Low Frequency Absorption Enhancement by Modification of Poro-Elastic Layered Sound Package

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Low Frequency Absorption Enhancement by Modification of Poro-Elastic Layered Sound Package

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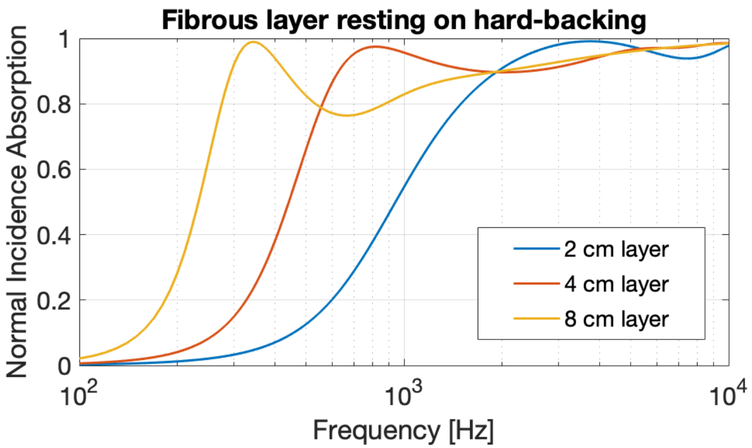
Motivation

- **Low Frequency Noise Control**
  - "The attenuation of low-frequency sound has been a challenging task because the intrinsic dissipation of materials is inherently weak in this regime." [1]
  - "The acoustic response of any structure or material must obey the causality principle, which relates the absorption spectrum of a sample to its required minimum thickness." [2]



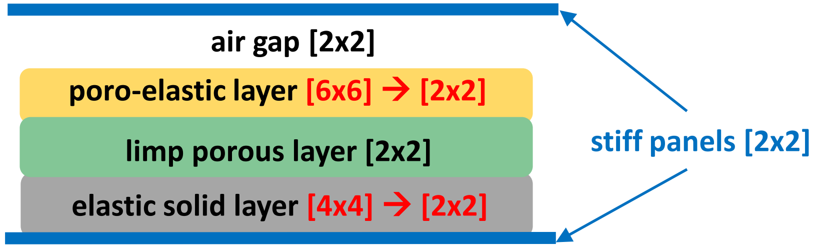
- **Existing Solutions and their Limitations**
  - Metamaterials – weight, volume, manufacturability, cost
  - Active Noise Control (ANC) – robustness, multiple sources, latency, cost

- **Current Study**

  Optimization of poro-elastic sound package using layered structure modeling tool

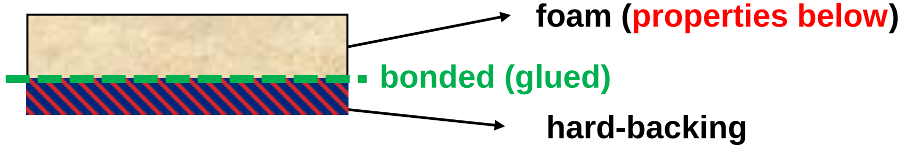
Modeling of Layered Sound Packages

- Transfer Matrix Method (TMM) [3]
  - Efficient modeling tool to predict absorption coefficient and transmission loss for complex multi-layer acoustical systems
  - Enabling design and optimization based on parametric study of sound packages



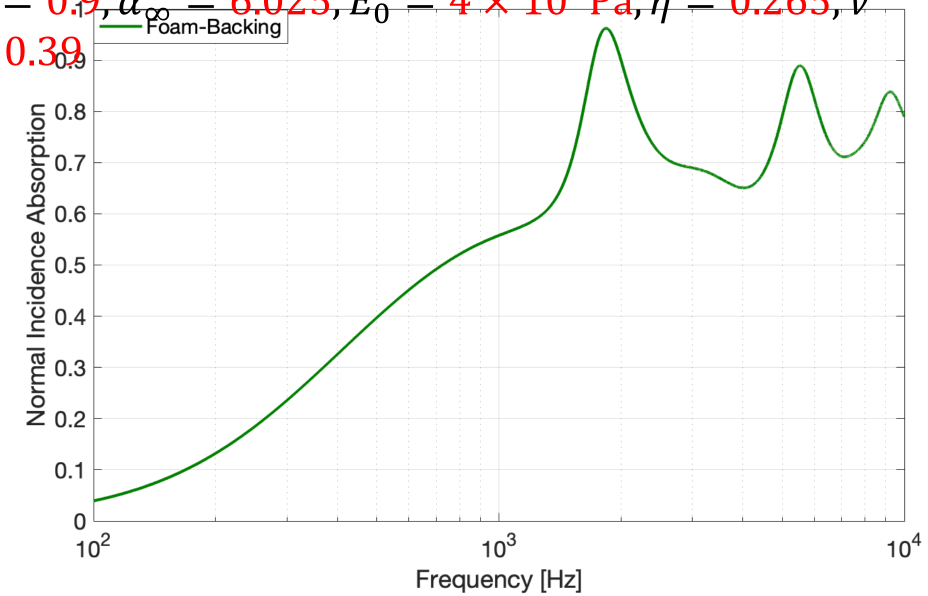
- **Big idea: [2x2] matrices multiplied in a series**

- Poro-elastic layer modeling example [4]

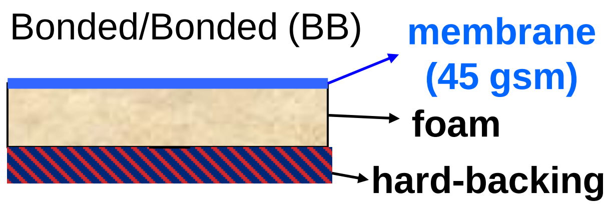


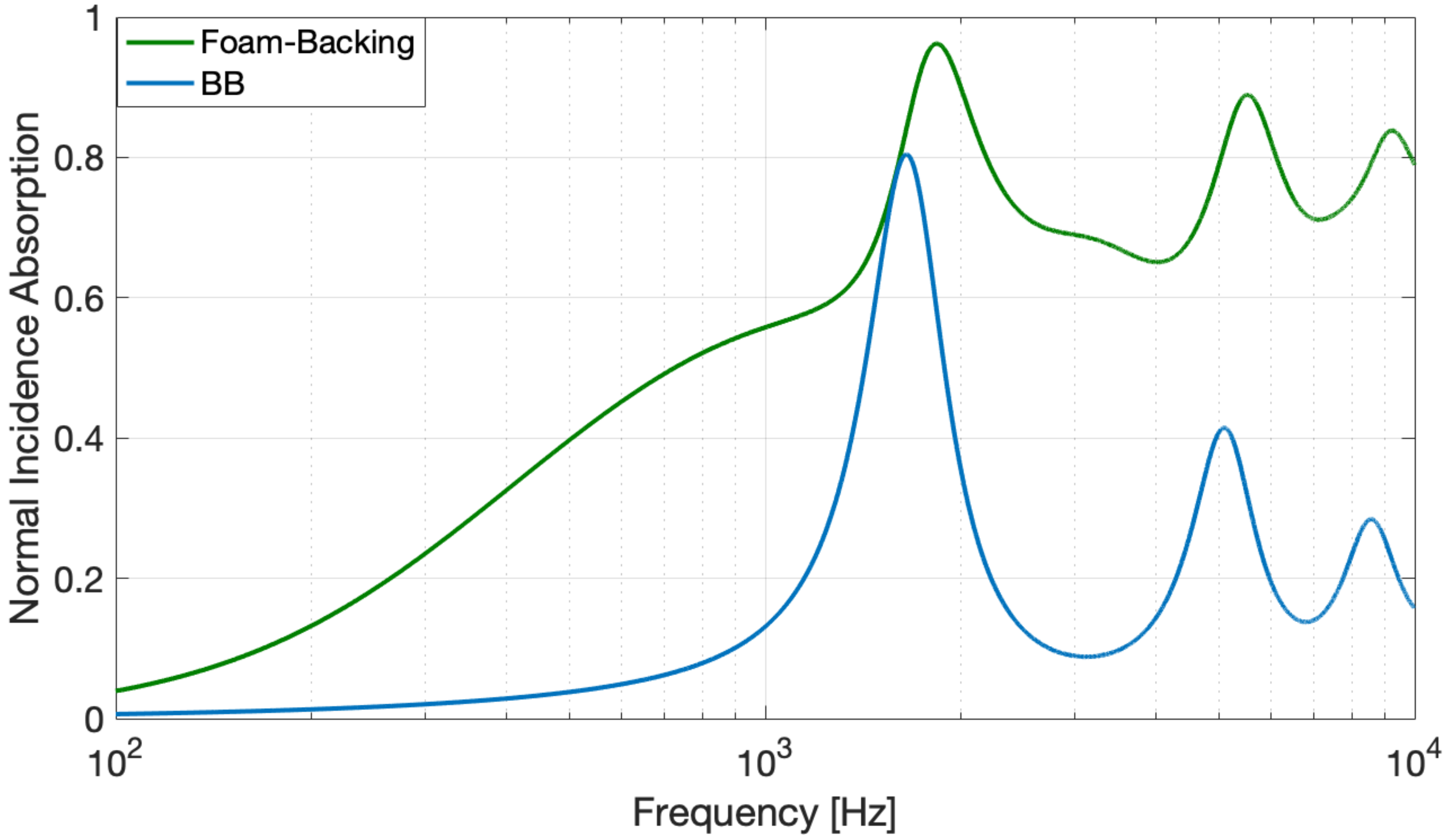
$\rho_b = 30\ \mathrm{kg/m^3}, d = 25\ \mathrm{mm}, \sigma = 130 \times 10^3\ \mathrm{MKS\ Rayls/m}$

$\phi = 0.9, \alpha_\infty = 6.025, E_0 = 4 \times 10^5\mathrm{Pa}, \eta = 0.265, \nu = 0.39$



