Presented at the COMSOL Conference 2008 Hannover

Identification of Noise Sources by Means of Inverse Finite Element Method

COMSOL Conference

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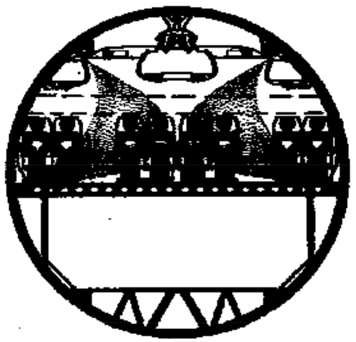
**Airbus Germany

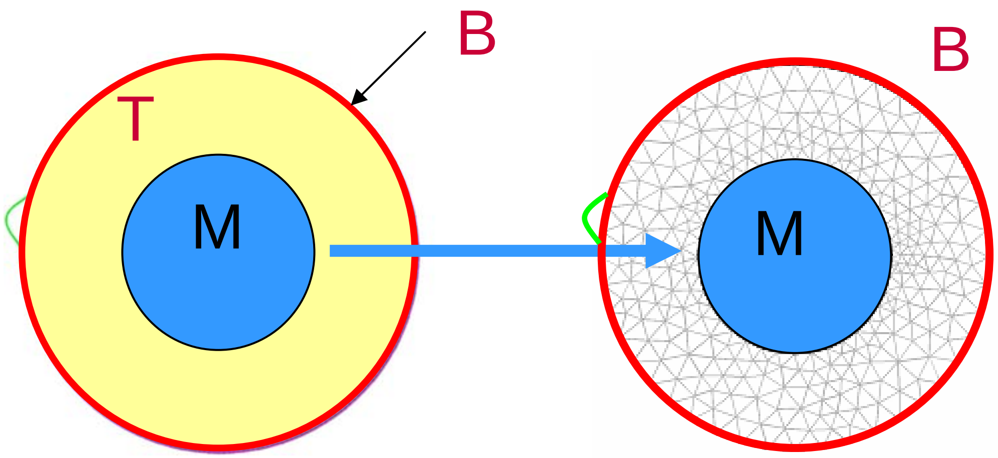
Identification of Acoustic Hot Spots in an Aircraft



Problem:

Standing waves and reflections

IFEM approach: Inverse Finite Element Method



Overview:

1. Motivation
2. Solution approach
3. 3D simulation
4. Experimental validation
5. Conclusion & outlook

Governing Equations

Wave Equation

$$\Delta p - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = 0$$

$$p = p(x, y, z, t)$$

Fourier Transform

$$\hat{p}(\omega) = \int_{-\infty}^{+\infty} p(t) e^{-j\omega t} dt$$

Helmholtz Equation

$$\Delta \hat{p} + \frac{\omega^2}{c^2}\hat{p} = 0$$

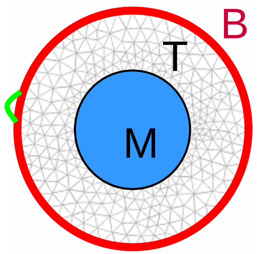
$$p = p(x, y, z, \omega)$$

Weak Formulation

Finite Element Formulation

$$\mathbf{K}\,\mathbf{p} = \mathbf{v}$$

Inverse Finite Element Method (IFEM)



$$\mathbf{Kp} = \mathbf{v}$$

$$\begin{bmatrix} \mathbf{K}_1 & \mathbf{K}_2 & \mathbf{K}_3 \\ \mathbf{K}_4 & \mathbf{K}_5 & \mathbf{K}_6 \\ \mathbf{K}_7 & \mathbf{K}_8 & \mathbf{K}_9 \end{bmatrix} \begin{bmatrix} \mathbf{p}_{MK} \\ \mathbf{p}_{TU} \\ \mathbf{p}_{BU} \end{bmatrix} = \begin{bmatrix} \mathbf{v}_{MK} \\ \mathbf{v}_{TK} \\ \mathbf{v}_{BU} \end{bmatrix} \rightarrow \begin{bmatrix} \mathbf{K}_2 & \mathbf{K}_3 & \mathbf{0} \\ \mathbf{K}_5 & \mathbf{K}_6 & \mathbf{0} \\ \mathbf{K}_8 & \mathbf{K}_9 & \mathbf{-E} \end{bmatrix} \begin{bmatrix} \mathbf{p}_{TU} \\ \mathbf{p}_{BU} \\ \mathbf{v}_{BU} \end{bmatrix} = \begin{bmatrix} -\mathbf{K}_1\mathbf{p}_{MK} \\ -\mathbf{K}_4\mathbf{p}_{MK} \\ -\mathbf{K}_7\mathbf{p}_{MK} \end{bmatrix}$$

$$\begin{bmatrix} \mathbf{K}_2 & \mathbf{K}_3 \\ \mathbf{K}_5 & \mathbf{K}_6 \end{bmatrix} \begin{bmatrix} \mathbf{p}_{TU} \\ \mathbf{p}_{BU} \end{bmatrix} = \begin{bmatrix} \mathbf{v}_{MK} - \mathbf{K}_1 \mathbf{p}_{MK} \\ \mathbf{v}_{TK} - \mathbf{K}_4 \mathbf{p}_{MK} \end{bmatrix}$$

$$\begin{bmatrix} \mathbf{K}_8 & \mathbf{K}_9 & -\mathbf{E} \end{bmatrix} \begin{bmatrix} \mathbf{p}_{TU} \\ \mathbf{p}_{BU} \\ \mathbf{v}_{BU} \end{bmatrix} = \begin{bmatrix} -\mathbf{K}_7 \mathbf{p}_{MK} \end{bmatrix}$$

ill-conditioned

over-determined for $n_M > n_B$

=> Regularization:

- Tikhonov
- Conjugated Gradients (CG)
- Truncated Singular Value Decompostion (TSVD)

Sachau, D.; Drenckhan, J.: Sound source localization in cabins by inverse finite element analysis, DAGA'06, Braunschweig

