

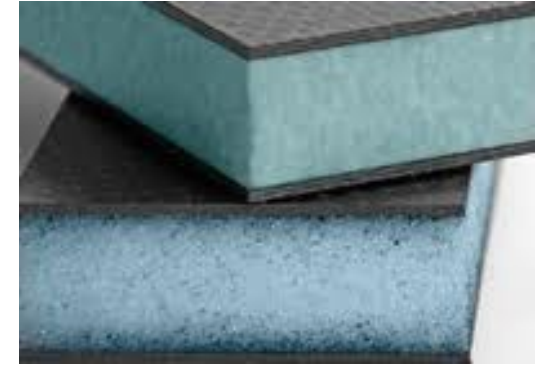
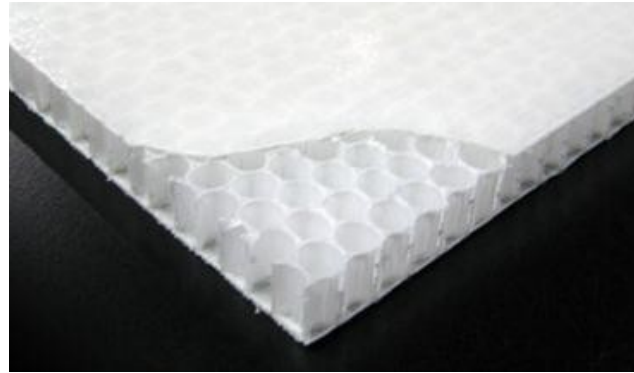
locally resonant vibro-acoustic metamaterials for compact lightweight noise control engineering solutions

Wim Desmet, Bert Pluymers, Elke Deckers, Claus Claeys, Lucas Van Belle, Noé G. R. de Melo Filho, Luca Sangiuliano, Matias Clasing Villanueva, Régis Boukadia, Sepide Ahsani, Felipe Alves Pires, Augusto Carvalho De Sousa, Zhang Ze, Marcelo de Lima Marcolin

overview

- **NVH challenges for lightweight materials**
- locally resonant vibro-acoustic metamaterials for compact lightweight noise control engineering solutions
 - demonstration
 - basic concept
 - applications

lightweight materials



motivation

- lower weight
- higher strength

price to pay

- worse NVH properties
- different (complex) dynamics

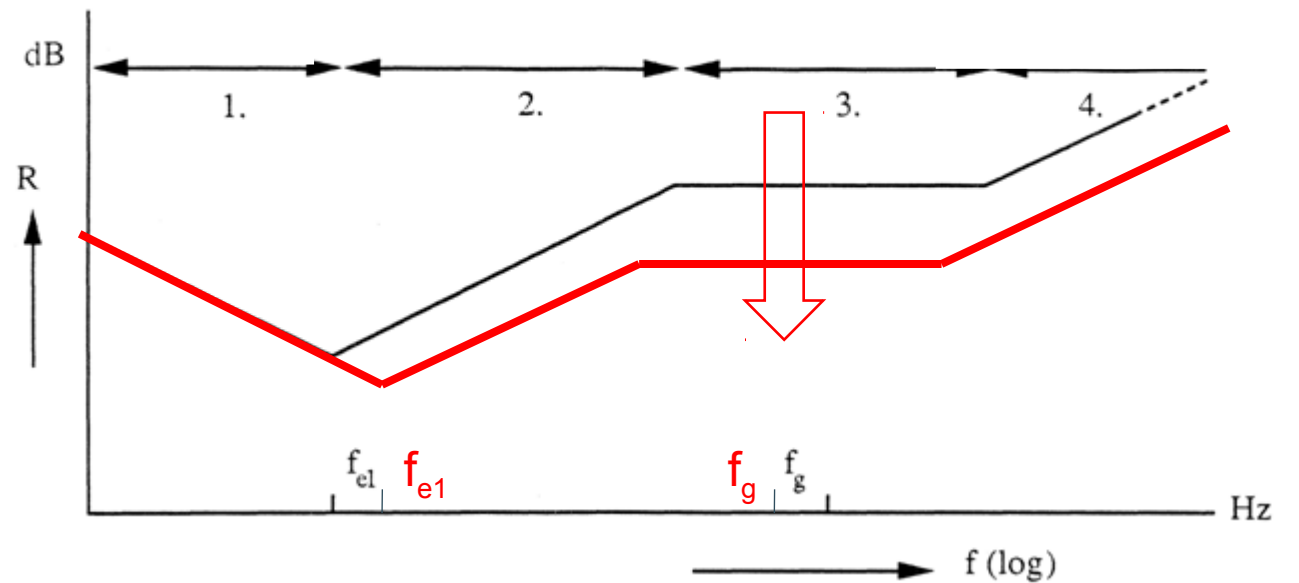
STL of lightweight materials

similar stiffness, lower mass

- f_{e1} ↑

- f_g ↓

⇒ strongly reduced insulation



(our) NVH challenge

material systems with good noise and vibration insulation properties at

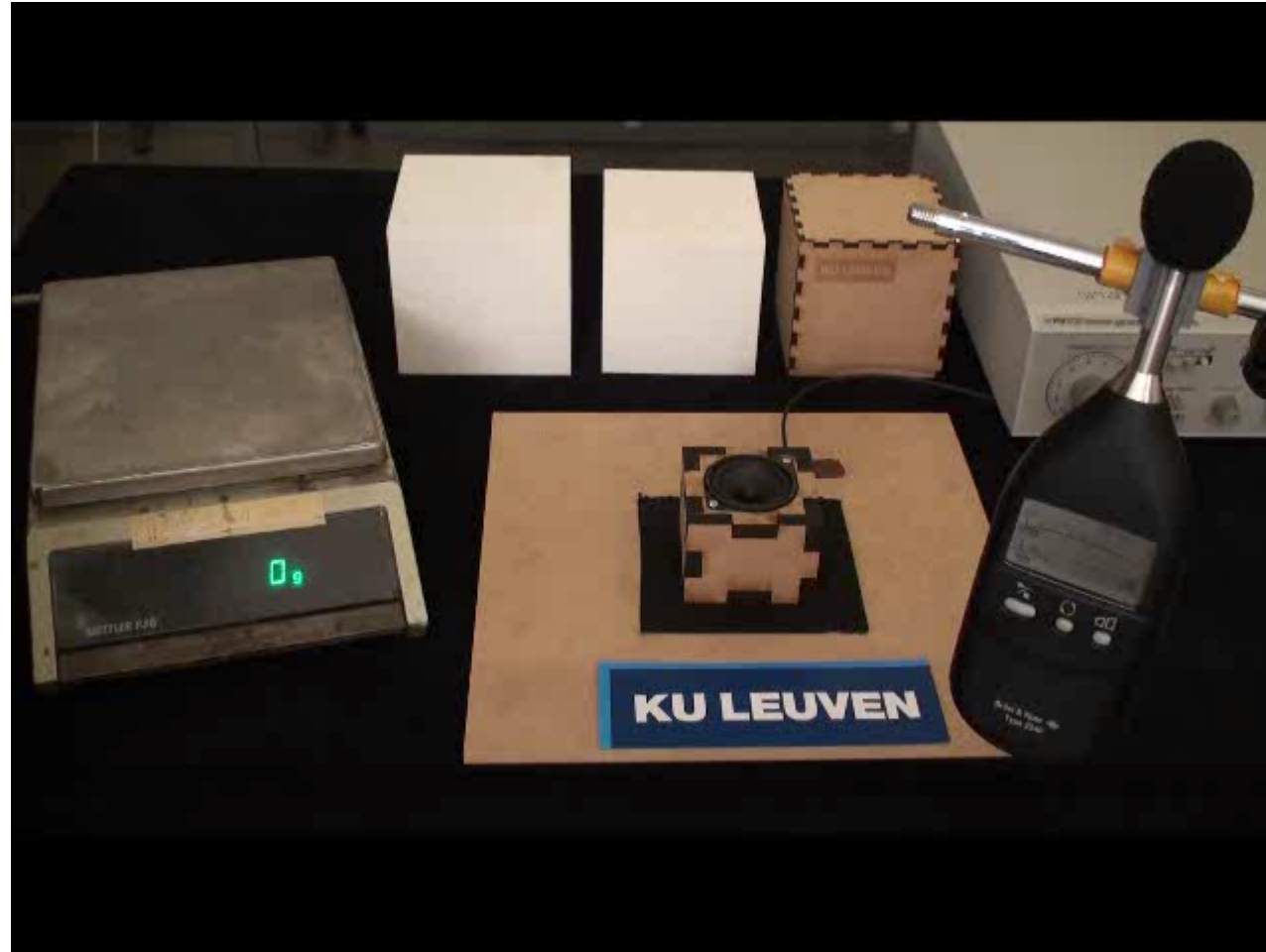
- low-mass
- low-volume
- low-frequency
- low-manufacturing cost



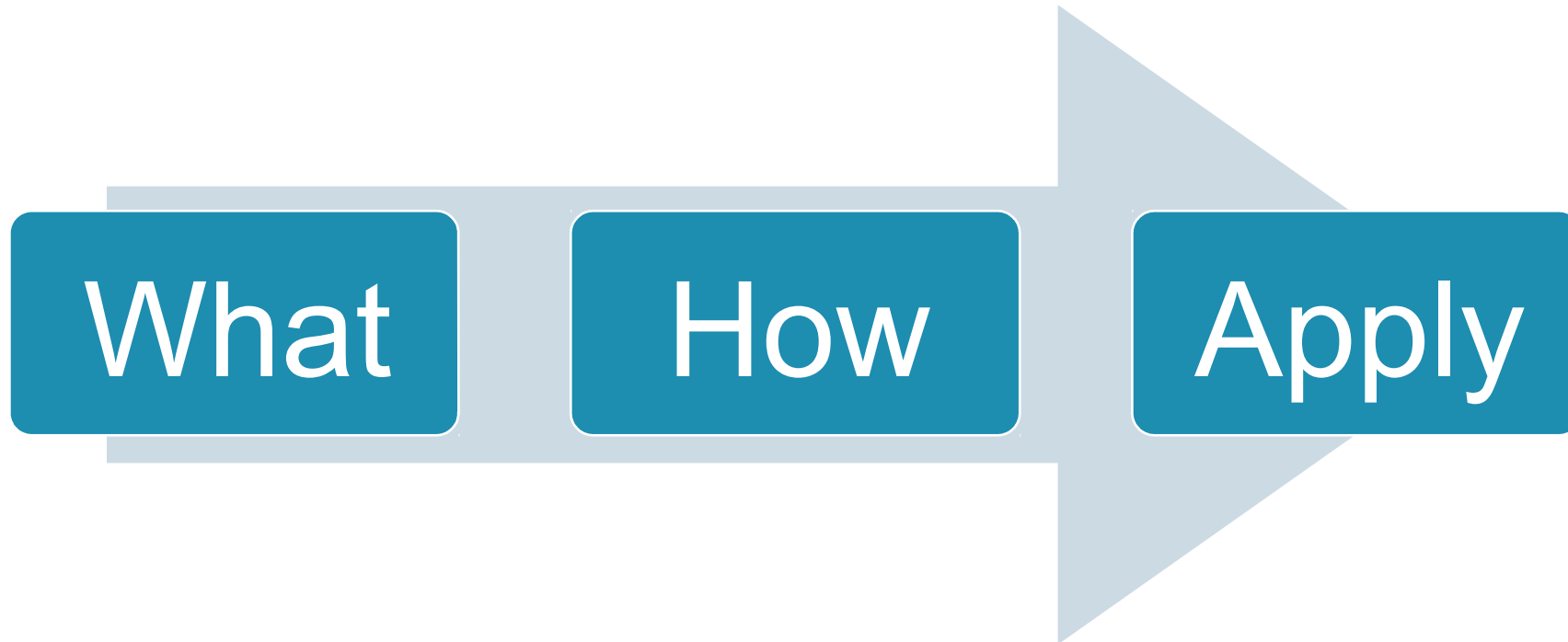
overview

- NVH challenges for lightweight materials
- **locally resonant vibro-acoustic metamaterials for compact lightweight noise control engineering solutions**
 - demonstration
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locally resonant vibro-acoustic metamaterials

