Title	NOVI - Advanced functional solutions for Noise and Vibration reduction of machinery, Deliverable D2.3 Virtual cabin model
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Business from technology

NOVI - Advanced functional solutions for Noise and Vibration reduction of machinery

D2.3 Virtual cabin model

Authors:	Denis Siponen, Antti Lehtinen, Seppo Uosukainen
Confidentiality:	Public

Aalto-yliopisto

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Summary

Project name Advanced functional solutions for Noise and Vibration reduction of machinery		Project number/Short name 71902–1.1.2 / NOVI-SP2
Author(s) Denis Siponen, Seppo Uosukainen, Antti Lehtinen		Pages 49
Keywords Cabin modelling, virtual testing		

Summary

A vibroacoustic model for Valtra cabin T888 M has been constructed. Cabinet interior and steel + glass + chassis structure model is valid up to 400 Hz with and without the inner roof. Wool is modeled with Biot's model and the inner roof is modeled as solid and as porous Biot material. Modes of empty cabin, the response to an internal loudspeaker, the response to structure-borne sound, the response to external diffuse sound field excitation, and parametric studies for inner roof properties have been simulated. Enhancing material models, increasing frequency range above 400 Hz, virtual testing of different materials, and model auralization are the most important targets for future.

Confidentiality	Public	

Espoo 19.12.2013

Written by Seppo Uosukainen Senior Scientist	Reviewed by Hannu Nykänen Principal Scientist	Accepted by Johannes Hyrynen Technology Manager

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- Introduction
- Vibroacoustic model
- Simulation results
- We have now
- Future work

Introduction

- Goals
  - ✓ Preparing the cabin geometry (dead-line 23.6.2011)
  - ✓ Acoustic eigenfrequency analysis (dead-line 31.8.2011)
  - ✓ Acoustic sound field analysis (dead-line 30.9.2011)
  - ✓ Model with inner roof element included (dead-line 31.10.2011)
    - o Sound field analysis with different roofs
  - o Model with additional absorbents / resonators included (dead-line 30.11.2011)
    - o Sound field analysis with different absorbents / resonators
  - ✓ (2012)
    - o Vibroacoustic model with cabin walls and windows included
    - o Vibroacoustic model for airborne sound from exterior to cabin
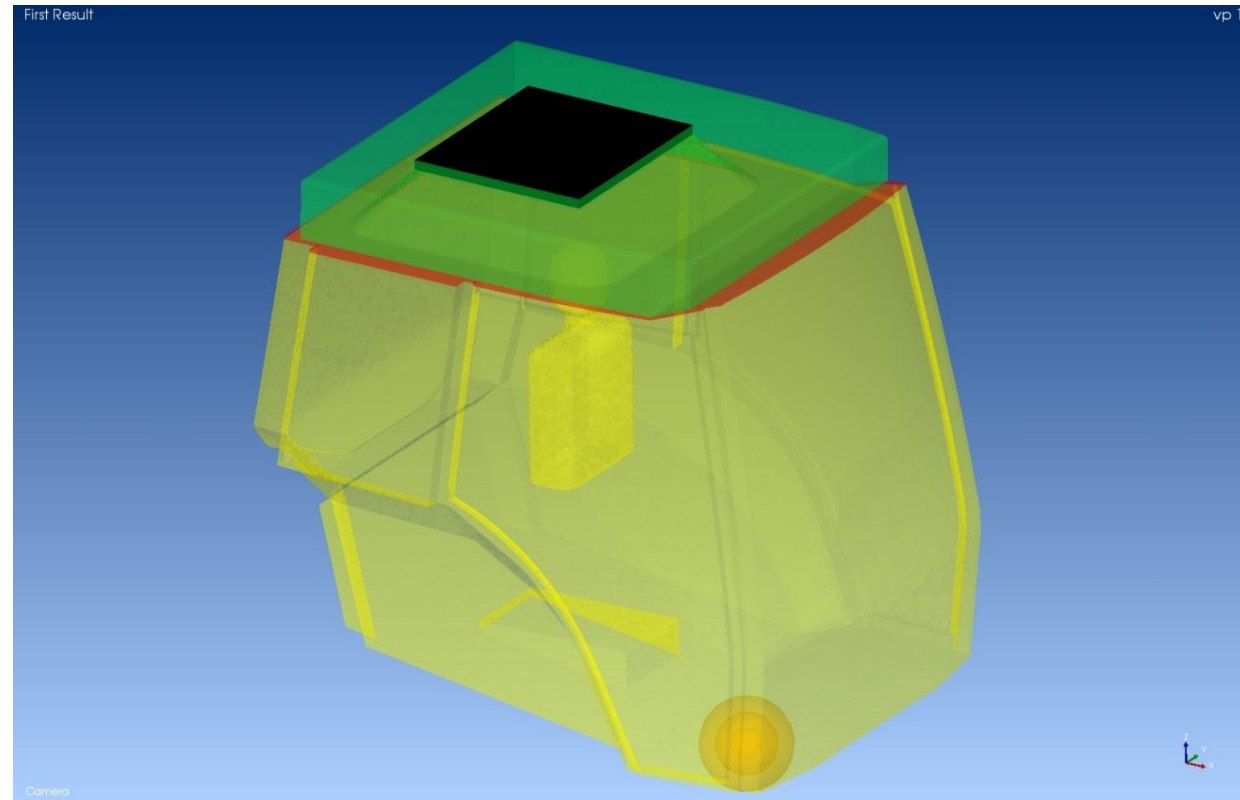   - o Sound field analysis: parametric study for the inner roof

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Acoustic model of the cabin interior (1)

- Cabin interior has been divided in 4 parts:
  - **Lower airspace + HATS**
  - **Inner roof**
  - **Inner roof wool**
  - **Upper airspace**
- The inner roof and the wool can be flexibly removed from the model

- Inner roof and wool modeled as solid or with Biot's model

Acoustic model of the cabin interior (2)

- Three different geometries has been provided by Valtra
  - Only one of them was valid for modeling purposes
- Geometry of the airspace of the cabin (up to inner roof) is simplified in Ansys
- This geometry is then exported into Abaqus, where various steps were made to get final geometry:
  - Creating geometry of airspace between inner roof and top roof
  - Creating geometry of HATS
 - Creating final geometry (lower airspace + upper airspace – HATS)
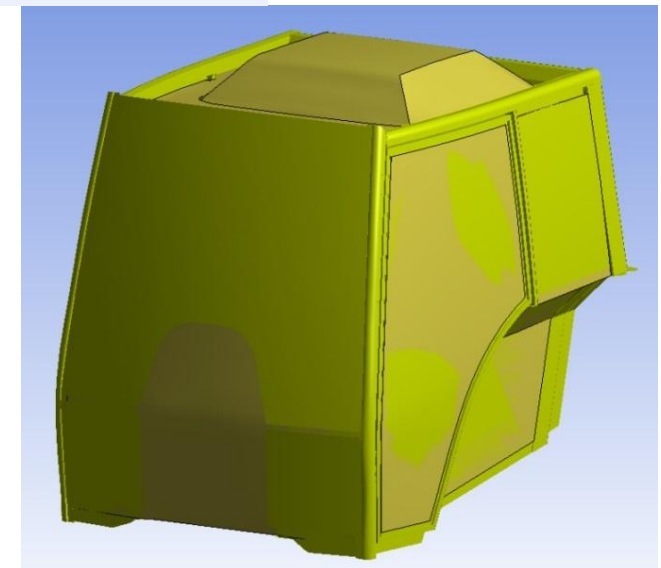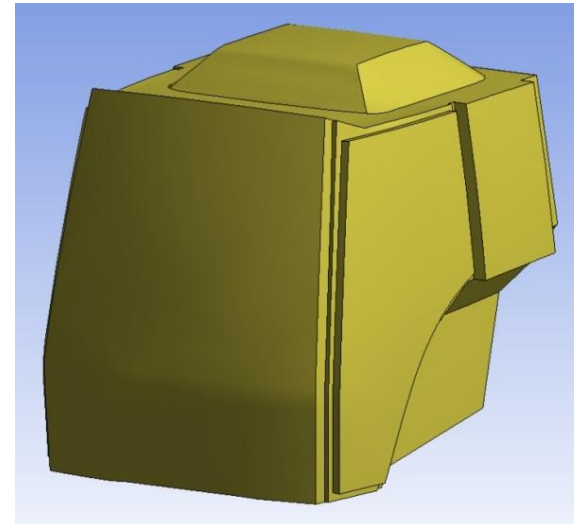
Cabin geometry (1)

- Created geometry of the inner roof
  - 8 mm thick instead of real 10 mm, this is because of defective cabin geometry
- Original geometry of the cabin body is not included, as it was too defective to be usable
  - Tried to repair geometry with Ansys Design Modeler and Space Claim (with support from Medeso staff) with no success
- Zone tempered glasses in lower air space
- Various other improvements
  - Simplified upper side of the lower air space
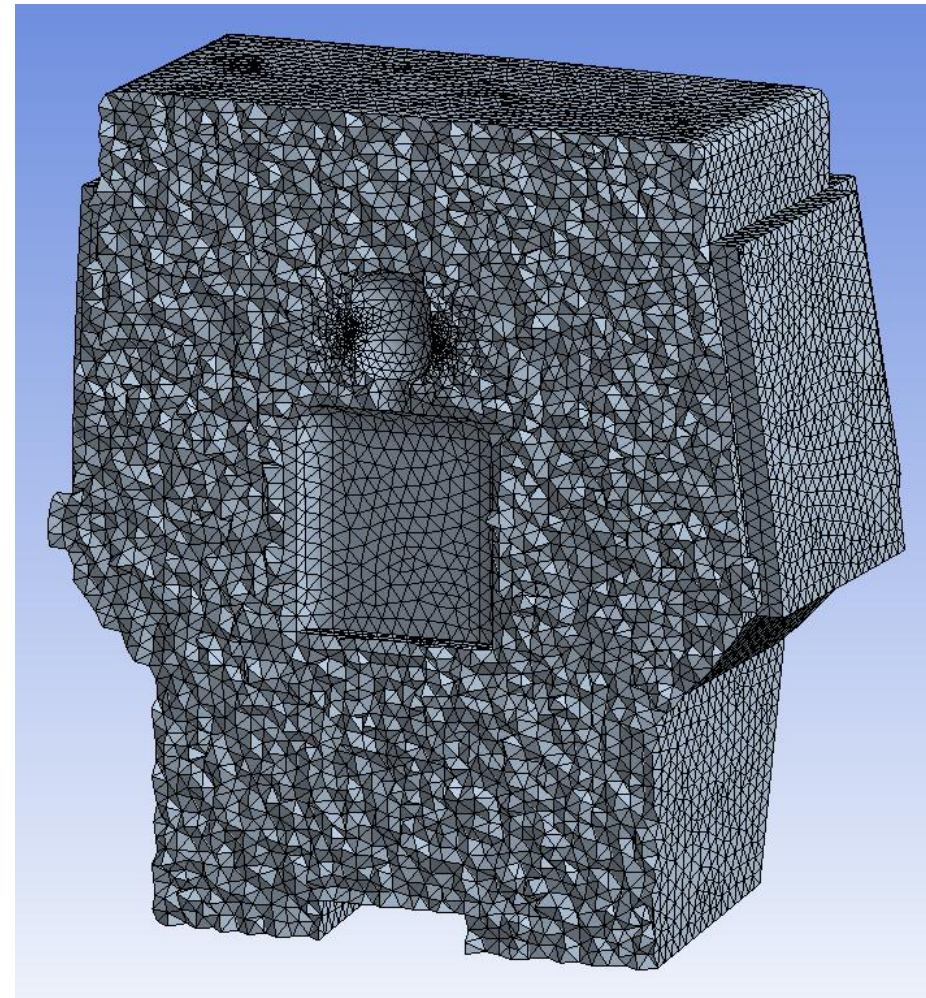 - Simplified upper air space
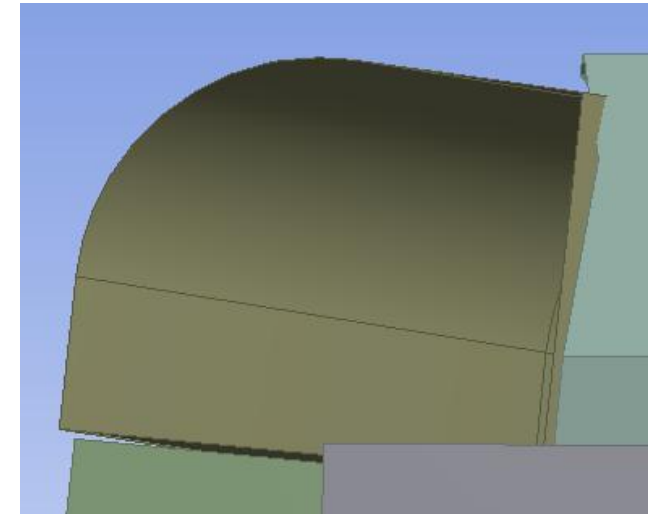
Example of defective cabin body geometry

Cabin geometry (2)
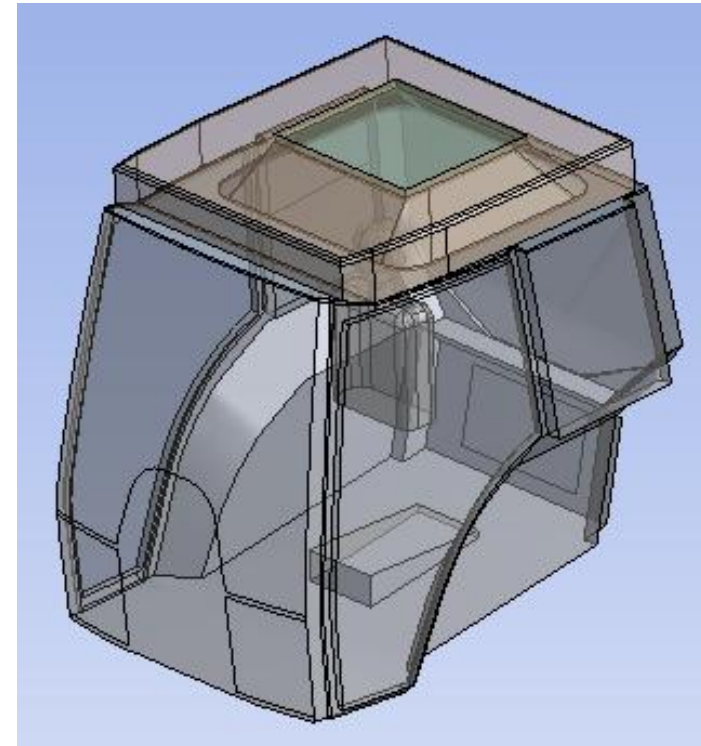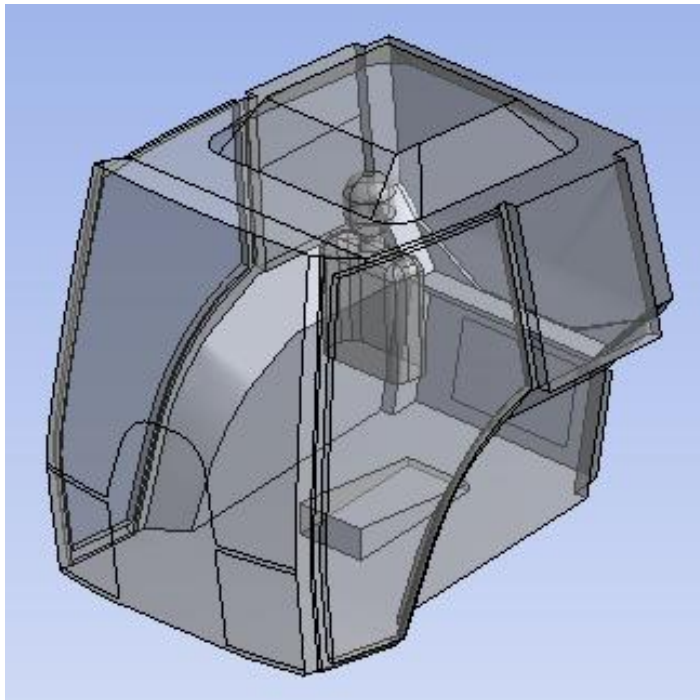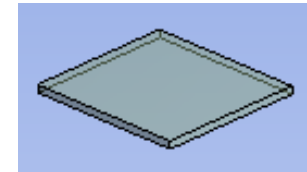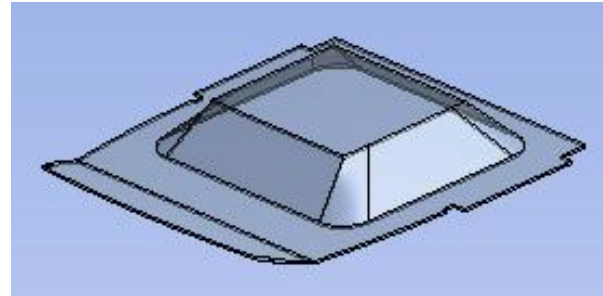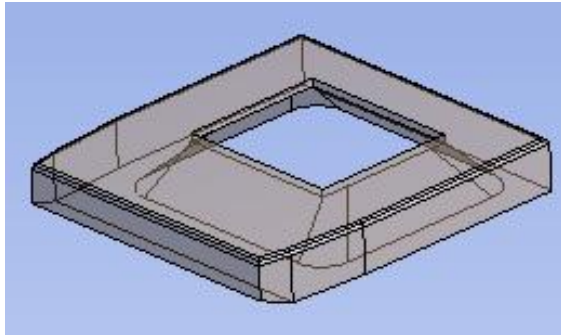
Mesh of empty cabin

- Mesh was done in Ansys
    - Nodes: 180 k
    - Elements: 1 M
    - Max element size: 30 mm
    - Acoustic, quadratic elements

    ➢ Mesh valid up to ~ 3000 Hz

Mesh of total cabin

- Improving the mesh of the cabin
  - Improved mesh around head of HATS
  - Inner-roof meshed with multizone method to achieve more precision along thickness
    - ➢ Mesh of the inner-roof is not conformal with other meshes
  - 113 k nodes
  - Quadratic elements

  ➢ Mesh valid up to 400 Hz
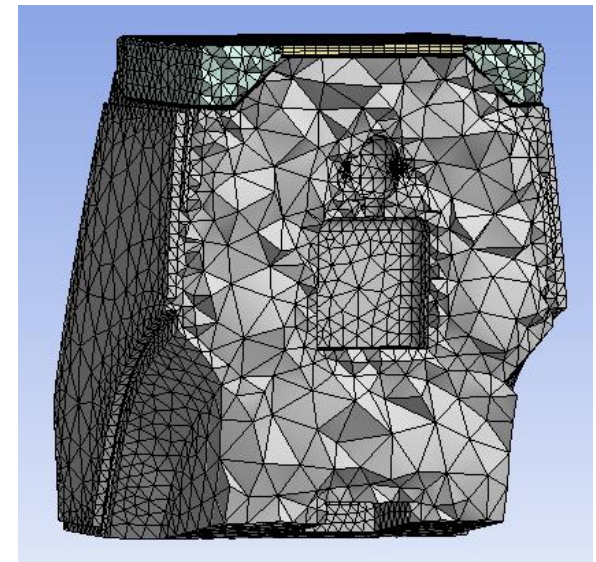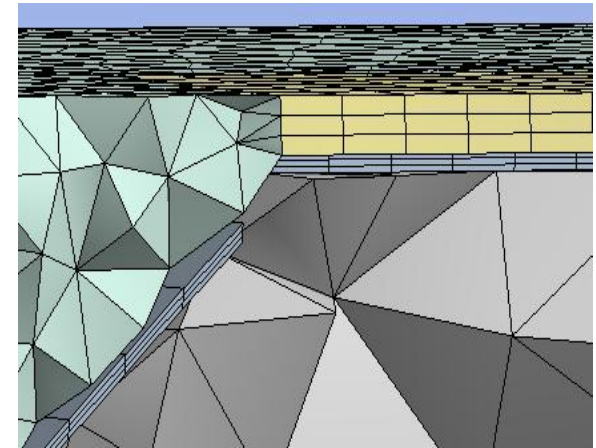
Modeling parameters