COMSOL / MATLAB Interaction

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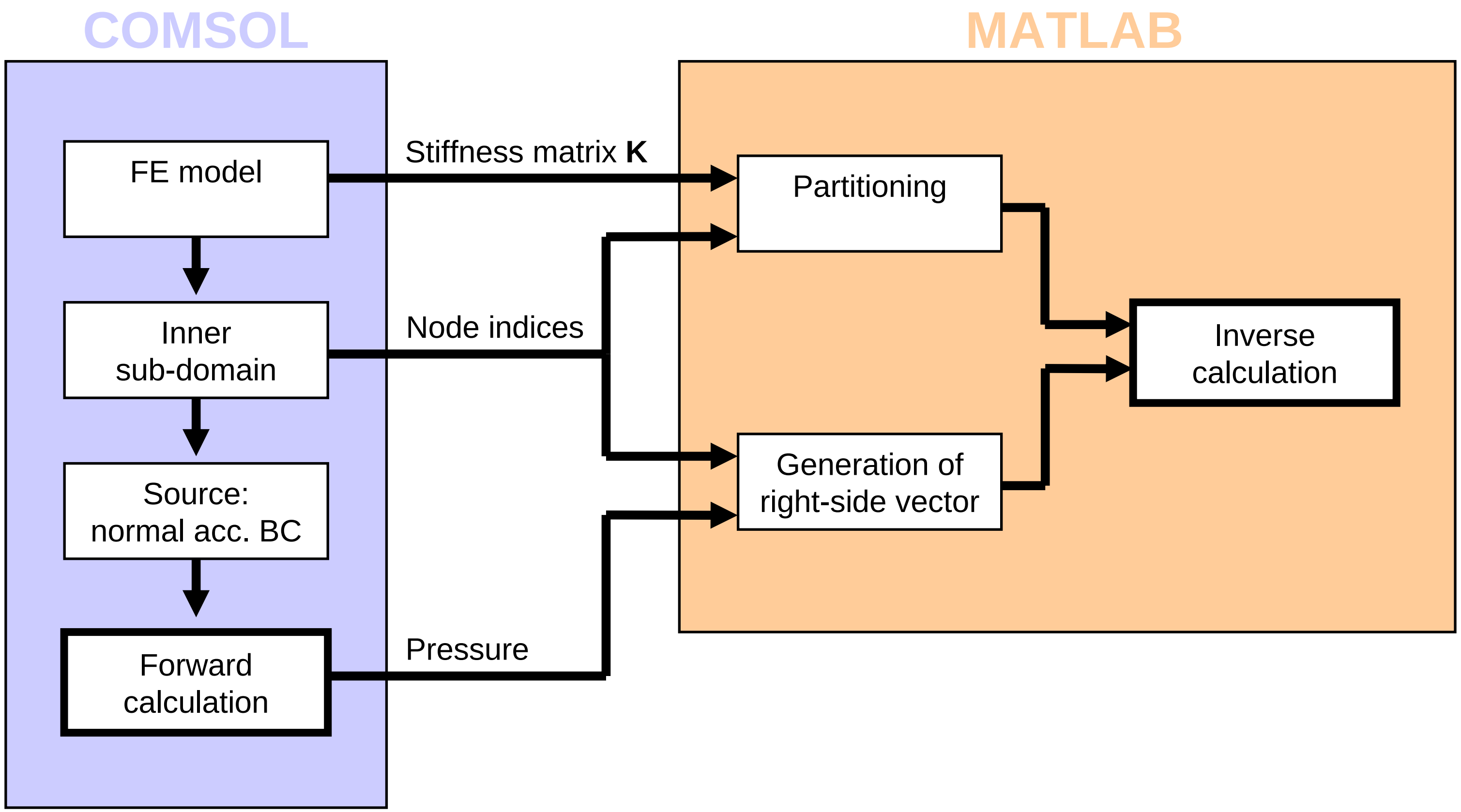
A) Simulated Data:



COMSOL / MATLAB Interaction

