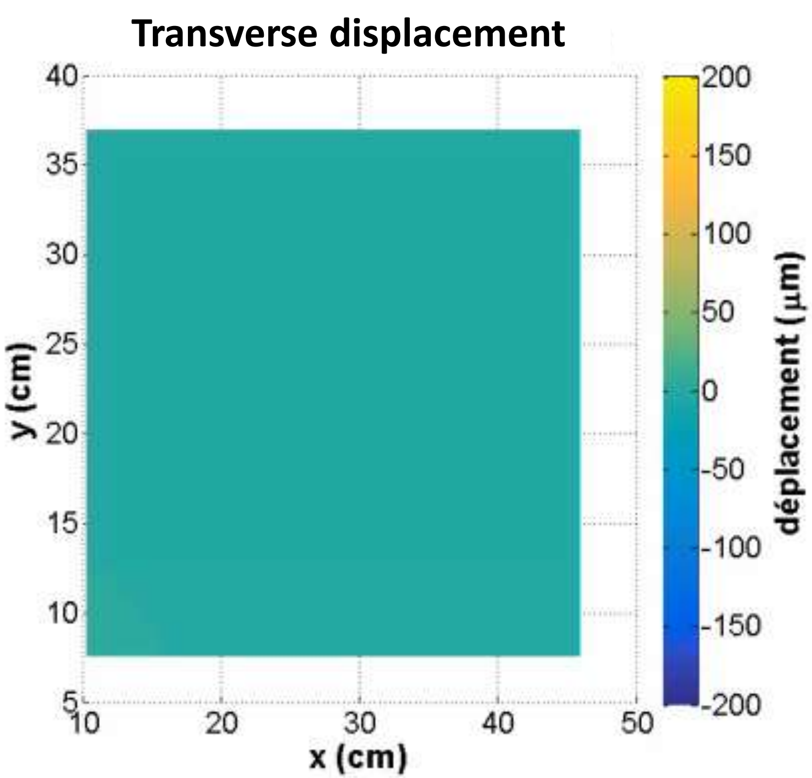
- Impact excitation (instrumented impact hammer)
  - Deflectometry, 169 x 169 pts, virtual window 9 x 9 pts

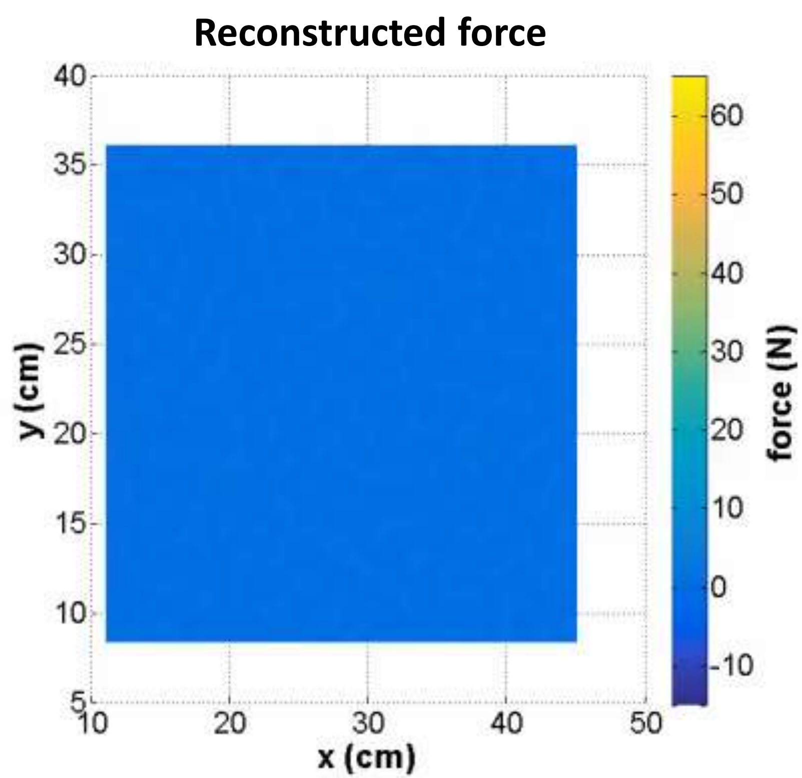




Loading identification (…)

- Impact excitation (instrumented impact hammer)
  - Deflectometry, 169 x 169 pts, virtual window 9 x 9 pts



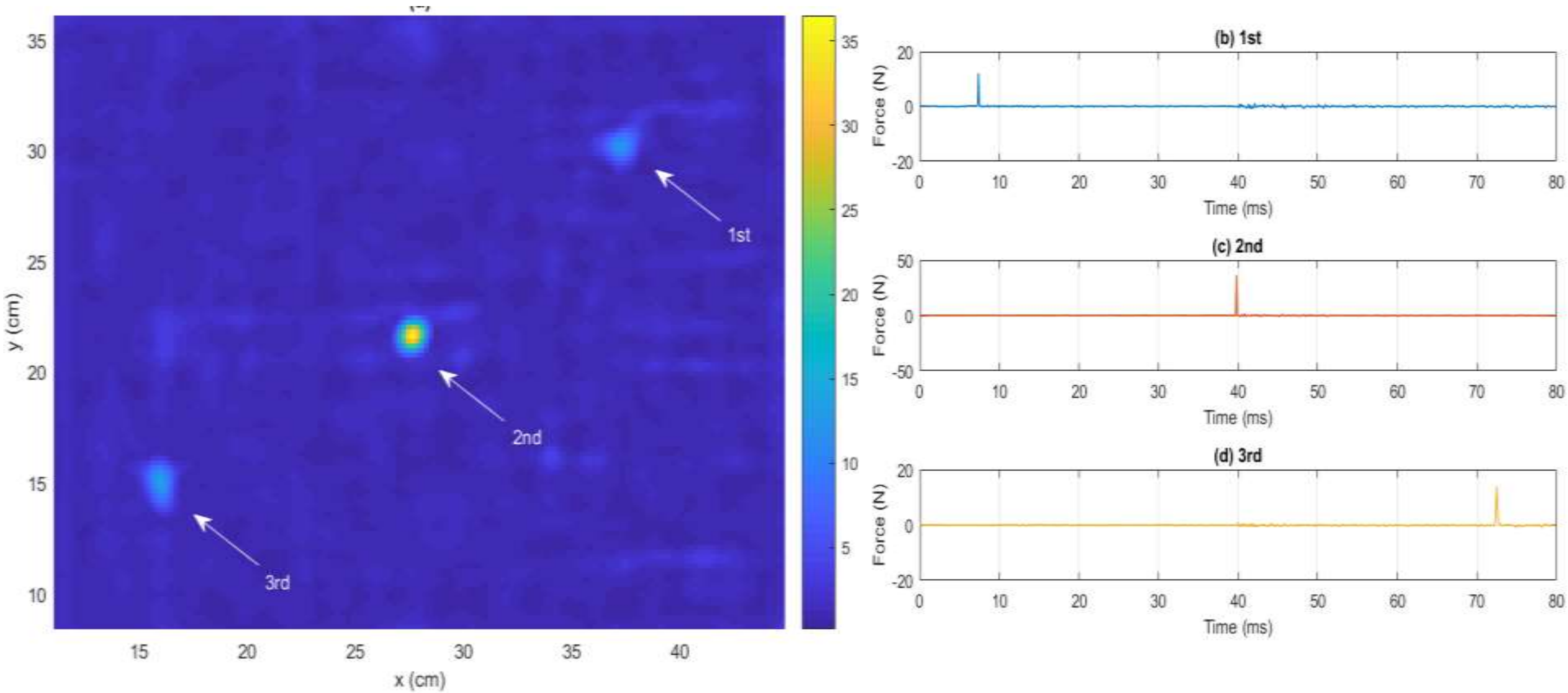


Loading identification (...)

- Multiples unknown impacts (three dropped marbles)
  - Deflectometry, 169 x 169 pts, virtual window 9 x 9 pts

Loading identification (…)

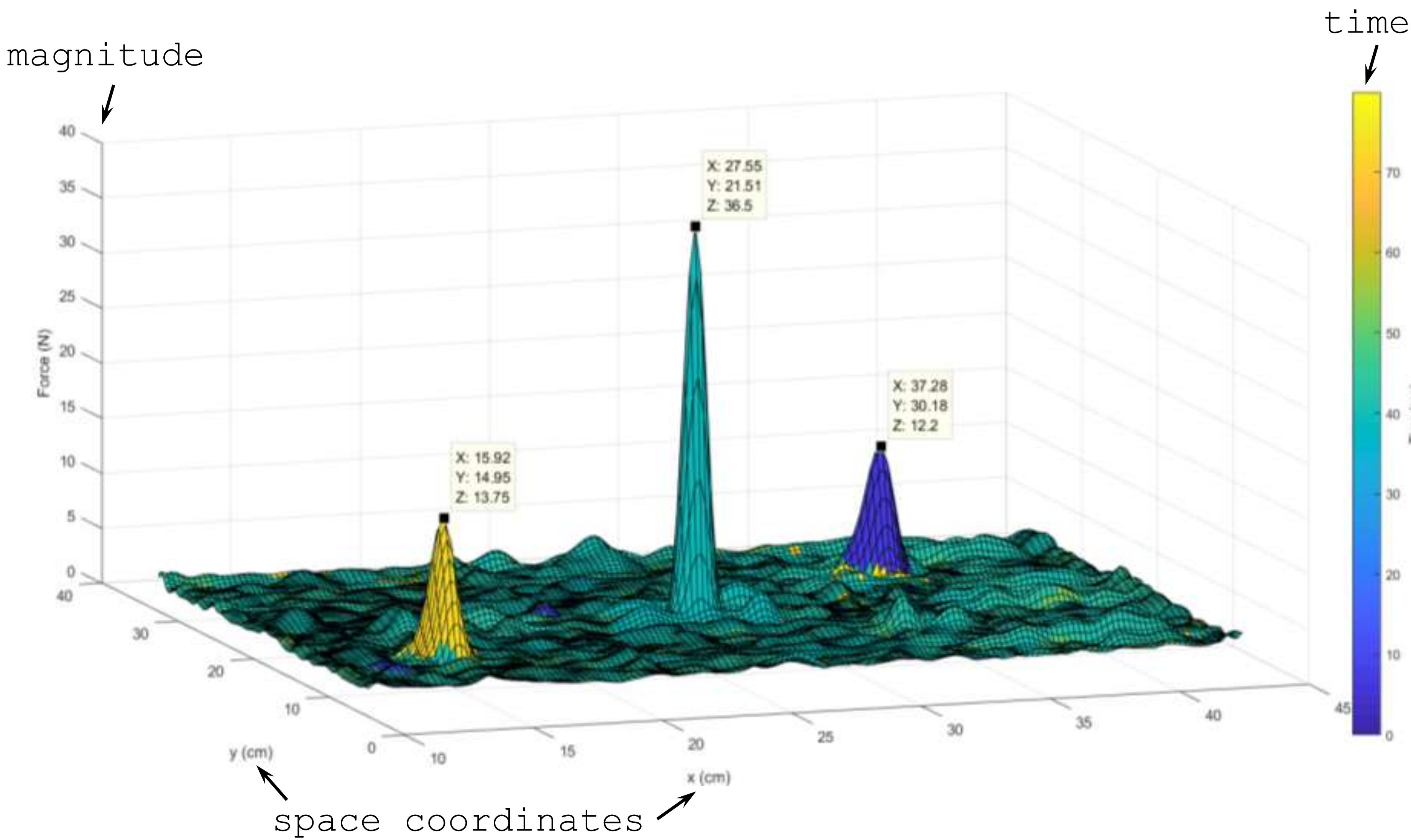
- Multiples unknown impacts (three dropped marbles)
  - Deflectometry, 169 x 169 pts, virtual window 9 x 9 pts



All impacts are localized in space and impact time history is obtained

Loading identification (…)

