Simulation of Alpha Cabin reverberant room to estimate absorption coefficient under diffuse sound field

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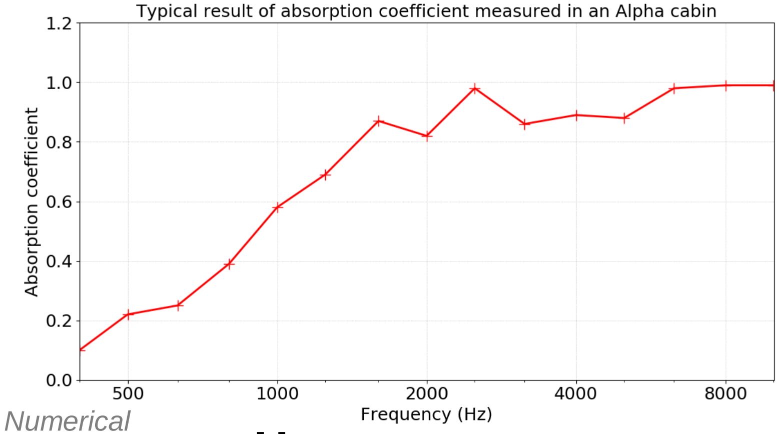
Introduction

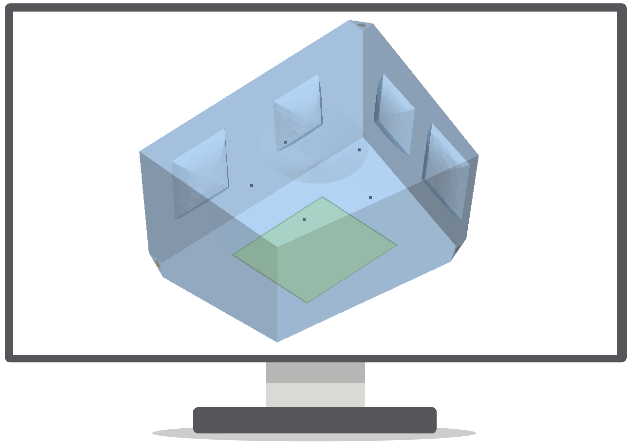
Alpha cabin measurements

From: https://www.autoneum.com/wp-content/uploads/2017/09/Alpha_Cabin_Flyer.pdf

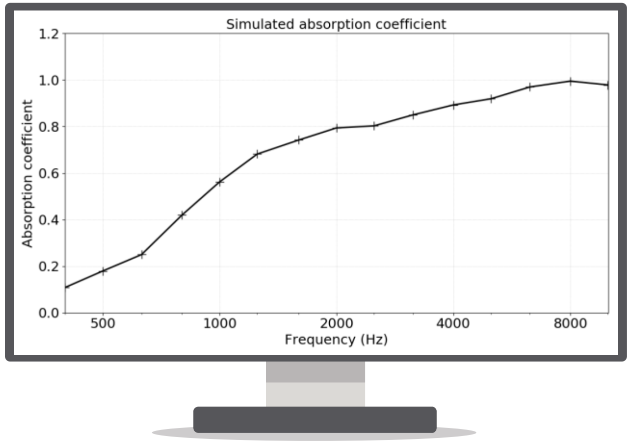


From: Bertolini C., Guj L. (2011). *Numerical Simulation of the Measurement of the Diffuse Field Absorption Coefficient in Small Reverberation Rooms*. SAE International

Modeling Alpha cabin



Computational challenges:
- Cabin size
- Frequency range of interest



How can we overcome computational challenges and reproduce absorption coefficient results with simulation?

Outline

- Context
- Modelling Alpha cabins: Challenges and Solutions
  - Challenge 1: Frequency resolution
  - Challenge 2: Mesh size
  - Challenge 3: Diffuse sound field
- Results and comparison with experimental results
  - Low frequency range: standard approach and experimental post-processing
  - Mid-range frequencies: energetical approach
  - High frequencies: energetical approach with scaling
- Conclusions

Context

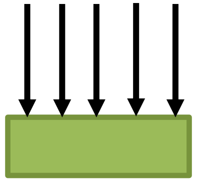
Absorption coefficient of trims

To select trims, we study their absorption coefficient

How can we get absorption coefficient in representative conditions?

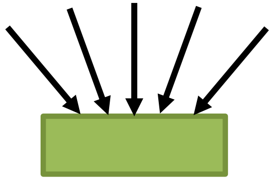
Standardized methods to measure absorption coefficient

- Kundt’s tube (or impedance tube)



Cjp24 (https://commons.wikimedia.org/wiki/File:Impedance_tube.jpg), „Impedance tube“, https://creativecommons.org/licenses/by-sa/3.0/legalcode

- Reverberation room



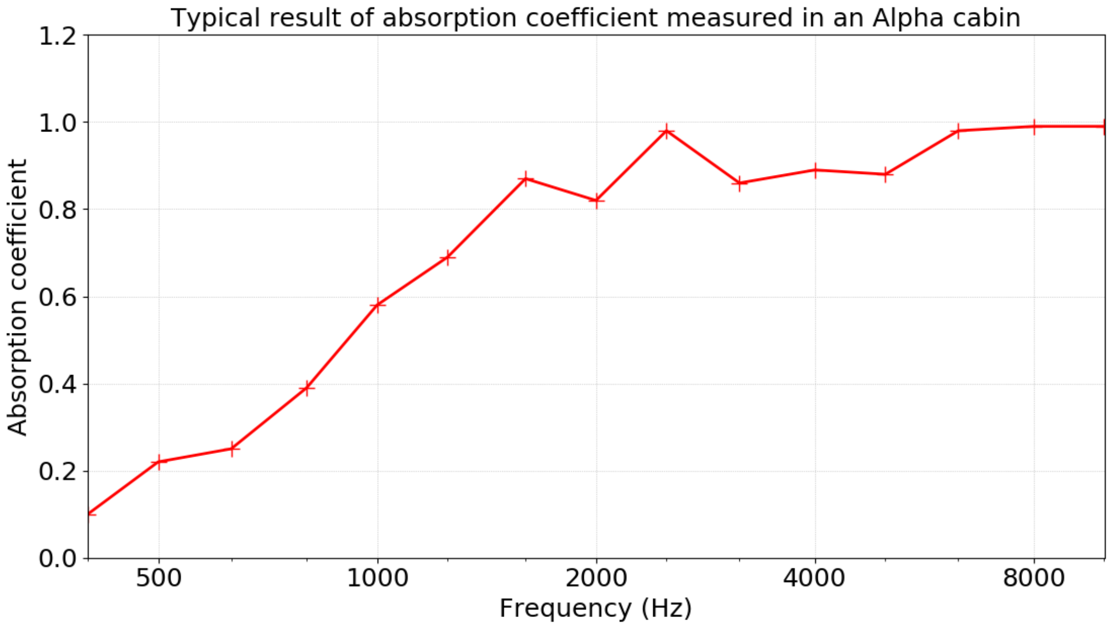
Henry Mühlpfordt (https://commons.wikimedia.org/wiki/File:Hallraum_TU_Dresden_2009-06-21.jpg), „Hallraum TU Dresden 2009-06-21“, https://creativecommons.org/licenses/by-sa/3.0/legalcode

Standardized methods can be limiting for industrial purposes

Measuring absorption coefficient with Alpha cabins

Small reverberant rooms called Alpha cabins are often used to evaluate absorption coefficient under diffuse field conditions

From: https://www.autoneum.com/wp-content/uploads/2017/09/Alpha_Cabin_Flyer.pdf



From: Bertolini C., Guj L. (2011). *Numerical Simulation of the Measurement of the Diffuse Field Absorption Coefficient in Small Reverberation Rooms*. SAE International

Characteristics:
- Small volume (6.5 m³)
- Complex shape
- Small sample (1.2 m²)

Absorption coefficient

Absorption coefficient α is computed as follows:

Absorption surface

Cabin volume

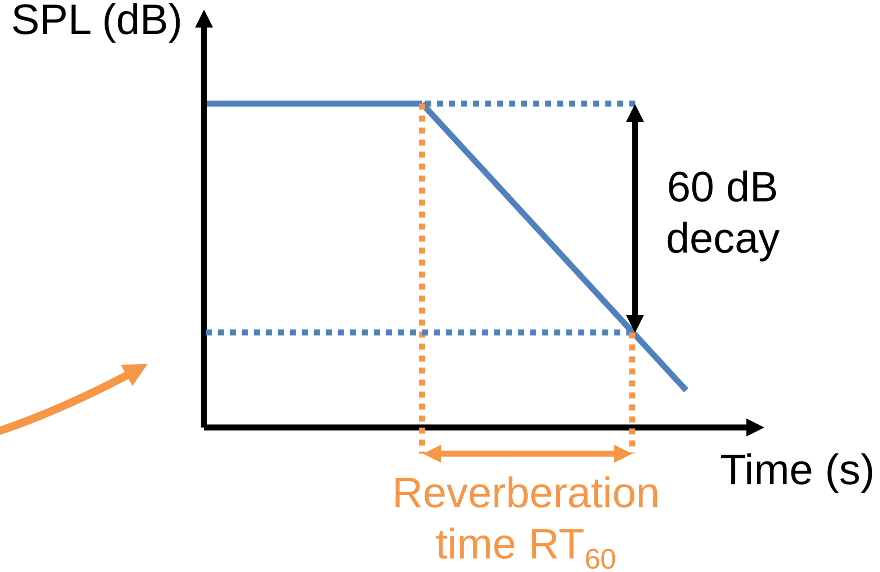
$$\alpha = \frac{A}{S} = \frac{55.3}{Sc}\left[\left(\frac{V}{RT_{60\ porous}}\right)-\left(\frac{V}{RT_{60\ bare}}\right)\right]$$

Top surface of the sample

Sound speed

Reverberation time

Reverberation time (RT_{60}) corresponds to the time needed for a decay of 60 dB after an excitation

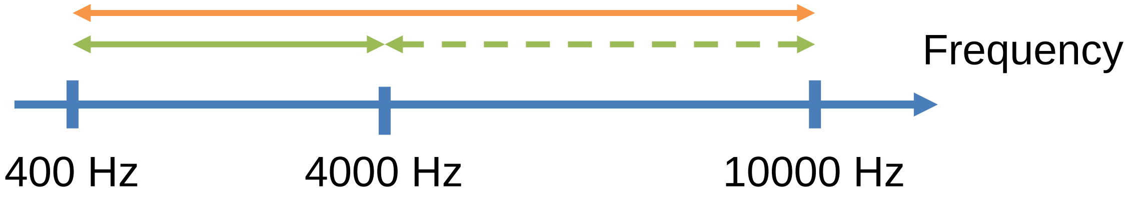


The absorption coefficient is deduced from geometrical parameters and reverberation times in the cabin with and without porous sample

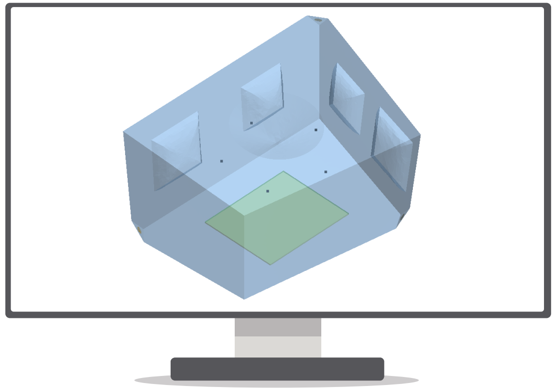
Modelling Alpha Cabins

From: https://www.autoneum.com/wp-content/uploads/2017/09/Alpha_Cabin_Flyer.pdf

- Existing studies:
  - **Finite Element method** gives accurate results in the mid-low frequency range
  - **Transfer Matrix Method** can be used up to 10 kHz, but comparison with experimental results is not good



Simulation can be used to:
- reduce the number of experiments
- re-use results in another simulation
- understand the physics

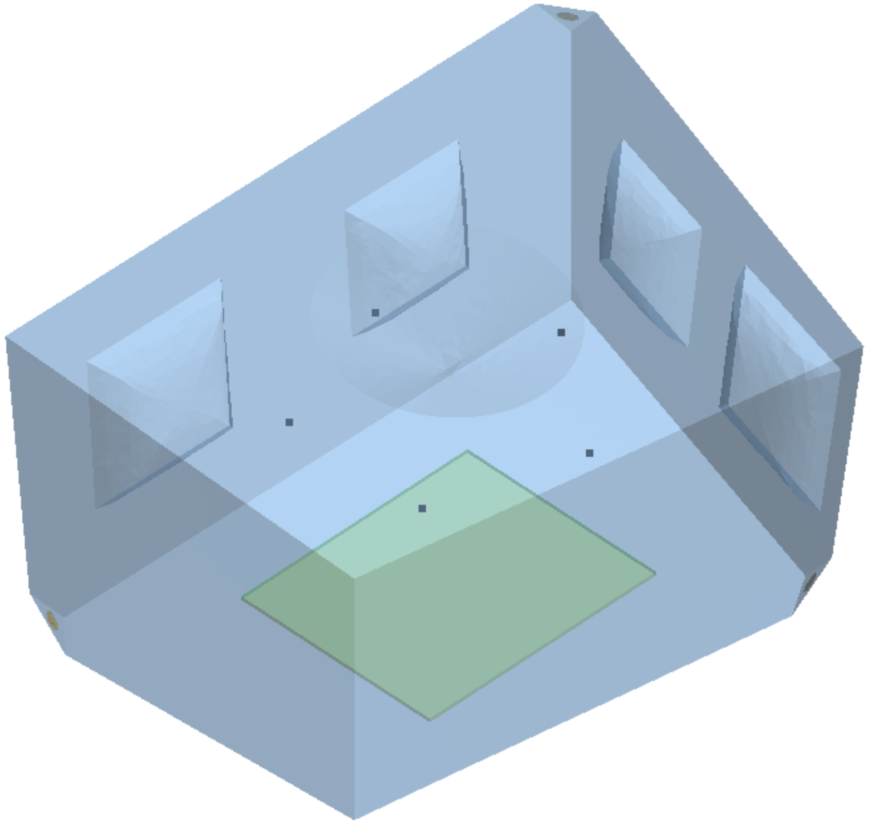


Is it possible to retrieve absorption coefficient results from 400 Hz to 10 kHz with Finite Element simulation?

MODELLING ALPHA CABINS: CHALLENGES AND SOLUTIONS

Modelling Alpha cabins

- **Goal:** reproduce absorption coefficient results with simulation
- To do so, we setup a model using the **Finite Element method**
- **Actran** acoustic simulation software suite is used
- Study takes place in **frequency domain:**
  - Frequency range from 400 Hz up to 10 kHz



Challenge 1: Frequency resolution

The challenge

- Time domain response is evaluated from an analysis in frequency domain

Length of the time response

$$T_{max} = \frac{1}{\Delta f}$$

Frequency step

- The reverberation time in a bare alpha cabin is about 2.5 s

We need a 0.4 Hz frequency step

Solution: Energetical approach

- We can express reverberation time as:

Energy contained in the cabin

$$RT_{60} = -\frac{E(0)}{P(0)}\ln(10^6)$$

Dissipated power in the cabin

- No Fourier transform is needed: no need of a small frequency step

If we compute RT_{60} from energetical quantities, we do not need a 0.4 Hz frequency step

