Analysis of small concert halls with BEM

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ABSTRACT

The so-called fast boundary element methods like the Regular Grid Method (RGM) or Multilevel Fast Multipole Analysis (MLFMA) enable us to solve problems of more than 100000 unknowns that stem from surface elements only. In a first example, a fictitious concert hall of a volume of about 1270 cubicmetres was analysed up to a frequency of 700 Hz. For that, transfer functions between a monopole source and arbitrary points in that hall are computed using RGM. Although it is now possible to evaluate the sound pressure distribution at the surface as usual, it is difficult to interpret the virtually diffuse sound pressure field. The authors wish to discuss possibilities to interpret results of these large-scale problems. Furthermore, we intent to find ways of efficient use of numeric methods like FEM or BEM for acoustic analysis of large rooms or halls.

DESCRIPTION

Herein, we consider a fictitious small concert hall. The hall is 20 meters long, between 12 and 16 meters wide and between 4 and 5 meters high. It contains a ditch sized 8 × 2 square meters and 1.5 meters deep. Its volume is about 1269 m^3 and the maximum (Euclidean) distance of two surface points is 23.8 meters. Figure 1 shows the geometry and the four meshes. Apparently, this is a fictitious geometry. However, this arbitrary geometry is well suited to test performance of boundary element methods. We are faced with local modes in the ditch and corners and edges around the ditch. A monopole source is assumed. This source is located in the ditch, two meters from the symmetry plane on the right hand side, i.e. $y = -2.0$m, cf. Figure 1. In x–direction, the source is assumed centrally in the ditch, i.e. $x = 2.0$m in global coordinates, while it is 80 cm above the ditch bottom, i.e. $z = -0.7$m. We assume uniform absorption with absorption coefficient $\alpha = 0.05$. For analysis, a real admittance value of $\rho c Y = 0.013$ is used.

This problem was analyzed as an example to test performance of iterative solvers for BEM and fast boundary element techniques [3, 4].

RESULTS

We consider a mesh of constant boundary elements. The mesh consists of quadrilaterals 28196 elements and has a maximum element size of 20 cm. This ensures a very regular discretization. According to previous investigations of the long duct and the sedan cabin [1, 2], a discretization error of about 10% (for sound pressure evaluation at field points) is expected if 3 to 4 constant elements per wavelength are used. Consequently, the mesh with maximum element size of 20 cm might be used up to a frequency of about 500 Hz. The highest frequency actually used in analysis is 400 Hz. So we have more than four elements per wavelength.

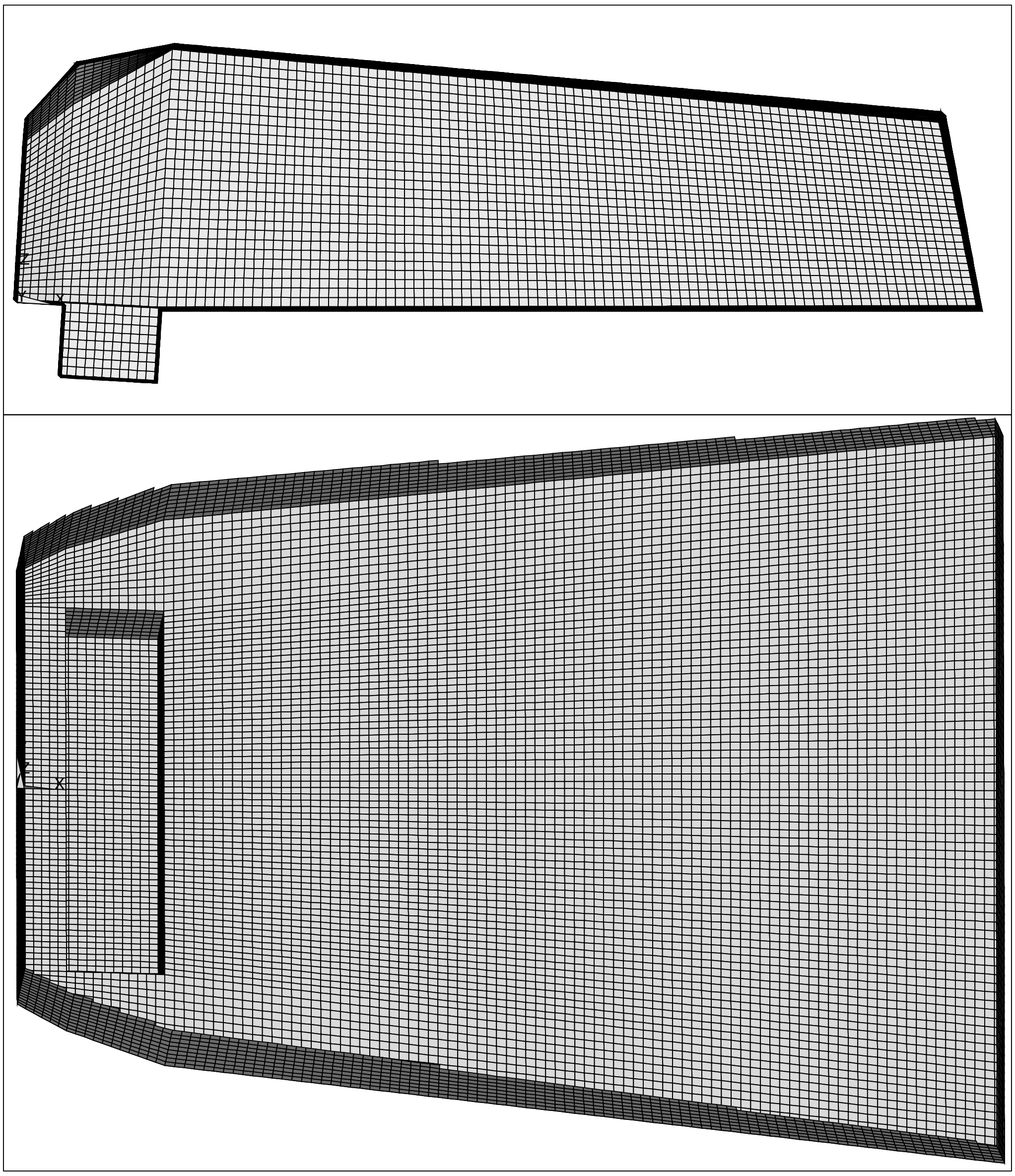

Figure 1: Fictitious small concert hall: Boundary element mesh of 28196 elements with element size ≤ 20 cm

Another mesh of maximum element size ≤ 10 cm was investigated for test purposes. There, the boundary element model consists of 108594 elements. Sound pressure distribution at 600 Hz is shown in Figure 3. In general, one can recognize numerous maxima and minima of the sound pressure at the floor. It is impossible to verify a modal pattern. However, high order mode shapes can be made out in the ditch, cf. Figure 4. Apparently, these mode shapes decay proportionally to the distance from the source since absorption is considered. Because of the extremely finely structured sound pressure distribution it is hardly possible to use these pictures for particular conclusions on the quality of the concert hall. For that, integration over a frequency band seems a useful and likely necessary extension of such a method.

An example for a noise transfer function as the sound pressure level at a certain position in the hall due to monopole excitation (particle velocity prescribed) is shown in Figure 5. A frequency resolution of 0.1 Hz was applied to scan the nose transfer function in the frequency range between 5 and 400 Hz. Noise transfer function is shown and compared in more detail for two frequency ranges, 5–100 Hz, cf. Figure 6, and 300–400 Hz, cf. Figure 7. It can be seen that a resolution of 0.1 Hz seems to suffice in this case.

Frequency averaging was applied in two ways. Linear averaging computes the an average in a

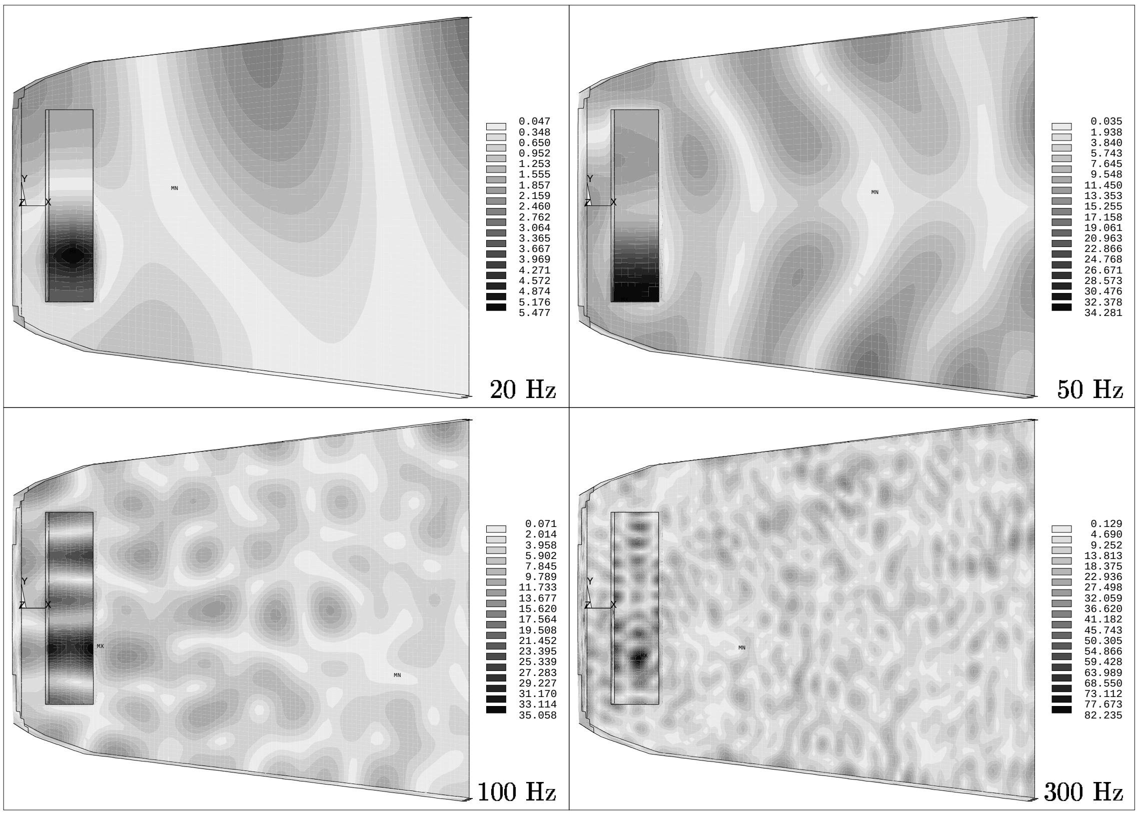

Figure 2: Fictitious small concert hall: Sound pressure magnitude at floor due to monopole excitation in ditch for different frequencies

10 Hz window, cf. Figure 8. This graph can be compared with the third–octave–band average as presented in Figure 9. The variation of the noise transfer function between different location is shown in Figure 10.

Basically, this paper presented a selection of first results of a principal investigation of a fictitious concert hall. The method can be applied to general geometries in the low frequency range. Even large scale models can be analyzed in a reasonable period of computation time. More investigation is required to use these results for practical applications in analyzing and designing concert halls.

References

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[4] S. Schneider and S. Marburg. Performance of iterative solvers for acoustic problems. Part ii: Acceleration by ilu–type preconditioner. *Engineering Analysis with Boundary Elements*, 2002. submitted.

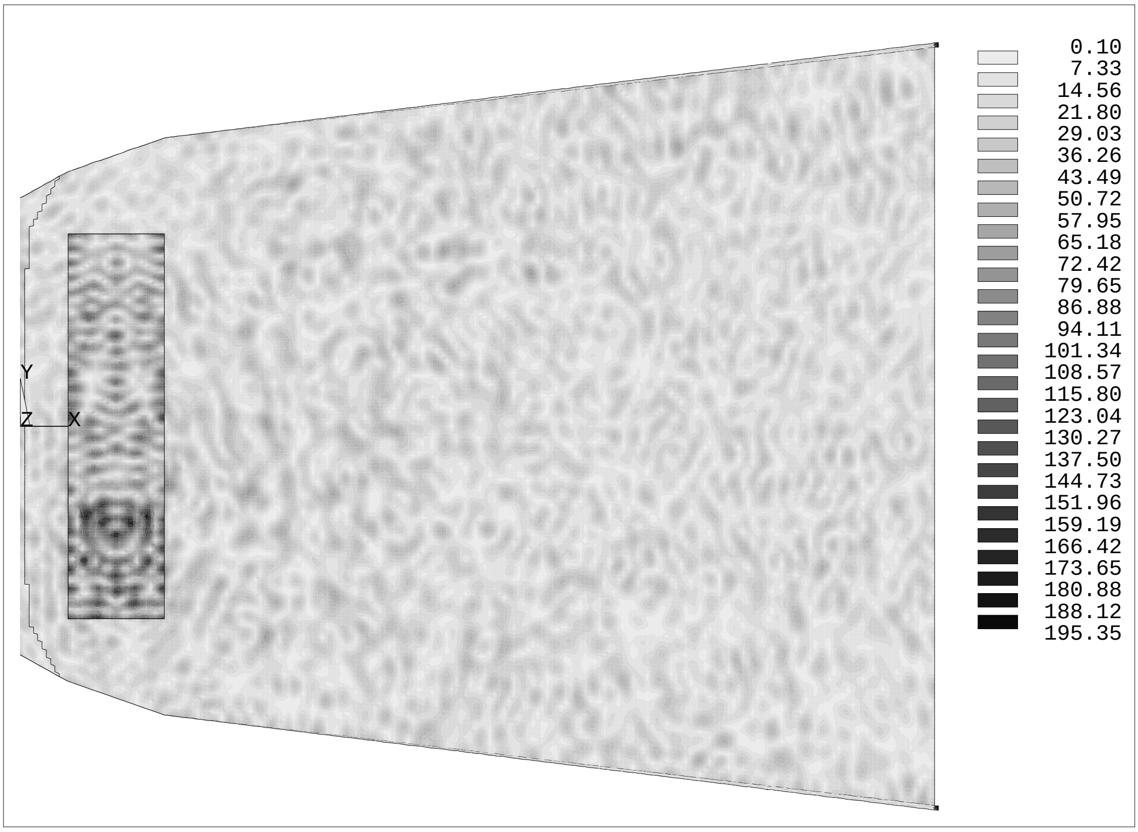

Figure 3: Fictitious small concert hall at 600 Hz: Sound pressure magnitude at floor due to monopole excitation in ditch, maximum element size $h_{\max} = 10\text{cm}$

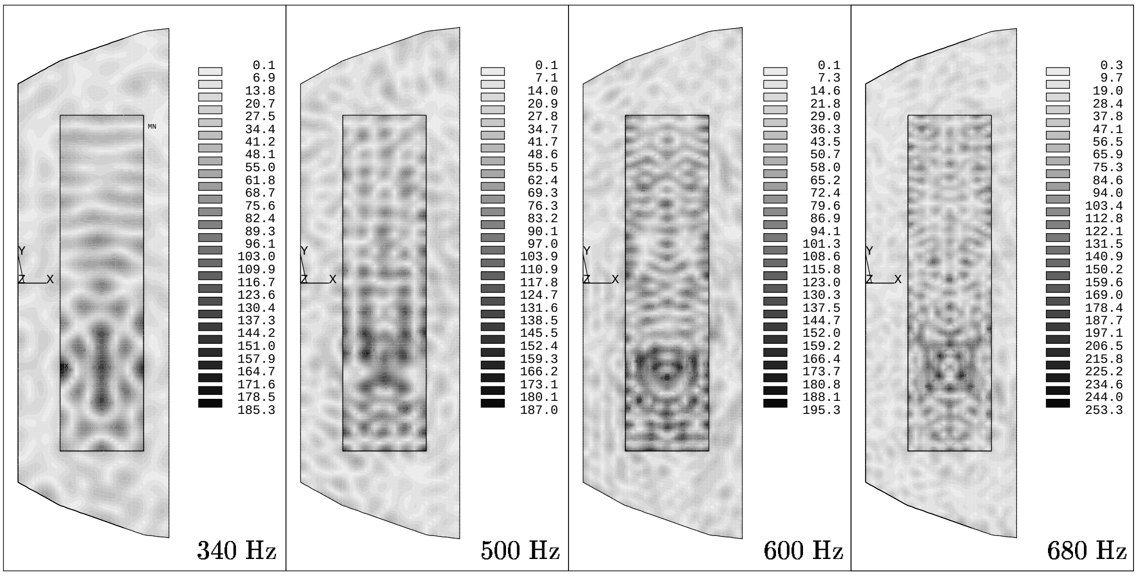

Figure 4: Fictitious small concert hall: Sound pressure magnitude in ditch due to monopole excitation in ditch at different frequencies, maximum element size $h_{\max} = 10\text{cm}$

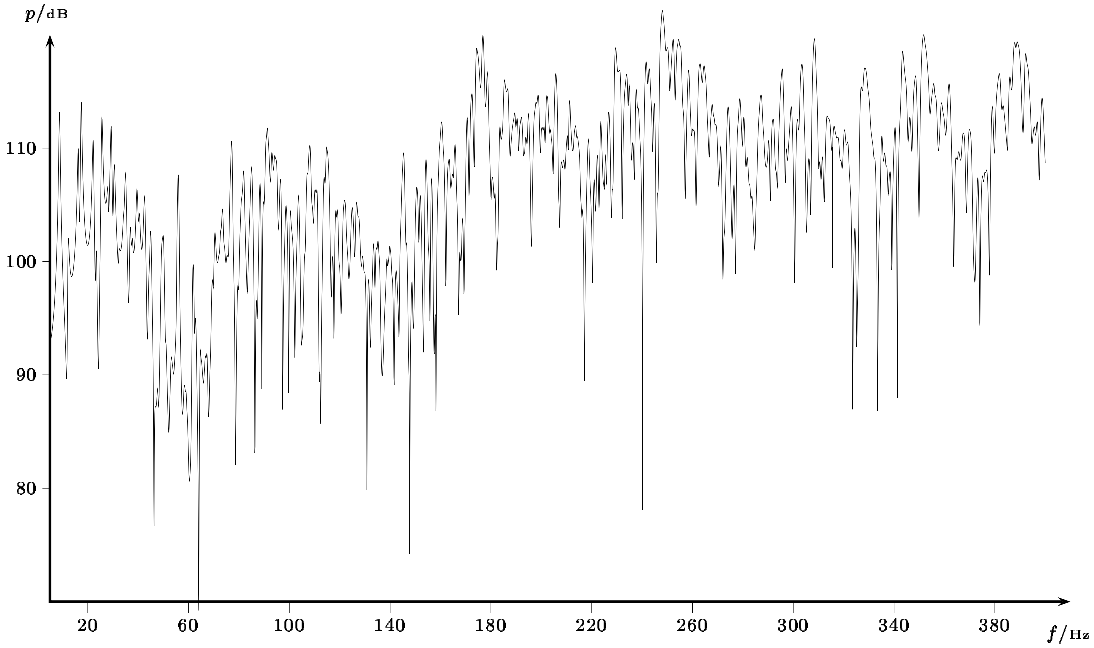

Figure 5: Noise transfer function for point in rear part in steps of 0.1 Hz (non–averaged)

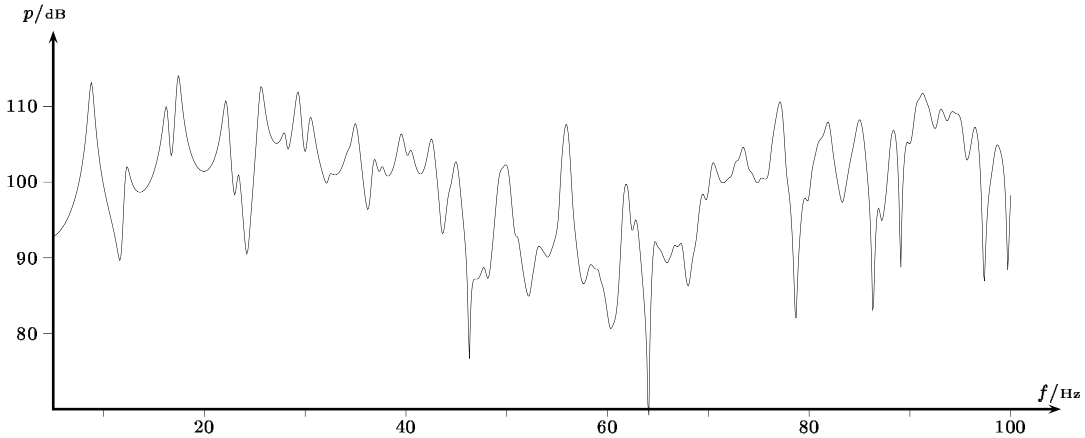

Figure 6: Noise transfer function for point in rear part in steps of 0.1 Hz (non–averaged)

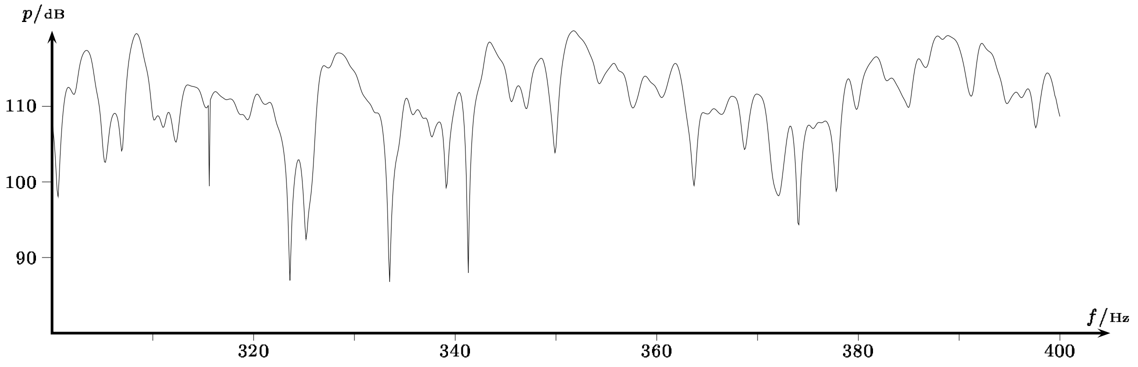

Figure 7: Noise transfer function (part) for point in rear part in steps of 0.1 Hz (non–averaged)

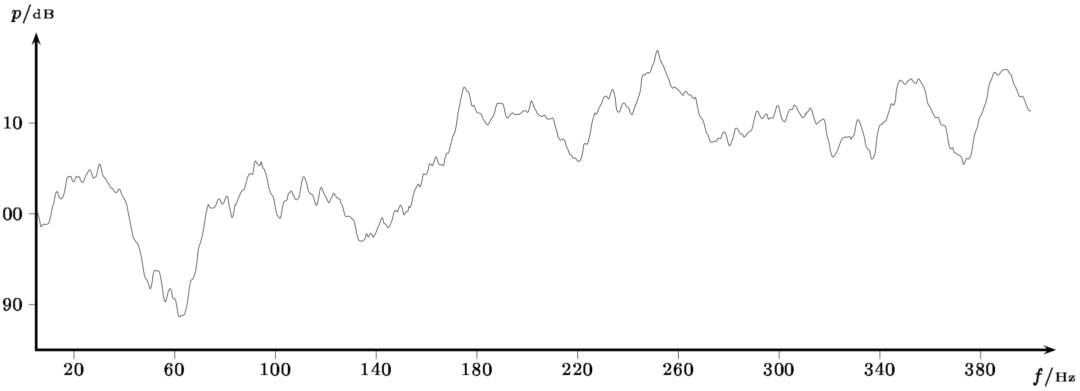

Figure 8: Noise transfer function for point in rear part in steps of 0.1 Hz (10 Hz average)

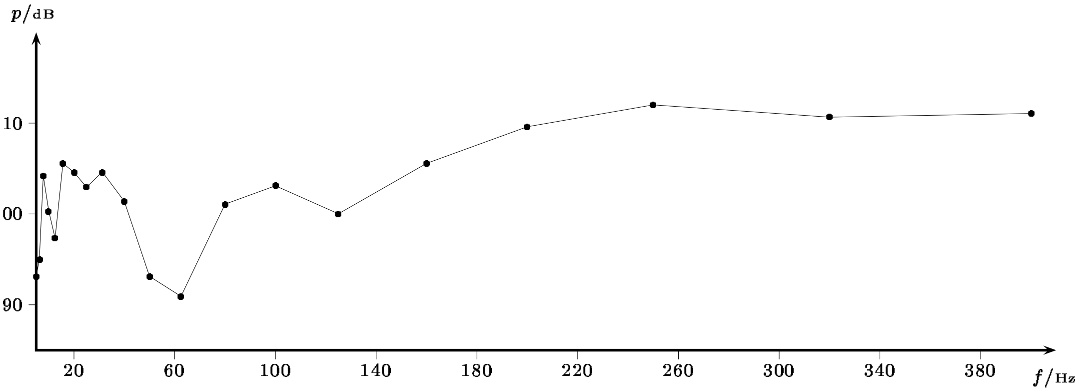

Figure 9: Noise transfer function for point in rear part (third octave band results)

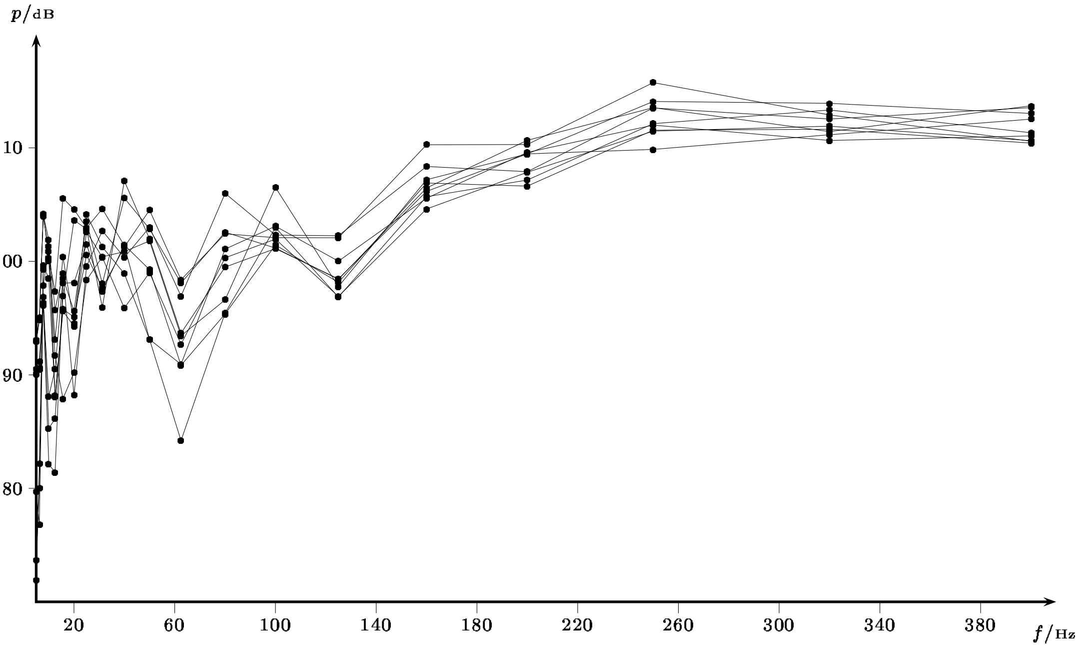

Figure 10: Noise transfer function for different points (third octave band results)