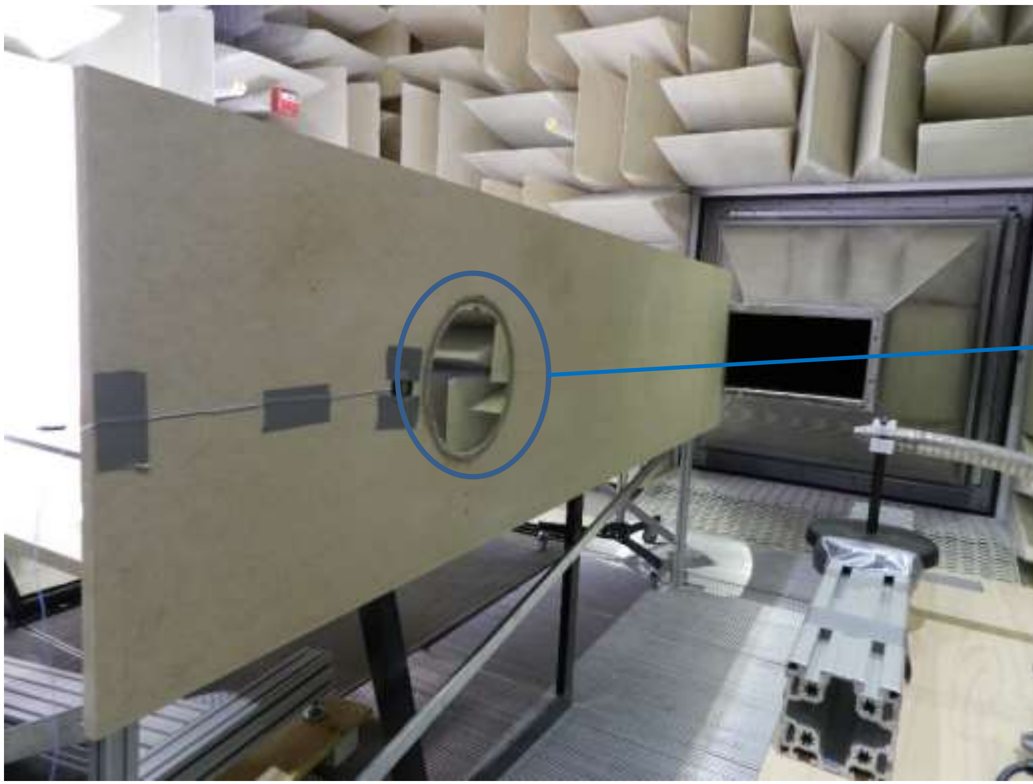
4D graphics that combine time history and localization of impact can be produced



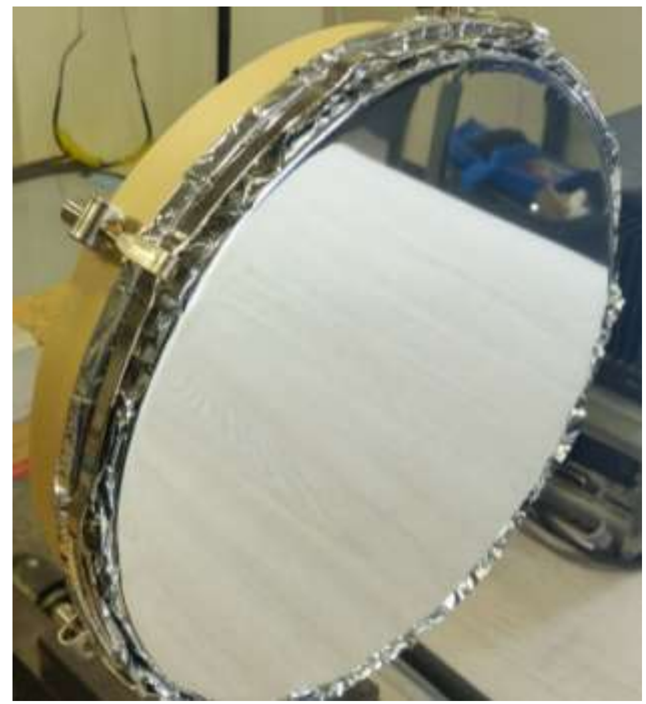
Loading identification (...)

- Turbulent boundary layer excitation

UdeS low speed anechoic, open wind tunnel



Reflective circular membrane



P. O'Donoughue et al., "*Inference of Random Excitations from Contactless Vibration Measurements on a Rectangular Panel or Circular Membrane using the Virtual Fields Method*», **Flinovia2017**.

(2) New acoustic materials designs

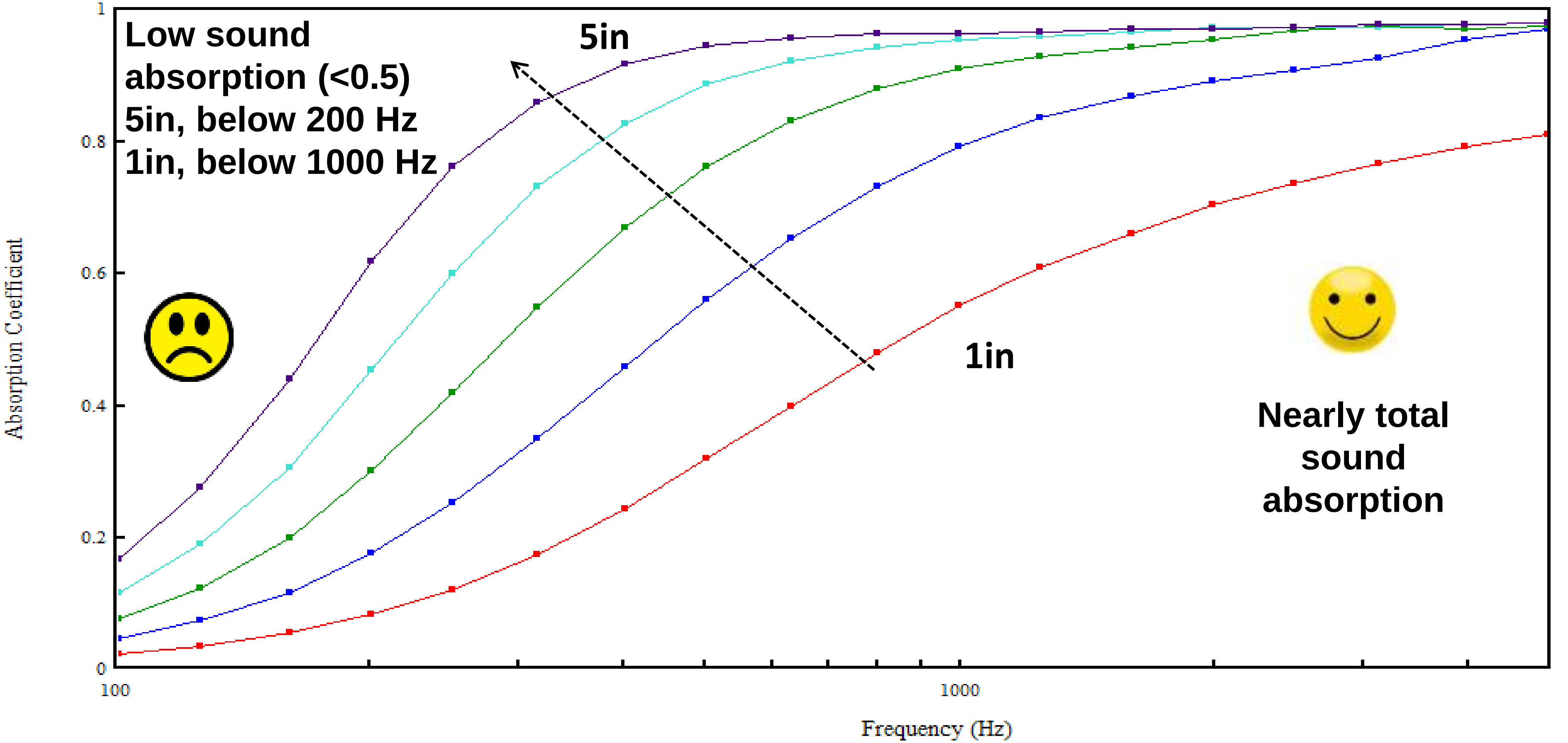
To tackle the lack of efficiency of passive sound absorbing treatments in the low frequency range, two solutions are proposed :

- Including resonant structures in a sound absorbing material (N.Atalla, GAUS, O.Doutres, ÉTS)

- Using a specific arrangement of a poroelastic material (N.Dauchez, UTC, B.Nennig, SupMeca)

(2) New acoustic materials designs

Melamine foam of different thicknesses : 1 inch -> 5 inches



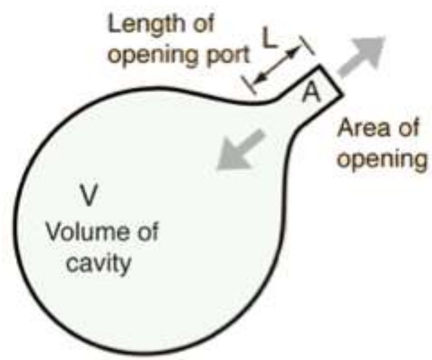
The term "metamaterials" was originally coined to denote structured composites whose wave functionalities arise as the collective manifestations of its locally resonant constituent units. (Ma and Sheng, Sci. Adv. 2016)

Embedded structures in foam

Foam + Helmholtz resonator (HR)

$$f_{resonance} = \frac{v}{2\pi}\sqrt{\frac{A}{V\,L}}$$

+



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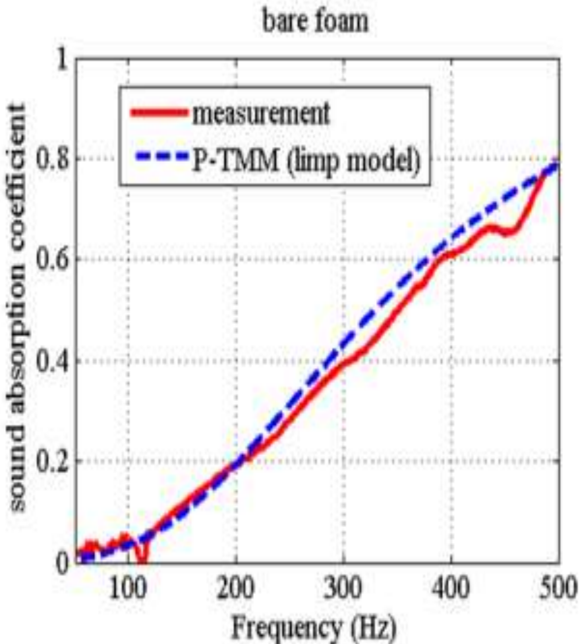
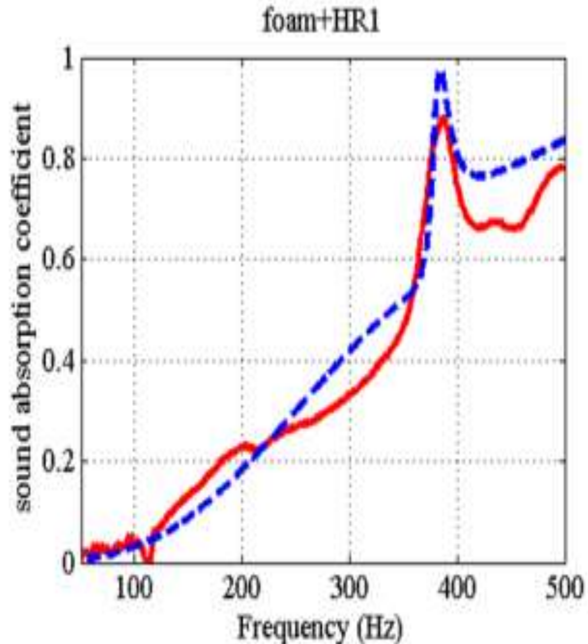
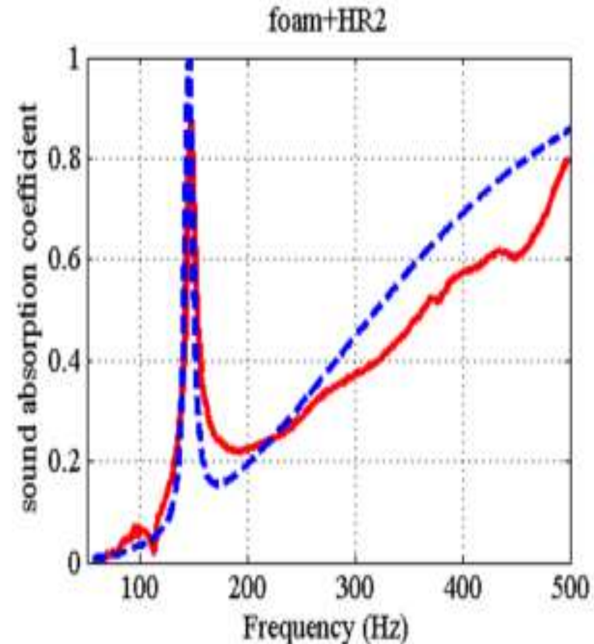


