Computerised planning aid for the design of anechoic chambers

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Introduction

The quality of an anechoic or hemi-anechoic room does not only and not the most depend on the absorption of its lining. Many other parameters, as room geometry, position of the source and receiver play an important role. The practical suitability proof of an anechoic room is possible by an examination of the sound pressure level drop according to the standard [1]. However, the suitability test of the anechoic room can be done only after it was already built. For the planning of new anechoic rooms it is important to predict and optimize its freefield.

Method of computation

A simulation program with mirror sources was employed. Suppose a point source (strength A_0) is located in a room, the sound pressure p at a distance r_0 is

$$p = \frac{A_0}{r_0} e^{-jkr_0} + \sum_{i=1}^{N} R_i{}^n \frac{A_0}{r_i} e^{-jkr_i} \qquad (1)$$

with k wave number, i index of the mirror sources, N total number of mirror sources, r_i the distance from the mirror source to the measuring position. $R_i = |R_i| e^{j\varphi_i}$ is the reflection factor of the respective surface, and n the order of the mirror source. The first term in equ. (1) is the direct sound; the second represents the response of the room. The reflection factor R_i is a complex number, which represents the energy loss and the phase shift φ_i of each reflection and depends on the angle of incidence Θ [2].

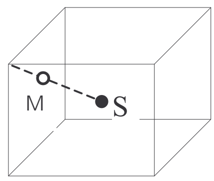
Exemplary results

Influence of absorption and symmetry: [1] suggests a value $\alpha_0 \geq 0.99$ for the anechoic linings measured in a standing wave tube. Figure 1 shows exemplary computational results of the deviations from the free field sound level decay along a diagonal path in a 6 x 6 x 6 m room for a central point source emitting sine waves. Dark (pink) cells show deviations, which exceed the tolerance range defined in [1]], namely ± 1 dB for 800 to 5000 Hz and ± 1.5 dB for $f \leq 630$ Hz and $f \geq 6300$ Hz. Only if a completely unrealistically high absorption coefficient of $\alpha_0 = 0.999$ were assumed, an ideal freefield would be achievable

Influence of room geometry: In the completely symmetric configuration of Figure 1 many reflections with almost equal wave path differences interfere at the measuring point. The effect of accumulated interferences may be diminished through asymmetric room geometry or by offsetting the same source from the room centre. Figure 2 shows calculated results for a freefield room with 7 x 5 x 6 m, i.e. approximately of the same volume as that in Fig. 1. The freefield range is considerably enlarged. A comparable result could be achieved if, in the 6 x 6 x 6 m cube the source were but slightly shifted from 0; 0; 3 m to 0.5; 0.3; 2.8 m.