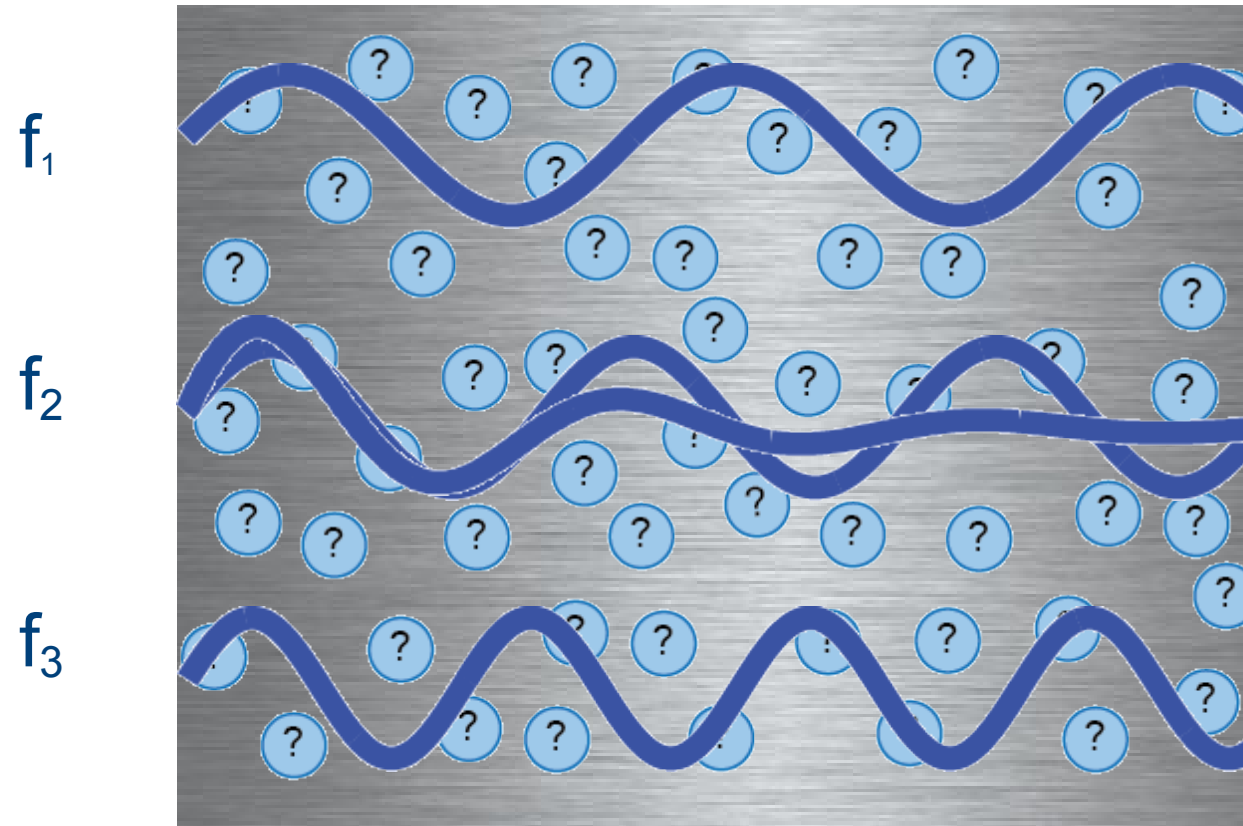


metamaterials with stopband behaviour

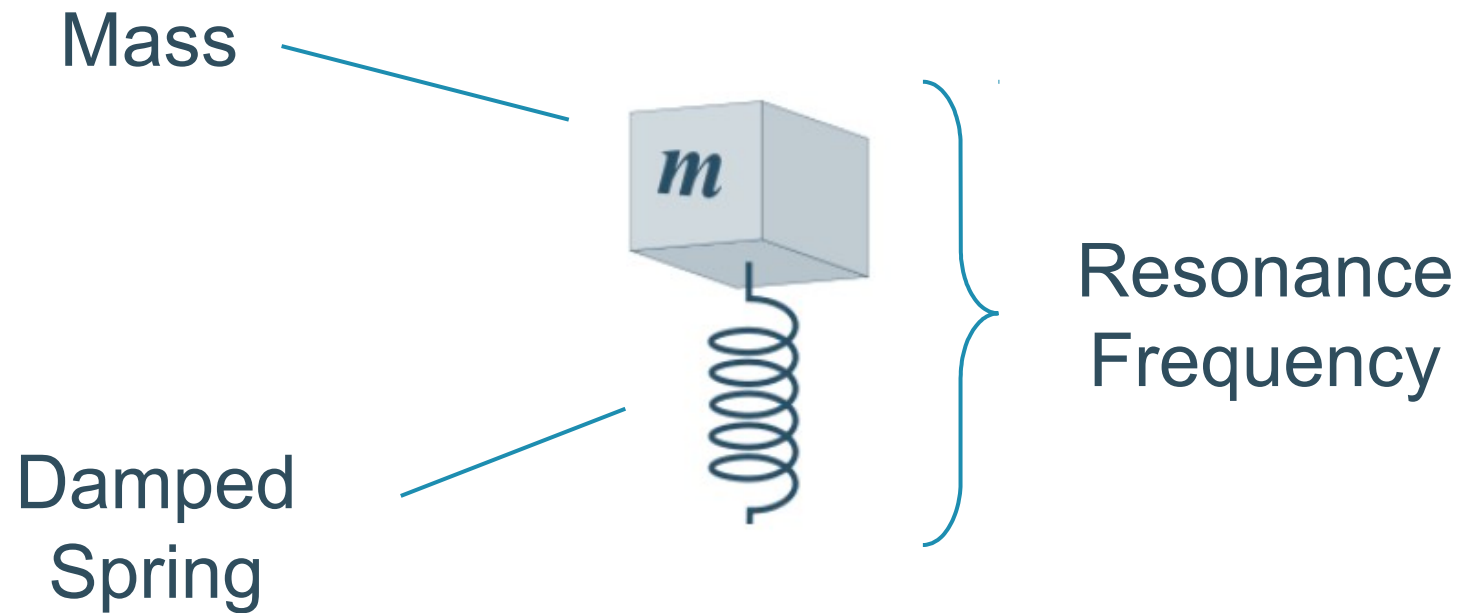


stopband behaviour

... certain frequency zones do not propagate

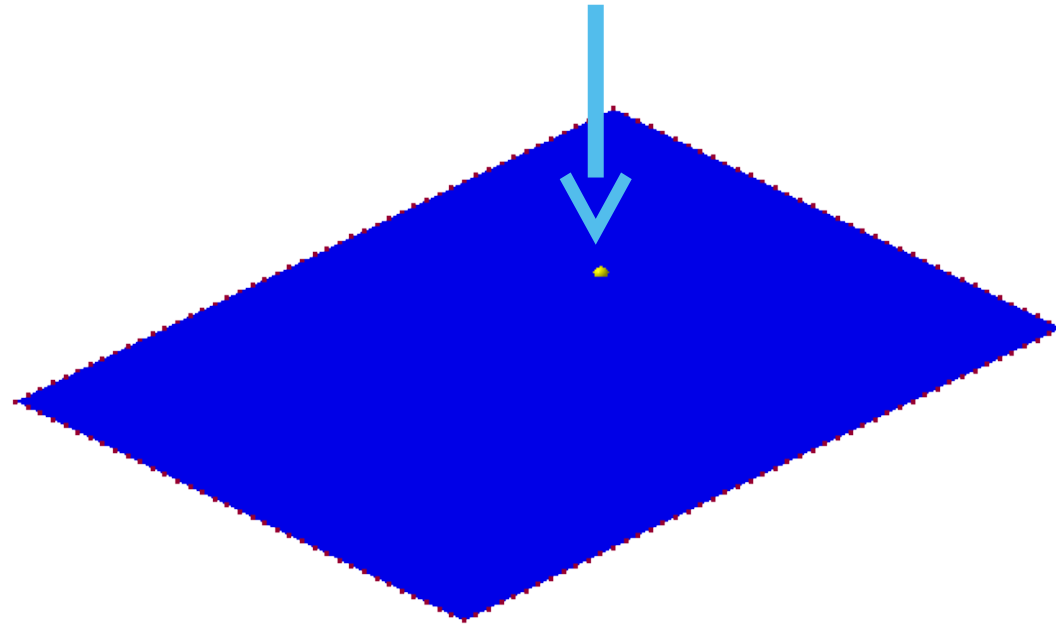


Tuned Vibration Absorbers



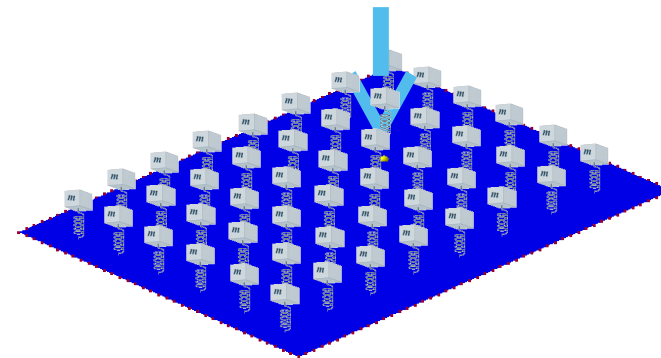
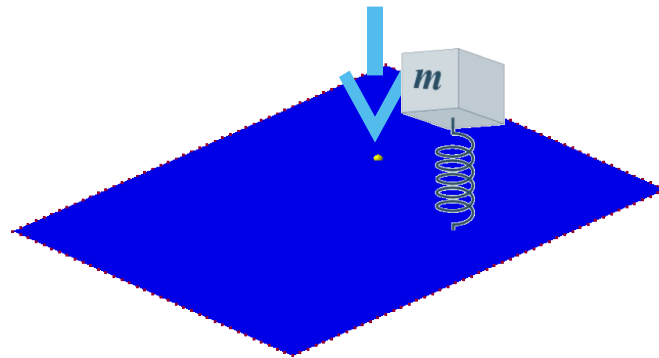
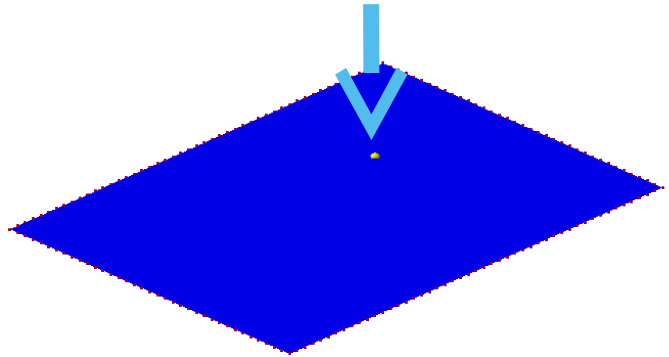
power of metamaterials - example

Localised input force

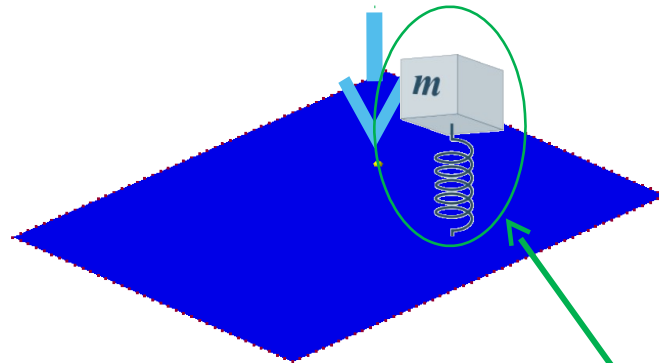
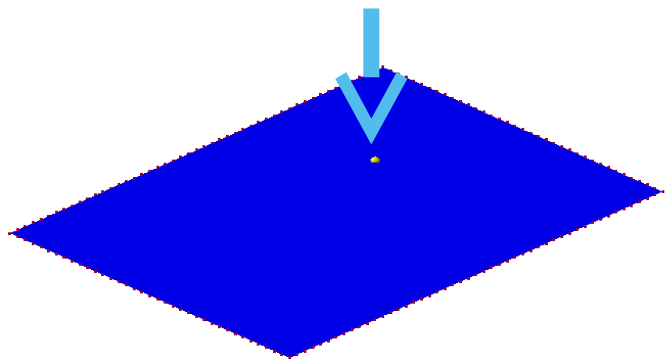


Study average (RMS) displacement of plates
under addition of tuned vibration absorbers (TVAs)

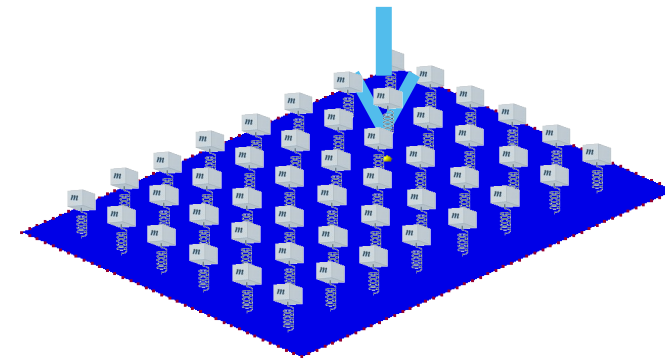
power of metamaterials - example



Case 1 and 2:
Same mass addition!

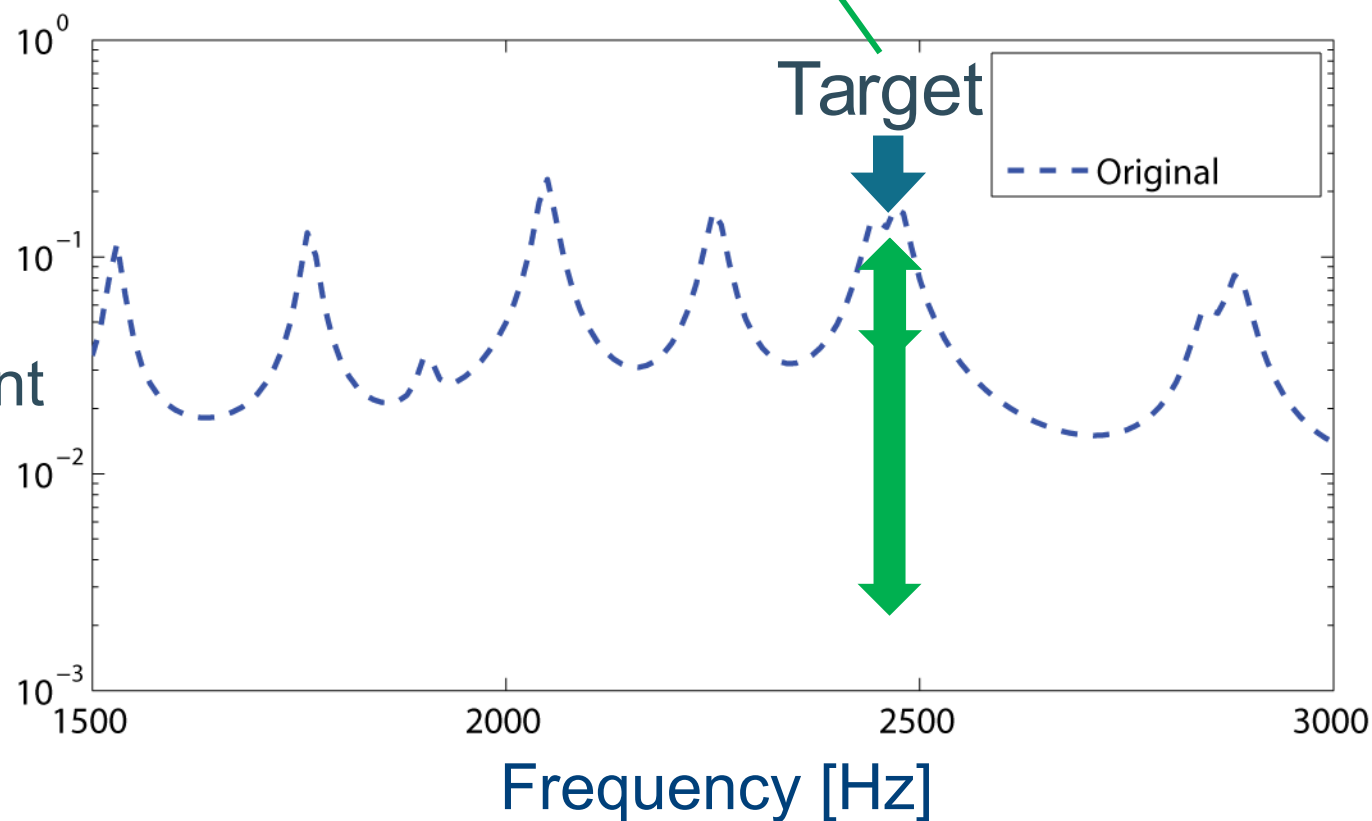


+20% mass (local)

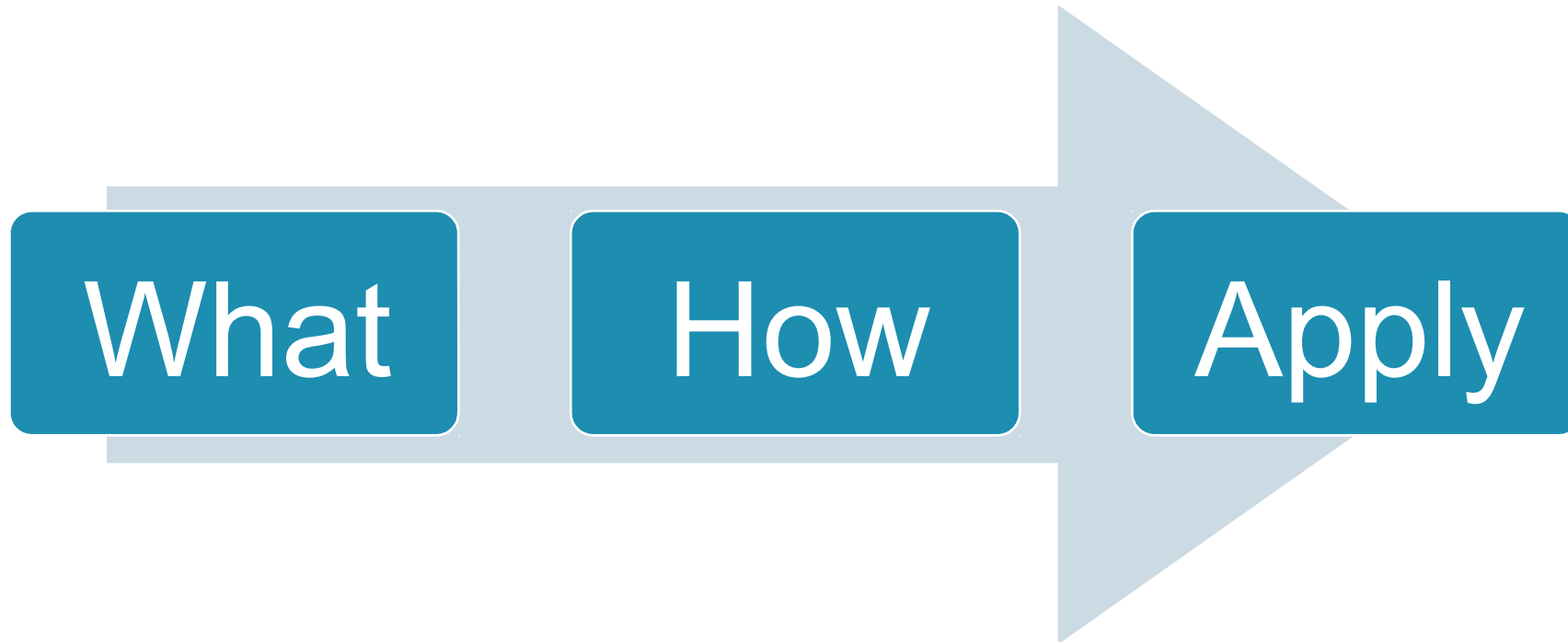


+20% mass (spread)