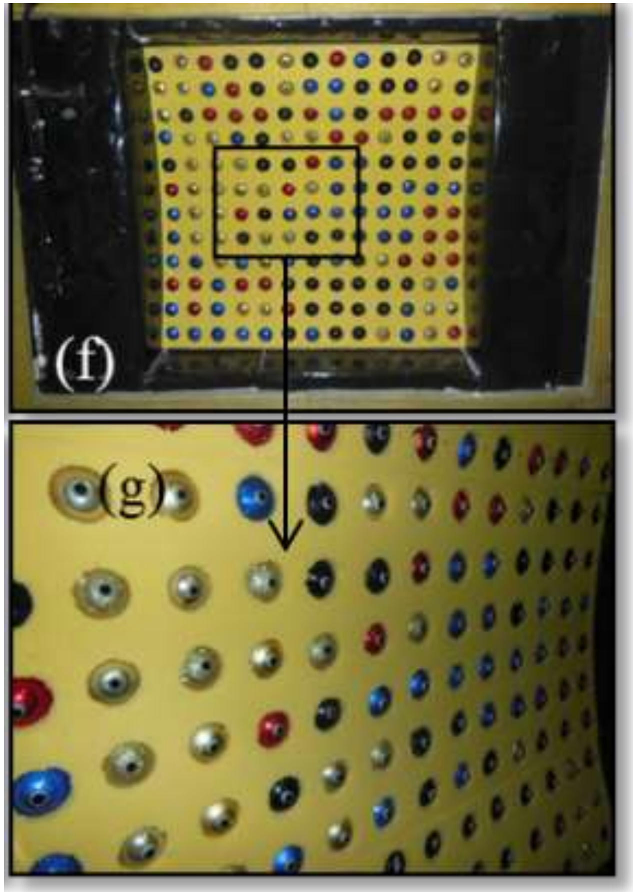


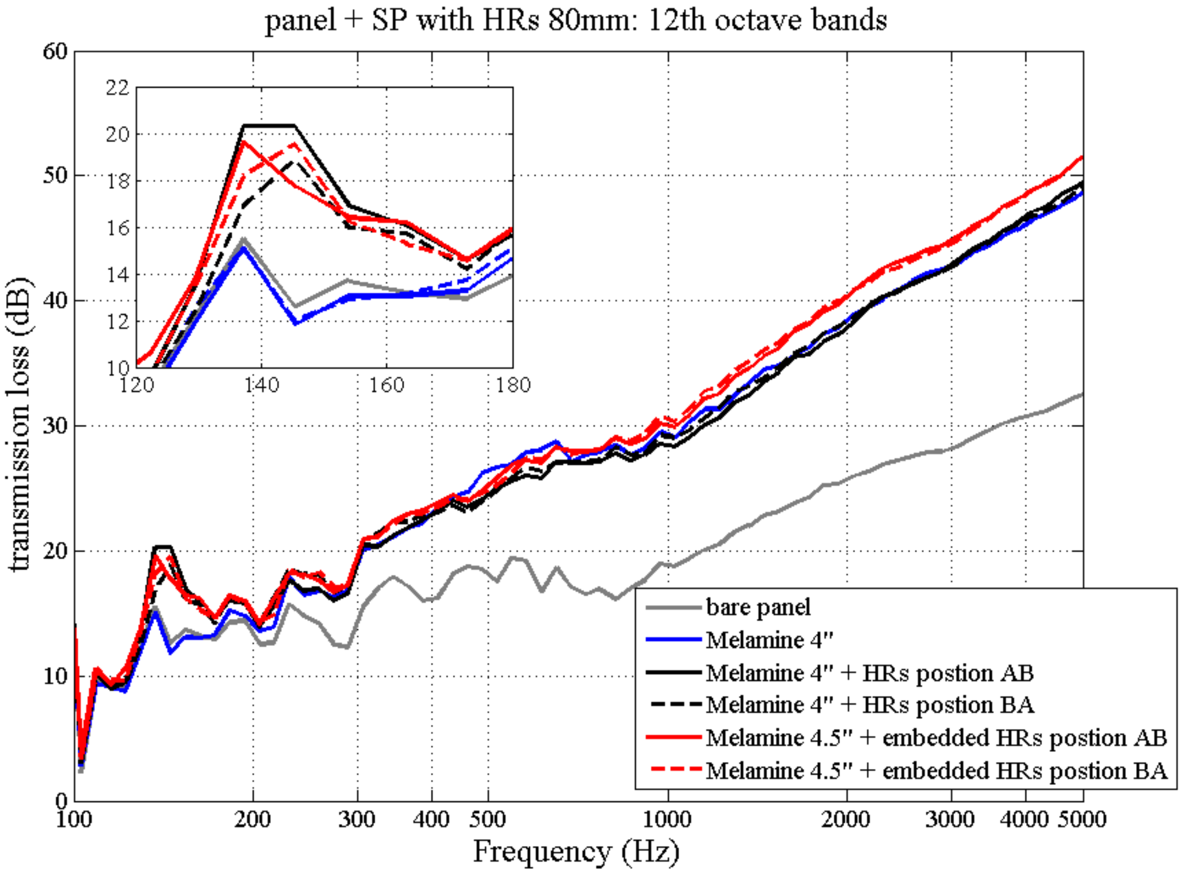


Embedded structures in foam

Resonators periodically embedded into a large sample

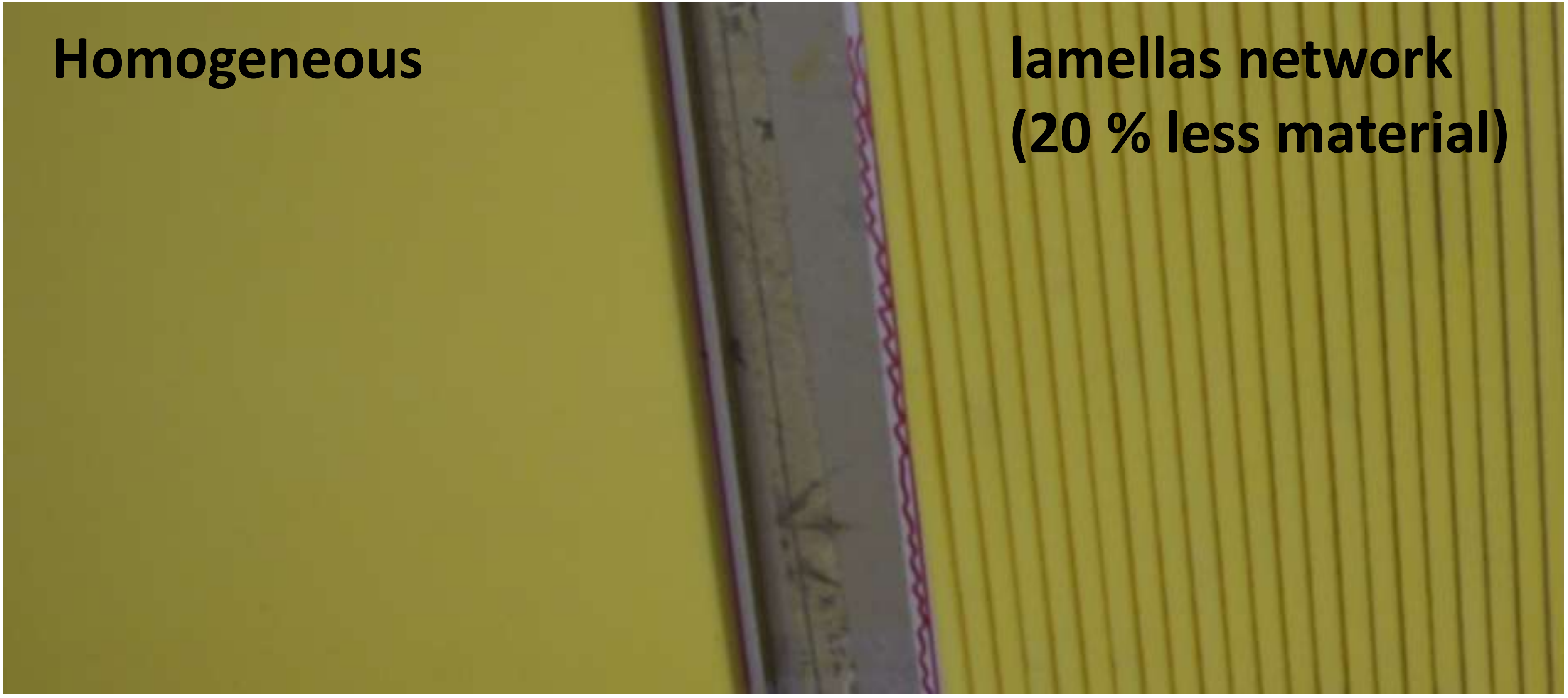
-> also improve sound transmission loss of several dB





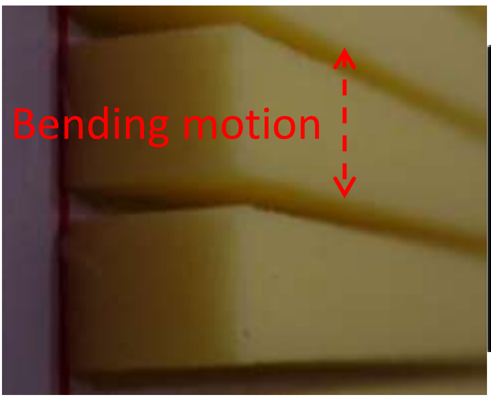
‘Structured’ foam

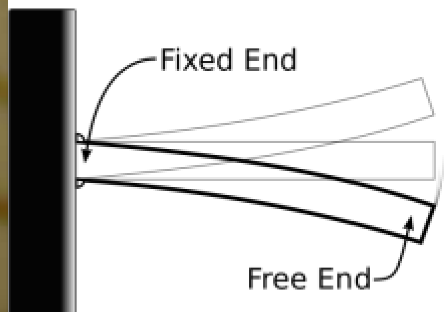
Melamine foam of 1 in. thickness
(low sound absorption < 0.5 below 1000 Hz)

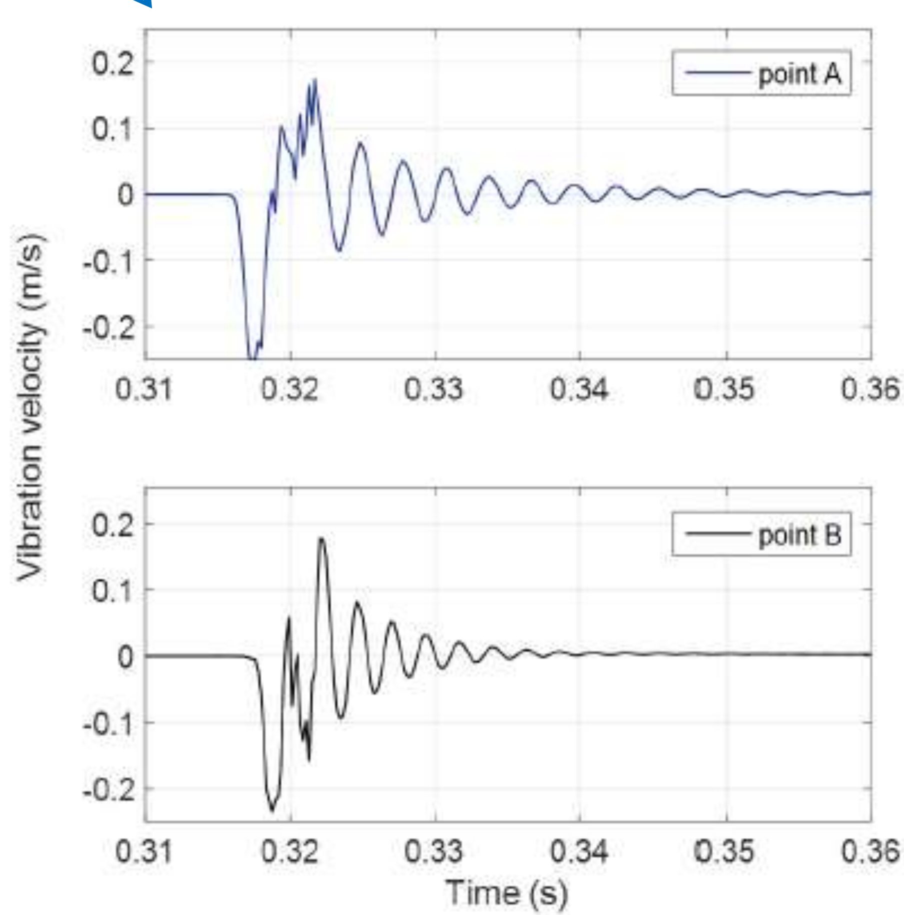


‘Structured’ foam

The foam provides sound absorption, but the lamellas have individual (and cumulative) bending and shear resonances



