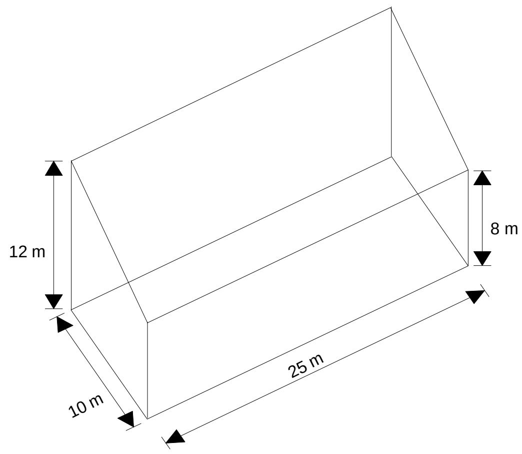
Kurt Heutschi, Acoustics I, 2011-10-03

Exercise A1-13: Room acoustics

1. A room according to the Figure below is given.



The room limiting surfaces have absorption coefficients α as shown in the Table.

	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
floor	0.01	0.01	0.02	0.02	0.03	0.03
walls	0.1	0.2	0.3	0.3	0.3	0.3
ceiling	0.5	0.3	0.2	0.2	0.1	0.1

a Calculate the reverberation time in each octave band according to Sabine and Eyring neglecting air absorption.

b Calculate the critical distance for the 500 Hz octave band and an omnidirectional radiating point source.

c Calculate the change in the critical distance from b) if a reflecting surface is installed directly behind the source.

2. The impedance on the surface of a locally reacting absorber is $Z = 2\rho c$ (ρ : density of air, c: speed of sound). Calculate the absorption coefficient for normal sound incidence.

3. The sound pressure transfer function is measured in a rectangular room between two corners. Thereby the following lowest resonance frequencies can be identified [Hz]: 28.3, 42.5, 51.1, 56.7, 68.0, 70.8, 73.7, 80.2, 85.0 and 88.5. Calculate the room volume.

4. If a sound source is placed at the focal point of a paraboloid, the radiation at high frequencies is strongly focused. Show that the paraboloid can be described approximately by a spherical surface and determine the optimal position of the source in the sphere. The considerations can be carried out for the two dimensional case (circle and parabola). The equation for a circle with radius R and center at (x_0, y_0) is: $(x - x_0)^2 + (y - y_0)^2 = R^2$. The equation for a parabola with axis = x-axis, vertex at (0,0) and focal point at $(x_F, 0)$ is: $y^2 = 4x_F x$.

Solutions

1.a
The following values are found as total absorption:

	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
floor (250 m^2)	2.5	2.5	5.0	5.0	7.5	7.5
walls (700 m^2)	70	140	210	210	210	210
ceiling (270 m^2)	135	81	54	54	27	27
total	207.5	223.5	269	269	244.5	244.5

With a room volume of 2'500 m^3, the reverberation time according to Sabine calculates as

	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Sabine-reverberation time [sec]	1.93	1.79	1.49	1.49	1.64	1.64

With a total room surface area of 1220 m^2 the average (area-weighted) absorption coefficients are found as:

	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
average absorption coefficient	0.17	0.18	0.22	0.22	0.20	0.20

With this the reverberation time according to Eyring is found as:

	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Eyring-reverberation time [sec]	1.76	1.62	1.32	1.32	1.47	1.47

b
critical distance r_H:

$$r_H = \sqrt{\frac{269}{16\pi}} = 2.3\text{m} \tag{1}$$

c
It can be assumed that the diffuse field is unaltered, but the direct sound is amplified by 3 dB. From this follows $r'_H = r_H \times 1.4 = 3.2$ m.

2.
The reflection factor R is found as

$$R = \frac{Z_1 - Z_0}{Z_1 + Z_0} = \frac{\rho c}{3\rho c} = \frac{1}{3} \tag{2}$$

For the absorption coefficient follows $\alpha = 1 - |R|^2 = 0.89$.

3.
The following relation is used

$$f_{\text{resonance}} = \frac{c}{2}\sqrt{\frac{n_x^2}{L_x^2} + \frac{n_y^2}{L_y^2} + \frac{n_z^2}{L_z^2}} \tag{3}$$

The lowest frequency (28.3 Hz) corresponds to the mode (1,0,0). With this the first dimension of the room is $L_x = 6$ m. The next frequency 42.5 Hz can not be the mode (2,0,0), therefore it has to correspond to the mode (0,1,0). With this the second dimension is found as $L_y = 4$ m. The next frequency 51.1 Hz could be the mode (1,1,0) or (0,0,1). A check yields that the frequency belongs to the mode (1,1,0). The next frequency 56.7 Hz can be identified as the mode (2,0,0). The next frequency 68.0 Hz finally can be identified as the mode (0,0,1). So the third dimension, the height of the room is found as $L_z = 2.5$ m. Consequently the volume is 60 m^3.

4.
The circle with radius = 1 and center at (1,0) can be described by

$$(x-1)^2 + y^2 = 1 \tag{4}$$

or equally

$$y^2 = 2x - x^2 \tag{5}$$

For small x the second order term can be neglected and therefore

$$y^2 \approx 2x \tag{6}$$

The equation of the parabola with vertex at (0,0) and focal point x_F is

$$y^2 = 4x_F x \tag{7}$$

The approximate equation for the circle corresponds to the equation of the parabola for $x_F = 0.5$. The optimal source position in the circle is thus (0.5,0) (corresponding to the focal point of the parabola).