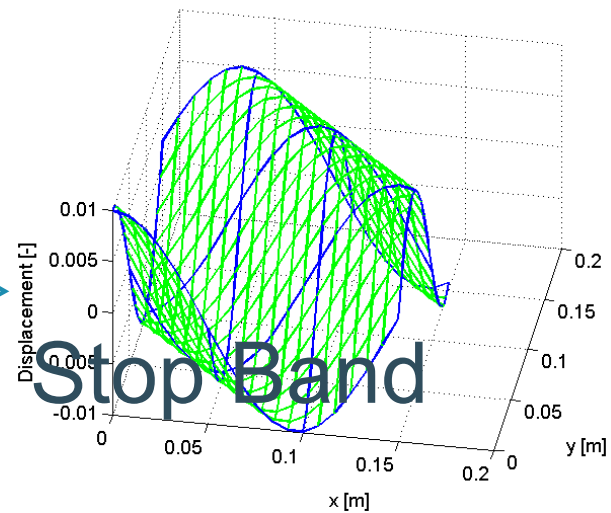
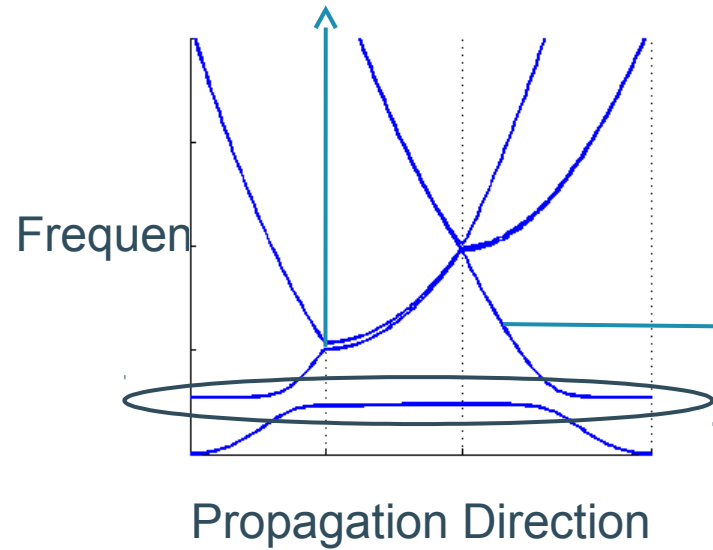
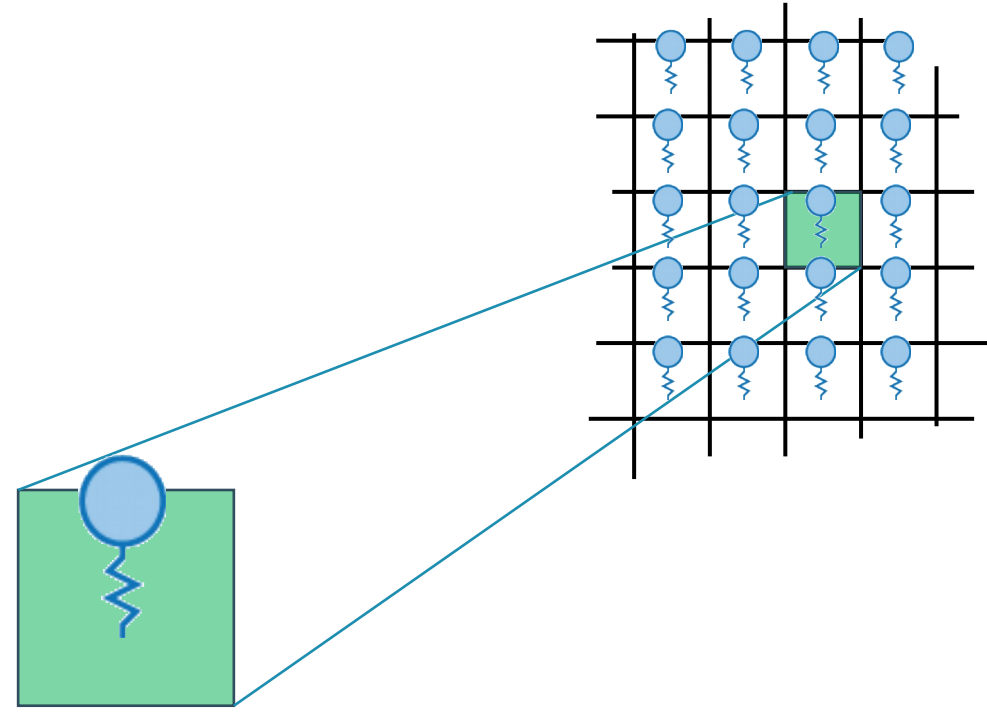
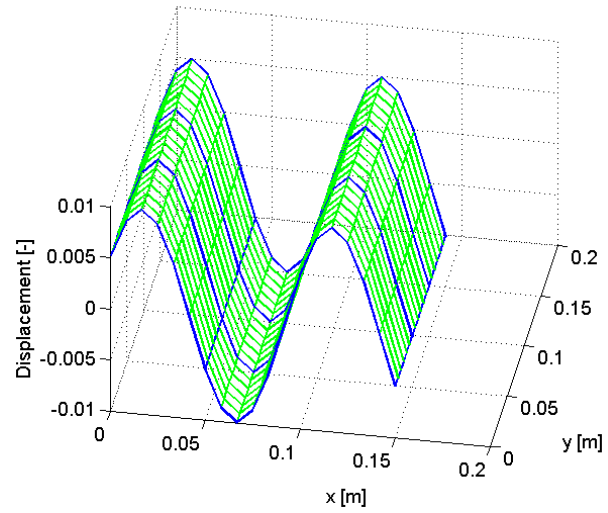
Average
Displacement
[dB]



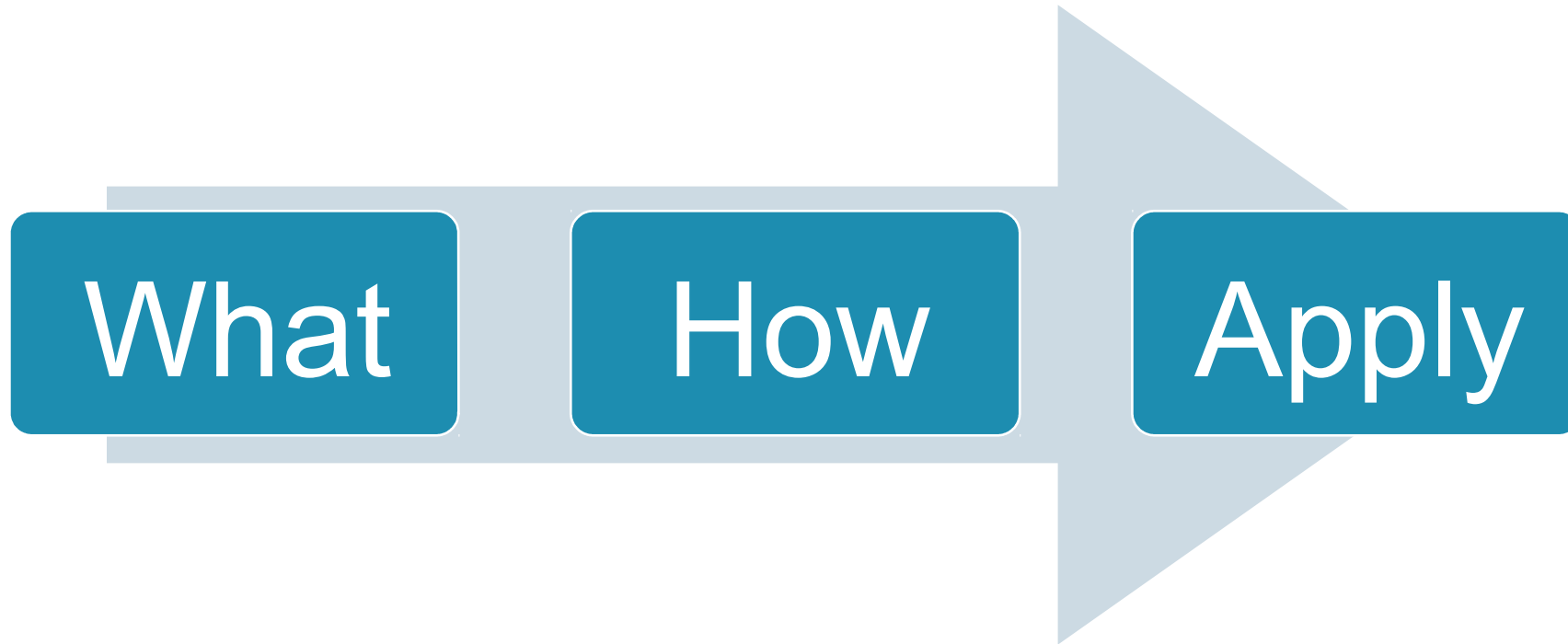
metamaterials with stopband behaviour



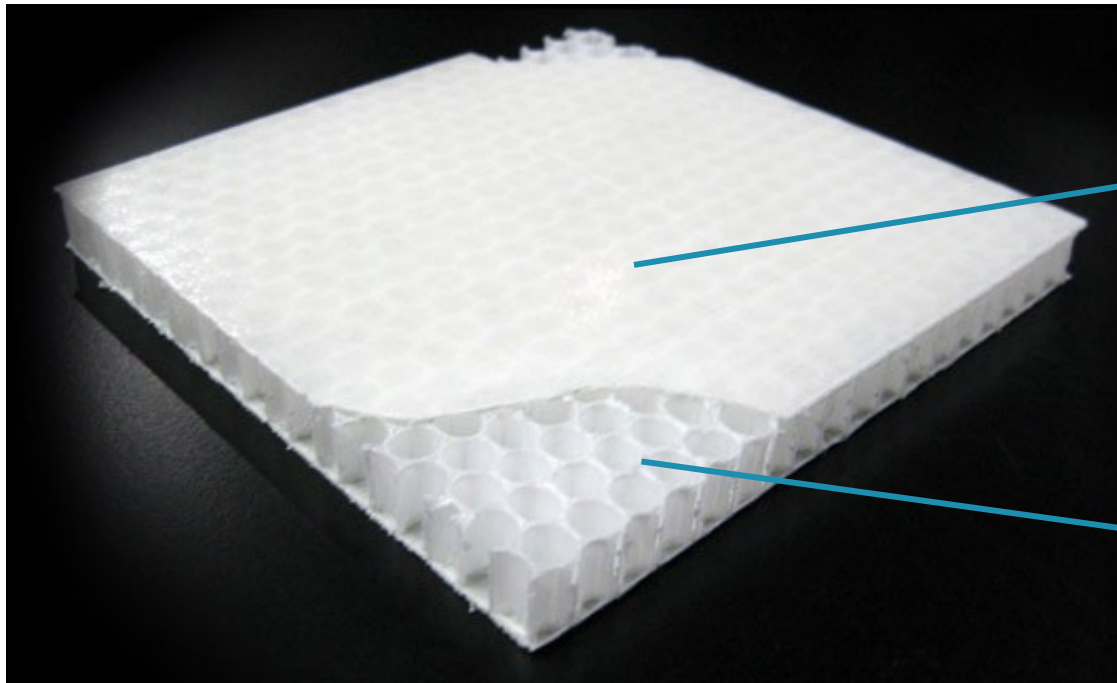
unit cell modelling



metamaterials with stopband behaviour



application: lightweight structures...



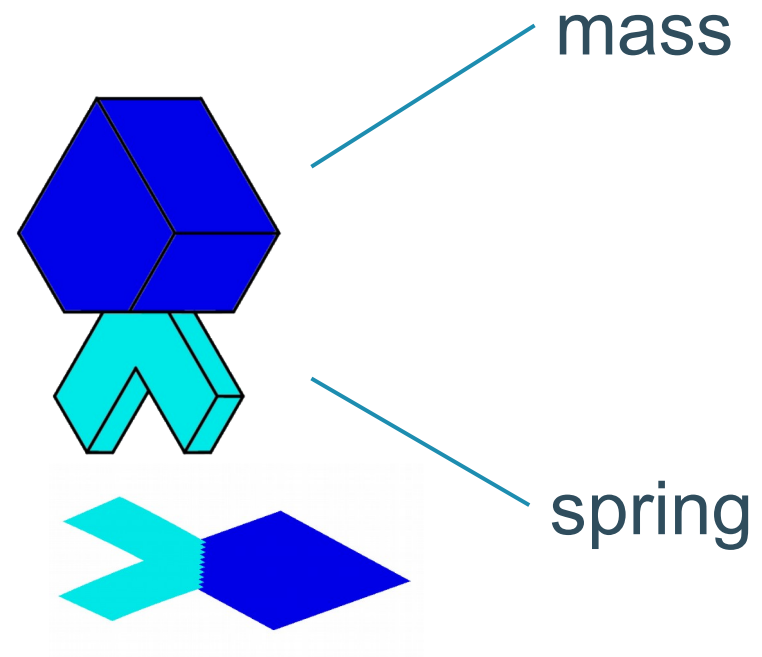
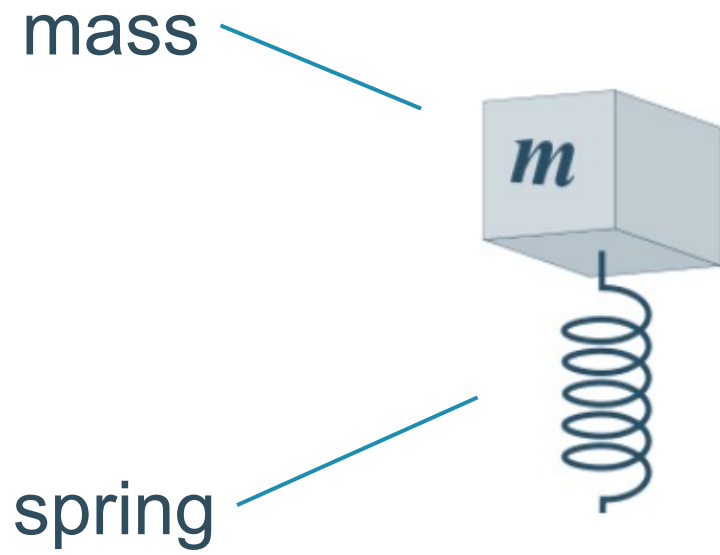
Cover layer

