Identification of absorption parameters using an optimization algorithm

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Abstract

For speech intelligibility, especially of aircraft public address systems, the regulations are defined by the civil aviation authority (CAA). The speech intelligibility is expressed by the Speech Transmission Index (STI) or the RApid Speech Transmission Index (RASTI) which is described in the standard IEC 60268-16. The STI is defined by a scale from 0 to 1, based on weighted contributions from a range of frequency bands present in speech. Values larger than 0.6 STI define acceptable speech intelligibility. The RASTI value depends on room impulse response, the signal strength of the source and the background noise at the receiver position. Due to cost intensive flight test the alternative way to certify the speech intelligibility is the use of simulation techniques. For predictions of speech intelligibility it is important to use sophisticated material parameters in room acoustic simulations to calculate accurate values for STI or RASTI. Changing the absorption coefficients by 20 % results in a change of the STI value about 0.03. In most cases the absorption coefficients used in simulation models are measured under lab conditions with normal or diffuse induced sound fields. In real aircraft cabins the sound fields are dominated by the incoming sound which is depending on the frequency range and affects the absorption of surface materials. To obtain real absorption coefficients in aircraft cabins, an optimization process has been developed to match the absorption coefficients from measured data. The optimization process depends on room acoustic simulation using an inverse ray tracing algorithm.

Measurement Methods of Sound Absorption Coefficients

Characterization of room acoustic boundary conditions is possible using the sound absorption coefficient α which is defined as the ratio of the absorbed sound power P_a to the incident sound power P_i. The absorption coefficient can also be expressed as a function of the reflection factor R by:

$$\alpha = \frac{P_a}{P_i} = 1 - |R|^2 . \tag{1}$$

Three state-of-the-art of measurement techniques ((A) impedance tube, (B) in-situ measurement, (C) alpha cabin) to determine sound absorption coefficients are described in the following.

The measuring method based on impedance tubes (A) is described in DIN EN ISO 10534-2 (two microphones) and calculates the absorption coefficient by the following formulation:

$$R = e^{i2kl} \frac{e^{iks} - H_{12}}{H_{12} - e^{-iks}} , \tag{2}$$

where k is the wave number, l is the distance from the sound source to the first microphone, s is the distance between the two microphones and H_{12} is the complex transfer function of the signal at the microphones.

According to DIN EN ISO 9614 the pressure-based in-situ method (B) is realized by using

$$R = \frac{z/(\rho_0 c)\cos(\vartheta) - 1}{z/(\rho_0 c)\cos(\vartheta) + 1} . \tag{3}$$

The in-situ method based on pressure-velocity relations uses the sound pressure p the particle velocity u to calculate the impedance Z.

$$Z = \frac{p}{u} \tag{4}$$

The in-situ impedance measurement device from Microflown Technologies (see Figure 1) has been used to determine the start values for the optimization algorithm which is described in the next section.

Figure 1: In-situ impedance measurement device from Microflown Technologies

The diffuse sound absorption coefficients, also known as Sabine absorption coefficients, are estimated in small/ large reverberation chambers (alpha cabin) according to DIN EN ISO 354 (C). The absorption coefficients can be calculated from the measured reverberation times of the empty chamber T_0 and with sample T_{Sample} (see Eq.5)

$$\alpha = \frac{55.3V}{S} \left[\frac{1}{T_{Sample}} - \frac{1}{T_0} \right] , \tag{5}$$

where V and S are the volume of the reverberation chamber and the area of the sample.

The described measurement methods (A, B and C) have been applied and compared to figure out the absorption coefficients for a certain material from 400Hz to 10kHz. The measurement in an Alpha Cabin (diffuse field from 400Hz onwards) is also included in this comparison. The result can be seen in Figure 2. The results show deviations for certain frequency bands. The Microflown device matches comparable data from other literature the best (not shown in Figure 2).