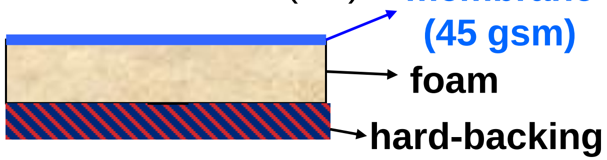
Effect of Surface & Back Treatments



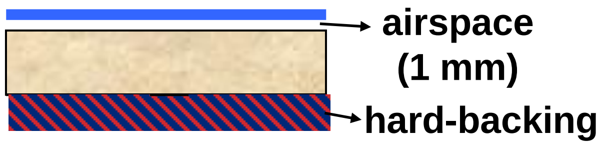


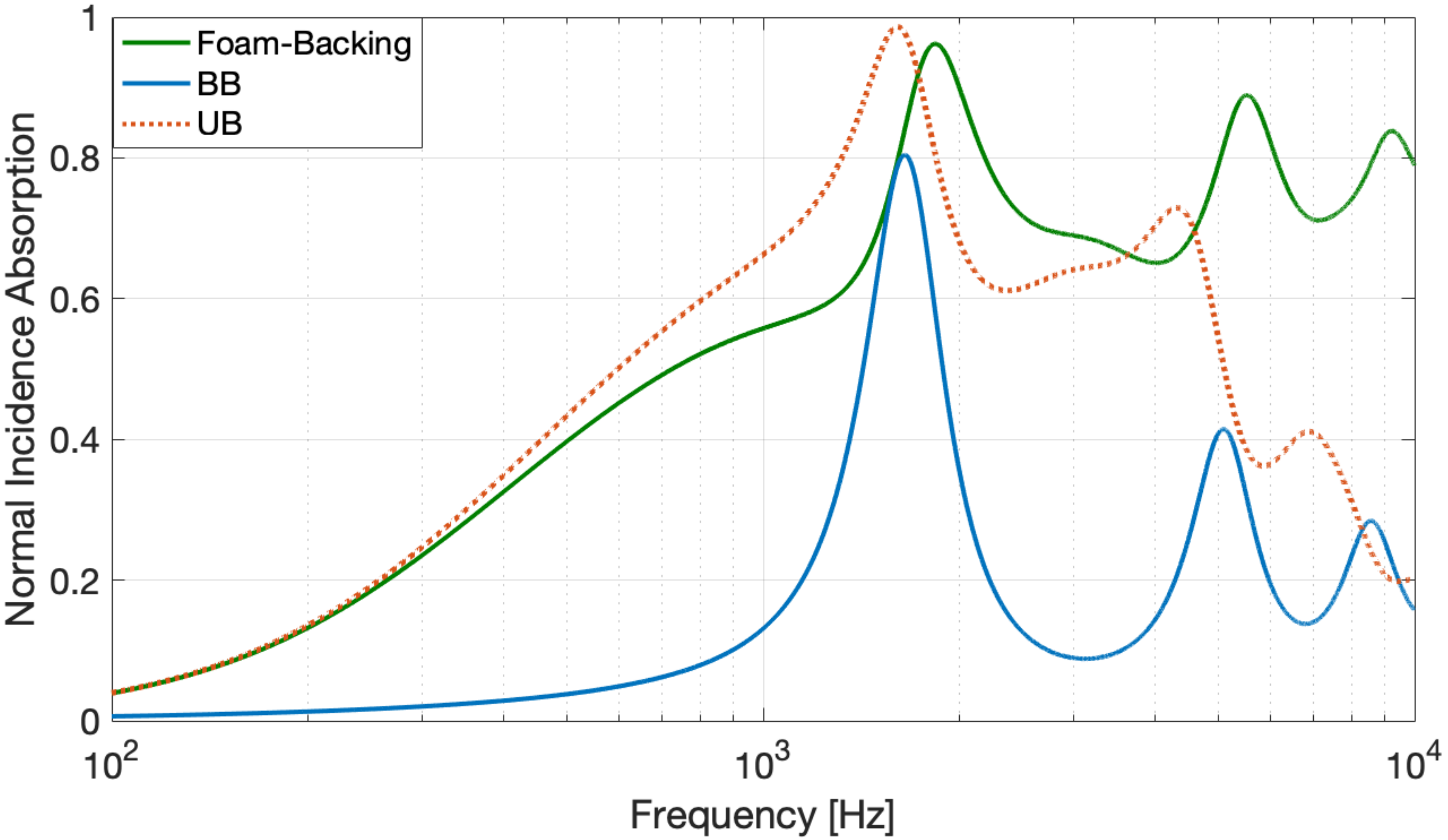
Effect of Surface & Back Treatments

Bonded/Bonded (BB)



Unbonded/Bonded (UB)





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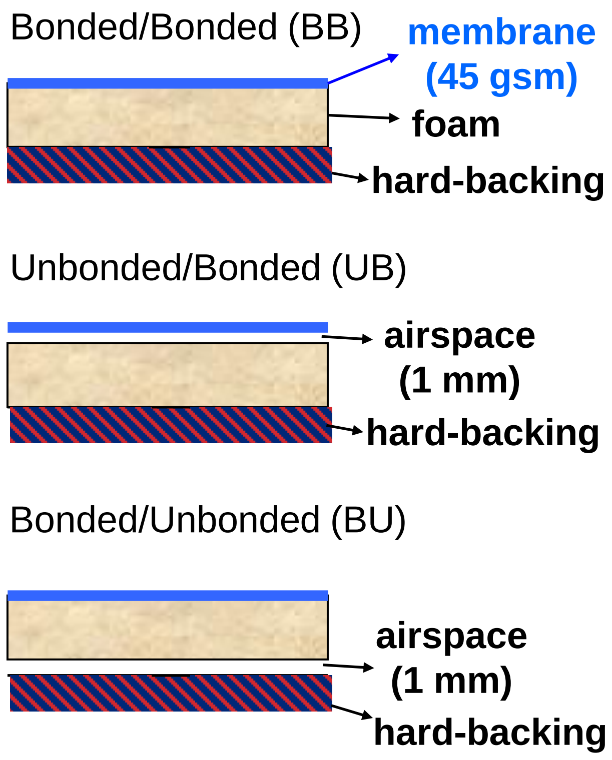