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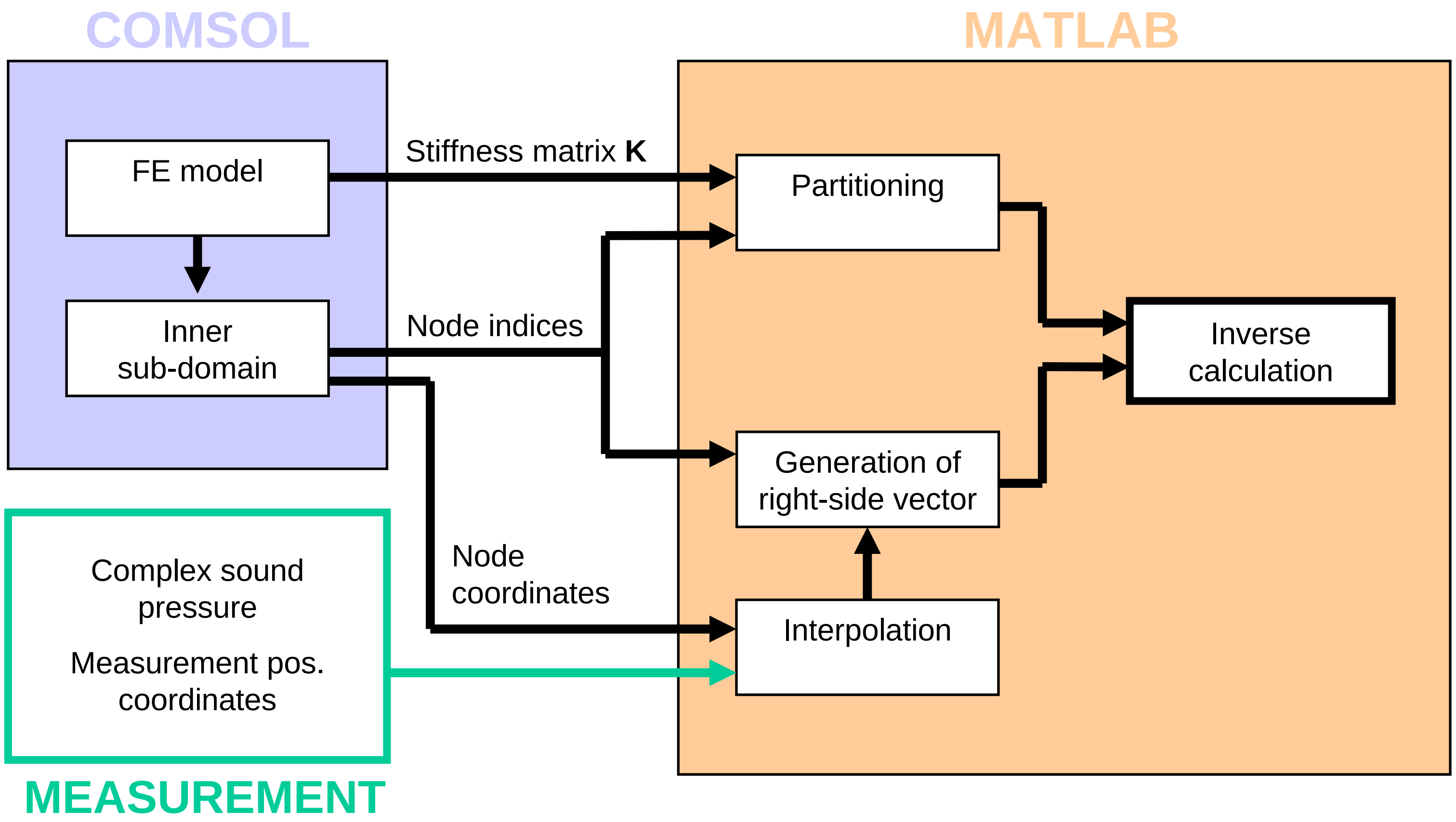
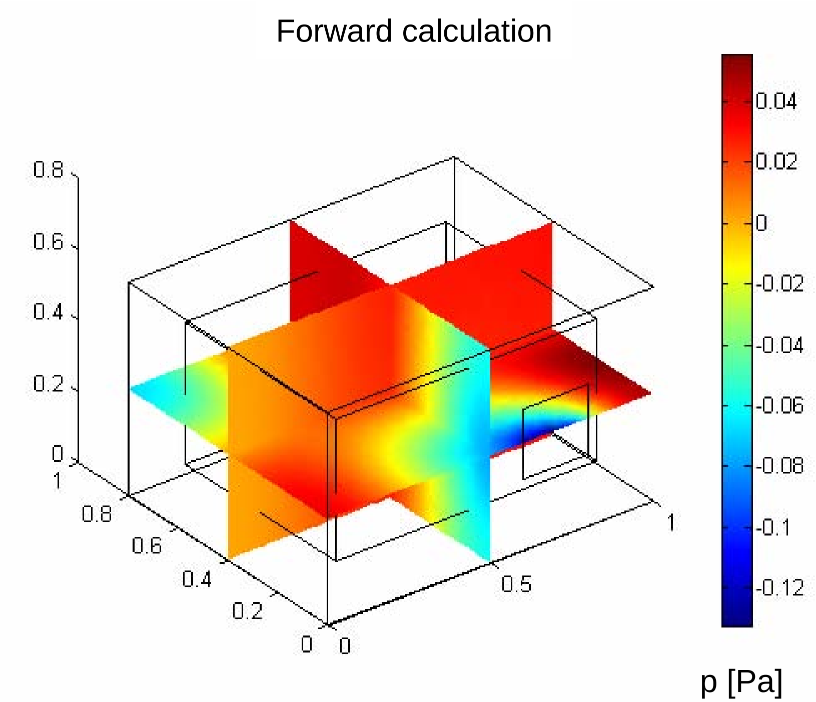
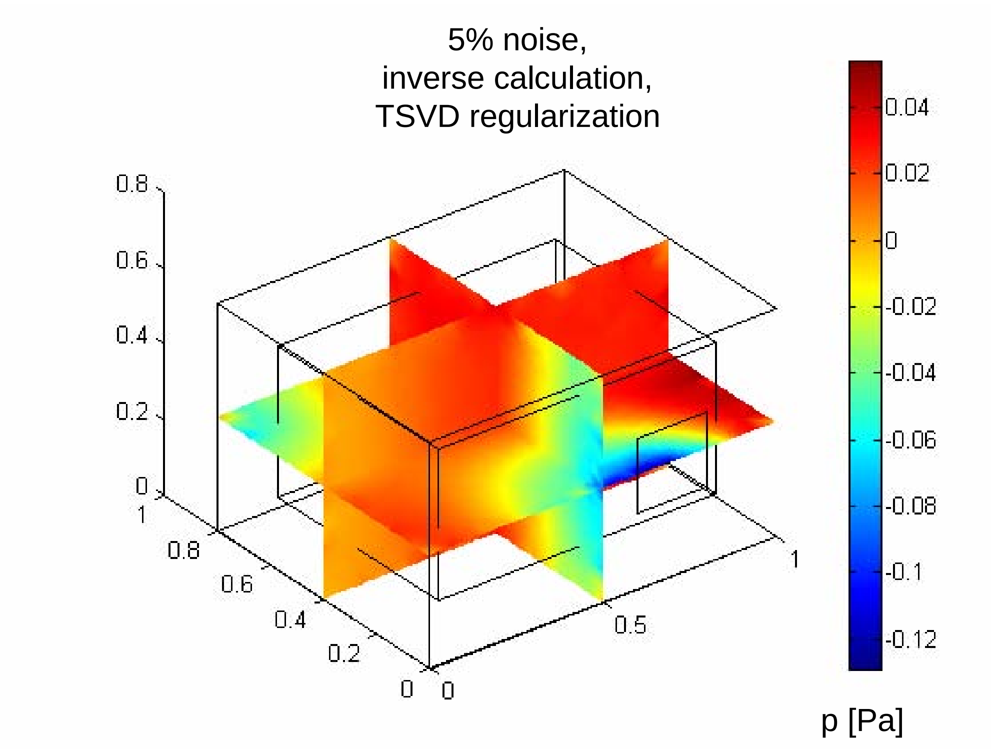
B) Measured Data:

