# Flexible Walls for Acoustic Liners

**Karsten Knobloch, Lars Enghardt, Friedrich Bake**
German Aerospace Center (DLR), Institute of Propulsion Technology, Berlin, Germany

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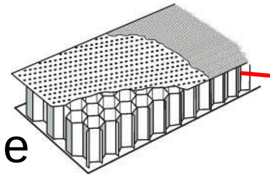
DLR

# General Motivation for Liner Improvements



Helmholtz-Resonator-Liner for aero-engine intakes, bypass- and exhaust-duct

Trent-XWB by Julian Herzog, CC-BY 4.0, https://commons.wikimedia.org/w/index.php?curid=65605861

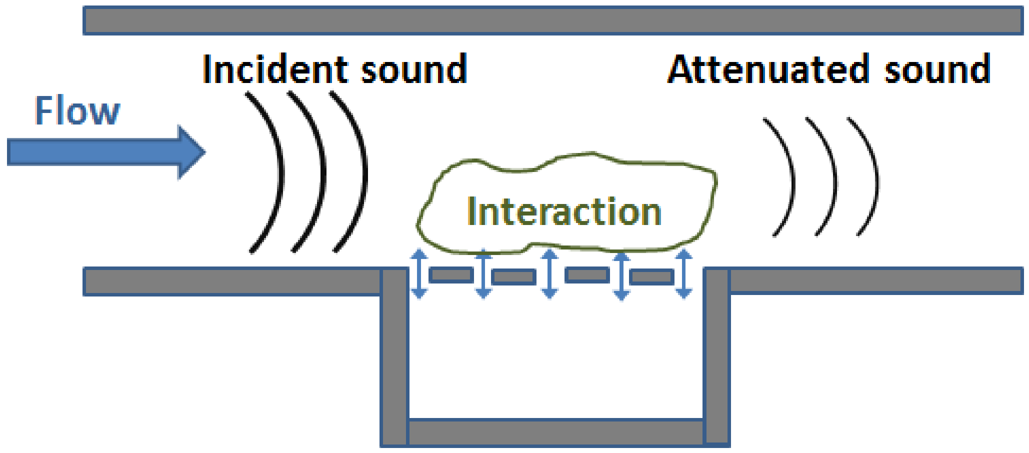
- Increase in BPR reduces jet noise, but comes with increase in nacelle weight and drag → may require shorter nacelles → less area/axial length of lined surface
- **Broadband** noise and **low-frequency** noise emissions **require efficient damping**

# Outline

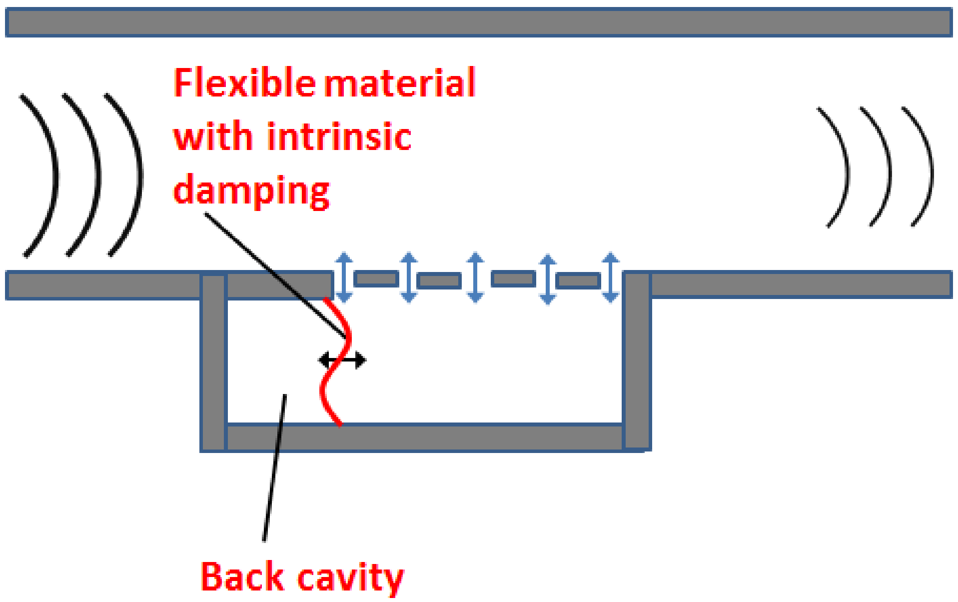
- **Liner with flexible walls**
  - Basic idea and materials with intrinsic damping
  - Liner design and aero-acoustic testing
- **Experimental Setup for Investigation of Flex. Walls**
  - Exp. setup for investigation of flexible walls
  - Data processing
- **Results**
  - Dissipation, Transfer functions, Vibrations
- **Conclusions/Outlook**

# Linerdesign – Basic Idea

**Conventional Helmholtz resonator (liner)**



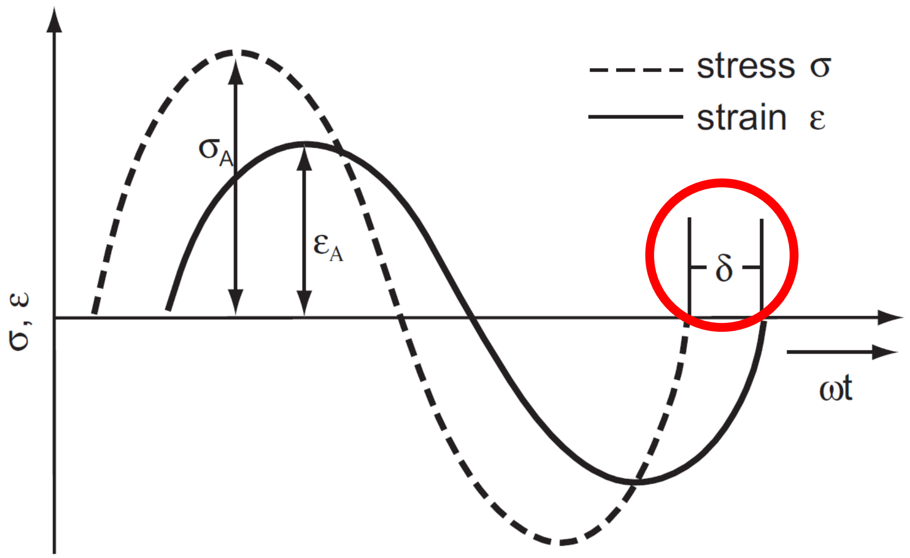

**Helmholtz resonator (liner) with flexible walls**




Exhibits Helmholtz resonance

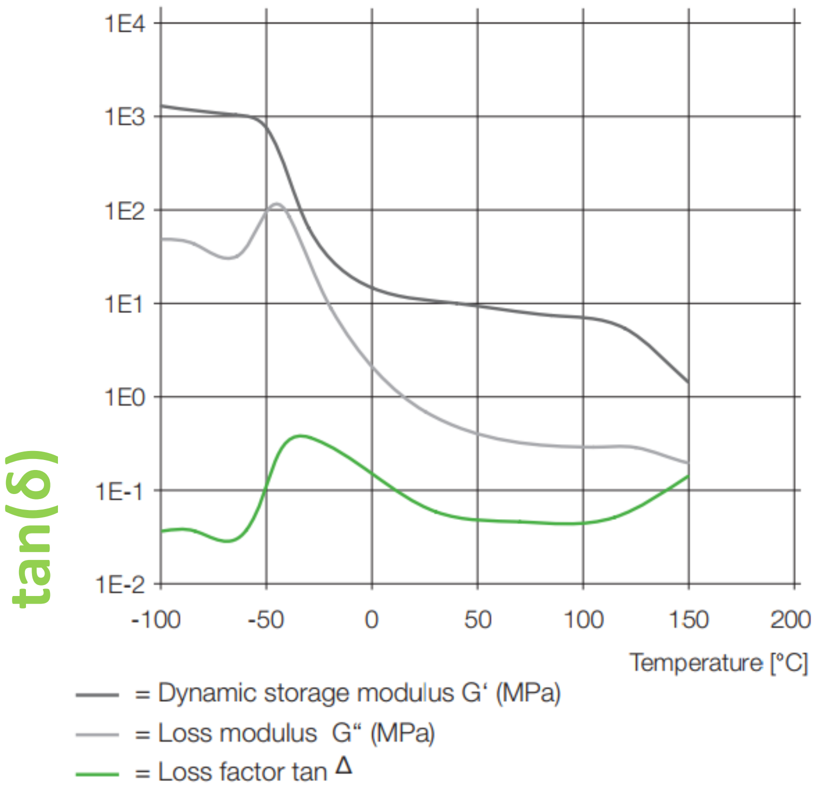
**+ energy extraction for movement of flexible wall**
**+ intrinsic damping**