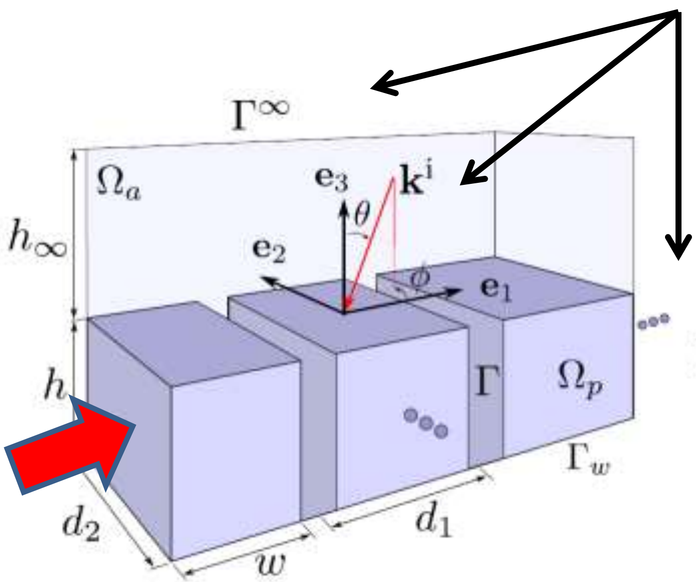


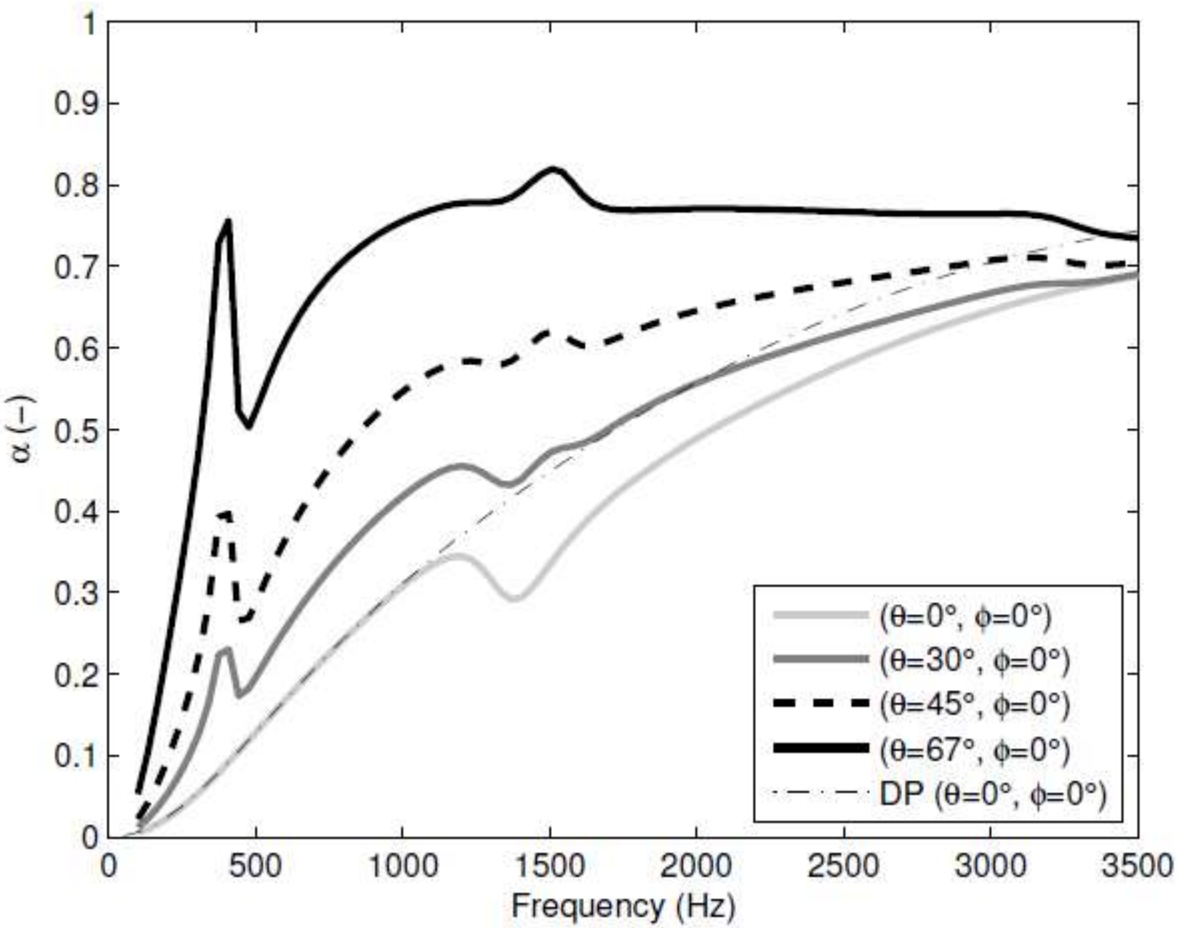


Contactless measurement with laser vibrometer
-> (damped) bending beam resonance ≈ 500 Hz

'Structured' foam: simulations results

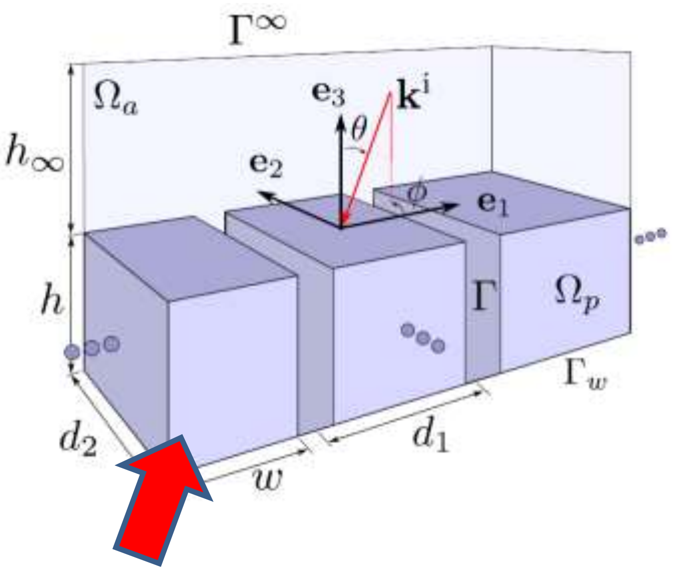
Acoustic wave propagating with a normal incidence to the lamellas main axis (different elevations)

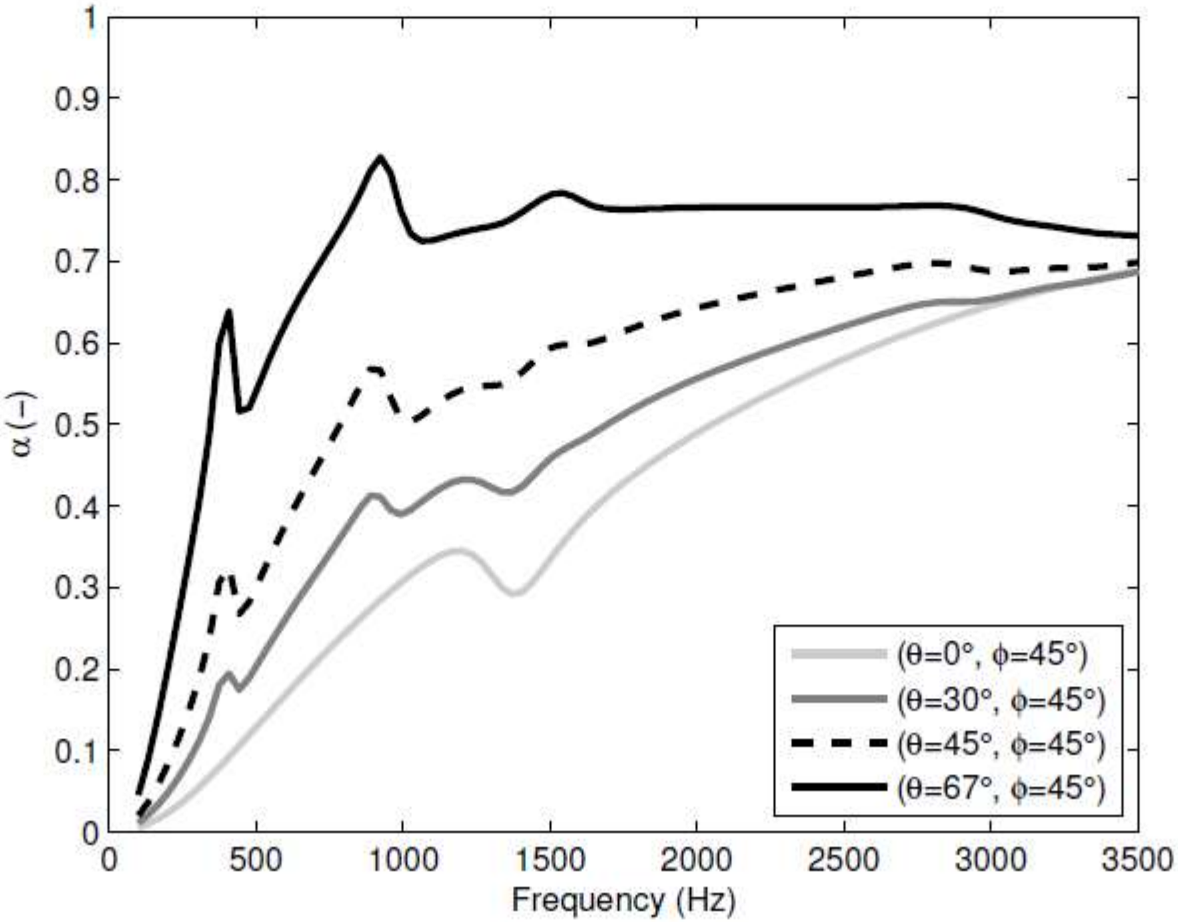




'Structured' foam: simulations results

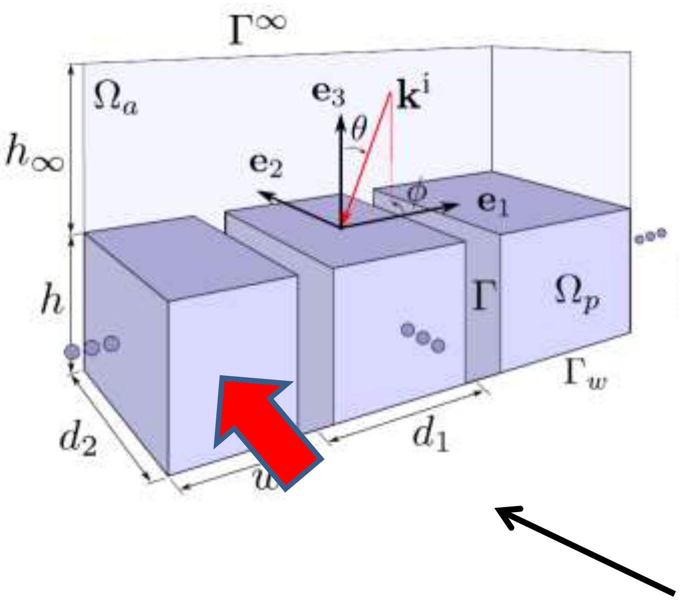
Acoustic wave propagating with an oblique incidence to the lamellas main axis (different inclinations)

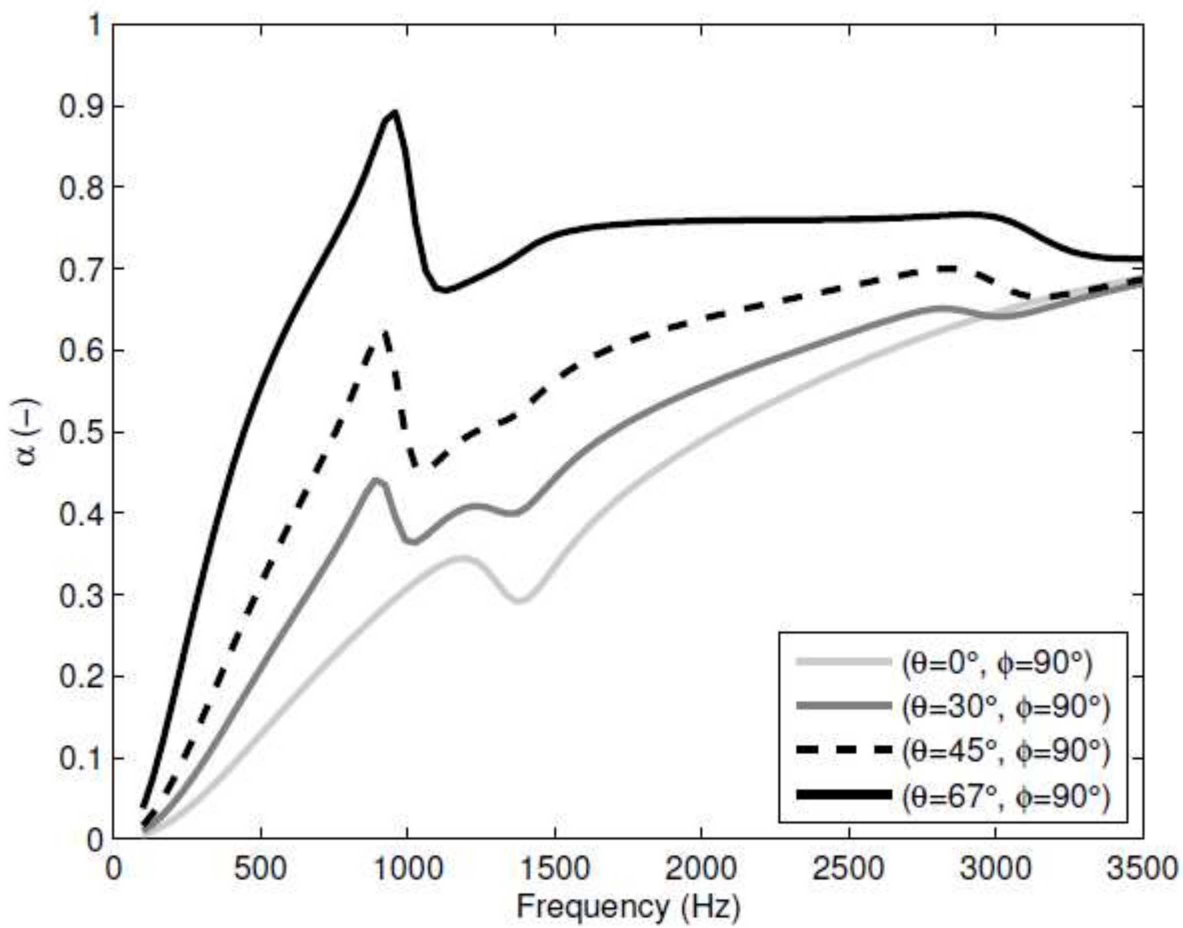




'Structured' foam: simulations results

Acoustic wave propagating along the lamellas main axis (different inclinations)

