Chapter III - Room acoustics

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Exercise 1. Low frequency response of a room

A technical room, assumed to be a parallelepiped of length $L = 5.6$ m, width $l = 3$ m and height $h = 3.53$ m, is available for use as music rehearsal room. Without treatment, the room is only composed of gypsum (ie. ideally reflective).

We measure the **low-frequency** response of the room, with the help of a loudspeaker and a measurement microphone, and obtain the solid-line curve of figure 1.

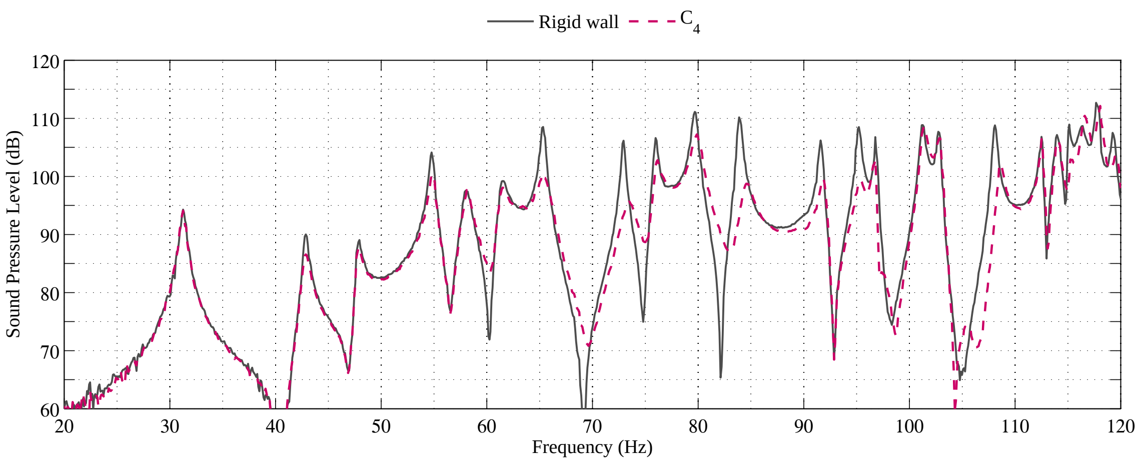


Figure 1 – Frequency response of the room at low frequencies (solid-line : in the empty room, dashed-line : with bass-traps)

1. Remind the general expression of the eigenfrequencies of the room. What do the peaks on the figure represent ? Table 1 gives the values of frequencies corresponding to the 15 first peaks.
2. What is the structure (triplet m_x,m_y,m_z) as well as the nature (axial/tangential/oblique) of the modes at 80 Hz and at 83 Hz ? Represent schematically the nodal lines and the signs of the acoustic pressure, in a cut-view in the horizontal plane for the eigenmode at 83 Hz.
3. What would be the best location of the loudspeaker and microphones used for these measurements ? Justify your answer.
4. Is this room well suited for sound diffusion at low-frequencies ? Why ?

Exercise 2. Standing waves in a tube (room modes in 1D)

We consider a cylindrical duct, of diameter $\emptyset = 20$ cm and length $L = 5$ m. The two walls facing each other at $x = 0$ and $x = L$ are supposed ideally rigid. At one termination ($x = 0$),

Table 1 – Natural frequencies of the room with dimension $(5.6 \times 3 \times 3.53)\,\mathrm{m}^3$. The parameters (m_x, m_y, m_z) indicate the structure of the mode.

m_x	m_y	m_z	Hz	Hz	
1	0	0	30.4	31.2	Axial
0	0	1	48.2	48.0	Axial
0	1	0	56.6	54.8	Axial
1	0	1	56.9	58.2	Tangential
2	0	0	60.7	61.5	Axial
1	1	0	64.3	65.3	Tangential
0	1	1	74.4	73.0	Tangential
2	0	1	77.5	76.0	Tangential
?	**?**	**?**	**80.3**	**79.7**	**?**
?	**?**	**?**	**83.0**	**83.9**	**?**
3	0	0	91.0	91.6	Axial
2	1	1	96.0	95.2	Oblique
0	0	2	96.3	96.8	Axial
1	0	2	100.9	101.3	Tangential
3	0	1	103.0	102.7	Tangential

a loudspeaker with the same cross-section as the duct is vibrating with velocity $v_0(t) = v_0 e^{j\omega t}$. The vibratory movement of the loudspeaker imposes a certain sound field $p(x,t)$ in the duct, depending on the boundary conditions at the other extremity ($x = L$).

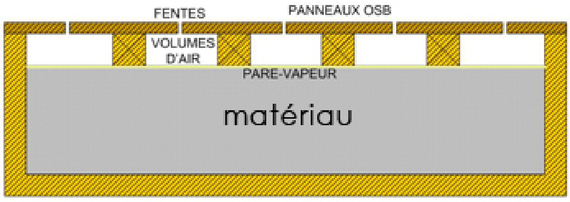
We remind the general expression of the pressure $p(x,t)$ in the duct, solution of the wave propagation equation in 1D (cartesian coordinates) :
$p(x,t) = p_{0+} e^{j(\omega t - kx)} + p_{0-} e^{j(\omega t + kx)}$

1. Knowing the local expression of Newton's law, derive the expression of the velocity $v(x,t)$ at every position of the duct.
2. How would you write the boundary condition at the loudspeaker position $x = 0$, assuming the loudspeaker is an ideal source of velocity ?

   We now consider the termination at $x = L$ as a hard wall.
3. What is the boundary condition at the position $x = L$?
4. Determine the expressions of p_{0+} and p_{0-}
5. Write the expression of the RMS value of pressure $p(x,t)$ at every position in the duct. What are the resonance frequencies of the duct ?

Exercise 3. Measurement of the absorption coefficient in the reverberant chamber

A material formed of flakes is used to fill the construction presented below :



Such a box measures 2.4×1×0.2 m, which corresponds to a volume of 480 l. The goal is to measure the absorption coefficient of said construction in the reverberant chamber. The characteristics of the chamber are given in the figure at the end of the exercise.

1. 5 boxes of this type are filled with flakes. The measurements of T_s in the empty chamber (T_1) and in the chamber with the samples under test (T_2) give the following results :

f (Hz)	125	250	500	1000	2000	4000
T_1(s)	21.4	19.8	15.0	11.1	5.9	2.4
T_2(s)	4.7	5.0	5.7	5.2	3.8	2.0

   Calculate the absorption coefficient of this material in each frequency band with Sabine's method. Comment on the performance of the material.

2. The panels which close the boxes are replaced by decorative tissue. The new measurements with the samples give T_3.

f (Hz)	125	250	500	1000	2000	4000
T_3(s)	7.0	3.7	2.4	2.12	1.8	1.3

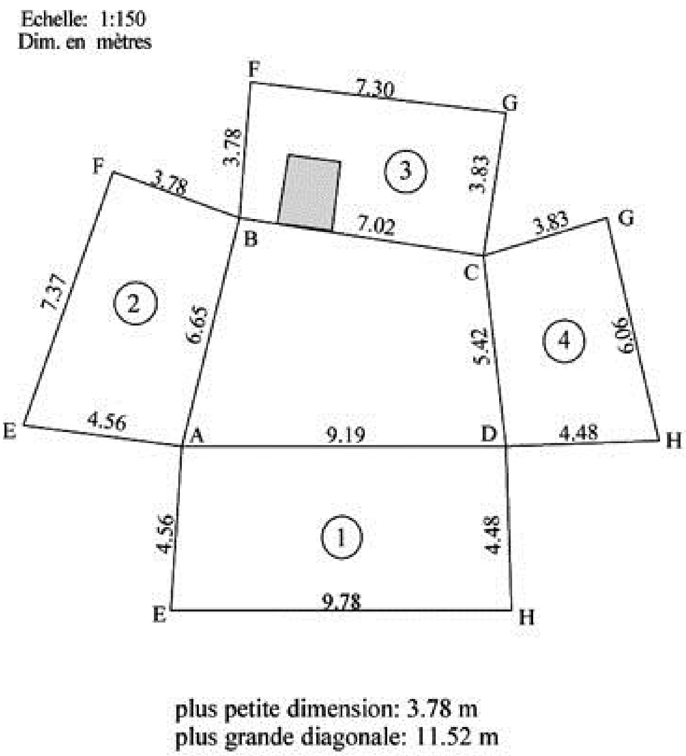
   Calculate and comment on the absorption coefficient of the modified construction.

3. The measurements are done a third time, but with less flakes in the boxes. (the flake density goes down from 78 kg/m^3 to 60 kg/m^3). The measurements give T_4.

f (Hz)	125	250	500	1000	2000	4000
T_4(s)	4.2	2.6	2.2	2.1	1.9	1.2

   What are your conclusions ?

4. During the measurements, the room temperature inside the chamber varied between 18.2°C and 18.4° C. What influence is there on the precision of the results of the measurements ?



Volume: 215.6 m3

Surface totale: 226.9 m2

Sol:	48.0 m2
Plafond:	56.2 m2
Paroi1:	42.8 m2
Paroi2:	29.0 m2
Paroi3:	27.2 m2
Paroi4:	23.7 m2

Exersice 4. Rehearsal room of an orchestra

An orchestra has a rehearsal room of 3'000 m^3 whose reverberation time is 1.6 s. The orchestra has to move to a new room of 1'500 m^3.
What does the reverberation time of the new room need to be, so that the reverberated level decreases by 10 dB relative to the old room ? Is this possible ?

Exercise 5. Critical radius

An omnidirectional sound source generates an acoustic power of 1 W. It is successively placed in two rooms. The first room has a volume of 500 m^3, whereas the second one has a volume of 5000 m^3. Both rooms have the same reverberation time T_{60} of 1.6 s.
Calculate and compare both reverberated levels and the critical radii.
Calculate the direct levels at 1 m from the source.