Max. Tol. [dB]	Frequency [Hz]	Distance Source - Microphon in [m]														
		1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50
1.5	20	-1.1	-1.0	-0.9	-0.7	-0.6	-0.4	-0.2	0.0	0.2	0.4	0.5	0.7	0.8	1.0	1.1
1.5	25	-1.0	-1.0	-1.0	-0.9	-0.7	-0.6	-0.4	-0.2	0.1	0.3	0.5	0.6	0.8	0.9	1.0
1.5	**31.5**	-0.8	-1.0	-1.0	-1.0	-0.9	-0.8	-0.6	-0.3	-0.1	0.1	0.4	0.6	0.8	0.9	1.0
1.5	40	-0.6	-0.8	-1.0	-1.1	-1.1	-1.0	-0.9	-0.6	-0.3	0.0	0.2	0.5	0.8	1.0	1.1
1.5	50	-0.4	-0.6	-0.9	-1.1	-1.2	-1.3	-1.2	-1.0	-0.7	-0.3	0.1	0.4	0.8	1.0	1.3
1.5	**63**	-0.5	-0.5	-0.7	-1.0	-1.2	-1.4	-1.5	-1.4	-1.1	-0.6	-0.1	0.4	0.8	1.2	1.5
1.5	80	0.2	0.3	0.3	0.1	-0.2	-0.7	-1.1	-1.3	-1.2	-0.7	-0.1	0.7	1.3	1.9	2.4
1.5	100	0.3	0.5	0.8	1.0	0.9	0.5	-0.3	-1.2	-2.2	-2.6	-2.2	-1.3	-0.3	0.6	1.3
1.5	**125**	-0.1	-0.3	-0.1	0.5	1.1	1.5	1.5	1.1	0.3	-0.8	-1.5	-1.6	-0.9	0.0	0.9
1.5	160	0.9	0.9	0.3	-0.7	-1.1	-0.4	0.8	1.4	1.3	0.4	-1.0	-2.0	-1.5	0.0	1.5
1.5	200	-1.4	-1.4	-0.5	0.2	0.0	-1.0	-1.4	-0.3	1.0	1.4	0.8	-0.6	-2.1	-2.2	-0.9
1.5	**250**	0.4	1.1	0.7	-0.2	0.5	1.5	1.0	-0.8	-1.5	0.2	1.3	0.7	-1.5	-4.1	-3.1
1.5	315	0.5	0.5	-0.2	1.0	1.2	-0.6	-0.1	1.3	0.1	-2.6	-1.3	0.7	0.3	-2.6	-4.4
1.5	400	-0.6	-0.5	-1.4	0.4	-0.9	0.2	1.4	-0.7	0.8	1.9	-0.6	-1.2	1.4	0.8	-2.9
1.5	**500**	-0.3	1.0	-0.1	1.3	-0.8	0.8	-1.4	-0.4	-0.3	-2.2	1.4	-0.7	-0.3	2.7	1.1
1.5	630	0.0	-0.3	1.2	0.3	0.3	0.6	-1.9	0.6	-2.6	1.5	-1.5	2.2	0.7	0.7	2.9
1.0	800	0.4	0.6	1.0	0.9	-0.1	-1.0	1.4	2.3	-0.2	2.1	0.1	-0.7	0.7	-1.8	1.5
1.0	**1000**	-0.3	0.4	0.8	0.4	-0.2	-0.2	-0.1	-0.7	-0.8	0.7	0.4	-3.1	-1.8	1.6	-2.0
1.0	1250	-0.4	0.9	0.9	-0.8	-1.0	0.9	2.1	1.9	1.2	1.0	1.7	1.7	-0.1	-0.8	1.5
1.0	1600	0.5	0.4	-1.0	1.0	-0.3	0.6	-1.4	0.9	2.0	-0.8	-3.1	-0.8	0.4	-0.5	-2.7
1.0	**2000**	-0.1	-0.2	0.6	-0.3	0.6	-0.8	-2.8	0.8	0.3	-2.7	0.8	0.7	-2.7	-0.2	1.3
1.0	2500	0.9	0.8	0.5	1.0	1.0	-1.0	2.1	1.5	2.2	2.8	0.4	-0.8	2.2	0.8	-0.8
1.0	3150	0.2	1.0	-0.2	-1.0	0.0	-1.1	1.8	-0.1	0.2	0.0	2.1	-1.7	-2.3	-1.1	-2.2
1.0	**4000**	-0.9	-0.2	0.4	0.7	-0.7	-2.2	1.0	-1.0	-2.9	0.3	-2.2	-1.5	-0.5	0.2	0.4
1.0	5000	-0.4	0.2	0.3	0.1	-0.9	0.4	-0.3	0.7	0.1	0.9	-0.9	-0.1	-1.9	-1.7	-3.0
1.5	6300	-0.5	0.6	-1.1	0.4	1.1	-0.1	1.0	-0.8	0.4	-0.1	0.4	0.2	0.9	2.1	0.6
1.5	**8000**	-0.1	0.1	0.7	1.1	-1.2	1.2	0.9	-1.0	1.2	-0.2	0.3	3.0	0.5	-0.2	2.3
1.5	10000	0.1	-0.3	-0.2	-1.1	-0.4	-0.9	-0.2	-0.3	2.0	-0.6	0.6	0.9	1.1	-1.1	-0.5
1.5	12500	0.3	0.1	-0.5	0.4	-1.5	1.1	1.5	1.4	1.8	-0.6	2.1	2.1	0.7	2.8	-2.2
1.5	**16000**	-0.6	-0.9	-0.8	-0.9	0.4	-1.2	-1.4	-0.6	-2.8	1.4	0.3	1.8	-0.2	1.4	-1.8
1.5	20000	0.1	-0.7	0.4	0.0	-1.0	0.9	-0.4	0.7	2.6	-0.4	-2.6	-1.3	1.3	-0.8	-1.0

Figure 1: Calculated deviations on a diagonal path in a 6 x 6 x 6 m room with a central sine source, $\alpha_0 = 0.99$



Max. Tol. [dB]	Frequency [Hz]	Distance Source - Microphon in [m]														
		1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50
1.5	20	-1.1	-1.0	-0.9	-0.7	-0.6	-0.4	-0.2	0.0	0.2	0.4	0.5	0.7	0.8	0.9	1.1
1.5	25	-1.0	-1.0	-1.0	-0.9	-0.7	-0.6	-0.4	-0.2	0.0	0.2	0.4	0.6	0.8	0.9	1.0
1.5	**31.5**	-0.9	-1.0	-1.0	-1.0	-0.9	-0.8	-0.6	-0.4	-0.1	0.1	0.3	0.6	0.7	0.9	1.0
1.5	40	-0.7	-0.9	-1.0	-1.1	-1.1	-1.0	-0.9	-0.6	-0.4	-0.1	0.2	0.5	0.7	0.9	1.1
1.5	50	-0.5	-0.7	-0.9	-1.1	-1.2	-1.2	-1.2	-1.0	-0.7	-0.3	0.0	0.4	0.7	1.0	1.2
1.5	**63**	-0.3	-0.4	-0.6	-0.8	-1.1	-1.3	-1.4	-1.3	-1.1	-0.7	-0.3	0.2	0.6	1.0	1.4
1.5	80	-0.1	0.0	-0.1	-0.2	-0.4	-0.8	-1.1	-1.4	-1.5	-1.2	-0.8	-0.2	0.4	1.0	1.5
1.5	100	-0.1	0.1	0.2	0.3	0.3	0.2	-0.2	-0.6	-1.1	-1.4	-1.3	-0.8	0.0	0.7	1.4
1.5	**125**	0.3	0.3	0.3	0.3	0.5	0.6	0.6	0.4	-0.1	-0.8	-1.3	-1.3	-0.6	0.3	1.3
1.5	160	0.5	0.5	0.6	0.7	0.7	0.8	0.9	1.1	1.1	0.8	0.1	-0.8	-1.1	-0.5	0.6
1.5	200	0.6	0.7	0.4	0.2	0.3	0.6	0.7	0.7	0.8	1.0	0.9	0.2	-0.7	-1.0	0.0
1.5	**250**	0.3	0.3	0.5	0.8	0.7	0.2	0.2	0.5	0.4	0.2	0.1	0.1	-0.8	-2.4	-2.5
1.5	315	0.9	1.1	0.9	1.2	1.1	1.1	0.9	0.1	0.0	0.3	0.0	-0.3	-0.1	-1.2	-2.7
1.5	400	0.0	0.3	-0.6	0.9	-0.2	0.0	0.4	0.1	0.1	-0.6	0.1	0.3	0.1	0.3	-0.9
1.5	**500**	-0.1	0.1	-0.6	0.7	-0.9	0.9	-0.4	-0.1	0.3	-0.2	-0.5	-0.1	0.6	0.3	0.4
1.5	630	0.3	0.9	0.8	1.3	0.6	0.5	-0.9	1.0	-1.5	1.5	0.5	1.1	1.1	1.7	1.3
1.0	800	-0.3	-0.2	0.7	0.8	0.3	0.5	-0.1	0.5	-0.4	1.7	-0.8	0.3	-0.1	-0.3	0.3
1.0	**1000**	-0.6	-0.3	-0.1	0.0	0.2	0.0	-0.7	-0.4	-0.5	-0.7	0.5	-2.0	0.7	0.1	0.2
1.0	1250	-0.6	0.5	0.7	-0.7	-0.6	0.3	0.7	0.8	0.5	-0.2	0.3	0.0	-2.4	-0.5	-0.8
1.0	1600	0.6	0.2	-0.3	0.2	0.2	0.6	0.4	0.2	-0.2	0.9	0.2	0.5	-0.2	-2.8	-0.9
1.0	**2000**	0.4	0.8	0.2	0.4	0.3	-0.8	0.1	0.4	-0.8	-0.5	0.8	2.6	0.0	-0.5	1.5
1.0	2500	0.7	0.3	0.4	0.2	0.5	-0.6	0.8	0.8	0.9	0.6	-0.9	0.4	1.8	0.6	1.5
1.0	3150	-0.2	0.7	-0.1	-0.3	-0.3	0.6	-0.1	0.0	0.2	-0.7	0.8	0.6	-0.8	1.8	-1.8
1.0	**4000**	0.2	0.1	0.4	0.5	0.6	0.6	0.0	0.2	0.3	-0.6	-0.3	1.6	0.6	0.1	-1.6
1.0	5000	-0.8	-0.1	-0.6	-0.9	-0.8	-0.2	-0.7	-0.1	-0.3	-0.8	0.9	-1.9	0.2	-0.3	-2.7
1.5	6300	0.3	0.7	0.2	-0.1	0.6	0.3	1.5	-0.6	-1.5	-1.1	1.9	0.3	-0.1	0.1	2.2
1.5	**8000**	0.3	0.0	-0.6	0.1	0.8	-0.4	-0.8	-0.8	-0.2	0.5	0.7	-0.3	-0.2	0.3	-0.6
1.5	10000	0.0	-0.3	0.0	-0.3	-0.8	0.1	-0.1	-0.3	0.6	0.5	-0.2	-0.5	-0.2	-1.2	1.2
1.5	12500	-0.6	-0.2	-0.1	0.2	-0.3	-0.8	-0.4	-0.5	-0.4	0.7	0.1	0.4	0.9	0.4	-0.9
1.5	**16000**	-0.5	-1.0	-0.4	-0.1	-0.7	0.4	0.3	-0.8	-0.7	-1.4	-0.1	1.4	-1.0	-1.9	-0.6
1.5	20000	0.1	0.3	0.0	0.1	0.2	1.2	-1.1	-1.0	0.7	-1.4	-0.1	1.4	-0.6	0.9	1.3

Figure 2: Calculated deviations on a diagonal path in a 7 x 5 x 6 m room with a central sine source, $\alpha_0 = 0.99$

Influence of floor reflections: If in a hemi-anechoic room (hard floor) a real sound source is placed not in but on or even above the floor, so that there exists a small, yet finite distance between the centre of the source and the floor, interference between the direct sound and the strong floor reflection is inevitable. Figure 3 shows calculated results at f = 500 Hz for a 6 x 6 x 6 m hemi-anechoic room. The "draw-away" path runs diagonal from the centre of the hard ($\alpha \approx 0.06$) floor to a corner. Figure 3 (A) shows the calculated results for a source in the floor, (B) for 20 cm above the centre of the floor.

Influence of source size: Sometimes a spherical loudspeaker complex (consisting typically 6 single speaker units) is used for qualification tests in an anechoic room. If the dimension of the complex is not small compared to the wave length, the path differences of the sound from different speaker units may cause interferences. A similar effect as in shown Fig. 3 could be observed. This effect is only partly compensated in practice by the superposition of several speaker units.

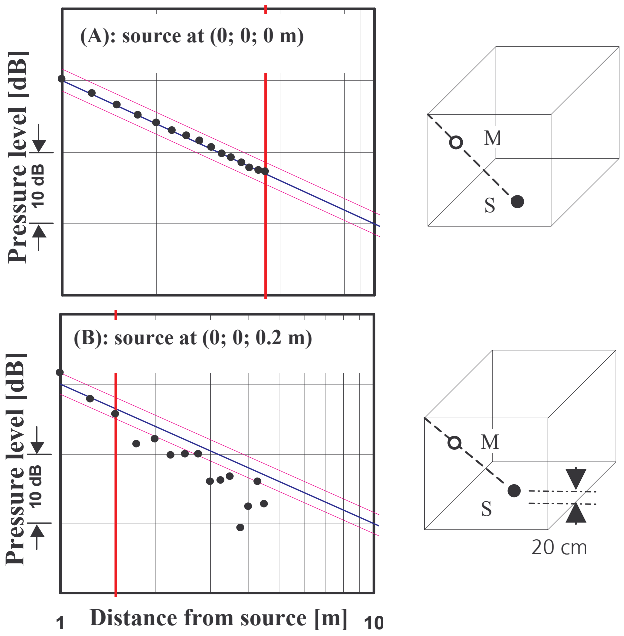


Figure 3: Calculations for a sine 500 Hz source above a hard floor in a 6 x 6 x 6 m hemi-anechoic room; $\alpha_0 = 0.99$
Theoretical freefield decay
Tolerance range according to [1]

Comparison with measurements: Fig 4 (A) shows a simulation example for a 7.6 x 4.5 x 5.7 m hemi-anechoic room which is described in detail in [3]. The point source emitting sine waves at 200 Hz is placed at the centre of the floor. The “draw-away” path follows a diagonal from the centre of the hard ($\alpha \approx 0.06$) floor to a corner of the room, path 5 in [3, Fig. 8]. The simulation with an assumedly constant absorption coefficient of $\alpha \approx 0.95$ of the anechoic lining shows a very similar level decay as the corresponding measuring results in Fig. 4 (B)

Summary

A computer simulation program for the sound field in anechoic rooms is presented. It shows the influence of a number of geometrical parameters which strongly affect the freefield conditions for a given source and receiver configuration in a comparably strong manner as the absorption of the acoustic lining. Some of the theoretically discussed problems of extreme symmetry do not occur in practice. Other very practical effects like finite size of sources and sources located above a reflecting floor can be shown to have a strong detrimental effect on the freefield achievable in the room, even if its walls and ceiling are completely cladded by ideal absorptive linings.

Likewise, additional reflecting surfaces are almost inevitable under all practical circumstances. For unfavourable geometric and experimental conditions one may therefore run into freefield problems, even when the $\alpha \geq 0.99$ requirement [1] is fulfilled. Under many practically prevailing conditions, on the other hand, the level decay requirements [1] may well be satisfied although α fails to exceed 0.99. The latter situation ($\alpha < 0.99$) occurs inevitably when residual waves interfere at a measuring position after they have been reflected under an oblique angle of incidence from a wall or ceiling, refer, e.g., to [2,4]. If, however, a specific room, source and receiver configuration can be clearly defined by a potential customer or user, it is now possible to predict and optimize the respective freefield conditions to be expected as e.g. in the new VW Acoustics Centre [4, 5].

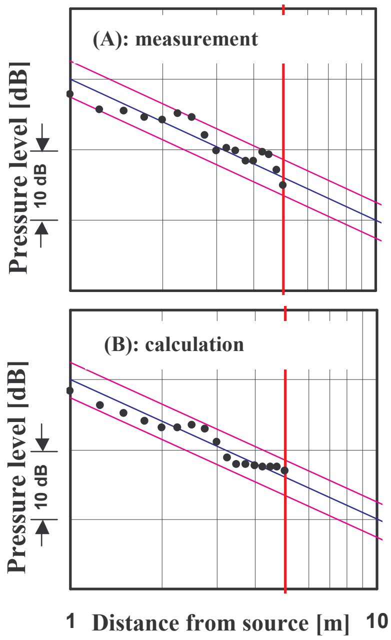


Figure 4: Measured (A) level decay for a 200 Hz sine source at the centre of the floor in an anechoic room [3] and calculations (B) with $\alpha = 0.95$.

Reference

[1] ISO 3745-2003 Acoustics – Determination of sound power levels of noise sources using sound pressure – Precision methods for anechoic and hemi-anechoic rooms.

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