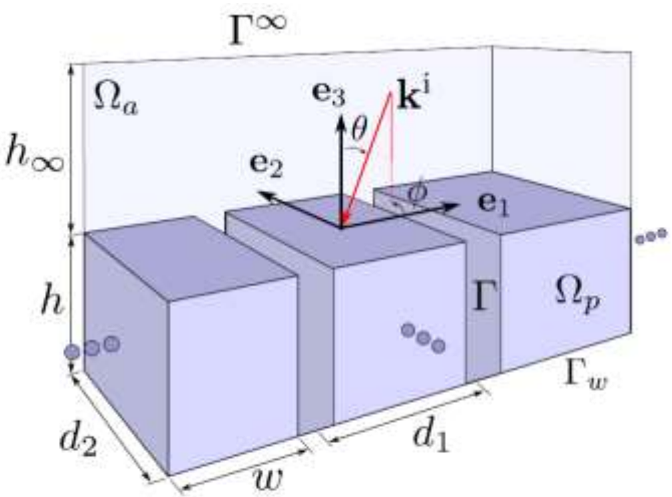


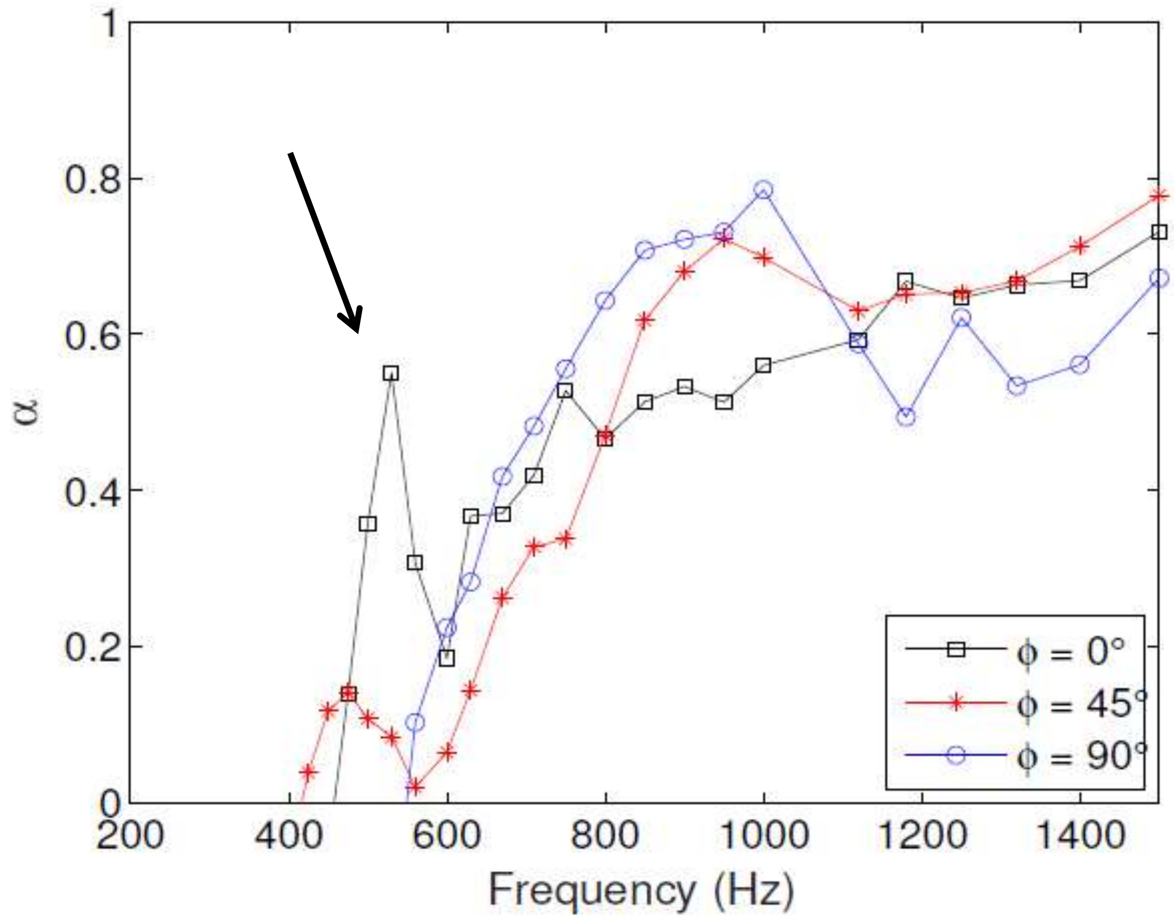


‘Structured’ foam: experimental results

Melamine foam of 1 in. thickness, 45° inclination angle

Important and supplementary sound absorption is brought at bending resonance (≈ 500 Hz)





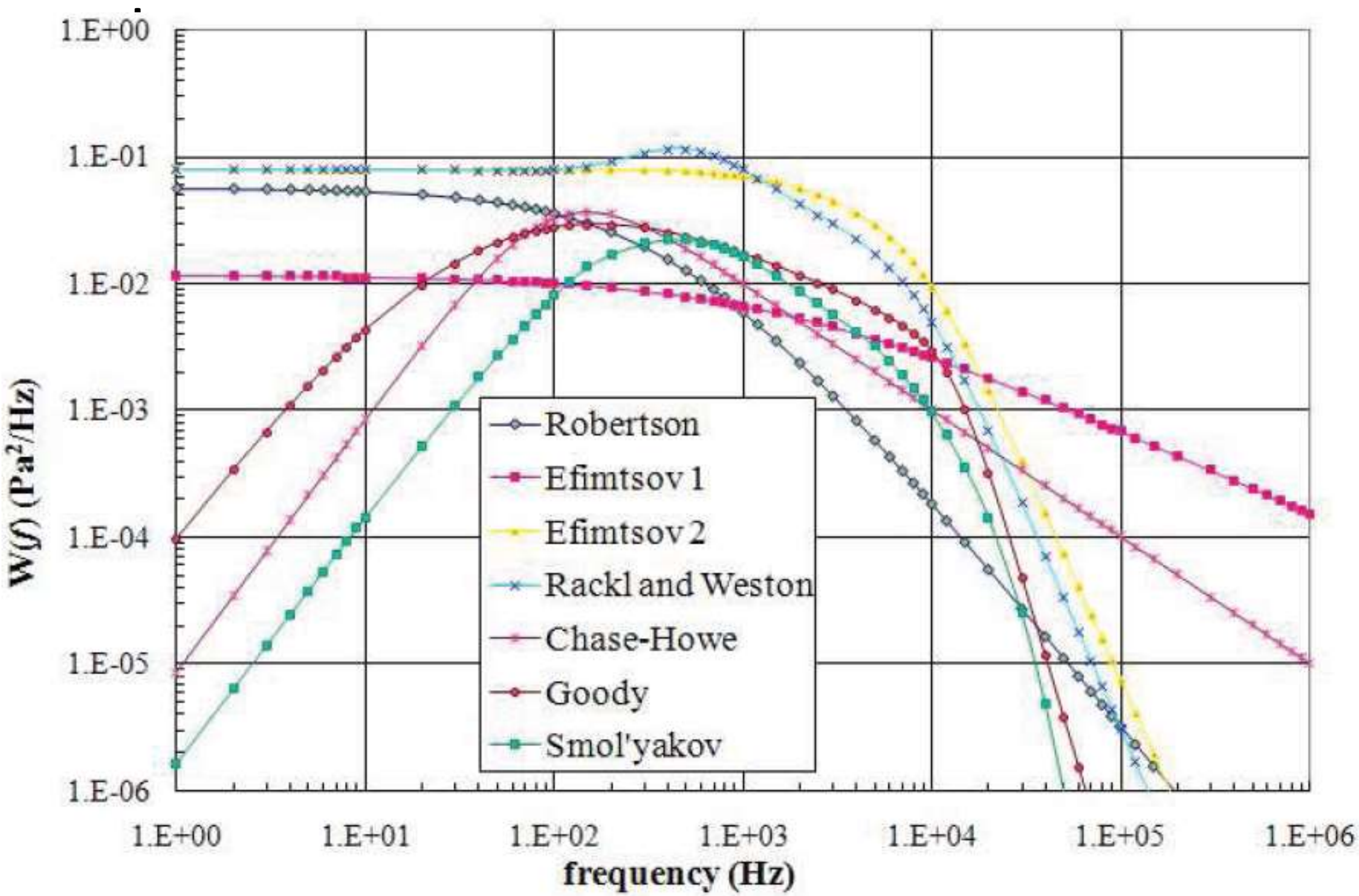
(3) Effect of Screens and Pinhole Size on Measured Fluctuating Surface Pressures Using a Micro-Electro-Mechanical Microphone Array

Chris Todter[*], Olivier Robin[+], Paul Bremner[#], Christophe Marchetto[+] and Alain Berry[+]

[*]Keppel Professional Services - [+]Université de Sherbrooke - [#]AeroHydroPLUS

Context

- Existing single point wall pressure spectrum models are derived from different engineering areas (with different spectral features) and different pressure sensor mounting



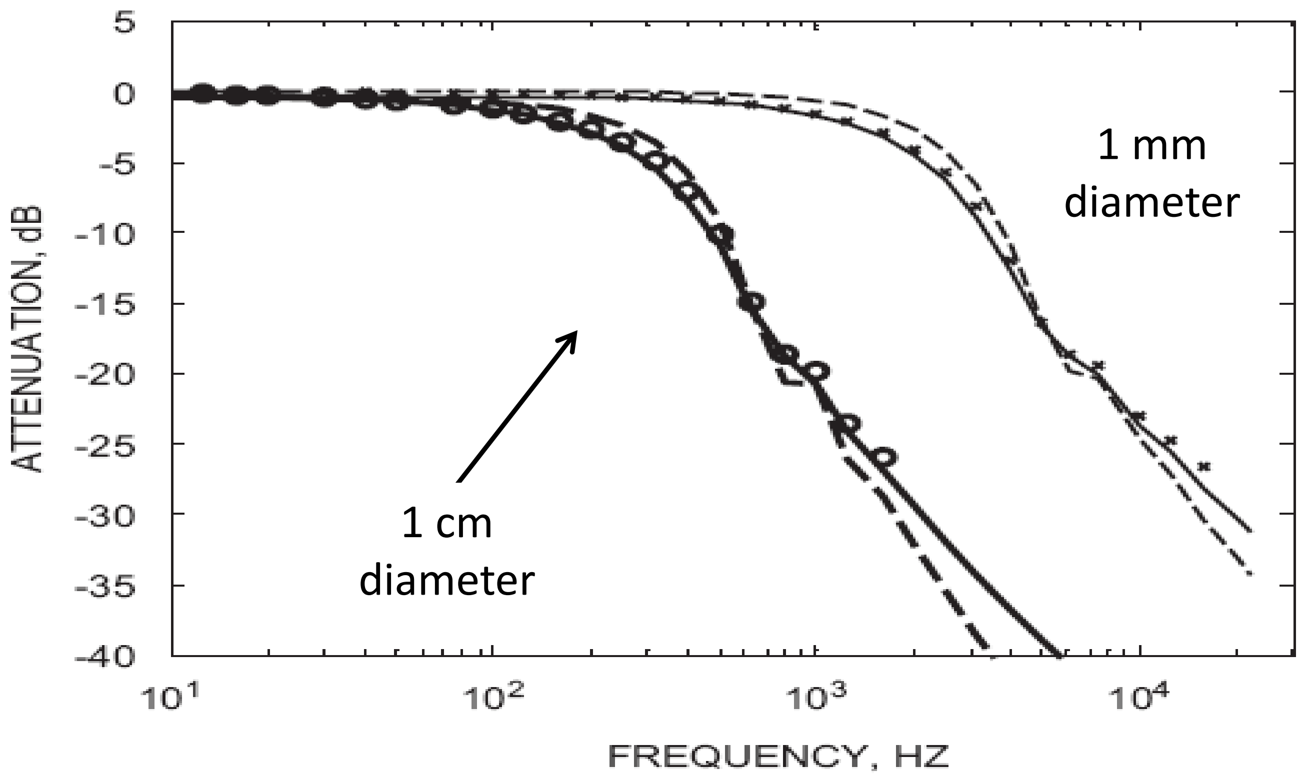
And thus provide very different predictions…

