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Predicting a room sound field to derive speech intelligibility criteria.

Application to Deutsche Bahn test train cabin.

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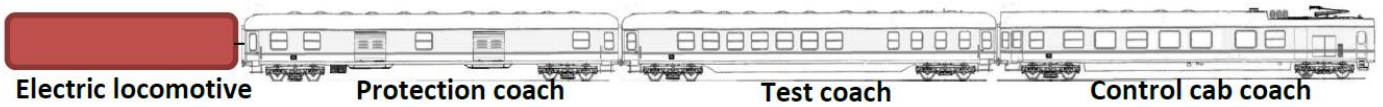
Introduction

- Phase 1 / Preliminary assessment:
  - Measurements of pressure and STIPA values in the train cabin.
    Driven by Céline Bacquet, for Master thesis.
  - Initial train cabin modeling and BEM computation.
    Driven by Kamel Amichi, for ESI Gmbh.



Outside view (top) and drawing (bottom) of the train used for testing.

Introduction

- Phase 2 / Simulation improvement:

  Objectives:

  - Improvement of pressure results accuracy.
  - Assessment of the influence of details in the cabin.

- Phase 3 / Simulation for Speech Transmission Index (STI) results.

Inside views of the train cabin.

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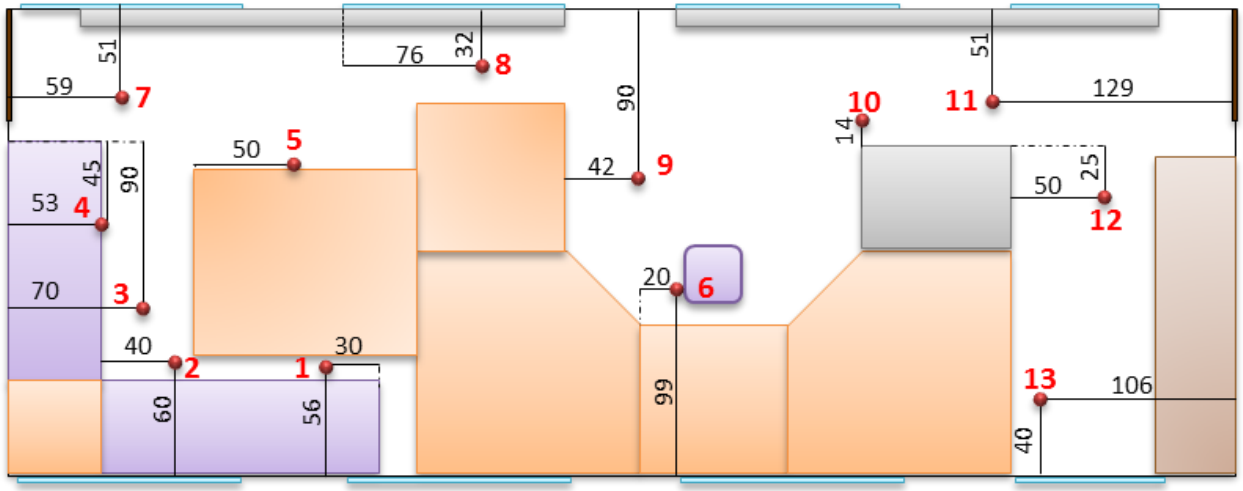
Measurements
Microphones distribution

- 13 microphones distributed in the cabin.
- Pressure and STIPA values recovered at each microphone.
- Microphones heights respect listeners condition.

Position type	Microphones	Height (m)
Sitting	1 to 6	1.20
Standing	7 to 13	1.60



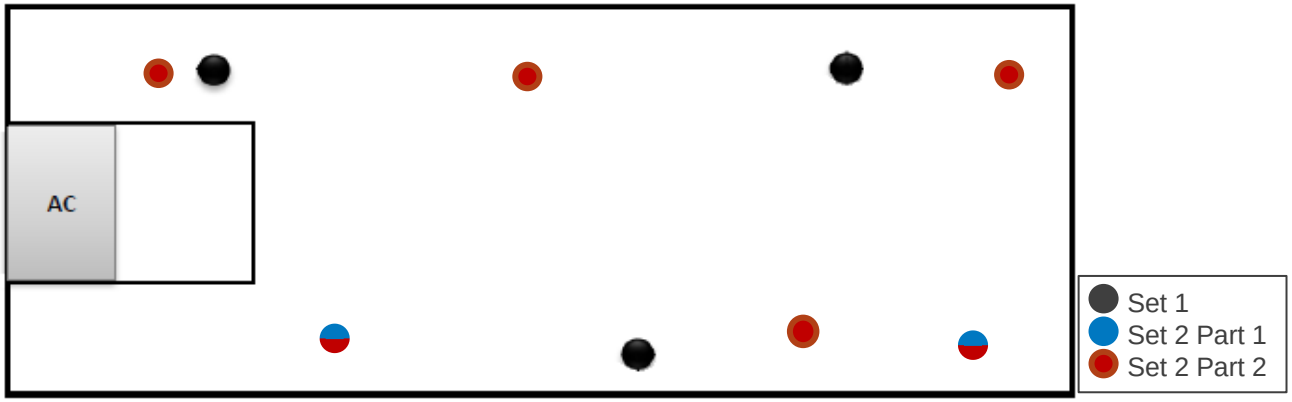
Drawing from top of the Train Cabin, with positions of the 13 microphones.

Measurements
Loudspeaker sets

- Three sets of loudspeakers (LSP) used for measurements.
- Possibility of muting LSP with Set 1.

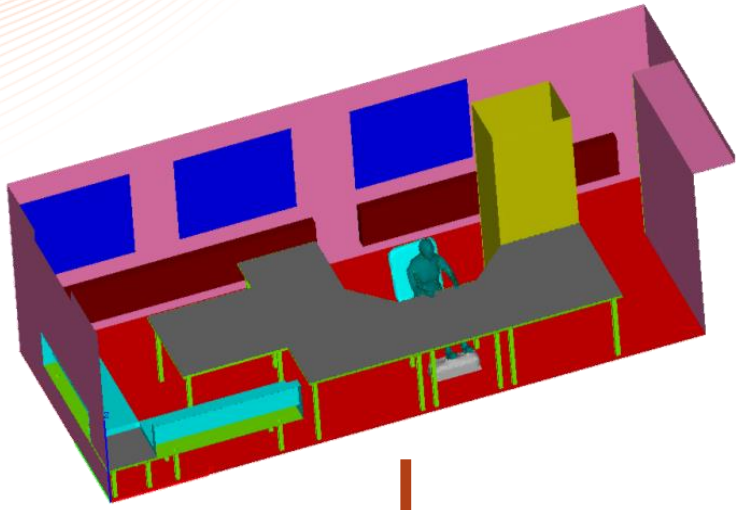
Configurations	LSP 1	LSP 2	LSP 3
1			
2			
3			
4			
5			
6			

Table showing six measurement configurations, depending on the activation of LSP (green is activated, red is muted).

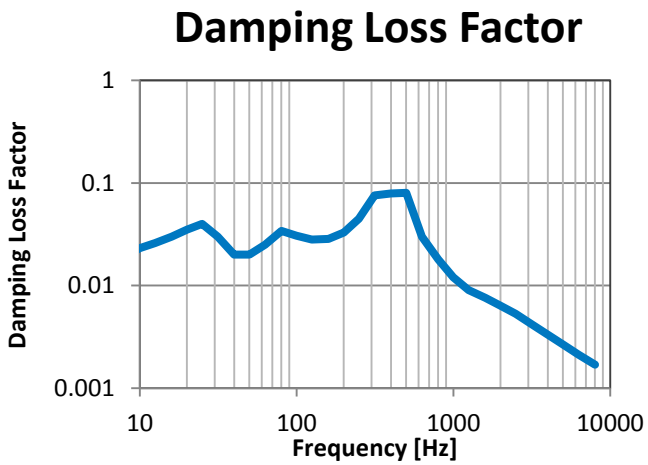


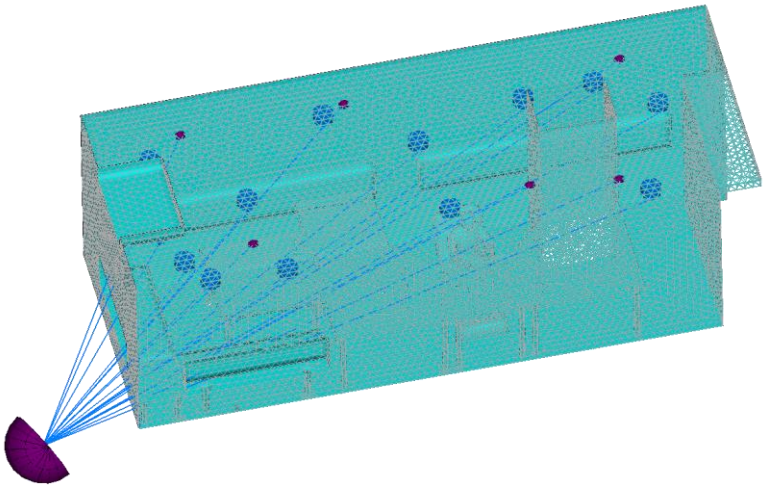
Drawing of different loudspeaker sets in the train cabin.

