Limits of intelligible speech in medium sized multi purpose spaces

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Introduction

Many medium-sized spaces are used for both speech and music. Examples include churches, school halls or local cultural spaces. The different requirements for speech and music make the acoustic design of such spaces difficult, in particular if a purely passive solution is sought. In acoustical terms, the question is to which limits reverberation time can be increased while still maintaining acceptable speech intelligibility.

Method

In this investigation, generic spaces have been examined by both, acoustic scale modelling (1:25) and computer simulation (CATT-Acoustic).

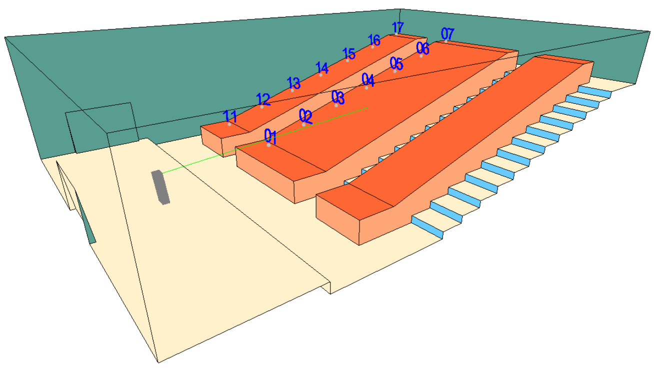

Figure 1: CATT model of a hall with raked audience seating. Shown are receiver positions (numbers) as well as source position and aim. The blocks represent the audience.

The halls provided 300 seats in either a flat or raked configuration of the audience seating. Adjustable ceiling heights of 4 to 8 m resulted in volumes ranging from 1500 to 3000 m^3. The scale model hall was constructed from plain veneered MDF, resulting in low absorption and scattering coefficients. For computer simulation, absorption coefficients for the veneered MDF were available. Scattering coefficients of the plain walls have been estimated to s = 0.1. The scale model audience consisted of model seats, covered with fabric to represent a seating audience. For computer simulation, absorption coefficients for occupied low absorption auditorium chairs according to Bradley [3] were used along with a scattering coefficient ranging from s = 0.3 to 0.8 for the octaves from 125 to 4000 Hz.

Scale model measurements and computer simulation were compared by means of reverberation metrics (EDT, T_{30}, T_{15}) and Deutlichkeit D. Especially for the raked audience seating, good agreement was found (mean deviation for the 500, 1000 and 2000 Hz octaves: T_{15}: ±2.9 %; D: ±4.6 %). Differences can be accounted for by properties of the scale model such as gaps, uncertainties of absorption and scattering coefficients and the neglect of noise and wave effects in computer simulation. Also, the way the audience is represented in the computer model may introduce additional error.

The main investigation was conducted using computer simulation only. It was assumed that D of 50 % will allow sufficient speech intelligibility. This target D, measured at 14 positions within the audience and averaged over the 500, 1000 and 2000 Hz octaves was achieved by placing absorbing surfaces with a flat absorption coefficient of α = 0.5 in the cornices of the hall [1]. The resulting reverberation times were analysed along with the aptitude for music expressed by clarity C_{80}.

Results

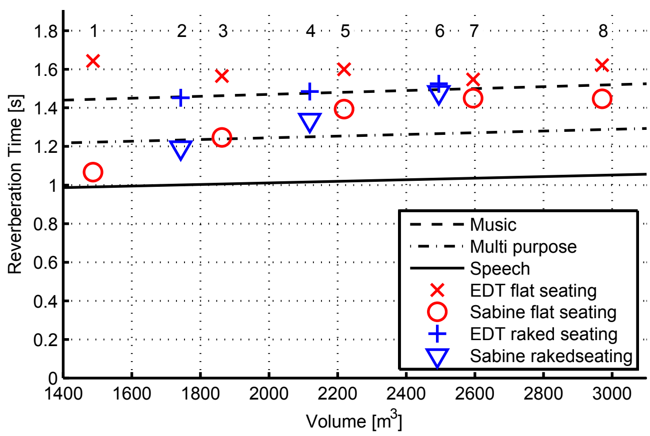

Figure 2: Comparison of Sabine predicted RT and CATT-simulated EDT for 8 different hall configurations (height/volume, audience seating). The lines indicate recommended RTs for speech, multi purpose use and music, according to [1], [2].

	hall configuration							
	1	2	3	4	5	6	7	8
seating	f	r	f	r	f	r	f	f
height [m]	4	6	5	7	6	8	7	8
D [%]	53	54	54	52	52	51	52	52
C80 [dB]	2.8	3	3	2.7	2.7	2.4	2.9	2.6

Table 1: Mean values of D and C_{80} (0.5 - 2 kHz) for the different hall configurations (flat (f)/raked (r) audience seating, ceiling height) corresponding to Fig. 2.

The admissible Sabine RT resulting from satisfactory speech intelligibility expressed by $D \geq 50\%$ is close to recommendations for musical performance for configurations with a volume from 2500 to 3000 m^3 (ceiling height $\geq$ 7 m), whereas the EDTs are close or slightly higher than recommendations for music for all volumes/ceiling heights (Fig. 2). Additionally, C_{80} confirms the aptitude for music (Tab. 1), which was expected considering the long RT.

The differences between the different reverberation metrics indicate a two dimensional, horizontal sound field resulting from unevenly distributed absorption. With the high-absorbing audience covering large areas of the floor and the rest of the room being reflecting, vertical components of the sound field get absorbed quickly while horizontal components are being reflected back and forth, leading to a slower rate of decay. Consequently, additional absorption on the ceiling away from the horizontal sound field has little to no impact on the late RT metrics, whereas the early metrics are influenced in a much stronger fashion. (Fig. 3). The decay curve reflects this with a non-linear, sagging decay (dual slope decay) compared with the linear decay expected from an ideal diffuse sound field Fig. 4).

Decreasing the volume of the halls by means of ceiling height intensifies the divergence of the different reverberation metrics which indicates a more distinct horizontal sound field for those conditions. This might be explained by a low ceiling increasing the chance of absorption via audience or absorbers whereas halls with a high ceiling are able to support a more diffuse sound field.

A brief examination of the influence of different scattering coefficients of the walls (s = 0.1, 0.3) showed no significant effect on D and therefore similar amounts of absorption were used. The increased diffusivity caused by higher coefficients resulted in reduced T_{30}, T_{15} and EDT values due to better utilisation of the absorbing surfaces. The differences for EDT range from 0.17 s for the smallest flat hall to 0.03 s for the larger volumes with raked seating. Another consequence is the convergence of the different reverberation metrics with increased scattering. As for D, the changing sound field has no significant impact on C_{80}, although it is expected that increased diffusivity is beneficial for the perception of music.

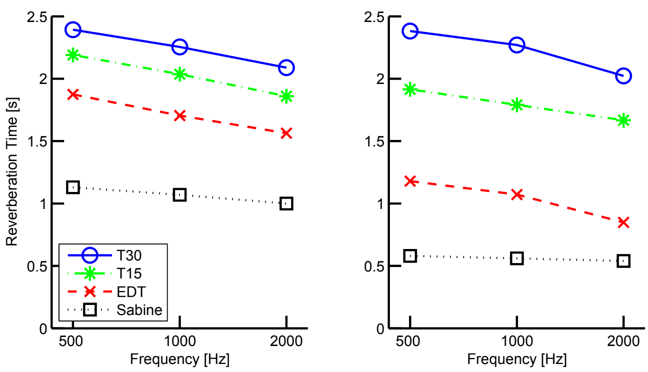

Figure 3: RTs for Hall with flat audience seating only (left) and additional absorbing ceiling (right) to demonstrate the effect of a horizontal sound field on different RT metrics.

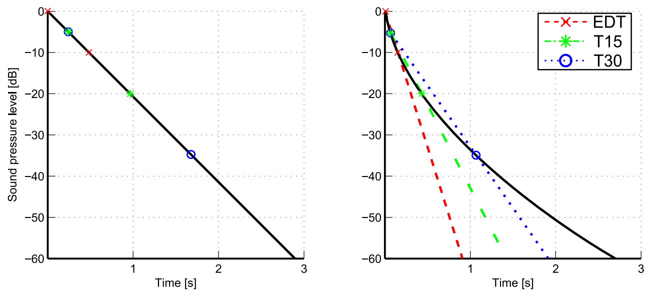

Figure 4: Illustration of the decay for a space with ideal diffuse sound field (left) and horizontal sound field due to unevenly distributed absorption (right) and the impact of the non-linear decay on EDT, T15 and T30.

Conclusion

The results indicate that the recommended reverberation time for speech can be exceeded while still maintaining adequate speech intelligibility. This could be valuable for small size multi purpose spaces, such as school halls, to give more responsive acoustics for music use. It is also shown that the examined types of rooms support a distinct horizontal sound field with short early and long late reverberation metrics. As long as the space offers few scattering surfaces and absorption is mainly located at the floor (the audience) and the ceiling (or ceiling cornices), this behaviour will always occur in a similar manner and could thus be exploited when projecting medium-sized spaces.

Considering the metrics used in this investigation, these two dimensional sound fields seem to have no negative impact on the acoustics of the examined spaces (also see [5]). Nonetheless, the findings should be verified by subjective listening tests.

References

[1] DIN 18041. Hörsamkeit in kleinen bis mittelgroßen Räumen, (2004-05)

[2] W. Fasold und E. Veres. Schallschutz und Raumakustik in der Praxis. Huss-Medien GmbH, 2003

[3] J. S. Bradley. The sound absorption of occupied seating. Journal of the Acoustical Society of America, **99** (1996), 990-995

[4] I. Borg. Report on the 3rd round robin on room acoustical computer simulation. Acta Acustica United with Acustica, **91** (2005), 740-763

[5] E. Meyer, H. Kuttruff und N. Roy. Raumakustische Untersuchungen an einem Modell der Stadthalle in Göttingen. Acustica, **19** (1957), 132-142