- Global damping: imaginary part of complex sound speed

$$\bar{c} = c(1 + \mathrm{j}\xi) \quad \xi = \frac{\eta}{2} \quad \eta = \frac{2.2}{fT} \quad (1)$$

c : sound speed	
f : frequency	
T : reverberation time	
ξ : damping ratio	
η : loss factor	

- Inner roof: solid
  - Young's modulus 75 MPa
  - Poisson's ratio 0.2
  - Solid density 316.5 kg/m^3
- Wool: solid or default Biot rockwool
  - Flow resistivity 75 kPas/m^2
- Windows: thin shell, 5 mm thick default glass
- Body: thin shell, 3 mm thick default steel

(1):
Actran 12.1 User's Guide – Volume 2a, p. 101.
Beranek, L. L., Noise and Vibration Control, pp. 434-439.

f [Hz]	T30 [s]	ξ	ξc
63	0.363	0.0481	16.354
80	0.362	0.0380	12.914
100	0.601	0.0183	6.223
120	0.590	0.0155	5.282
160	0.551	0.0125	4.242
200	0.933	0.0059	2.004
250	0.921	0.0048	1.624
315	0.822	0.0042	1.444
400	0.734	0.0037	1.274
500	0.739	0.0030	1.012
630	0.793	0.0022	0.749
800	0.960	0.0014	0.487
1000	0.843	0.0013	0.444
1200	0.819	0.0011	0.381
1600	0.865	0.0008	0.270
2000	0.813	0.0007	0.230
2500	0.730	0.0006	0.205
3150	0.763	0.0005	0.156
4000	0.734	0.0004	0.127
5000	0.695	0.0003	0.108

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■

■

■ Simulation results

  ■ Modes of empty cabin

  ■ Response to internal loudspeaker

    ■ Sound field distributions

    ■ Sound field in the ears of HATS

  ■ Response to structure-borne sound

  ■ Response to external diffuse sound field excitation

 ■ Parametric study for inner roof properties

■

■

Calculated modes of empty cabin (1)

- Calculated in Abaqus and Actran
- Methods used: AMS (Automatic multi-level substructuring) and Lanczos algorithm
- All modes in 0 – 2000 Hz frequency range
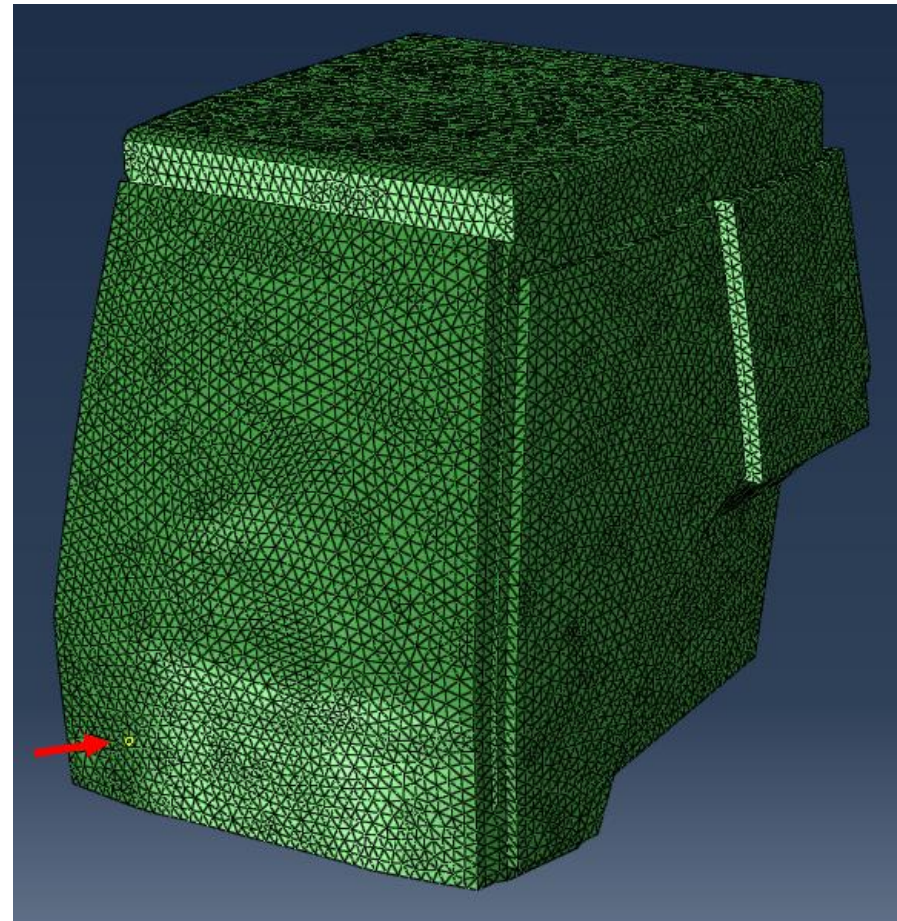
Calculated modes of empty cabin (2)

| mode n.	Abaqus	Actran
1	98.3Hz	98.4Hz
2	121.4Hz	121.5Hz
3	131.0Hz	131.1Hz
4	161.5Hz	161.7Hz
5	163.8Hz	163.9Hz
6	192.6Hz	192.8Hz
7	207.5Hz	207.8Hz
8	219.7Hz	219.9Hz
9	220.4Hz	220.6Hz
10	240.3Hz	240.6Hz
11	251.2Hz	251.5Hz
12	253.5Hz	253.9Hz
13	261.3Hz	261.6Hz
14	267.4Hz	267.7Hz
15	273.6Hz	273.9Hz
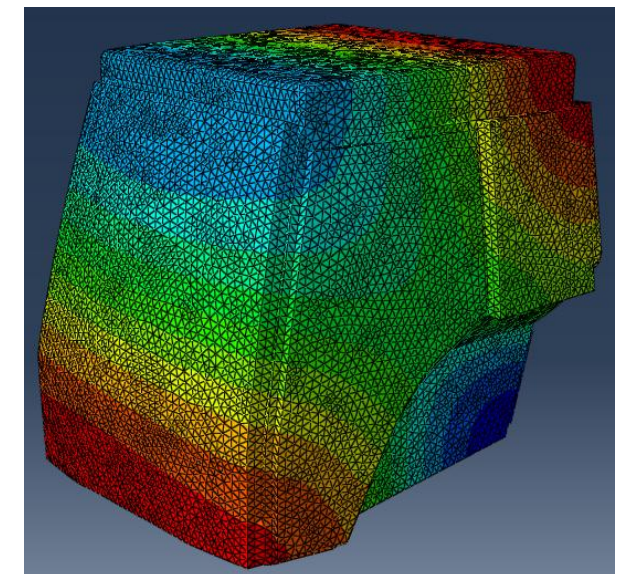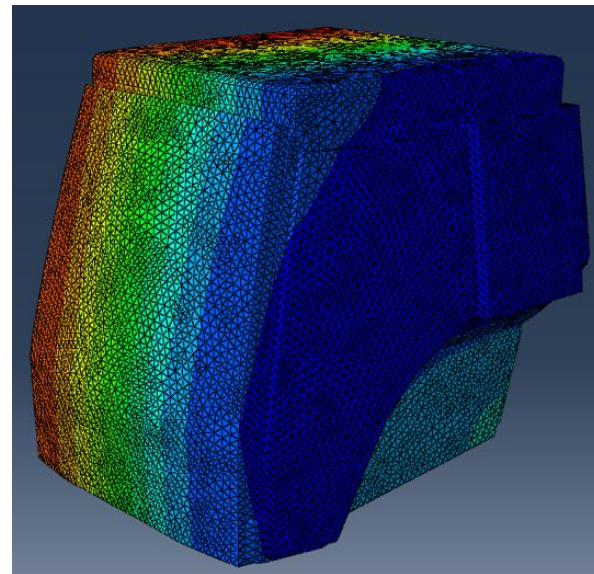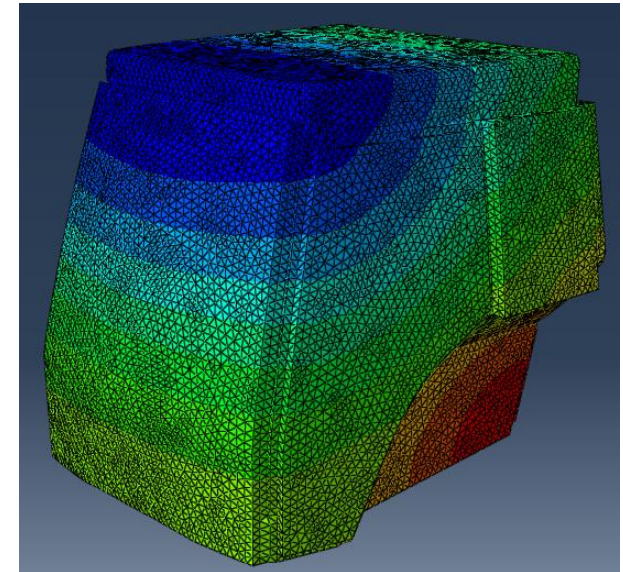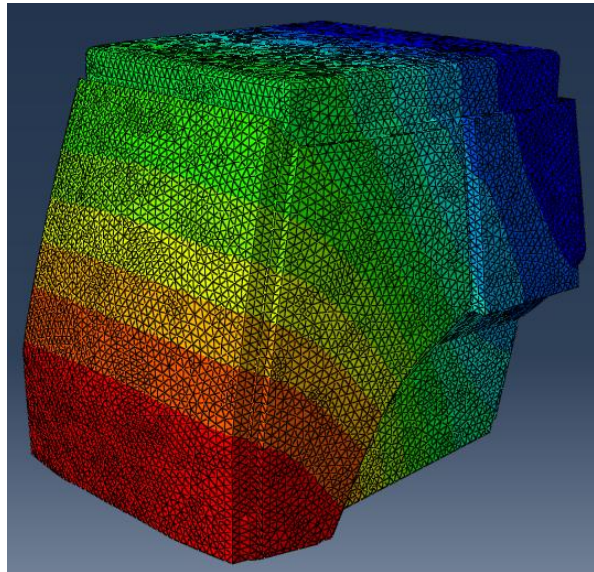
Measurement setup, camera positioning
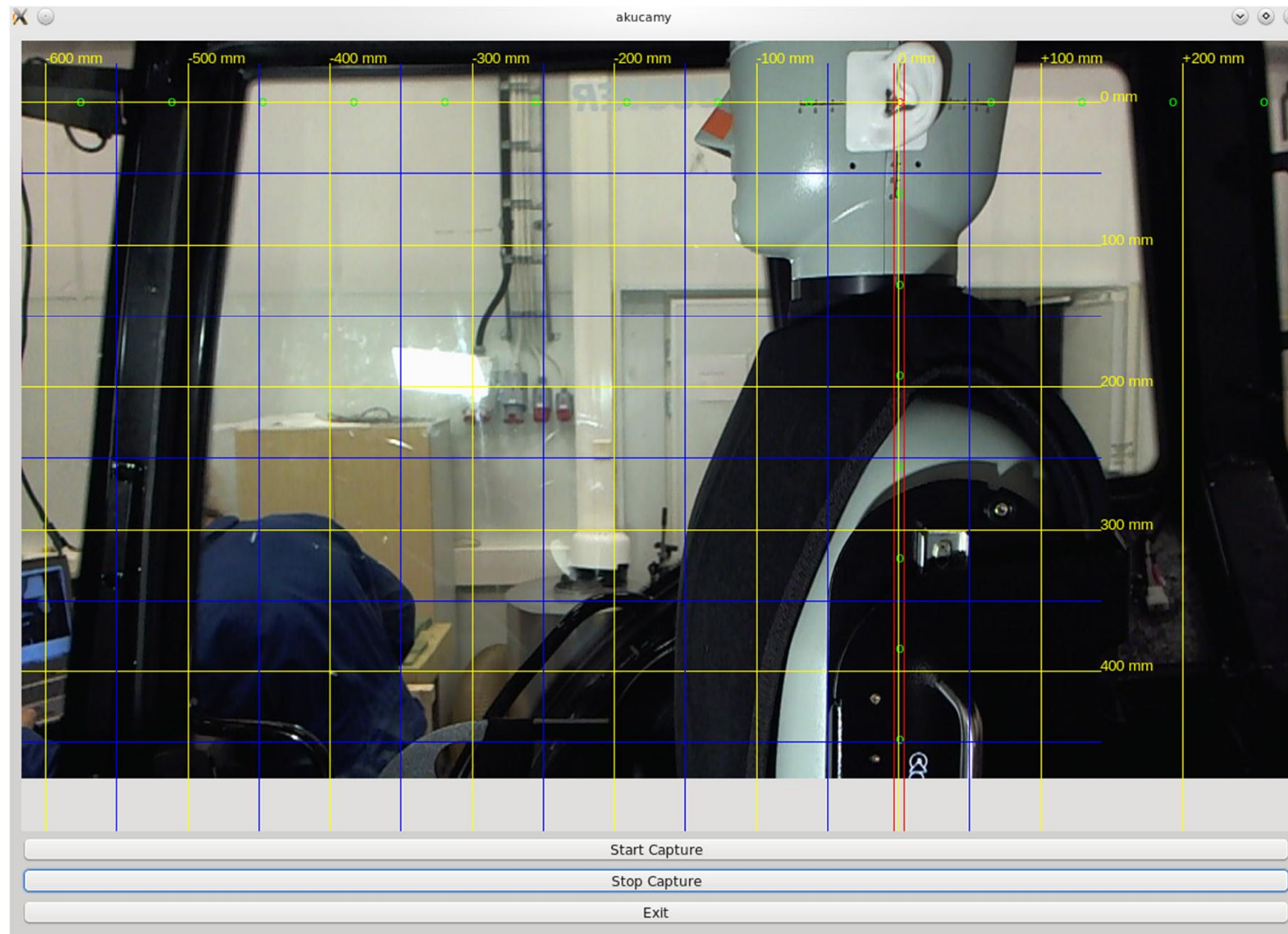
Response to internal loudspeaker (1)