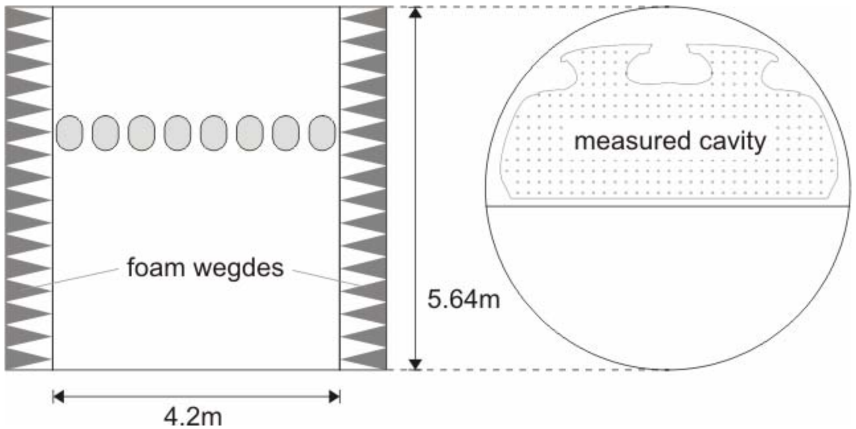


3D Simulation with Artificial Measurement Noise





Mapping of a Long Range Airliner Cross Section



Wideband noise excitation

- inner loudspeaker

- outer loudspeakers

Microphone distance: 0.17m

► 7172 positions

FE Model of the Cavity

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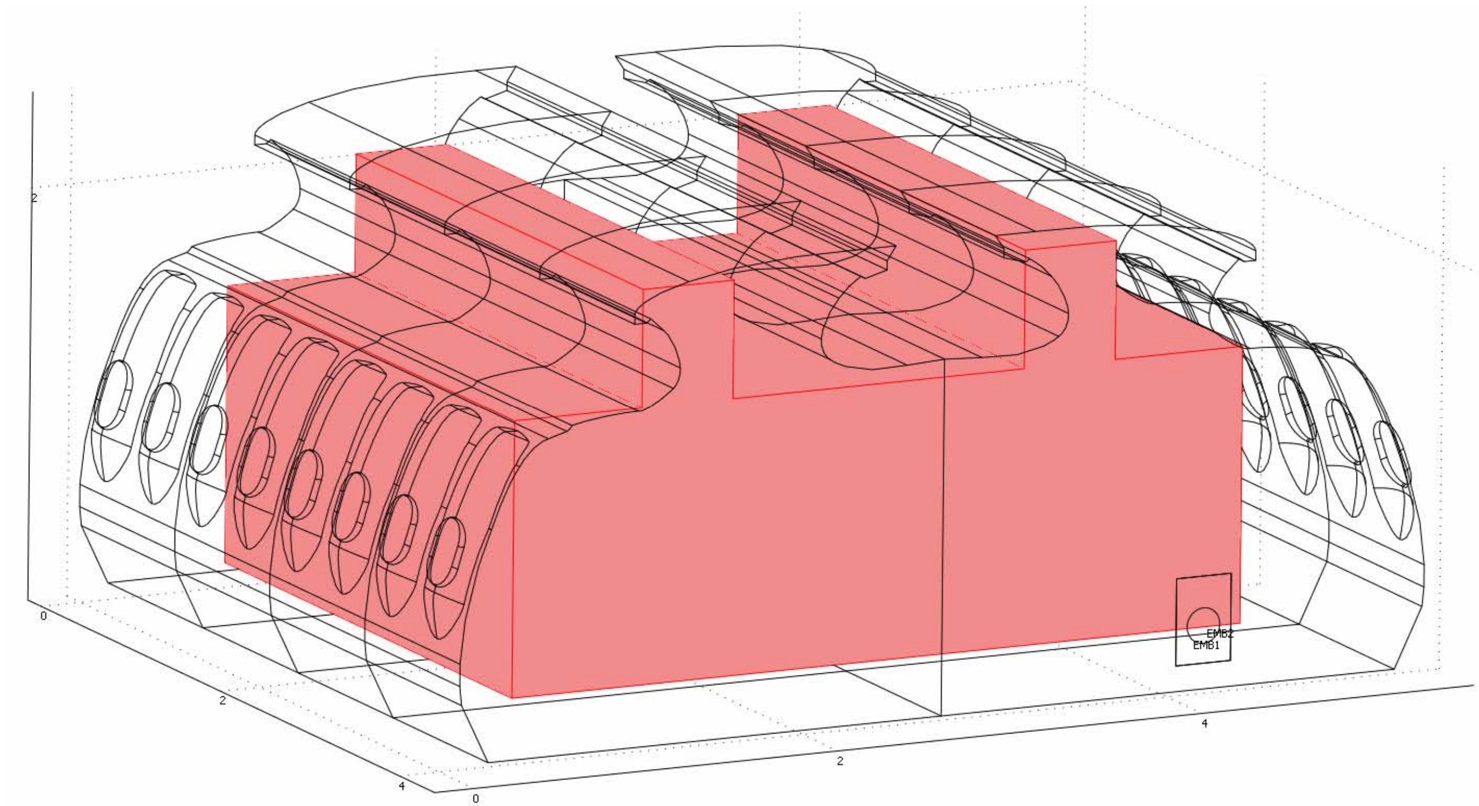