Single point wall pressure spectrum predicted by seven models at *M* = 0.11

Miller et al., AIAA 2011

Context: Effect of microphone size and spacing

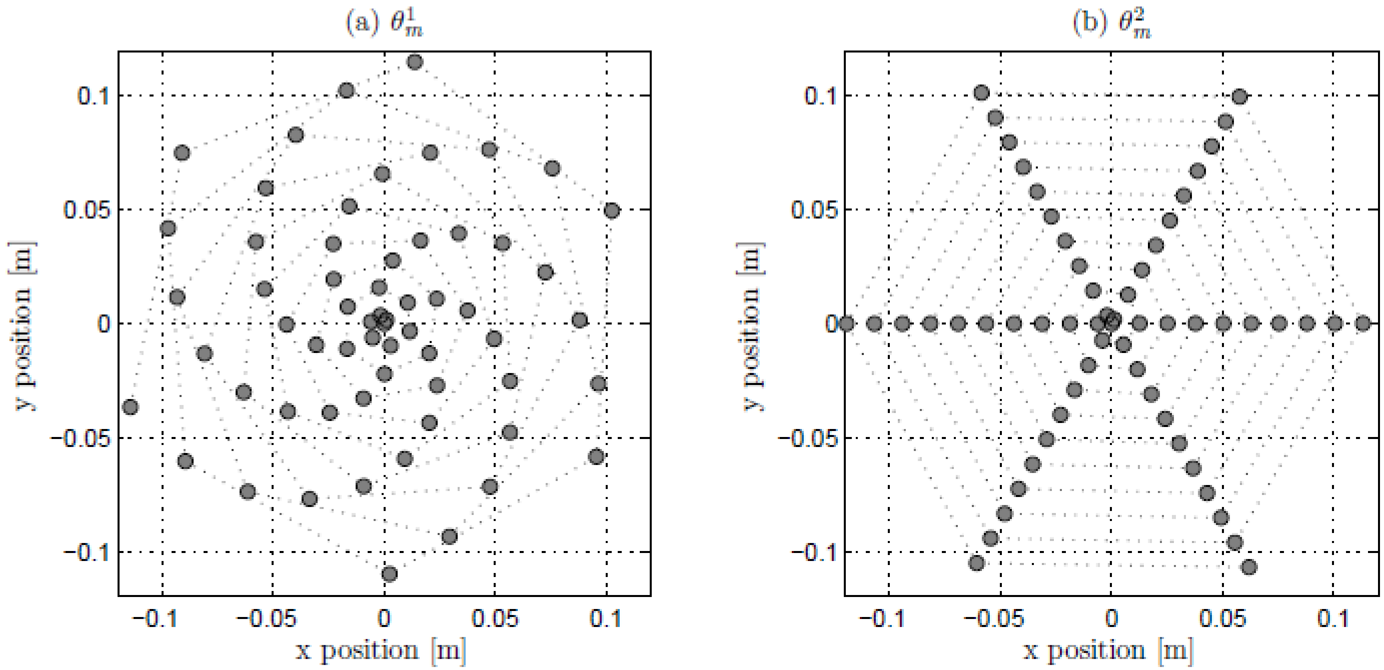
Sensing diameter must be of the same order to the turbulent scale to be resolved -> surface averaging effect in the frequency domain



A small spacing between transducers is also required in order to be able to fully resolve spatial variations (i.e. resolving wavenumber)

Context

- Some sensors arrangements can help reaching this needed compromise between sensor diameter and consecutive sensors spacing (sufficient spatial resolution and avoid spatial averaging)



Measurement of the wavenumber-frequency spectrum of wall pressure fluctuations: spiral-shaped rotative arrays with pinhole-mounted quarter inch microphones, Robin et al., AIAA paper 2013-2058

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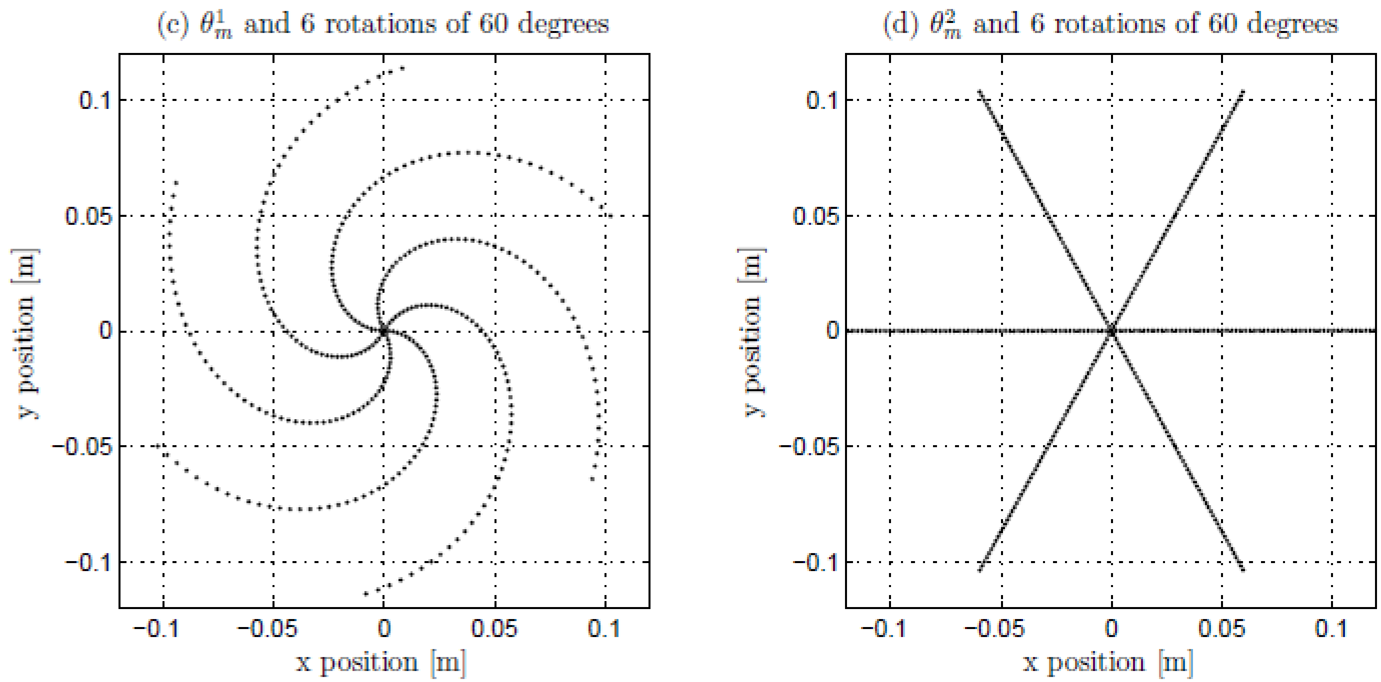

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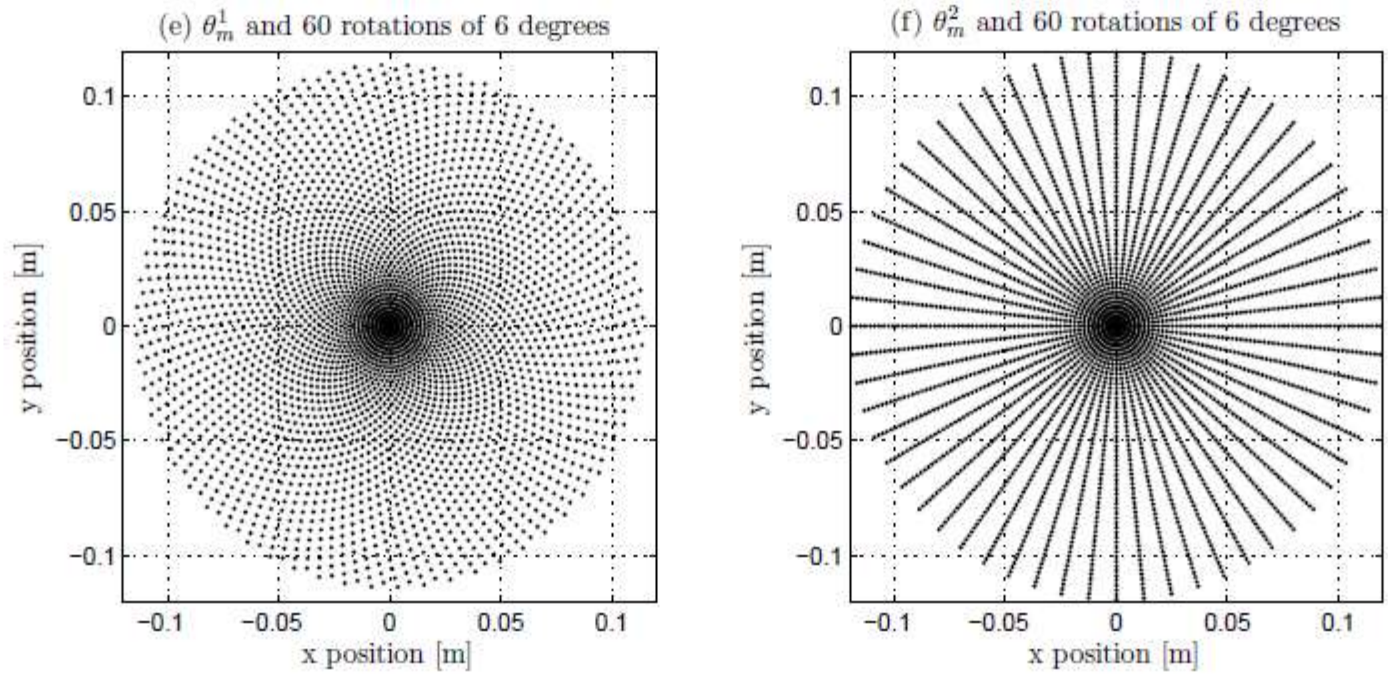
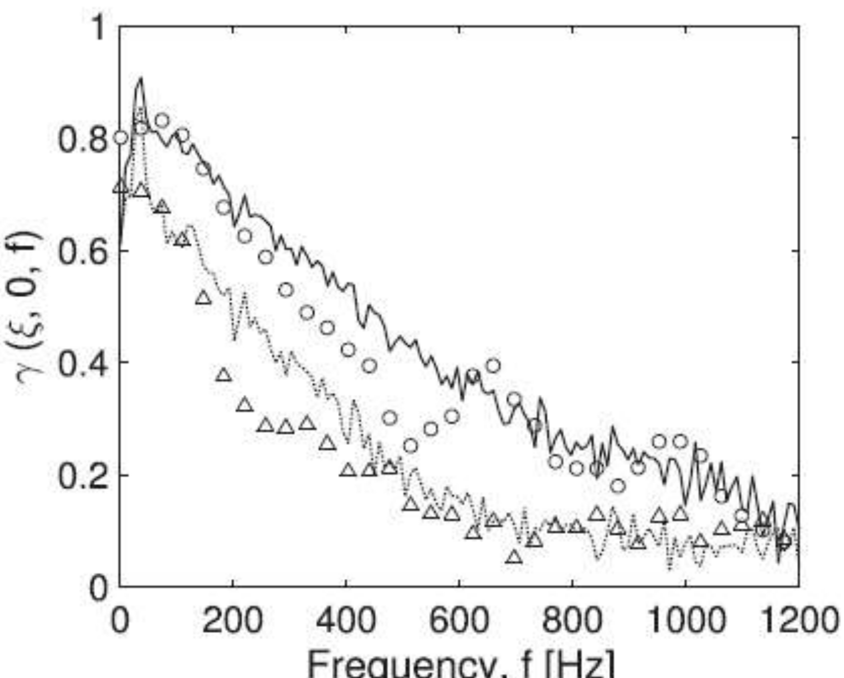


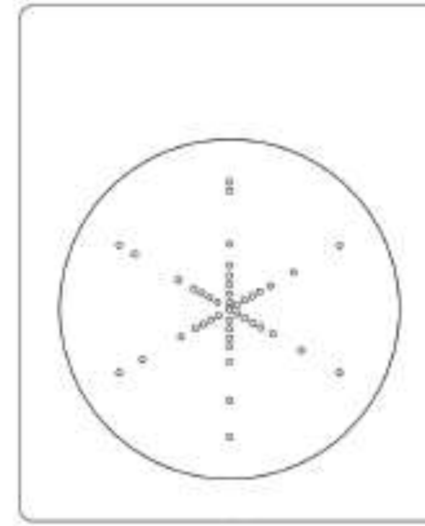
Measurement of the wavenumber-frequency spectrum of wall pressure fluctuations: spiral-shaped rotative arrays with pinhole-mounted quarter inch microphones, Robin et al., AIAA paper 2013-2058

Context

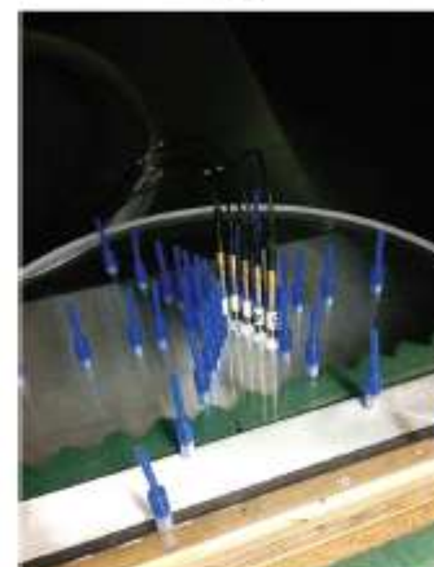
An experimental study of the wall-pressure fluctuations beneath low Reynolds number turbulent boundary layers, Van Blitterswyk, Da Rocha JASA2017