- Method: steady-state dynamic, modal

- Sound field distributions
- Sound field in ears of HATS

- Empty cabin
- Effects of inner roof, windows and chassis
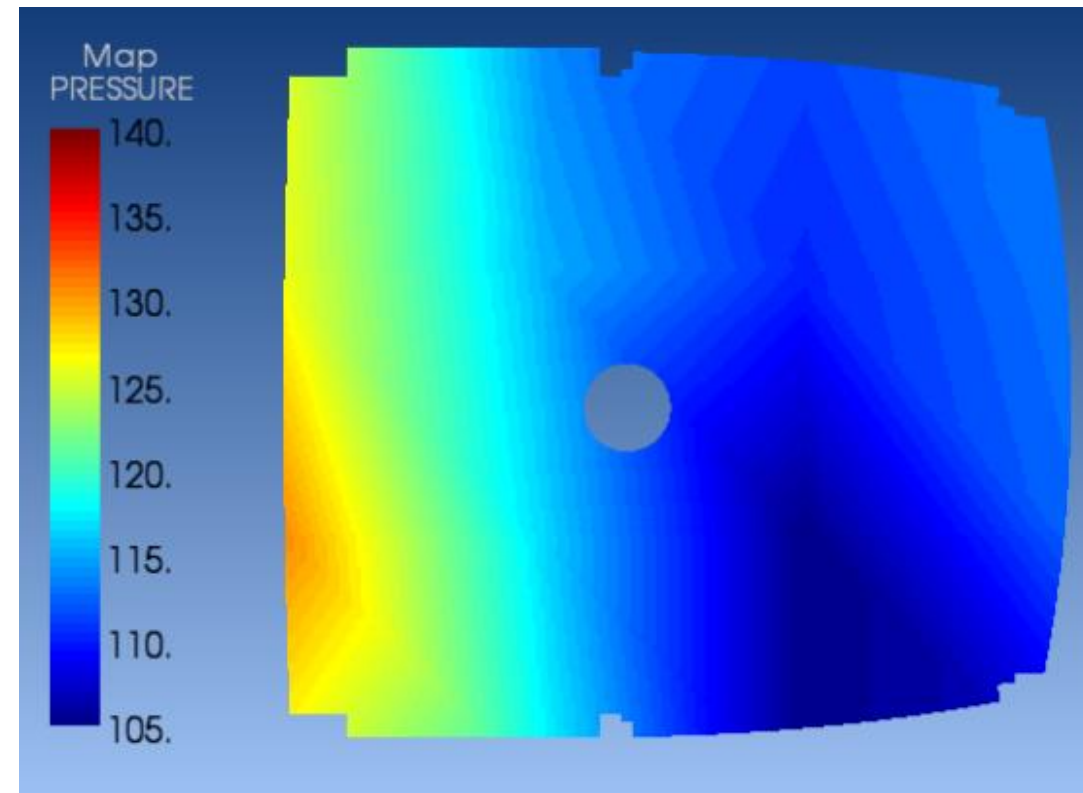
- Comparison with measurements
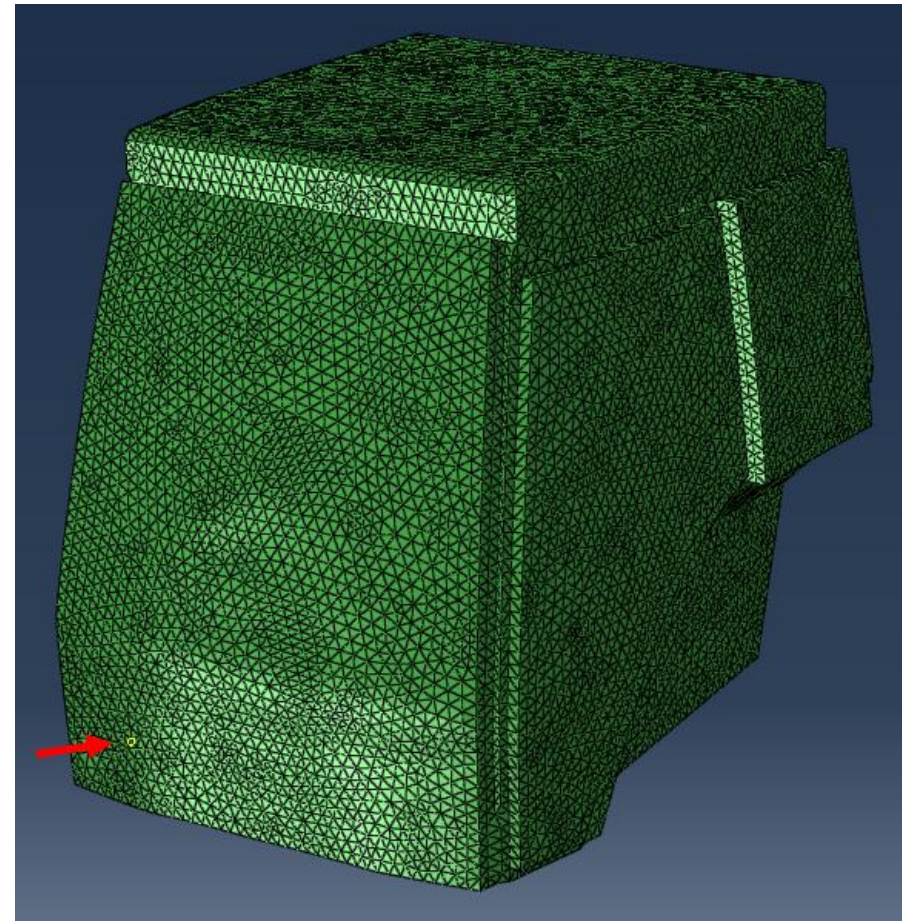
Response to internal loudspeaker (2)
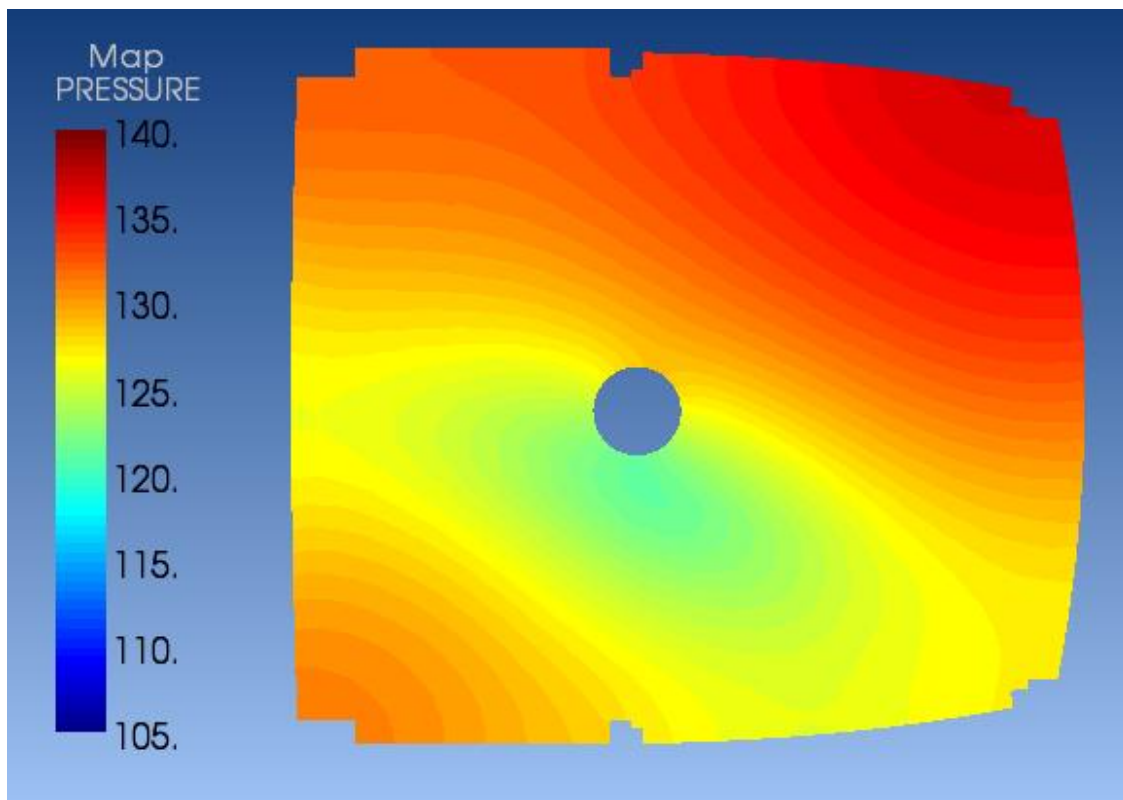## Empty cabin, cross section at the level of ears, 1/3 oct.
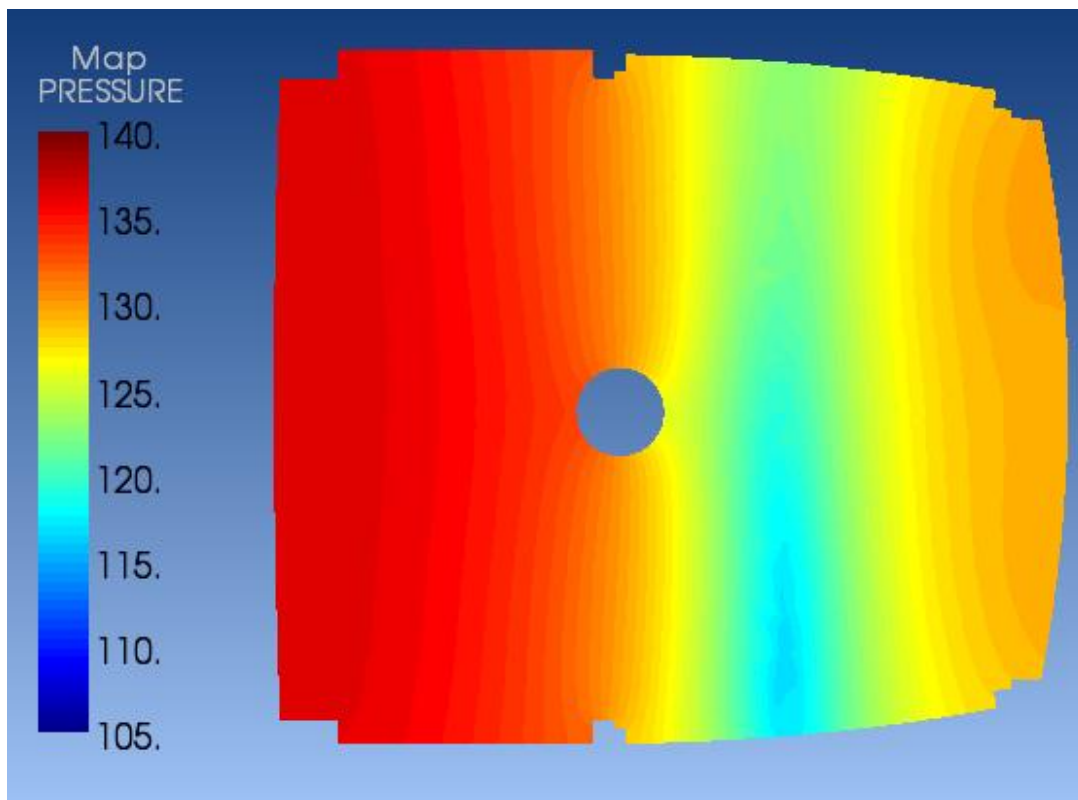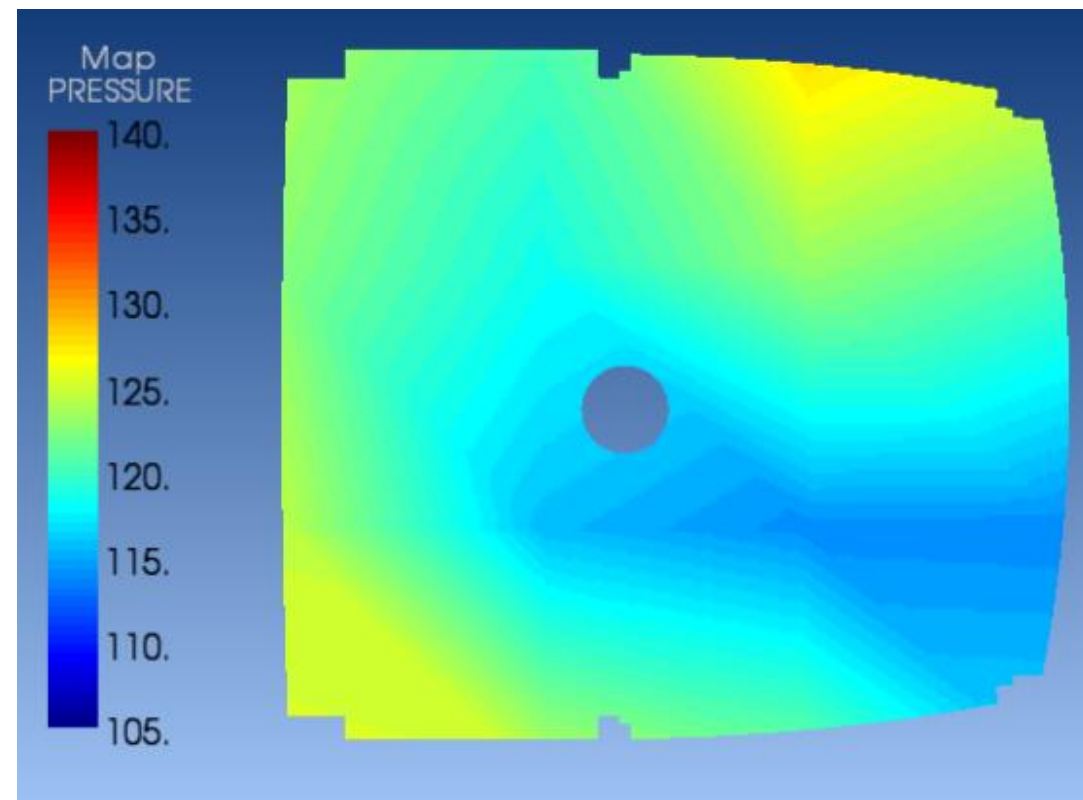

Model   100 Hz   Measurements

Response to internal loudspeaker (3)
Empty cabin, cross section at the level of ears, 1/3 oct.

Model   125 Hz   Measurements

Response to internal loudspeaker (4)
Empty cabin, cross section at the level of ears, 1/3 oct.

Model   160 Hz   Measurements

Response to internal loudspeaker (5)
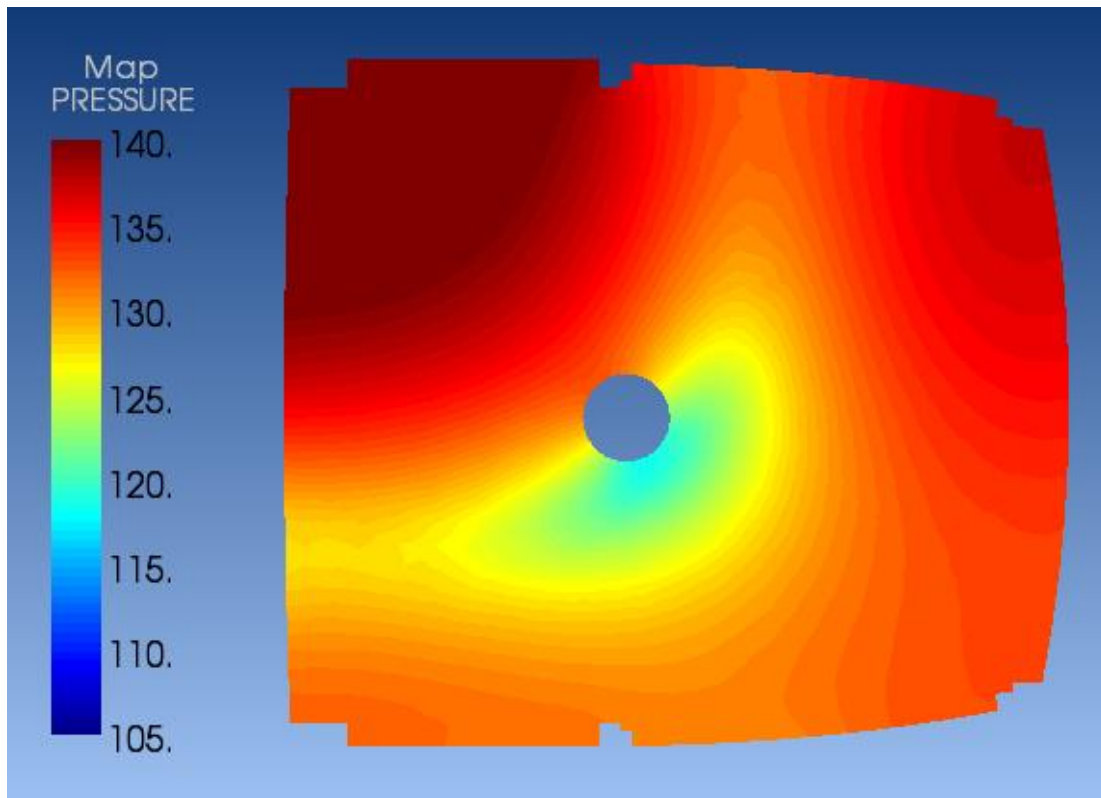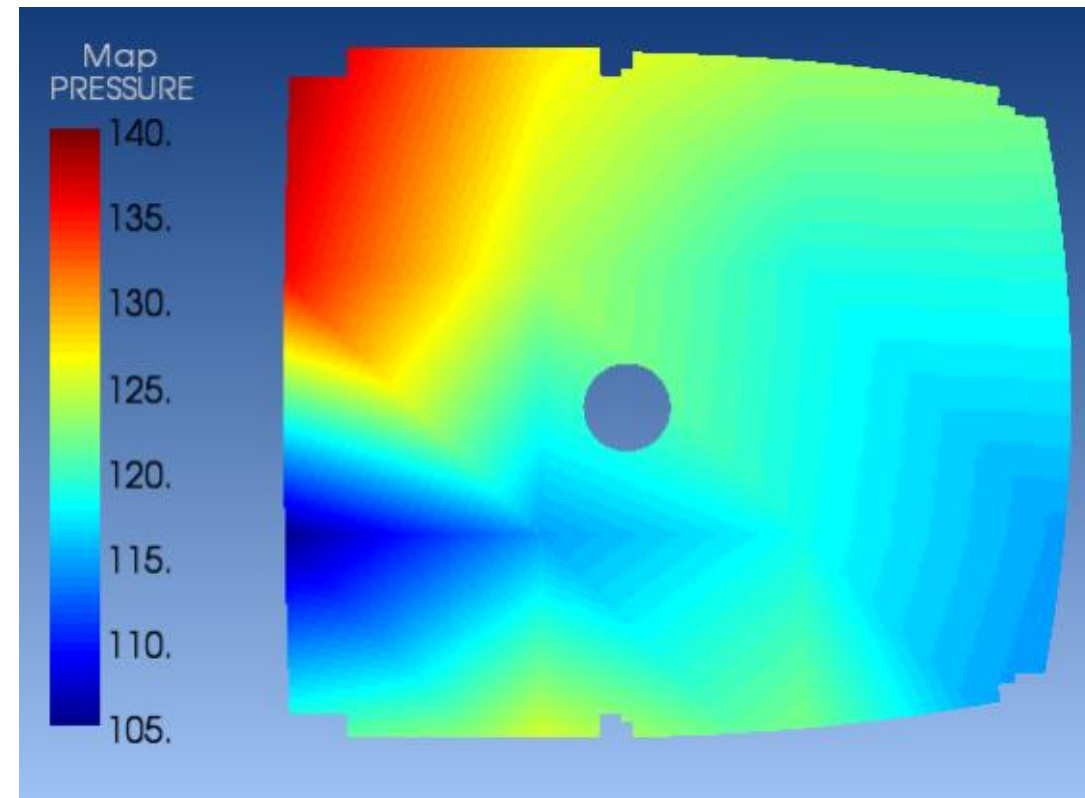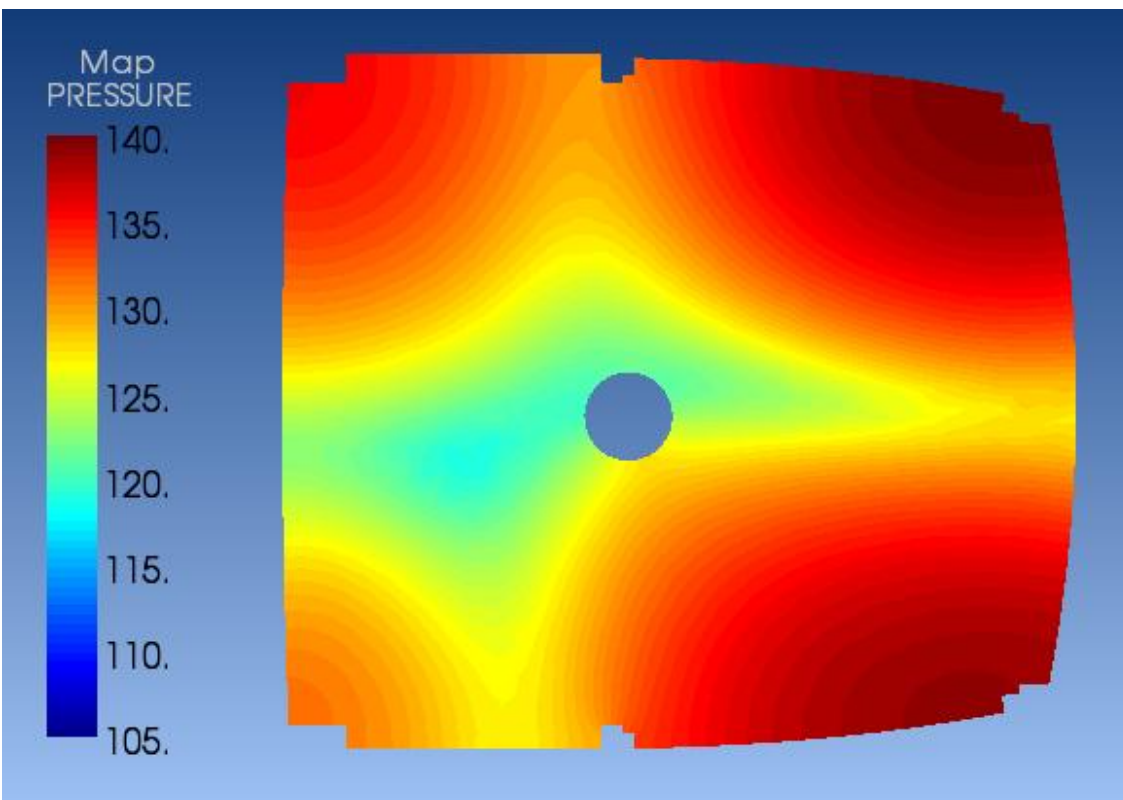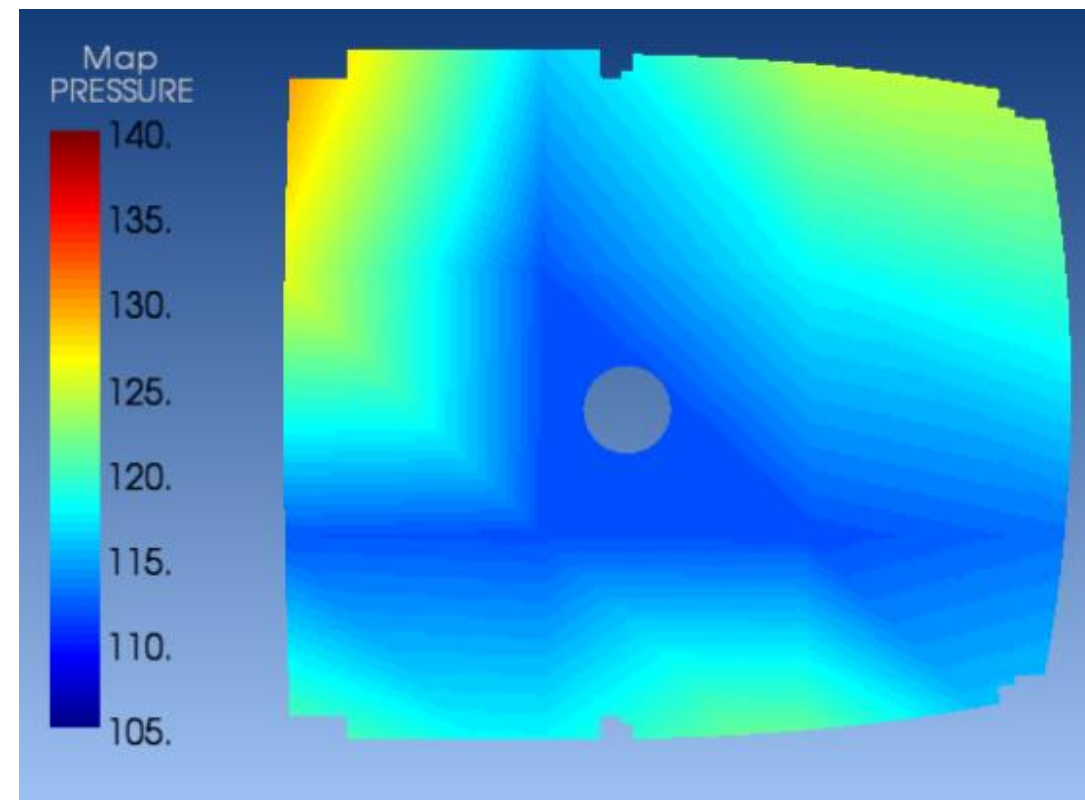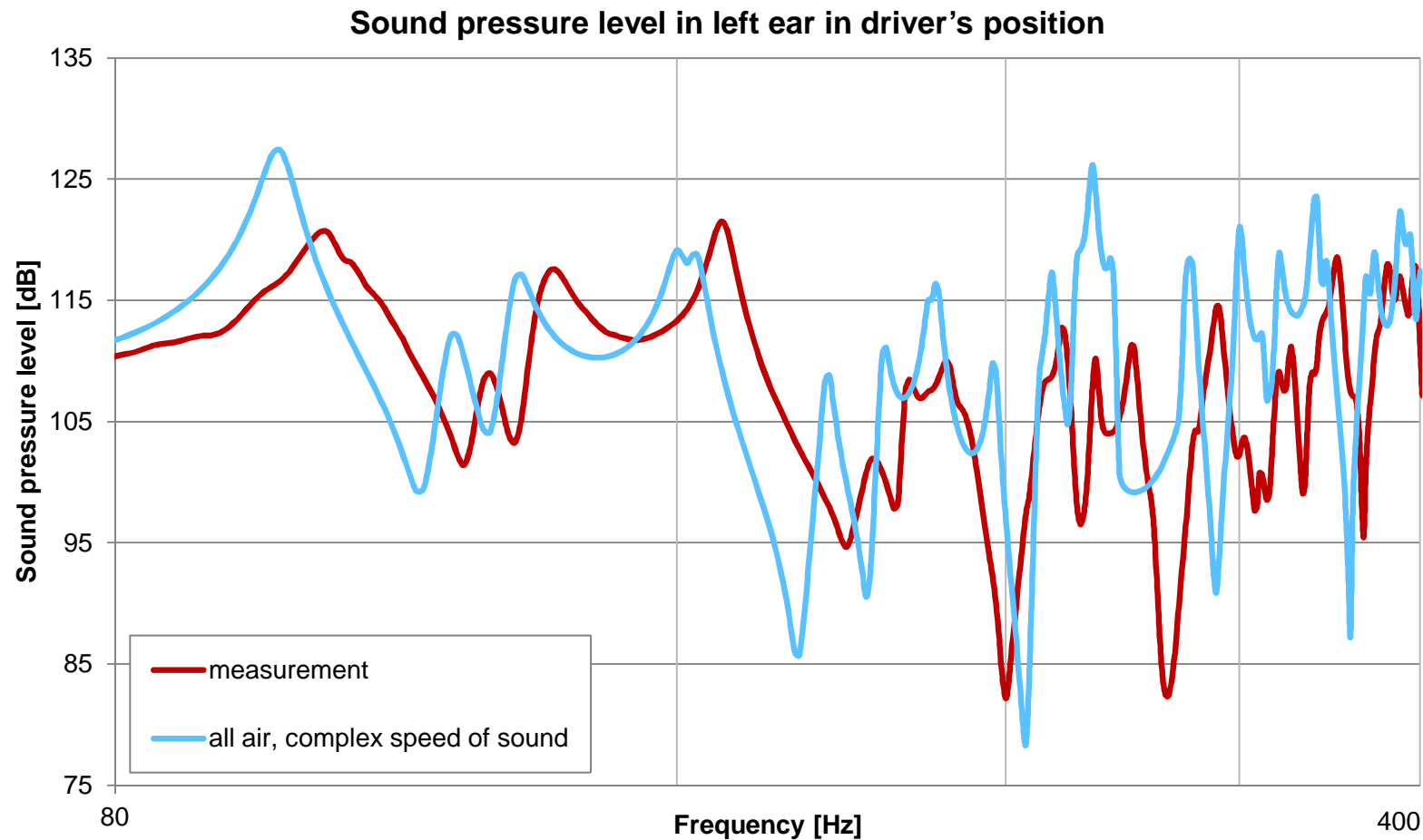## Empty cabin, cross section at the level of ears, 1/3 oct.

Model   200 Hz   Measurements

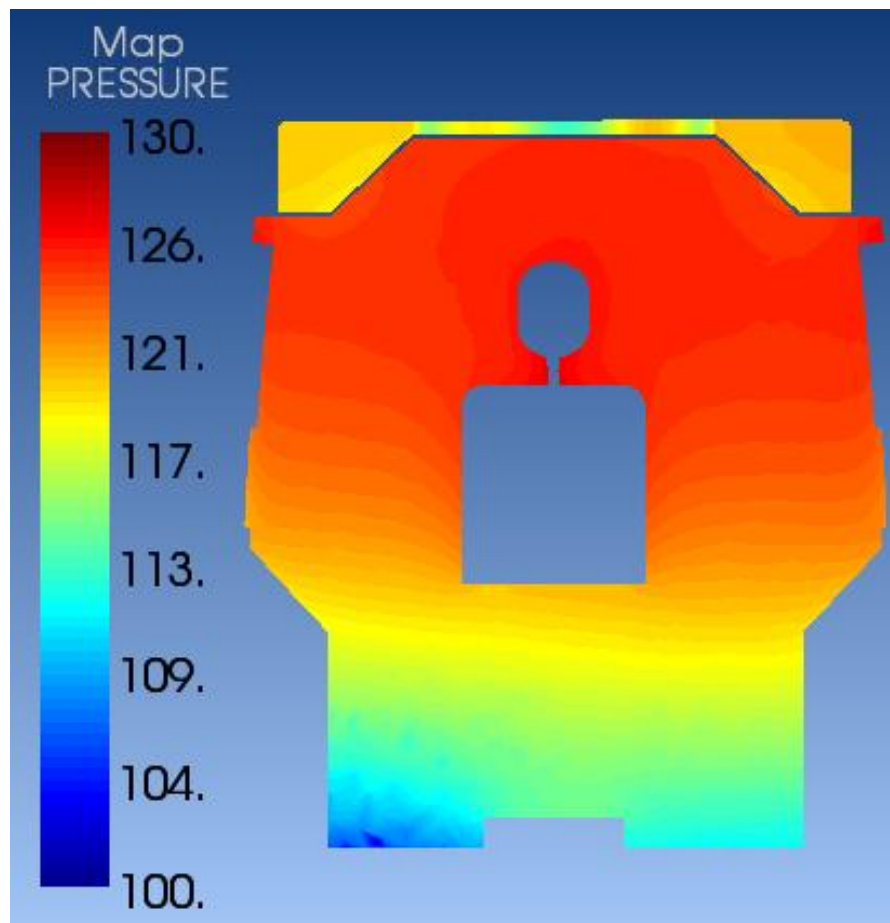# Response to internal loudspeaker (6)
Response in ears of HATS
Measurement vs. calculated globally damped empty cabin

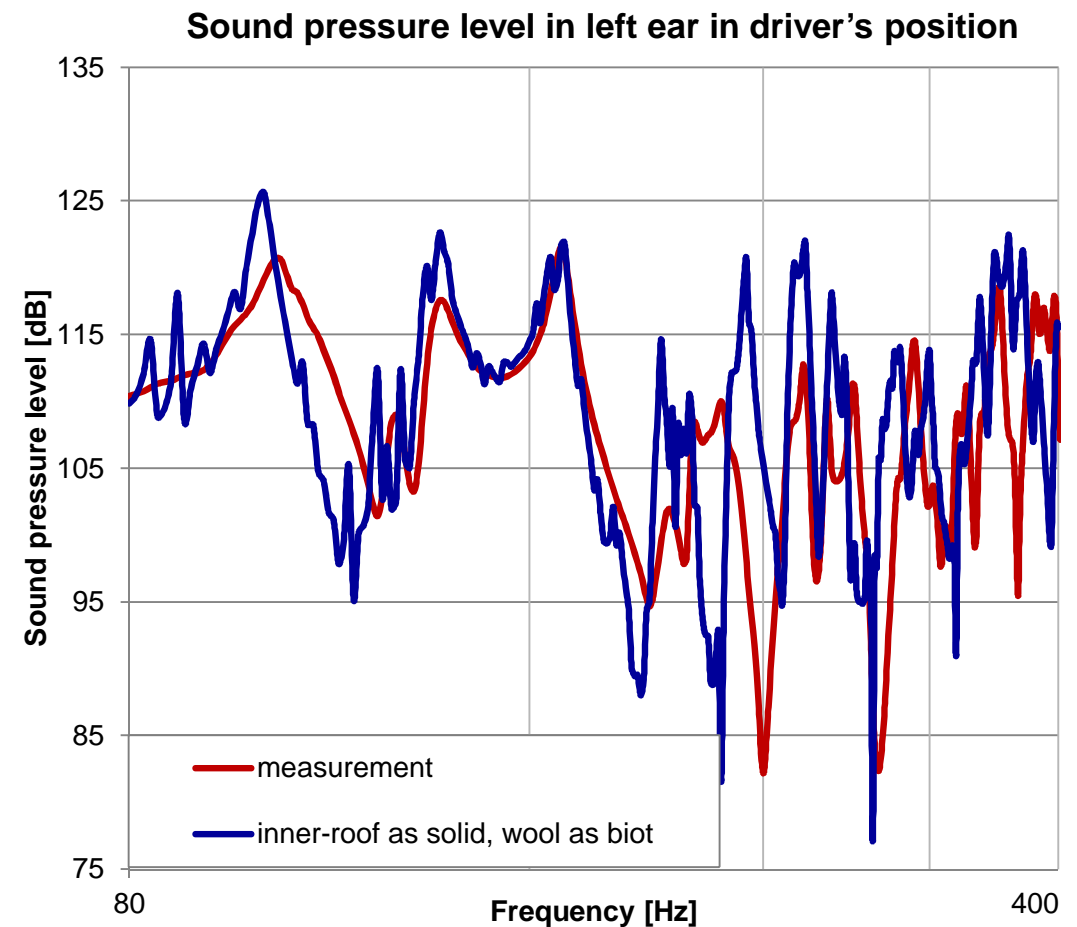**Sound pressure level in left ear in driver's position**

Response to internal loudspeaker (7)
Cabin with inner roof
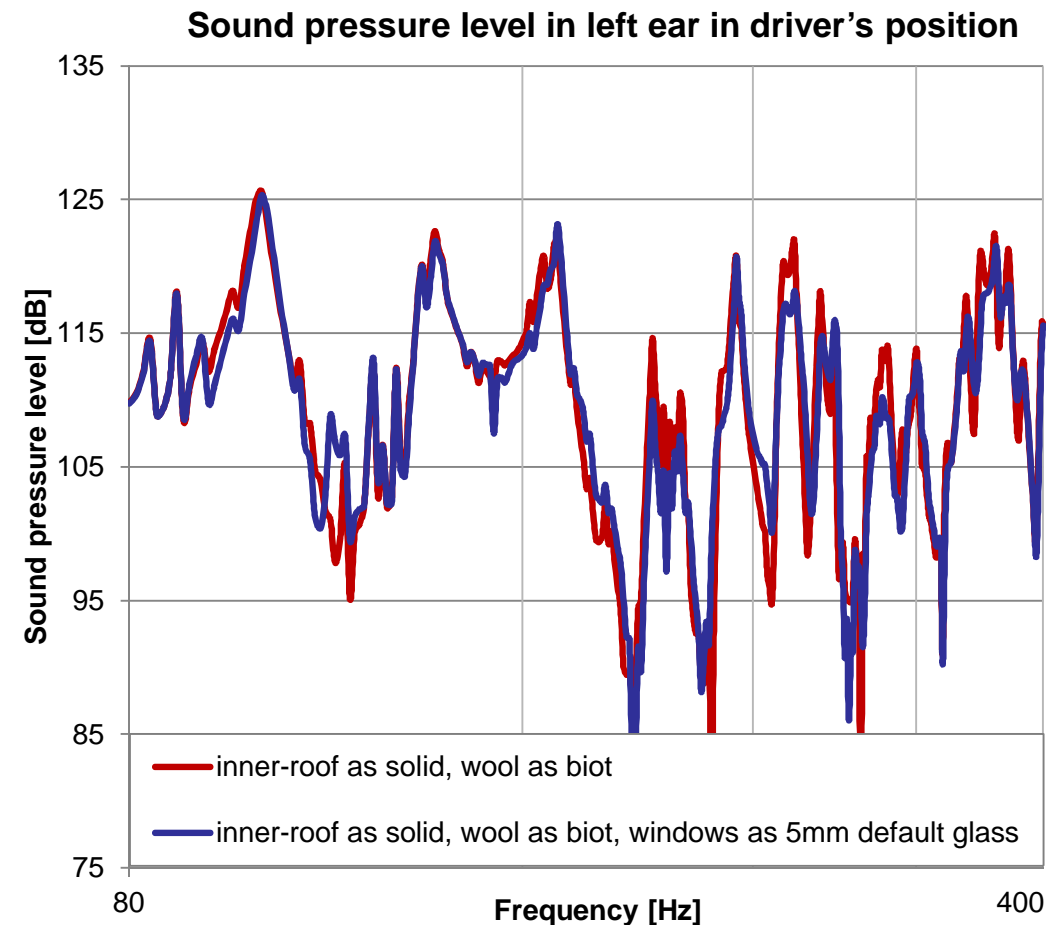## Measurement vs. calculated globally damped cabin with inner roof modeled as solid, wool as porous (Biot's model)
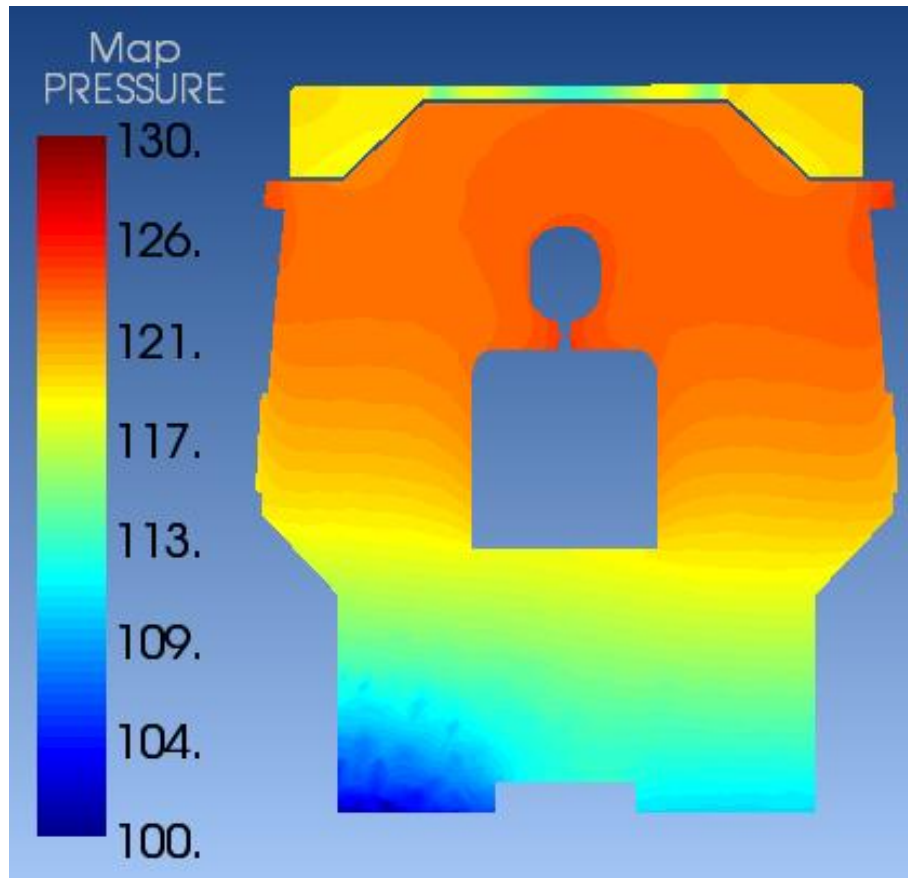

100 Hz

Response to internal loudspeaker (8)

Effect of window vibrations in cabin with inner roof, calculated
Globally damped cabin with inner roof as solid, wool as porous (Biot's model), windows as 5 mm thick default glass, edges of windows fixed

100 Hz

Response to internal loudspeaker (9)
Empty cabin, windows and steel chassis included, calculated
Globally damped empty cabin vs. globally damped empty cabin with windows as 5 mm thick default glass, body as 3 mm thick of default steel, edges of windows fixed