1. Coarse Mesh

Total nodes:	27,000
Inner sub-domain:	9,900
Boundary:	8,700

2. Fine Mesh

Total nodes:	68,000
Inner sub-domain:	31,000
Boundary:	12,500

Exemplary Comparison of Model and Mapping (f = 293Hz)

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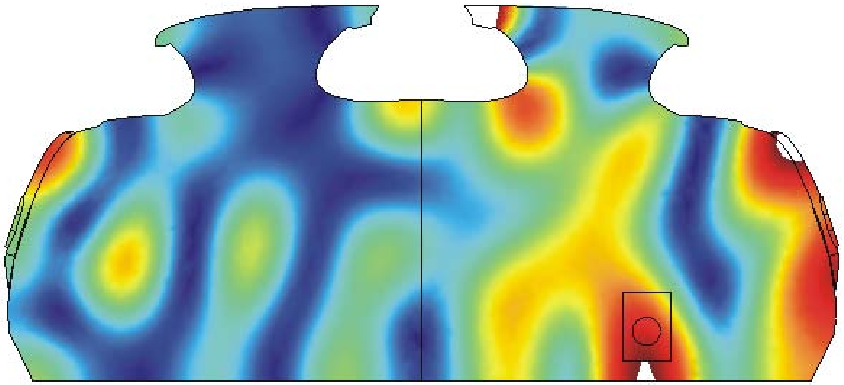
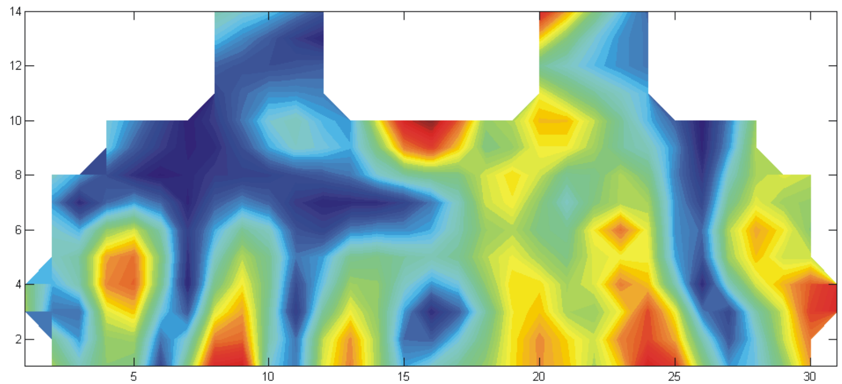


Simulated sound pressure from source with normal acceleration BC



Measured sound pressure from excitation with internal loudspeaker

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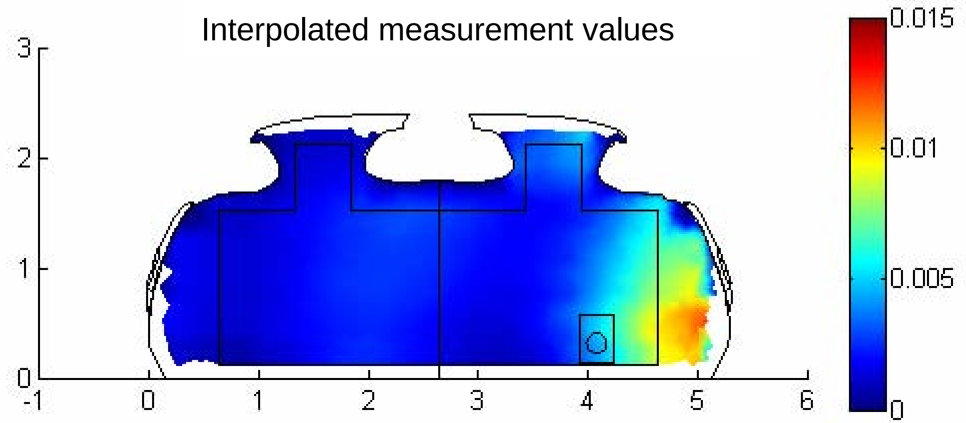
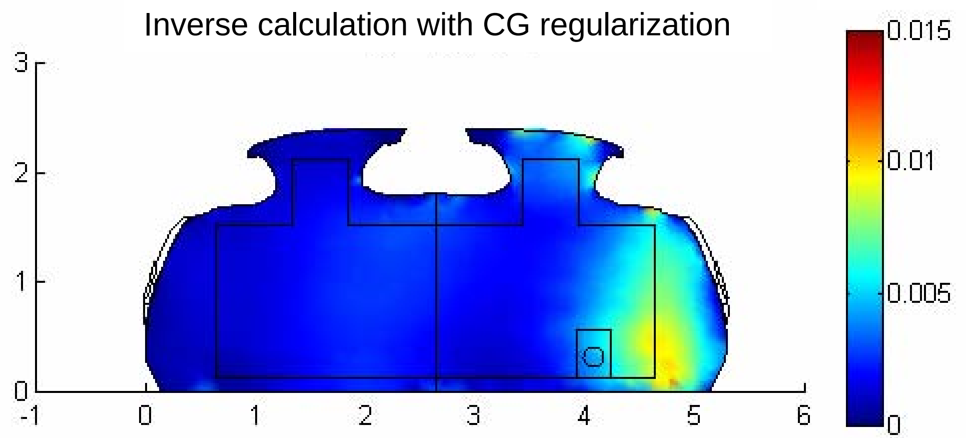
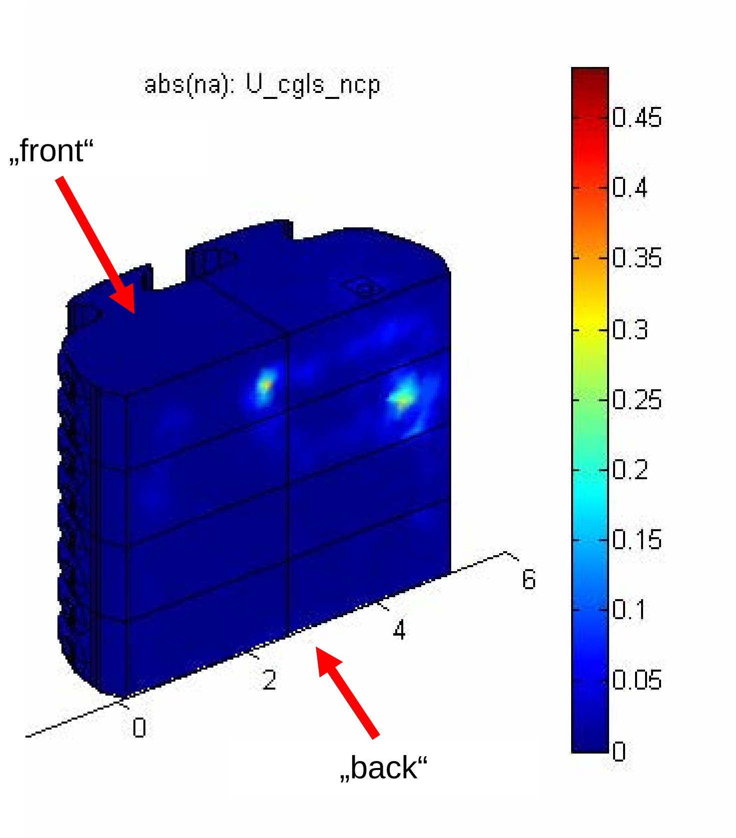
Inverse Calculation: Sound Pressure (Magnitude)
(Inner Loudspeaker, f = 90Hz)

