Simulation and auralization of broadband room impulse responses

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Abstract
Computer modelling in room acoustics can today not only be done by using ray-based methods but also with wave-based methods. The acurracy provided, however, is only apparent since the uncertaintied in the input data for the computer methods are not adequately small to allow for simulation of the fine structure of stationary room transfer functions. Accordingly it is the question at which frequency the user could stop using wave-based methods and switch to ray-based methods. The Schroeder frequency could be chosen, but it is not clear in which way the uncertainties in input data influence the results quantitatively.In this paper first attempts are made towards an investigation to evaluate best cross-over frequency between wave-based and ray-based methods by discussing the fine structure in frequency response curves.

Keywords: Room acoustics, Simulation, Finite Elements, Ray Tracing

1 Introduction

Room acoustic simulation is usually done by using Ray Tracing or Image Source algorithms. The foundations for both is geometrical acoustics (ray-based models), where sound propagates in rays rather than in waves. On the other side of acoustic modelling, there are wave models such as Finite Element Methods (FEM). Also, it depends strongly on the sound signal of interest, which method is appropriate. Whether it is broadband or narrowband in nature, stationary or transient? In case of stationary pure-tone signals, wave effects are more relevant than for transient sounds. Also, when it comes to small rooms or small design elements such as balconies, wave effects cannot be neglected. In the same time, for low-reverberant rooms, geometrical models fail due to violation of the plane-wave approach for the definition of wall impedance and absorption. The methods available are thus not useful throughout the frequency range of interest, and combinations of wave and ray models are an interesting option indeed. Nevertheless this combination was only applied in few cases [1, 2, 3].

Today, we have more and more computer speed and memory size available, so that Finite Element Modelling is feasible up to rather high frequencies. The question, however, is up to which frequency wave models should be used. This question relates not only to limits of computation time, but also to the physical meaning of the results.

This contribution gives an overview of previous work and an insight into ongoing work at RWTH Aachen University in this field.

2 Frequency regions in room acoustical frequency curves

The Schroeder frequency is usually the critical frequency to separate the modal region from the statistical region in stationary room transfer functions is the famous

$$f_S = 2000\sqrt{\frac{T}{V}} \quad , \qquad (1)$$

where three modes overlap within their average bandwidth [4, 5].

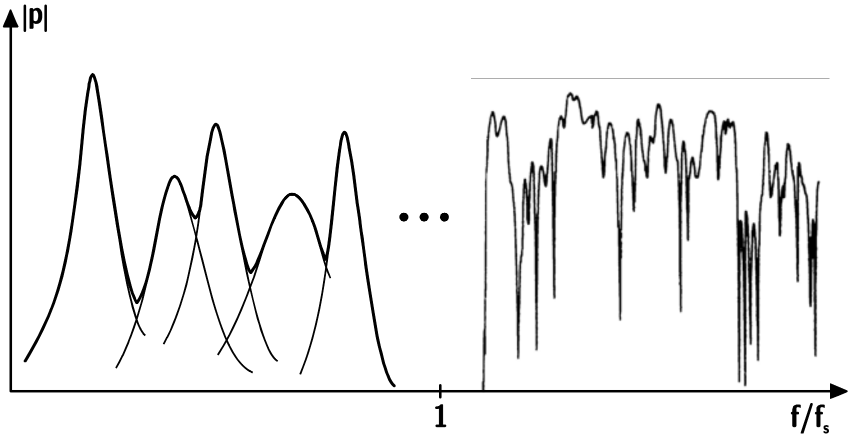

Fig. 1 Stationary room transfer function of sound pressure magnitude at an arbitrary receiver point.

Another frequency limit could be defined by the smallest object of relevance, or by the smallest room dimension. After all, a final guideline cannot be given since the importance of wave effcts depends on numerous details which may differ in each case. Ongoing work, for example, is focused on car cabins, and the questions is if the Schroeder frequency marks the transition frequency for less significant wave effects or rather the wavelength in comparison with the size of a headrest.

2.1 Case study

In order to start with a simple volume and in order to allow for easy measurements, a scale model was constructed from wooden (MDF) plates (Fig. 2). It consists of a box with a volume of 1.25 x 1.00 x 0.75 m^3. The measured reverberation time is between 1 s and 0,6 s. The measured frequency range was 400 Hz to 5 kHz (see [6]).