100 Hz
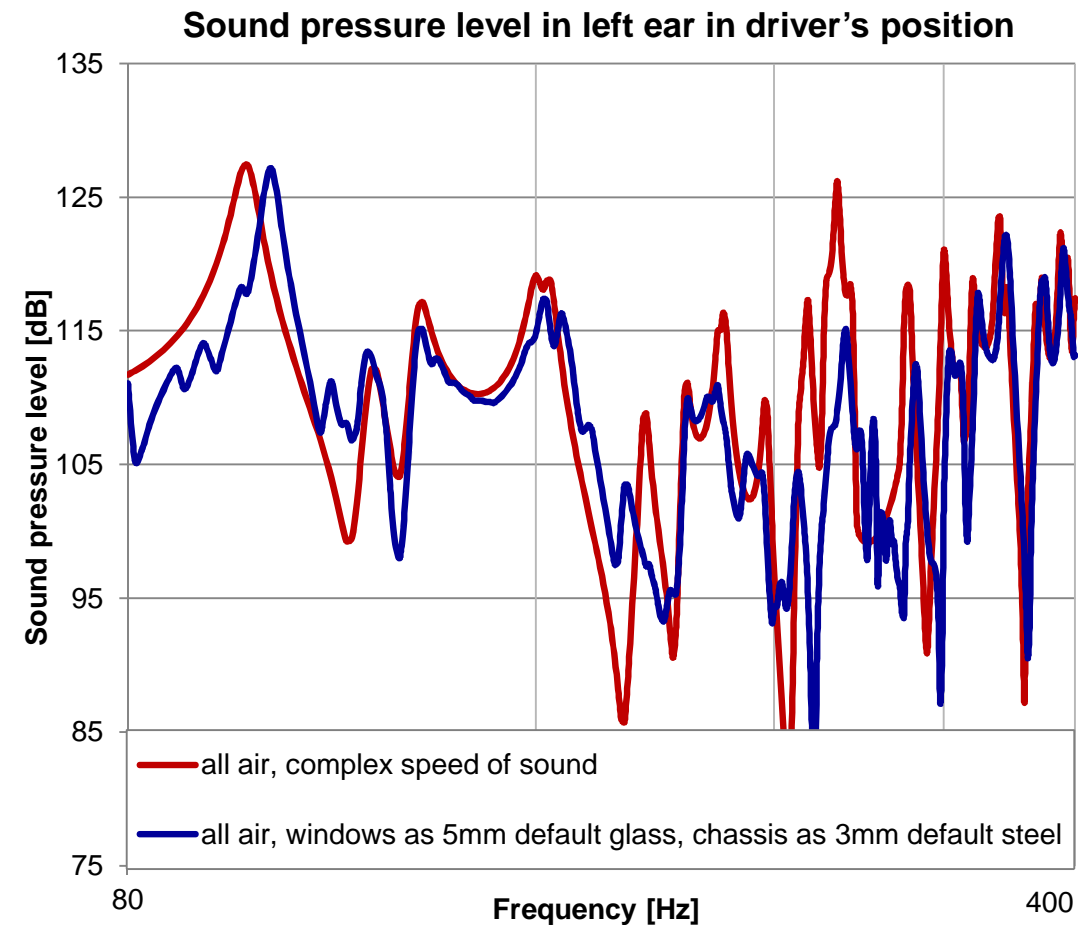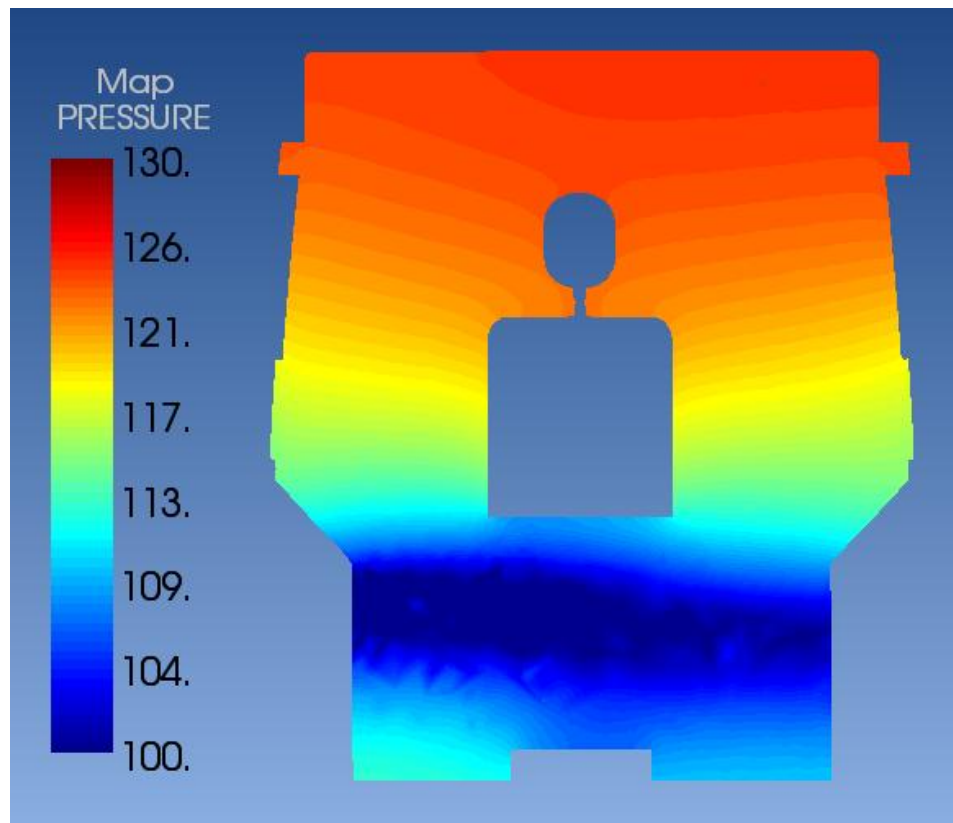
Response to internal loudspeaker (10)
Inner roof, windows and steel chassis included
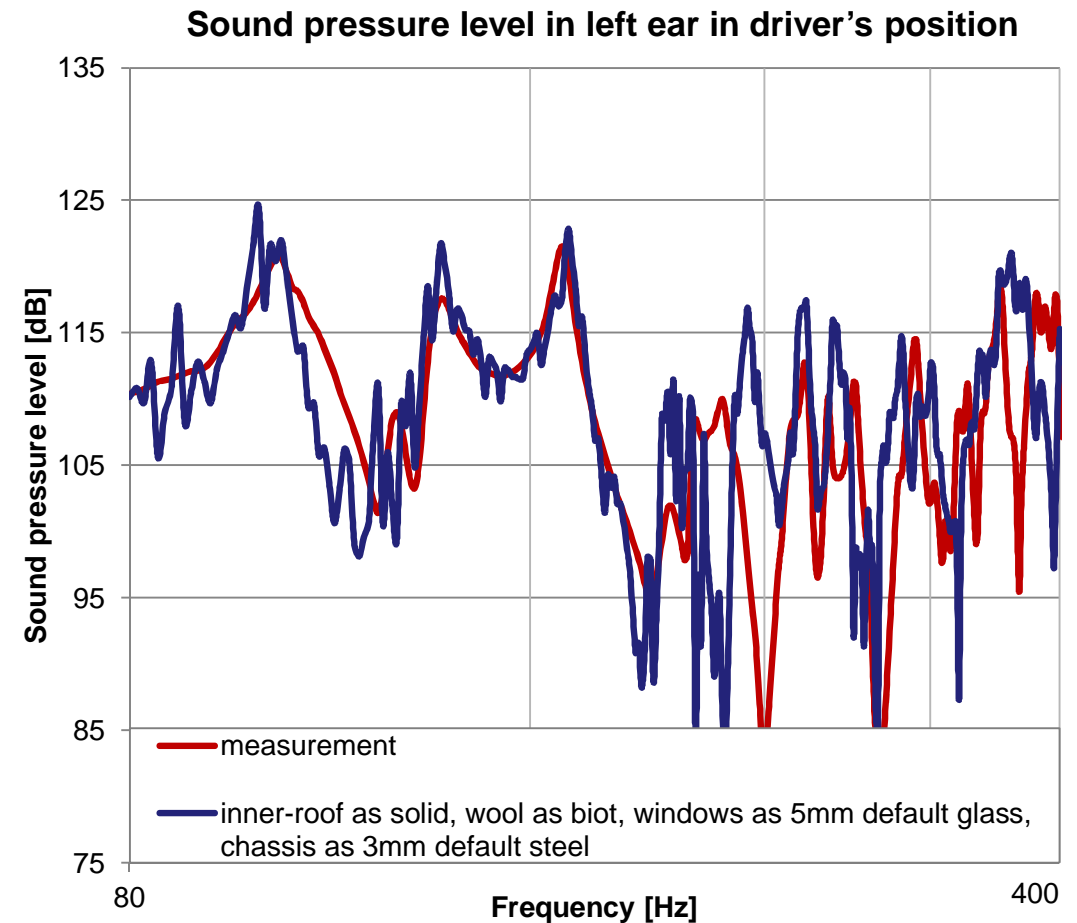## Measurement vs. calculated globally damped empty cabin with inner roof as solid, wool as porous (Biot's model), windows as 5 mm thick default glass, body as 3 mm thick of default steel

100 Hz

Sound pressure level in left ear in driver's position

— measurement

— inner-roof as solid, wool as biot, windows as 5mm default glass, chassis as 3mm default steel
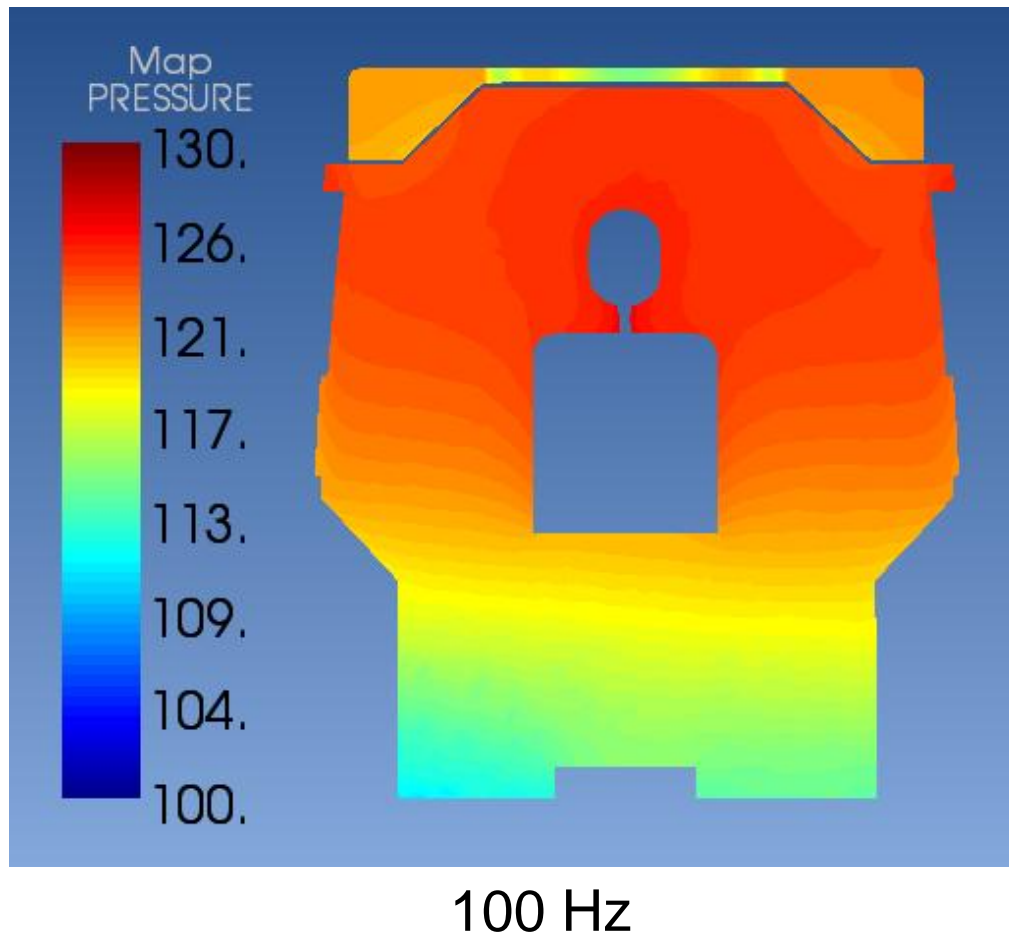
Response to internal loudspeaker (11)
100 Hz 1/3 octave band, ear level, calculated
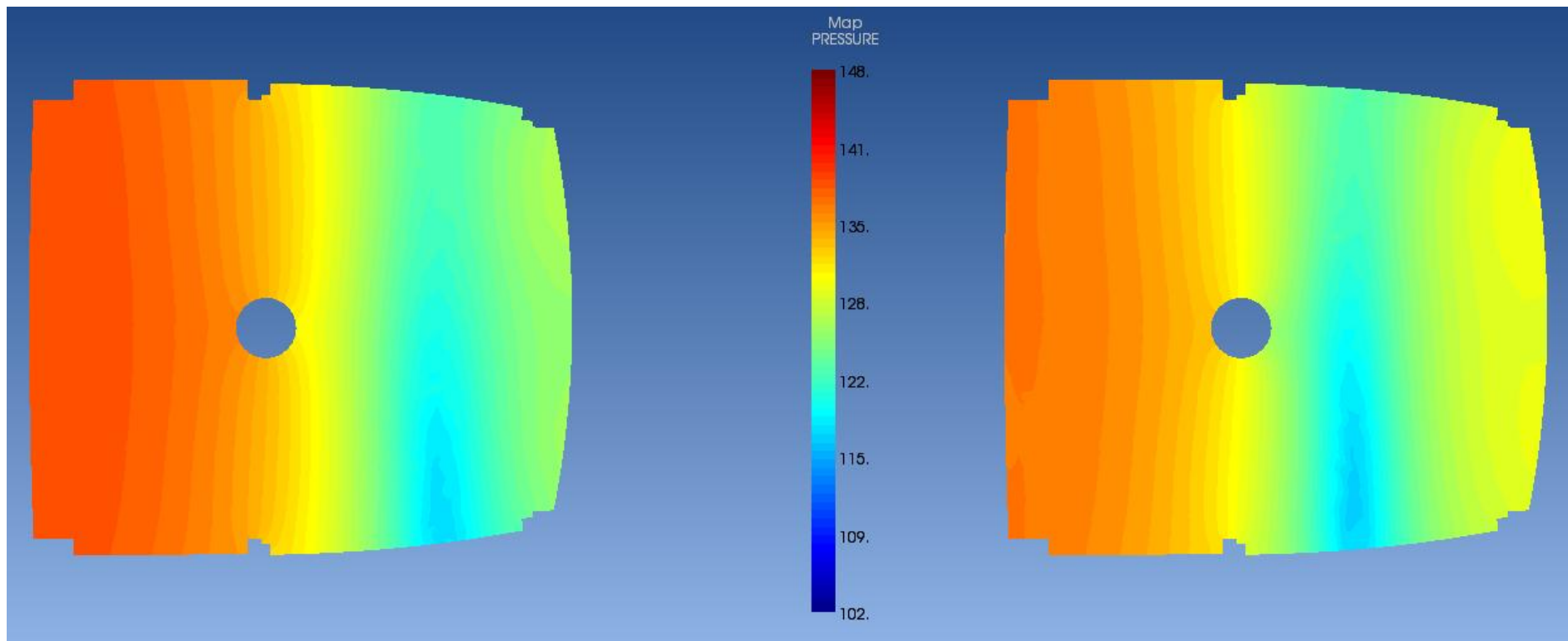
without inner roof   with inner roof

Response to internal loudspeaker (12)
100 Hz 1/3 octave band, ear cross section, calculated

without inner roof

with inner roof

Response to internal loudspeaker (13)
125 Hz 1/3 octave band, ear level, calculated

without inner roof   with inner roof

Response to internal loudspeaker (14)
125 Hz 1/3 octave band, ear cross section, calculated

without inner roof   with inner roof

Response to internal loudspeaker (15)
160 Hz 1/3 octave band, ear level, calculated
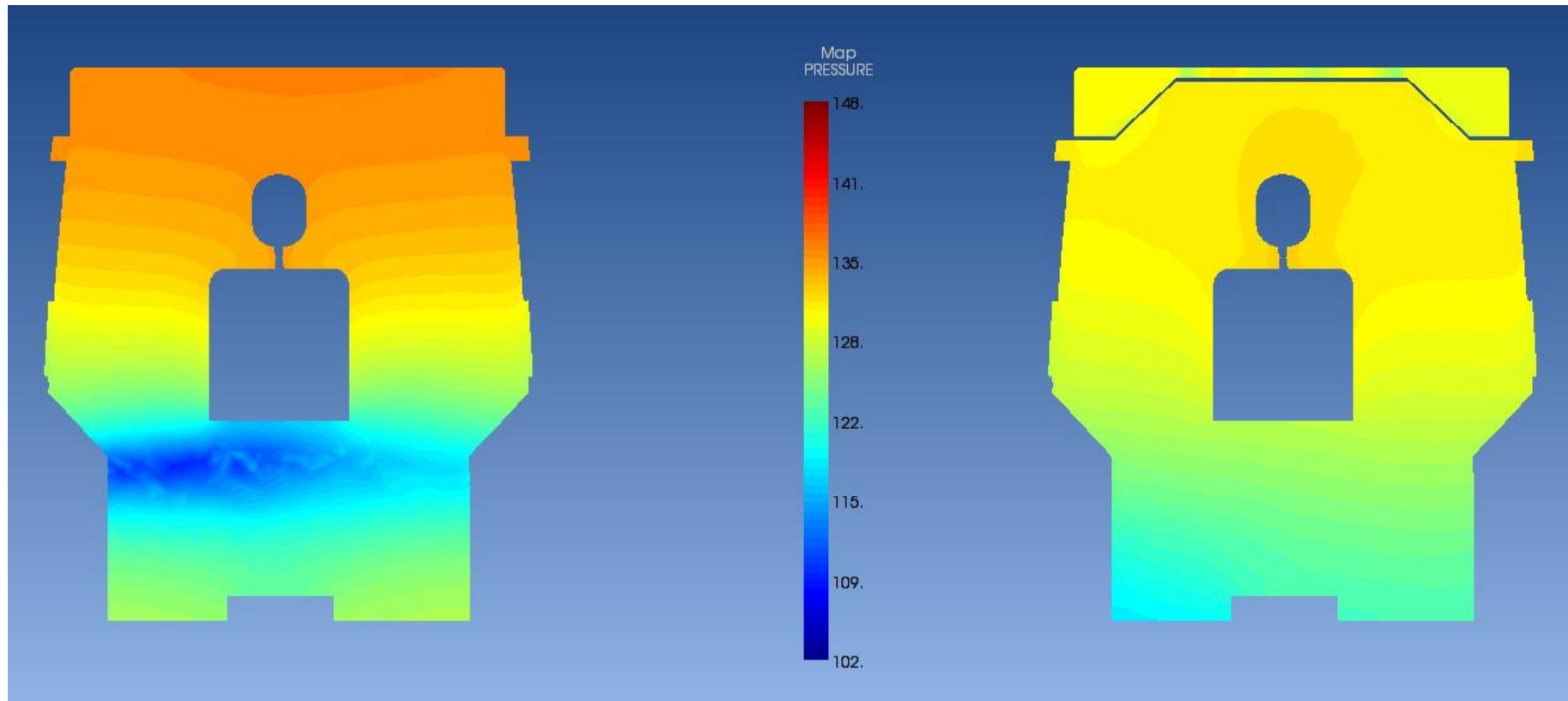

without inner roof   with inner roof

Response to internal loudspeaker (16)
160 Hz 1/3 octave band, ear cross section, calculated

without inner roof   with inner roof
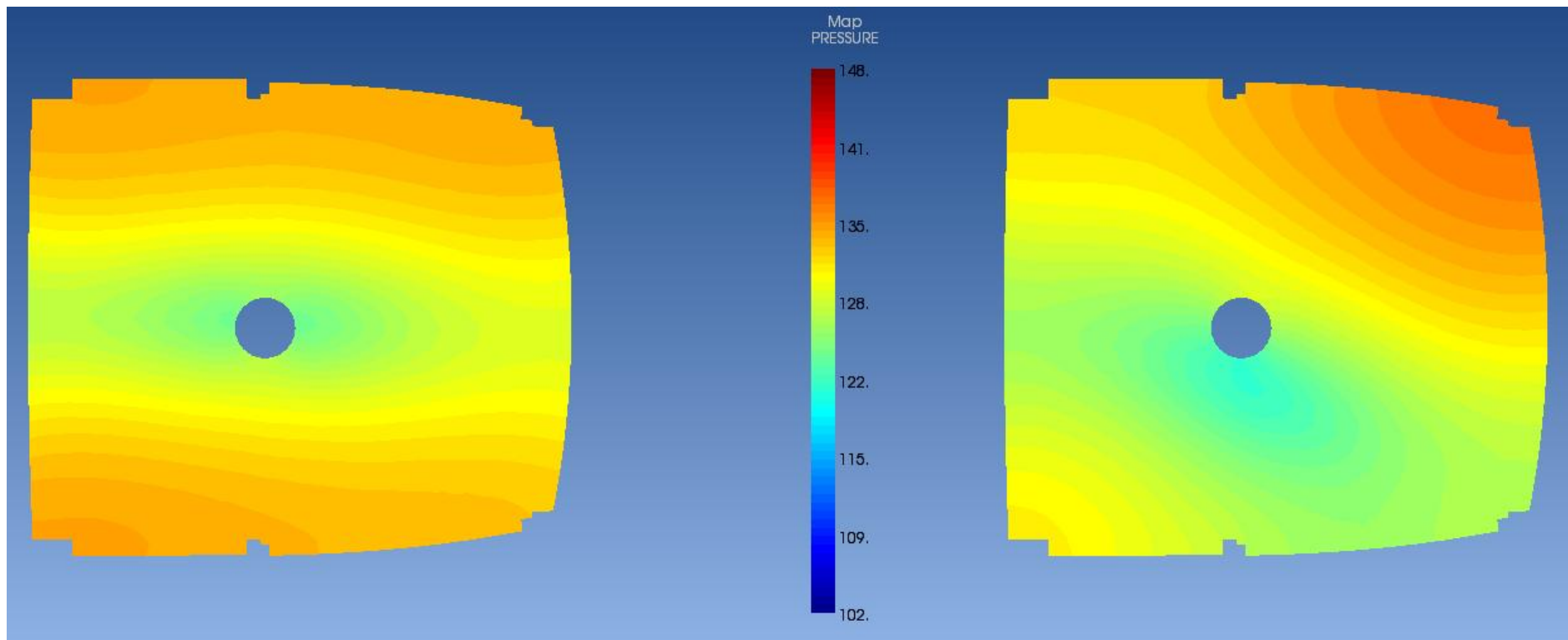
Response to internal loudspeaker (17)
200 Hz 1/3 octave band, ear level, calculated
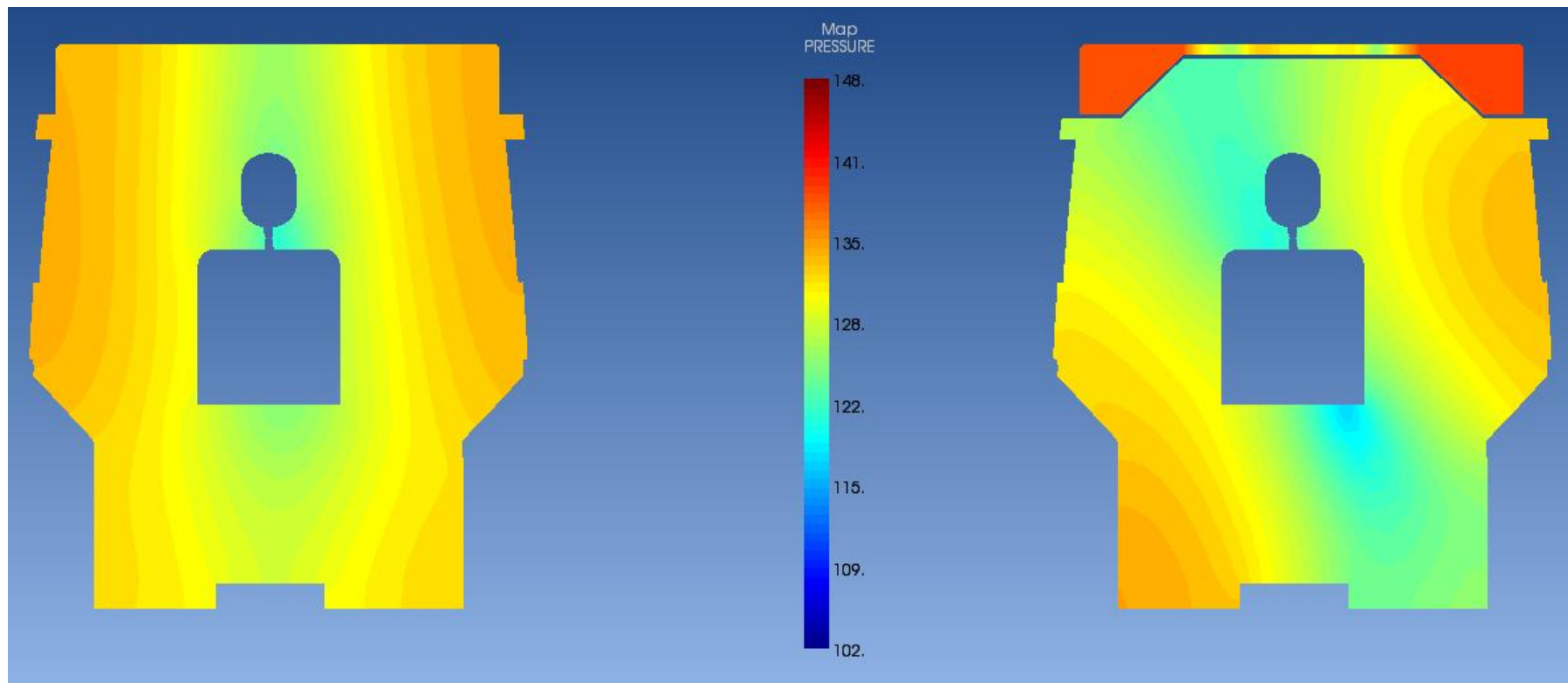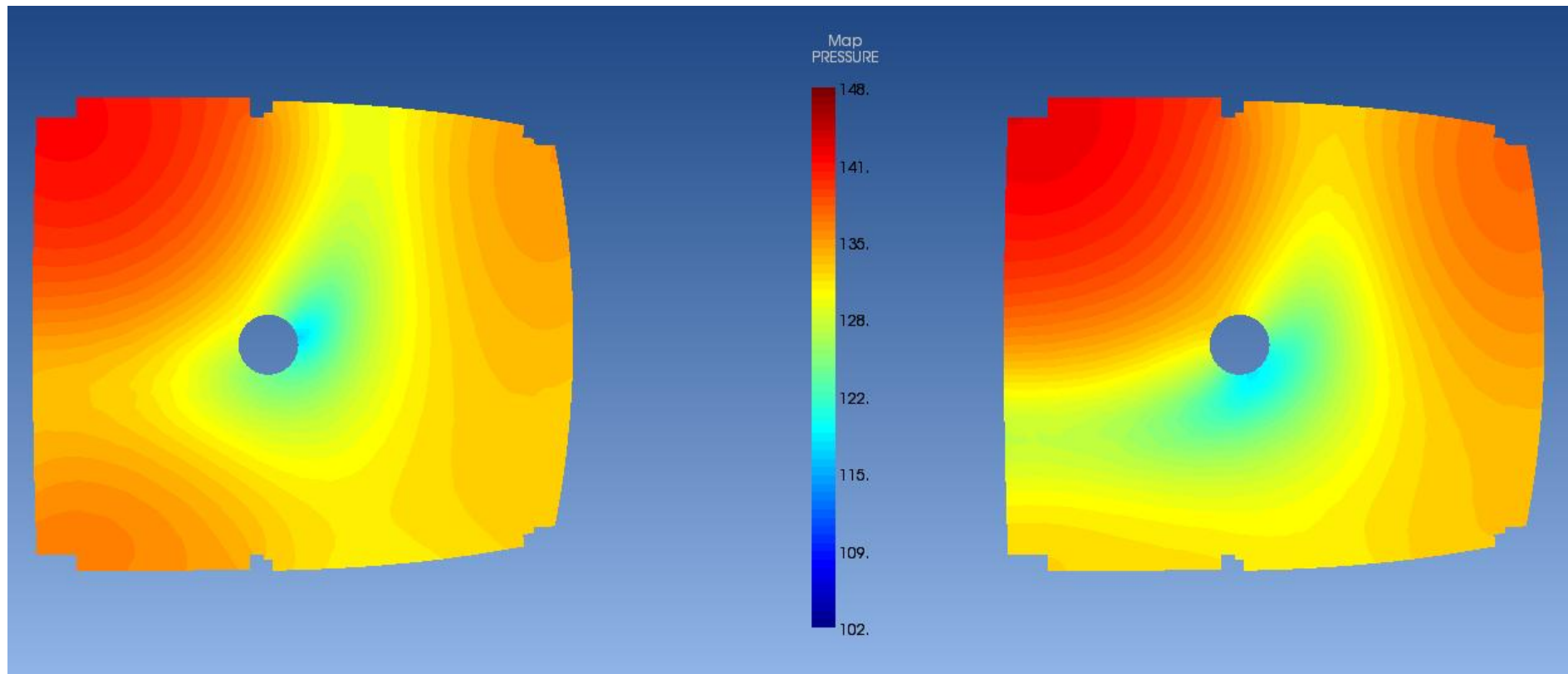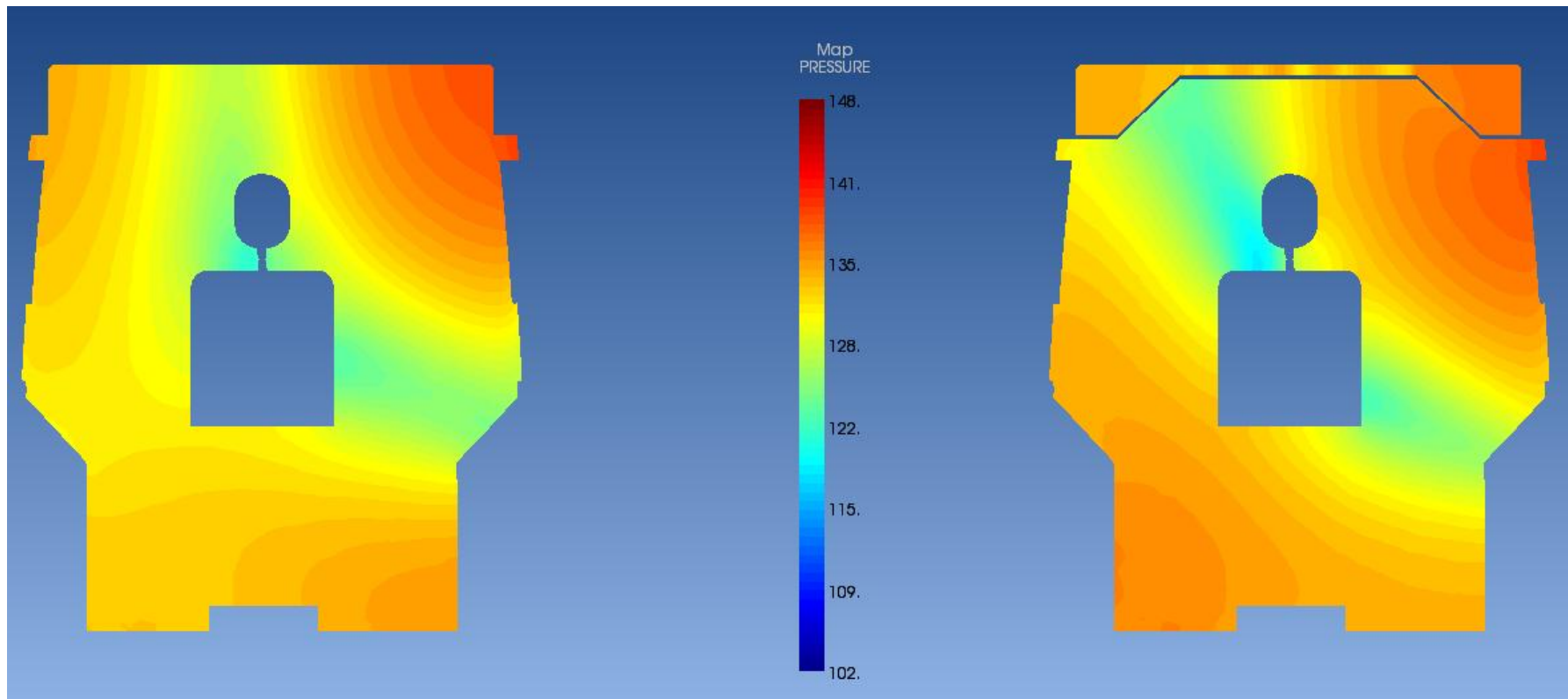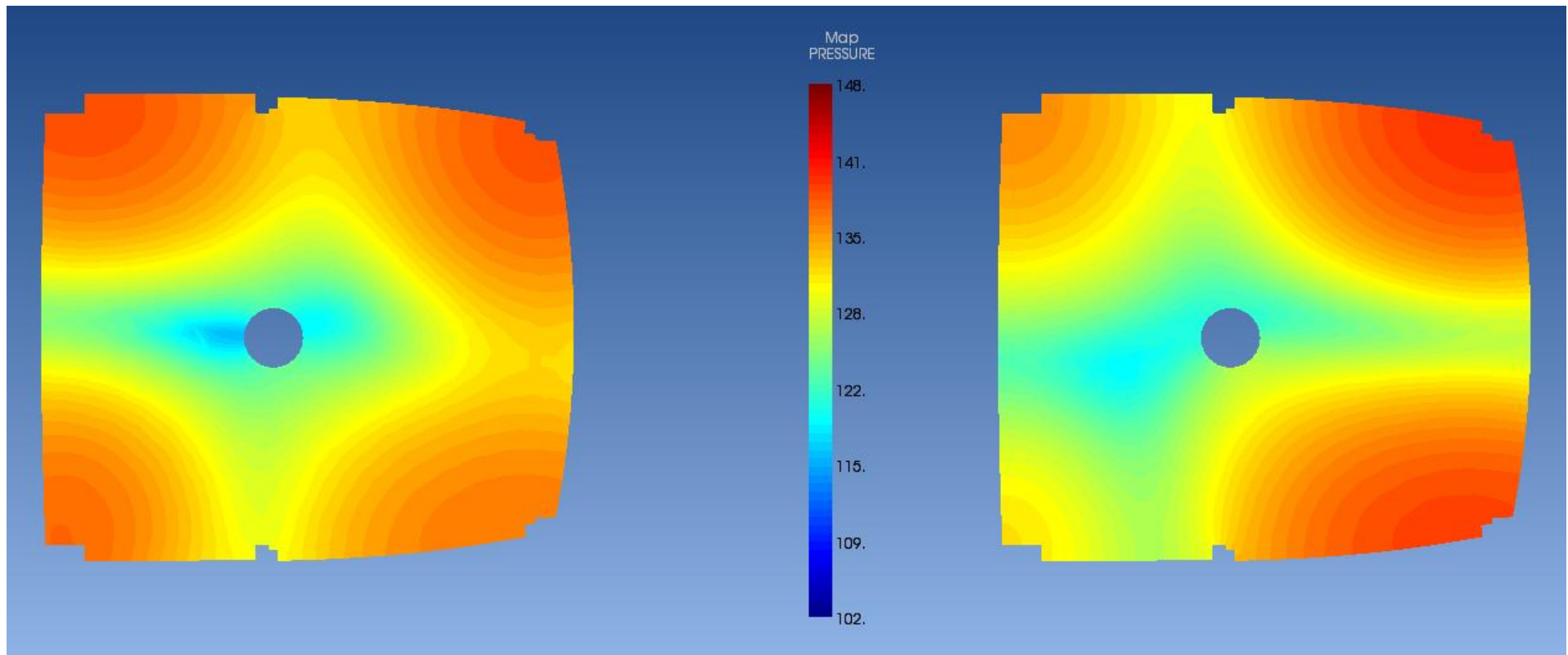

without inner roof   with inner roof

Response to internal loudspeaker (18)
200 Hz 1/3 octave band, ear cross section, calculated
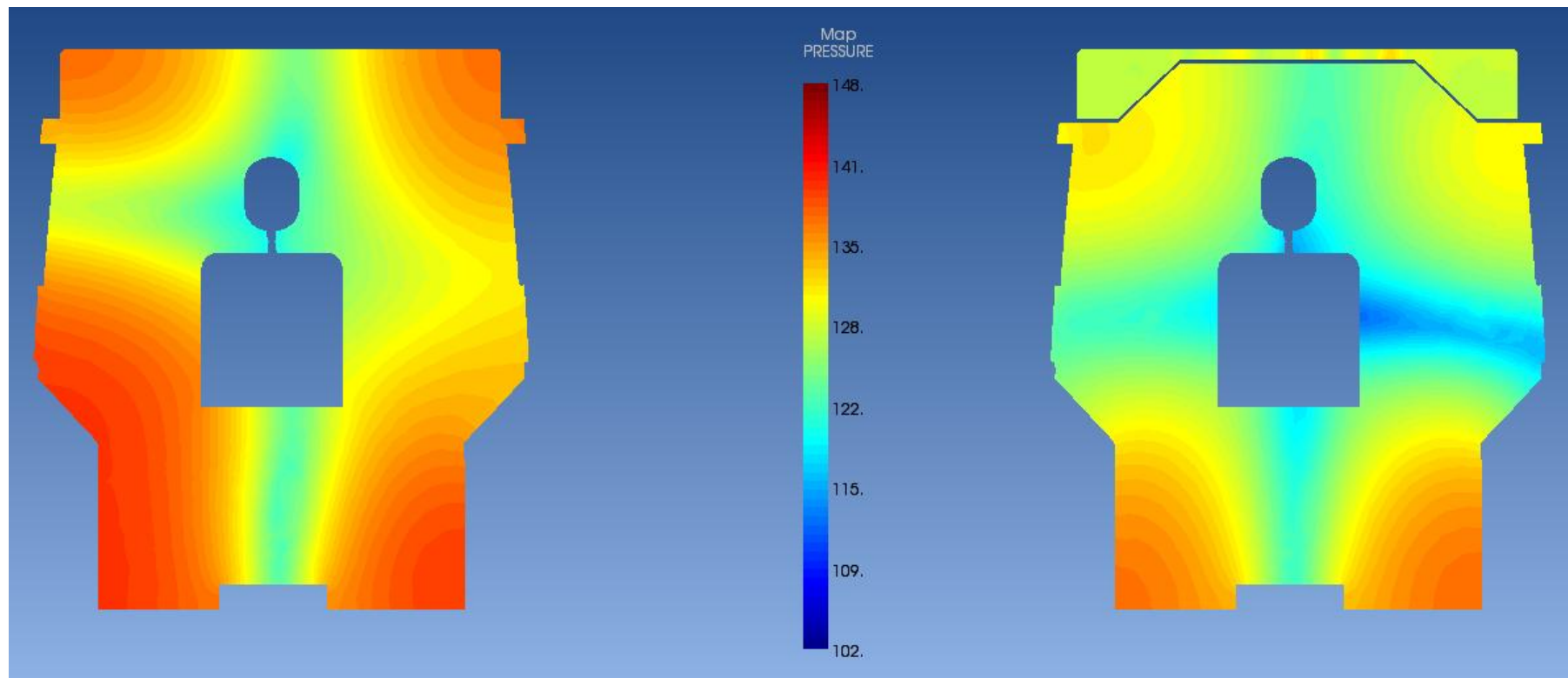
without inner roof   with inner roof

Response to internal loudspeaker (19)
Inner roof, windows and steel chassis included, calculated
Inner roof as solid, wool as porous & developed inner-roof material and MEL as wool

Sound level in left ear in drivers position
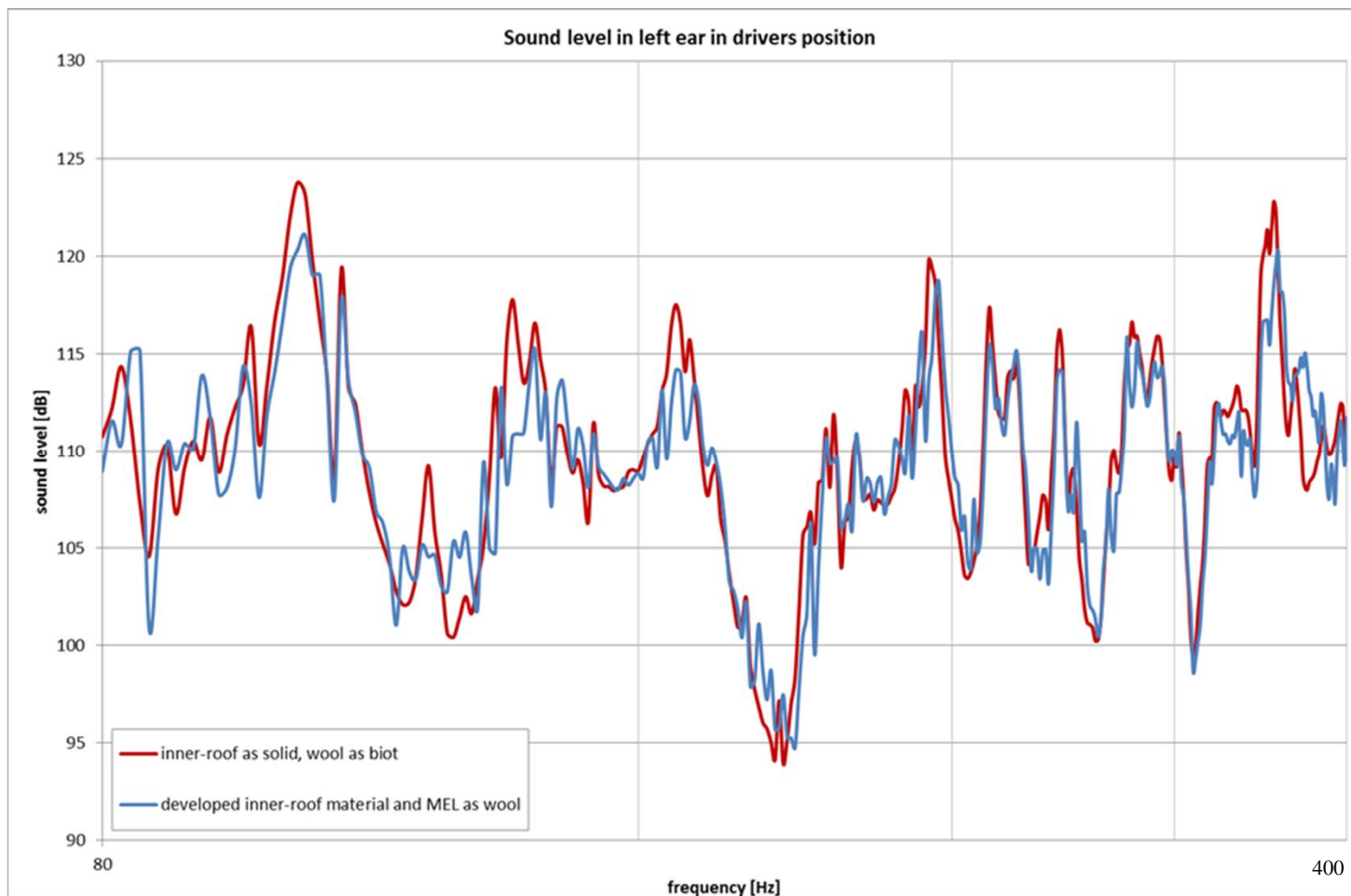
Response to internal loudspeaker (20)

- Calculated field distributions rather similar to measured ones
  - Amplitudes do not agree very well
- Inner roof affects the calculated response most towards the measured one
  - Glasses and chassis do not affect that much
- Inner roof
  - Reduces sound pressure levels
  - Affects sound field distributions

Calculated response to structure-borne sound (1)
Excitation at front vibration isolator

Sound pressure level in left ear in driver's position
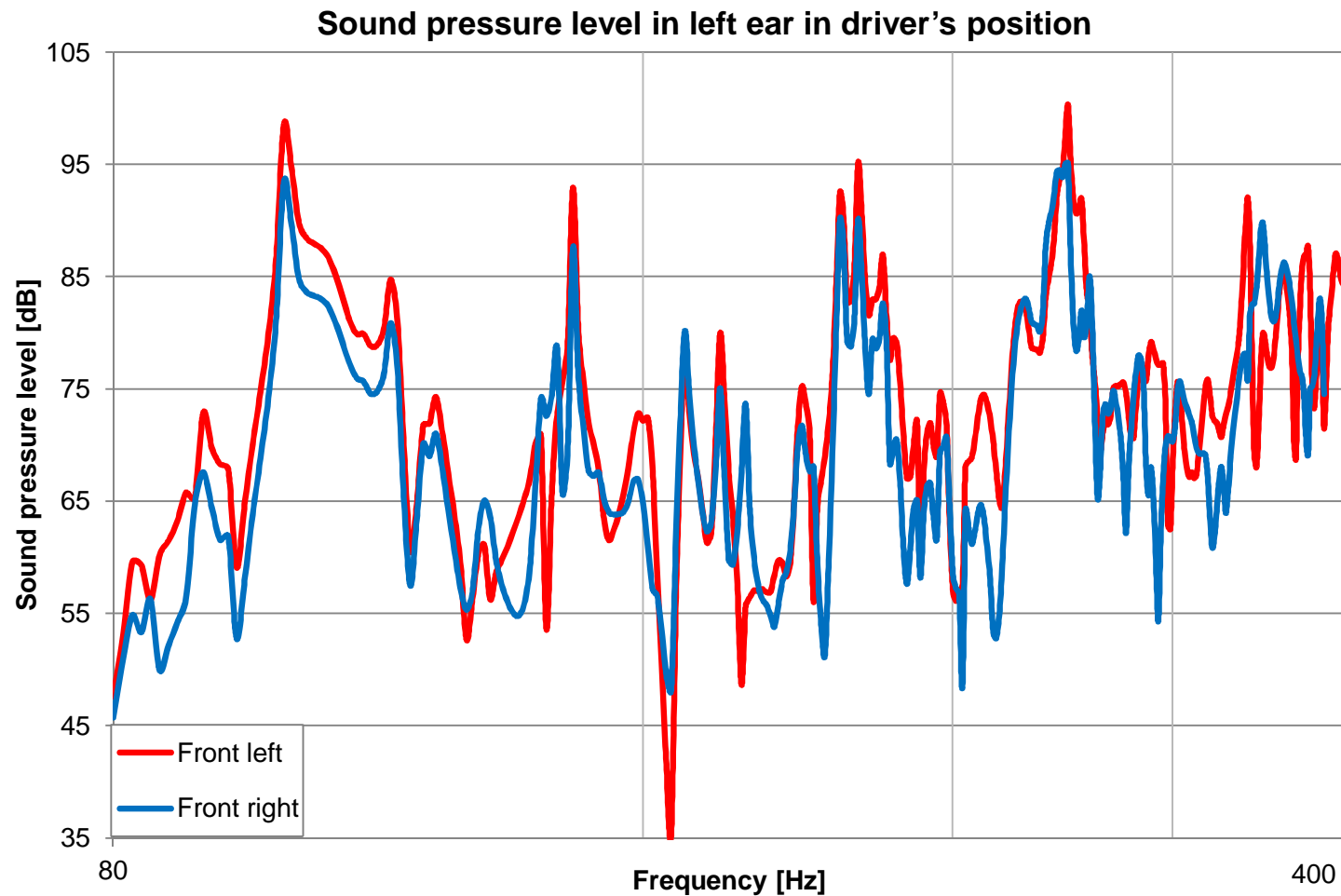
Calculated response to structure-borne sound (2)
Excitation at back vibration isolator

Sound pressure level in left ear in driver's position
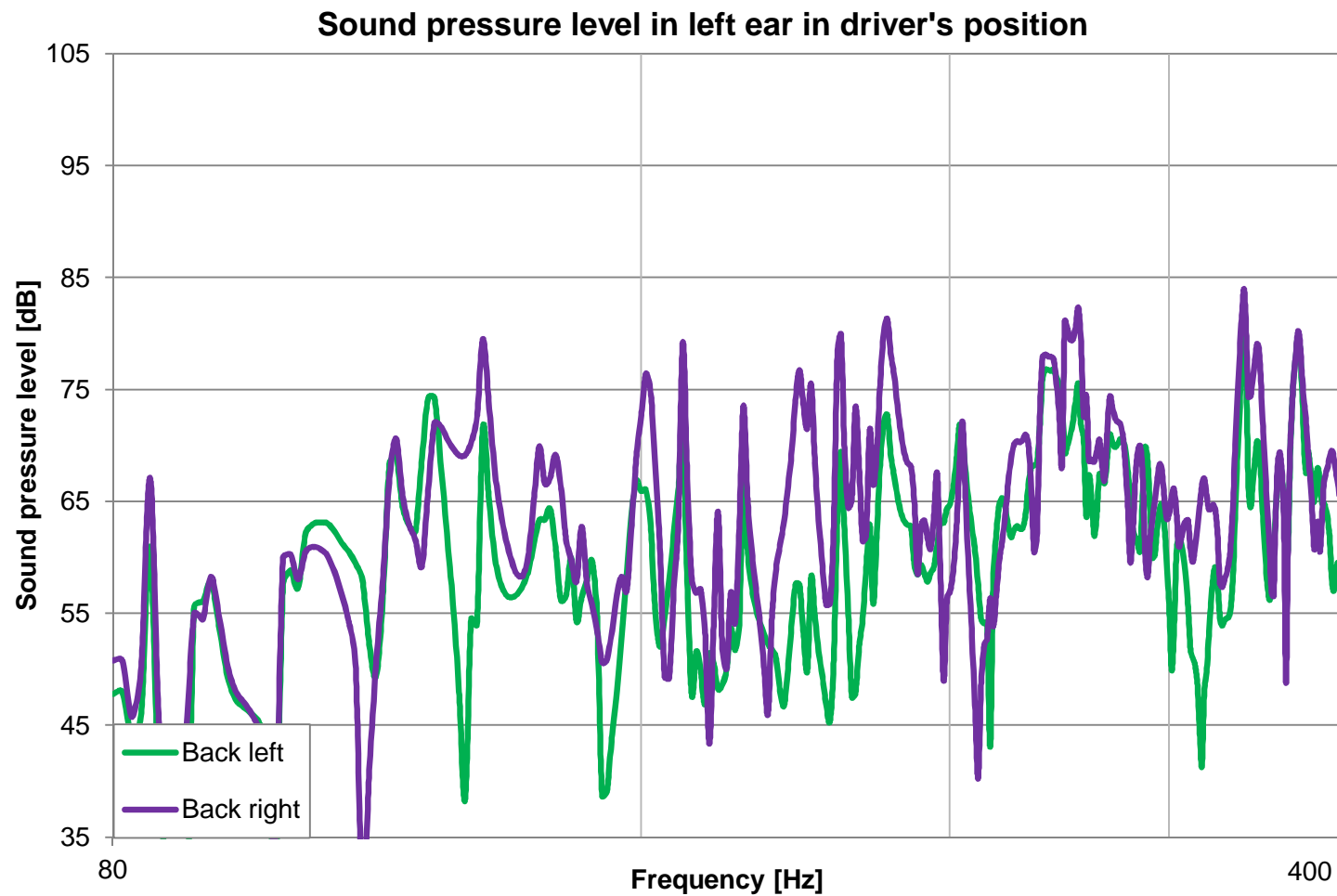
Calculated response to structure-borne sound (3)
Excitation at all vibration isolators, different phases

Sound pressure level in left ear in driver's position

Legend:
- All in phase (red)
- Front 90 deg, back 0 deg (green)
- Front 0 deg, back 90 deg (purple)

Y-axis: Sound pressure level [dB] (35 to 105)
X-axis: Frequency [Hz] (80 to 400)
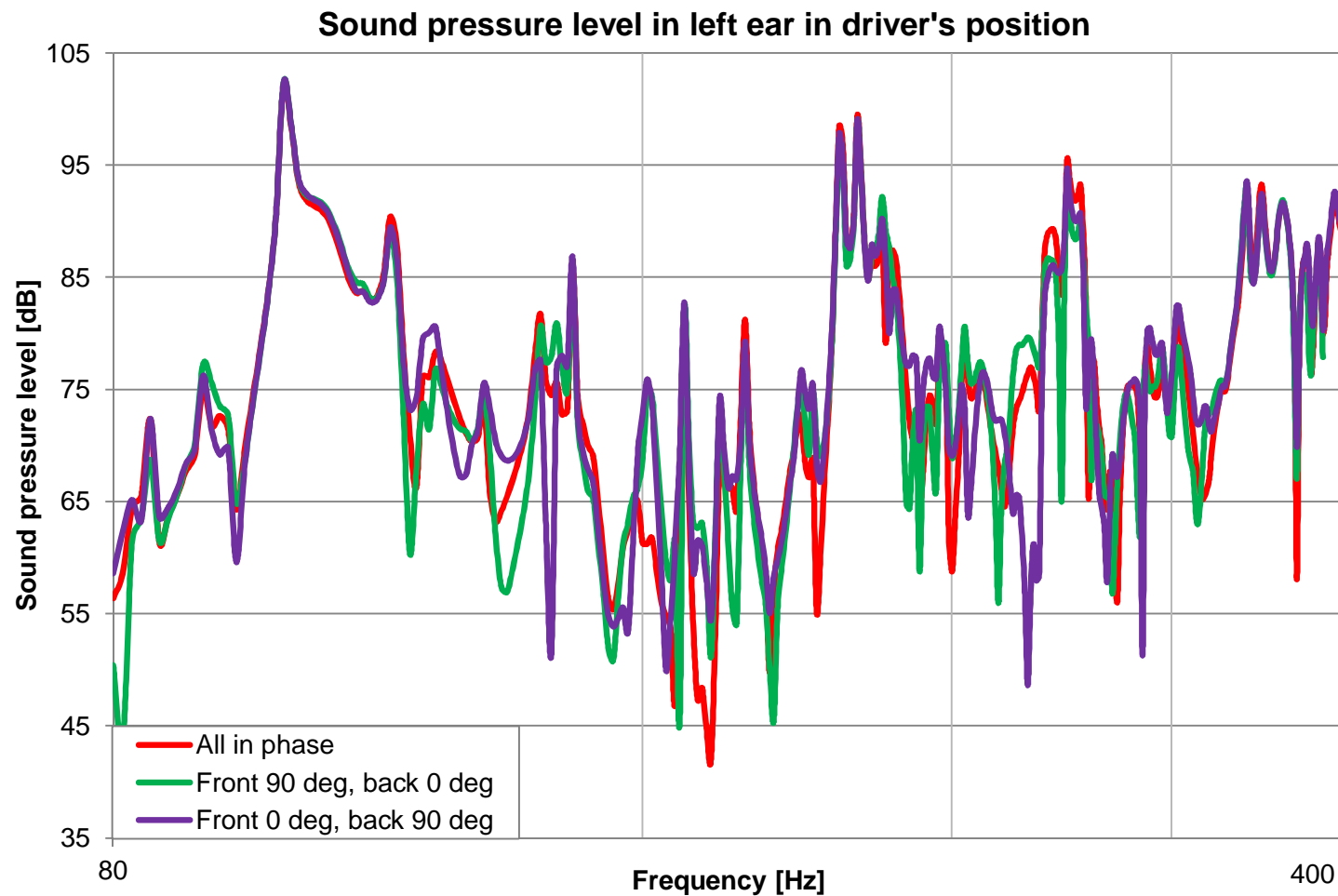
Calculated response to structure-borne sound (4)

- With the same excitation, more sound originates from front vibration isolators
- Mutual phases of excitations only have a minor effect

Calculated response to external diffuse sound field excitation (1)

Structure displacement magnitude (logarithmic) at 100 Hz
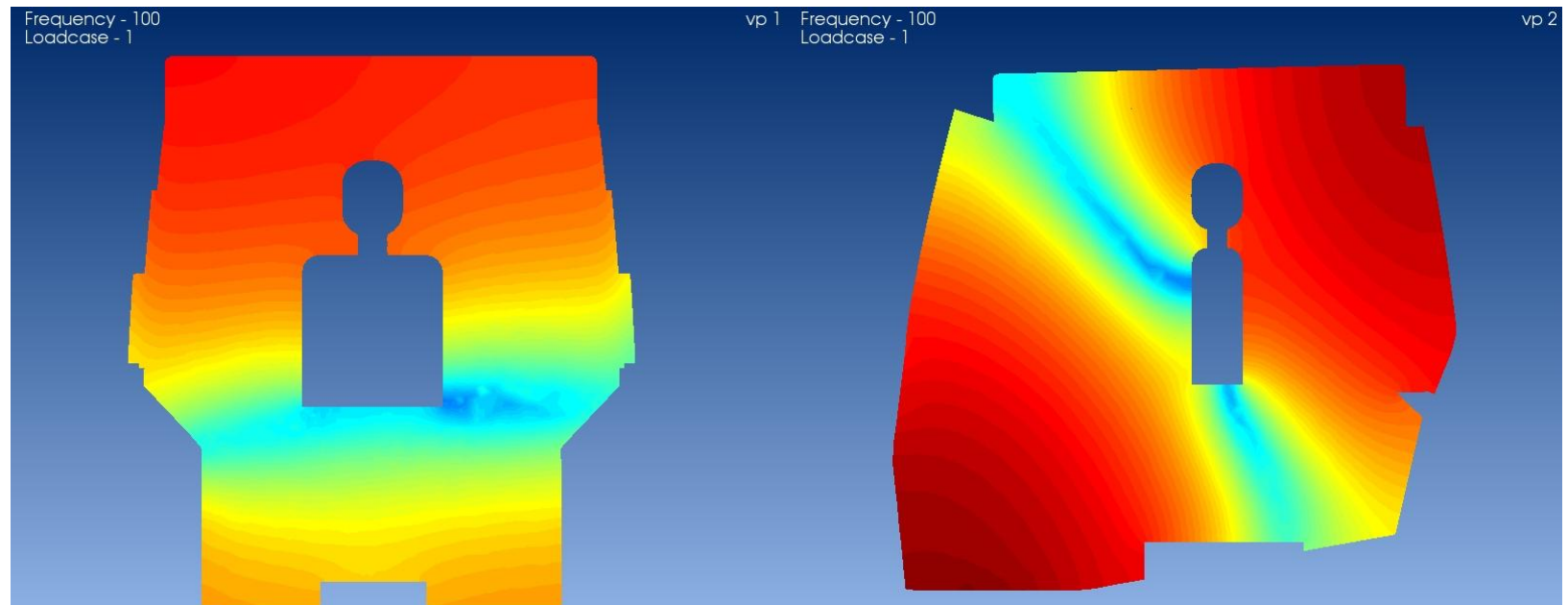
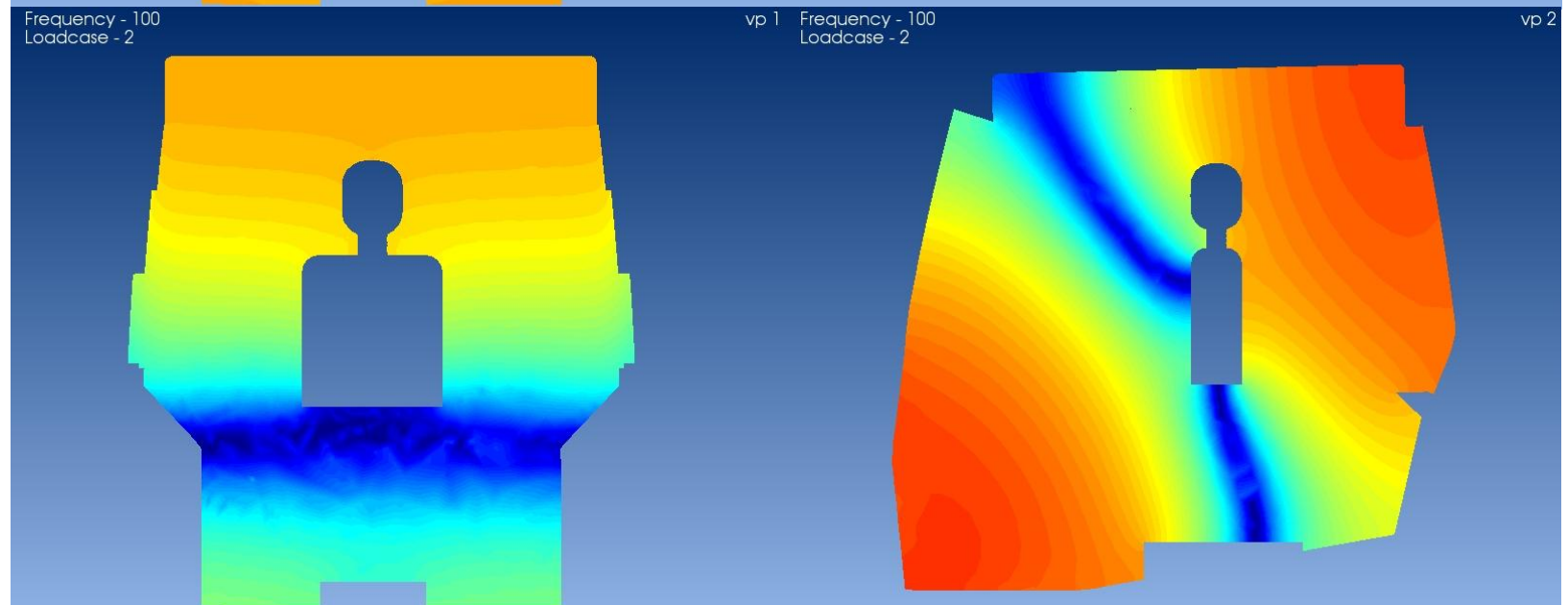## Diffuse sound field at exterior of walls, windows and floor
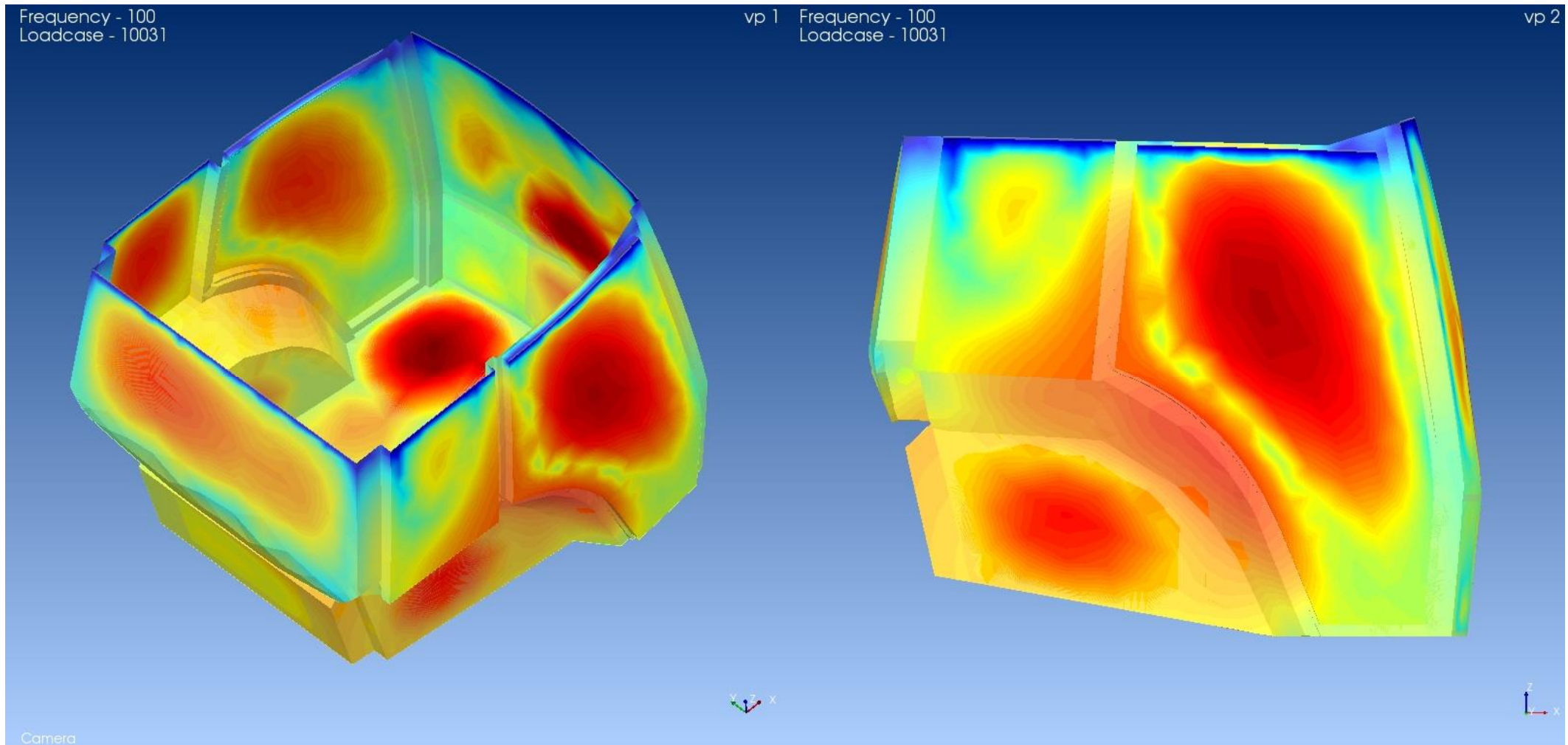
Calculated response to external diffuse sound field excitation (2)

Sound pressure level in cabin at 100 Hz

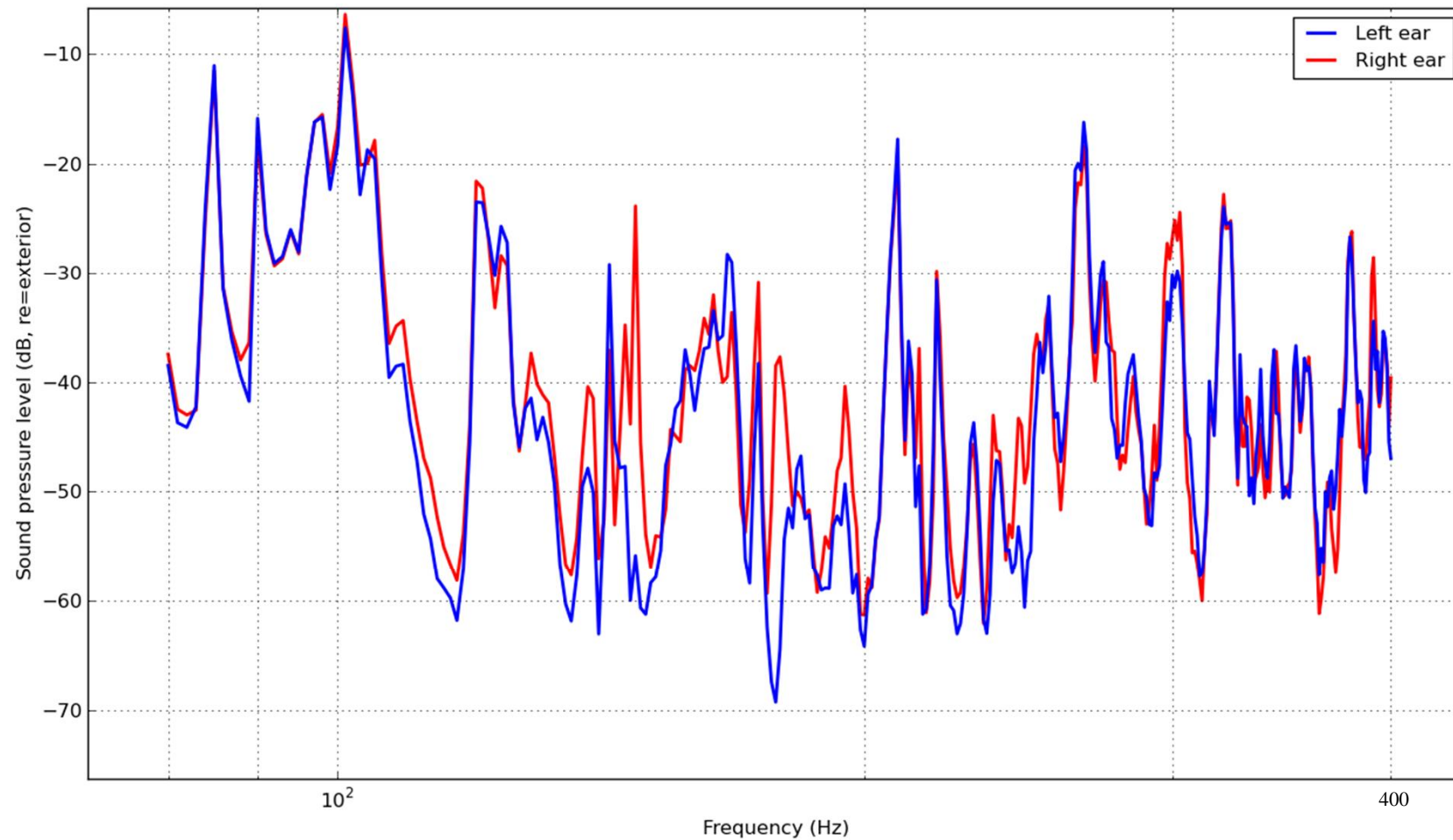**Diffuse sound field at all windows, walls and floor**

Diffuse sound field at upper front window

Calculated response to external diffuse sound field excitation (3)

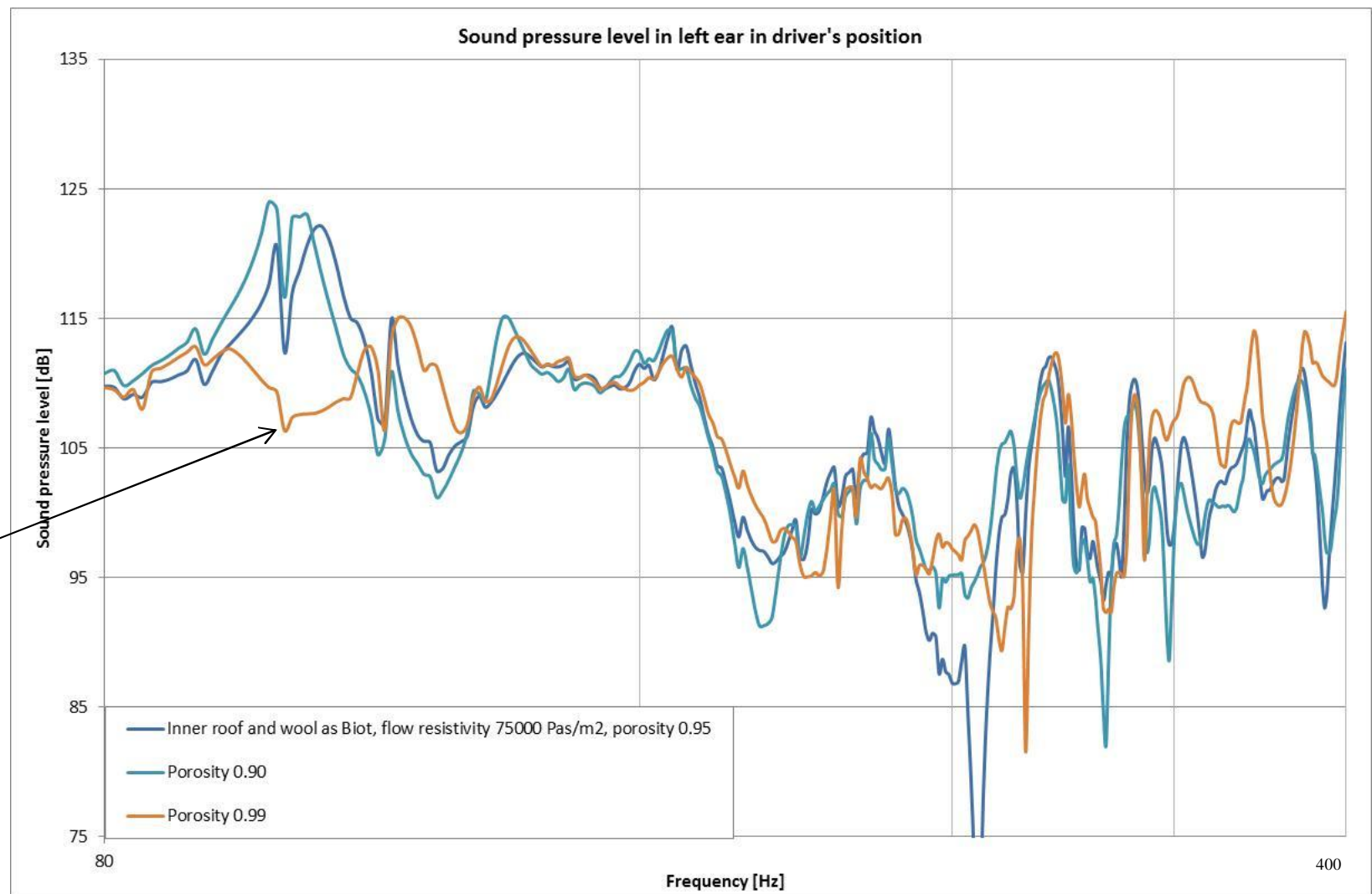## Response in ears of HATS
External diffuse sound field excitation

Parametric study for inner roof properties (1)

Porosity
Internal loudspeaker excitation

Increasing porosity leads to better absorption in the vicinity of 100 Hz peak

Parametric study for inner roof properties (2)
Flow resistivity
Internal loudspeaker excitation

Reducing flow
resistivity
leads to
slightly better
absorption in
the vicinity of
100 Hz peak

Sound pressure level in left ear in driver's position

Inner roof and wool as Biot, flow resistivity 75000 Pas/m2, porosity 0.95

Flow resistivity 35000 Pas/m2

Flow resistivity 100000 Pas/m2
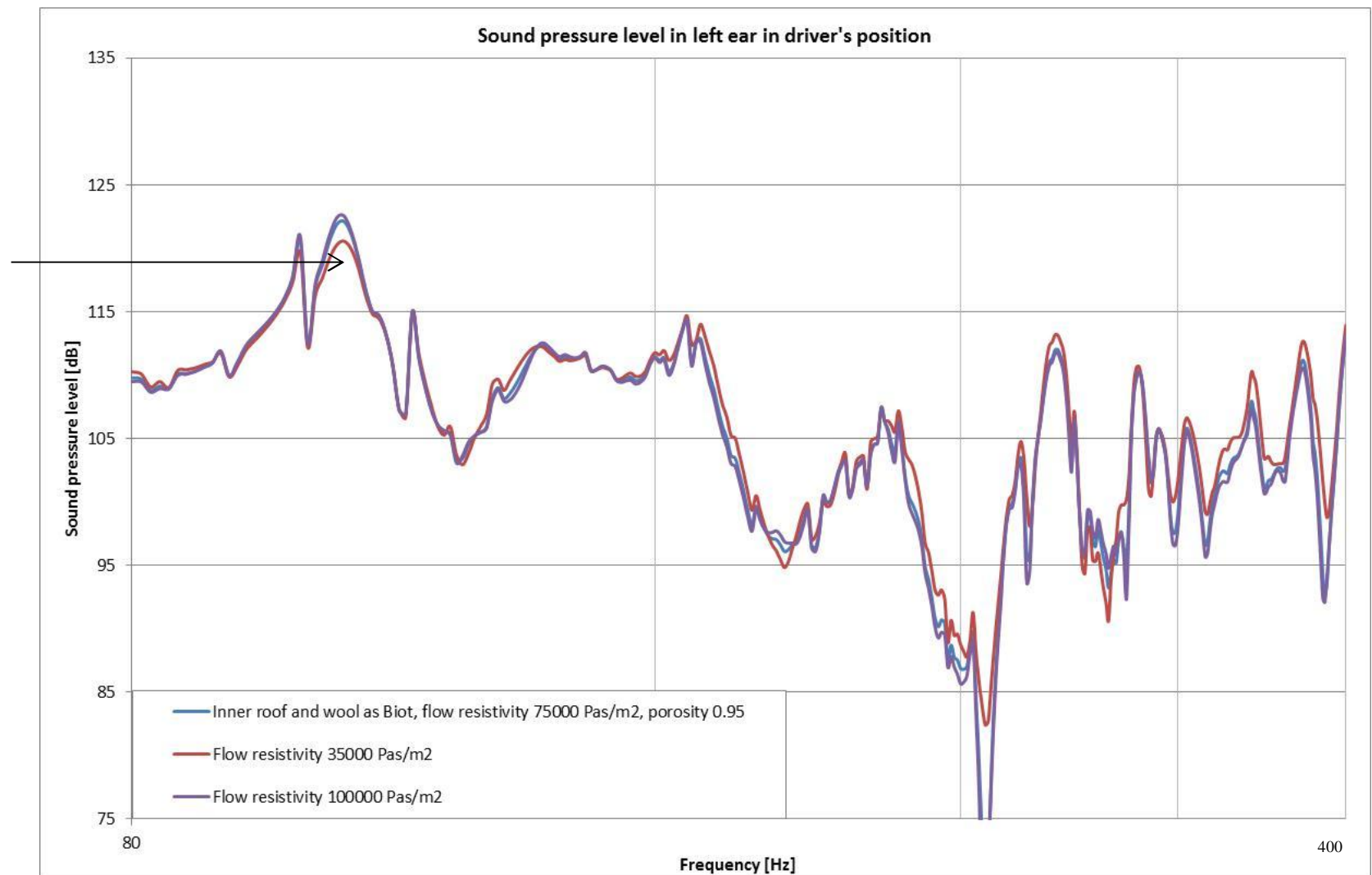
Parametric study for inner roof properties (3)
Tuning inner roof as panel resonator to 100 Hz
Internal loudspeaker excitation
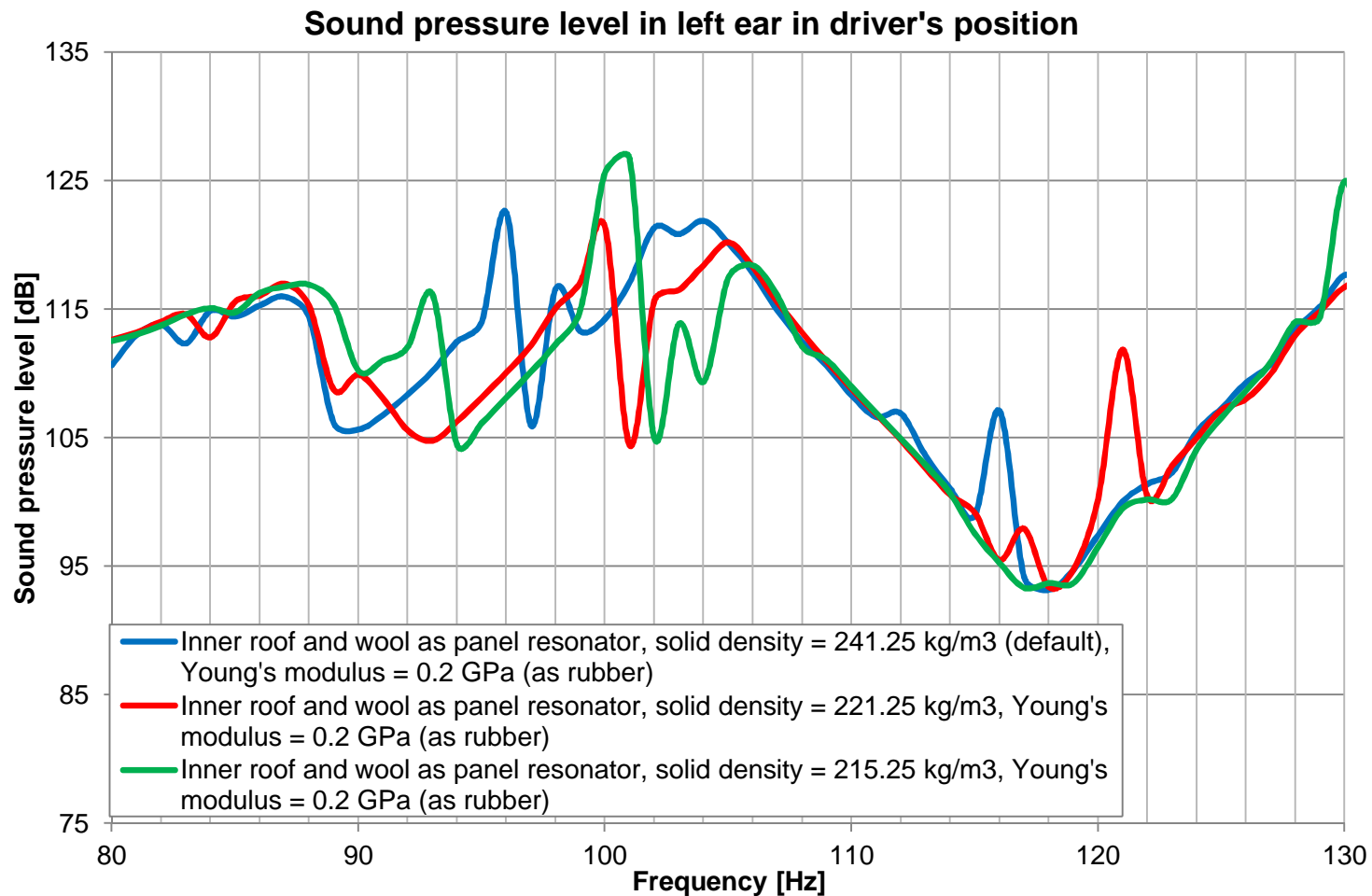
- Tuning is very sensitive to small changes
- Absorption band is very narrow
- Not very useful to be applied

We have now

- Cabinet interior and steel + glass + chassis structure model valid up to 400 Hz with and without the inner roof
    - Damping calibrated with the reverberation times
        - Some disagreement remains with respect to measurements
- Wool modeled with Biot's model (Actran database material)
- Inner roof modeled as solid and as porous Biot material

- Calculated example results with internal loudspeaker excitation and external diffuse sound field excitation

Future work

- Enhancing material models and models for glass (layers, viscoelasticity, mounting)
- Including acoustic radiation to exterior air
- Increasing frequency range from sub – 400 Hz
- Experimental validation of airborne sound model
- Sound field analysis with different inner roofs
- Vibration damping materials
- Virtual testing of different materials
- Model auralization

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