VA One initial simulation

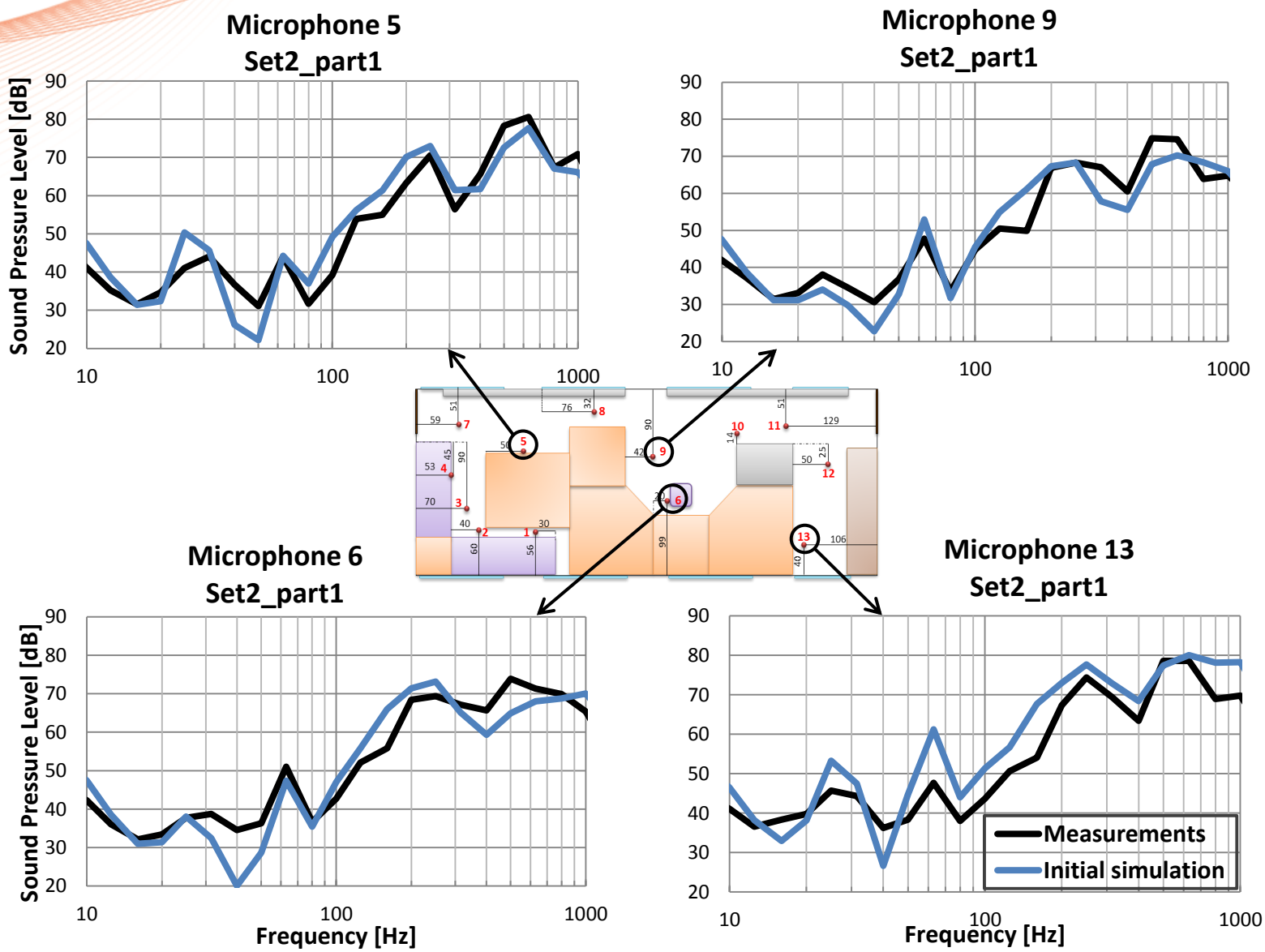


- SEA Model with surfaces absorption.
- Damping Loss Factor from SEA computation.
- BEM computation with Damping Loss Factor.
- Monopoles sources located 10 cm under real loudspeaker‘s locations.
- Pressure recovered on the 13 microphones.





Initial simulation results



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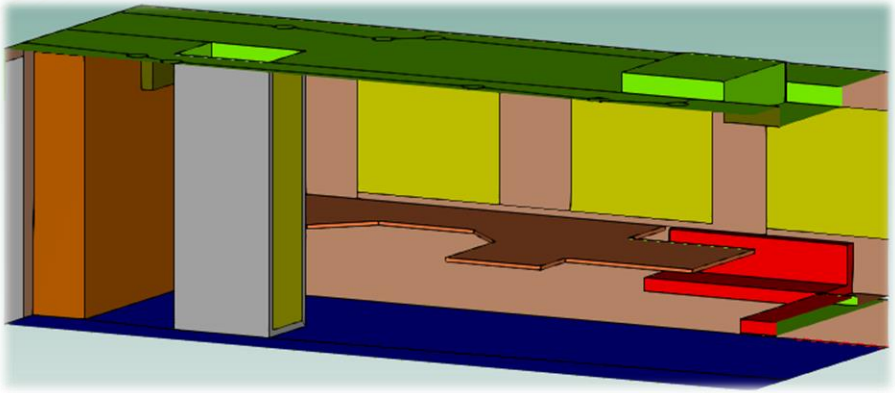
Objectives

- Improve accuracy of pressure results in the cabin.
- Assess the influence of details in the model.
- Compute STI simulation and compare with measurements.

Models creation

Simplified Model



Detailed Model

- Geometry improvement.
- Various details depending on the model.
- Precise research on absorption values corresponding to the Train Cabin surfaces.

Absorption Coefficients

Sabine absorption coefficient table – Deutsche Bahn Train Cabin								
Cabin Composition	Material Name	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	Reference
Ceiling	Plasterboard ceiling on battens with large air-space above	0,20	0,15	0,10	0,08	0,04	0,02	Lawrence: Architectural Acoustics
Floor	Carpet thin, cemented to concrete	0,02	0,04	0,08	0,20	0,35	0,40	L. L. Beranek and T. Hidaka, "Sound absorption in concert halls by seats, occupied and
Double Glazed Windows	Double glazing, 2–3 mm glass, >3 cm gap	0,15	0,05	0,03	0,03	0,02	0,02	C. Lynge, ODEON Room Acoustics Program, User Manual, DTU, Denmark (2001).
Back Seats*	Empty chairs, upholstered with cloth cover	0,44	0,60	0,77	0,89	0,82	0,70	'Beranek, L.L., 'Music, Acoustics and Architecture', John Wiley, 1962.
Operator's Chair	Seat fully occupied, medium upholstered	0,54	0,62	0,68	0,70	0,68	0,66	L. L. Beranek and T. Hidaka, "Sound absorption in concert halls by seats, occupied and
Operator	From equivalent absorption of a person - Area 1,12 m2	0,13	0,22	0,30	0,39	0,47	0,47	http://www.acoustique-materiaux.net/acoustique/reverberation.html
Plywood Furnitures*²	Plywood panelling, 1 cm thick	0,28	0,22	0,17	0,09	0,10	0,11	C. M. Harris (ed), Handbook of Noise Control, 2nd edn, McGraw-Hill (1991).
Ordinary Glass	Ordinary window glass	0,35	0,25	0,18	0,12	0,07	0,04	C. M. Harris (ed), Handbook of Noise Control, 2nd edn, McGraw-Hill (1991).
Curtains	Medium velour, draped to half Area	0,07	0,31	0,49	0,75	0,70	0,60	L. L. Beranek, Acoustics, McGraw-Hill (1954).
Plastic*³		0,02	0,02	0,03	0,03	0,03	0,03	
Metal**		0,01	0,01	0,01	0,01	0,01	0,01	

** Two couches in the corner, Chair's cushions.*

**² Table, Baffle, Back Seats Feet, Back Seats Table, Small Table, Furniture, Armory.*

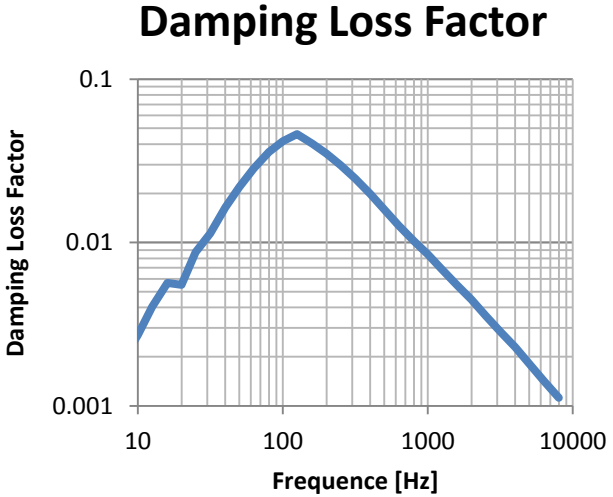
**³ Air Conditioner, Printer, Computer screens, Speed screens.*

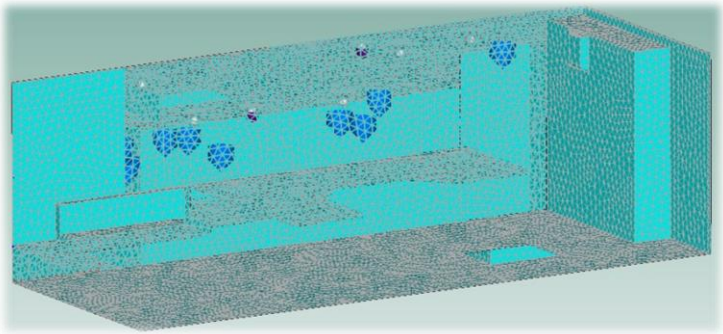
*** Radiator, Computer, Extinguisher, Column, Equalizer, Table's feet, Chair's feet.*

First Method

Acoustic Damping with monopole sources

- Same Method as Phase 1 study.
- All faces are considered rigid.
- Monopoles located 10 cm under real Loudspeaker‘s locations.
- Pressure recovered on the 13 microphones.