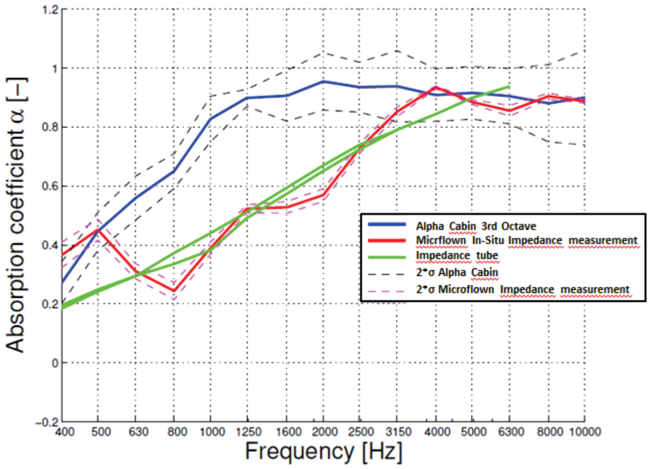

Figure 2: Comparison of different measurement methods for the absorption coefficient

Room Acoustic Property Optimizer

In a previous work [2] the base version of the Room Acoustic Property Optimizer (RAPO) has been developed. The main goal of RAPO is to fit the energy decay of the simulation model to the measured one by adapting the absorption coefficients of the material parameters. The schematic functional diagram is given in Figure 3. The software MATLAB has been used to implement the optimization algorithm of RAPO. For the development of RAPO in the version v2, the optimization algorithm has been changed from LSQCURVEFIT to LSQNONLIN to be able to handle an increased number of input parameters (i.e. material parameters, number of source and receiver positions and complexity of the room).

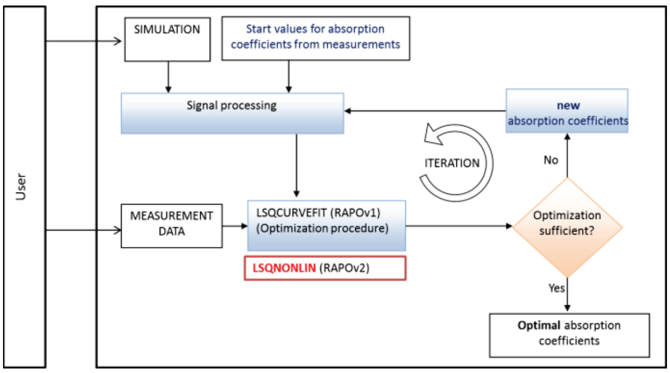

Figure 3: Schematic functional diagram of RAPO

The energy decay histograms of each source-receiver combination were fitted simultaneously for a certain time stamp t_{ts} for more accuracy of the absorption coefficient estimation [1]. Each optimization run takes about 20 minutes (Intel i5 processor, 8GB memory) to minimize the cost function exemplarily for a certain α (Eq.6 – LSQNONLIN, an algorithm to solve nonlinear least-squares problems) for this complex test case:

$$\min_{\alpha} \left\| e_{ts}(\alpha) \right\|_2^2 = \min_{\alpha} \left(e_{1_{ts}}(\alpha)^2 + \ldots + e_{n_{ts}}(\alpha)^2 \right) \qquad (6)$$

Both inputs (simulated and measured energy decay) will be fed into the optimization algorithm to find the minimum of the cost function in a loop process (see Figure 3).

Test Case for RAPO v2

The optimization of a generic aircraft cabin (see Figure 4) was carried out using 24 different materials: materials for seats, materials for linings, partitions and floors. For this optimization a number of approximately 40 loudspeaker models at special positions with 170 microphone called listener positions have been used. The reverberation time of this generic model is between 200 and 300ms. The first test case for RAPO in Version1 [2] had two materials, six faces, one loudspeaker, two listener positions and a reverberation time of 1.5s.

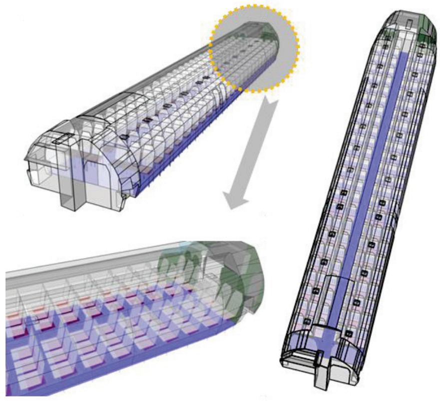

Figure 4: Generic aircraft cabin used as a test case for RAPO v2, [3]

Optimization Results

The optimization algorithm is capable to detect the absorption coefficients which have the most influence on the simulation result. Figure 5 and 6 show the optimization results of RAPO in the frequency range from 100Hz to 10kHz for two different materials.