Challenge 2: Model size

The challenge

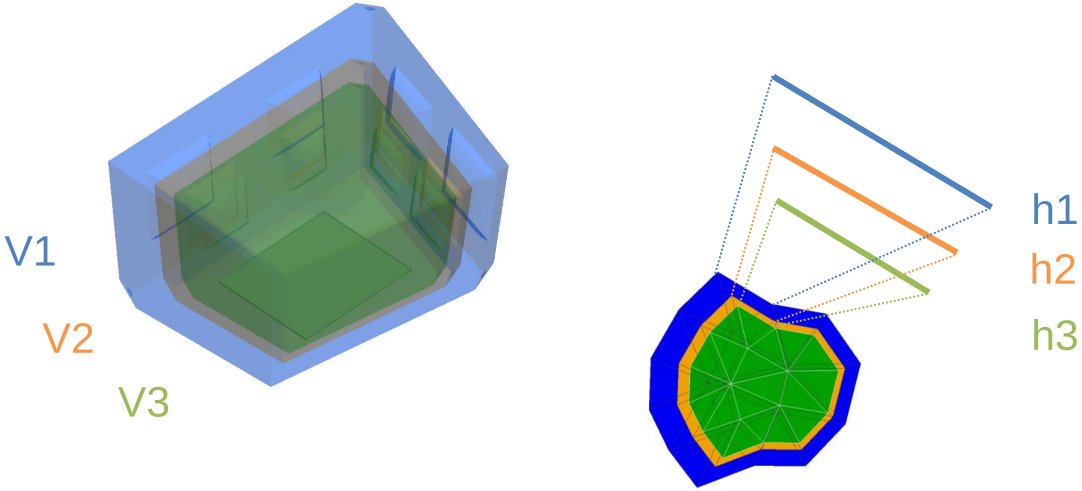
- To reach high frequencies, the cabin mesh needs to be sufficiently refined

- Common advice: at least 8 linear elements per wavelength → at 10 kHz element size should be 4 mm

Meshing the cabin (6.5 m³) with 4 mm elements would lead to ~100,000,000 degrees of freedom

Solution: Energetical approach with scaling

- Scaling the cabin volume reduces the element size without adding degrees of freedom



In the scaled cabin the mesh is refined, we can study higher frequencies

Challenge 3: Diffuse sound field

The challenge

- Energetical approach is only valid if the energy repartition in the cabin is homogeneous

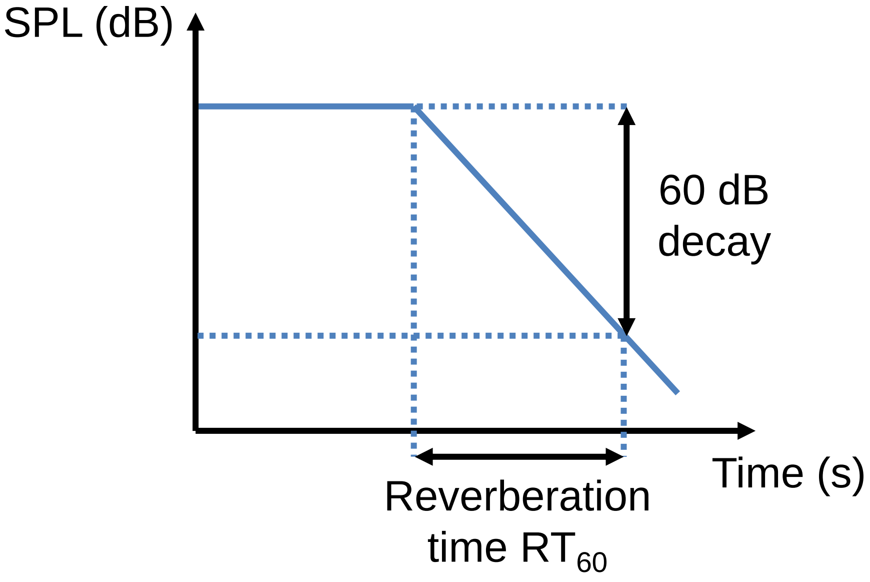
- Below Schroeder frequency sound field in the cabin cannot be considered as diffuse

$f_{Sch} \approx 2000 \left(\frac{RT_{60}}{V}\right)^{1/2}$ in an alpha-cabin $f_{Sch} \approx 1250\ Hz$

We cannot use the energetical approach at low frequencies

Solution: Standard approach and experimental post-processing

- At low frequencies, RT_{60} is computed as in the experiments from microphones time domain response



Summary

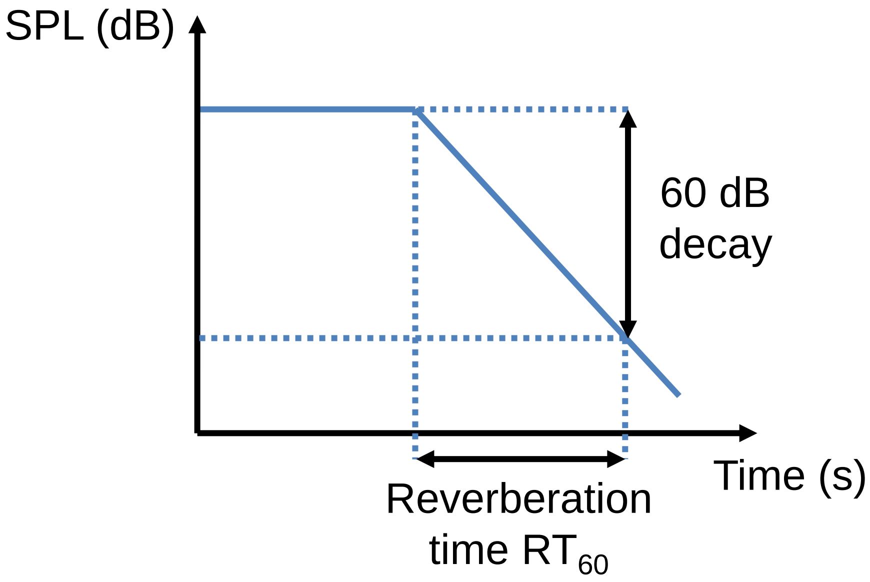
	Standard approach and experimental post-processing	Energetical approach	Energetical approach with scaling
Frequency range	Low frequencies	f_{Sch} Mid-range frequencies	High frequencies
	400 Hz	~1200 Hz	~3000 Hz 10000 Hz
Frequency step	0.4 Hz	5 steps per third-octave	5 steps per third-octave
Model size	~ 700,000 dofs	~ 3,600,000 dofs	~ 3,600,000 dofs
Diffuse sound field	Not assumed	Assumed	Assumed