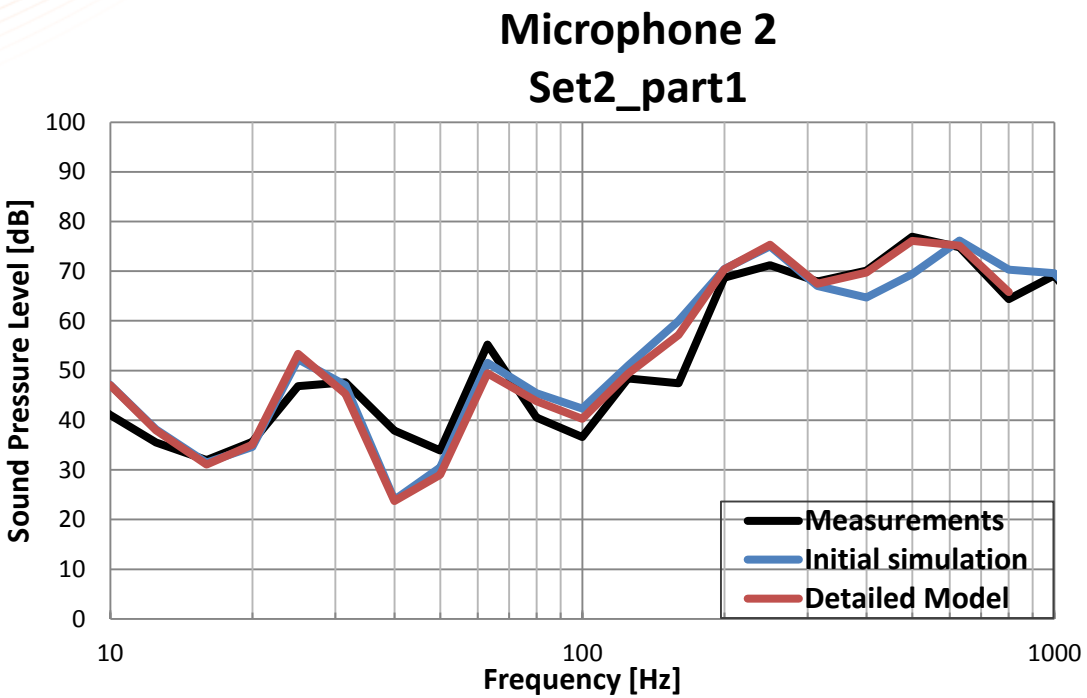




First Method

Comparison New / Initial simulation

Acoustic Damping with monopole sources



→ **Better accuracy on the pressure results: 16.4% improvement.**

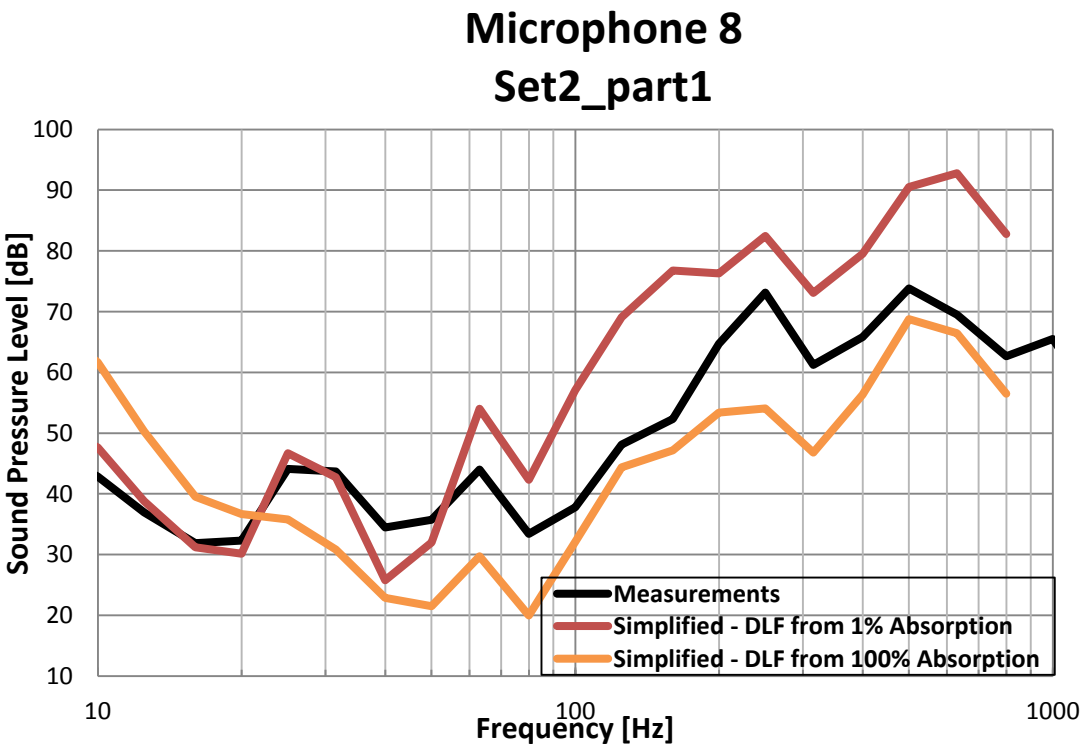
Models	Configuration	Global Error indicator*	% Improvement**
Initial simulation	Set2 Part1	1382	
Simplified	Set2 Part1	1225	11,4%
Detailed	Set2 Part1	1156	16,4%

**Sum of the absolute dB difference between measurement and simulation pressure values, for 13 microphones and 21 frequencies (273 values).*
***100% of improvement would mean that pressure results from simulation fit perfectly with the measurement datas.*

First Method

Comparison 100% / 1% absorption in the cabin

Acoustic Damping with monopole sources



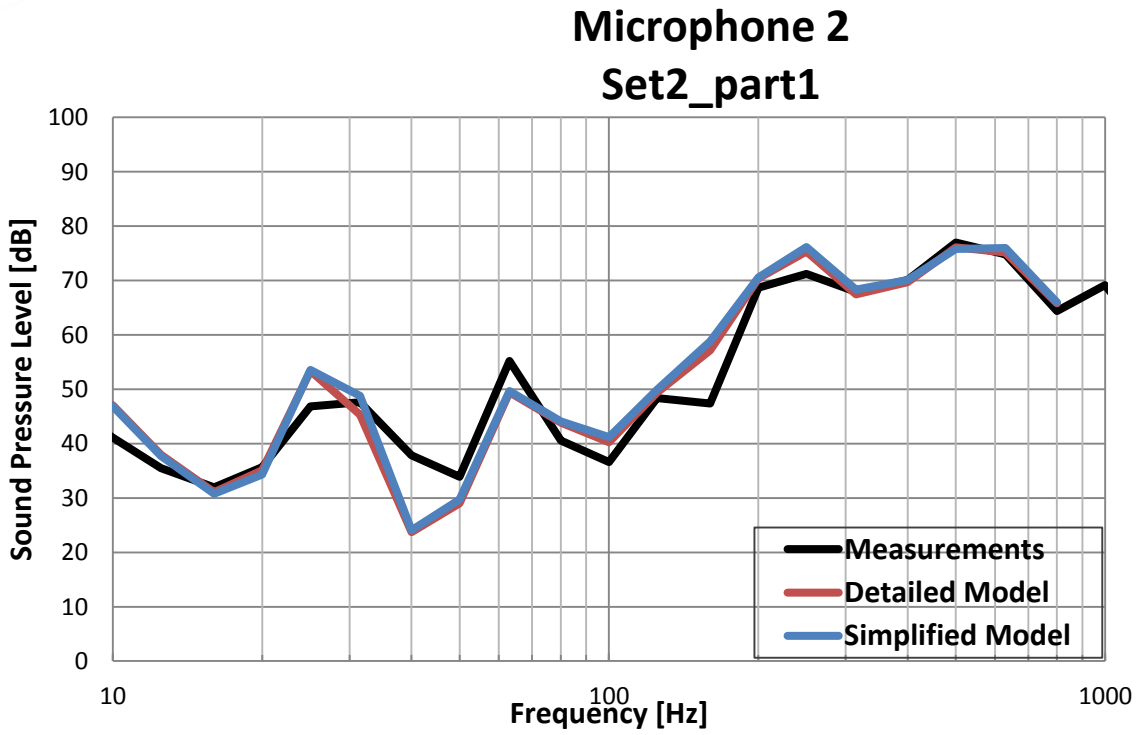
→ F<60 Hz, the model is not reliable.

→ F>60 Hz, the model can agree with measurements by defining a damping.

First Method

Comparison Simplified/Detailed model

Acoustic Damping with monopole sources

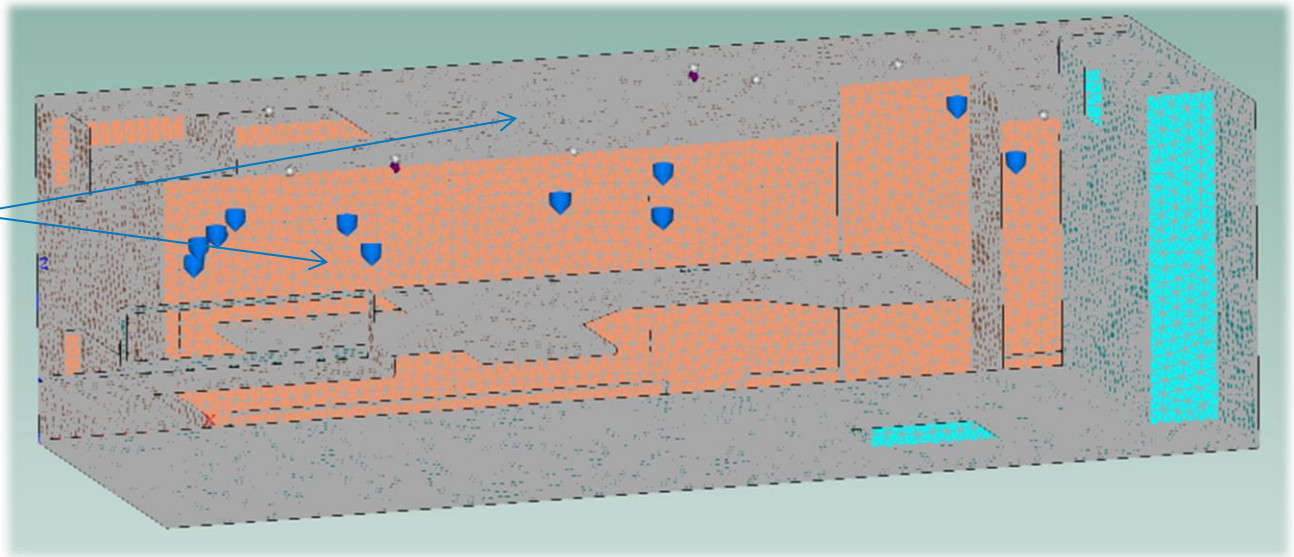


→ **Low influence of the detailed objects on the pressure results, f < 1000Hz.**

Second Method
Process

Area Isolators with monopole sources

- Transfer from absorption to Area Impedance spectrums.
- No Damping in the Air.
- Acoustic ernergy is damped only in contact with the surfaces.
- Monopoles located 10 cm under real loudspeaker‘s locations.



Second Method
Process

- From Delany-Bazley formulas:

$$\alpha = 1 - |R|^2$$ and $$R = \frac{Z - \frac{Z_c}{\cos(\theta)}}{Z + \frac{Z_c}{\cos(\theta)}}$$

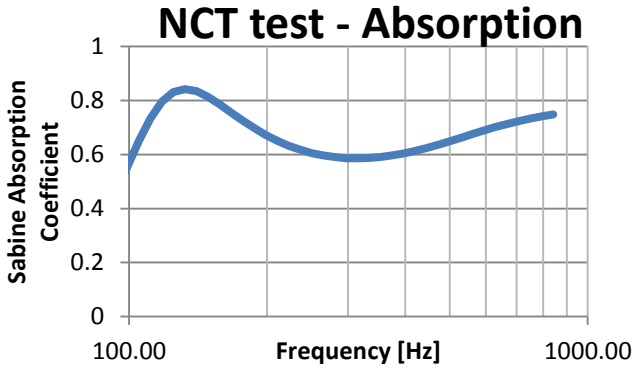
- Which leads, by neglecting the imaginary part of impedance:

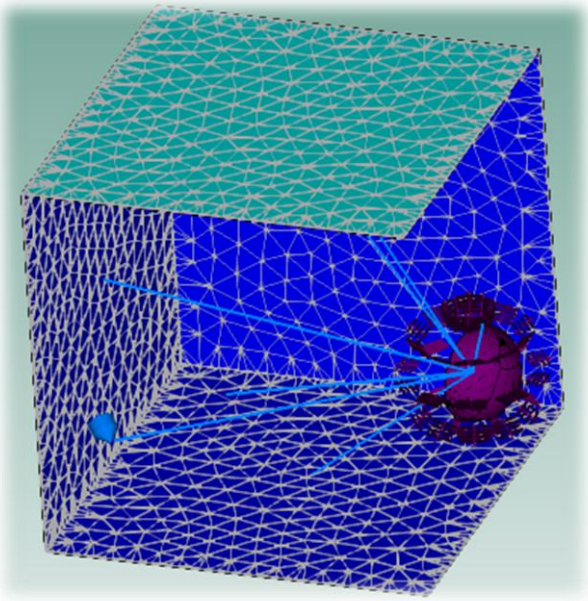
$$Z = \frac{Z_c * (2 - \alpha + 2 * \sqrt{1 - \alpha})}{\alpha}$$

Second Method

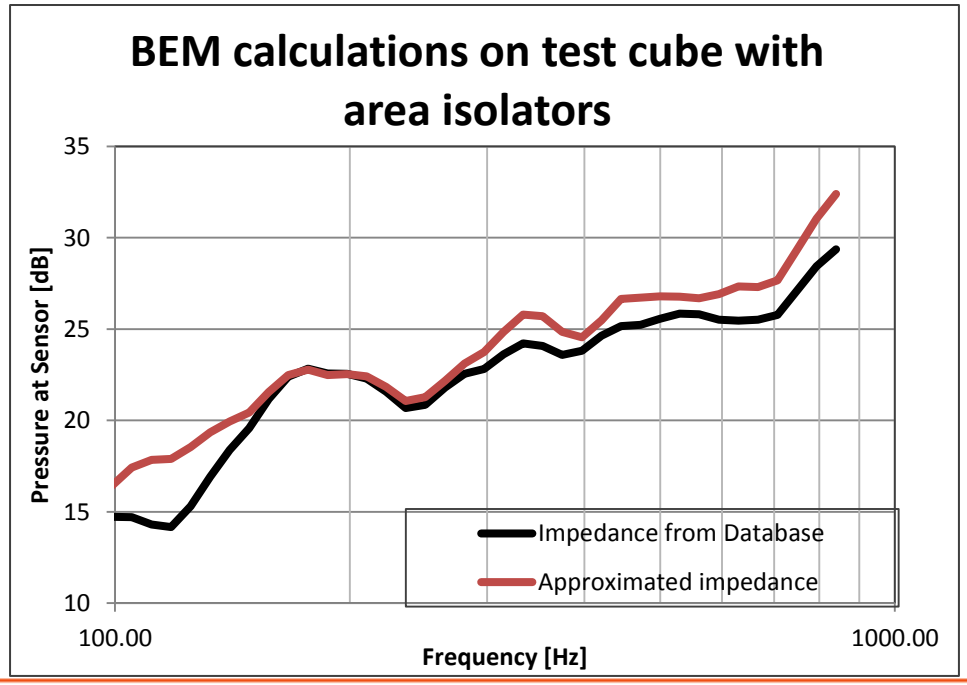
Validation test with fiber

- Test cube of $1\mathrm{m}^3$, all rigid faces.
- Diffuse Acoustic Field source.
- Impedance applied on surfaces (from VA One Database compared to Theory approximation)
- Pressure recovered at sensor.

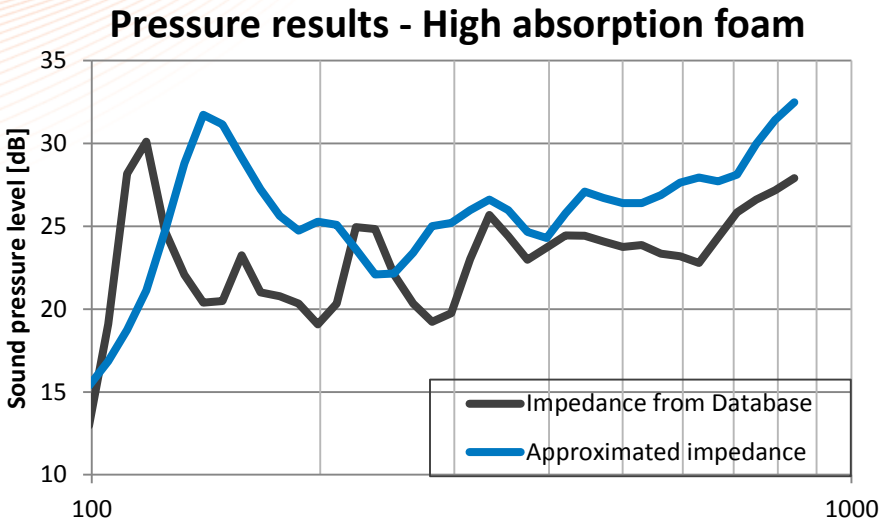


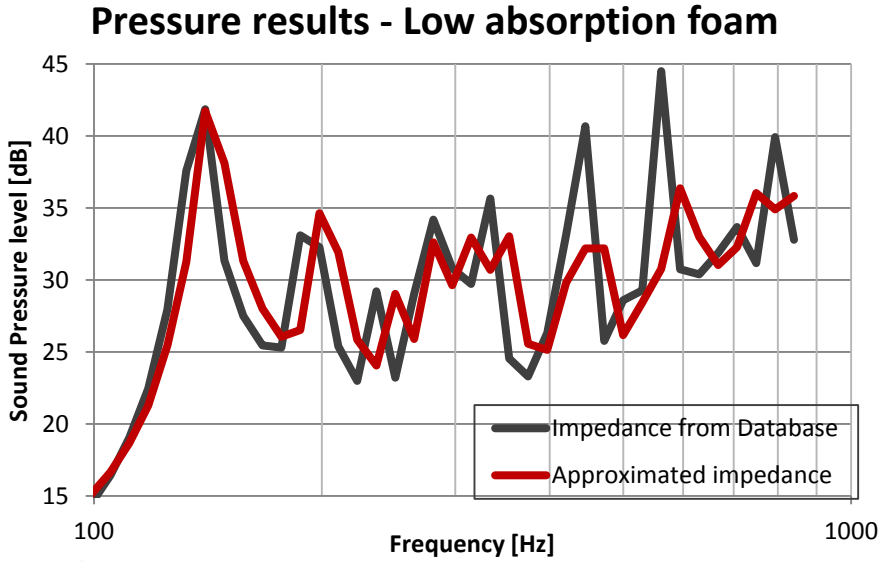


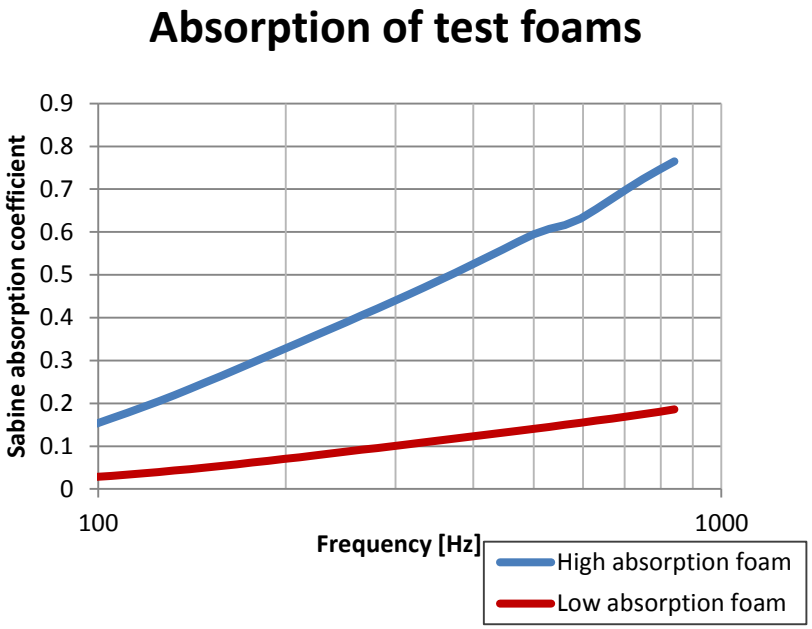
Screenshot of test cube



Second Method
Validation test with foam



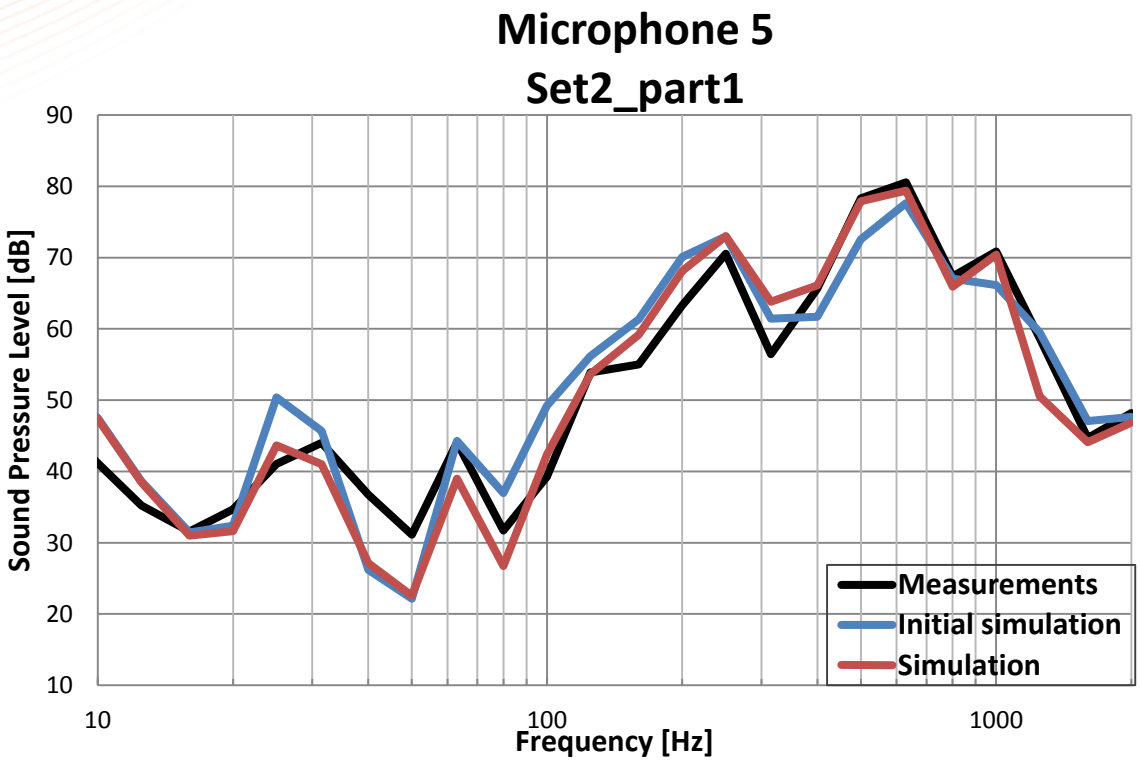




- Agreement of the results depending on properties of materials.
- Method to be applied with caution.

Second Method
Application to the cabin

Area Isolators with monopole sources



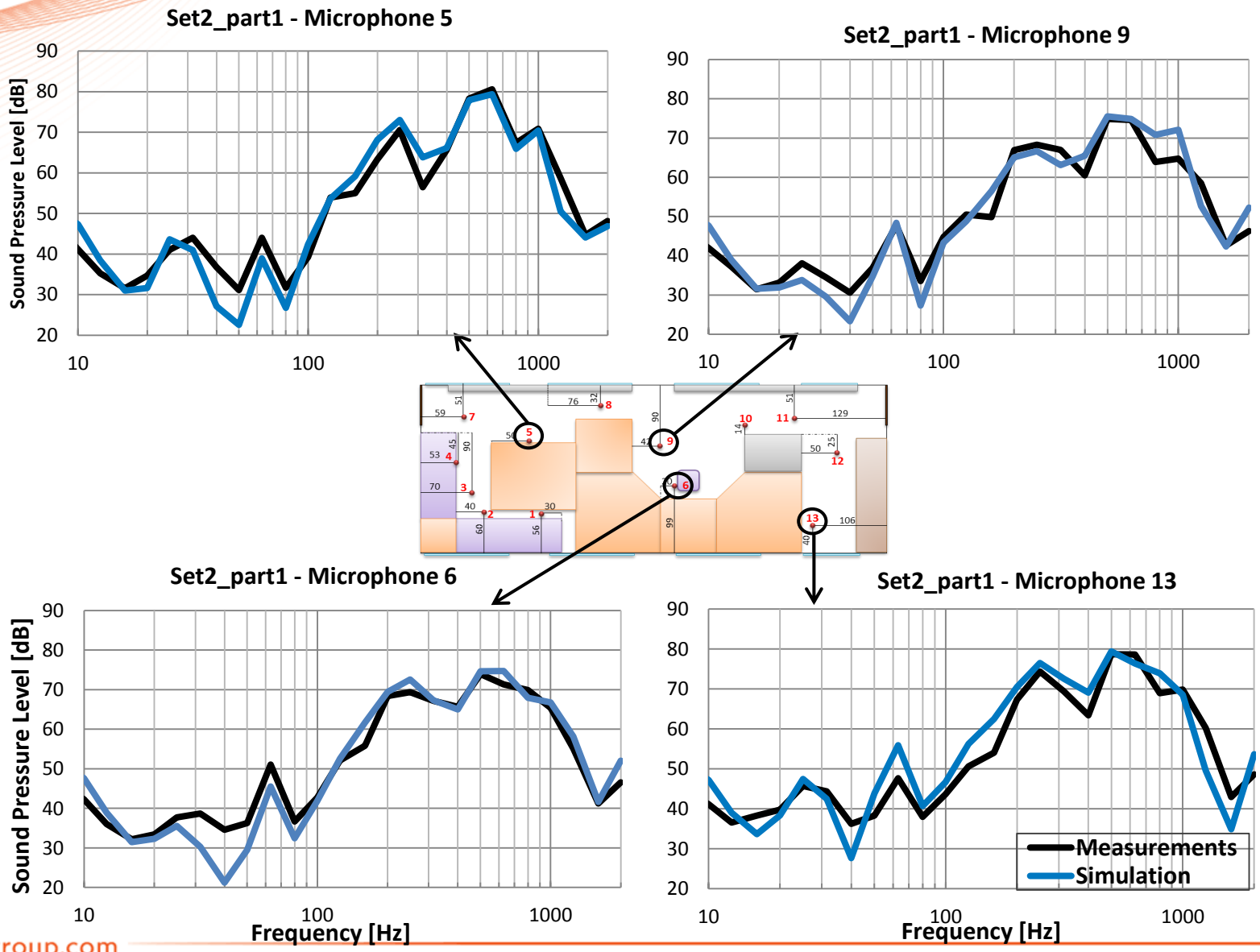
→ **Pressure results improved by 21.6 %.**

- Show the importance of located absorption.
- Better results can surely be obtained with a better approximation of the impedance.

Models	Configuration	Global Error indicator	% Improvement
Initial simulation	Set2 Part1	1382	
Simplified	Set2 Part1	1137	17,7%
Detailed	Set2 Part1	1083	21,6%

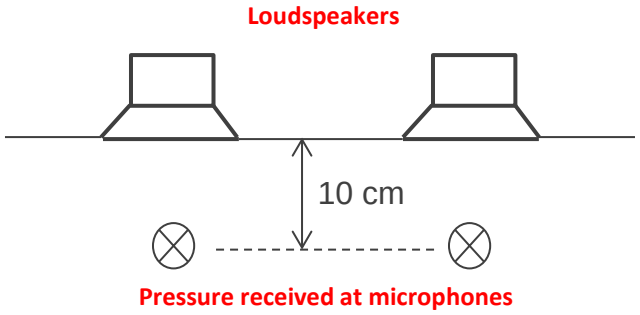
Second Method

Application to the cabin

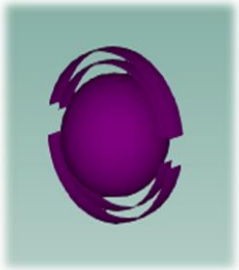


Third Method
Process

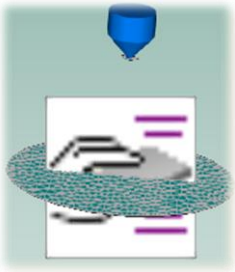
Calibration of surface sources



- Creation of 165mm diameter membranes.
- Apply surface constraint.
- Obtain same pressure as measurements at 10 cm.



Monopole



Surfacic pressure constraint

Third Method
Process

Complex correlation coefficients

Received complex pressure at 10 cm

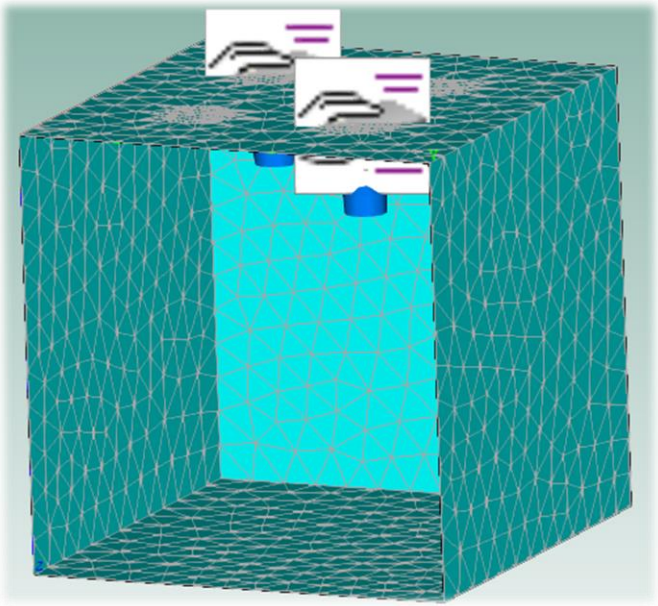
$$\begin{bmatrix} R_1 \\ R_2 \\ \vdots \\ R_n \end{bmatrix} = \begin{bmatrix} \alpha_1 & \alpha_{12} & \cdots & \alpha_{1n} \\ \alpha_{21} & \alpha_2 & \ddots & \vdots \\ \vdots & \ddots & \ddots & \vdots \\ \alpha_{n1} & \cdots & \cdots & \alpha_n \end{bmatrix} \cdot \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_n \end{bmatrix}$$

Input Pressure (surface constraint)

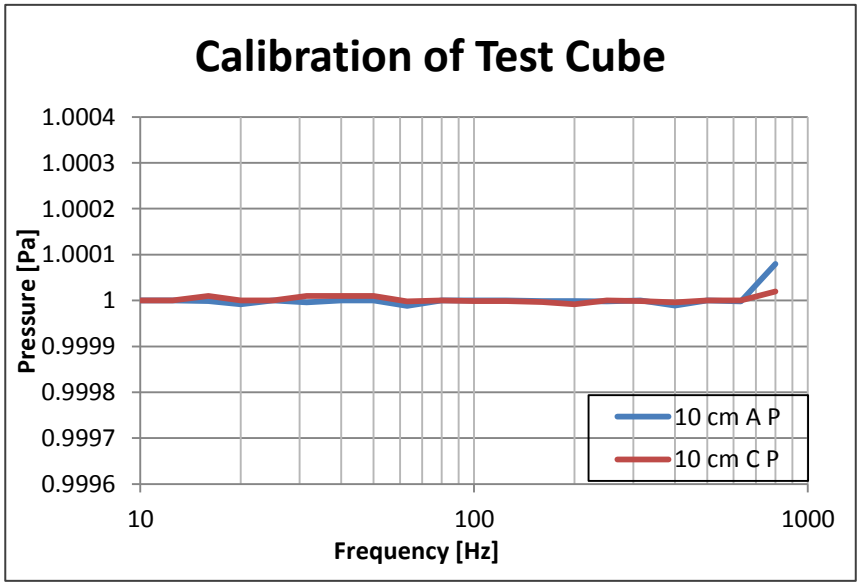
The number of input tests is equal to the number of membranes to calibrate.

Third Method
Validation test

- Test cube of $1\mathrm{m}^3$, all rigid faces.
- Two membranes wetted both sides.
- Sensors located 10 cm under membranes.



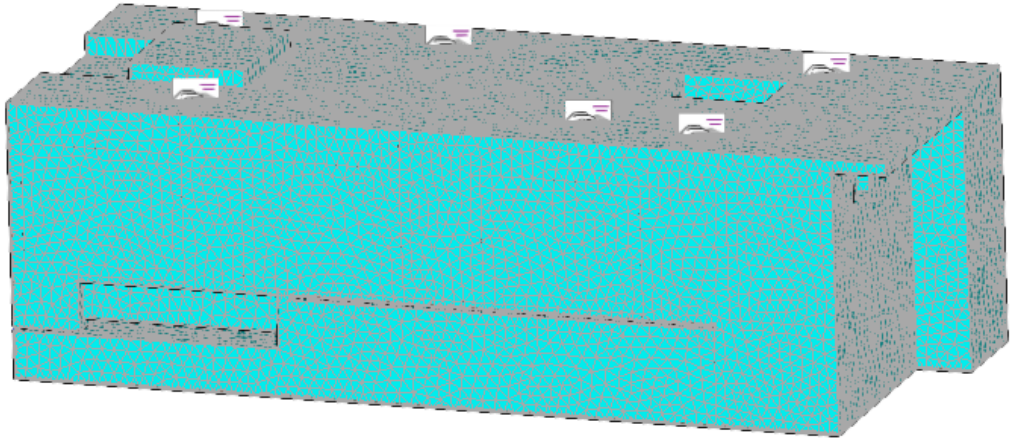
Test Cube for calibration of surface constraints.



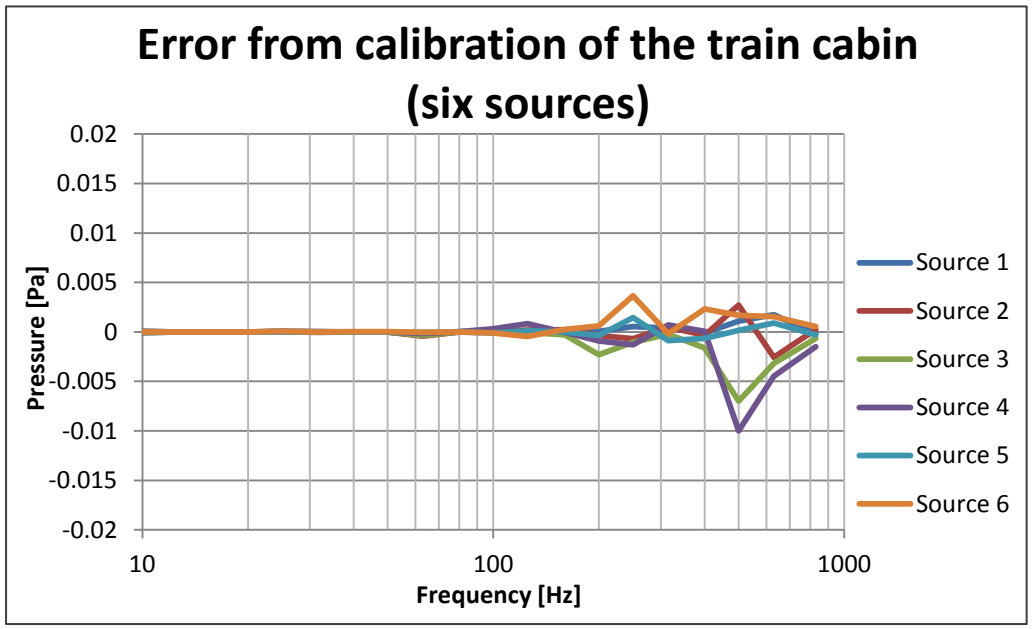
Highest error of 0.0007dB at 830 Hz.

Third Method

Calibration on cabin model for six sources



- Rigid faces and elastic membranes.
- Impedance spectrum applied on each surfaces.



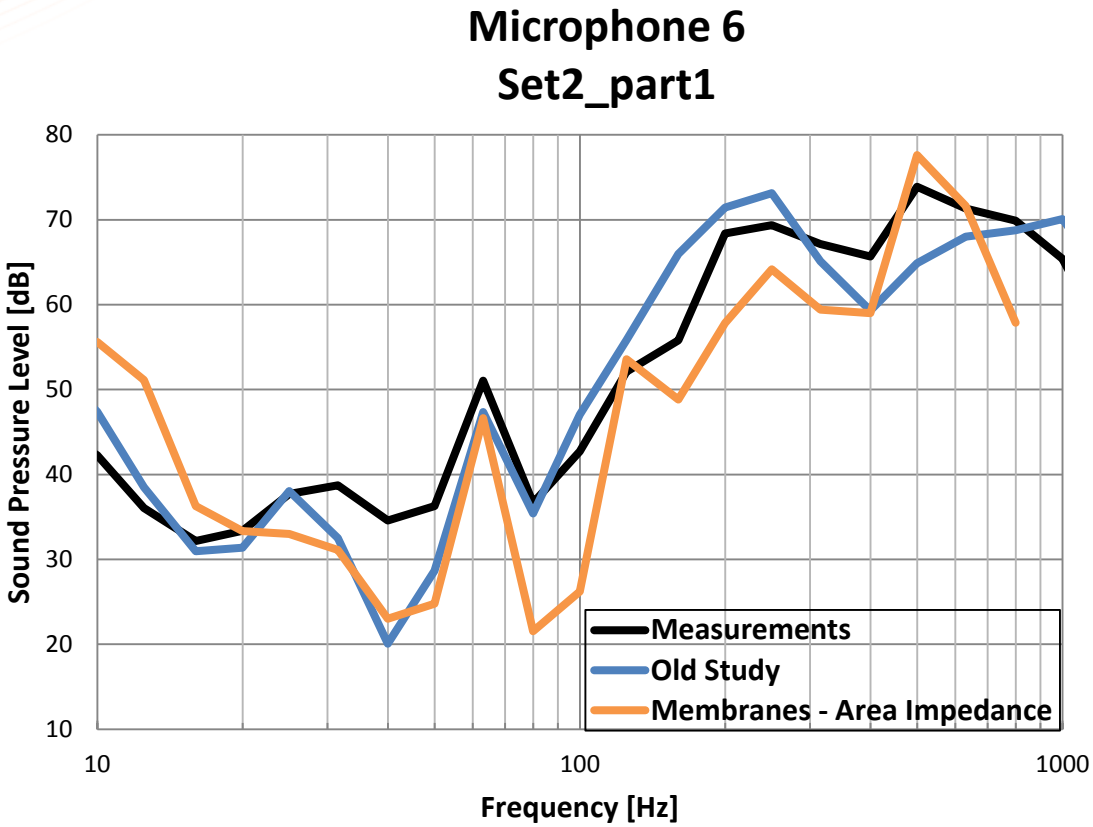
- Successfull calibration of six sources.
- Long computation time.

Highest error of 0.9 dB at 63 Hz.

Third Method

Comparison with previous results

Calibration of surface sources



- Pressure results less accurate.
- Non realistic directivity of sources.

Potential improvements by:

- Considering structural radiation of the membranes.
- Calibrating the directivity of the membranes with measurements.

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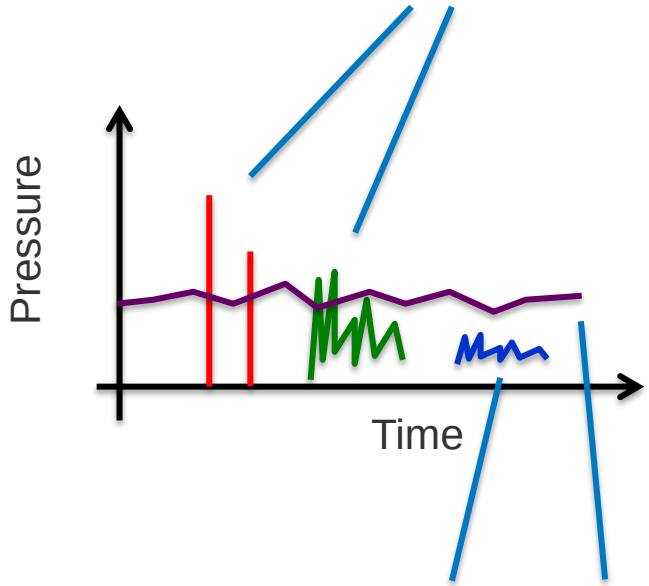
Implementation of STI in VA one

Ray/Beam tracing



SEA

Direct field (from source)

First few reflections of direct field (from source)

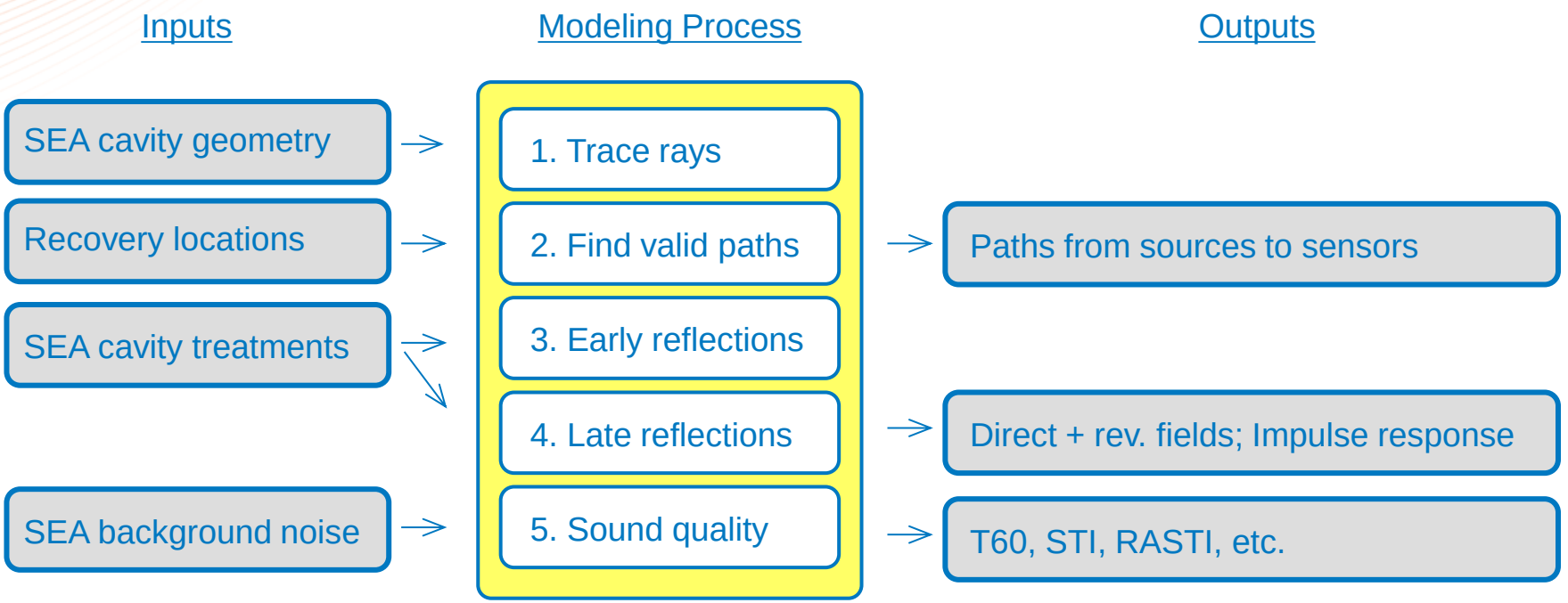
A VA One SEA model contains sufficient details about sound package (layered noise control treatment) to make accurate direct field predictions.

Late reflections (reverberant field from source)

Background noise (reverberant field from noise)

Implementation of STI in VA one

REPRESENTATIVE OF PROTOTYPE IMPLEMENTATION

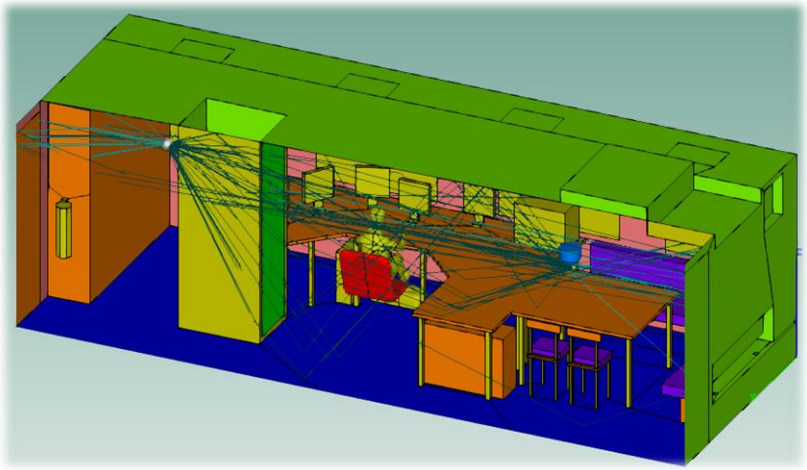


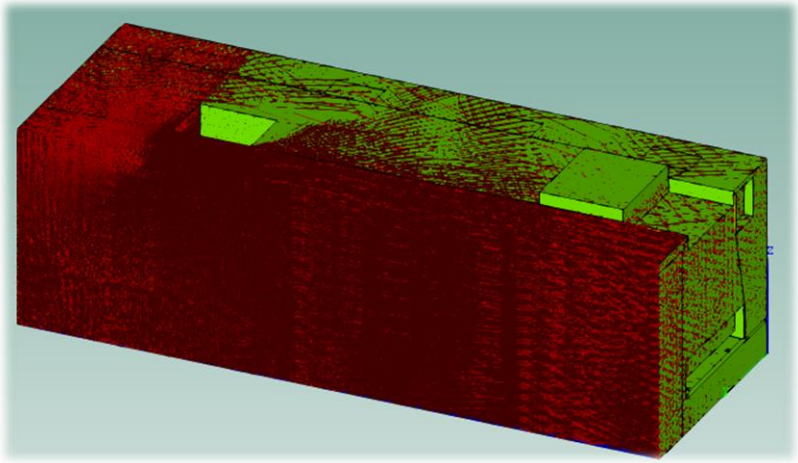
NB:

- Steps (1) and (2) are **frequency independent**
- **Early reflections** (3) use the **paths** computed in (2)
- **Late reflections** (4) use **energy remaining in all rays** computed in (1) and **assumes a diffuse field**

Speech Clarity Module

- Source located at 1 mm from surface.
- STI / STIPA / RASTI values obtained for each microphone.
- Contour plot of STI values on chosen surfaces.

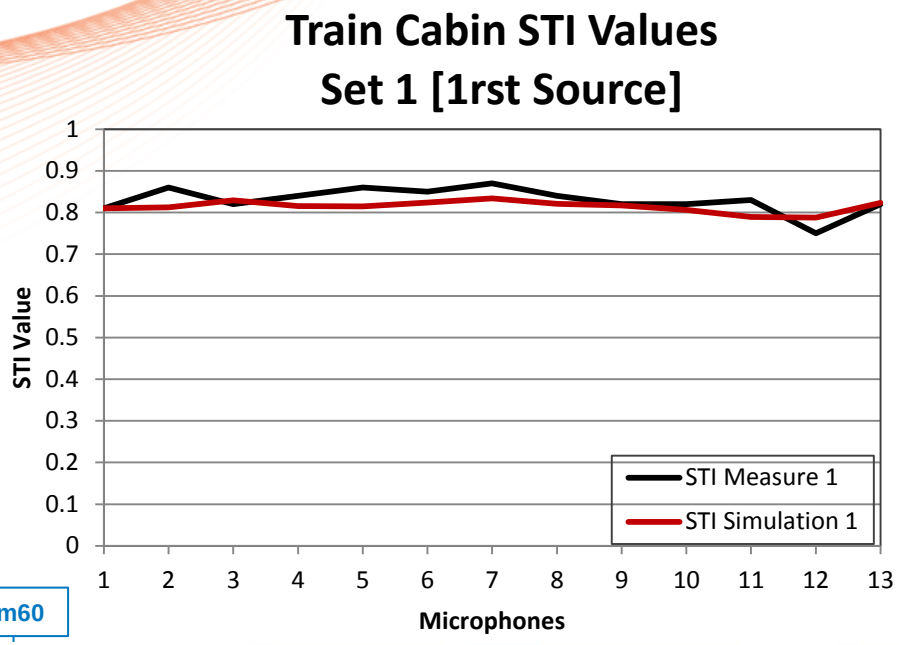




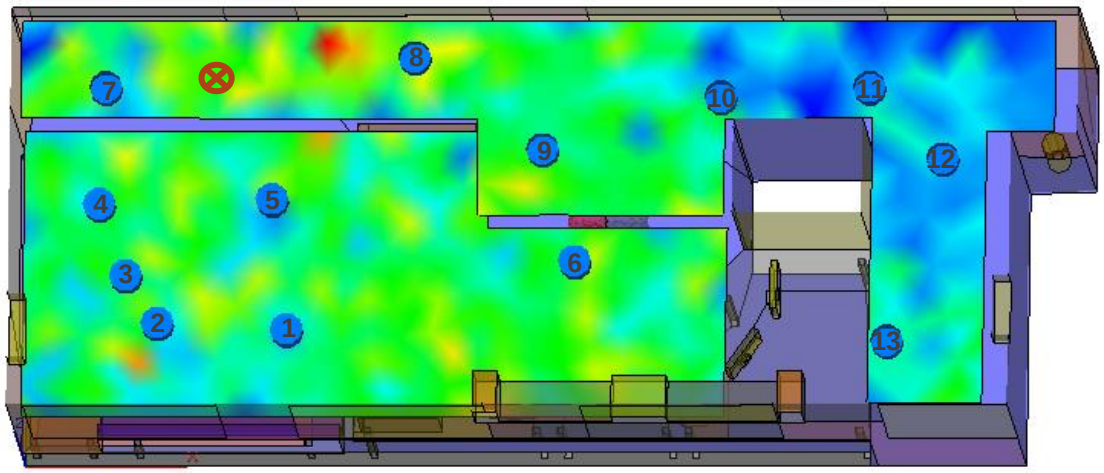
Ray tracing visualisation, all rays that cross microphone 5 after 3 reflections (left) and all the casted rays (~50000) for the STI computation of the train cabin (right).

STI Results Source 1

Compared to STIPA Measurements

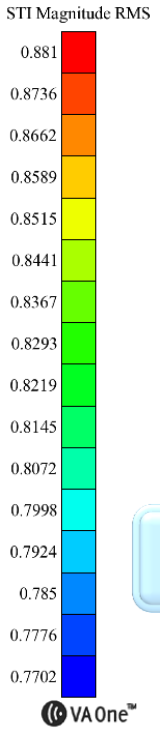


1m60



1m20

⊗ *Position of the source*



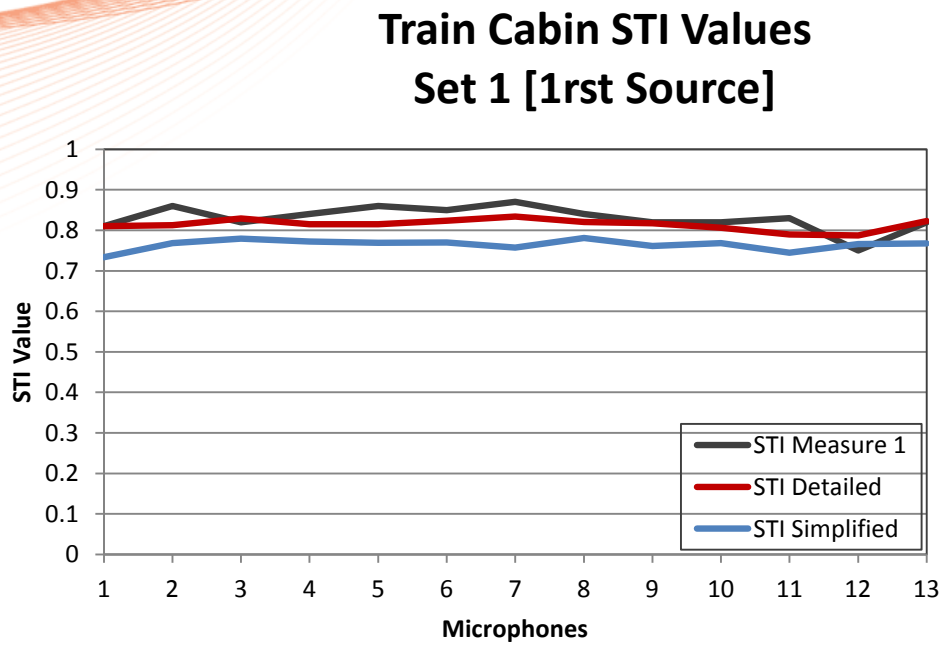
- Accurate results of STI values comparing to the measurements.
- Contour plot shows the repartition of the speech clarity in the room.

Max Error: 0.05
Average Error: 0.02

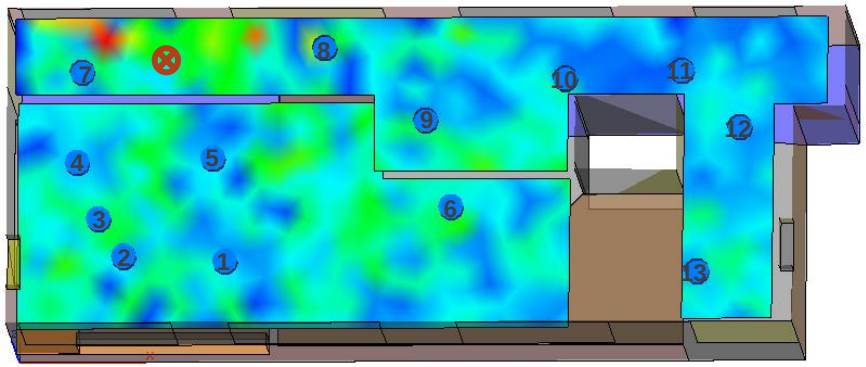
„Changes in STI values smaller than 0.03 are inaudible“

STI Results Source 1

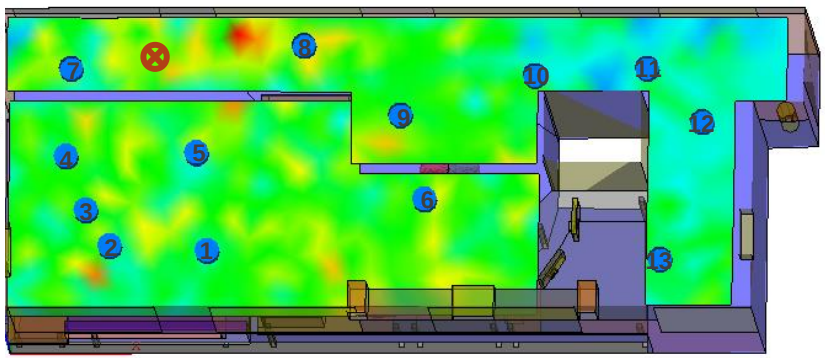
Comparison Detailed / Simplified Model



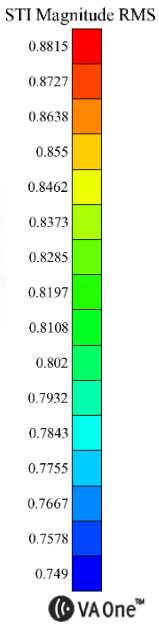
- STI Results from simplified model are lower than with the detailed model.
- The presence of detailed objects in the models have an affectr on the speech clarity distribution.



Contour plot of STI values for Simplified Model.

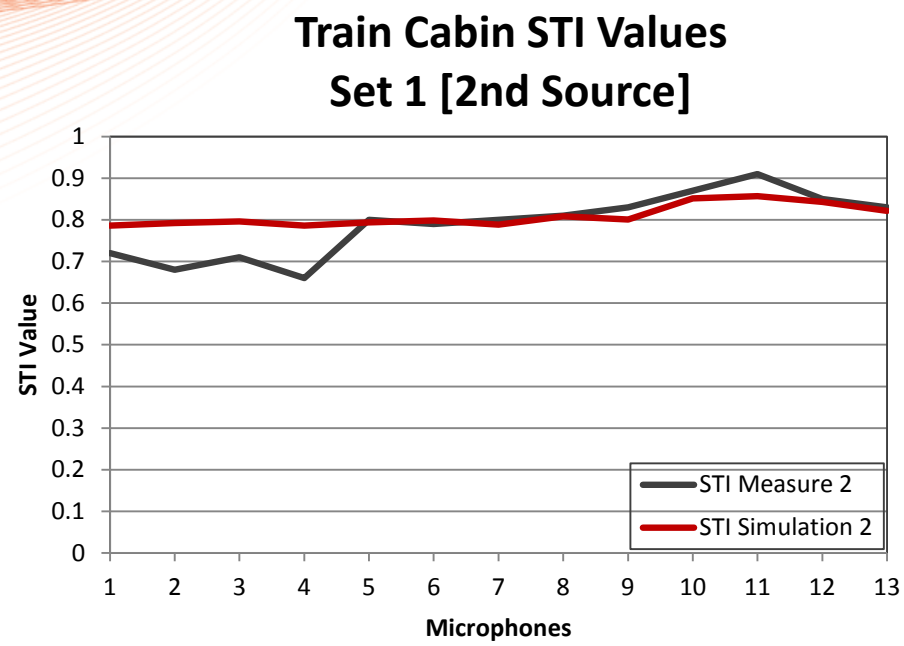


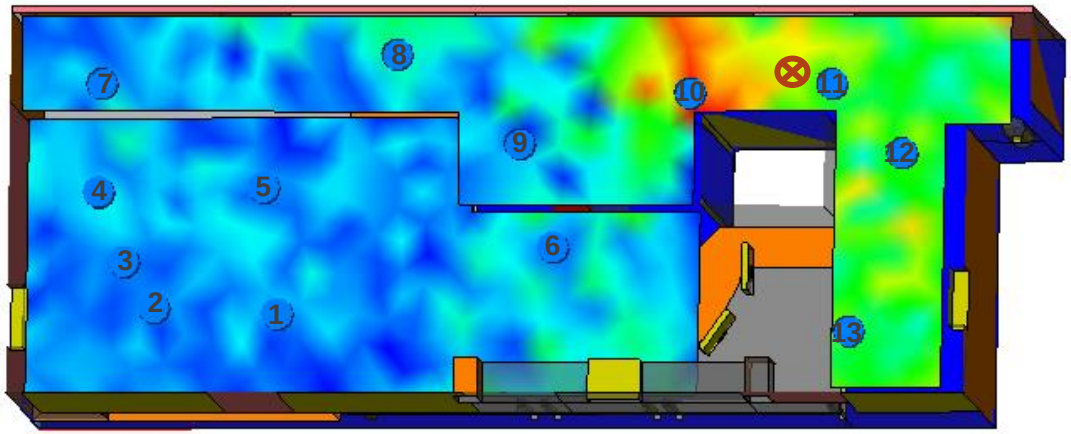
Contour plot of STI values for Detailed model.



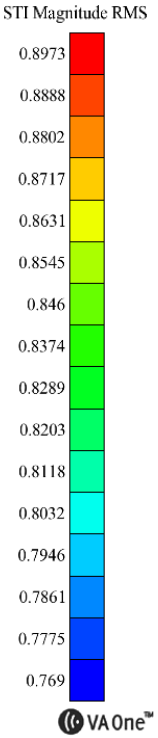
STI Results Source 2

Compared to STIPA Measurements





- Accurate results of STI values comparing to the measurements, except for microphones 1,2,3 and 4.
- Contour plot shows the repartition of the speech clarity in the room.



Max Error: 0.13
Average Error: 0.04

„Changes in STI values smaller than 0.03 are inaudible“

Conclusion

- Approximation of the absorption properties of the train Cabin surfaces.
- BEM computations:

Method	Results
Damping Loss Factor + monopole sources	16,4 % of improvement /previous study
Surface impedances + monopole sources	21,6 % of improvement /previous study
Surface impedances + constrained membranes	Regression of results /previous study

- Ray tracing + SEA:
  - → Comparison of STI / STIPA at 13 microphones /0,03 of average error.
  - → For two sources, results disparities at 4 microphones located in the same area.
  - → STI contour plots provide good agreements with measures.
- Potential improvements of simulations:
  - → Reverberation time measurement for adjustement of materials acoustic properties.
  - → Measurements of loudspeaker‘s directivity and modeling of this directivity.

Acknowledgement

Many thanks to DB Systemtechnik Gmbh,
for providing the train and test datas for this study.

Thank you for your attention

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