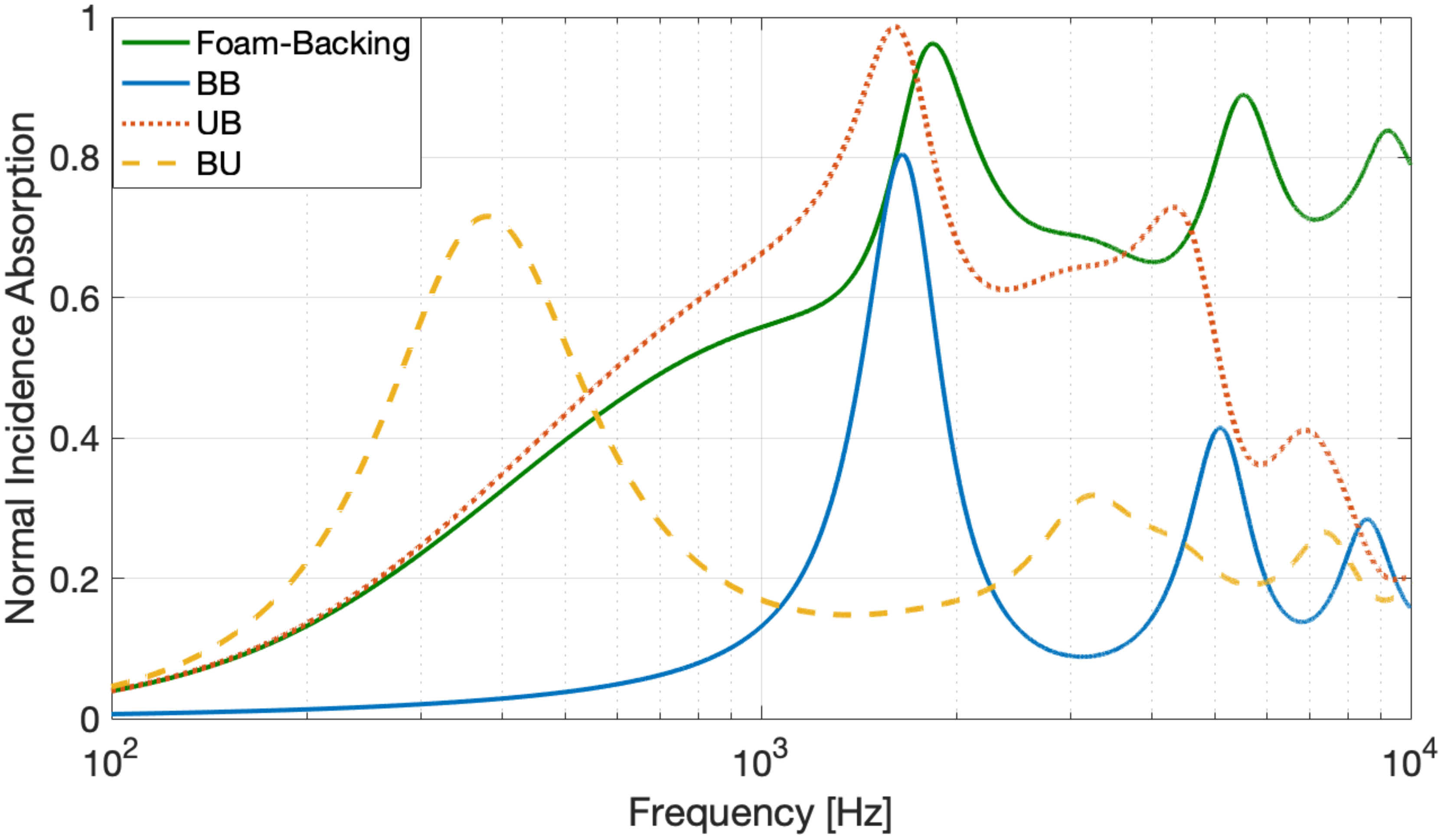

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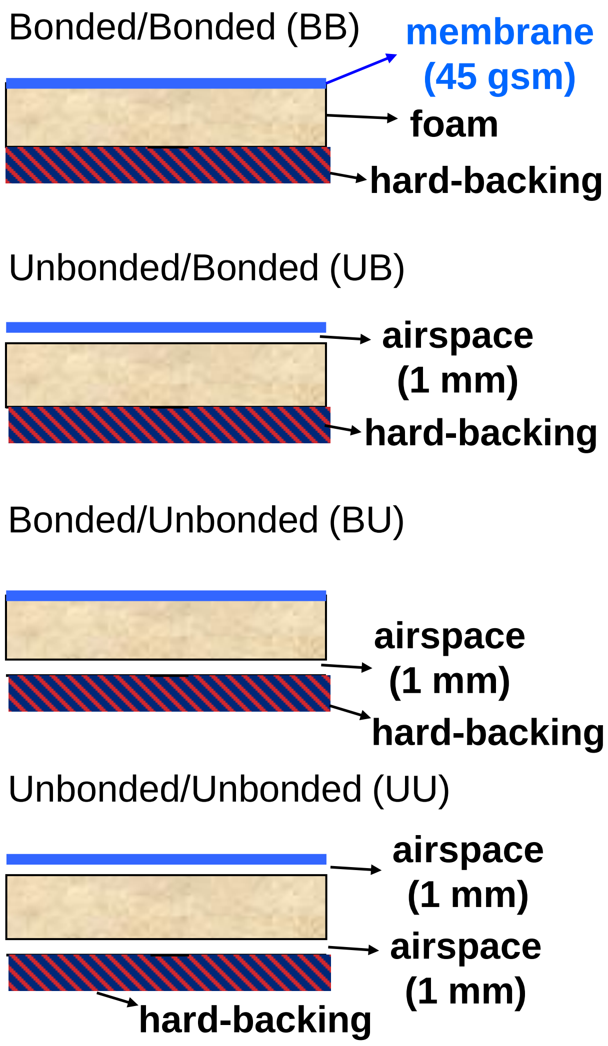
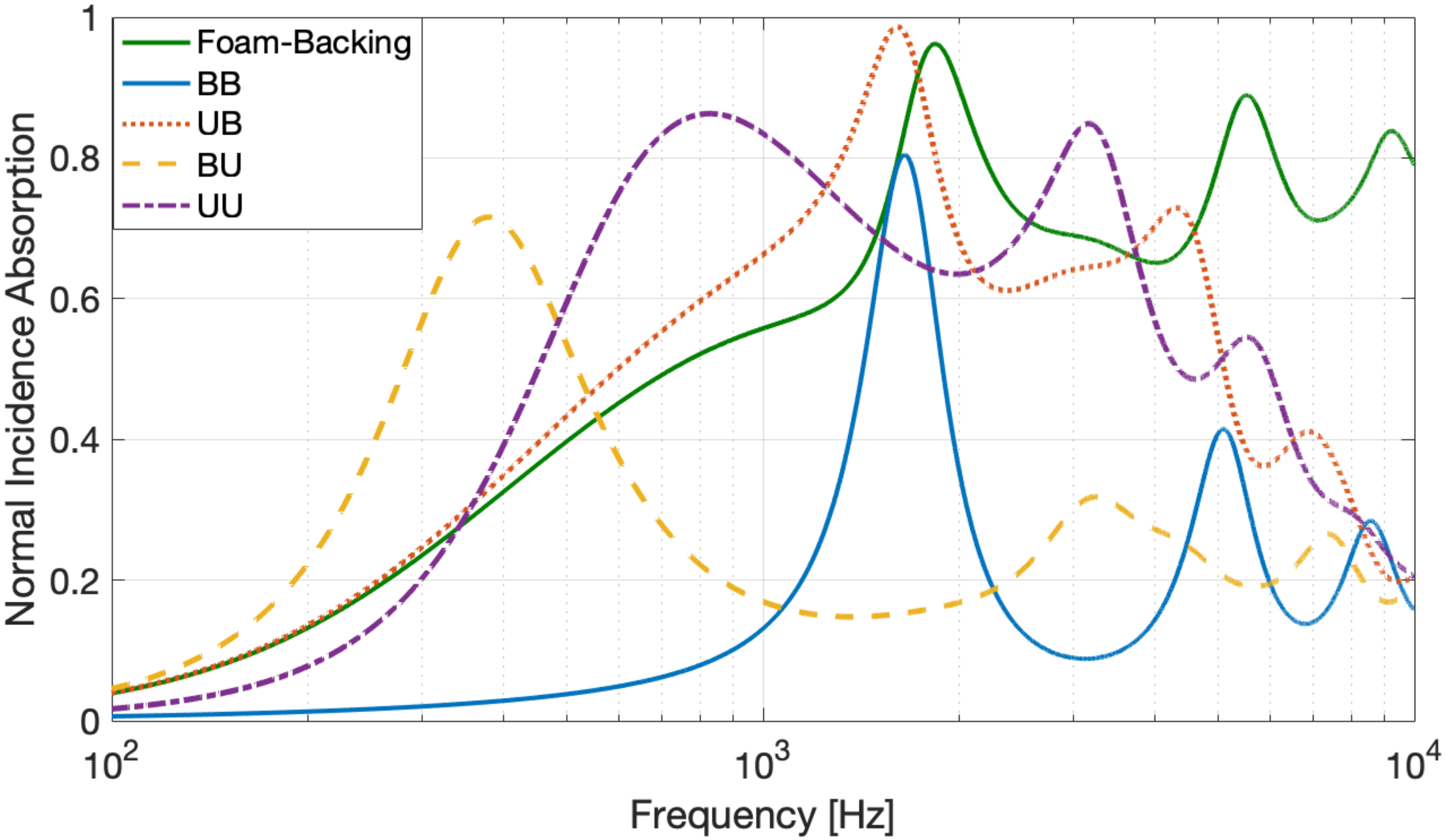
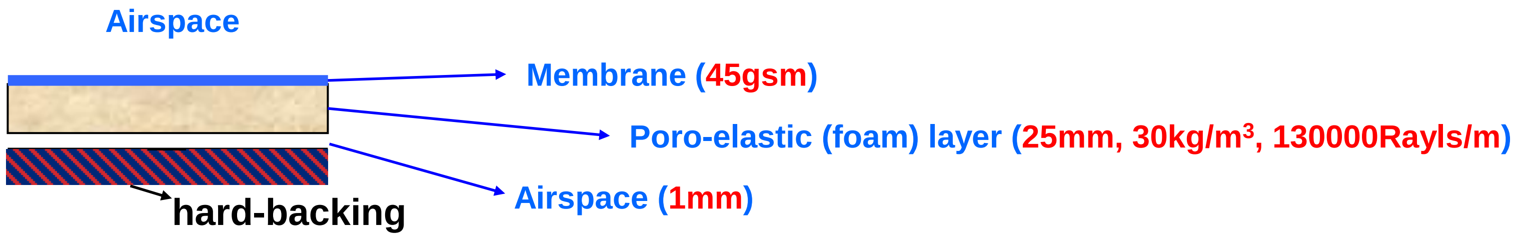
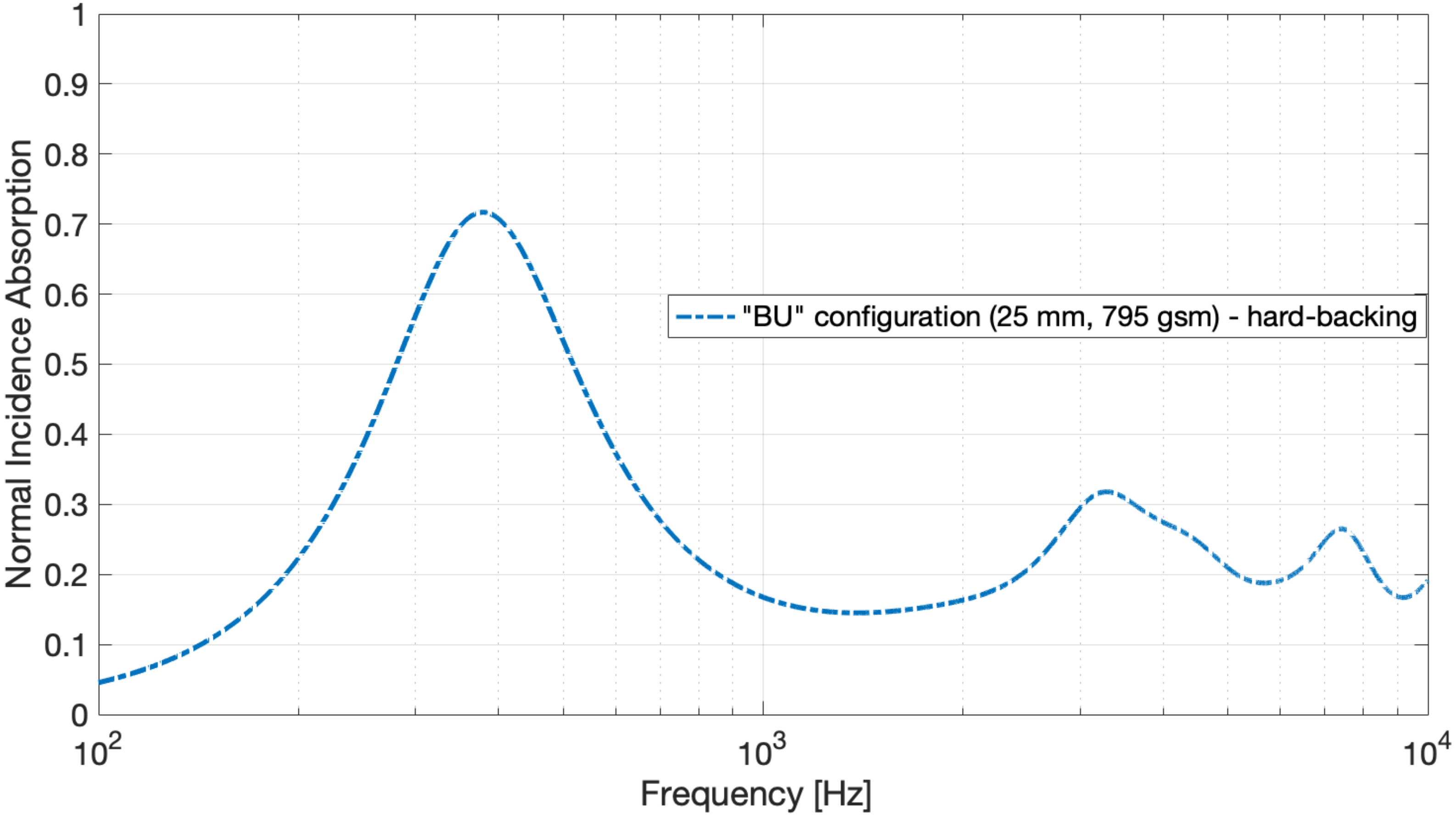




Effect of Additional Top Absorbent

- BU configuration





Effect of Additional Top Absorbent

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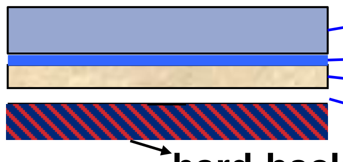

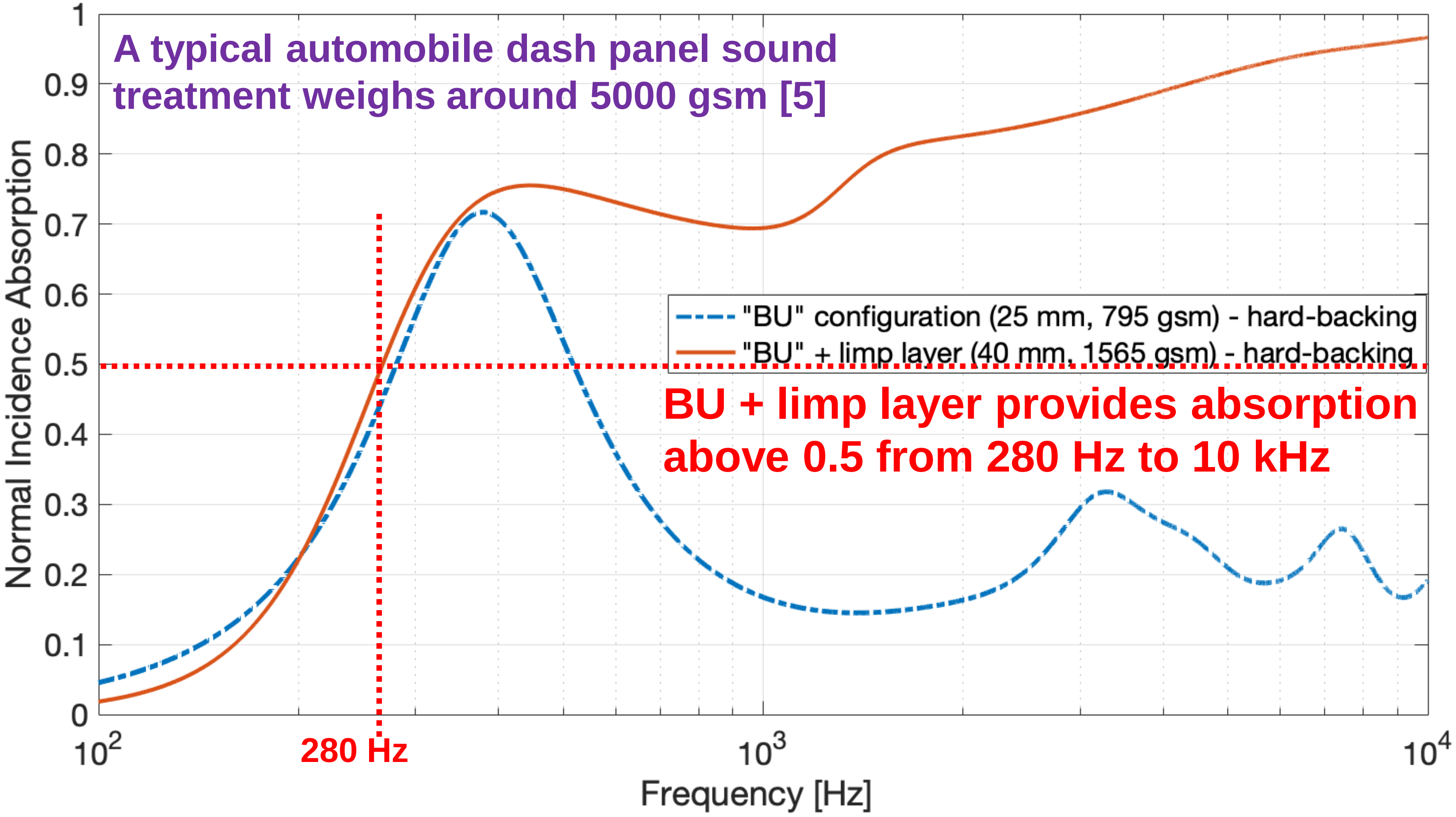

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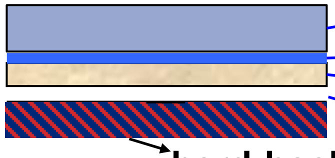
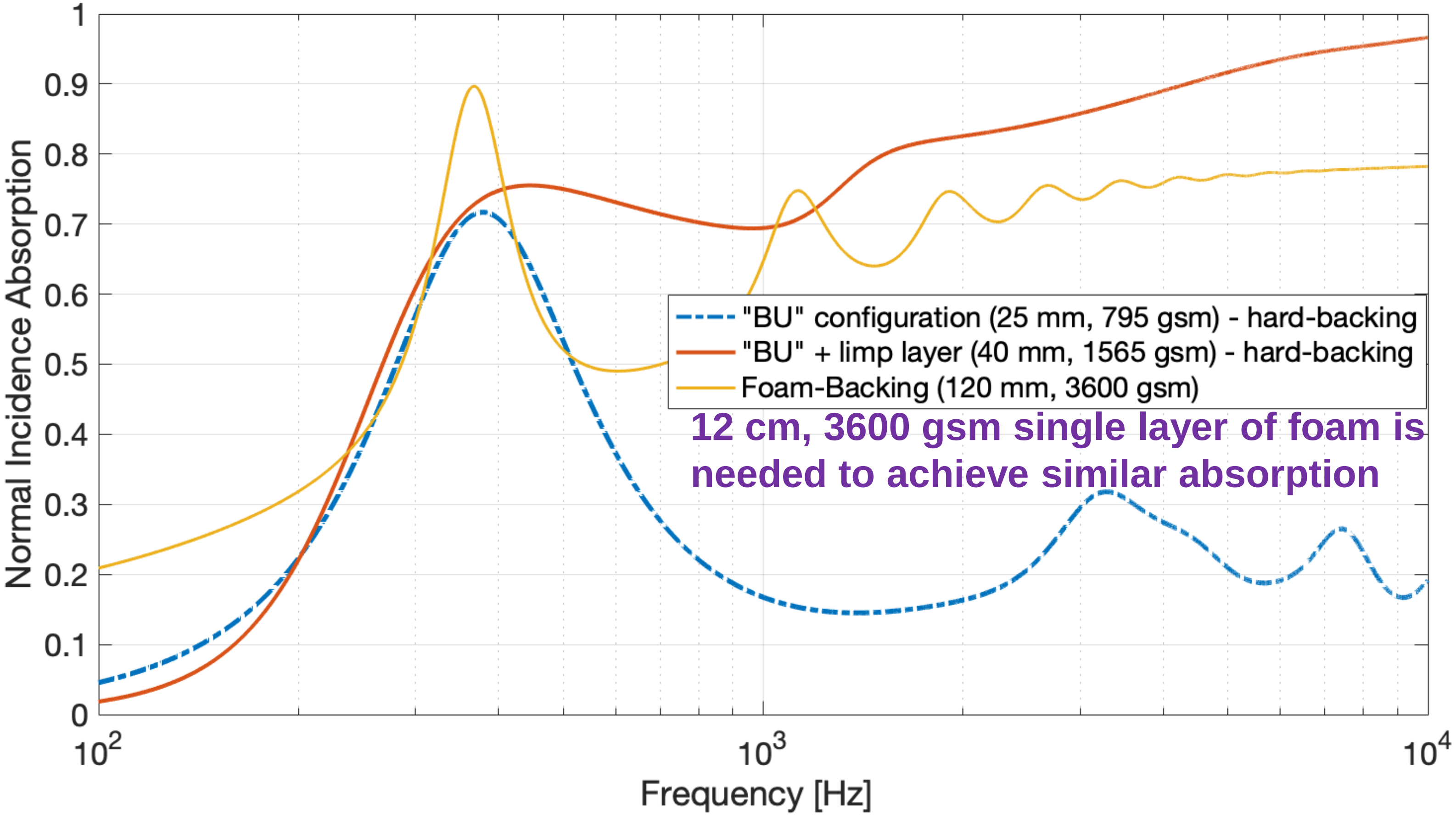


Adding a limp porous layer (3.2cm, 40kg/m^3, 80000Rayls/m) on top to improve high frequency absorption

Membrane (45gsm)

Poro-elastic (foam) layer (8mm, 30kg/m^3, 130000Rayls/m)

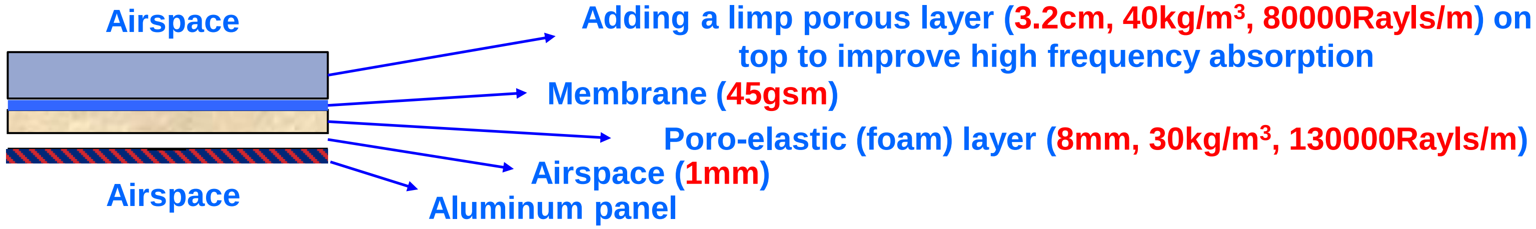
Airspace (1mm)

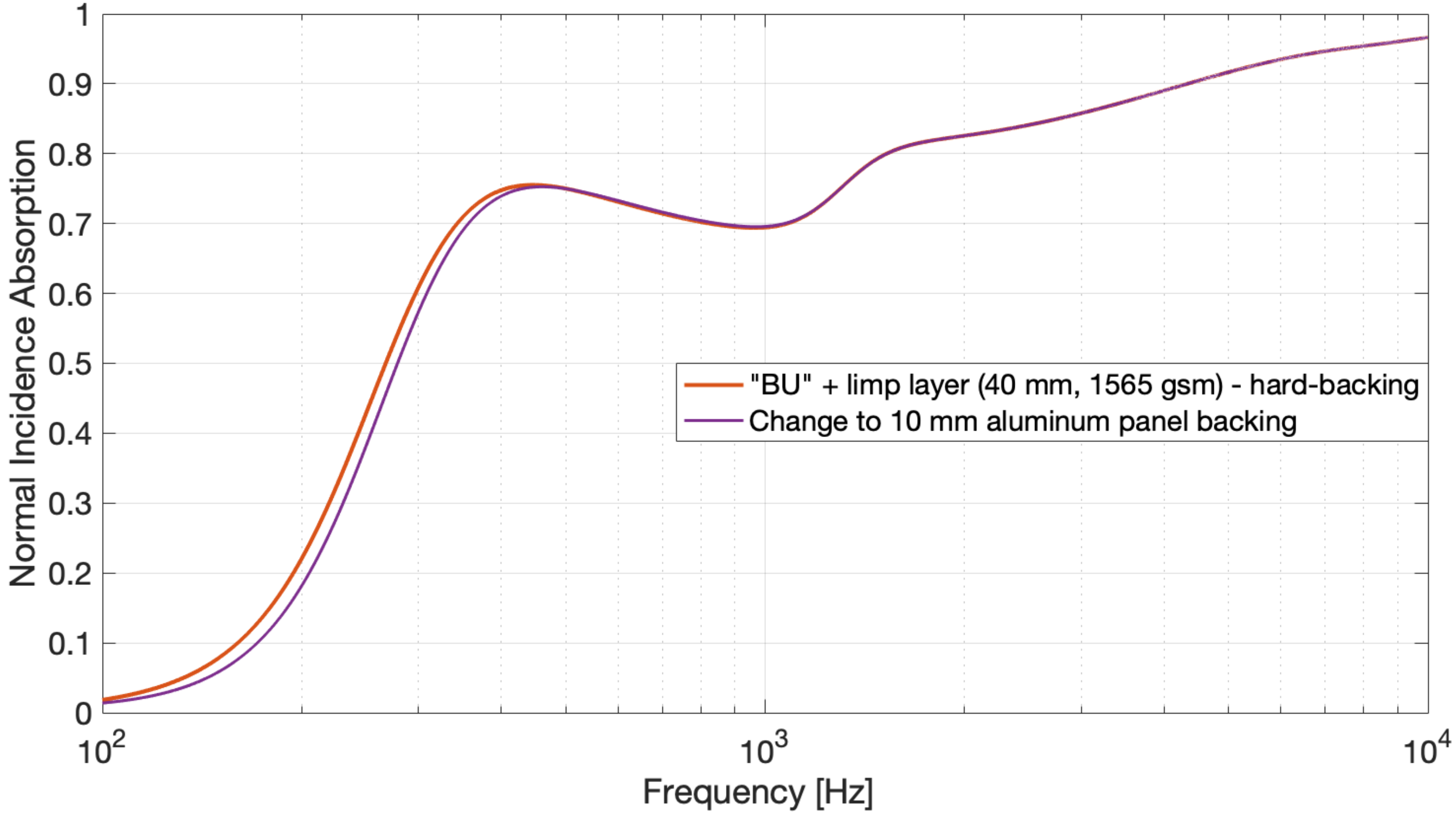


12 cm, 3600 gsm single layer of foam is needed to achieve similar absorption

Effect of Flexible Backing

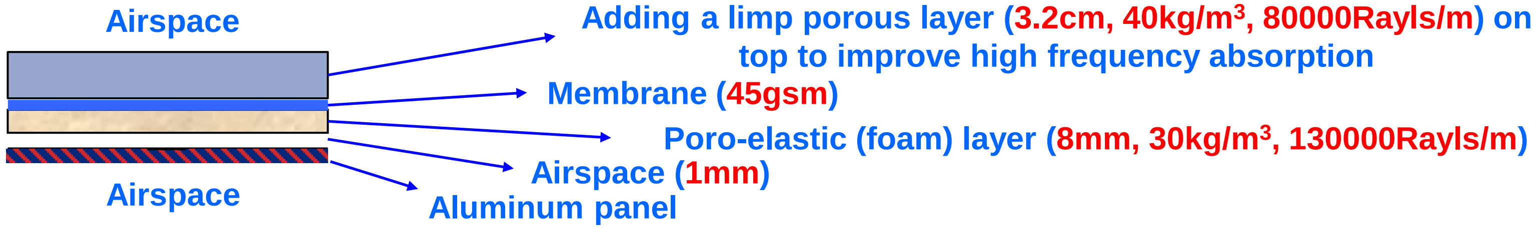
- BU configuration

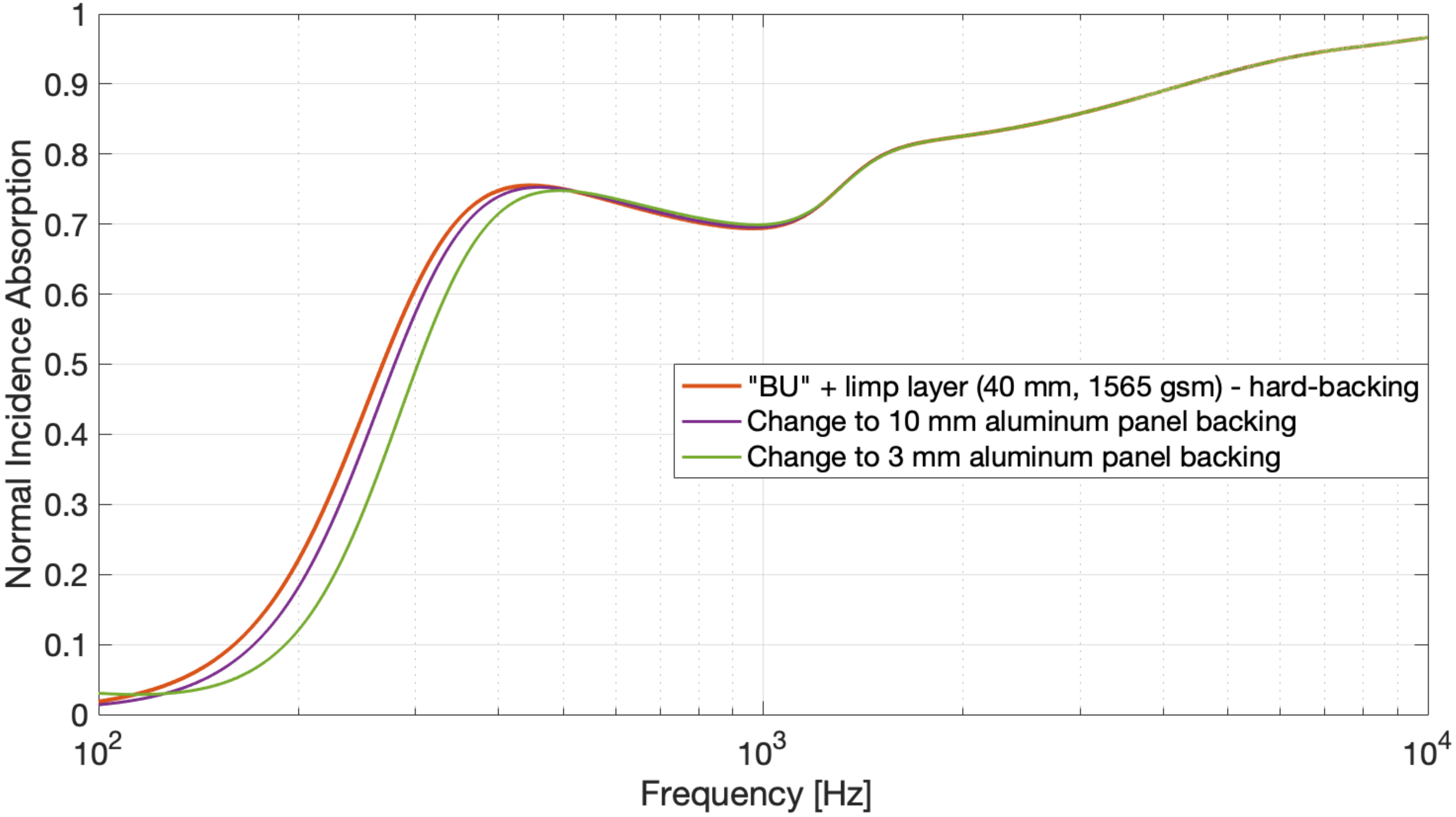




Effect of Flexible Backing

- BU configuration





Effect of Flexible Backing

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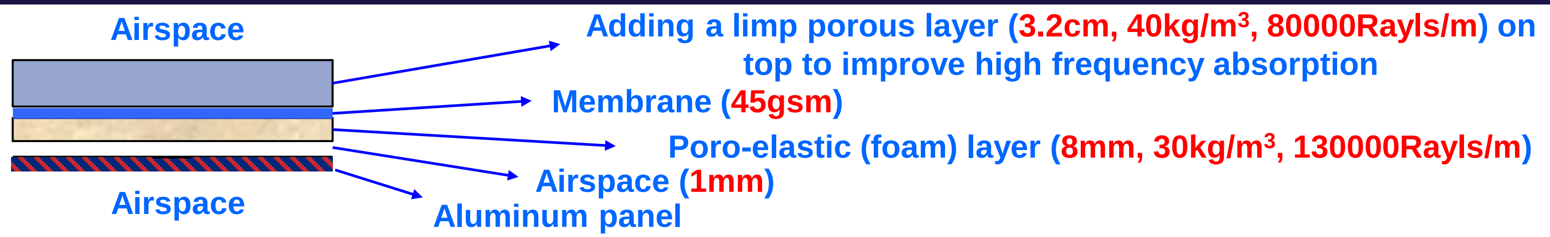
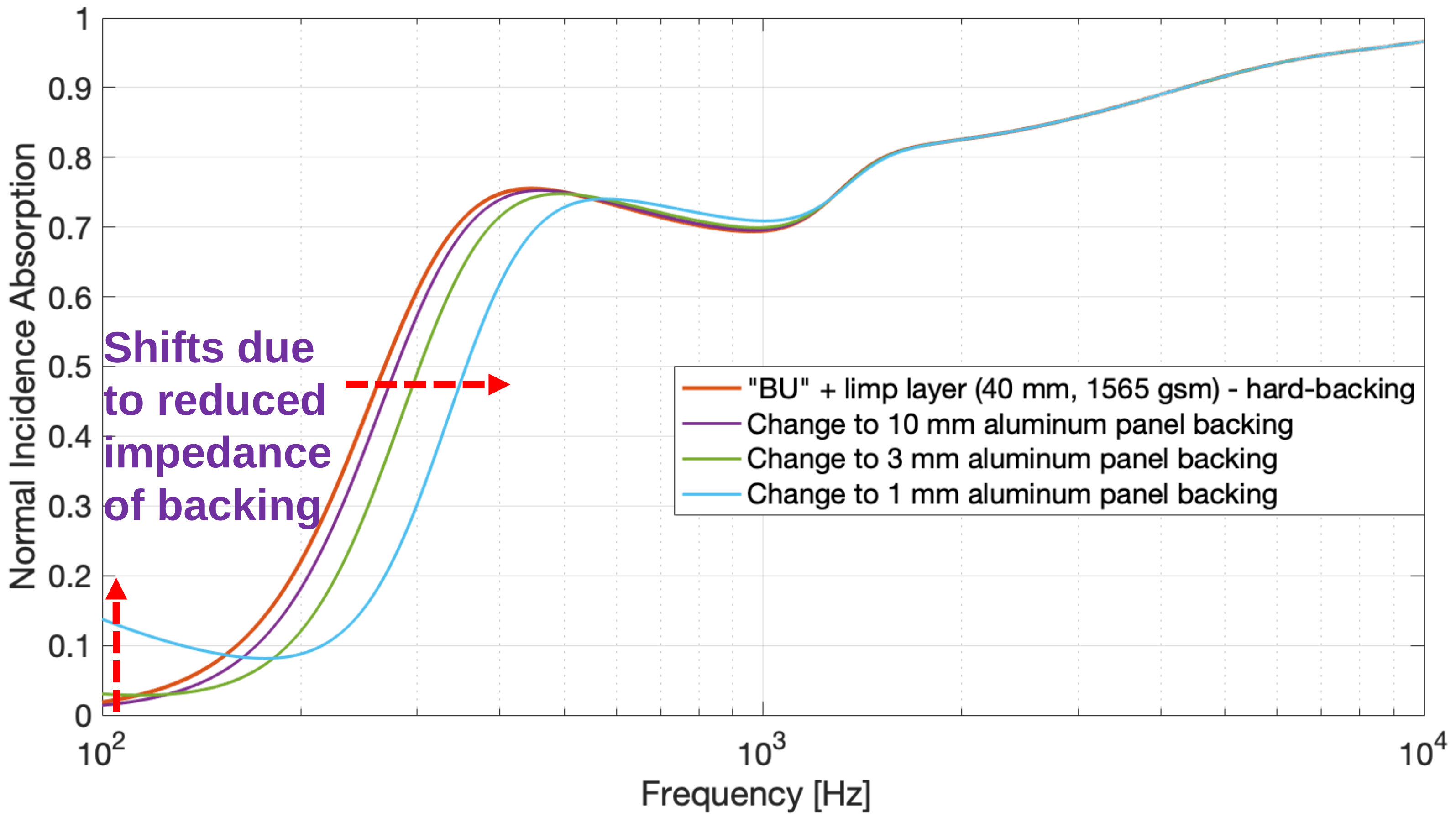




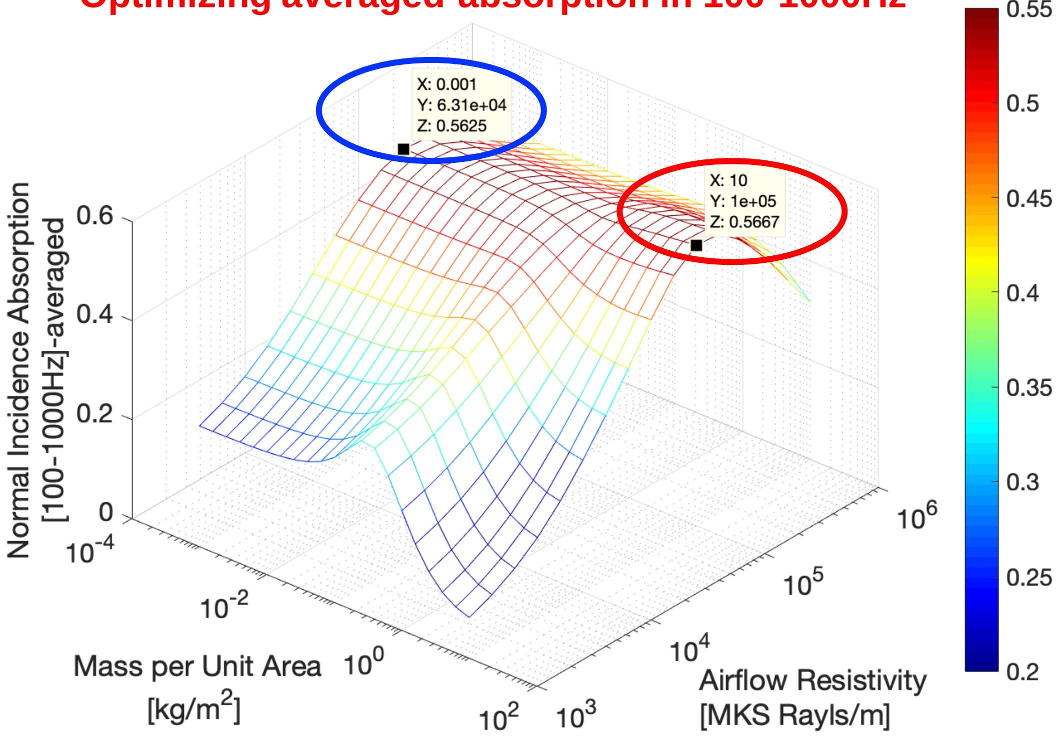
Low Frequency Absorption Optimization

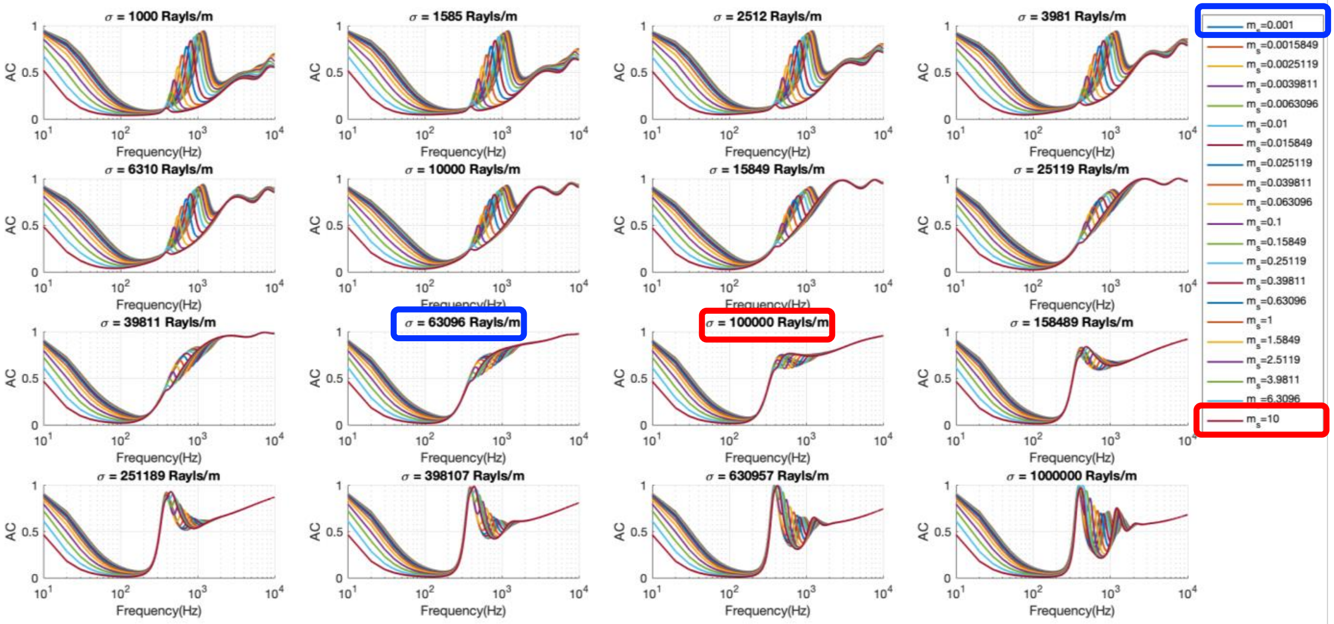
Airspace

- Limp porous layer (32mm, 40kg/m^3, σ)
- Limp membrane (m_s)
- Foam (8mm, 30kg/m3, 130000Rayls/m)
- Airspace (1 mm)
- Aluminum panel backing (1 mm)

Airspace

Optimizing averaged-absorption in 100-1000Hz





- Two optimal solutions were acquired, in both of which the performance was dominated by the airflow resistivity

Low Frequency Absorption Optimization

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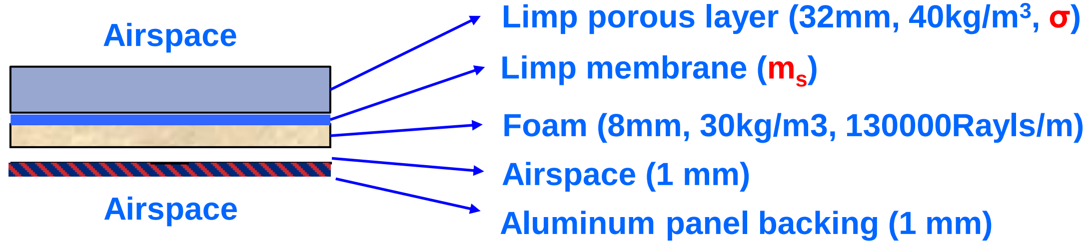
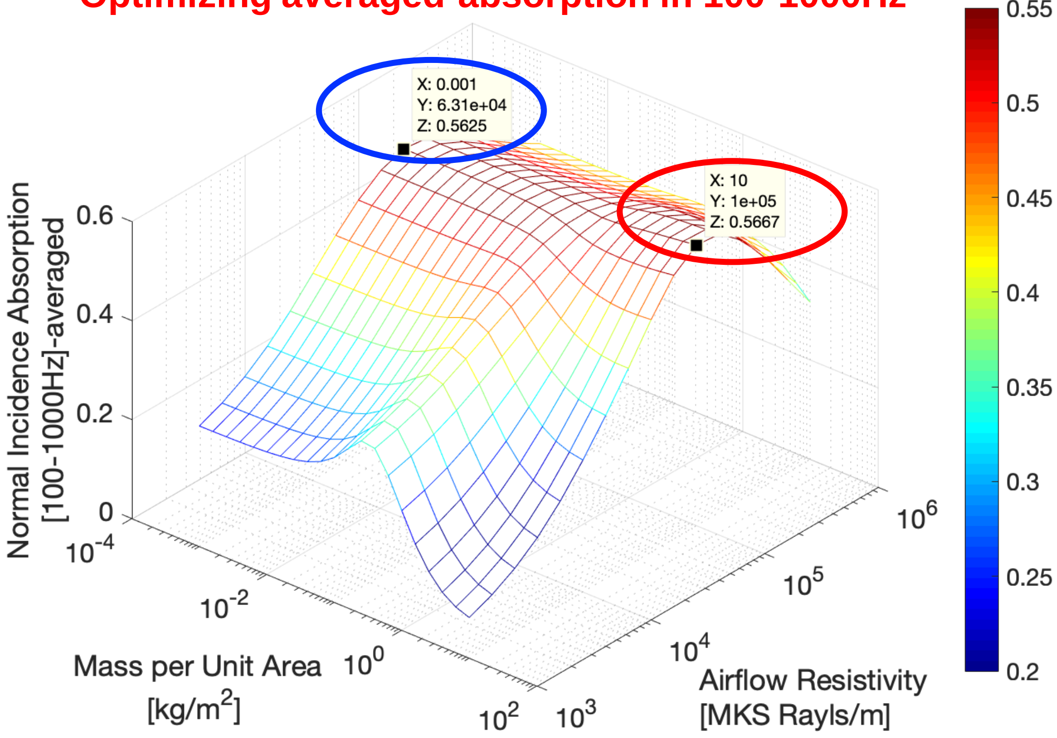
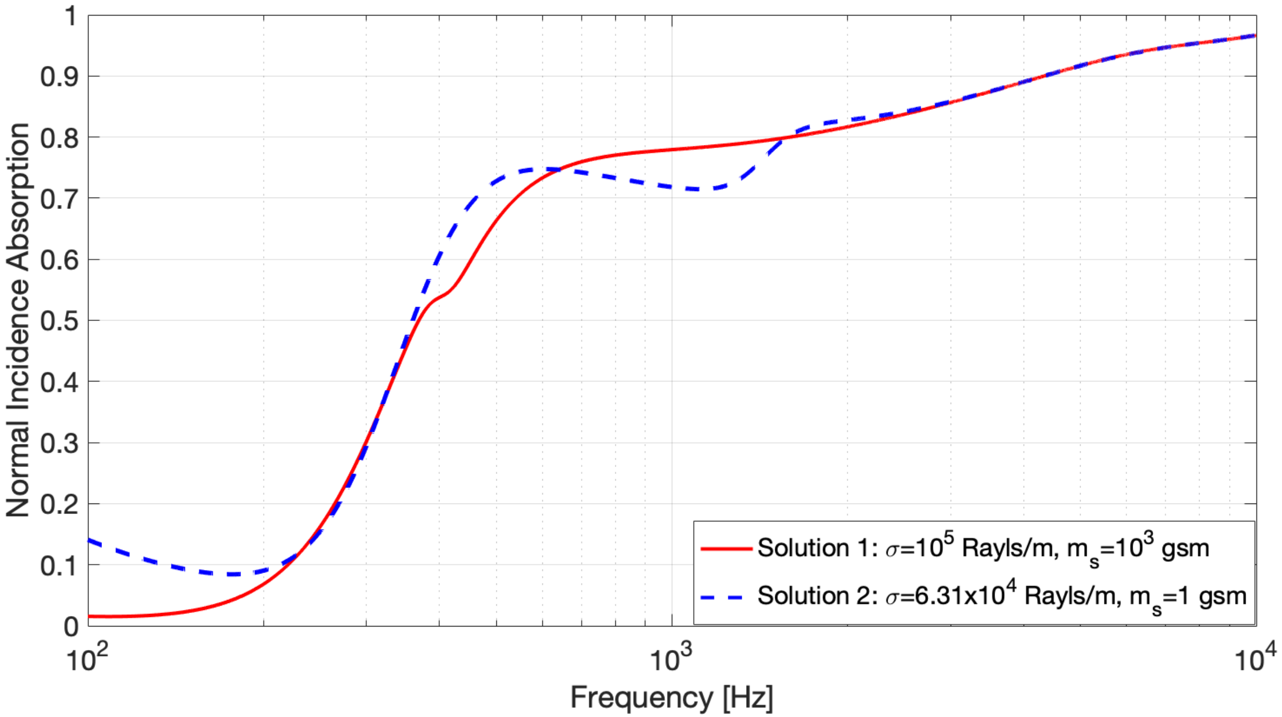


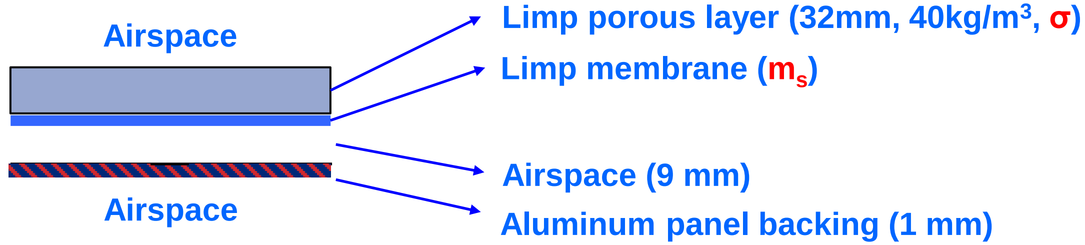
Optimizing averaged-absorption in 100-1000Hz



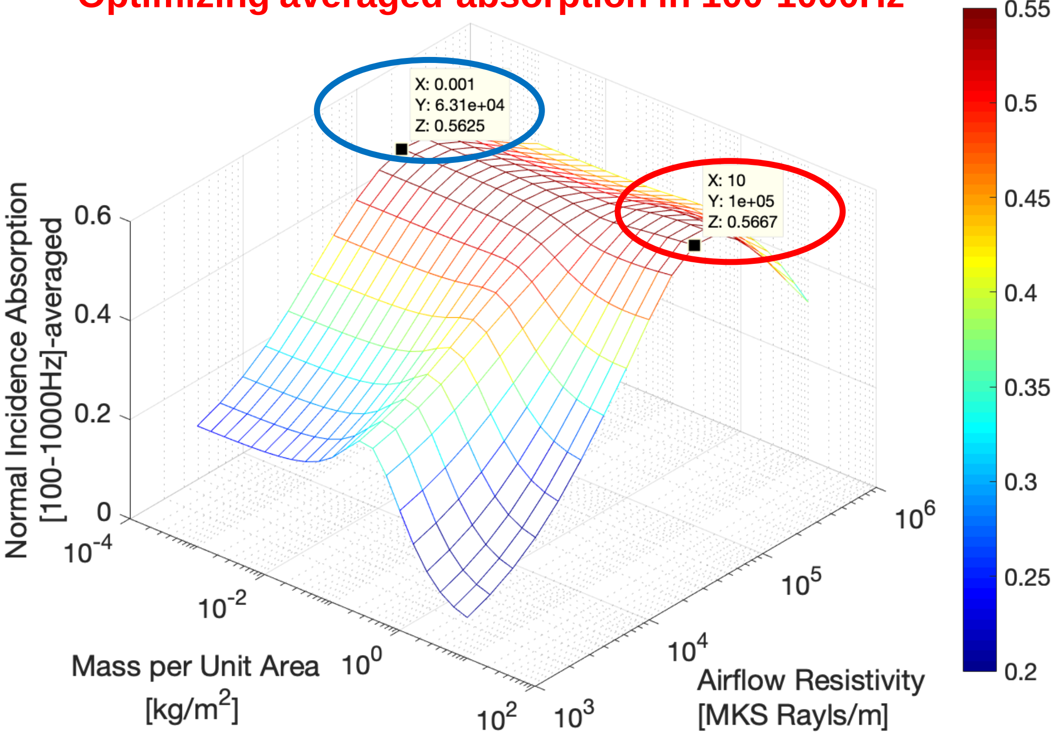


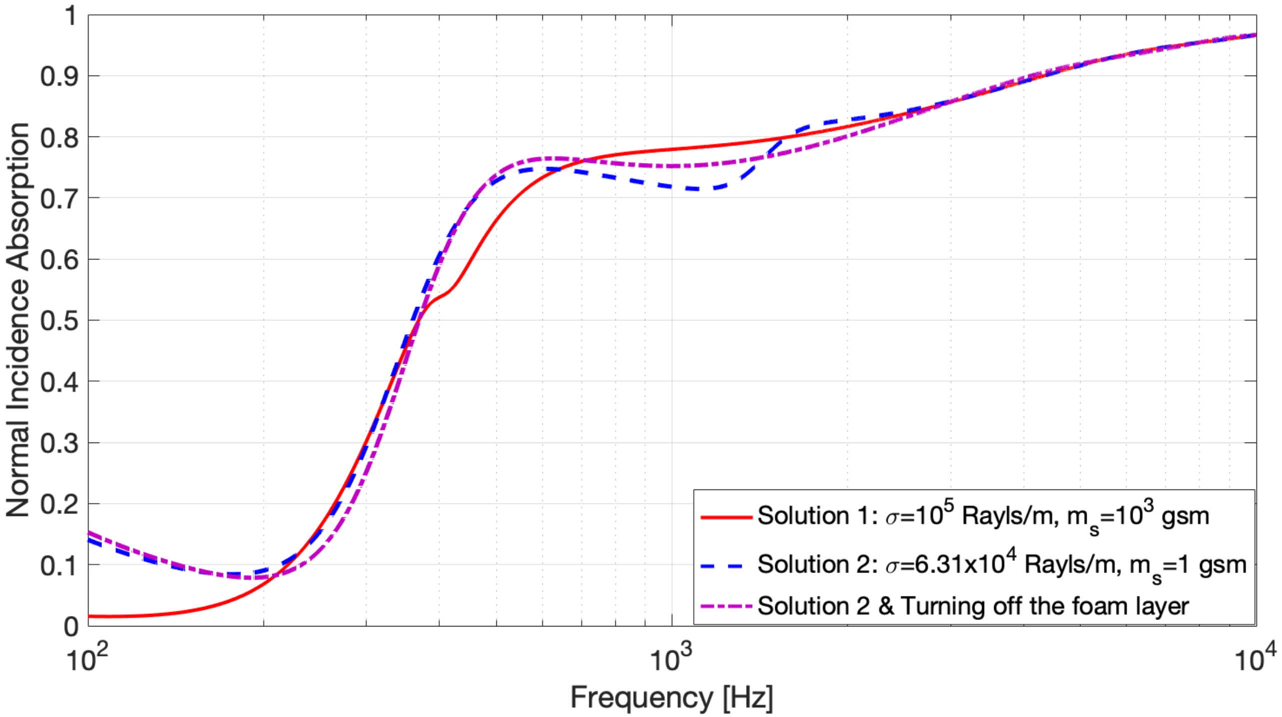
- Two optimal solutions were acquired, in both of which the performance was dominated by the airflow resistivity
- The optimal absorption can be achieved by either an extreme light or heavy membrane, which indicates that the performance was controlled by B.C.s

Low Frequency Absorption Optimization



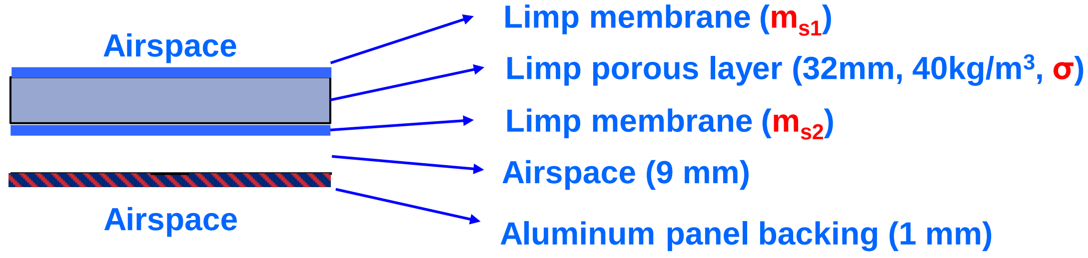
Optimizing averaged-absorption in 100-1000Hz



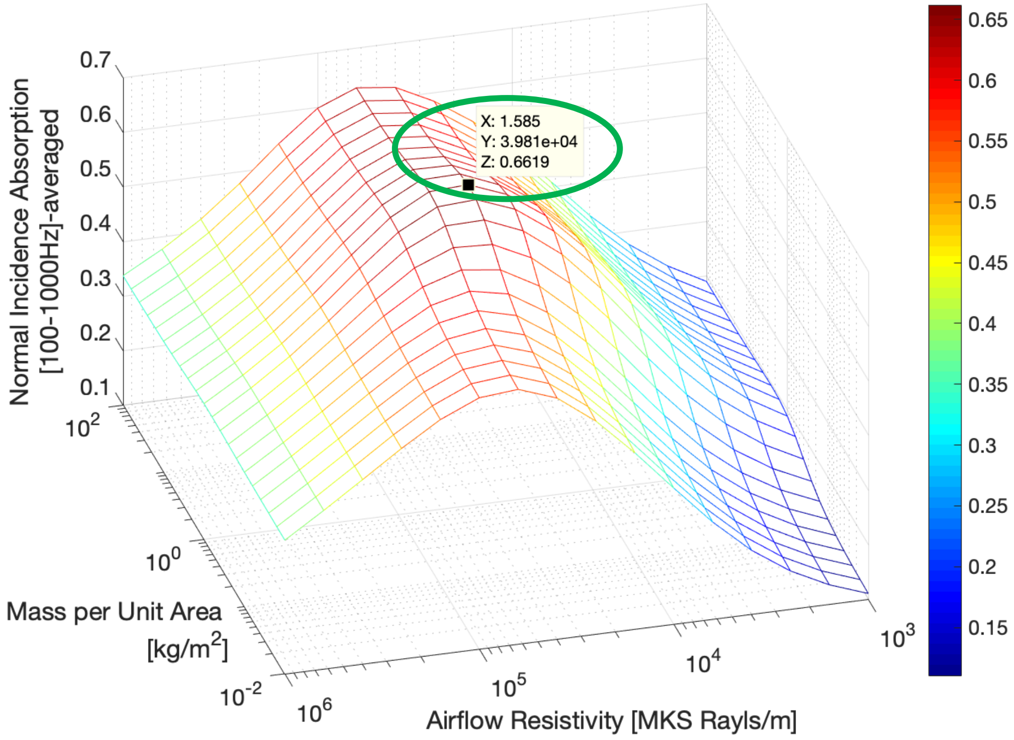


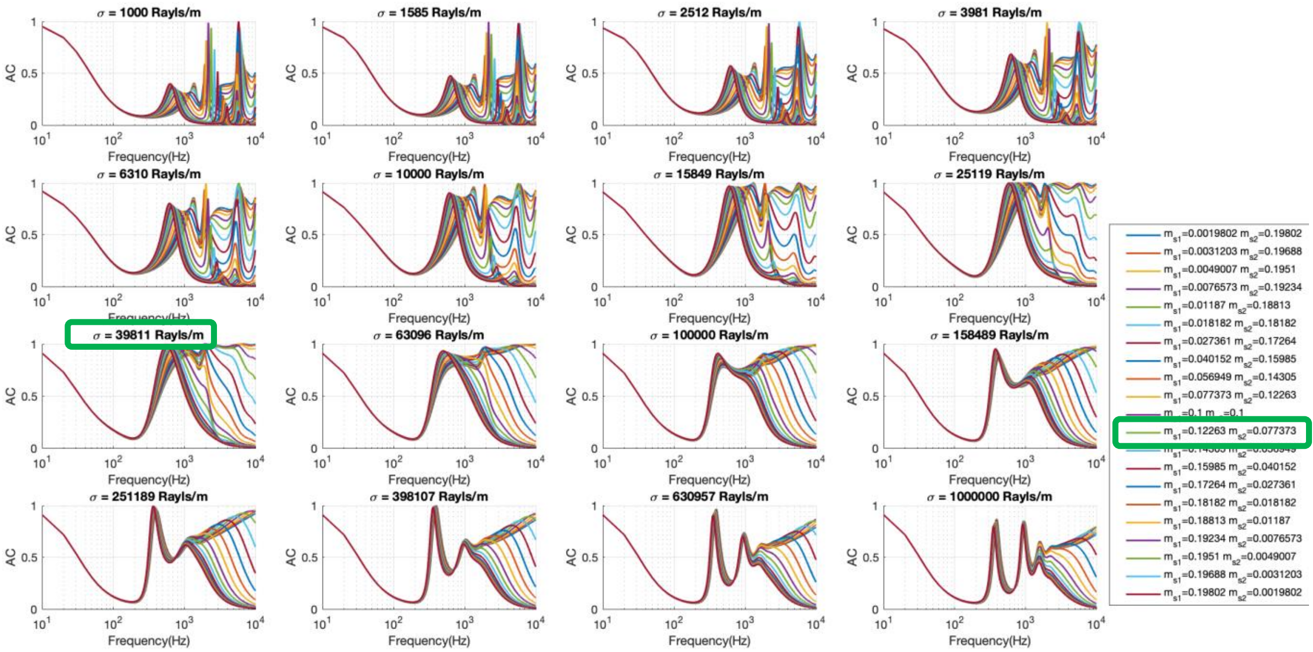
- Two optimal solutions were acquired, in both of which the performance was dominated by the airflow resistivity
- The optimal absorption can be achieved by either an extreme light or heavy membrane, which indicates that the performance was controlled by B.C.s
- Switching off the foam would not affect much of the optimal absorption

Low Frequency Absorption Optimization



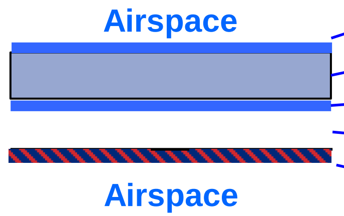
Optimizing averaged-absorption in 100-1000Hz





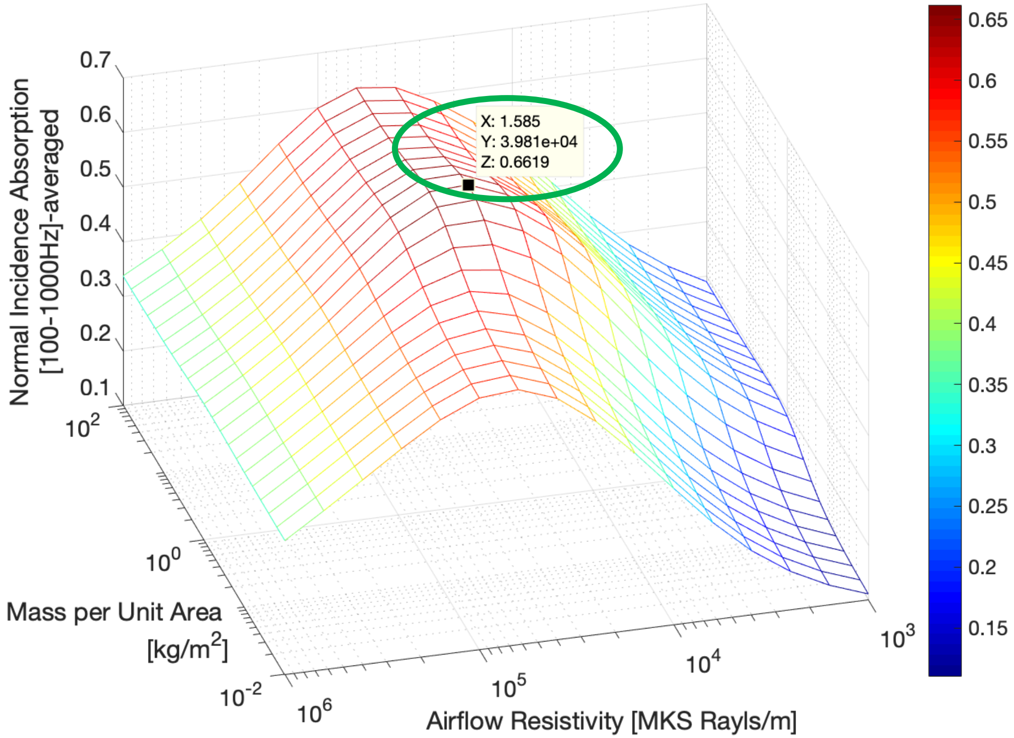
- One optimal solutions were captured with top membrane~120 gsm, bottom membrane~80 gsm, and limp porous layer σ=~4x10^5 Rayls/m, in which the airflow resistivity of the limp porous layer still dominates the performance

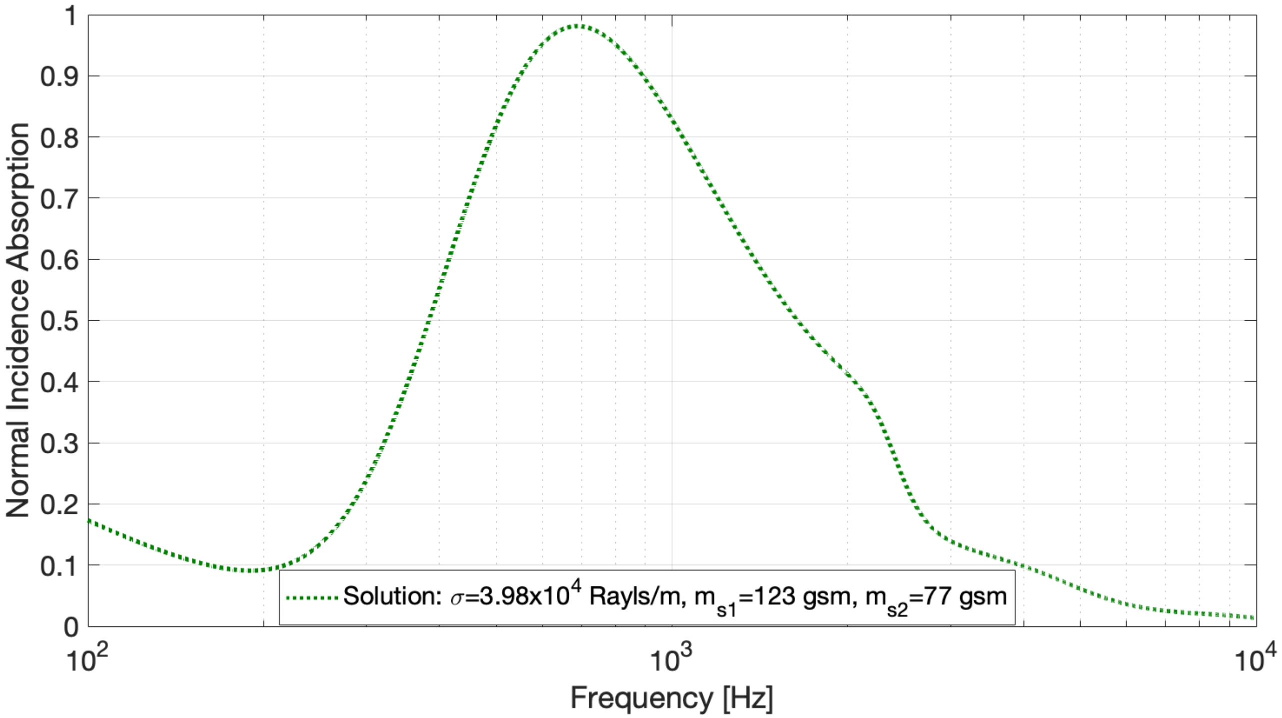
Low Frequency Absorption Optimization



- Limp membrane (m_{s1})
- Limp porous layer (32mm, 40kg/m³, σ)
- Limp membrane (m_{s2})
- Airspace (9 mm)
- Aluminum panel backing (1 mm)

Optimizing averaged-absorption in 100-1000Hz





- One optimal solutions were captured with top membrane~120 gsm, bottom membrane~80 gsm, and limp porous layer σ=~4x10⁵ Rayls/m, in which the airflow resistivity of the limp porous layer still dominates the performance
- Averaging among a continuous band of frequencies does not help the whole picture and does not guarantee good performance at all frequencies
- This configuration provides +0.1 absorption than previous one, but would trade off high frequency performance

Summary

- Low frequency sound absorption can be optimized for conventional sound package involving porous layers (fibers, foam) to provide industry-acceptable performance while maintaining cost-effective features including lightweight and thinness
- TMM model serves as an efficient multi-layer sound package modeling tool to enable optimization of complex layered structures
- Boundary conditions (unbonding vs. bonding) plays an significant role for low frequency absorption
- Finite impedance backing (panel) is more practical when optimizing absorption
- An optimized sound package (40mm, 1520 gsm) with a highly-resistive absorbent (32mm, at front) and a surface-bonded foam (8mm, at back) can achieve an averaged sound absorption **> 0.55 among 100-1000Hz**
- An alternative optimized sound package (40mm, 1435 gsm) with a highly-resistive absorbent (32mm) plus two limp membranes without the foam layer can achieve an averaged sound absorption **> 0.65 among 100-1000Hz**, but would trade off high frequency performance

References

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