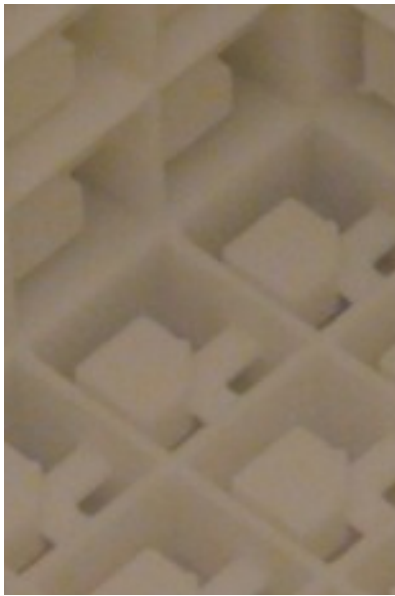
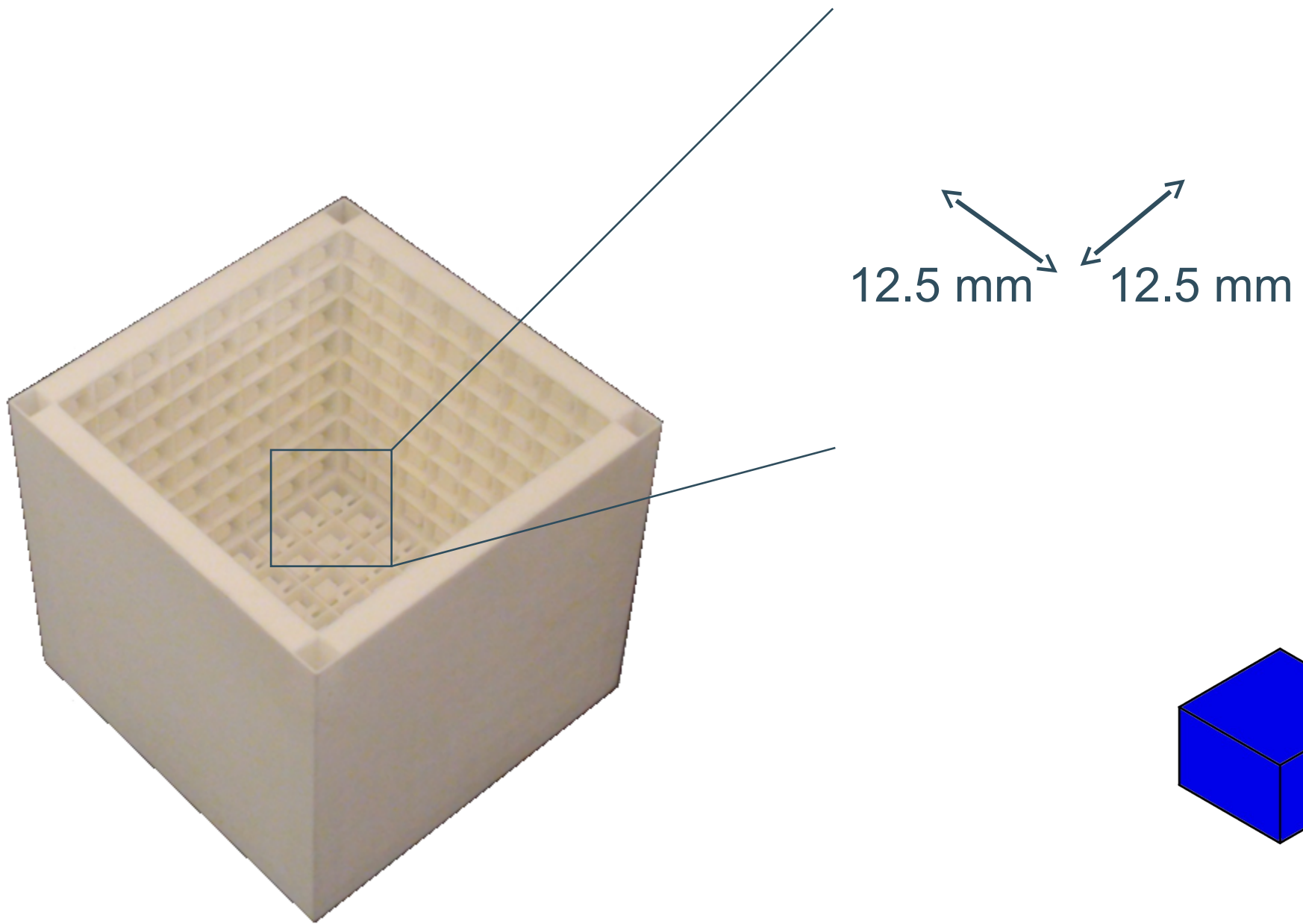
(Hollow) Core

... good weight/stiffness

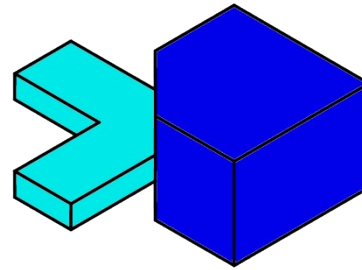
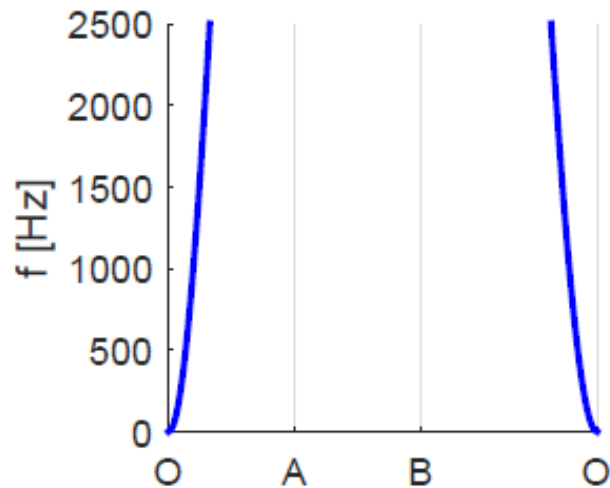
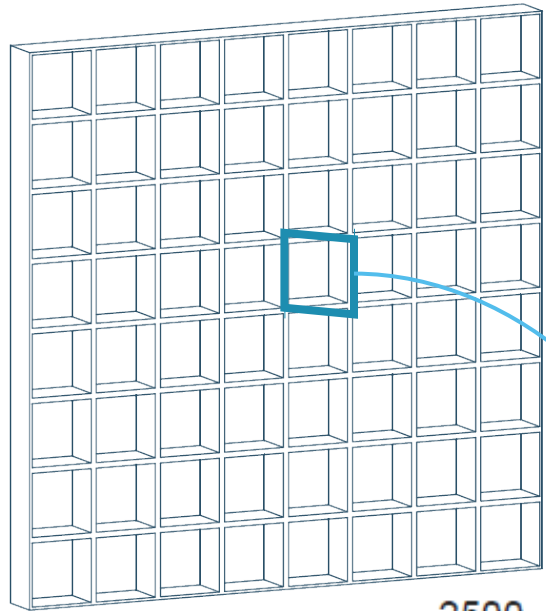
... impaired vibro-acoustic behaviour

resonant inclusion

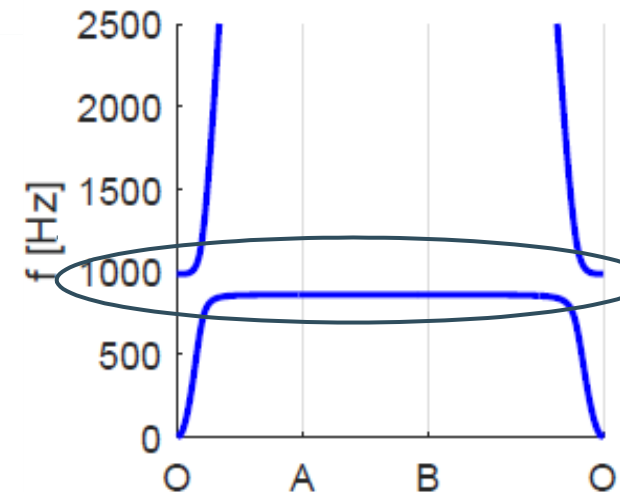
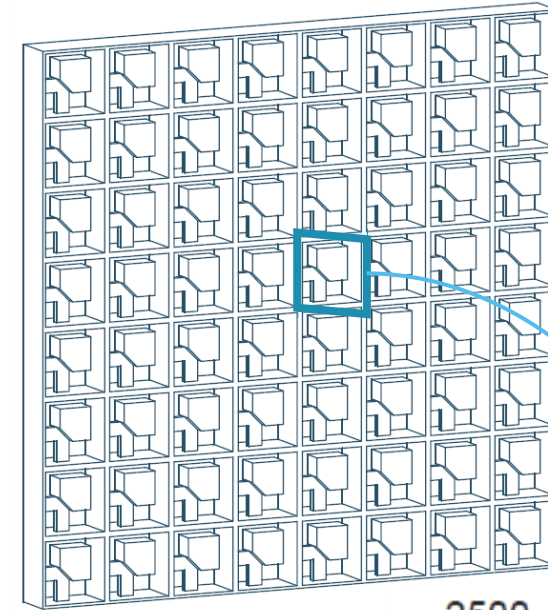




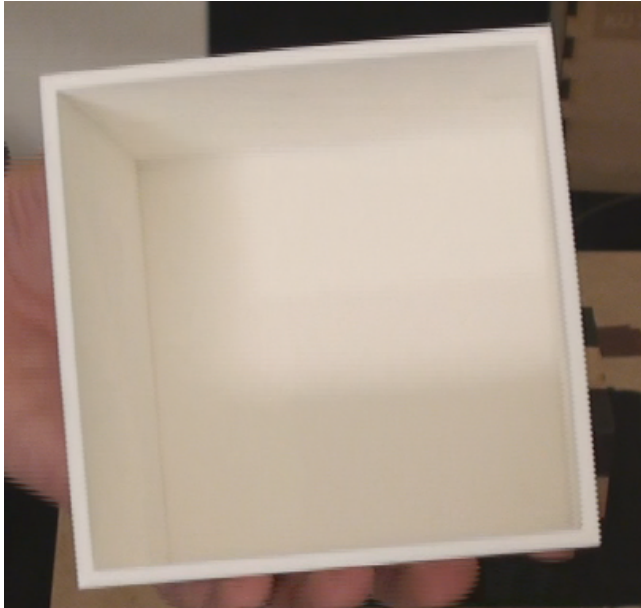
metamaterial concept



Resonant Inclusions



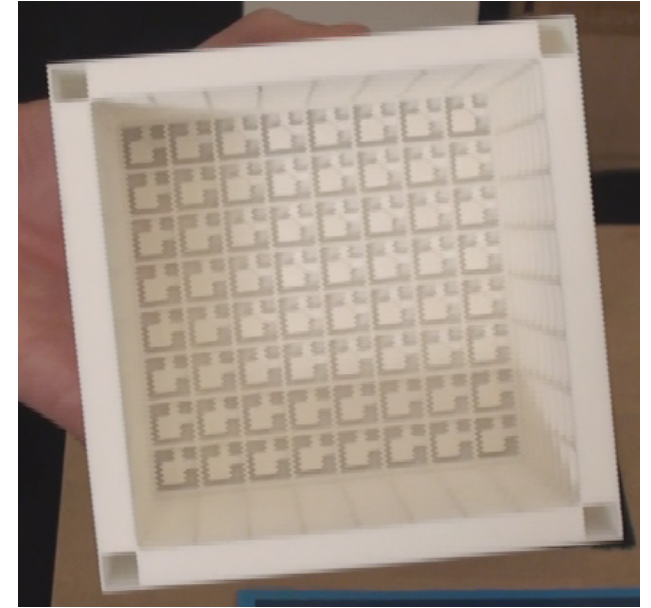
metamaterial demonstrator



Intelligent material use



15 dB additional noise reduction,
no added weight



overview

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 - demonstration
 - basic concept
 - **applications**

vibro-acoustic metamaterials for compact lightweight noise control engineering solutions



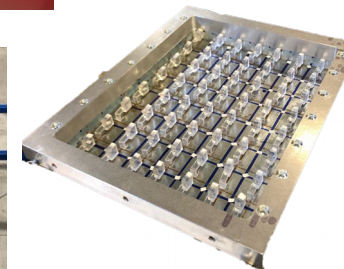
sound transmission through lightweight panels produced by thermoforming



structure born noise in vehicles with 3D printed patches



vibration reduction along piping with aluminum additions



reduction of TBL induced radiated noise through lasercutted additions

Problem definition

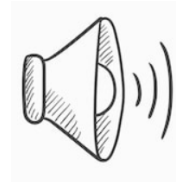
Harvester cabine

- Engine noise outside
- Driver inside
- Acoustic mode $\sim 200\text{Hz}$

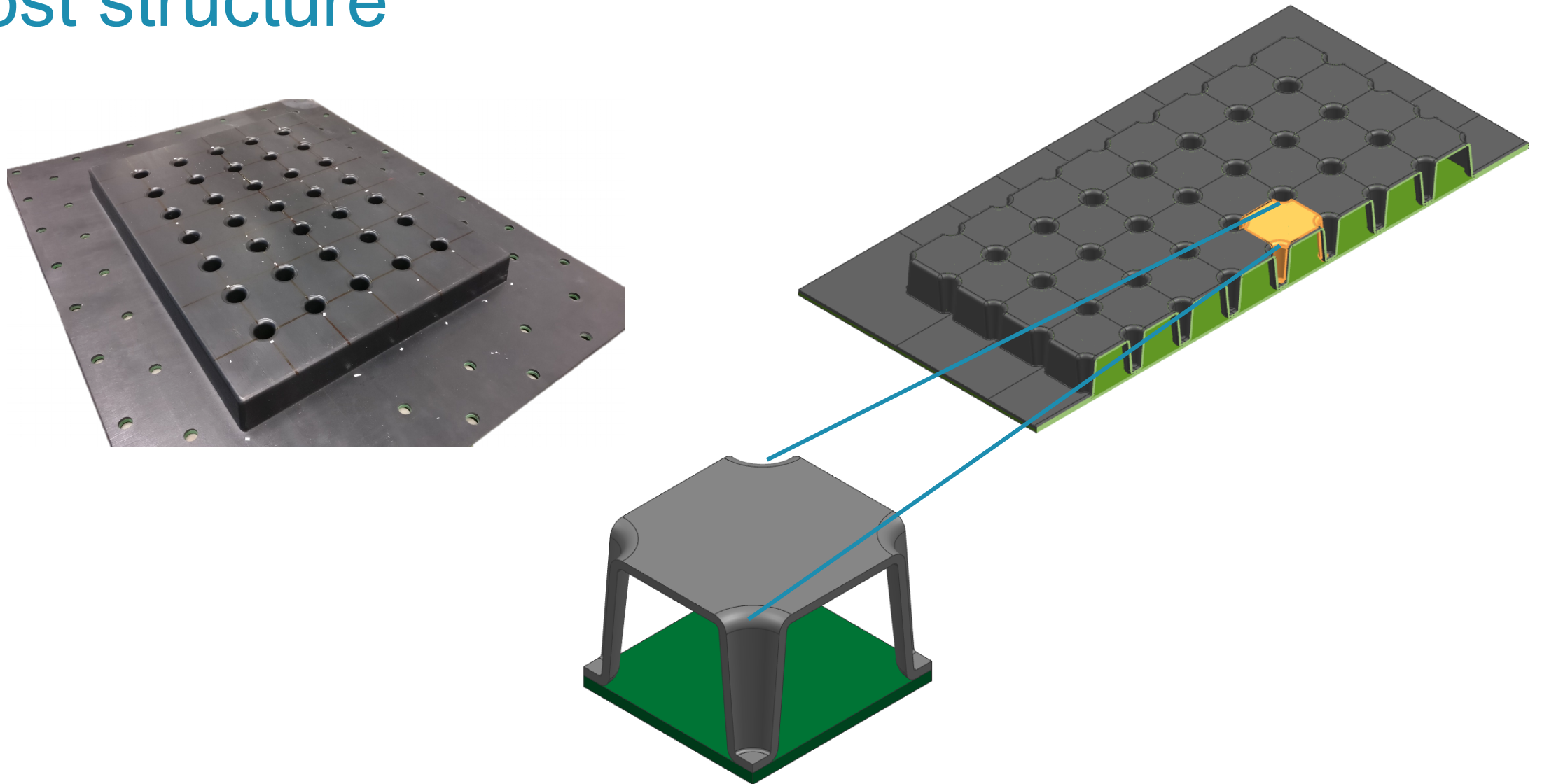


KU Leuven soundbox

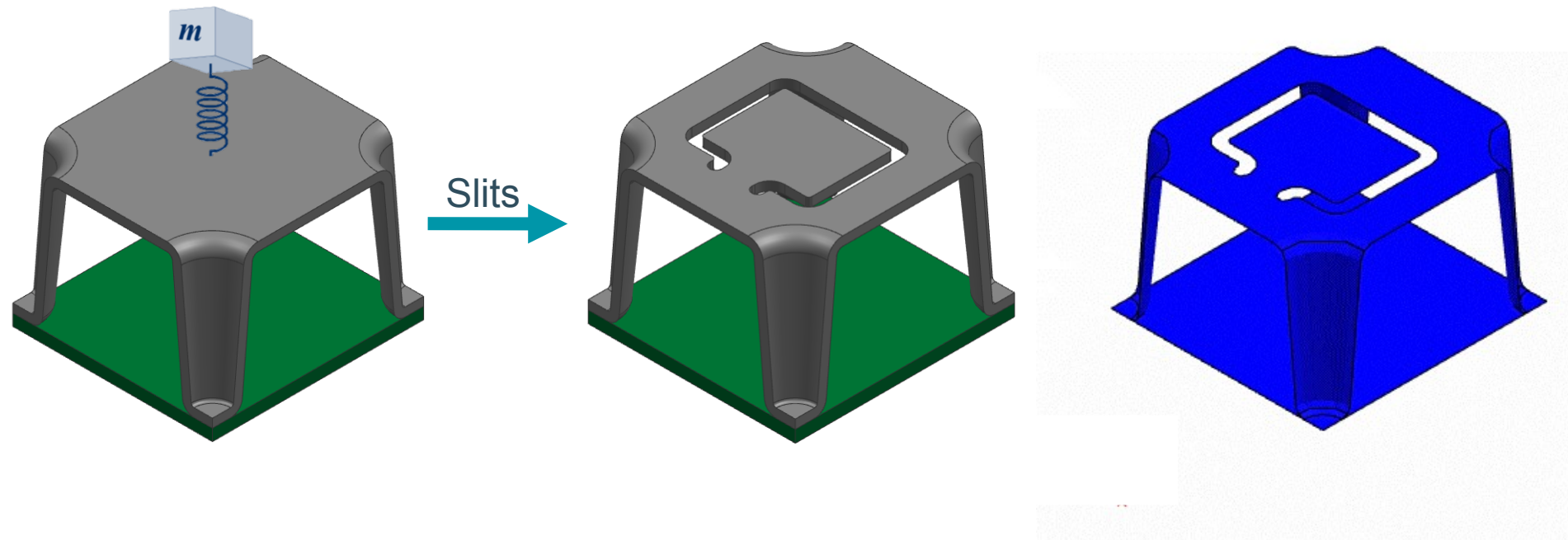
- Loudspeaker
- Microphones
- Acoustic mode: 156Hz



Host structure



Metamaterial solution



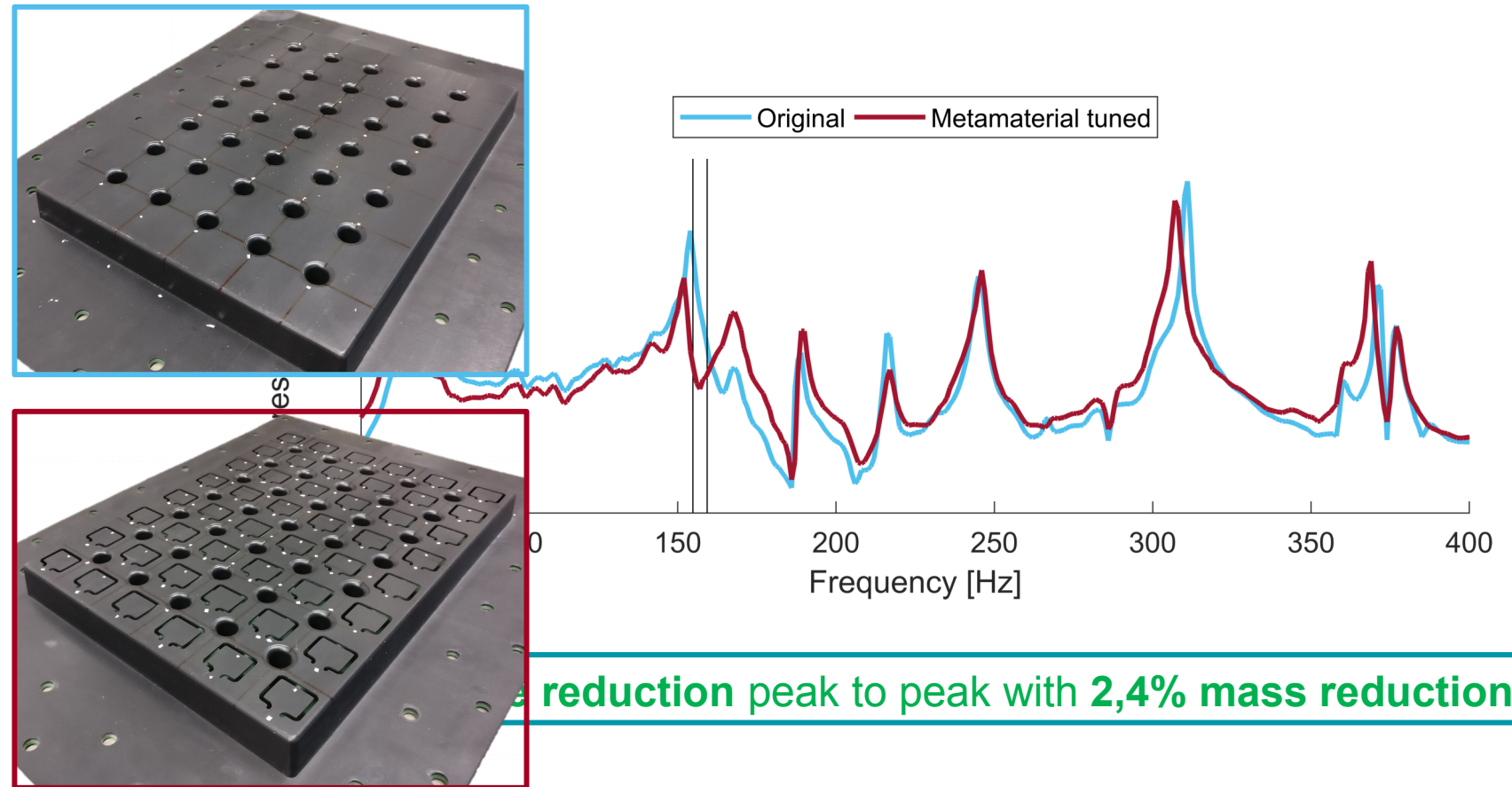
Pressure level inside the cavity



Original vs Metamaterial
thermoformed
twinsheet panel



Sound Pressure Level inside the cavity



vibro-acoustic metamaterials for compact lightweight noise control engineering solutions



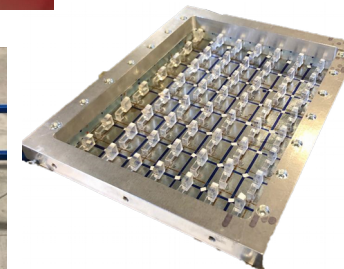
sound transmission through lightweight panels produced by thermoforming



structure born noise in vehicles with 3D printed patches



vibration reduction along piping with aluminum additions



reduction of TBL induced radiated noise through lasercutted additions

Case study

- Unwanted NVH due to tire air resonances excited by road excitation
- F
S
S



Case study



<https://youtu.be/MdHVCnvj9x0>

Configurations tested

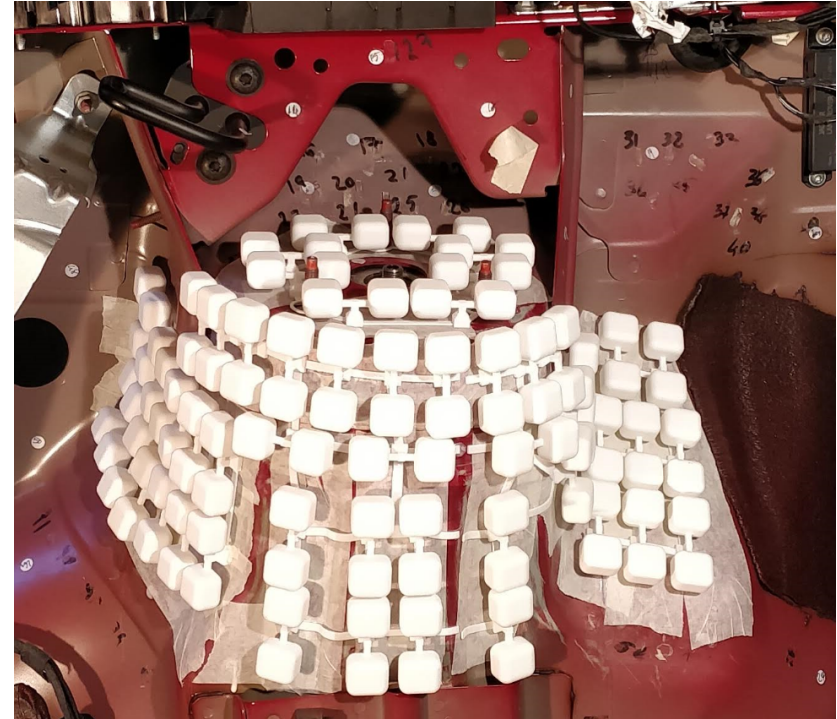
Bare



TVA: 2,92kg



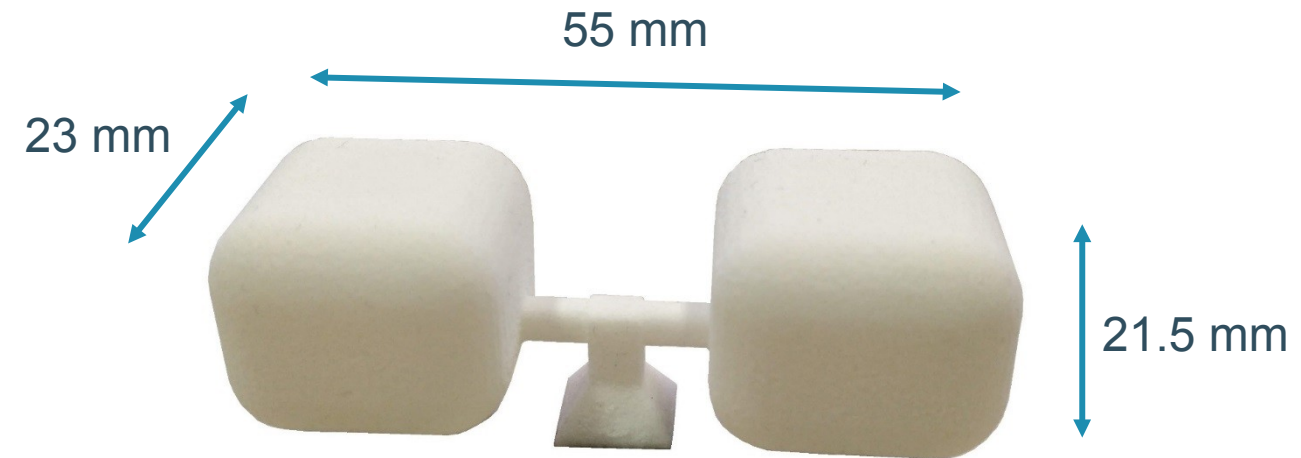
Metamaterial: 1,52 kg



Both left and right rear areas are treated

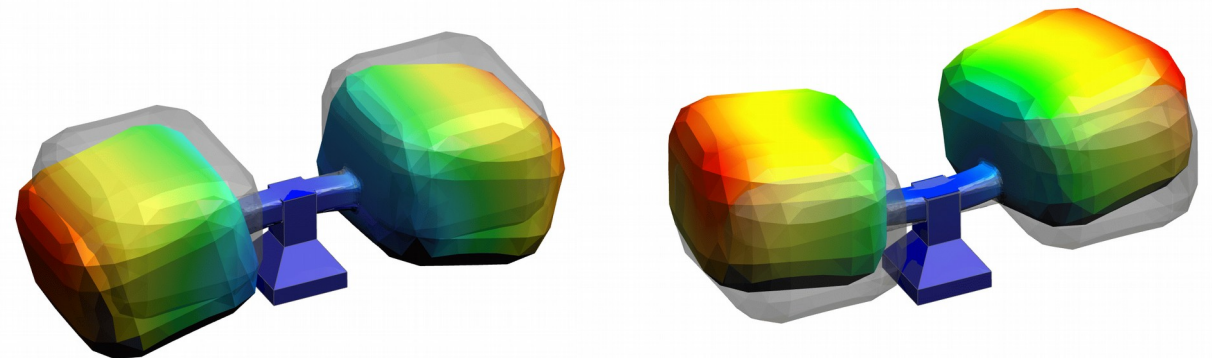
Resonant element design

- Design:
 - Easy to tune
 - Low frequent bending mode
 - SLS with Polyamide
- Frequency: 193 Hz
- Dual mode resonator