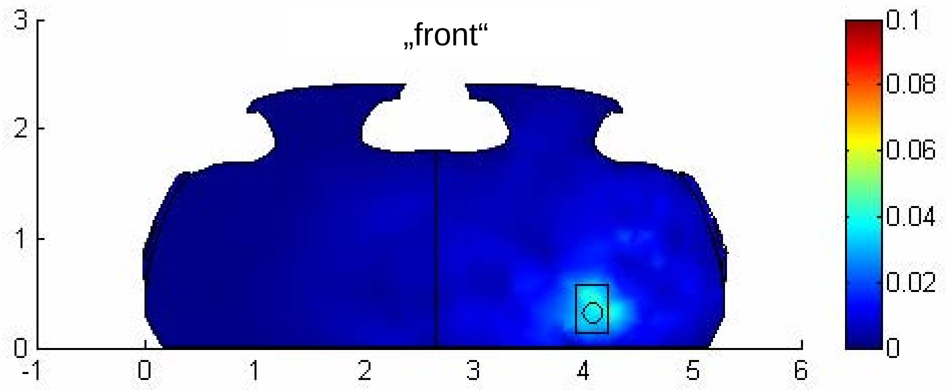


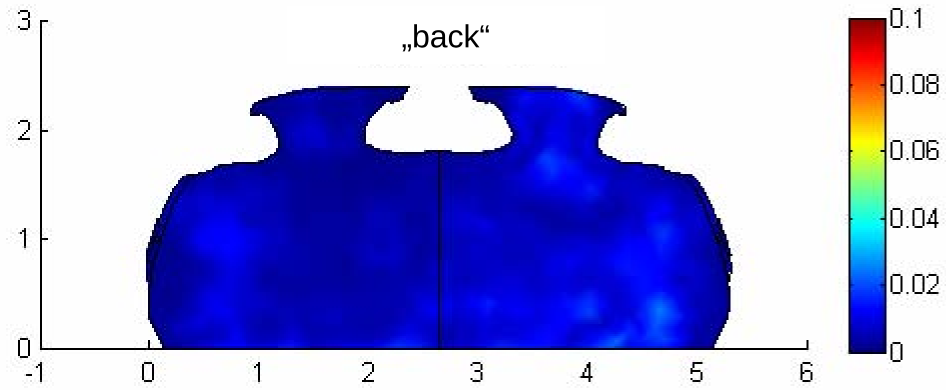


f = 90Hz, coarse mesh

max. element size: λ/20



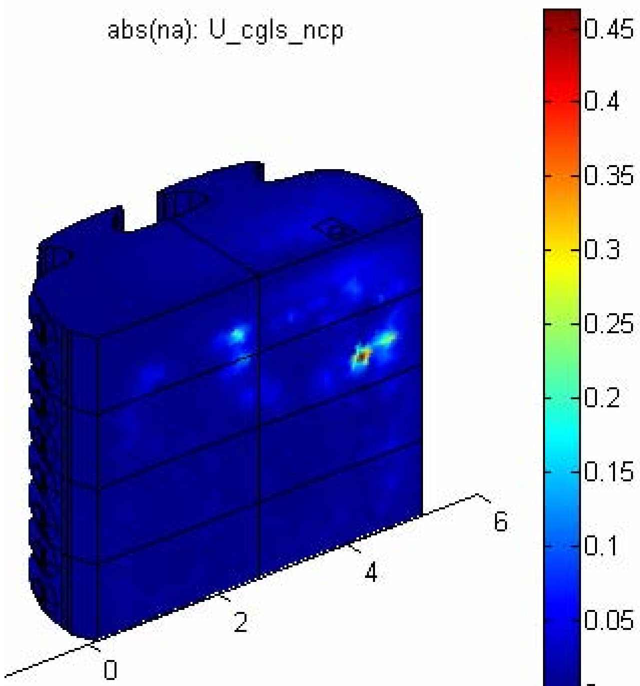


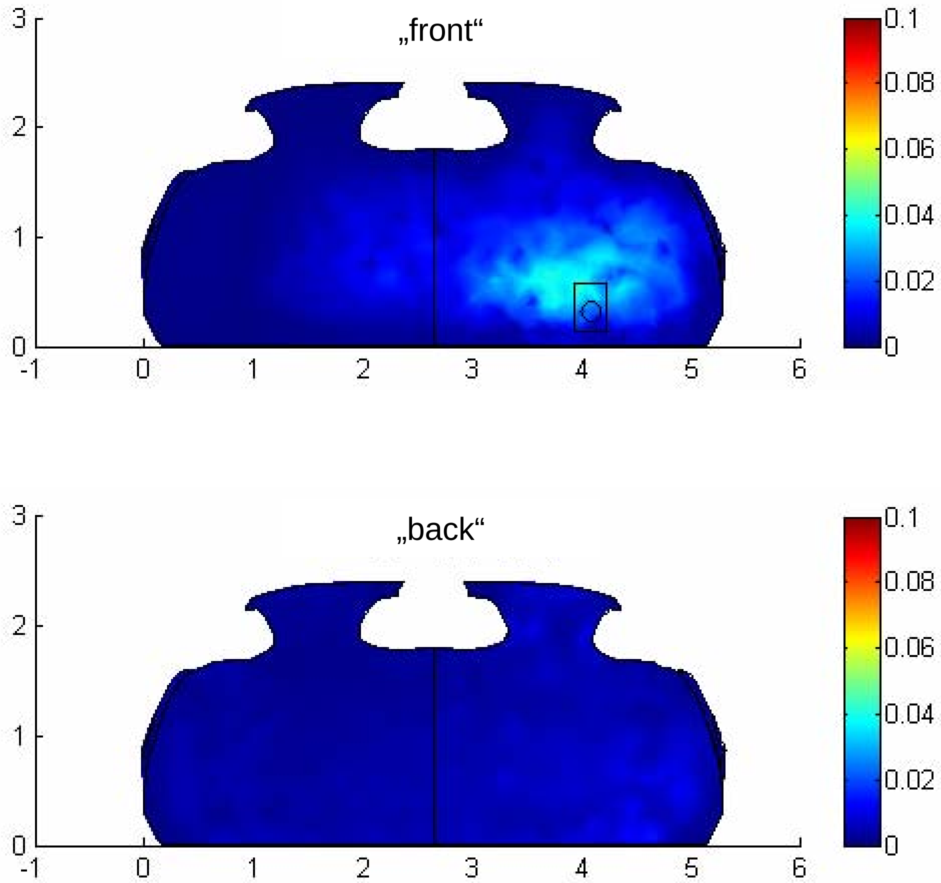


Inverse Calculation: Normal Acceleration (Magnitude)
(Inner Loudspeaker)

f = 90Hz, fine mesh

max. element size: λ/30

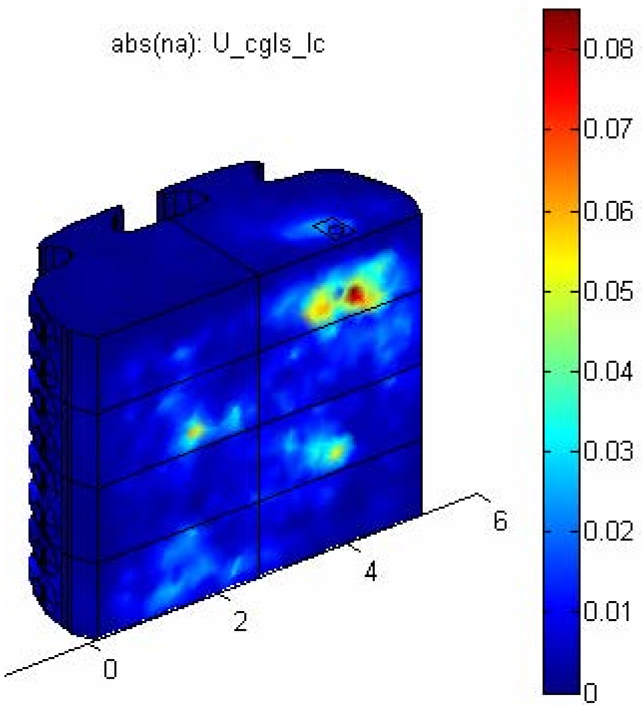


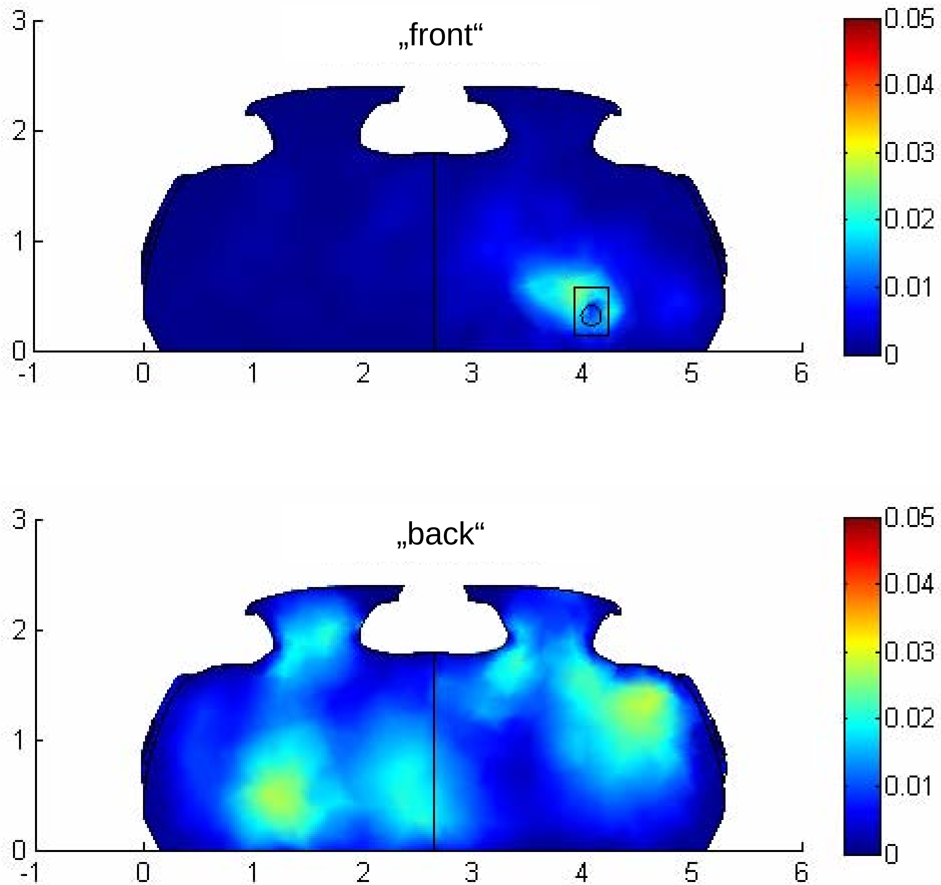


Inverse Calculation: Normal Acceleration (Magnitude)
(Inner Loudspeaker)