# Material for flexible walls




**Intrinsic damping**

…often described by the loss factor **tan(δ)**



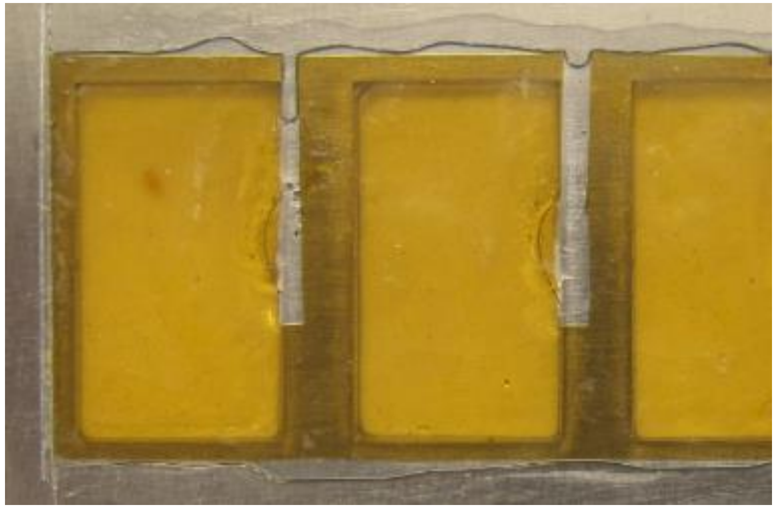

**Thermoplastic Polyurethane Elastomers (TPU)**

- exhibit a medium intrinsic damping tan(δ)≈0.1
- are available in a large variety of material compositions and thicknesses

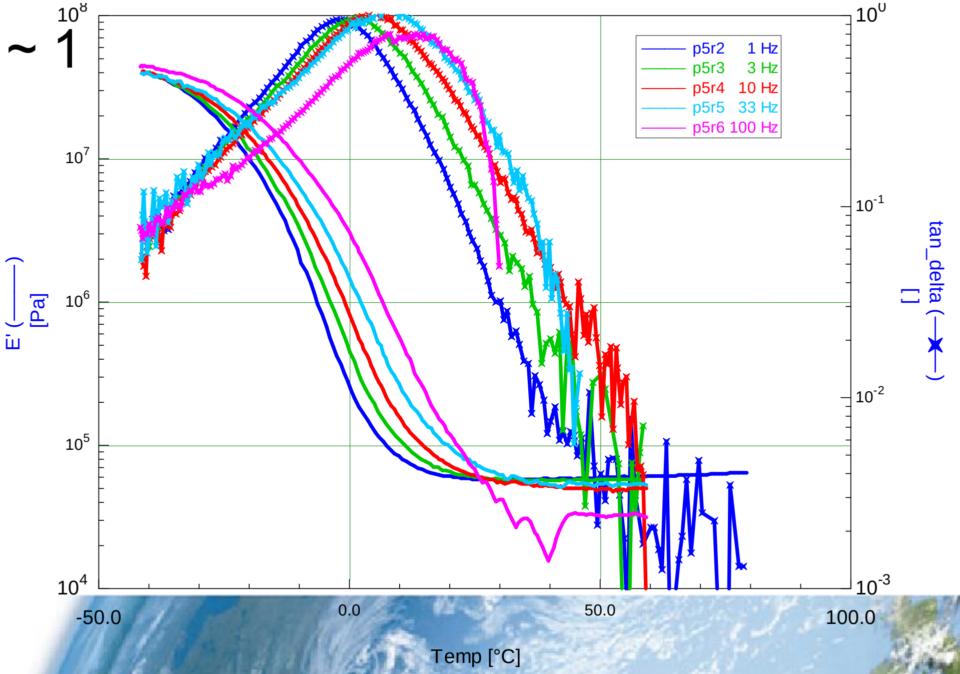
- tan(δ) depends for given material on temperature and frequency

Source: Fig. 8 (Elastollan® C85A10) taken from TPU Elastollan® material properties (BASF, 2017-09) http://www.polyurethanes.basf.de/pu/Elastollan/Elastollan_Materialeigenschaften

# Custom made material

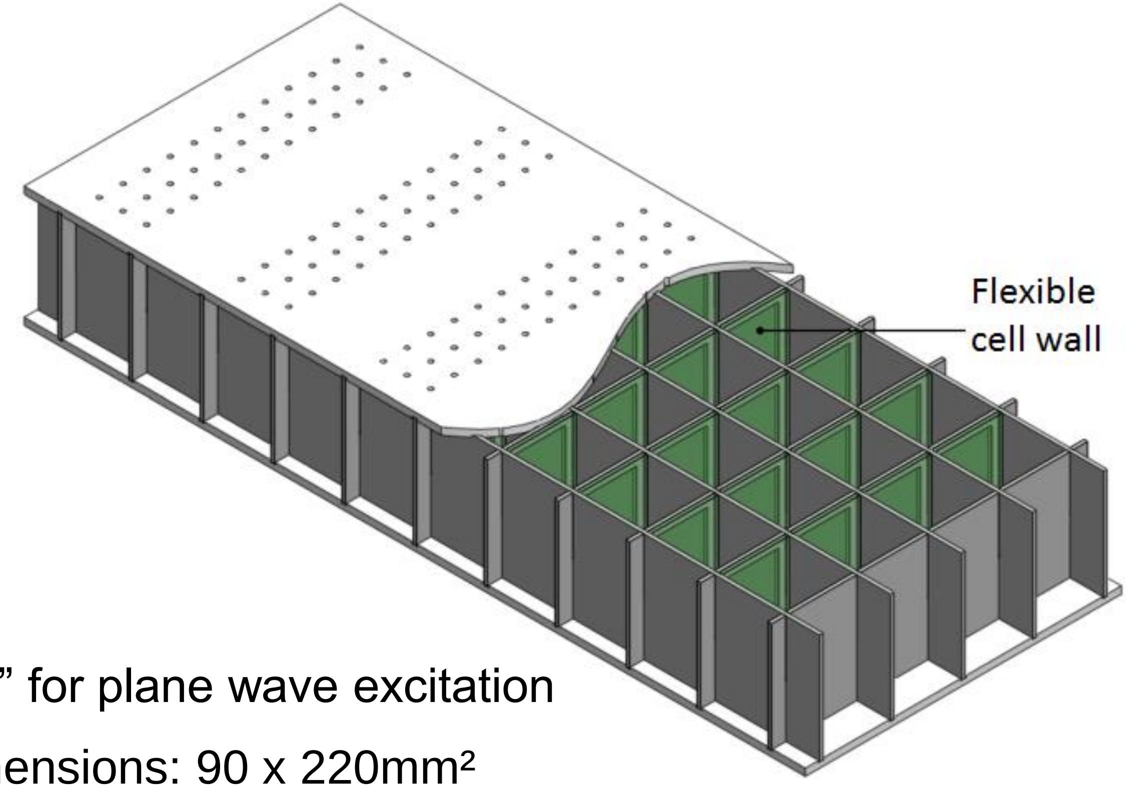


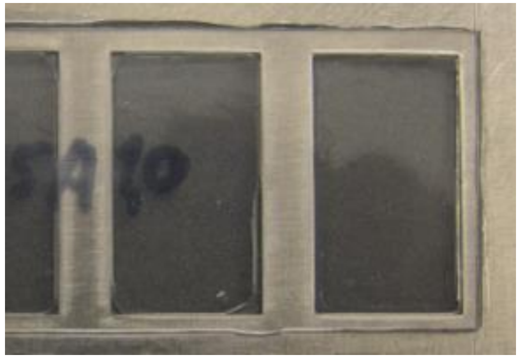
- Aim for material with high loss factor tan(δ)
- Rubber-like material mixed from two components (epoxy resin+ hardener Jeffamin)
- Material testing shows tan(δ) ~ 1




Flexible wall material “EP-0.5“ (thickness 0.5mm)

# Liner Design – Sample for Flow Duct



**Eigenfrequency of flexible wall close to HR-frequency**
+ good excitation
+ broadening of effective damping range of liner

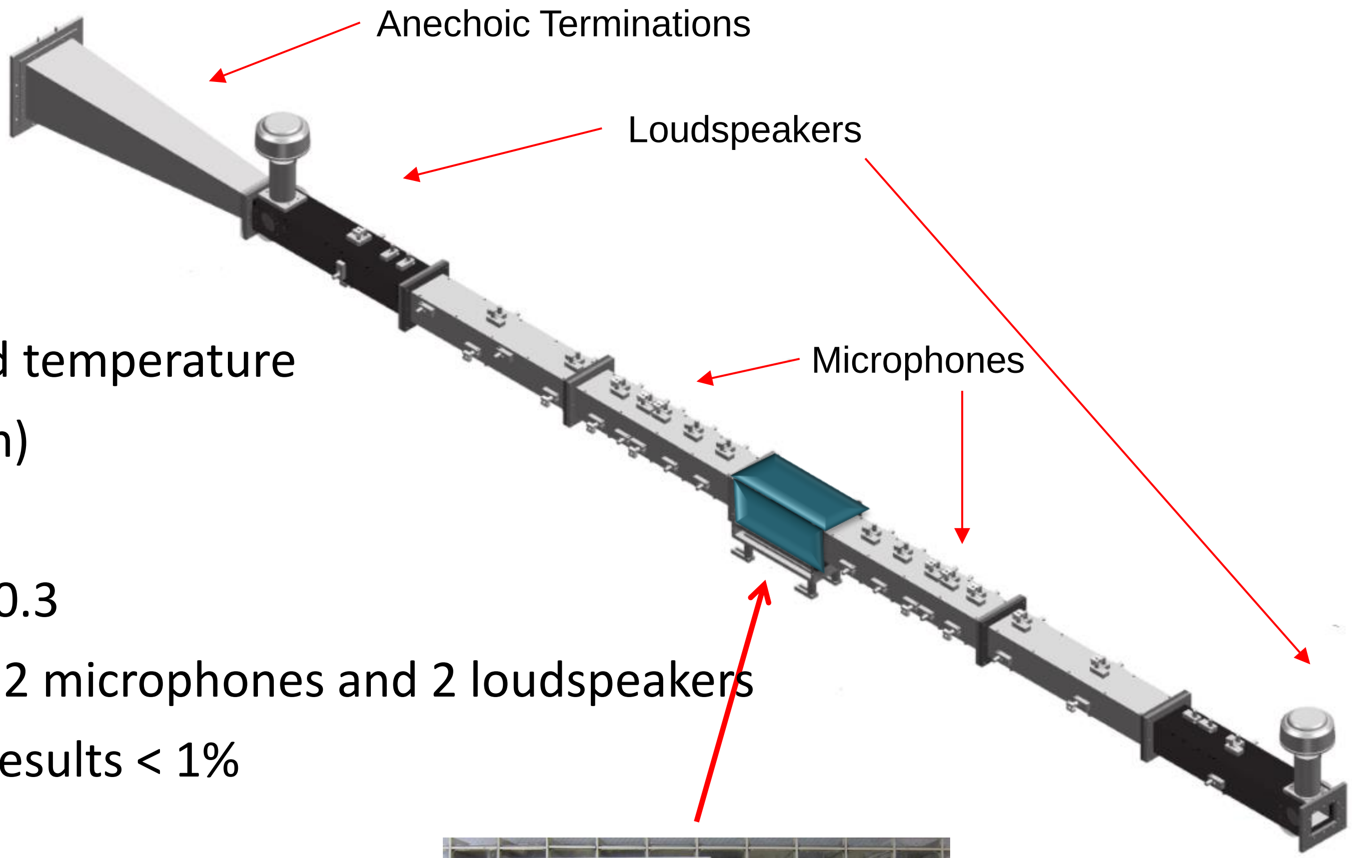
- “2-D design” for plane wave excitation
- Sample dimensions: 90 x 220mm²
- Cell dimensions 19 x 19 x 30mm³
- 9 holes (d=1.3mm) → porosity 3.3%
- Helmholtz-resonance near 1000Hz, λ/4 ~ 2.8kHz