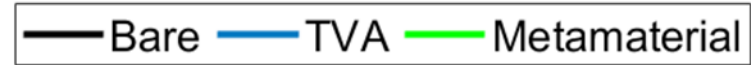


out-of-plane

In-plane



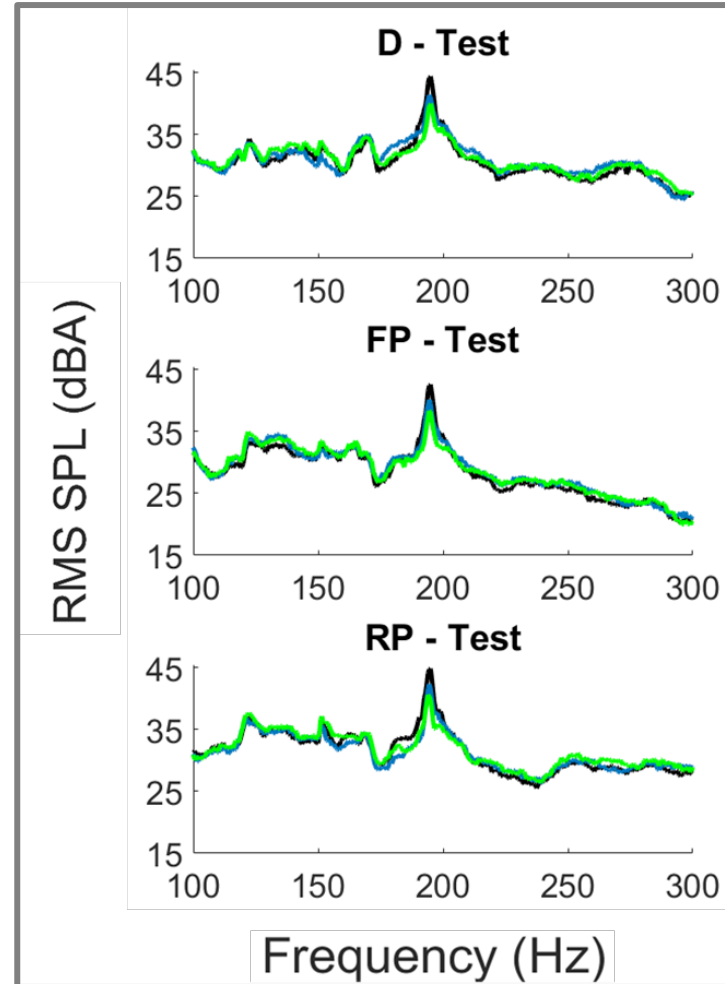
On road results



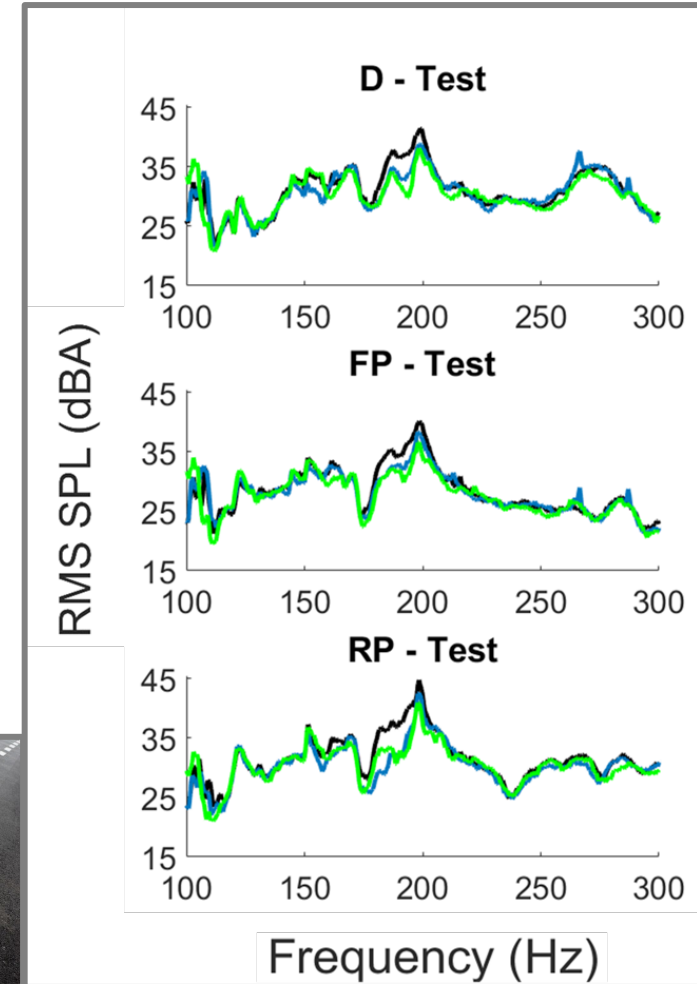
- SPL at ear positions



- Improvement
 - TVA:
3 dB (p2p)
 - Metamaterial:
4 dB (p2p)



30 kph

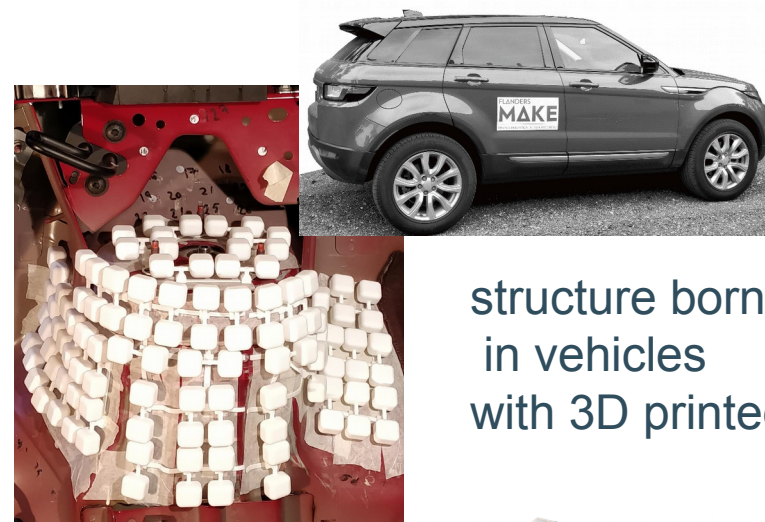


50 kph

vibro-acoustic metamaterials for compact lightweight noise control engineering solutions



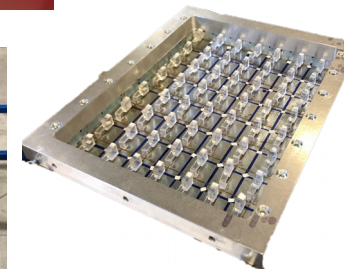
sound transmission through lightweight panels produced by thermoforming



structure born noise in vehicles with 3D printed patches



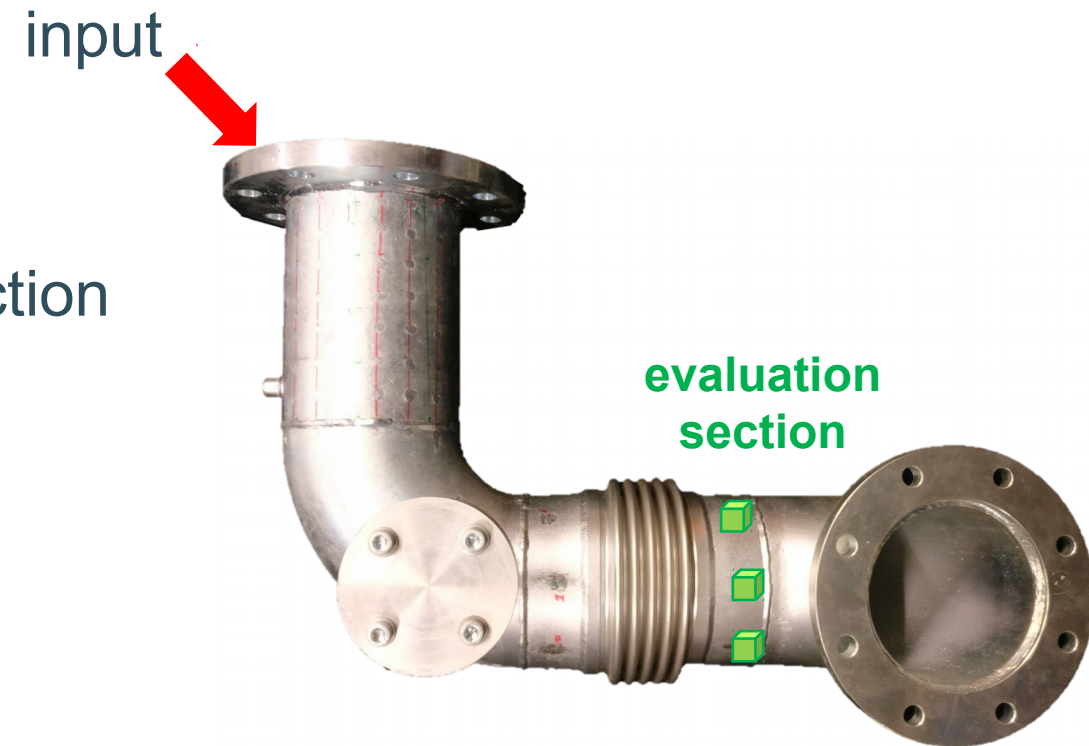
vibration reduction along piping with aluminum additions



reduction of TBL induced radiated noise through lasercutted additions

Compressor piping

- Case: vibration transmitted from compressor pump to compressor vessel
- Test:
 - Structural excitation: shaker on flange in a 45° angle
 - Evaluate 3D acceleration levels on 8 points per section



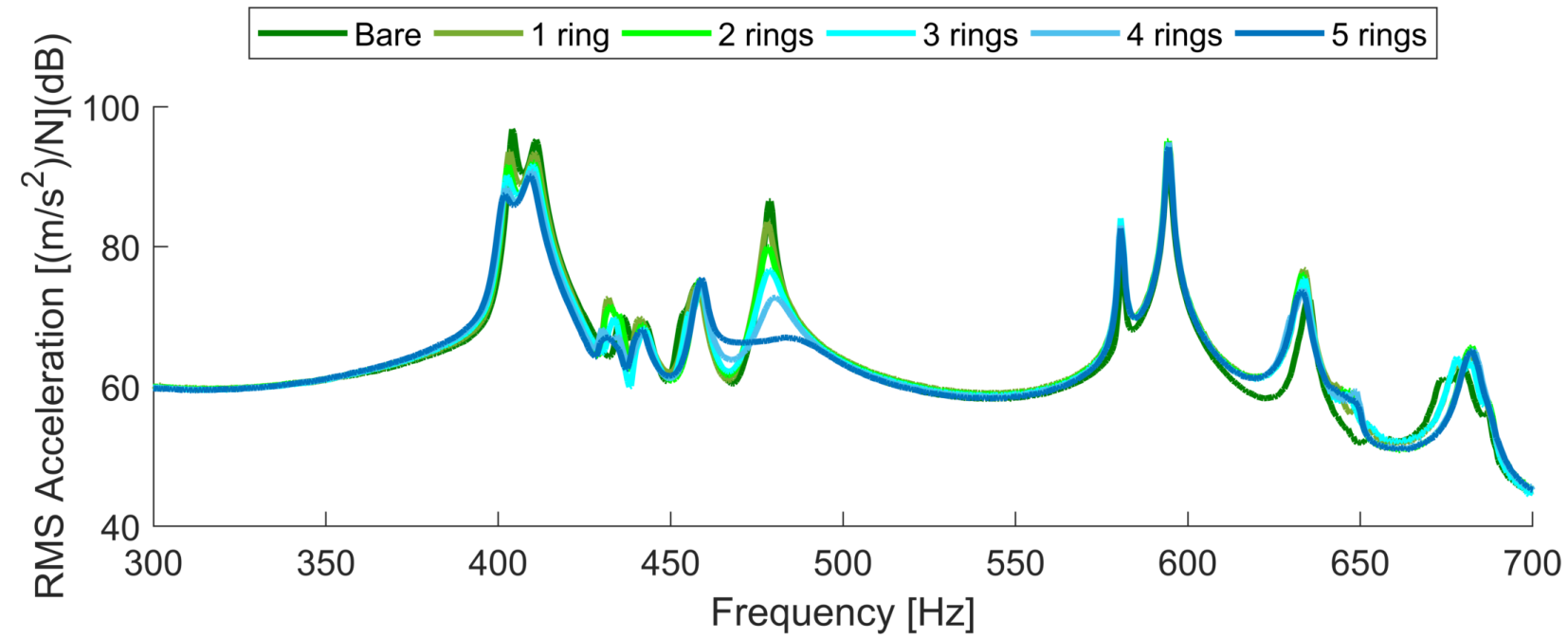
Resonant structure design

- Straight aluminum rings
- Laser cut
- Targeted frequency 470 Hz
- Mass of one ring: 197 g
- Maximum mass addition: 14%



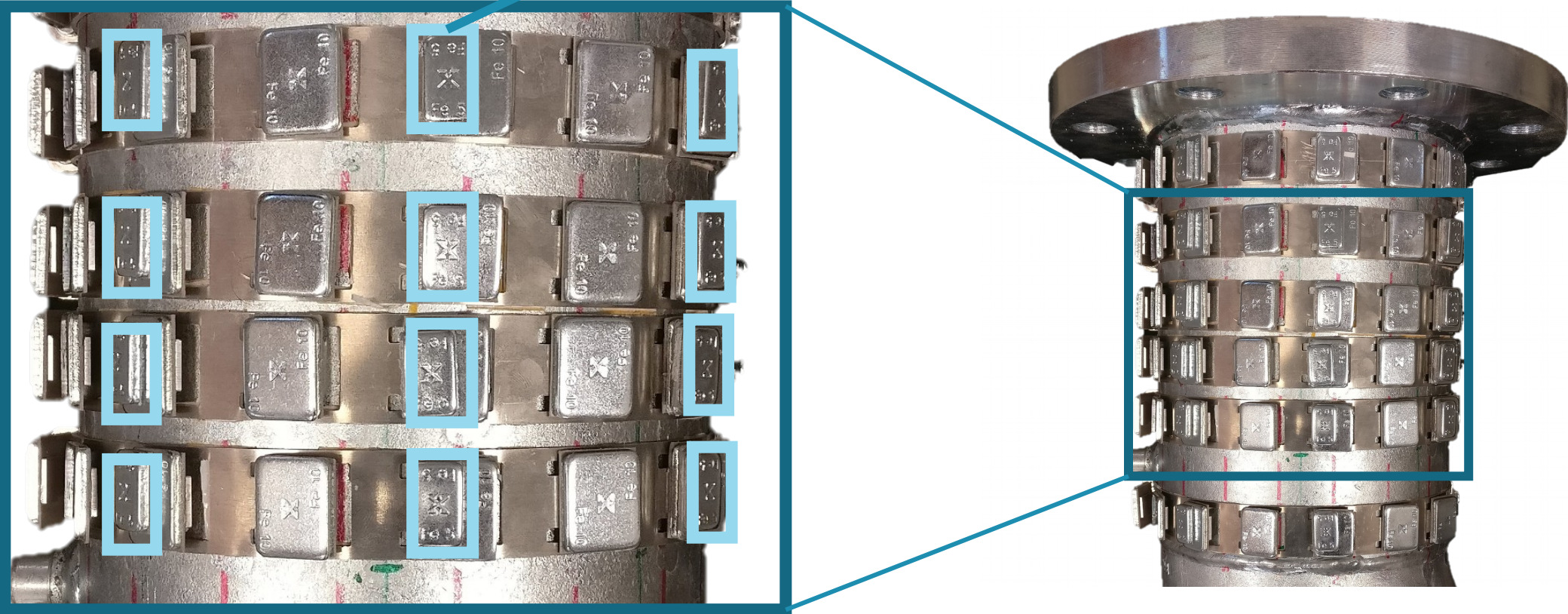
Auto-adhesive 10g steel mass

Vibration attenuation

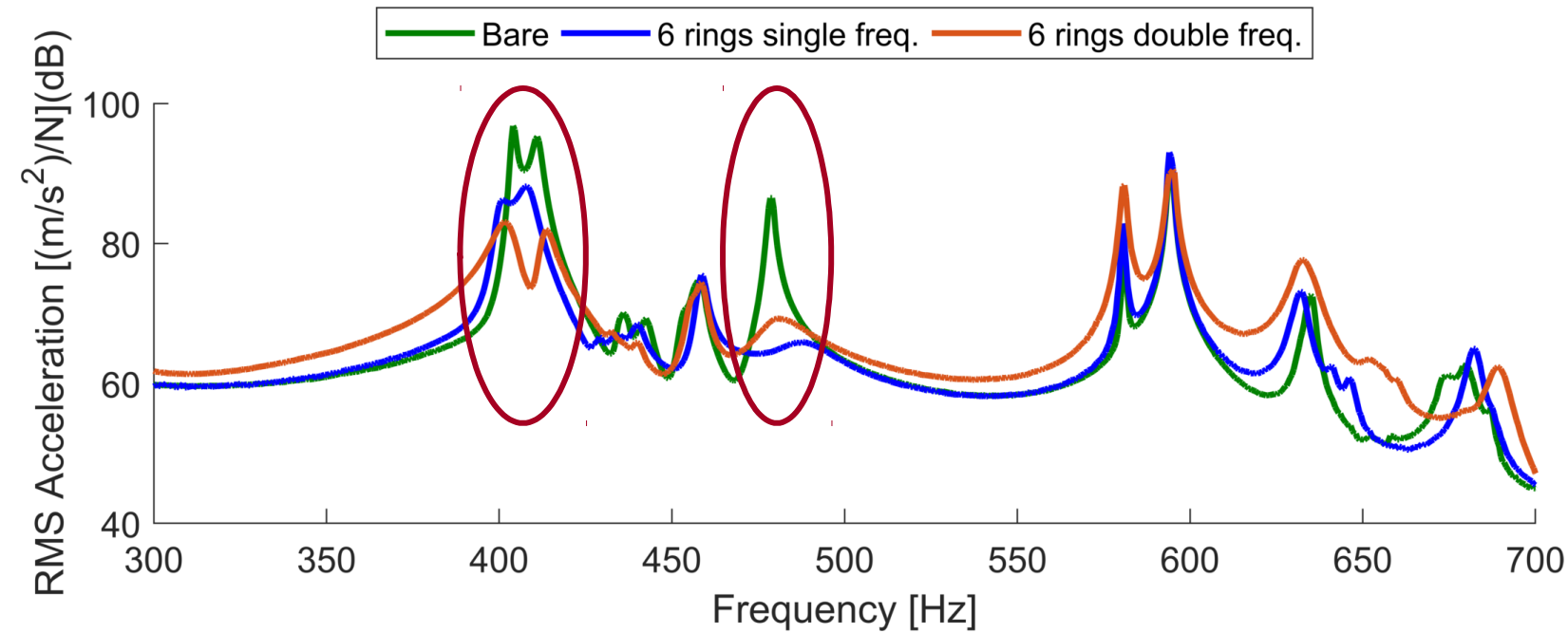


Mixed case

5 g steel masses
Tuned frequency 410 Hz



Vibration attenuation – Mixed case



vibro-acoustic metamaterials for compact lightweight noise control engineering solutions



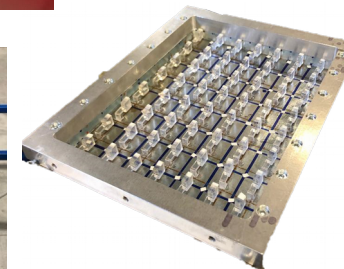
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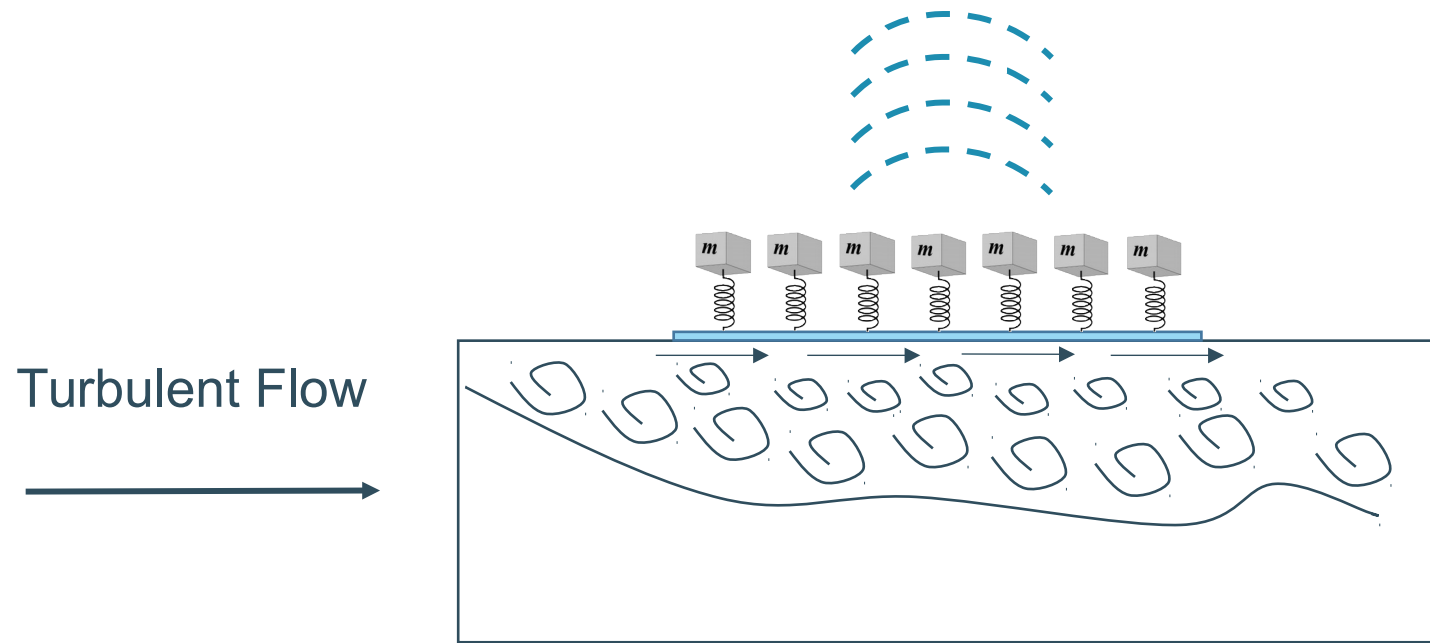


vibration reduction along piping with aluminum additions



reduction of TBL induced radiated noise through lasercutted additions

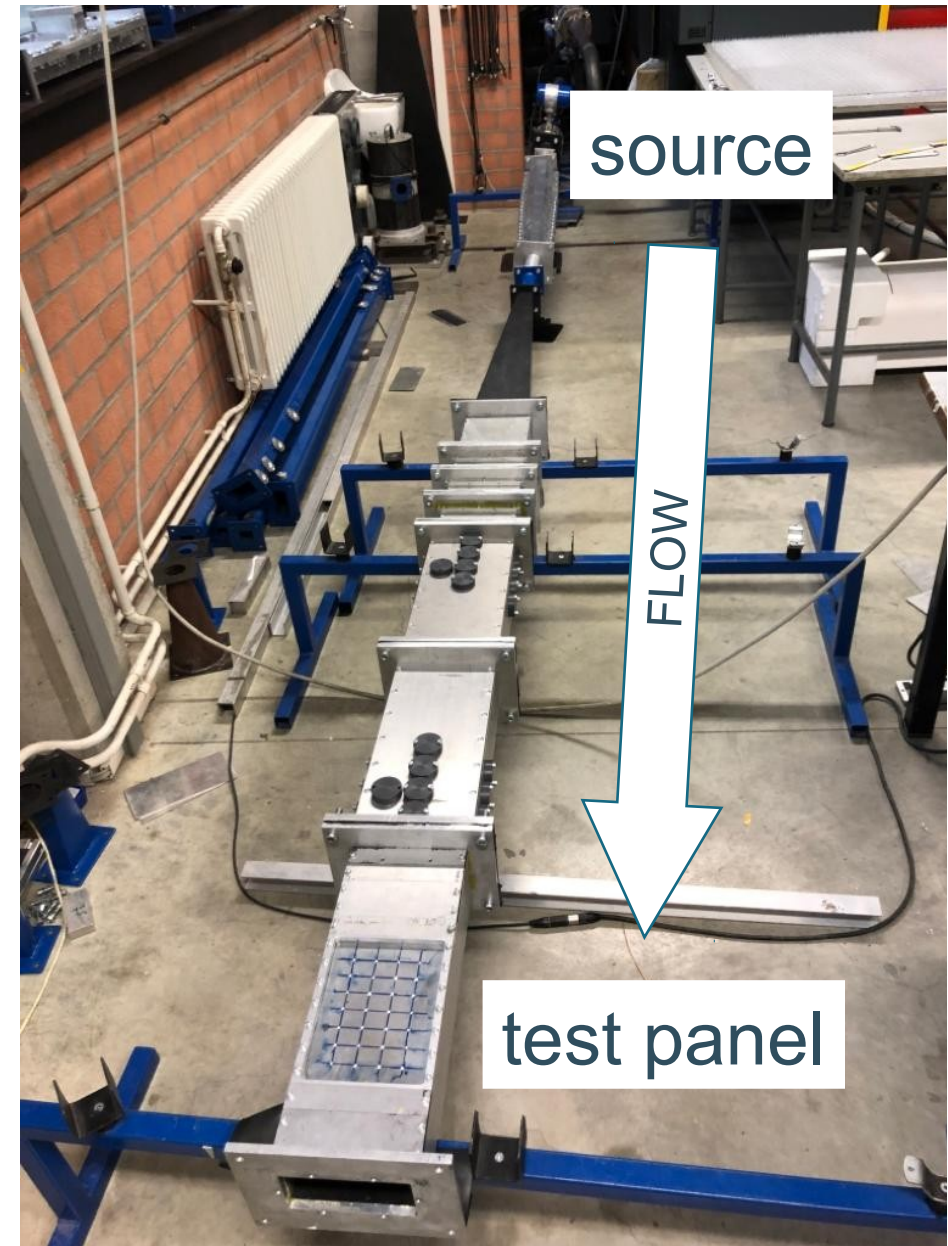
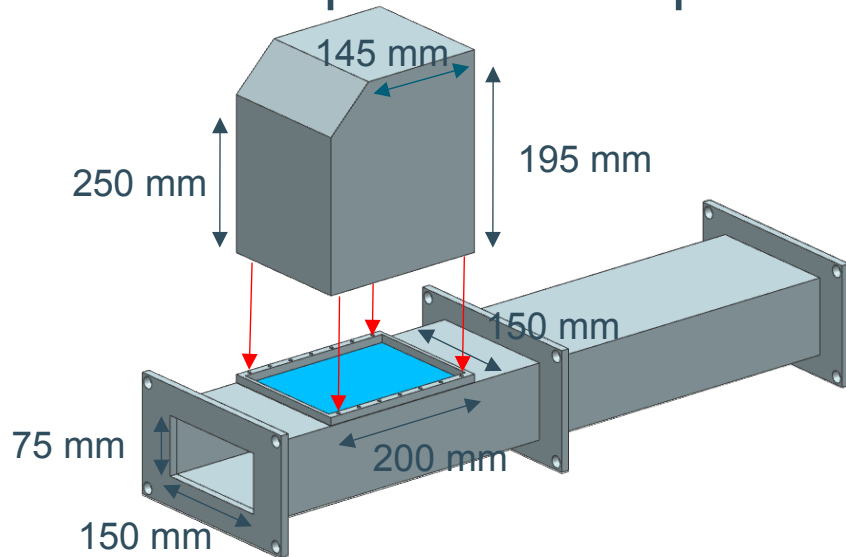
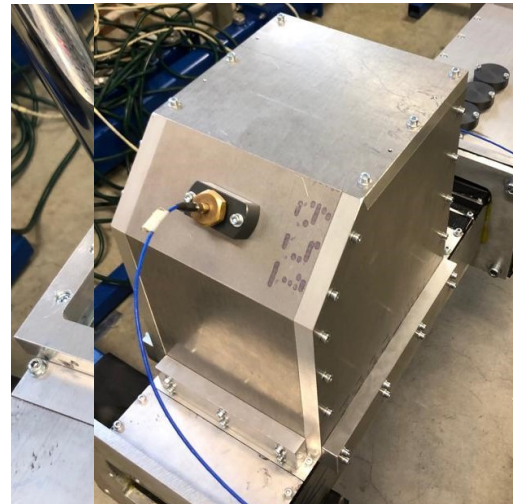
Objectives



Investigate the potential of metamaterials to reduce flow-induced noise and vibrations

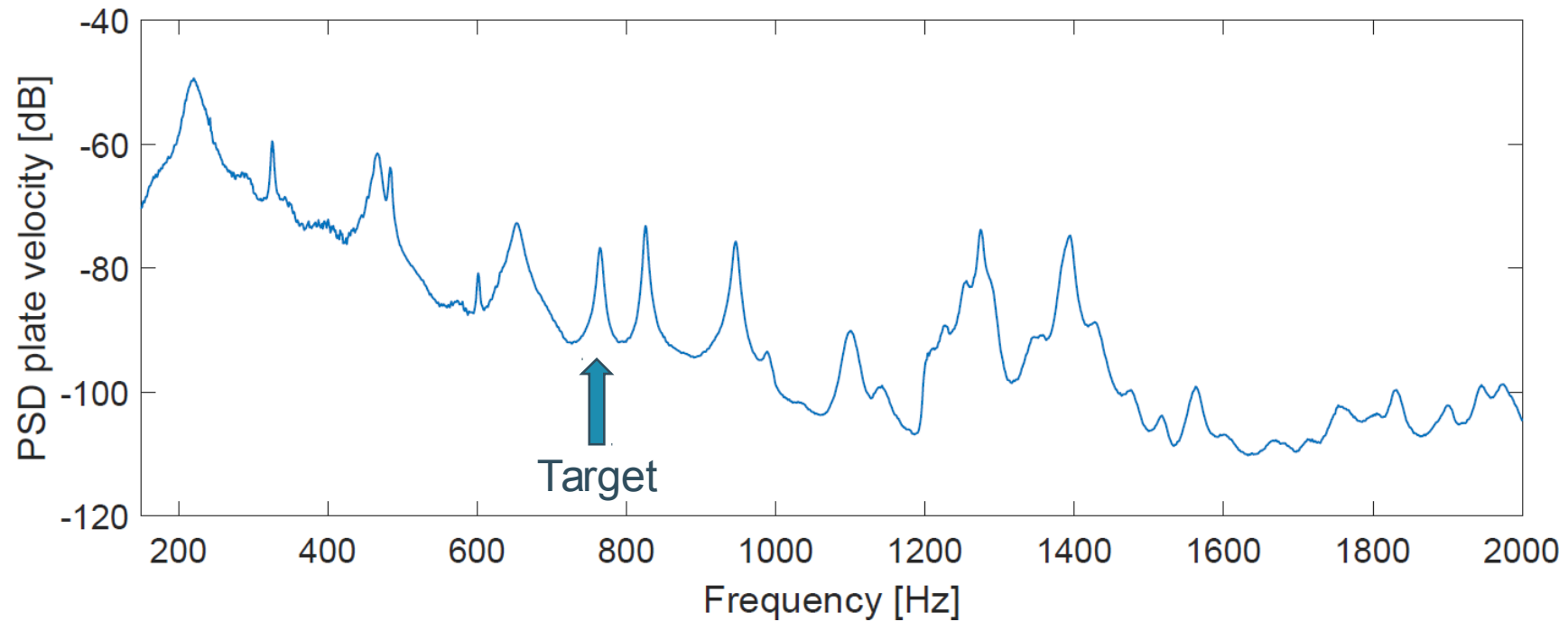
test rig

- flow 0.05 Mach, duct length 5m
- vibrations evaluation:
 - scanning laser vibro-meter in open case
- acoustic evaluation:
 - microphones in top cavity



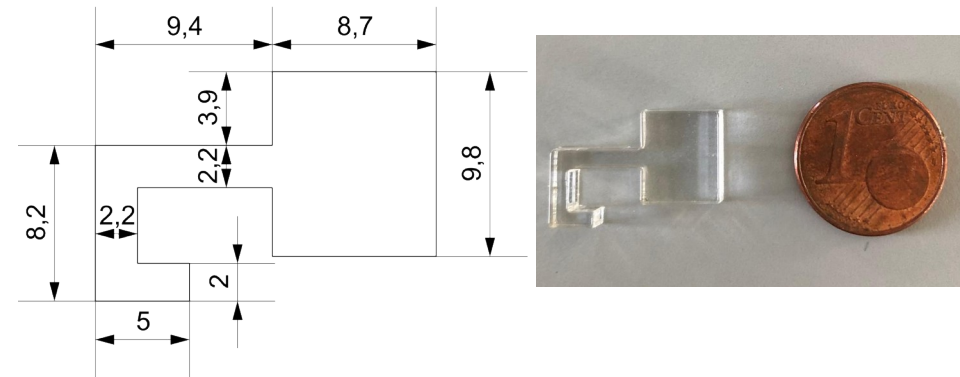
Vibration evaluation

- RMS PSD velocity of 72 points on the bare plate

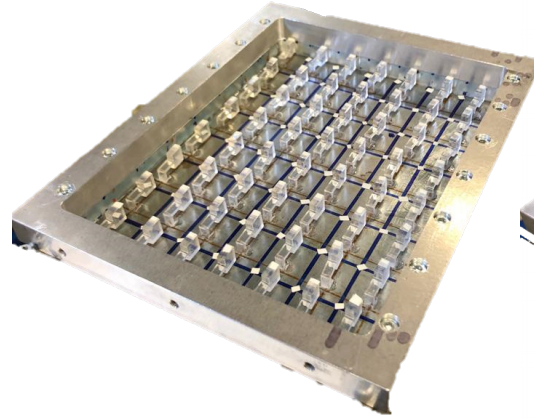


Metamaterial solution (27% mass addition)