f = 200Hz, coarse mesh

max. element size: λ/9

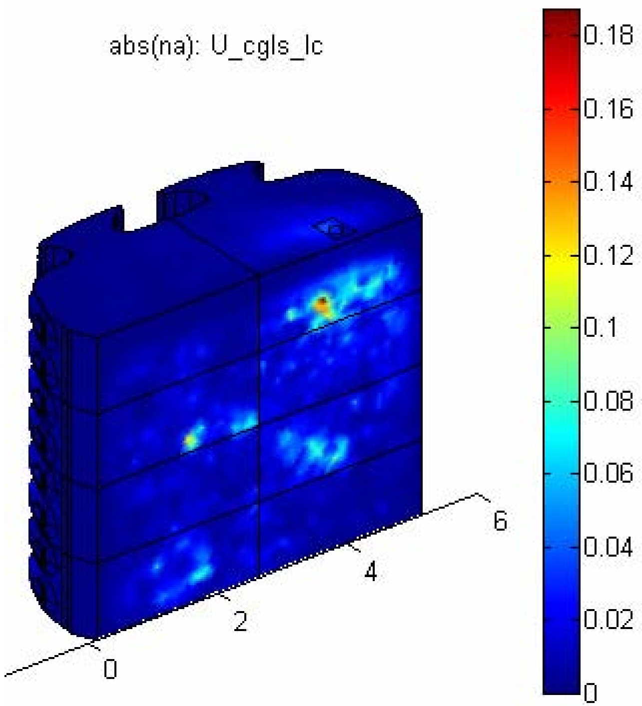


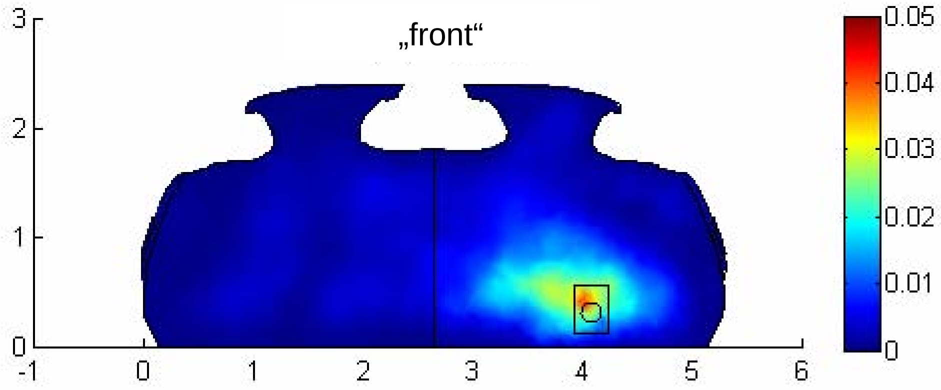


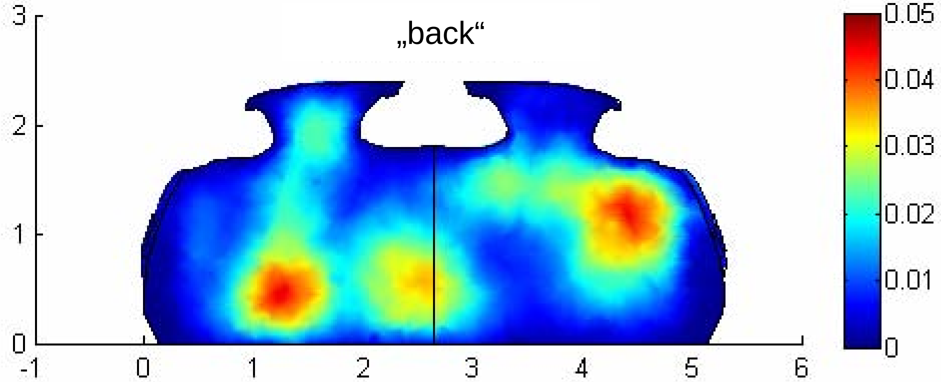
Inverse Calculation: Normal Acceleration (Magnitude)
(Inner Loudspeaker)

f = 200Hz, fine mesh

max. element size: λ/13







Conclusion

- The primary source and possible other sources and sinks could be identified.
- The absorbing quality of the foam wedges was confirmed for high frequencies.
- Obviously there is an optimal mesh density dependent on the frequency.

Next Steps

- determine optimal mesh density
- thin out measurement grid / narrow inner sub-domain
  => change determinedness of the equation system
- enforce nodes at measurement positions to minimize interpolation error

Acknowledgement:

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Validation of the FE Model

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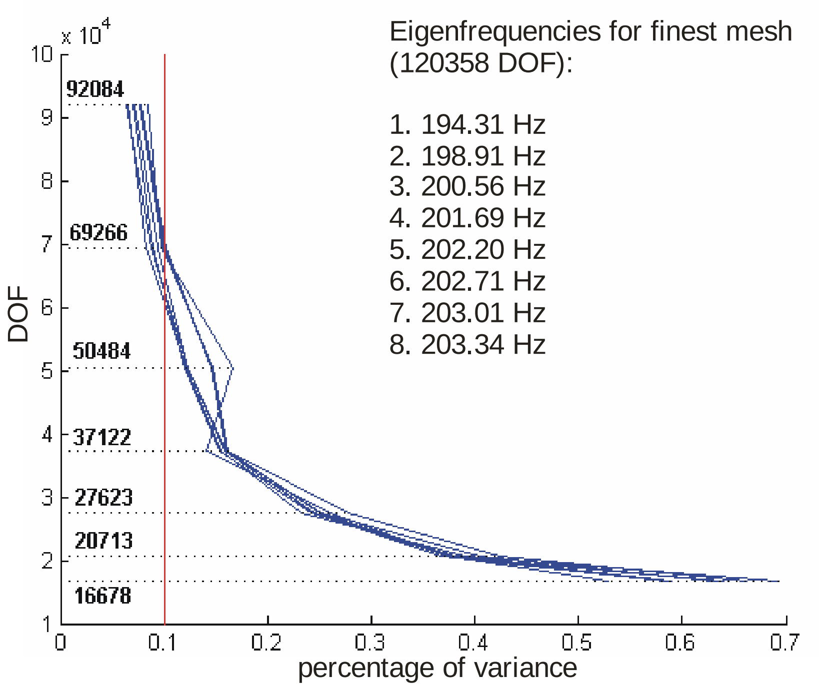
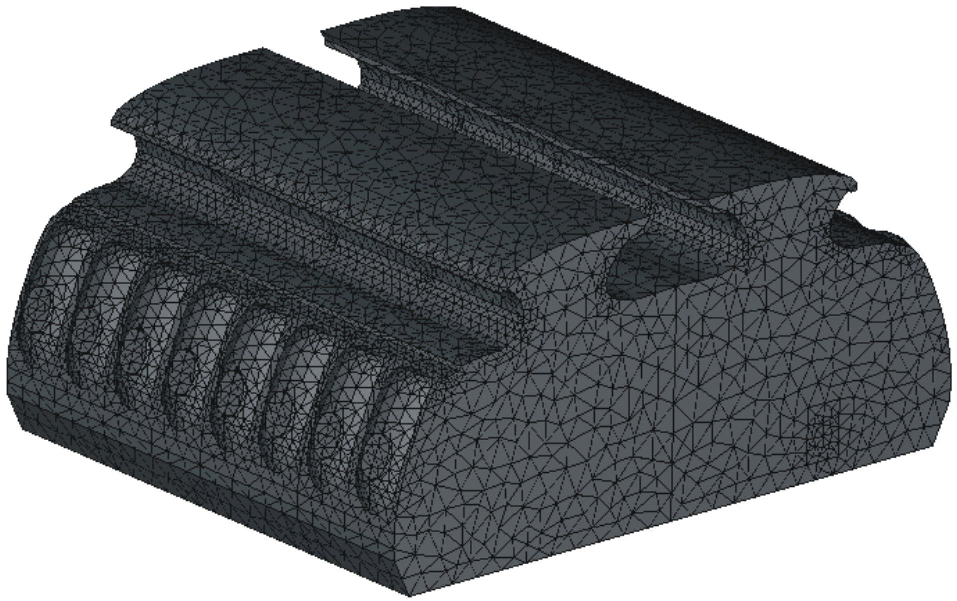
Model convergence: - calculate some eigenfrequencies around 200Hz

- increase number of DOF and re-calculate

- repeat until eigenfrequencies vary < 0.1% (identification via MAC)