**4 Liners with flexible walls manufactured:**

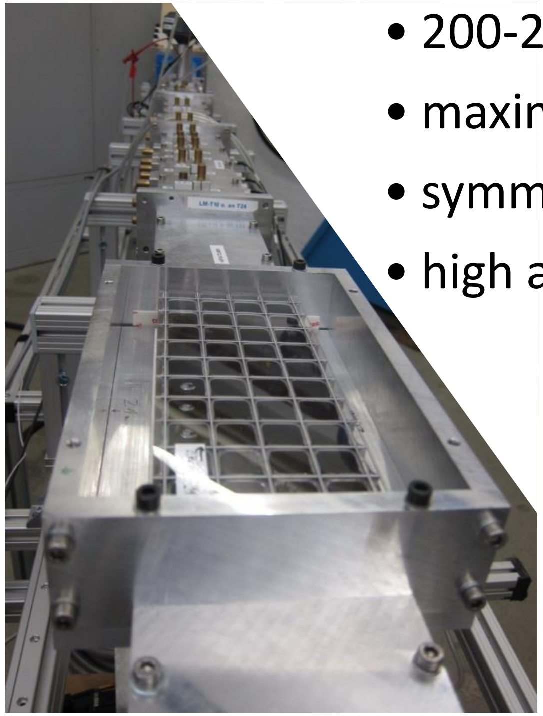
- TPU 1170A-0.3mm,
- TPU 1195A-0.1mm and -0.5mm,
- EP-0.5mm

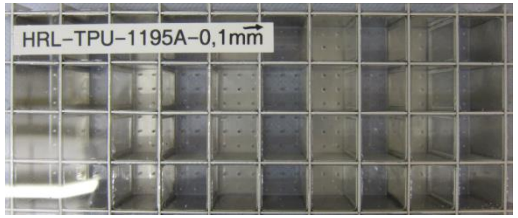
**1 reference sample with rigid walls**

# Test setup - DUCT-R



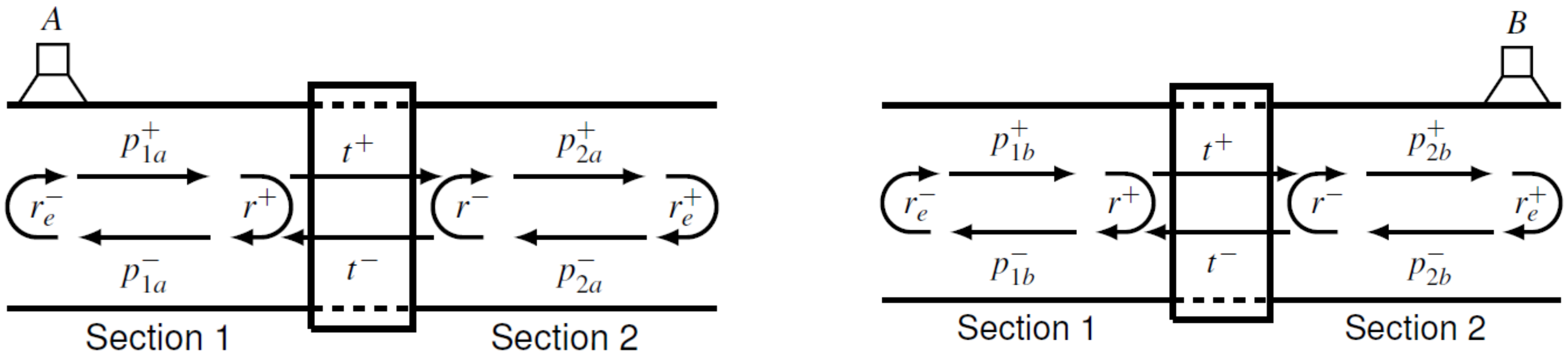

- operates at ambient pressure and temperature
- rectangular duct (80 mm x 60 mm)
- 200-2100 Hz (plane waves)
- maximum grazing Mach number 0.3
- symmetric layout with (at least) 12 microphones and 2 loudspeakers
- high accuracy: error of damping results < 1%






**Determination of Reflection (R), Transmission (T), and Dissipation (Δ)**

# Determination of Reflection (R), Transmission (T), and Dissipation (Δ) of Acoustic Energy



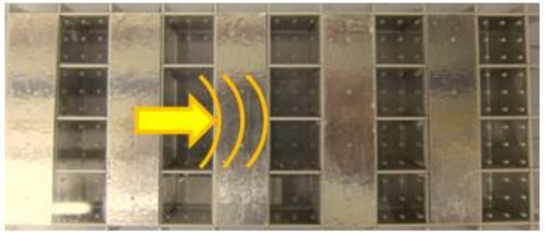

2 consecutive excitation cases (upstream speaker A, downstream speaker B)

$$R^{\pm} + T^{\pm} + \Delta^{\pm} = 1$$

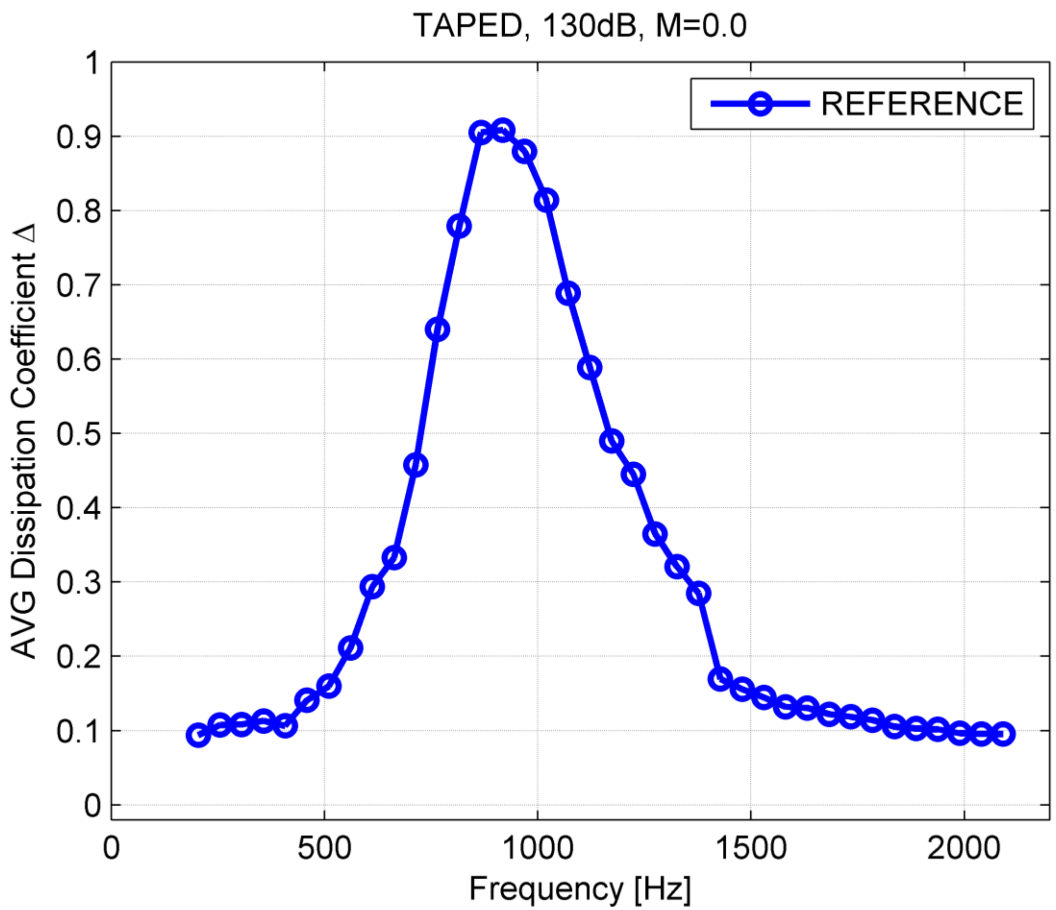
$$\Delta^{+} = 1 - \left( \frac{(1-M)^2}{(1+M)^2} \cdot \left| r^{+} \right|^2 + \left| t^{+} \right|^2 \right)$$

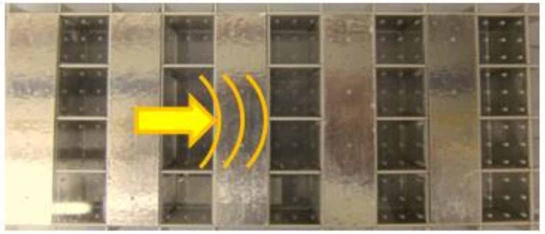
$$\Delta^{-} = 1 - \left( \frac{(1+M)^2}{(1-M)^2} \cdot \left| r^{-} \right|^2 + \left| t^{-} \right|^2 \right)$$

$\Delta_{avg} = \Delta^{+}/2 + \Delta^{-}/2$



# Results – no flow





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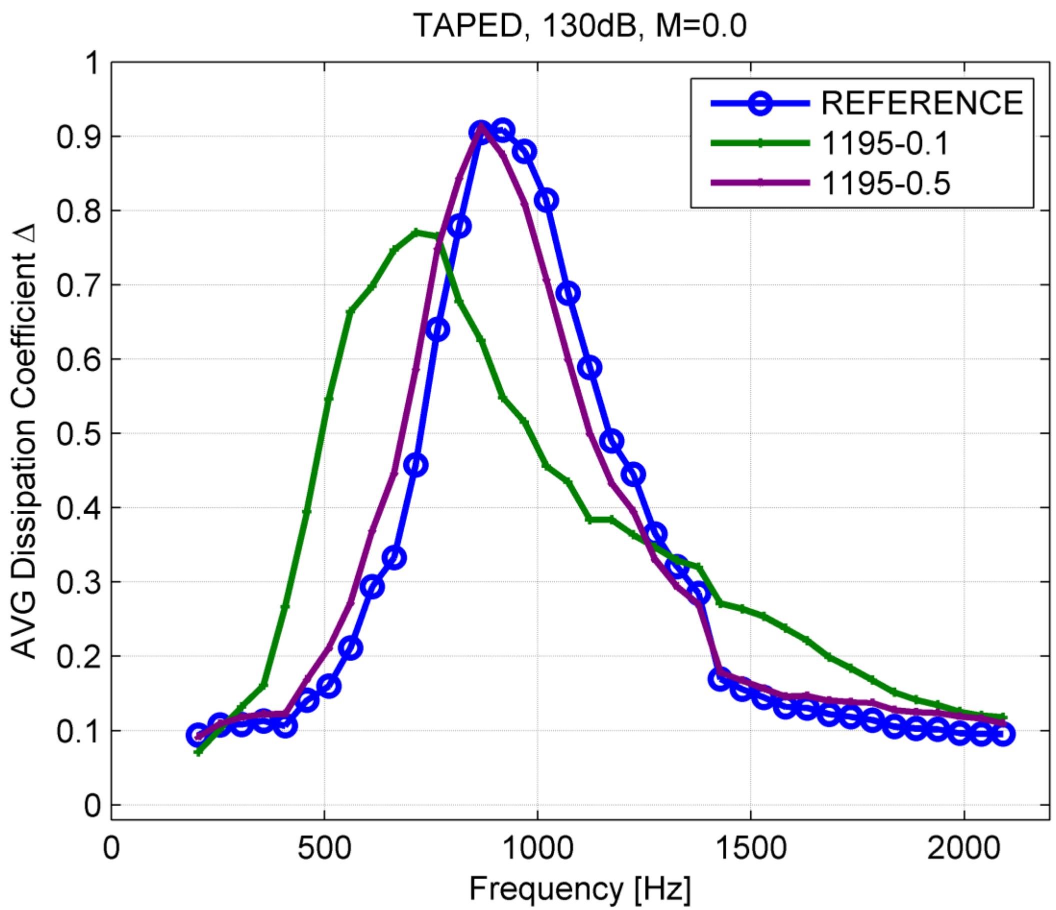
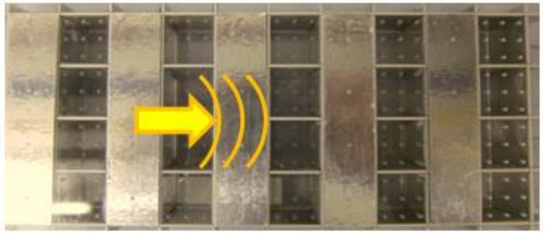



Reduction in major damping peak for flexible walls, but

- Shift to lower frequencies



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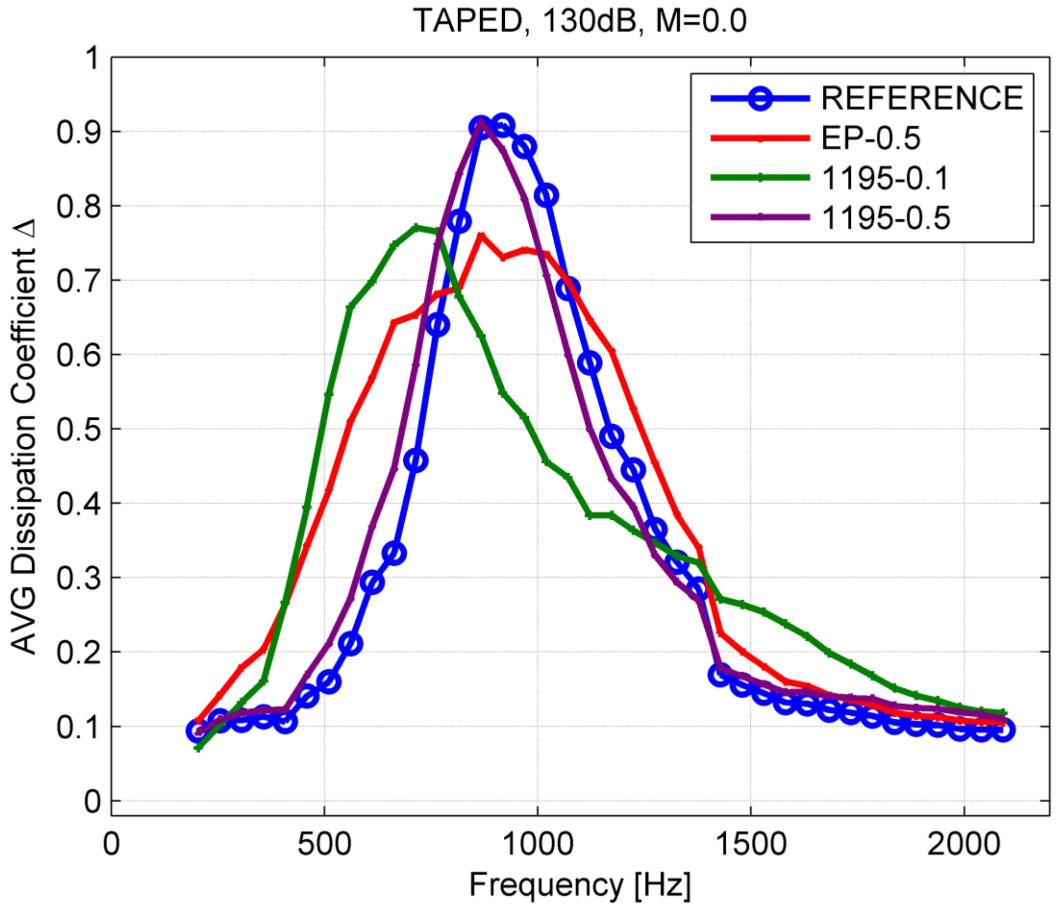
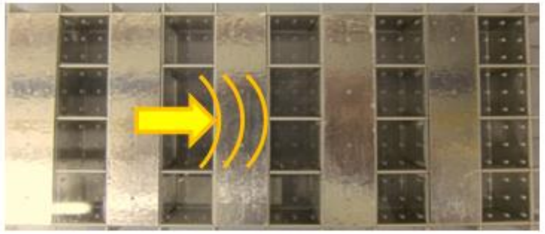
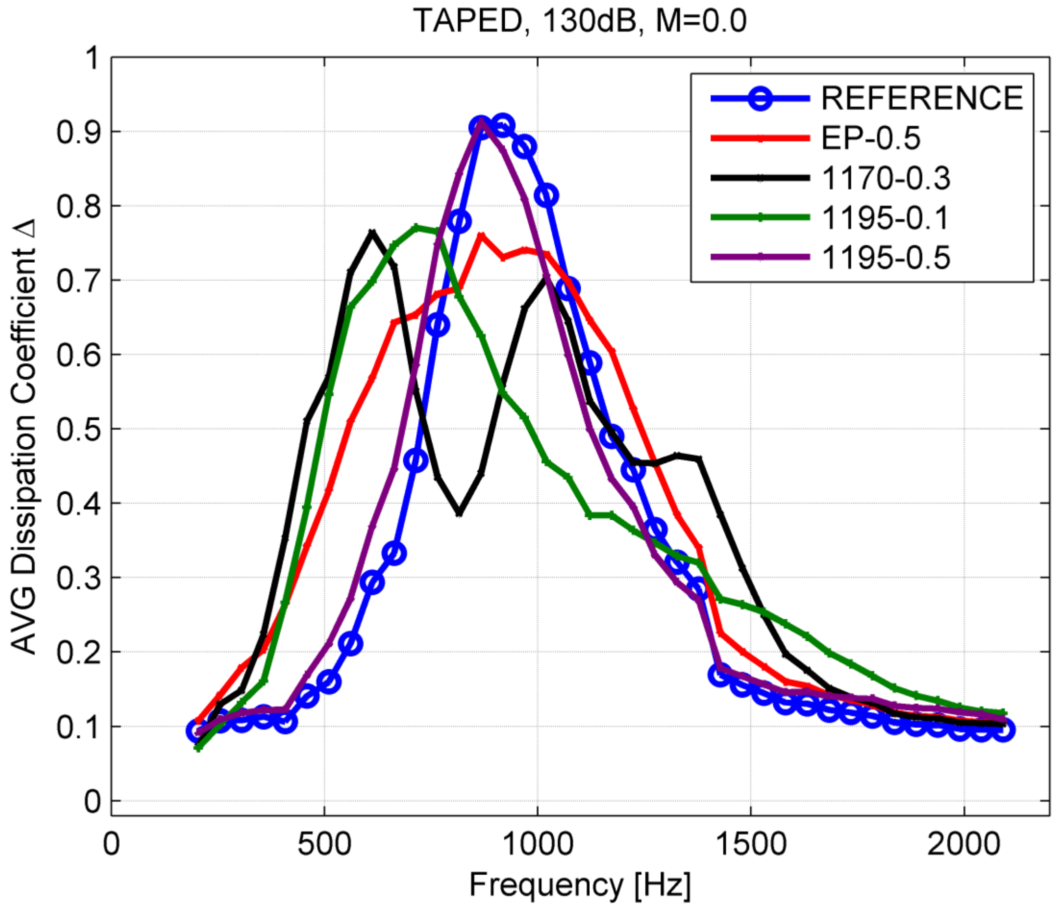



Reduction in major damping peak for flexible walls, but

- Shift to lower frequencies
- Enlarges frequency range



# Results – no flow

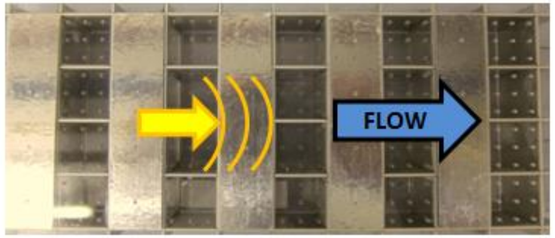


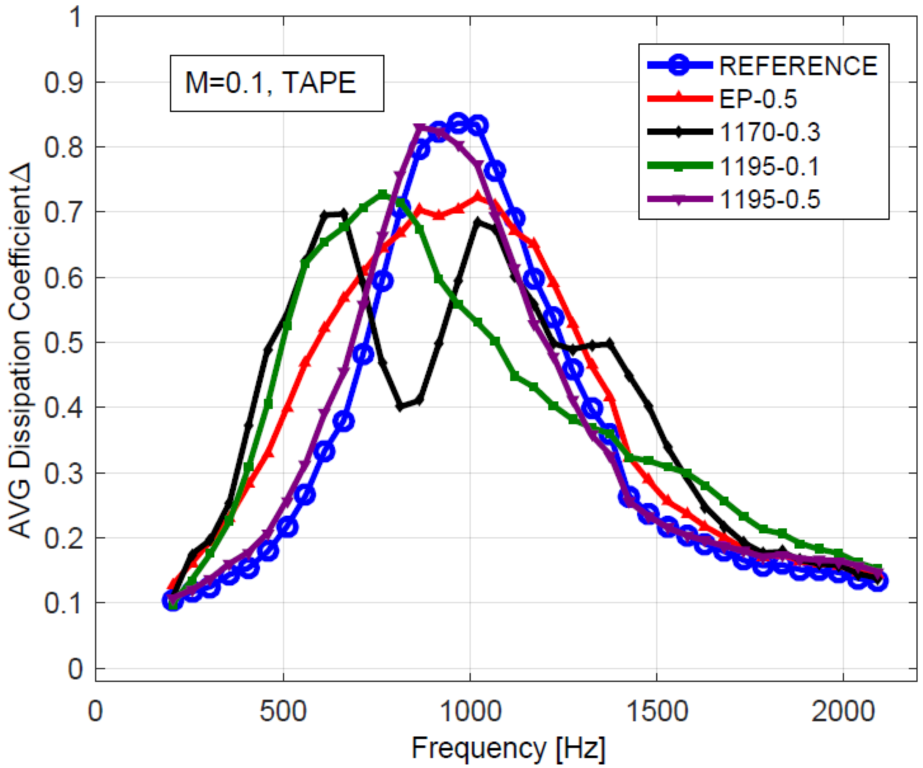

Reduction in major damping peak for flexible walls, but

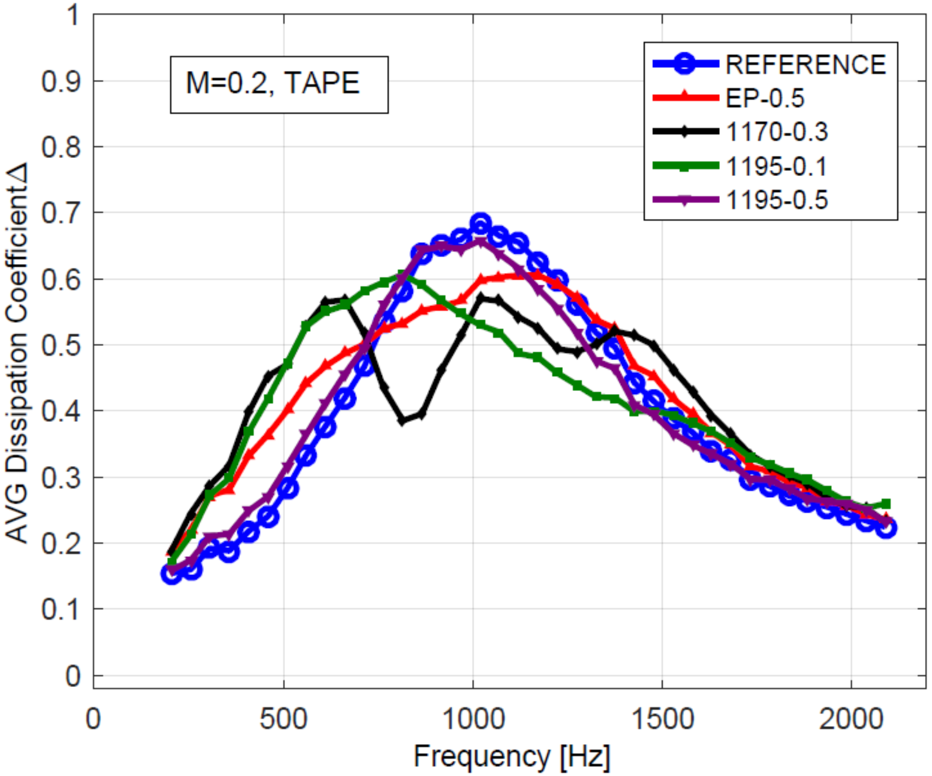
- Shift to lower frequencies
- Enlarges frequency range
- 3 (local) damping maxima for 1170-0.3

Deflection of flexible walls broadens frequency band of effective damping and increases overall damping.

# Results with grazing flow



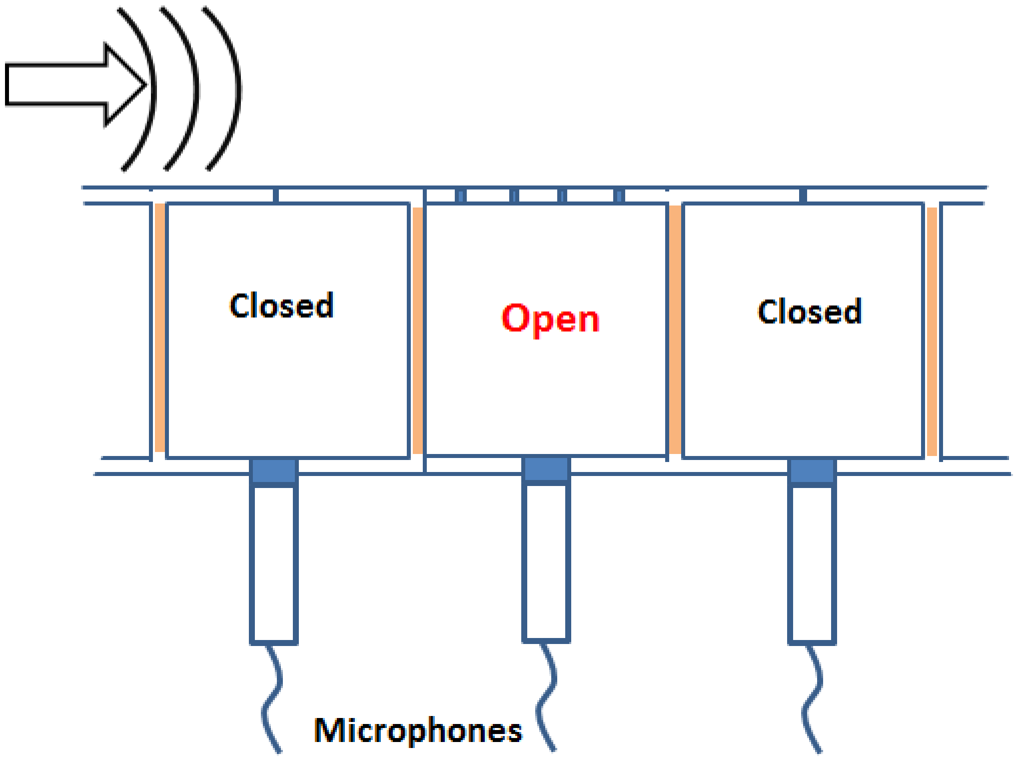




Change in damping characteristics persist also when grazing flow is present.

# In-Cell measurements

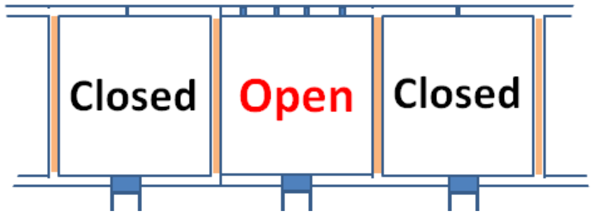
What is happening inside the cells?

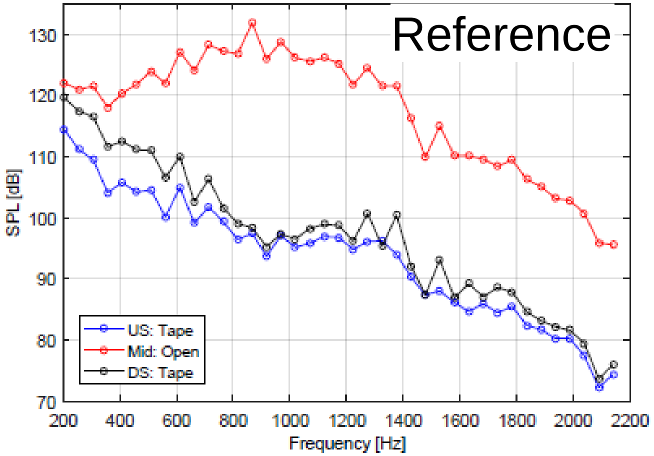


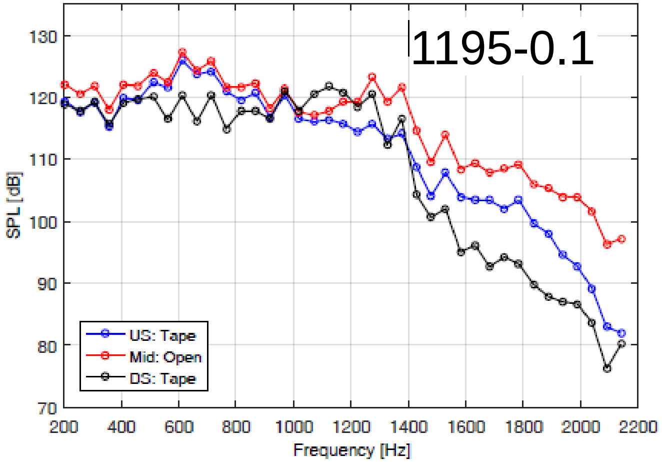

Install flush mounted microphones in the lower cell wall:

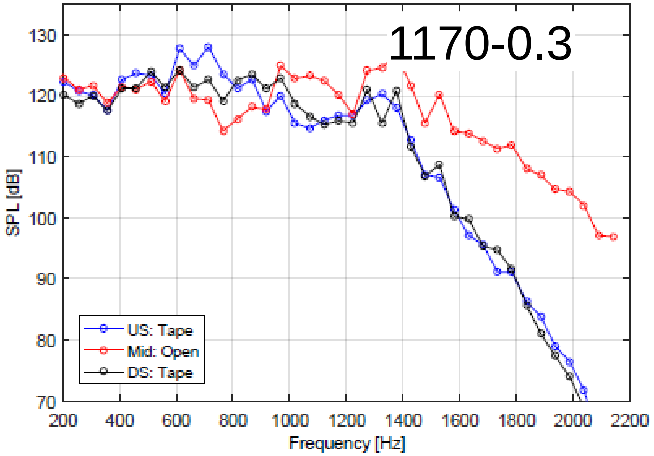
- Can measure SPL and phase
- Provide insight into inter-cell interactions

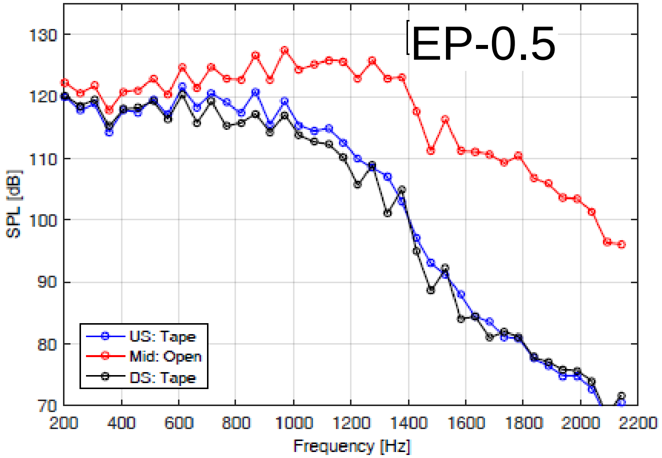
# In-cell Microphones „TAPED“ => SPL




**Reference:**

- SPL in open cell >> closed cells

**1195-0.1 and 1170-0.3**

- Flexible walls transmit pressure to closed cells

**EP-0.5:**

- „mixture“ of rigid wall/flexible wall behaviour

# Conclusions

- **Additional damping** mechanism through movement of **flexible walls** could be **demonstrated**
- Contrary to DDOF liner, the **intrinsic damping** of material **adds to the acoustic damping**
- **In cell microphone** measurements **support** the expected **wall deflections**
- So far, a large **inactive part**/cavity were used for sufficient excitation of flexible walls => **optimization** is possible and **needed**

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DLR

Technische Universität Berlin

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Technische Universität Dresden

Fraunhofer PYCO

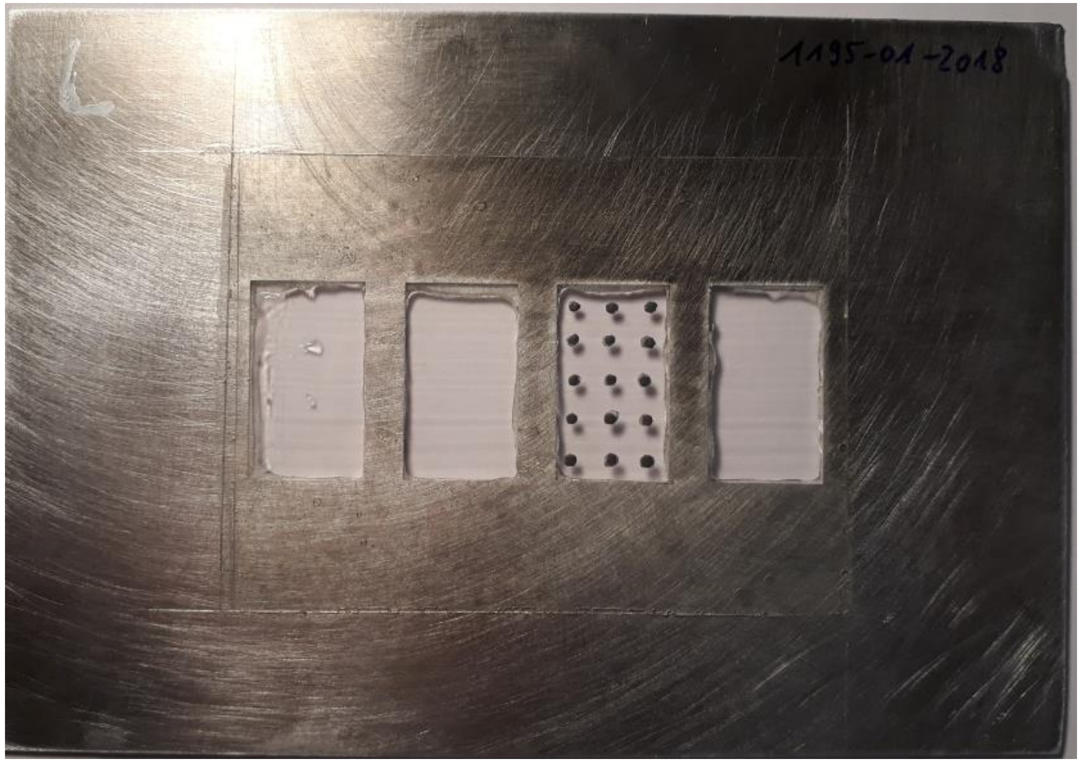
# Investigation of Flexible Walls

Movement of flexible walls inside the liner difficult to assess!

Quantities of interest:
- Vibration frequency,
- Deflection, vibration velocity
- Spatial modes of vibration

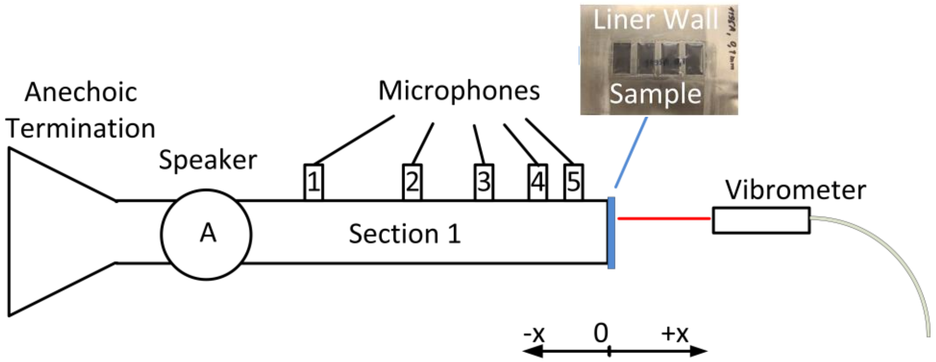
→How do the flexible walls contribute to the acoustic dissipation of the liner?

→ How can this be modeled?




Liner wall samples with 4 flexible wall segments used for further investigation

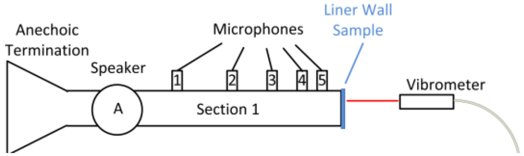
# A setup for further investigation of flexible walls



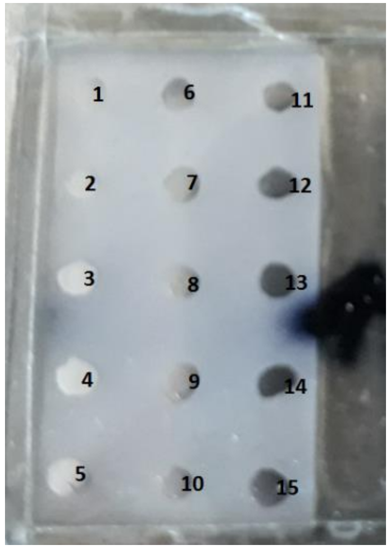

Incident wave $p^+$ and Reflection (R) via wave decomposition in upstream part.

Deflection and vibration velocity via vibrometer (Polytec 5000 with OFV-200 fiber head)

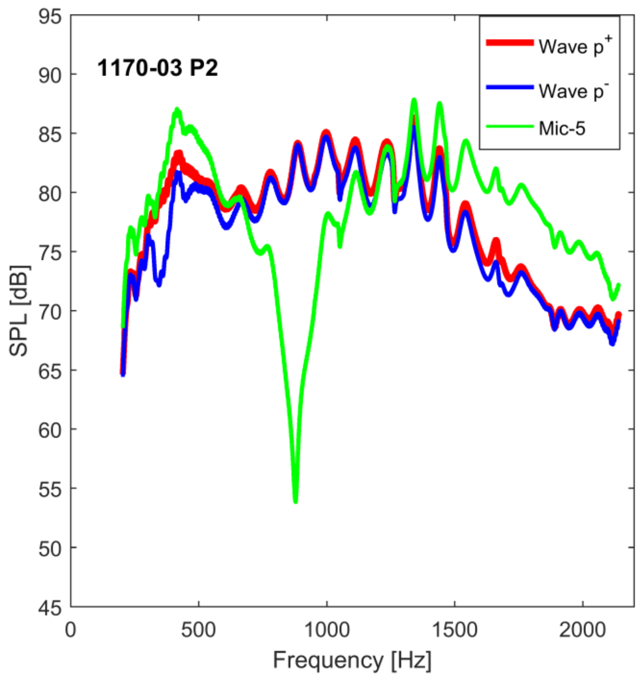
No flow, normal incidence of sound field



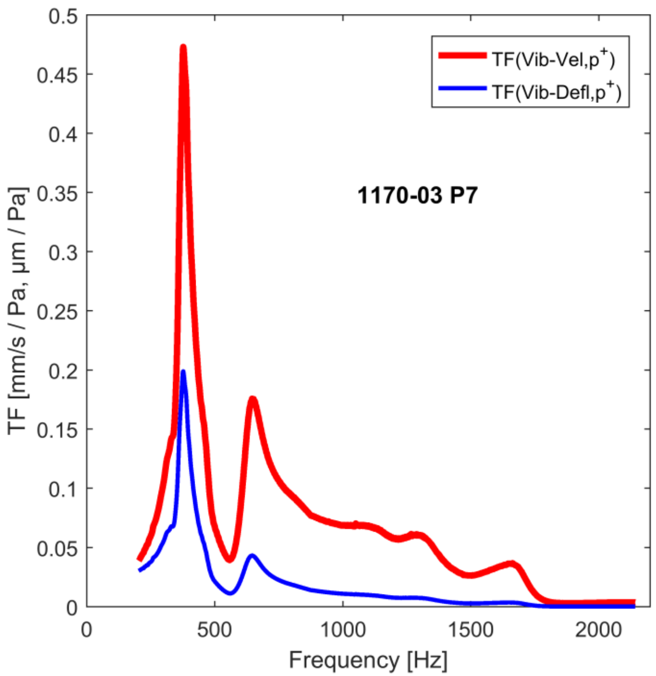

# Data Processing for Vibrometer




Simultaneous acquisition of vibrometer output (velocity, deflection) and microphone signals (mic 1-5) for points P1-15

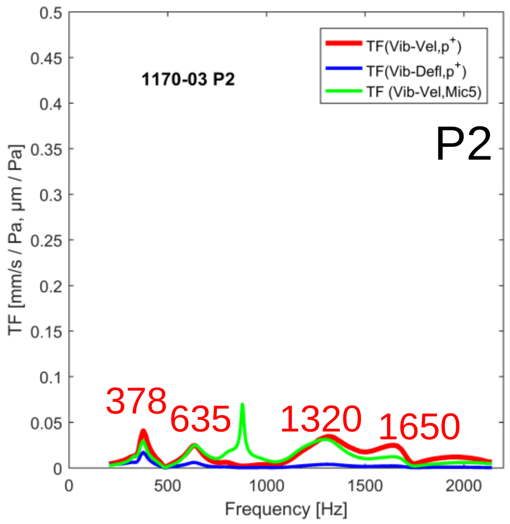


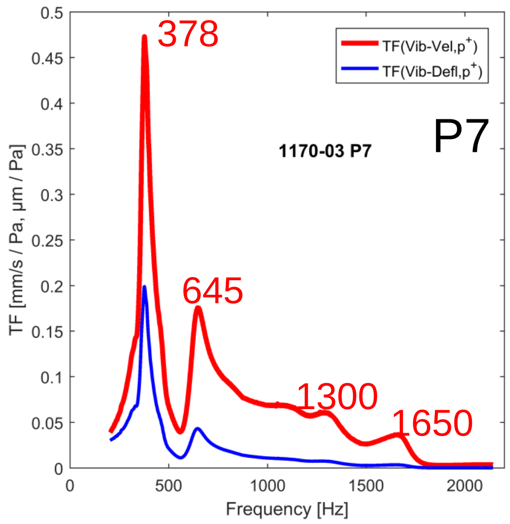

Wave decomposition for incident wave $p^+$ and reflected wave $p^-$

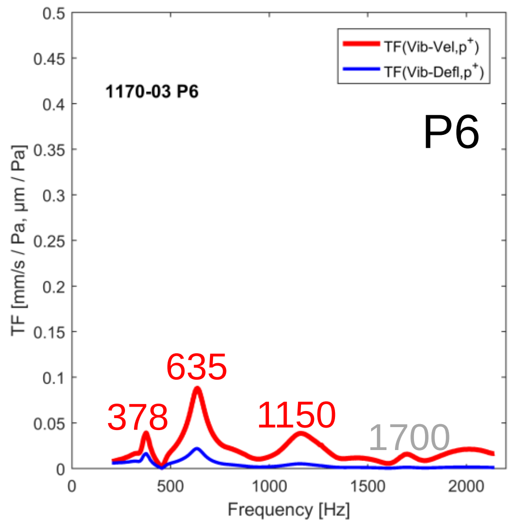


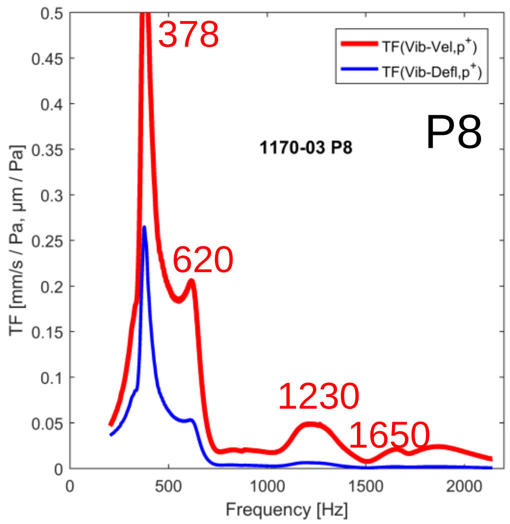

Calculation of transfer function between vibrometer signal (**velocity**, **deflection**) and $p^+$

# Identification of Peaks …Obtaining Spatial Information





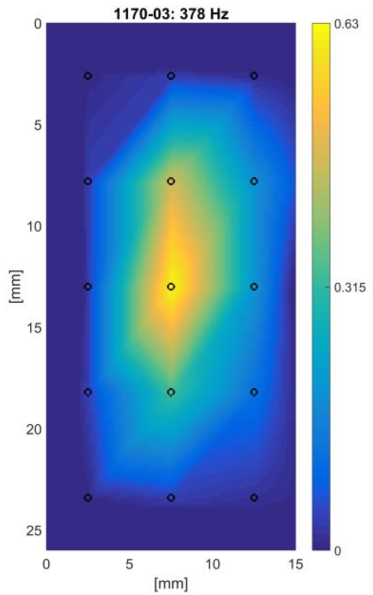
Peaks transfer function
TF (Vib-Vel, p+) P2, P6, P7:

378, 635, 1161, 1310, 1650 Hz

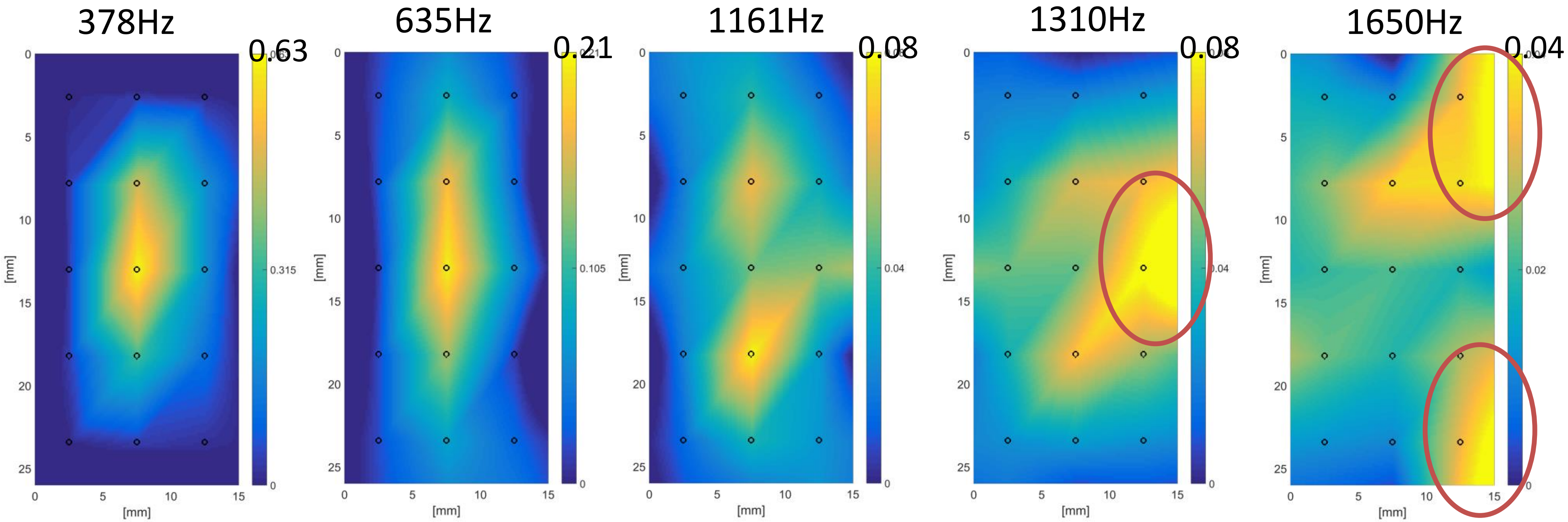
Retrieve max. TF values for all 15 points P1-P15

for those frequencies
(within some interval) f±20Hz

…and inter-/extrapolate

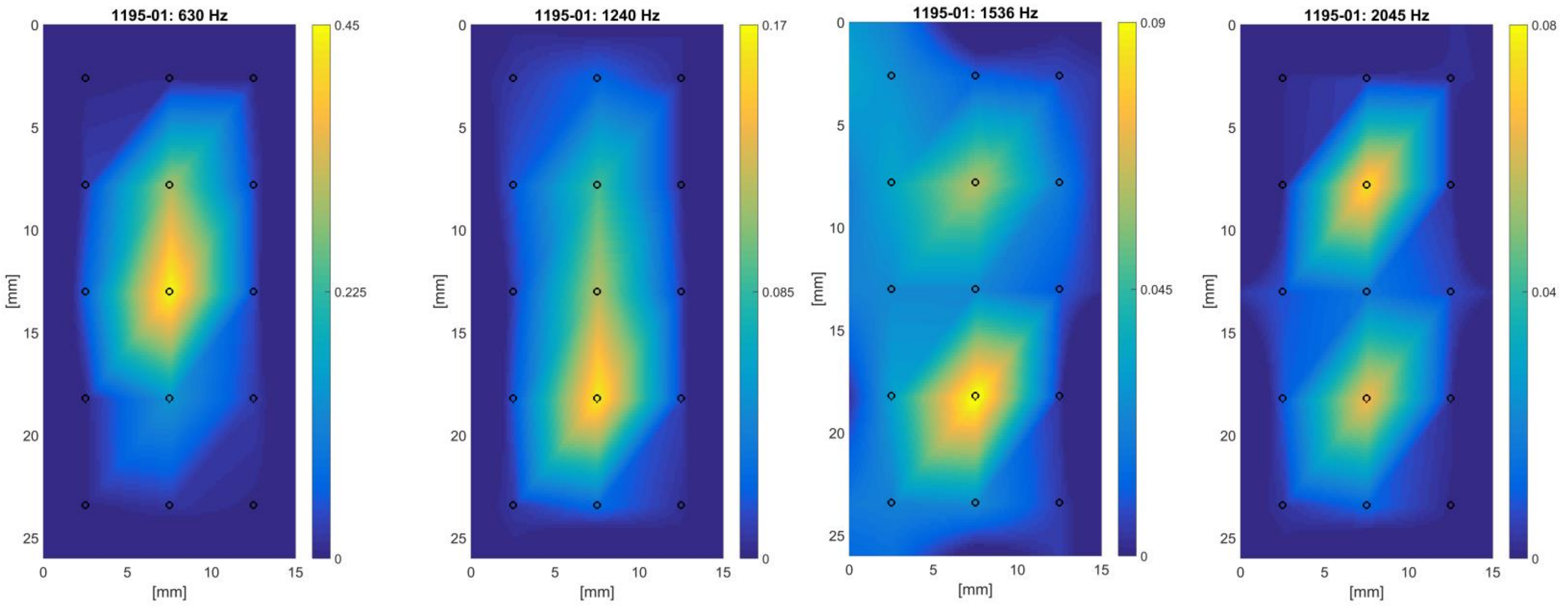


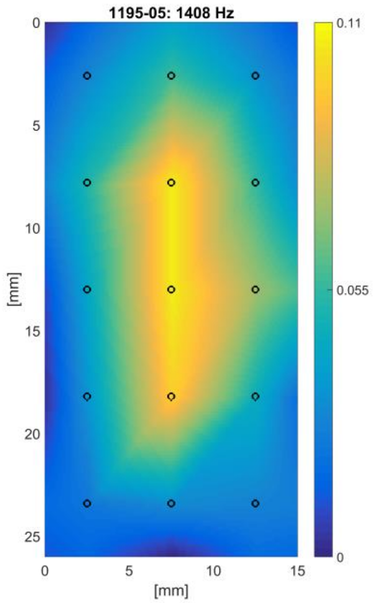
# Vibration Mode Shapes 1170-03




- Fundamental mode for 378Hz and 635Hz
- Higher mode in vertical direction for 1161Hz and 1310Hz
- Maximum scaling might be misleading with respect to actual vibration deflection
- Extrapolation artifacts

# Vibration Mode Shapes 1195-01 and 1195-05




1195-01

- Fundamental mode for 630Hz and 1240Hz (asymmetric)
- Higher mode in vertical direction for 1536Hz and 2045Hz

1195-05

- Fundamental mode for 1408Hz

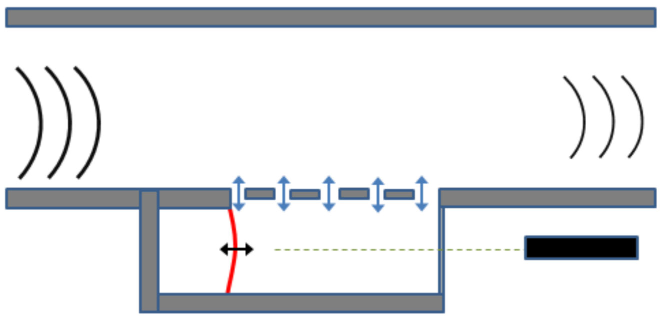
# Summary & Conclusions

- A mock-up has been used to determine the vibration characteristics of flexible elements used in novel liner concept
- Local measurements of vibration velocity and deflection reveal at least two different spatial vibration modes of the flexible elements
- Correlation between results of different measurements and observed dissipation characteristics of liner are not perfect, but significant for materials 1195-01 and 1170-03 (which exhibit stronger vibrations and substantial change of liner dissipation characteristics)
- Possible reasons for deviation: material and mounting variations, different boundary conditions for in-cell-application and generic setups used here, …

… more detailed experiments needed as basis for modelling!

# Outlook

Further understanding of excitation and deflection (spatial distribution) of flexible walls is needed.



→ Do this by single element model experiment and numerical simulations

→ Modelling of flexible element…
…and finally cell with flexible element

**With respect to liner concept:**

Size and arrangement/coupling of inactive back cavities need to be investigated

Is there an aging effect/high cycle fatigue issue?

What are efficient arrangements of cells and backing cavities