Optimal interior sound management for public and individual transportation systems: Evaluation of objective acoustic parameters

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Introduction

This PhD thesis deals with the research on how rooms have to be acoustically designed and excited, to guarantee an optimal perception of sound in the mid and high frequencies.

Sound management is defined as an interaction of the three factors ***Safety***, ***Comfort*** and ***Privacy*** (Figure 1).

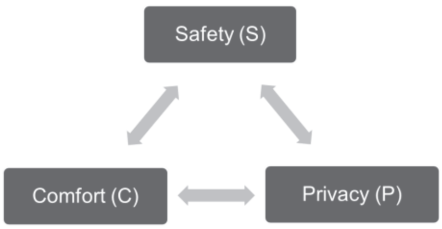

Figure 1: Factors for sound management

Up to now, sound management in not a major design criterion and is only benchmarked by performing test using prototypes. The design of the interior has to be known.

Numerical simulation can be performed; however the implementation into the design process is small due to the fact that the accepted validation processes are still not established. Especially the coupling to optimization problems is still not a simple approach. Also the sufficient modelling of room acoustical problems involves a number of parameters (e.g. material-based absorption coefficients) which are currently not easy to implement.

Objective

The goal of the research is to solve an appropriate optimization problem based on acoustic quantities for optimal acoustic interior sound management in public and individual transportation systems (Figure 2 and Figure 3) as well as to validate solutions for Safety, Comfort and Privacy (SCP)- optimization with simplified test rigs.

The developed method can then be applied to consider optimal interior sound management in a very early stage of the cabin design process. Solving this problem will result in a fast, cheaper and more efficient development of cabins, ensuring SCP.

Moreover, this might be interesting with regards to future vehicles and drive concepts "e-vehicles" closely linked to lightweight construction (e.g. electric mobility in the automotive industry where the sound spectrum in the interior varies significantly due to the elimination of the combustion engine)

Figure 2: Interiors for application of method

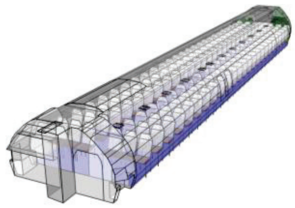

Figure 3: First acoustic model of a generic aircraft cabin

Concept

The concept is based on the following five major steps:

1. Research of the state of the art,
2. Analysis and building of room acoustic models for specific interiors,
3. Formulation of a sufficient optimization approach (cost-function),
4. Solving the optimization problem based on numerical simulations of sound fields within the different interiors,
5. Validation of the optimization results using simplified test rigs.

Project Indicators

This PhD Thesis is in cooperation with the University of the West of Scotland (UWS) in the part-time MPhil/PhD program and the University of Applied Sciences Hamburg.

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Implementation and Results

According to the IEC international standard 60268-16:2011, [1], the influence of the measured reverberation time on the RASTI value can be quantified. For this purpose, the modulation transfer function (MTF) has been calculated by applying the formulas given in the IEC norm on page 36 onwards (Eqn. 1).

$$m_k\left(f_m\right) = m_{SNR} \cdot m_{(f_m)}, \quad (1)$$

with $m_{SNR} = \frac{1}{1+10^{\left(-\frac{SNR}{10}\right)}}$ and

$$m_{(f_m)} = \frac{1}{\sqrt{1+\left(\frac{2\pi \cdot f_m \cdot T_{20}}{13.8}\right)^2}}$$

(SNR is the signal-to-noise ratio in dB, f_m the modulation frequency and T_{20} the reverberation time in seconds)

Afterwards the effective SNR_{eff} can be calculated as follows (Eqn. 2):

$$SNR_{eff,k,f_m} = 10\log\left(\frac{m_k\left(f_m\right)}{1-m_k\left(f_m\right)}\right) \quad (2)$$

With knowledge about the effective SNR it is possible to calculated the transmission index (TI) according to the IEC norm (Eqn 3). A change in the SNR according to the reverberation time of the room (change of damping parameters) is neglected.

$$TI_{k,f_m} = \left(\frac{SNR_{eff,f_m}+15}{30}\right) \quad (3)$$

The derived transmission indices are averaged over the modulation frequencies to obtain the modulation transfer index (*MTI*), Eqn. 4, per octave band *k* (for RASTI 500Hz and 2kHz):

$$MTI_k = \frac{1}{n}\sum_{m=1}^{n} TI_{k,f_m} \quad (4)$$

(TI_{k,f_m} is the transmission index for each octave band k and modulation frequency f_m, m is the index of modulation frequency and n the number of modulation frequency per octave band).

Finally the RASTI value can be calculated as followed (Eqn. 5):

$$RASTI = \alpha_k \cdot MTI_{500Hz} + \beta_k \cdot MTI_{2KHz} \quad (5)$$

(α and β are frequency weighting factors, which are applied using four contributions for the 500Hz octave band and five for the 2kHz octave band. The factors are respectively $4/9$ (0.45) and $5/9$ (0.55). The modulation frequencies for the RASTI method are given in table 1.

Table 1: Modulation frequencies for the RASTI method [1]

Modulation frequency [Hz]	f_1	f_2	f_3	f_4	f_5
500 Hz octave band	1.0	2.0	4.0	8.0	---
2 kHz octave band	0.7	1.4	2.8	5.6	11.2

To state how accurate the reverberation time has to be measured, the deviation of the RASTI value has been plotted over the signal-to-noise ratio (figure 2).

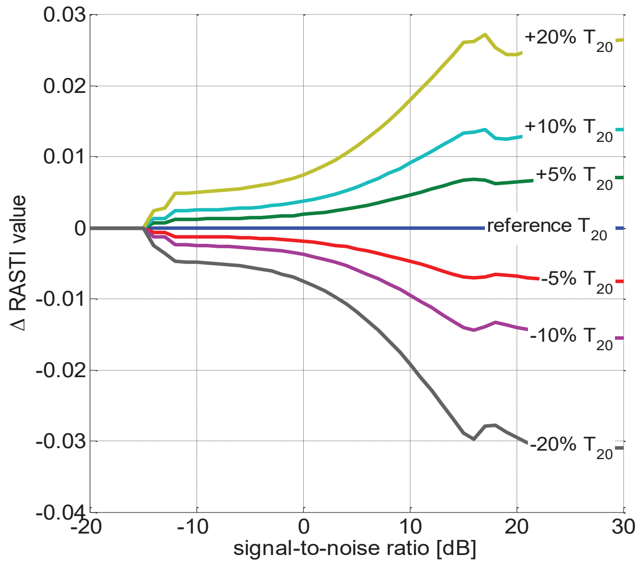

Figure 4: Effect on the RASTI Value

According to [1], the values for the effective signal-to-noise ratio are limited to the range of -15dB to +15 dB. Values less than -15dB are given the value of -15dB and values greater than +15dB are given the values +15dB.

Conclusion

A measurement error of the reverberation time of 5%, 10% and 20% has been calculated. It can be noticed, that within a small SNR of 0…+10dB the influence of the measurement error is comparably small (maximum +/- 0.02 RASTI). Even for higher SNR and a measurement error of 10% in the reverberation time, the deviation to the RASTI value reaches a maximum of 0.014. From 20% failure in the measurement of T20 onwards, the influence is rather high with a deviation of about +/-0.03 RASTI.

References:

[1]. **International Standard IEC 60268-16**. *2011-06. International Electrotechnical Commission : s.n., Sound system equipment - Part 16: Objective rating of speech intelligibility and speech transmission index*. 978-2-88912-672-9.