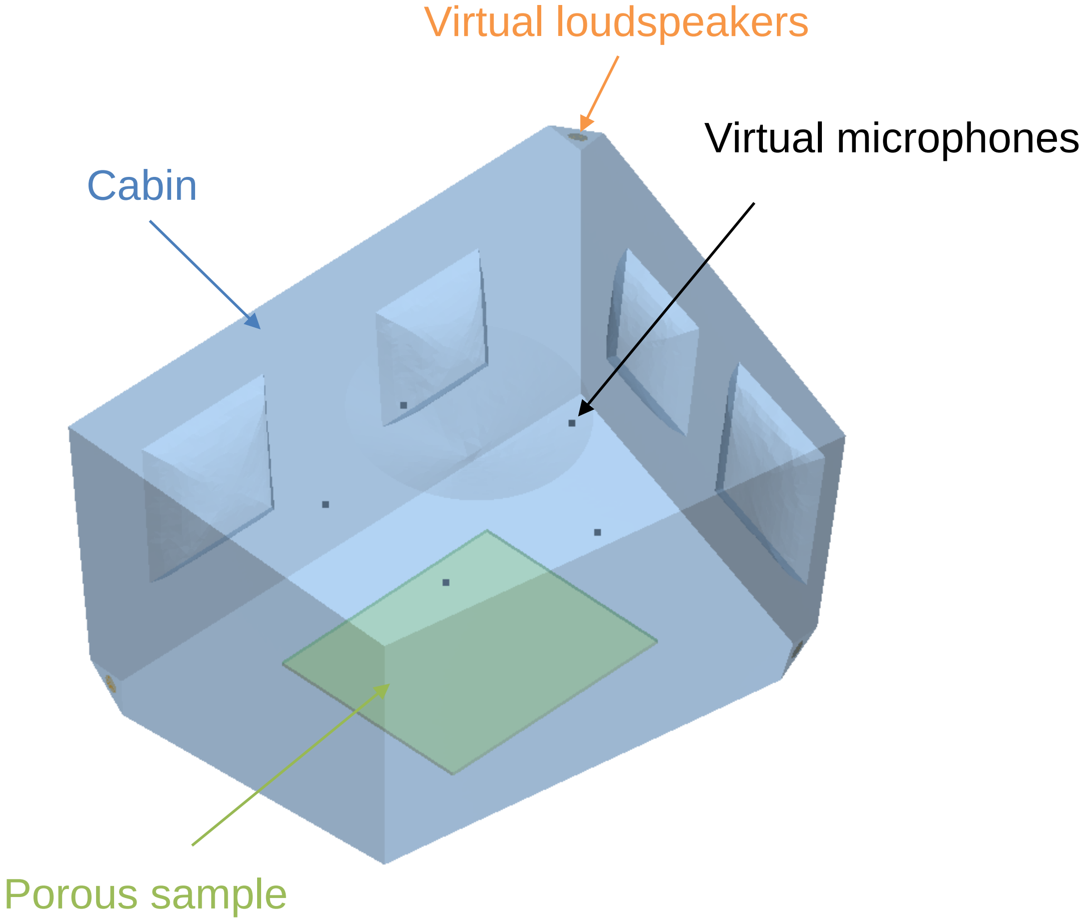
RESULTS

Low frequencies

Standard approach and experimental post-processing

Reverberation time is computed from time domain response at microphones





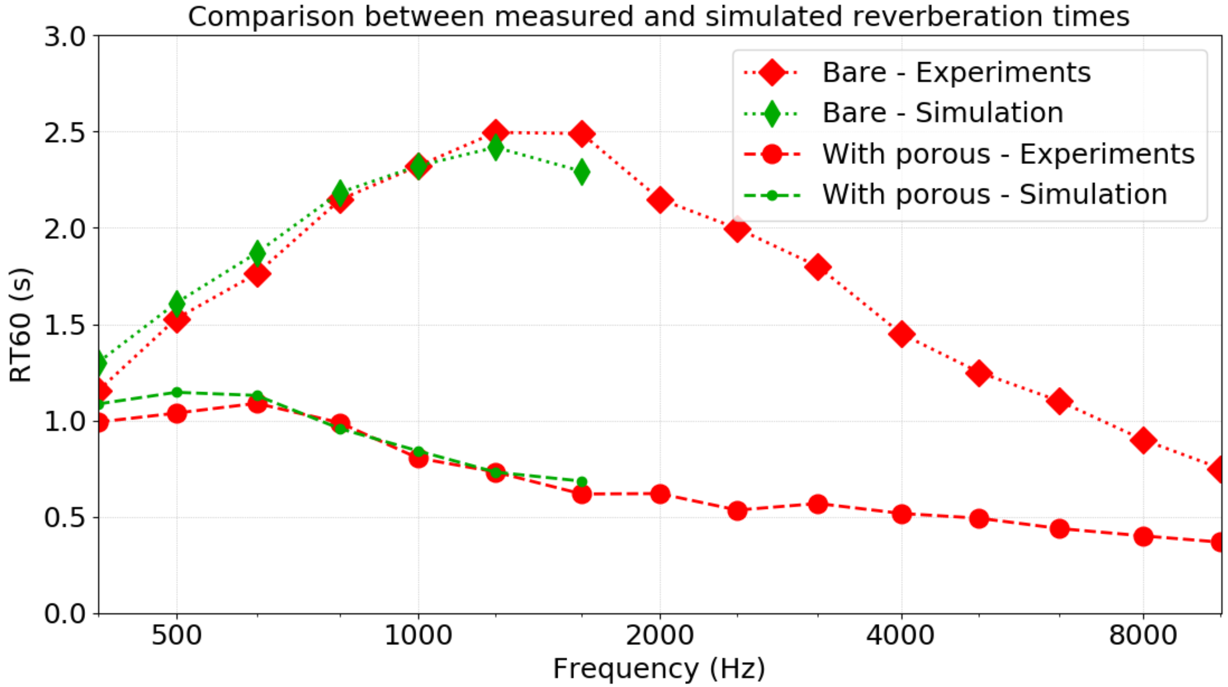
Studied porous sample

- Biot-Allard parameters:

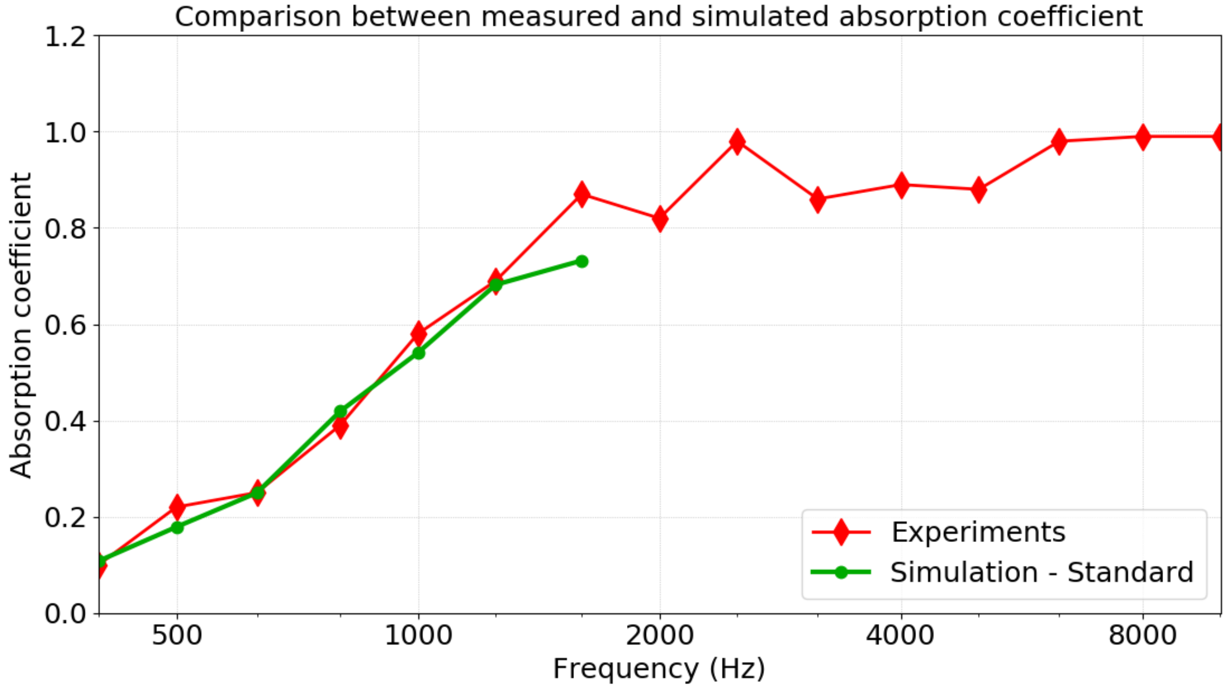
	Carpet felt 13 mm
Structural density [kg/m^3]	1480
Porosity [-]	0.944
Air-flow resistivity [Ns/m^4]	48600
Tortuosity [-]	1.16
Viscous char. Length [µm]	37.7
Thermal char. Length [µm]	134
Skeleton Young’s modulus [Pa]	32700
Skeleton Poisson’s ratio [-]	0.01
Skeleton loss factor [-]	0.173

- From: Bertolini C., Guj L. (2011). *Numerical Simulation of the Measurement of the Diffuse Field Absorption Coefficient in Small Reverberation Rooms*. SAE International

Results



Comparison between measured and simulated reverberation times
Bare - Experiments
Bare - Simulation
With porous - Experiments
With porous - Simulation
RT60 (s)
Frequency (Hz)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
500
1000
2000
4000
8000



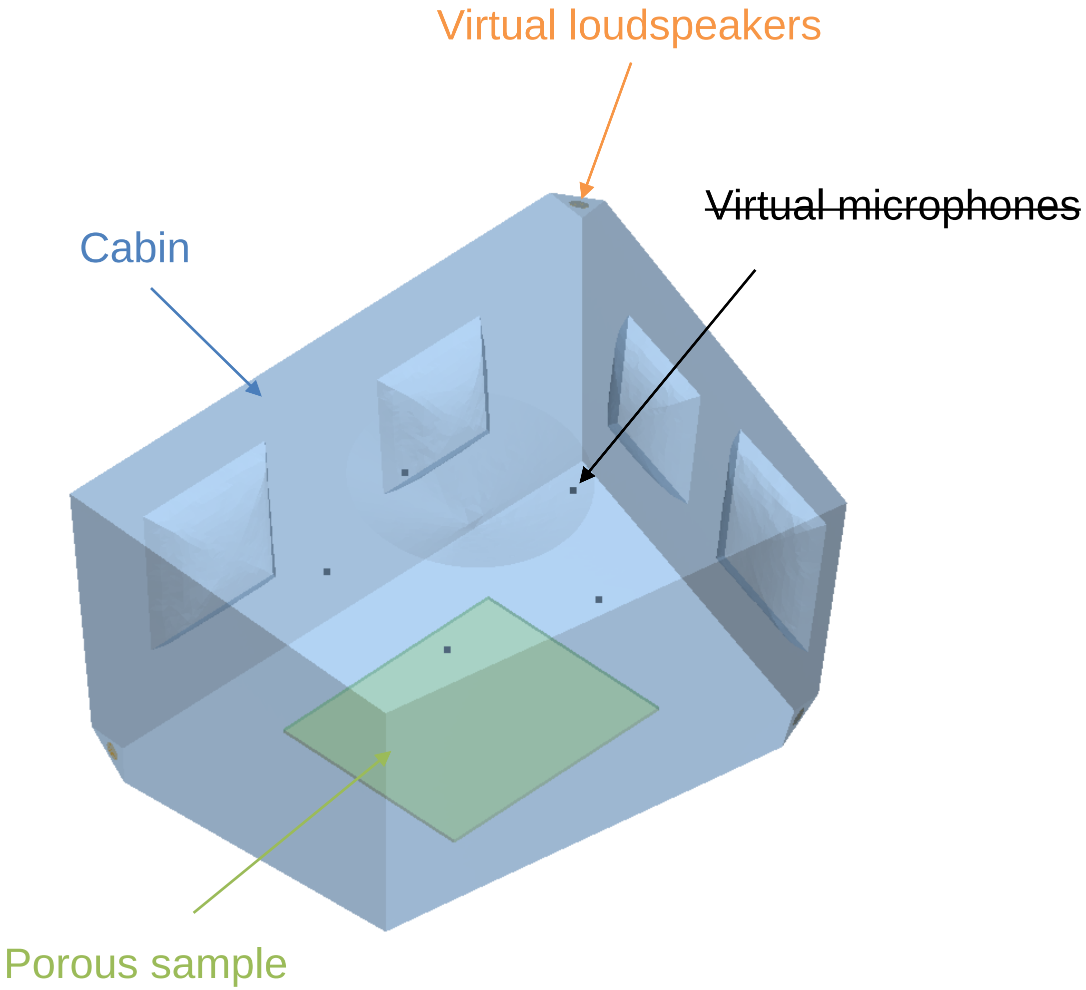
Comparison between measured and simulated absorption coefficient
Experiments
Simulation - Standard
Absorption coefficient
Frequency (Hz)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
500
1000
2000
4000
8000

Mid-range frequencies
Energetical approach

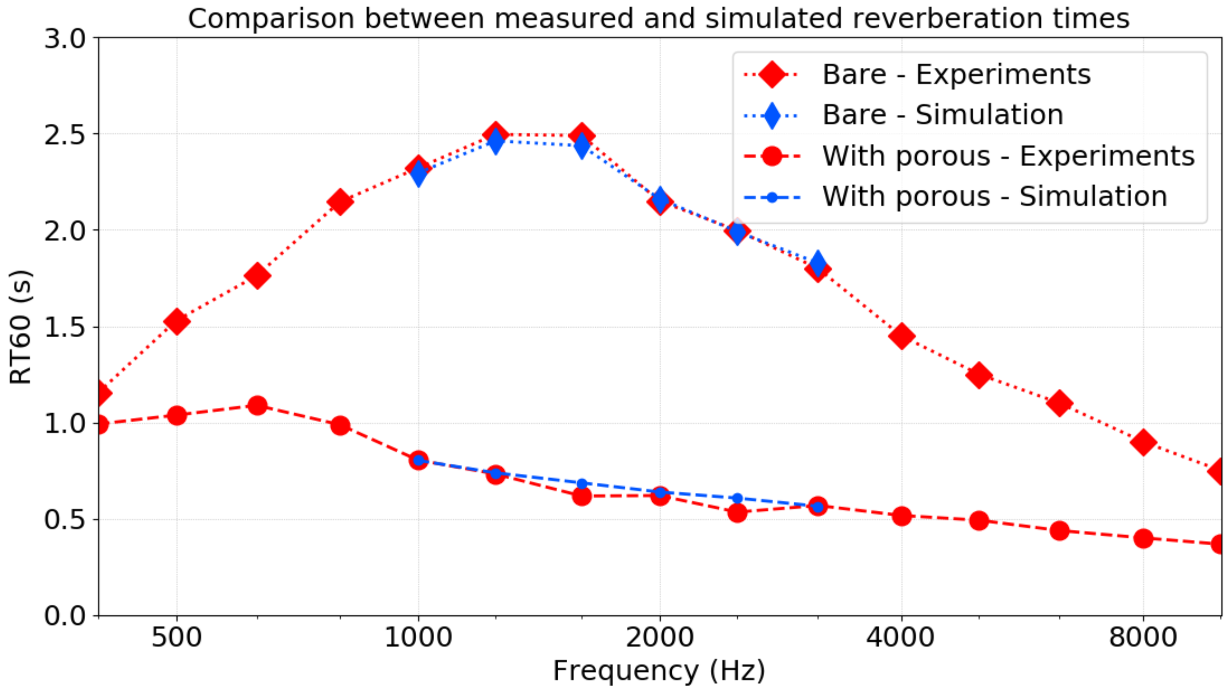
- With this approach RT_{60} is evaluated from energetical quantities:

$$RT_{60} = -\frac{E(0)}{P(0)}\ln(10^6)$$

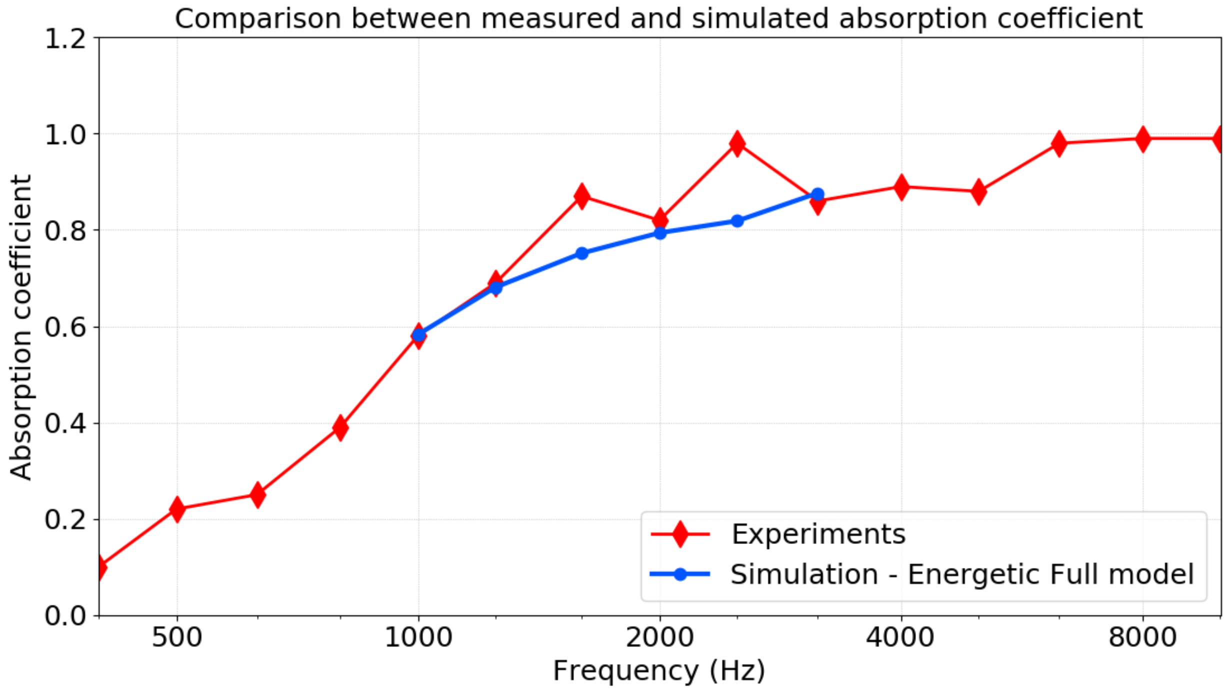
- The frequency step is not linked to RT_{60} anymore, it is increased in order to have 5 frequency steps per third-octave band



Results



Comparison between measured and simulated reverberation times
RT60 (s)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Bare - Experiments
Bare - Simulation
With porous - Experiments
With porous - Simulation
500
1000
2000
4000
8000
Frequency (Hz)

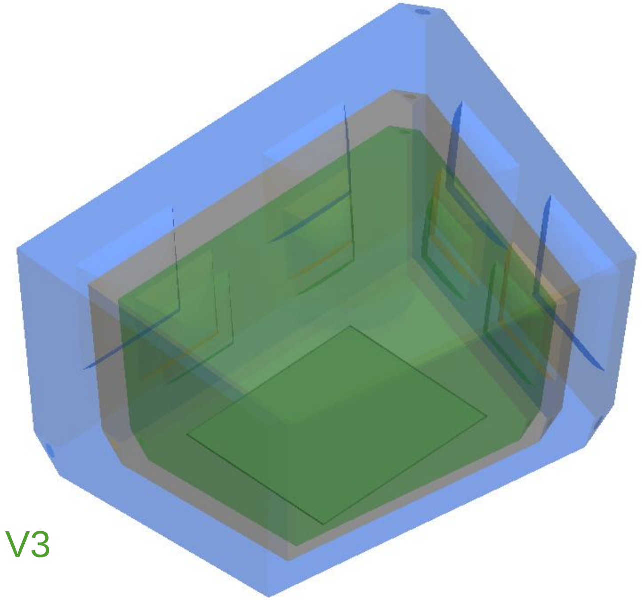


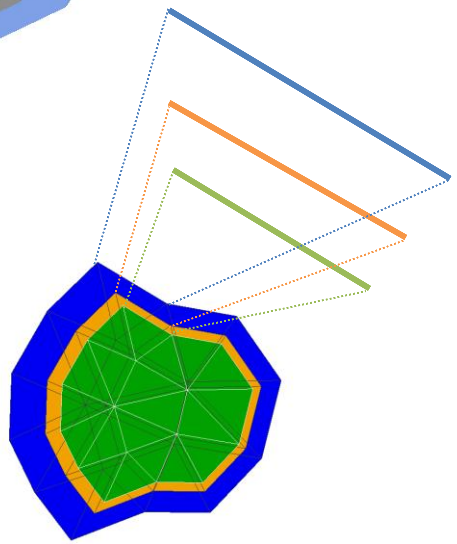
Comparison between measured and simulated absorption coefficient
Absorption coefficient
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Experiments
Simulation - Energetic Full model
500
1000
2000
4000
8000
Frequency (Hz)

High frequencies

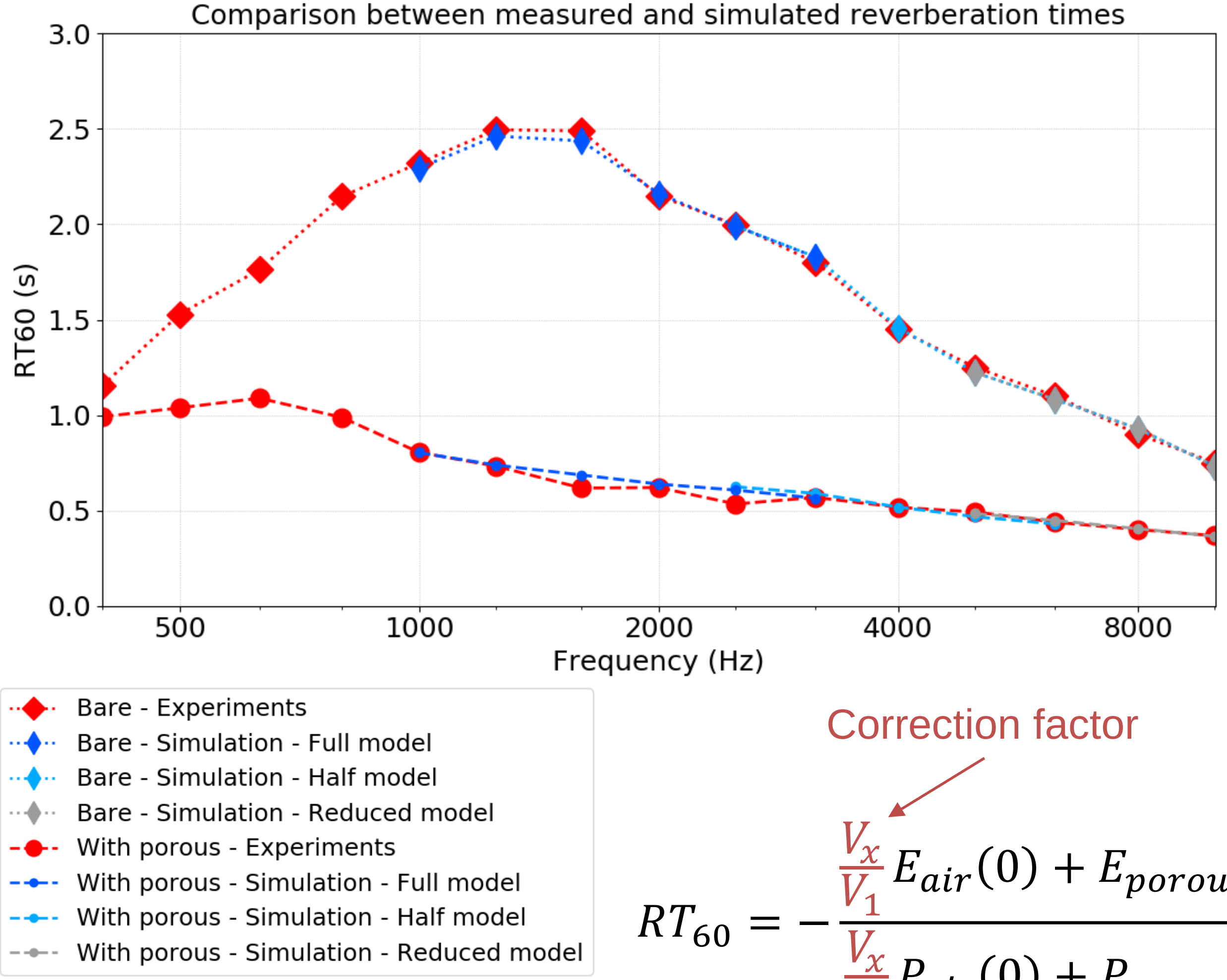
Energetical approach with scaling

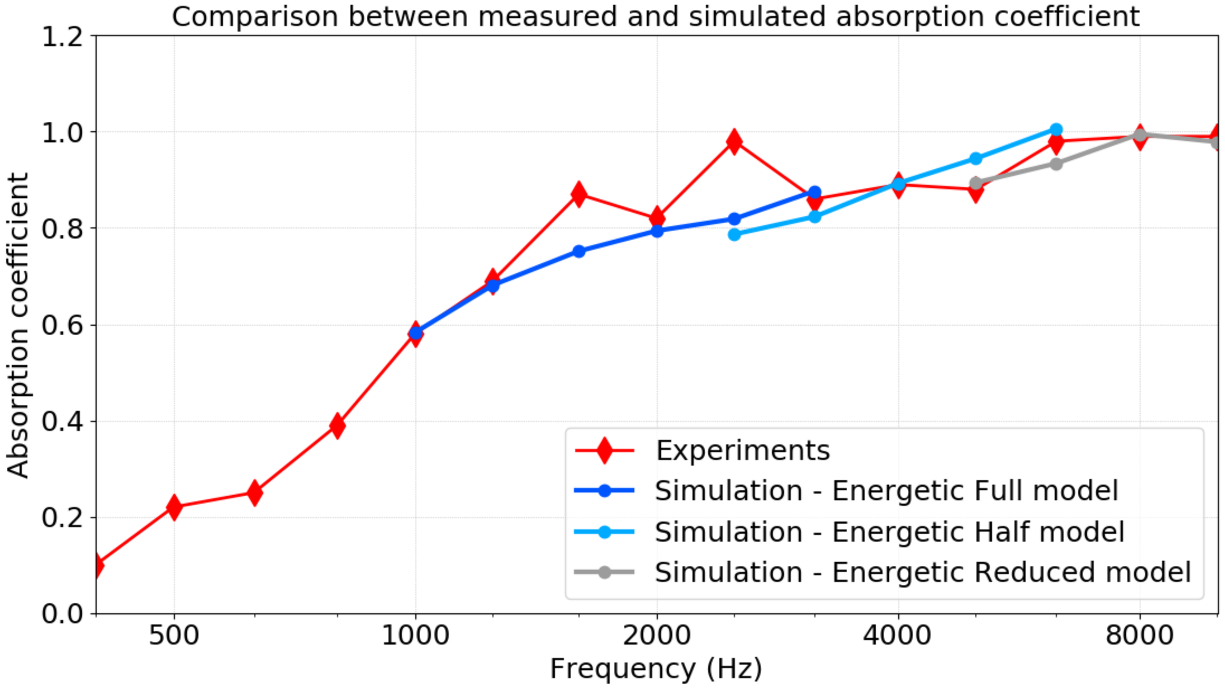
- To reach high frequencies we scale the previous model
- Only the cavity is scaled, not the porous sample
- Two new configurations are added:
  - Half model: $V2 = \frac{V1}{2}$
  - Reduced model: $V3 = \frac{V1}{(\sqrt{2})^3} = \frac{V1}{2.82}$





Results (with correction)

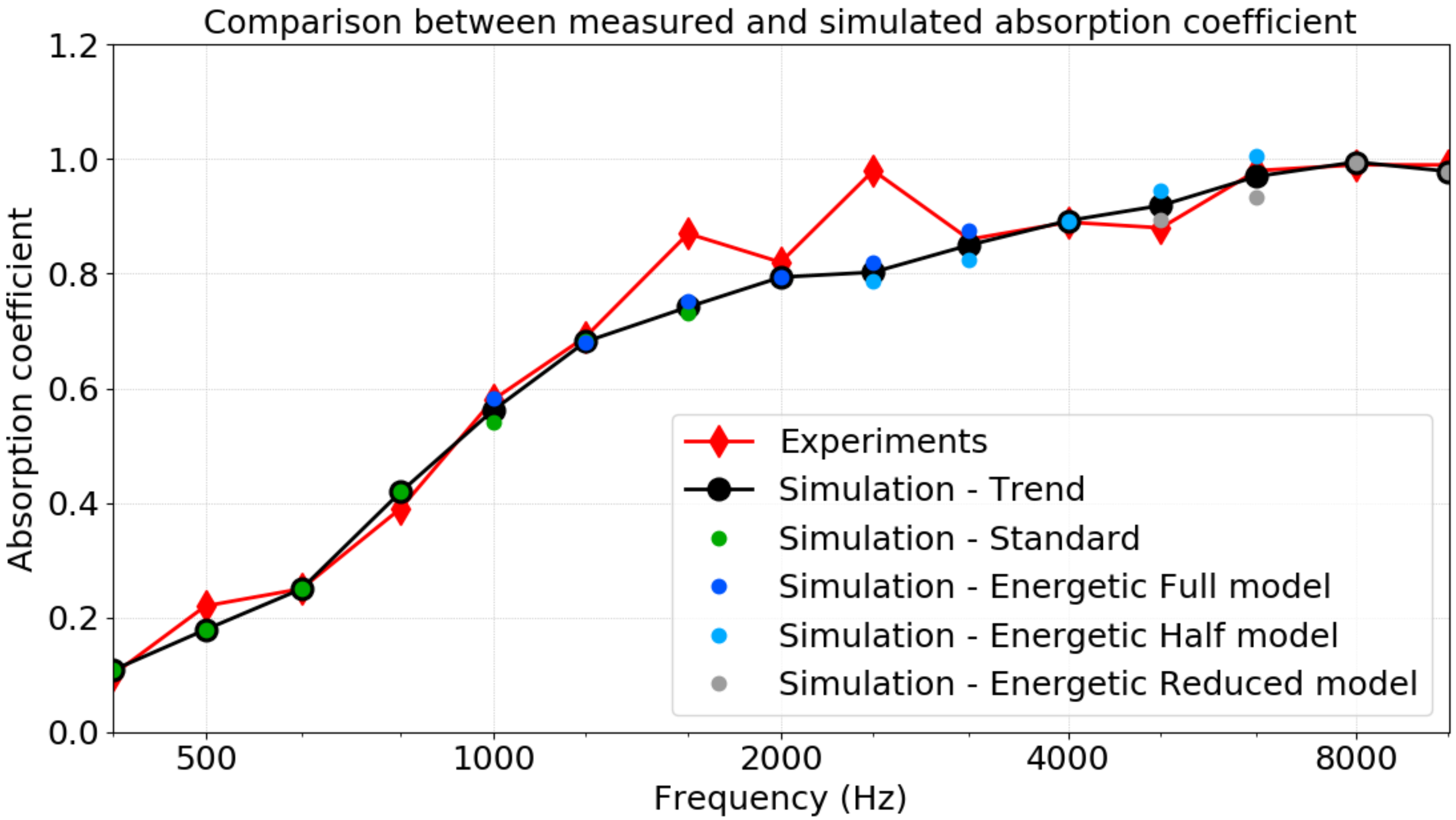




Correction factor

$$RT_{60} = -\frac{\frac{V_x}{V_1} E_{air}(0) + E_{porous}(0)}{\frac{V_x}{V_1} P_{air}(0) + P_{porous}(0)} \ln(10^6)$$

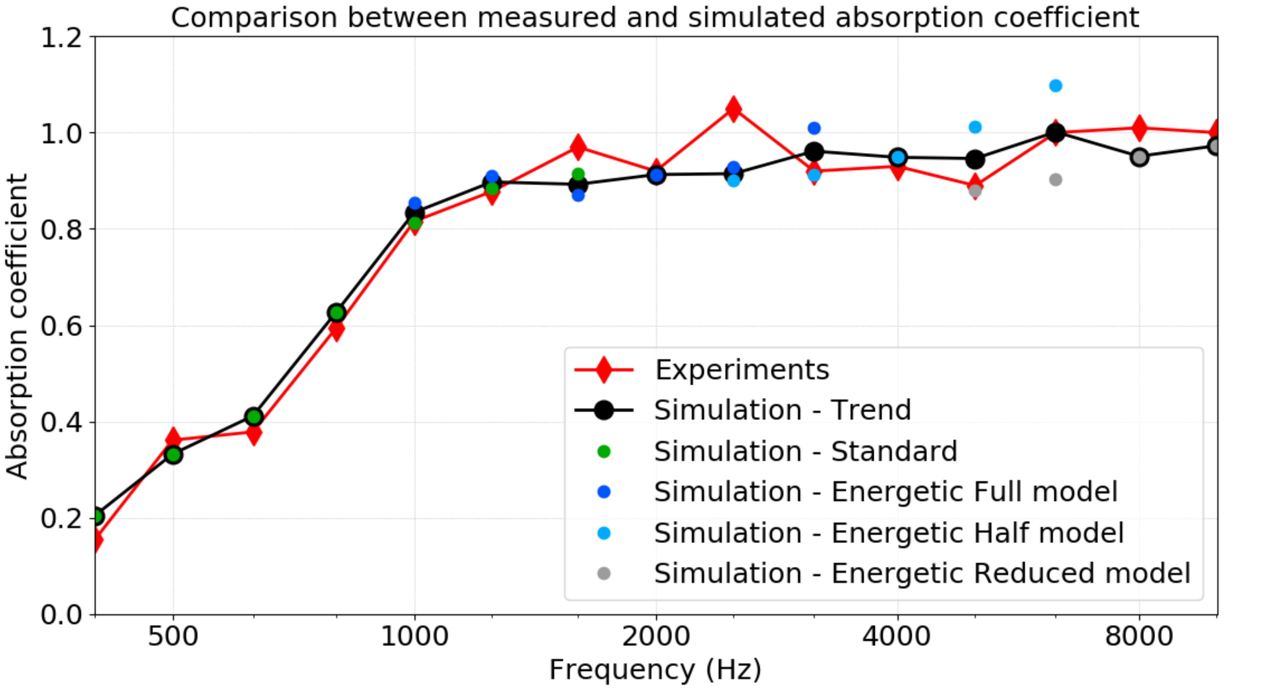
Results on the whole frequency range



Full results with another porous sample

	Carpet felt 20 mm
Structural density [kg/m³]	1471
Porosity [-]	0.9584
Air-flow resistivity [Ns/m⁴]	27700
Tortuosity [-]	1.14
Viscous char. Length [µm]	51.7
Thermal char. Length [µm]	168
Skeleton Young’s modulus [Pa]	22950
Skeleton Poisson’s ratio [-]	0.01
Skeleton loss factor [-]	0.179

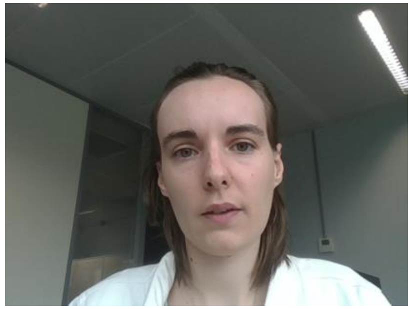
From: Bertolini C., Guj L. (2011). *Numerical Simulation of the Measurement of the Diffuse Field Absorption Coefficient in Small Reverberation Rooms*. SAE International



Computational needs

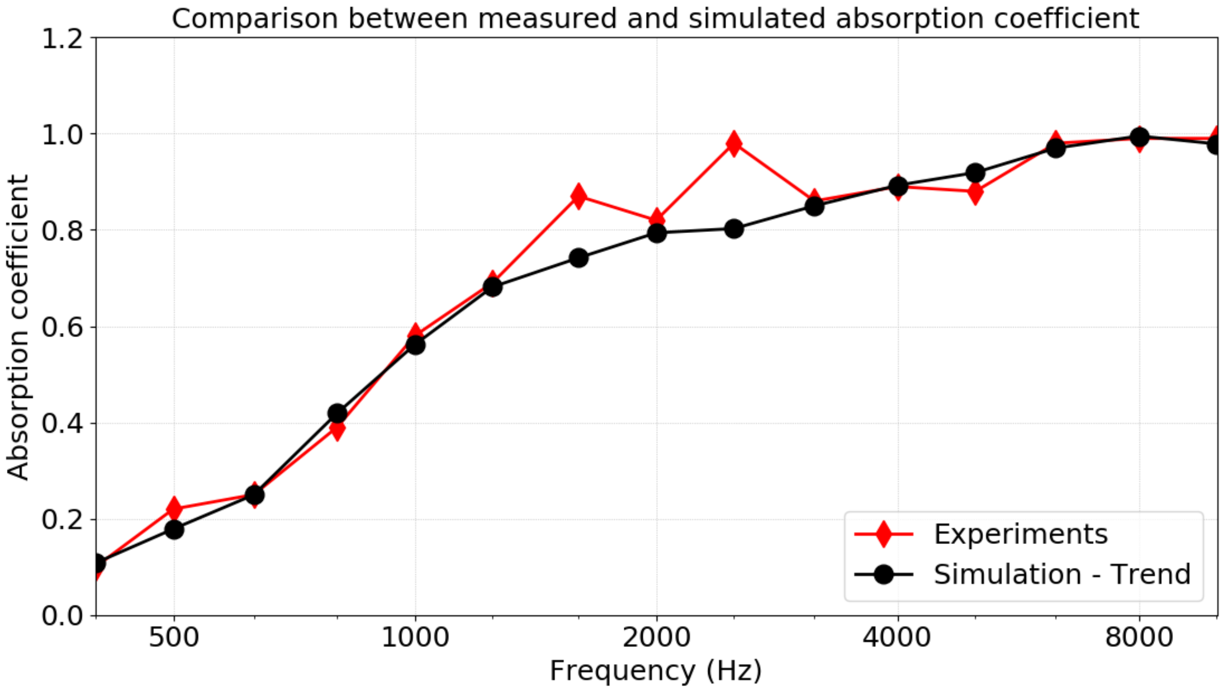
	Standard approach and experimental post-processing	Energetical approach	Energetical approach with scaling
Number of process	24	4	
Memory needs (RAM)	170 GB	360 GB	
Computational time	**5 h**	**1 h 30**	

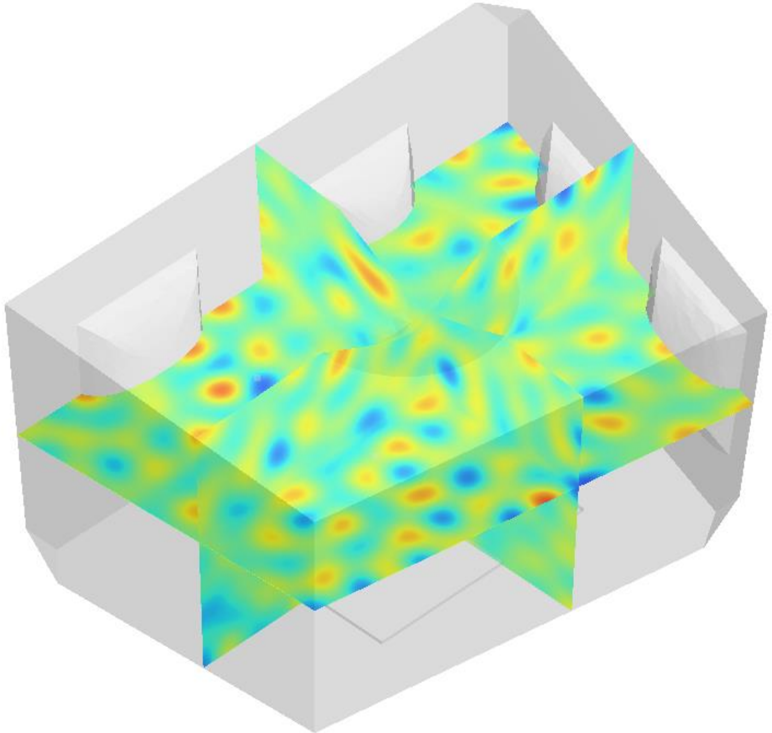
In 1 working day, we can perform the whole simulation



Conclusion

- **Goal:** reproduce absorption coefficient results with simulation
- Computational challenges overcome with a **three-step procedure**
- Enables to get absorption coefficient with simulation from 400 Hz to 10 kHz
- Good correlation with experimental results
- Whole Alpha cabin simulation in 1 working day





For questions, please contact:

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APPENDIX

References

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