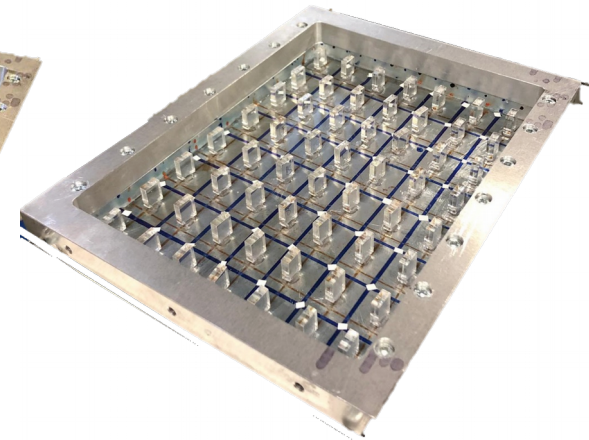
Resonator design



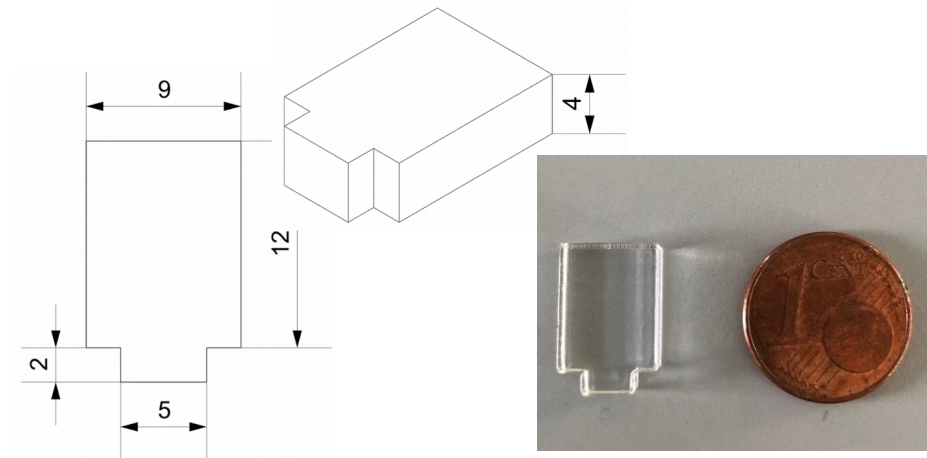
Entirely covered



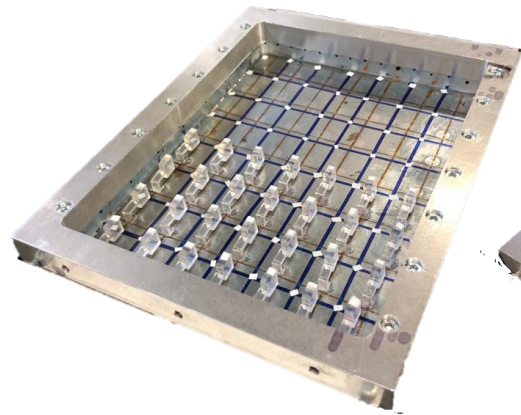
Equivalent mass



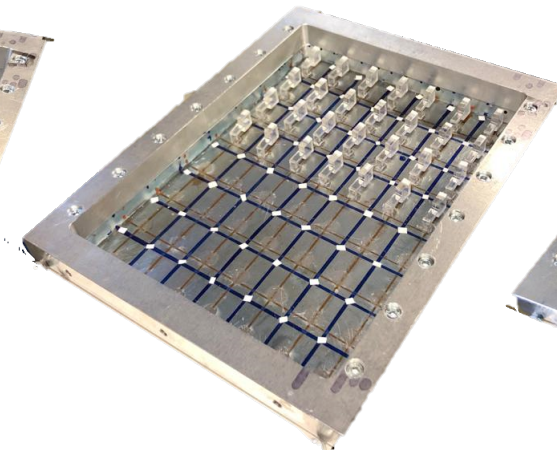
Equivalent non-resonant mass



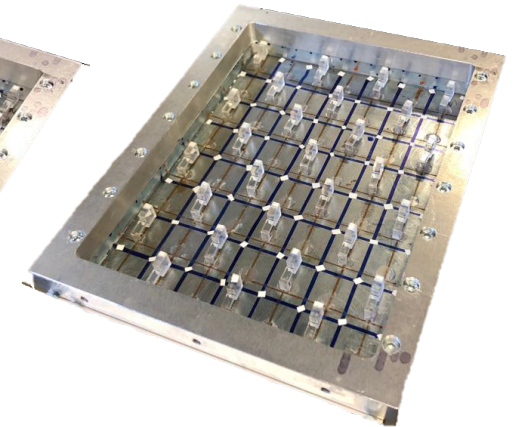
Downstream half



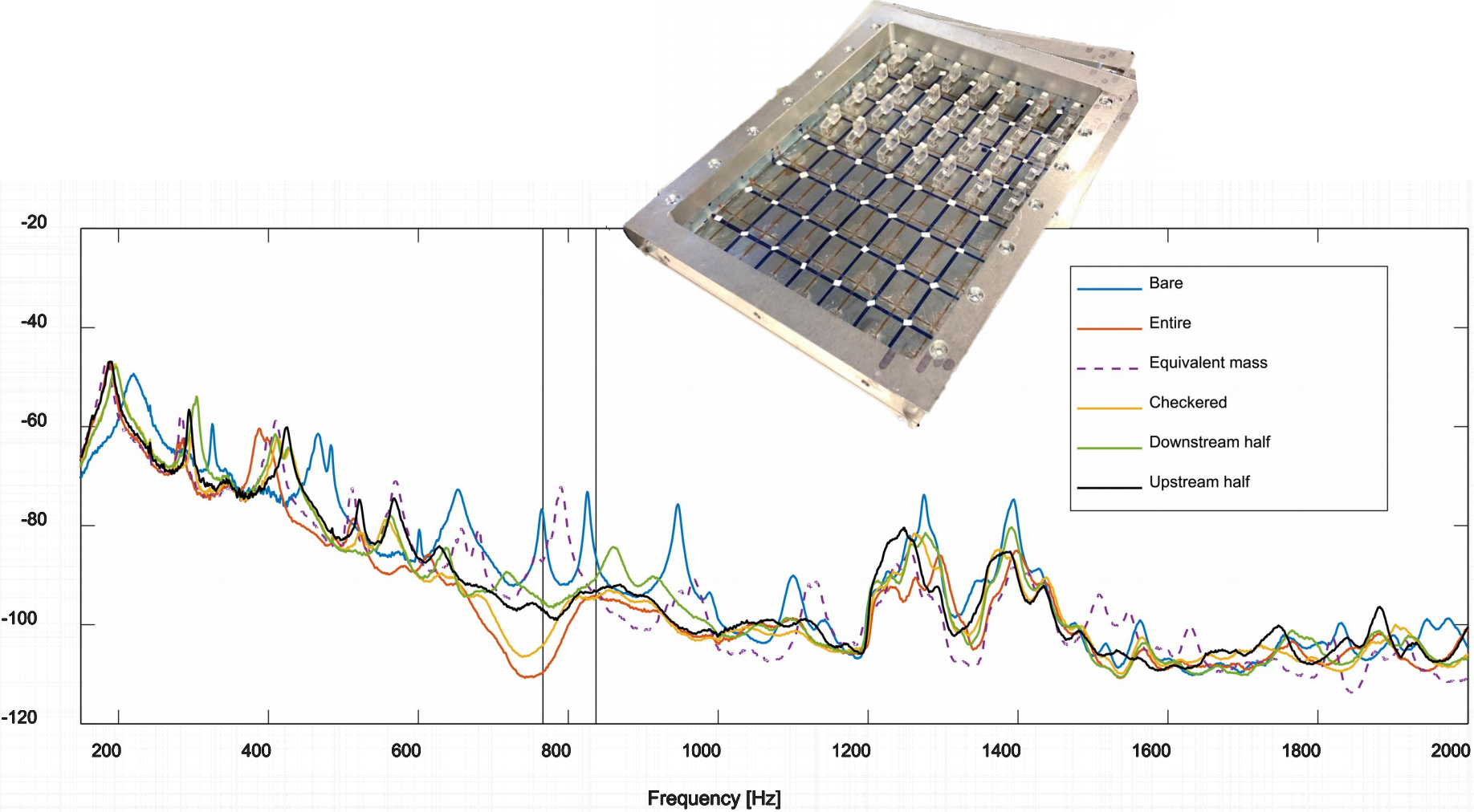
Upstream half



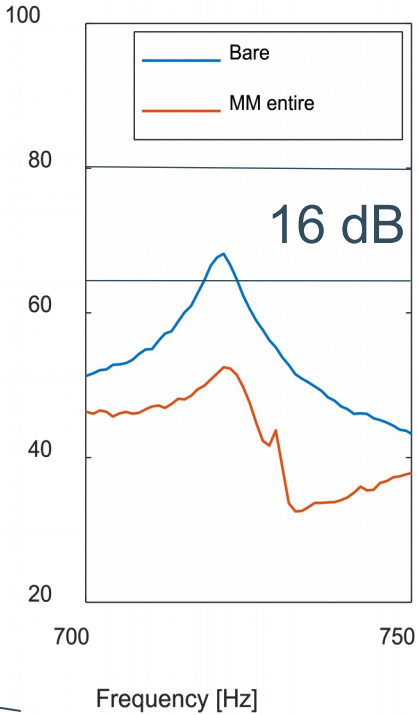
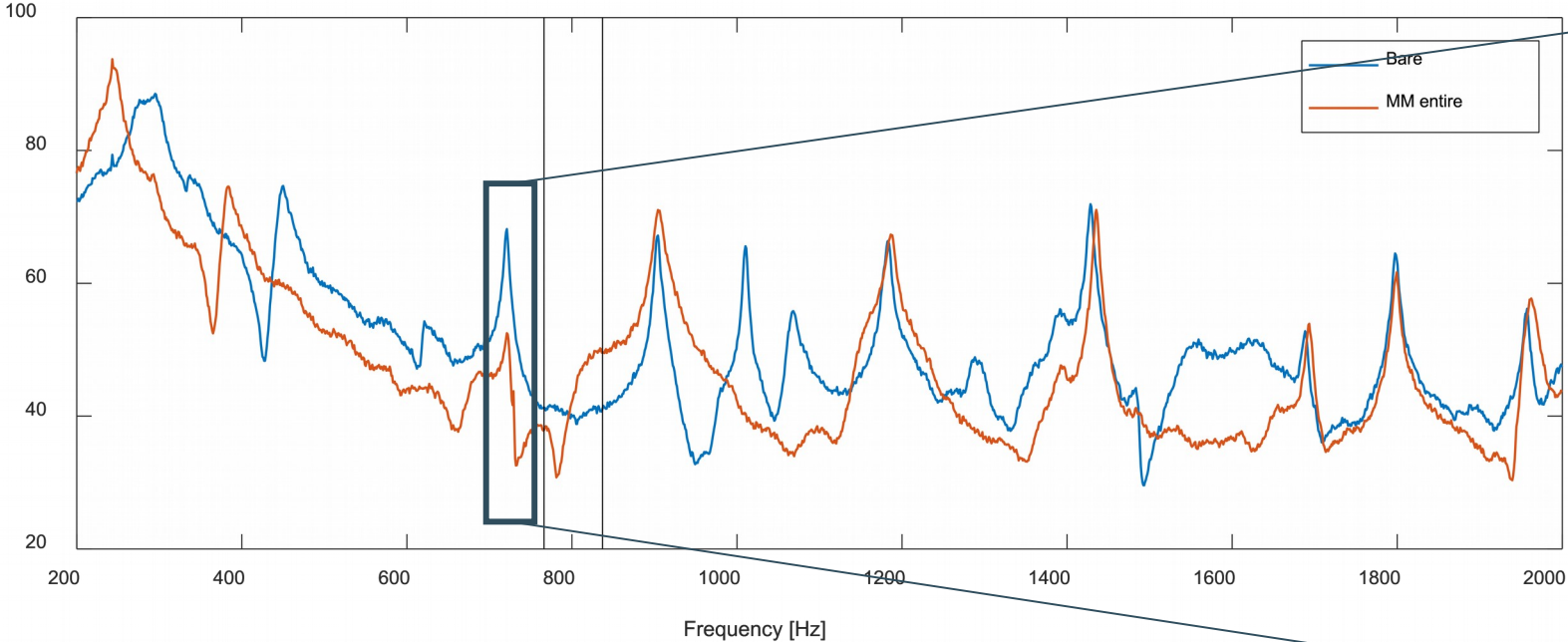
Checkered pattern



Experimental results: vibration levels



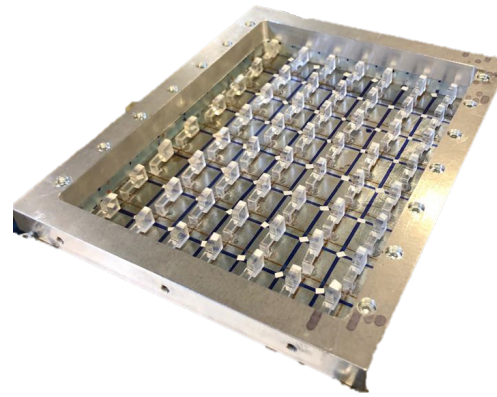
Experimental results: acoustic radiation



In conclusion

Concept

- Incorporation of structural elements
- sub-wavelength scale
- favourable vibro-acoustic behaviour (transmission loss) in desired frequency bands

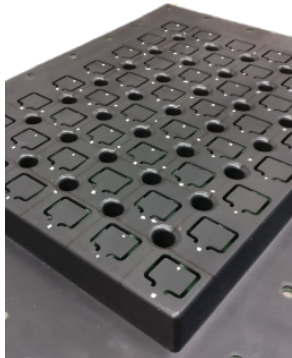
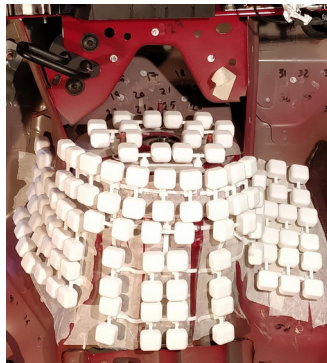


Low
frequency

Low
mass

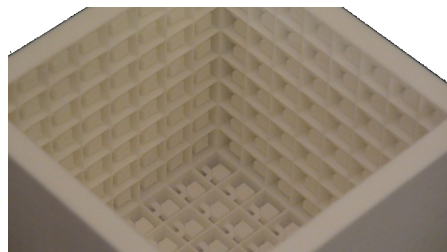
Low
volume

Low
cost



Main advantages

- a priori tuneable frequency zones of attenuation
- both conventional and non-conventional materials are qualified.
- structural elements can be enclosed for use in contaminated environments or when aesthetically desired.
- eligible for low cost manufacturing and integration





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