~70 000 DOF equals $\lambda/9$ for f_{max} = 300Hz

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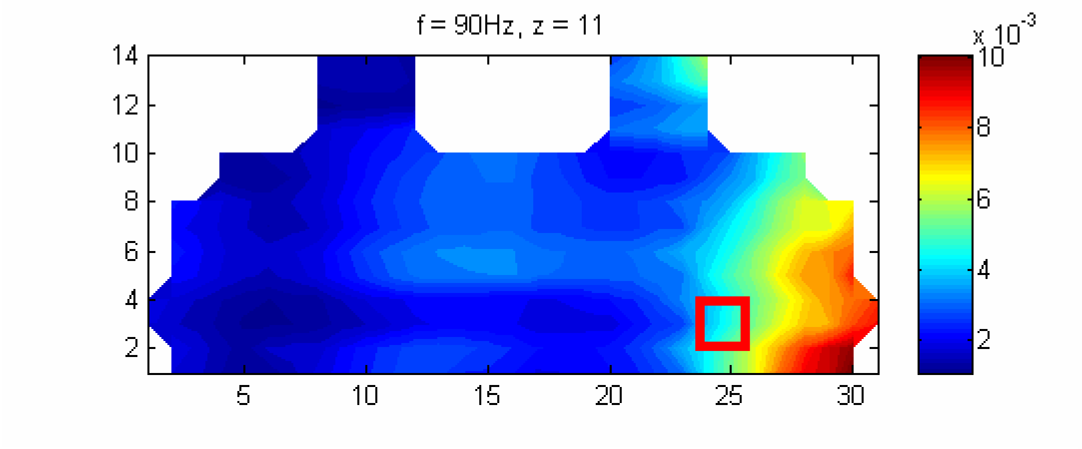
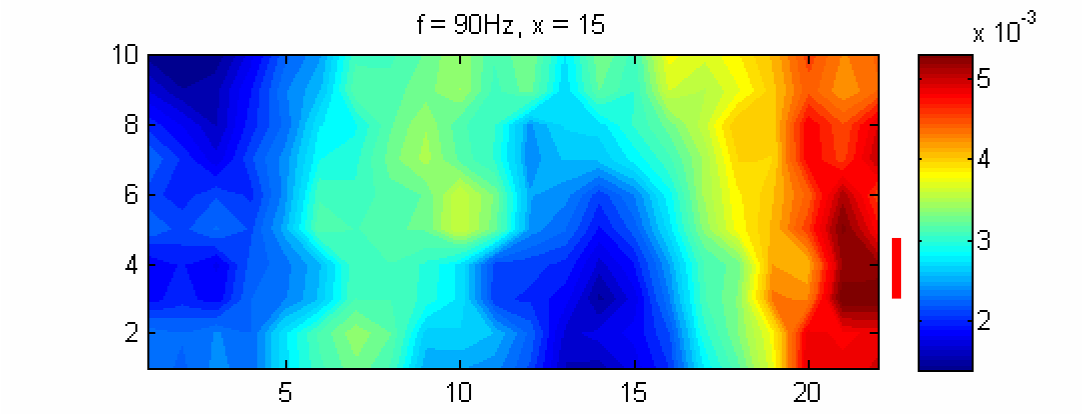
Mapping: Slice Plots, Sound Pressure (Magnitude), f = 90Hz

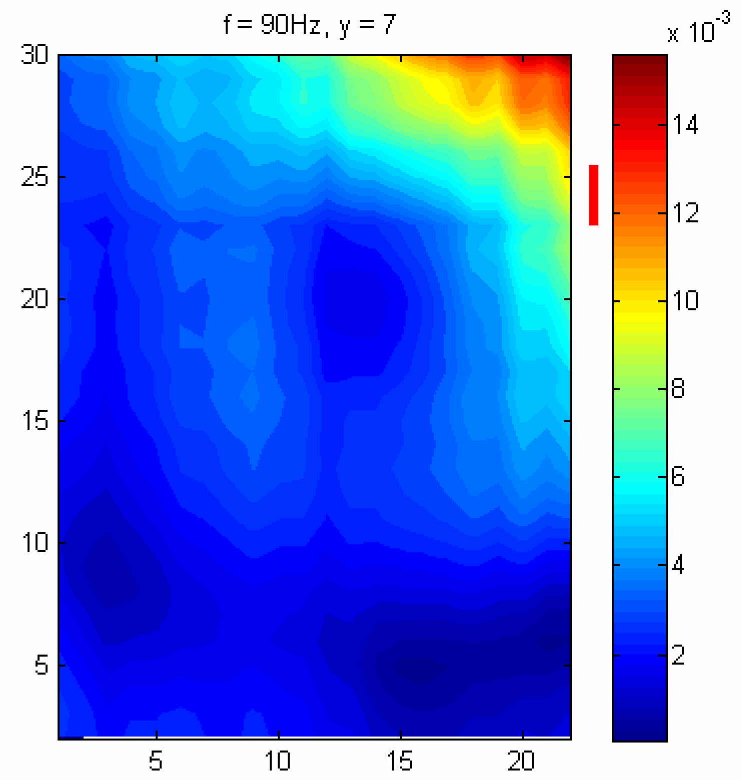
Front view:



Side view:



Top view:



Mapping: Slice Plots, Sound Pressure (Magnitude), f = 200Hz

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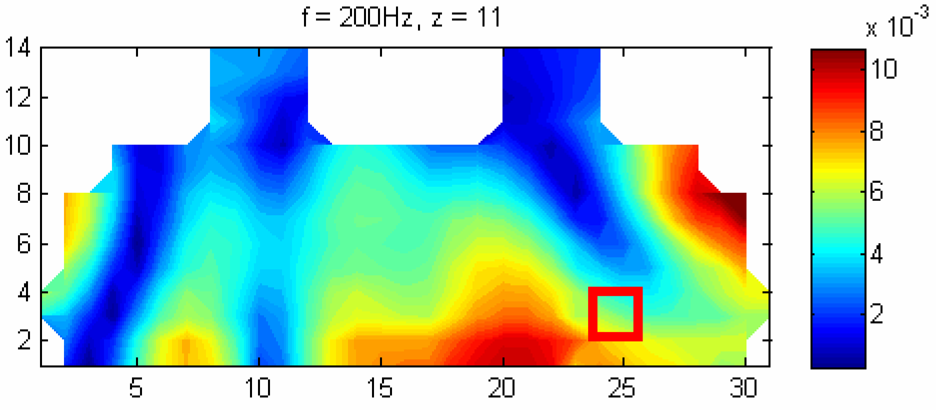
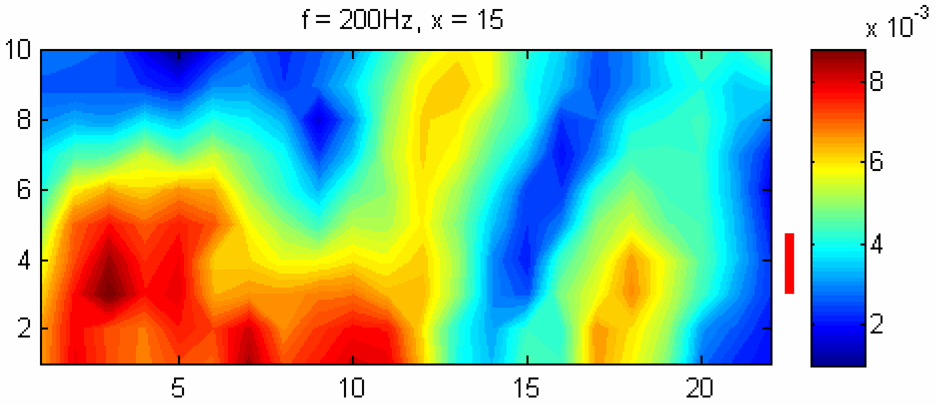
Front view:



Side view:



Top view: