BOUNDARY CONDITIONS FOR ROOM ACOUSTIC SIMULATIONS

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ABSTRACT

Research on room acoustic simulation focuses on more accurate modeling of wave effects in rooms. Today, also wave models (e.g., the boundary element method and the finite differences in time domain technique) can be used for higher frequencies, thus, in the geometrical acoustics (GA) domain. Simulations in architectural acoustics are powerful tools but their reliability depends on the input data of boundary conditions such as absorption and scattering coefficients. The influence of uncertainties of this data on room impulse responses and room transfer functions is discussed in comparison of wave and geometrical acoustics.

RESÚMEN

La investigación en simulación acústica de salas se está enfocando hacia un modelado más preciso de los efectos ondulatorios en los recintos. Actualmente, también los modelos ondulatorios (por ejemplo el método de elementos frontera y las técnicas de diferencias finitas en el dominio temporal) pueden utilizarse para frecuencias más altas, por tanto, en el dominio de la acústica geométrica (GA). Las simulaciones en acústica arquitectónica son unas herramientas muy potentes pero su fiabilidad depende de los datos de entrada sobre las condiciones de contorno, tales como los coeficientes de absorción y de difusión. La influencia de la incertidumbre de estos datos sobre las respuestas impulsivas y las funciones de transferencia se analizan comparativamente, para acústica ondulatoria y geométrica.

1. INTRODUCTION

In this contribution the basics in the field of indoor sound field simulation are briefly summarized with regard to the boundary conditions. The algorithms of standard programs in room acoustics and noise immission outdoors are based on geometrical acoustics. According to the particle-wave dualism, the description of sound fields is based on energy decays and the direction of particles or rays incident on the receiver. This approach is correct as long as the relevant dimensions of the room geometry are large compared with wavelengths and broadband signals are taken into account. Very important sources of uncertainties are material data of the boundaries.

Here, we focus on the boundary data of absorption and scattering. They are usually obtained by standard measurements in reverberation chambers according to ISO 354 [1] and ISO 17497-1 [2]. These measurements have unavoidable uncertainties. Also impedance boundary conditions are required, and this is for wave models such as the finite element method (FEM) and the boundary element method (BEM). Impedance measurements can be performed by using impedance tubes according to ISO 10534-2 [3]. Also in the interest in research are in-situ measurement methods, which could be used in any cases of boundaries in the field. However, there is not yet available a robust in-situ method for application in general.

2. BOUNDARY CONDITIONS IN GEOMETRICAL ACOUSTICS

In geometrical acoustics the two basic models of geometrical sound propagation, ray tracing and image sources, are used. It is important to highlight the differences: Ray tracing describes a stochastic process of particle radiation and detection. This concept is based on energy propagation while the phases are only included in the delay between radiation and detection. In contrast, image sources are geometrically constructed sources which correspond to specular paths of sound rays. Worth mentioning is that image sources can be also constructed by using rays, beams or cones, via a kind of "tracing". Nevertheless these models are still "image source models". The fundamental difference between image sources and ray tracing is the way contributions in impulse responses are calculated. Ray tracing only yields impulse response low-resolution data like envelopes in spectral and time domains (Fig.1). Image sources in the classical algorithm or constructed via tracing rays, beams, cones, etc., may be used for an exact construction of amplitude and delay of reflections.

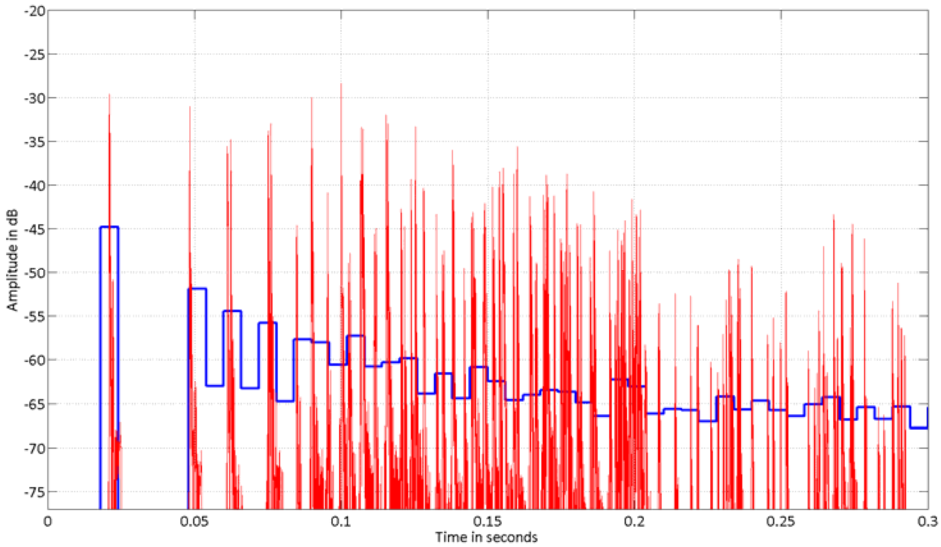


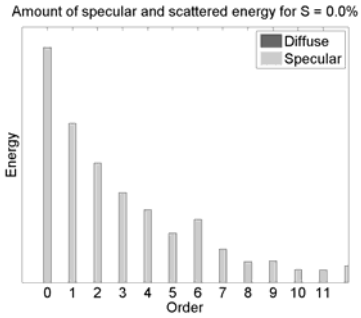
Figure 1. Fundamental energy impulse response computed by using image sources (detailed response) and ray tracing (histogram). (from [4])

The consequence is that post-processing to obtain binaural impulser responses can be done straightforward with image sources but not with ray tracing or similar techniques of articificial reverberation processing. The most simple approach is an omnidirectional reverberation with stochastic interaural phases. In specific situations, however, this approach fails because it cannot give a certain directional impression in its spectral and temporal features. This, for example might occur, in room with localized absorption, or in coupled spaces ehere the late reverberation basically comes through a well-localized aperture.

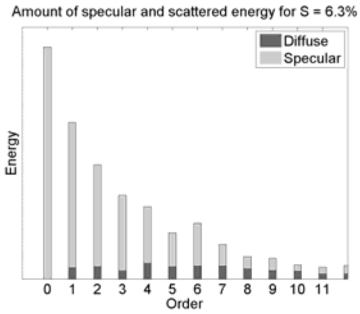
The boundary conditions are crucial at the point where the transition from image source to ray tracing is concerned. This typically is related to problems of calculation time and choice of a low-order image source model. And it depends strongly on the amouint of scattering, as explained in the next section.

2.1 Upper time limit for image sources

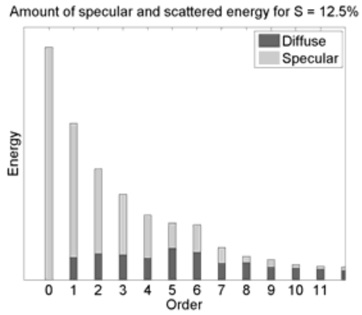
In room acoustic software the transition order of the early to late simulation part must be chosen. The early part calculated by using image sources is typically more exact. The rule of thumb that after the third reflection order the scattering processes dominate the impulse response, can be confirmed in case of a mean boundary scattering coefficient of 25%, as illustrated in fig. 2. Thus, according to the mean scattering coefficient the transition order can be chosen safely.



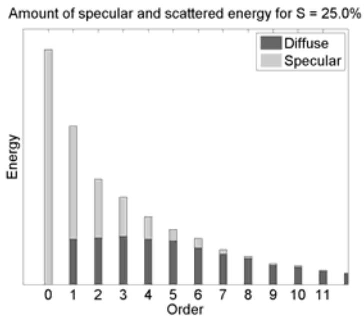
a) at 0% mean scattering



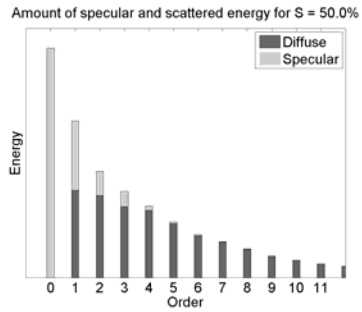
b) at 6.3% mean scattering



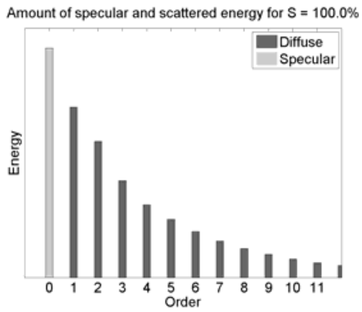
c) at 12.3% mean scattering



d) at 25% mean scattering



e) at 50% mean scattering



f) at 100% mean scattering

Figure 2. Ray tracing simulations for determination of specular and scattered energy for various mean scattering coefficients.

Fortunately, the precision of scattering coefficients does not need to be high. In listening tests with variation of the mean scattering coefficient, test subjects can't distinguish very well between variations of the scattering component, as long as there is scattering at all [5]. This, however, needs a more quantitative approach and more focused research.

2.2 Lower frequency limit for image sources

Boundary conditions for image source algorithms have been investigated in several studies. This aspect is very important as it is related to the strong early reflections and thus to significant contributions to perception. This problem is usually focused on the angle-dependence, on the necessity of the inclusion of spherical wave effects, and on the relevance of complex data of refection factors and/or impedance data [6, 7, 8].

For rectangular rooms of variable proportions the image source model provides an acceptable approximation of the sound field as long as frequency and angle-dependent complex reflection factors are applied [9]. The errors in narrow bands are typically small in the frequency range above twice the Schroeder frequency. It is important to mention that the low frequency limit depends on the room shape, as illustrated in fig. 3. The more the room differs from normal proportions to flat or long shapes, the errors get larger.

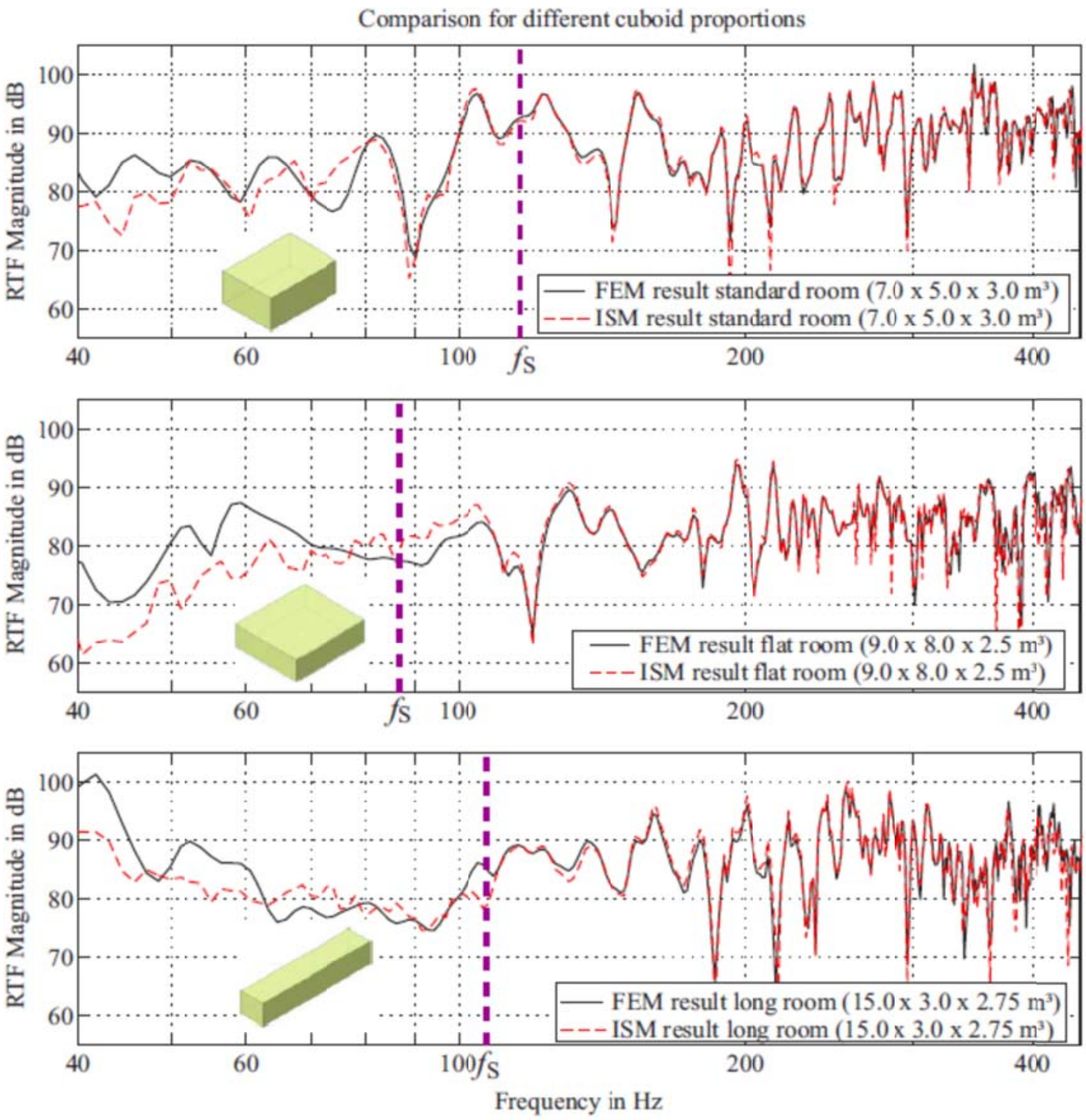


Figure 3. Room transfer functions calculated by using the image source model and FEM [9]

3. ARE WAVE MODELS BETTER?

As discussed by Pelzer et al. in [10] the correct input data for simulations is usually a crucial point and source of uncertainties. To avoid ambiguities in the identification of weak points of a simulation, the input data has been gathered in detailed and independent measurements and calculations. This has put the focus on the actual simulation algorithms themselves. The results showed that a combination of FEM and GA based techniques provides reliable results and bears comparison with real world measurements. This conclusion could be verified in preliminary listening tests, which indicated a very promising agreement between auralizations with measured and with simulated binaural impulse responses using the presented software [10].

When it comes to problem with non-perfectly controlled boundary condition, such as in a vehicle compartment, larger differences must be expected [11]. Aretz shows in his dissertation [12] that this part is in fact the biggest problem in acoustic engineering and sound design. Layered materials as used in a car seat, or the compelx structure of the dashboard with all its ventilation openings sets a very big demand for having better tools material characterization.

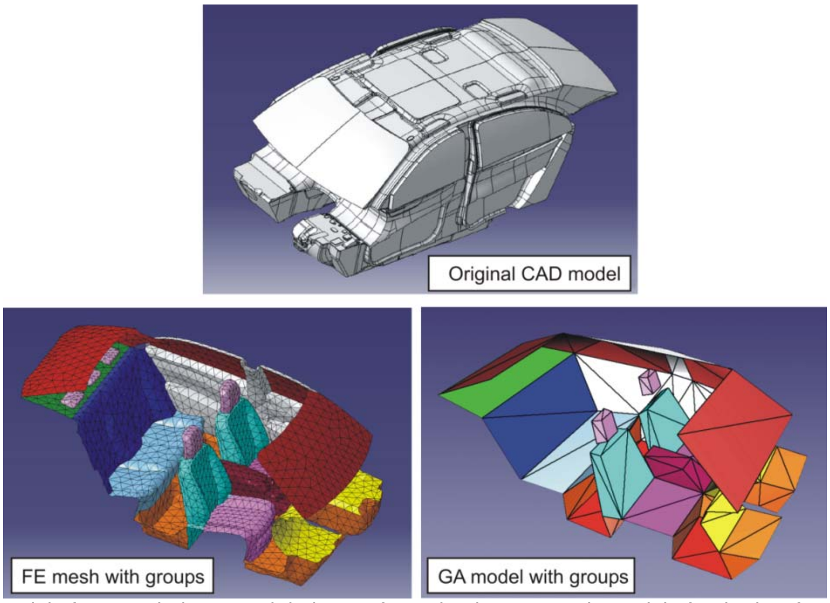


Figure 4. CAD models from car industry and their transformation into acousrtic models for the low frequency part (left) and the high frequency part, from [12]

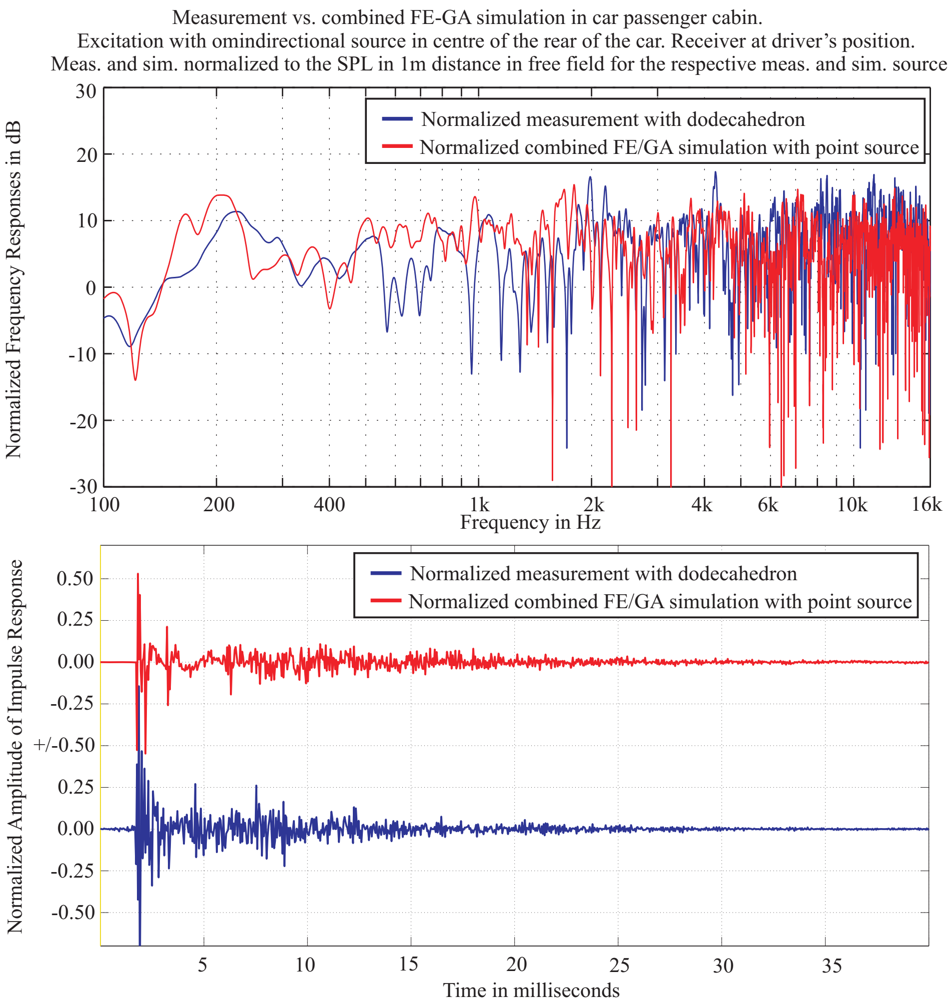


Figure 5. Comparison of simulated and measured frequency response in the passenger cabin, from [12]

4. CONCLUSION

The uncertainties in results of acoustic simulations strongly depend on the quality of the boundary conditions. After a decade of rapid development of numerical methods and computation hardware, the next improvement in acoustic simulation is expected not to be in the numerical methods and their implementation, but in the determination of boundary conditions in the laboratory and in in-situ.

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REFERENCES

[1] ISO 354: Acoustics - Measurement of sound absorption in a reverberation room (2003)
[2] ISO 17497-1: Acoustics - Sound-scattering properties of Surfaces, Part 1: Measurement of the random- incidence scattering coefficient in a reverberation room (2004)
[3] ISO 10534-2: Acoustics - Determination of sound absorption coefficient and impedance in impedance tubes - Part 2: Transfer-function method (1998)
[4] Vorländer, M., Computer simulations in room acoustics – concepts and uncertainties. J. Acoust. Soc. Am. 133 (3) (2013), 1203
[5] Shtrepi, L., Pelzer, S., Rychtarikova, M., Vitale, R., Astolfi, A., Vorländer, M., Objective and subjective assessment of scattered sound in a virtual acoustical environment simulated with three different algorithms. Proc. Internoise 2012, New York, August 2012
[6] Suh, J.S., Nelson, P.A., Measurement of transient response of rooms and comparison with geometrical acoustic models. J. Acoust. Soc. Am. 105 (1999) 2304
[7] Jeong, C.-H, Absorption and impedance boundary conditions for phased geometrical-acoustics methods. J. Acoust. Soc. Am. 132 (4) (2012) 2347
[8] Yousefzadeh, B., Hodgson, M., Beam-tracing prediction of room-acoustical parameters using different boundary conditions. J. Acoust. Soc. Am. 132(3) (2012) 1450
[9] Aretz, M., Dietrich, P., Vorländer, M., Application of the mirror source method for low frequency sound prediction in rectangular rooms. Applied Acoustics (in review).
[10] Pelzer, S., Aretz, M., Vorländer, M., Quality assessment of room acoustic simulation tools by comparing binaural measurements and simulations in an optimized test scenario. Proc. Forum Acusticum, Aalborg, Denmark, July 2011
[11] Behler, G.; Aretz, M.; Vorländer, M., Complete system theoretical model of the car-infotainment system. Aachener Akustik Kolloquium, Aachen, Germany, November 2010
[12] Aretz, M., Combined Wave And Ray Based Room Acoustic Simulations Of Small Rooms. Doctoral Dissertation, RWTH Aachen University, Germany 2012.