Figure 5 presents the characteristic of the absorption coefficient for a lining panel. Figure 6 presents those of a seat. The red curve shows the initial absorption coefficient (measured with the Microflown device) whereas the blue curve shows the optimization results of RAPO. One may see that no optimization results are available for the frequency range below 500Hz and above 5kHz – this belongs to the fact that the loudspeaker in the aircraft cabin is not able to perform good enough in those frequencies. The signal-to-noise ratio is below 10dB in the energy decay so that no appropriate absorption coefficient can be calculated.

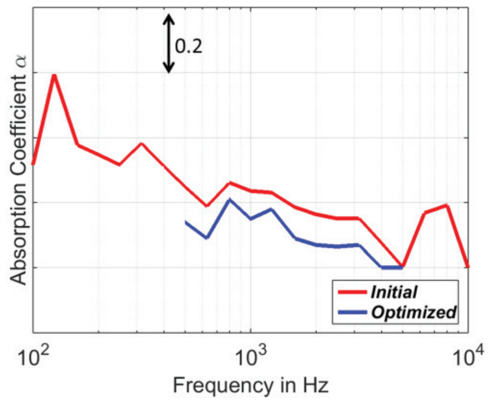

Figure 5: Absorption coefficient for a lining panel

From Figure 5 it can be seen that the optimizer reduced the absorption coefficients in the frequency range from 500Hz to 5kHz.

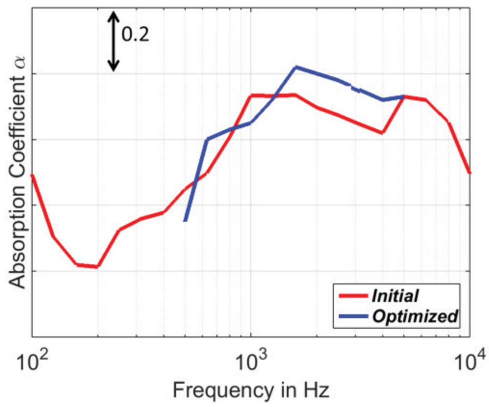

Figure 6: Absorption coefficient for a seat

The absorption coefficient for a seat is mainly affected above 1.6kHz. For the frequency range from 500Hz to 1kHz the absorption is mainly unaffected. To be able to see whether the optimized absorption coefficients minimize the difference between the simulated energy decay of the measurement and the simulation, the simulation including the new dataset of absorption coefficient has been included in Figure 7. Here, the energy decay of a selected octave band is shown for a certain listener position within the aircraft cabin. The red curve shows the initial dataset of absorption coefficients which have been measured with the in-situ absorption measurement device from Microflown. The blue curve shows the new dataset of RAPO and the black curve shows the actual measurement. It can be noticed that the deviation of the energy decay $\Delta e_{ts\,simulation-measurement}$ decreases which is an indicator that the new dataset provides a better pattern quality.

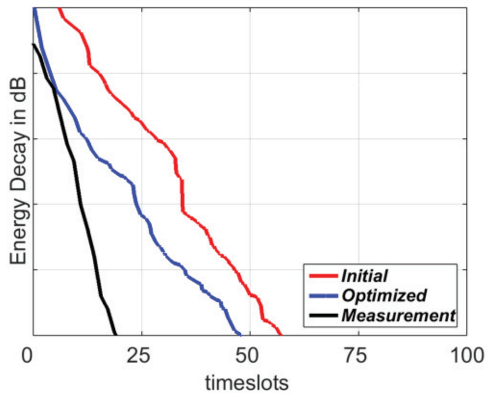

Figure 7: Energy decay for a certain listener position

Conclusion

The study describes an optimization process for absorption coefficients based on an inverse ray tracing method to improve room acoustic simulations of speech transmission intelligibility. It is shown that the inverse method can be applied to a complex aircraft cabin and still provides results which improve the quality of the room acoustic model. The next steps would be to perform additional validation runs with loudspeakers which are able to perform from 100Hz to 10kHz. Moreover the optimization time should be reduced by optimizing the signal processing in RAPO and the integration of scattering as the second main driver for material properties in the room acoustic software. Additionally one may think of the implementation of a generic algorithm to find good start values for the optimization of absorption coefficients instead of measure those and use a Newton's method afterwards to find the optimum.

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