Fig. 2 Scale model room with measurement loudspeaker and microphone (after [6])

2.2 Simulation input data
With input data available for ray models (absorption coefficients), there remains the problem of converting them into impedances which are the input data for FE. At this point the phases of the surface impedances and the general question of locally reacting panels or materials come into play.

For the empty room shown in Fig. 2, absorption coefficients of the MDF wood were estimated from the measured reverberation time and converted into real-valued surface impedances. For materials placed into the room such as foam layers, measured and calculated impedances were used (see [7]).

3 Results
The initial observation is that the FE results of the empty rooms agree extremely well with the measurements up to 1.3 kHz, also in the details of the peaks and dips. Above this frequency, however, only the average response agrees well. And this is true for both simlation methods. Above 1.3 kHz the FE results look realistic, but the precision is only apparent. Already above 700 Hz the group delay shows difference between FE and measurements results. At low frequencies the ray-based results are not correct, but this is to be expected anyway.

Above 1.3 – 1.4 kHz, the ray-based method yields basically the same results are the FEM. Why is that? The answer was given by Schroeder in 1954 when he discussed the fine structure above Schroeder frequency. It is characterized by stochastic peaks and dips which occur due to multiple overlap of modes. These modes are sensitive to input data such as speed of sound, static pressure and complex wall impedances. It is hardly possible to find exact input data in order to get “exact” frequency curves.

Furthermore, it is hardly sensible to calculate all these details exactly since they refer to the stationary case of pure tones only. With broadband signals, only smoothed frequency curve is relevant, and the one detail ensemble is as good as the other, as long as they follow the same statistics.

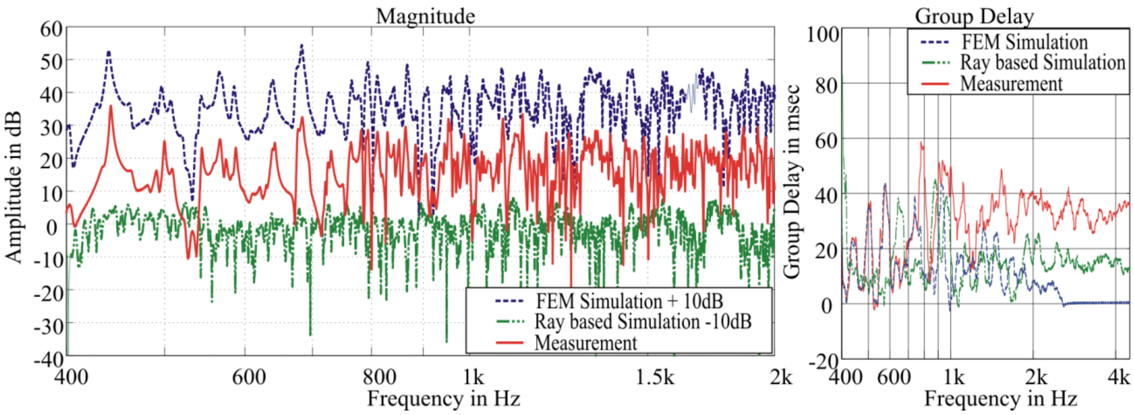

Fig. 3 Modulus and group delay of the room transfer function between loudspeaker and microphone. Results shifted by 20 dB for better visibility of details (example from [6]).

3.1 Parameter studies
Now, in order to preliminarily study the influence of the input data quantitatively, simulations were performed with varying temperature and impedance phases. The results are shown in Figs. 4 and 5. The illustrate that the fine structure is very sensitive to small changes. Imagine a large room where the HVAC system is moving the air. In

this case, even worse, the modes will fluctuate in time. The temperature shift creates shifts in frequency, whereas the impedance phase changes the overall modal superposition. Let's consider the measurement result as being exact. If all input data and particularly the impedance phase is not met exactly, the modal overlap will hardly meet the exact measured frequency curve. What is the point in aiming at calculating those details, in spite of FEM being capable of the performing reasonably with regard to computation time and memory size? The real problem is uncertainties in input data. Fortunately, all these effects are not audible: Temperature changes, moving air due to HVAC, or other aspects which influence the fine structure.