Measured cross-spectrum between two points





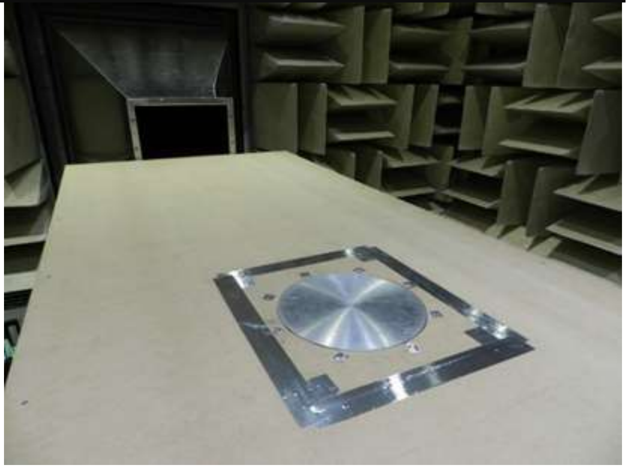
(a)



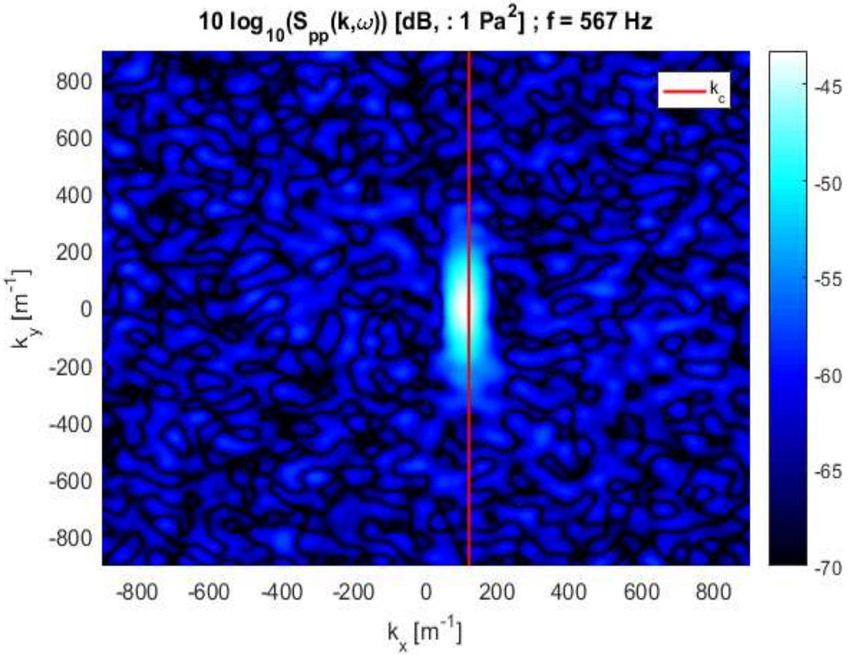
(b)

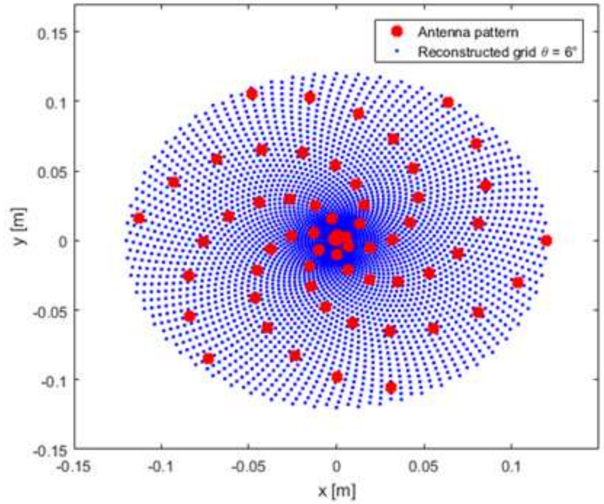
Context

Measurement techniques of the sensitivity functions to characterize the vibroacoustic response of panels under random excitations, Marchetto at al., Flinovia 2



Measured wavenumber spectrum at 40 m/s





But array diameter = 240 mm,

Array weight ≈ 11 kg, many cables…

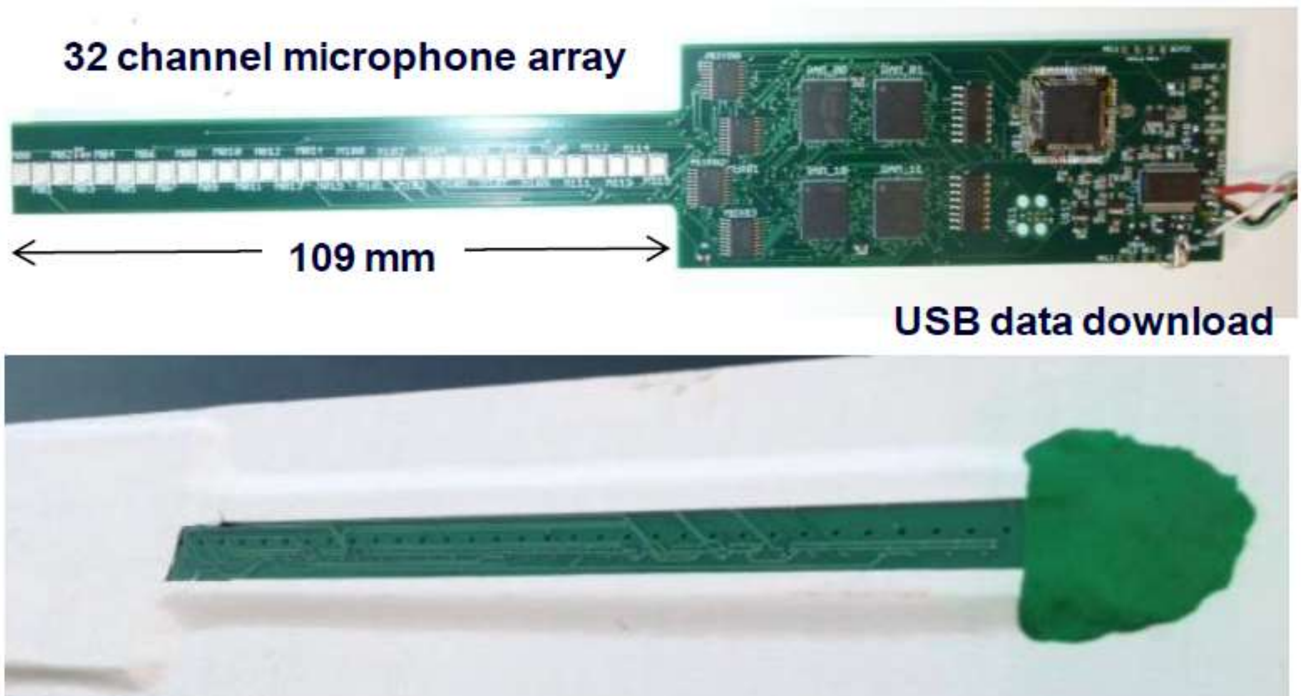
Context

- Micro-electro-mechanical (MEMS) surface microphone arrays can provide high spatial resolution and allow precise wavenumber analysis
- Microphone mounting has also different effects on acoustic and convective excitations
- Measured surface pressure at each microphone can be influenced by self-noise induced by the microphone "packaging", and can be attenuated with a windscreen

- Results of wind tunnel tests using a MEMS microphone array with different sensing ports and windscreens are briefly presented

The 32-microphone array

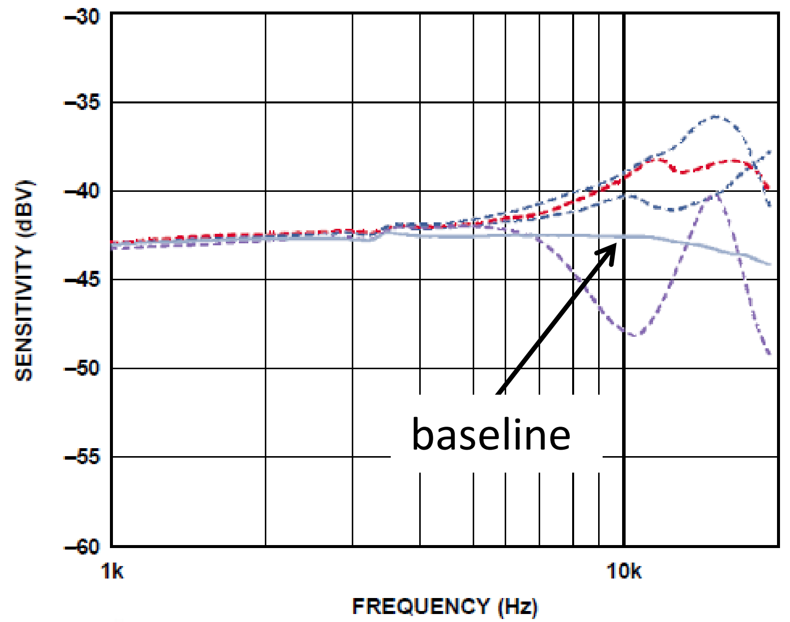
- ‘Stick on – peel off’ array, conformable surface, 40 g weight
- Small sensing diameter (1mm) and sensor spacing (3.2 mm)
- PDM digital output from each microphone directly stored to digital random access memory chips

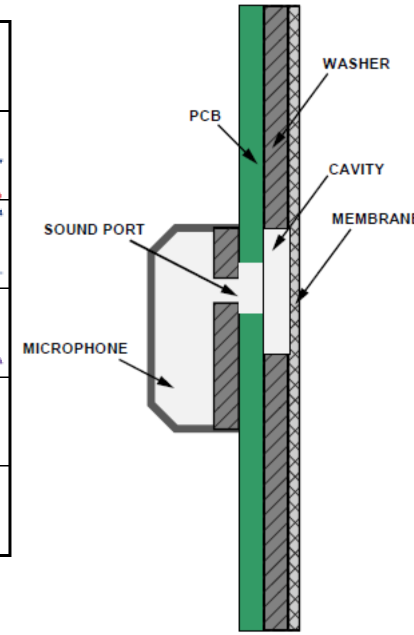


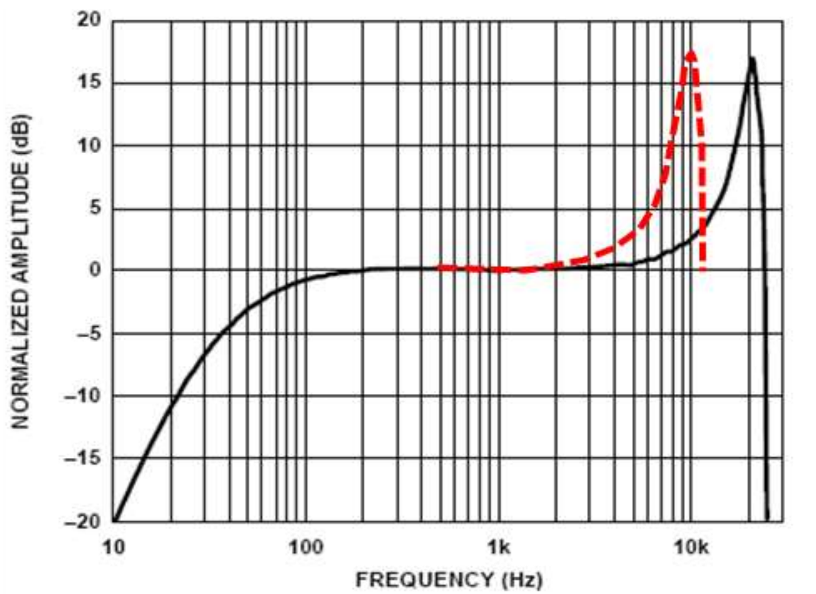
SAE Paper 2015-01-2325
Sideglass Turbulence and Wind Noise Sources Measured with a High Resolution Surface Pressure Array

Facts: Effect of microphone packaging

Microphone response with different washer / protective seal material arrangements
Analog Devices, Application Note AN-1124



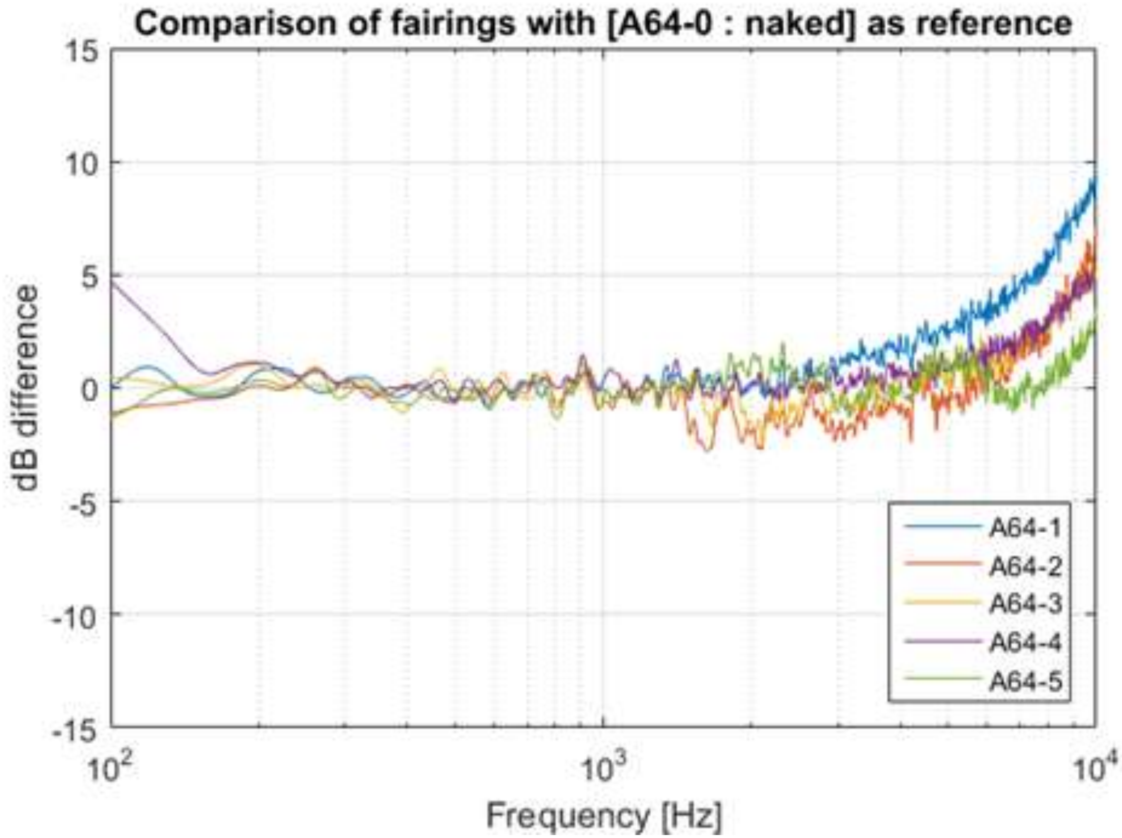




Acoustic frequency response of MEMS microphone in two configurations :
manufacturer packaging
same packaging mounted on a PCB with 1mm diameter sensing port

Results : fairing (packaging) effect

<u>Acoustic</u> frequency response of MEMS microphone with various fairing designs (<u>no windscreen</u>).

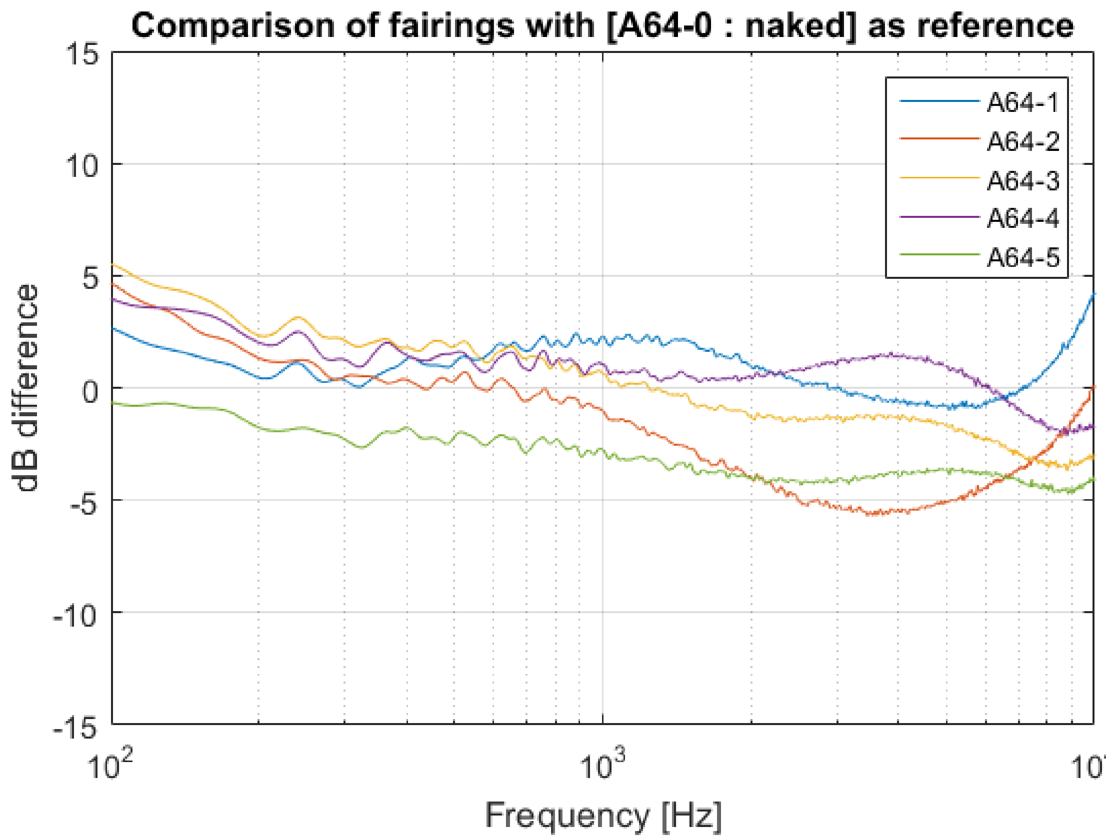


array line-averaged autospectra

-> The different fairings mainly affect the microphone sensitivity at high frequencies

Results : fairing (packaging) effect

<u>Convective</u> frequency response of MEMS microphone with various fairing designs (<u>no windscreen</u>) – 35 m/s flow speed.

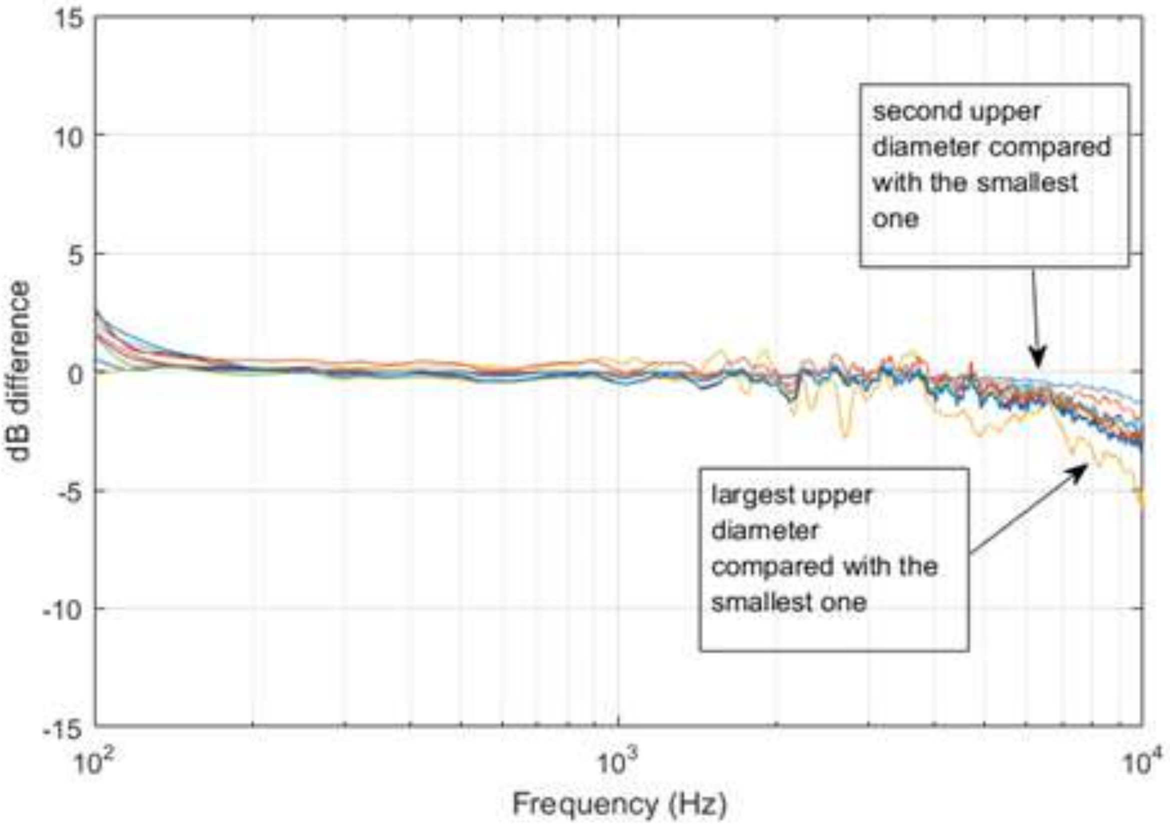


array line-averaged autospectra

-> The different fairings have a more distributed effect (a lower amplitude variation that affects the whole frequency range)

Results : port shapes and dimensions effect

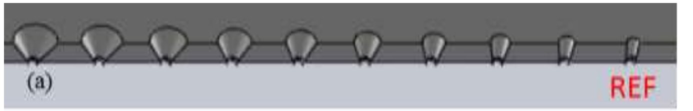
Acoustic frequency response of MEMS microphone with various conical opening and 0.5 mm microphone port

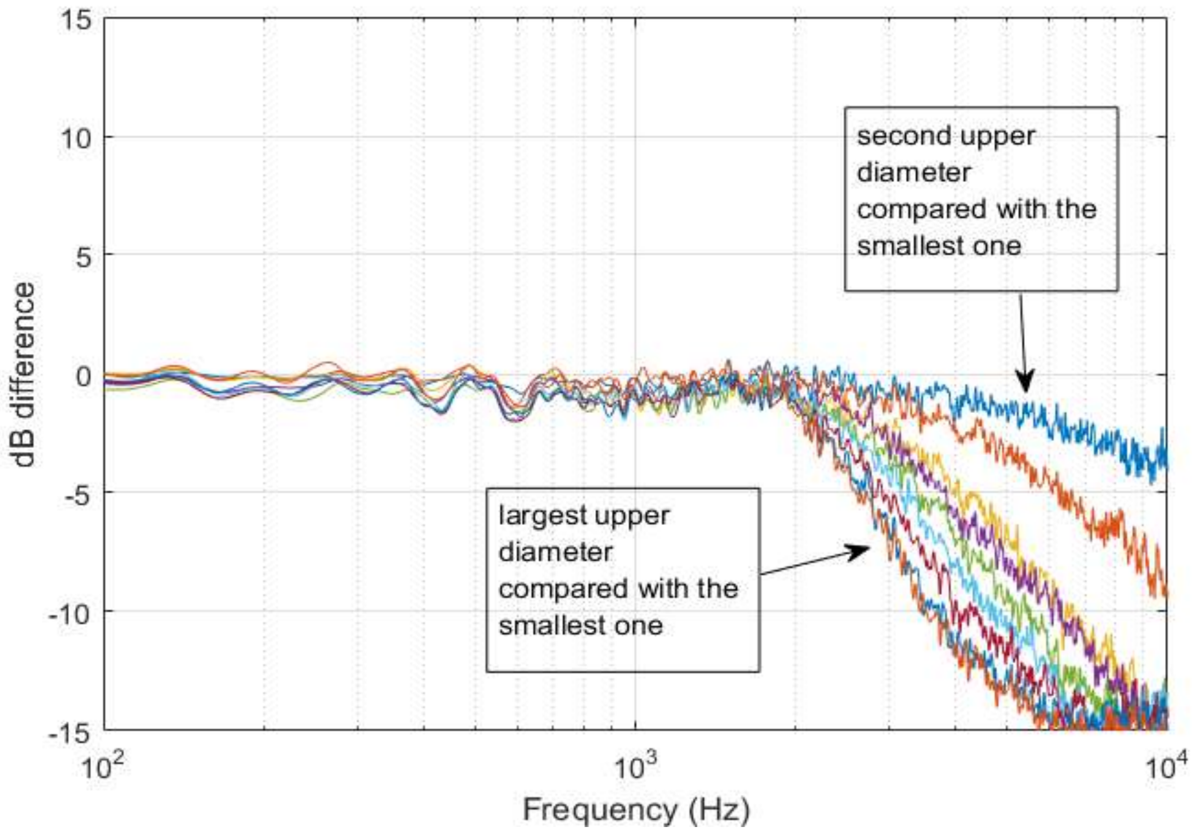


-> limited effect of conical opening diameter on acoustic excitation

Results : port shapes and dimensions effect

Turbulent frequency response of MEMS microphone with various conical opening and 0.5 mm microphone port





-> the larger the opening, the higher the high frequency filtering effect

Conclusion / discussion

- Thanks for your attention

- Questions are welcomed