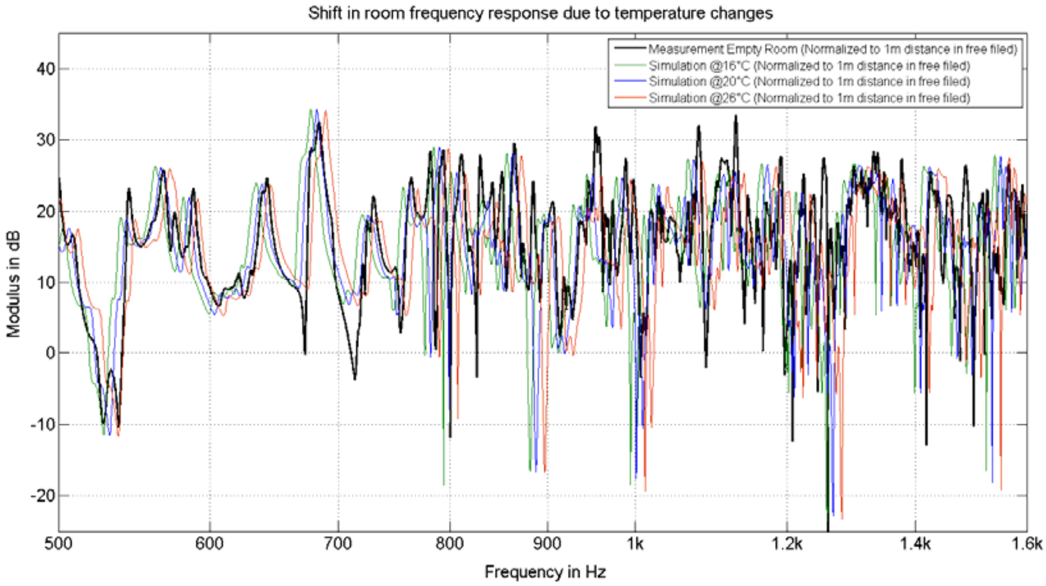

Fig. 4 Empty room frequency responses (examples) for temperature variations.

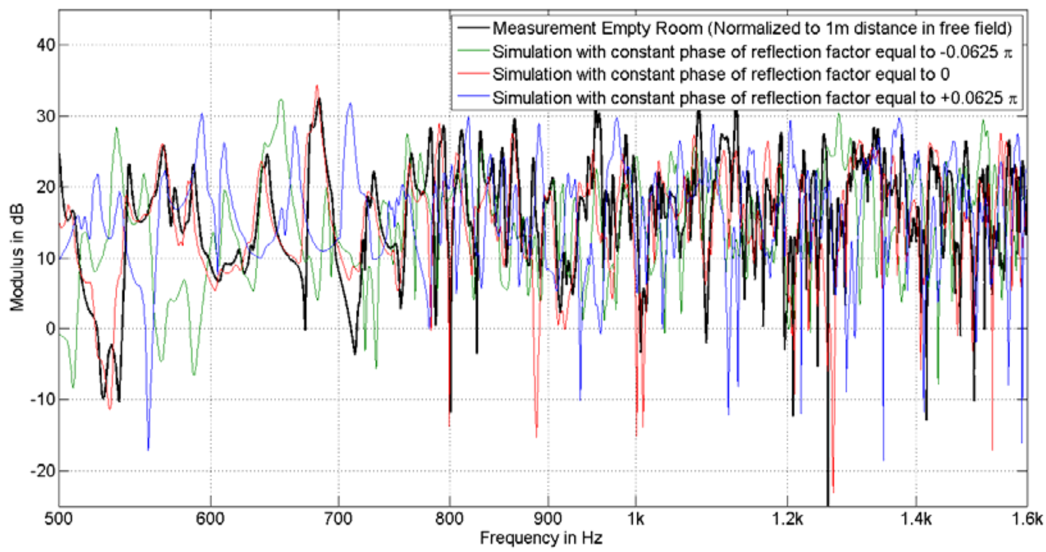

Fig. 5 Room frequency curves (examples) for phase variations of the reflection factor.

4 Conclusions

Following the progress in computer technology, wave-based models are going to be used for room acoustic simulation. Up to now, ray-based models must still be added to cover the high frequency range. The question is which transition frequency should be chosen.

It was shown that small changes in input data for wave-based simulations change the fine structure of the stationary room transfer function. At that point the result is as good as the result from ray-based methods, which are, however, faster by order of magnitude. Further improvement can only be reached if the input data can be fixed more precisely. This improvement, however, is not at all needed for auralization of broadband sound in rooms. There is just one example where exact pure-tone and wave-based simulation would be necessary, which is the calculation of the exact hum frequency in feedback loops.

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