ACS 597: Noise Control Applications
Acoustic enclosures

1 Modal behavior of a cylindrical room

A cylindrical room with hard walls has radius 3 m and length 10 m. The room modes are given by

$$p_{(n_x,n_r,n_\theta)} = \cos\left(\frac{\pi n_x x}{L_x}\right) J_{n_\theta}\left(\psi_{(n_\theta,n_r)}\frac{r}{a}\right)\cos\left(n_\theta \theta\right) \tag{1}$$

where $\psi_{(n_\theta,n_r)}$ are given by Table 1, and J_{n_θ} are Bessel functions of the first kind of order n_θ. The natural frequencies are given by

$$f_{(n_x,n_r,n_\theta)} = \frac{c}{2}\sqrt{\left(\frac{n_x}{L_x}\right)^2 + \left(\frac{\psi_{(n_\theta,n_r)}}{a}\right)^2} \tag{2}$$

You can evaluate Bessel functions in MATLAB using the `besselj`. There is a function posted to Canvas called `circular_mode_shape.m` that calculates the ψ parameter based on Table 1. The function also returns the circular mode shape that is the part of Equation 1 without the axial (x) dependence. You can call the function with the syntax
`psi = circular_mode_shape(n_r, n_theta, a, plot_shape)`
where `n_r` and `n_theta` are mode numbers, and `a` is the cylinder radius. If `plot_shape` is `true`, the function will also plot the mode shape.

(a) What are the lowest ten resonance frequencies of the room? What mode orders (n_x, n_r, n_θ) do they correspond to?

(b) A machine that acts as a compact source will be making noise at 53 Hz. What are the two modes with the closest resonance frequencies?

(c) Where should the machine be located in the room to prevent excitation of these two modes?

Table 1: Bessel function parameters, $\psi_{(n_\theta,n_r)}$.

n_θ \ n_r	0	1	2	3	4
0	0	1.2197	2.2331	3.2383	4.2411
1	0.5861	1.697	2.714	3.7261	4.7312
2	0.9722	2.1346	3.1734	4.1923	5.2036
3	1.3373	2.5513	3.6115	4.6428	5.6624
4	1.6926	2.9547	4.0368	5.0815	6.1103
5	2.0421	3.3486	4.4523	5.5108	6.5494
6	2.3877	3.7353	4.86	5.9325	6.9811
7	2.7034	4.1165	5.2615	6.3477	7.4065

2 Sabine room

A room of dimensions $8\,\mathrm{m} \times 6\,\mathrm{m} \times 3\,\mathrm{m}$ high has an average absorption coefficient of 0.05 on the walls and floor and 0.15 on the ceiling, for the 125 Hz octave band.

(a) Estimate the reverberat field sound pressure level due to a broadband source in the room that radiates 25 mW of acoustic power in the 125 Hz octave band.

(b) At what distance from the source do you expect the direct and reverberant sound pressure levels to be equal, if the source is omnidirectional and not near any walls?

3 Transmission loss measurement

You are tasked with measuring the transmission loss of a panel. One way of measuring transmission loss is by installing the panel in between two reverberant rooms and measuring the average sound pressure level in each room. First, a rigid panel with very high transmission loss (the “calibration panel”) is installed in place of the panel under test. Then the average absorption in the receiver room is found, either with a source of known sound power or with reverberation time measurements. Then, the panel under test is installed, and a source is placed in the source room. The difference in sound pressure levels in the two rooms can then be used to determine the transmission loss. Results at multiple frequencies are calculated.

The two rooms are each 4 m cubes, and the panel is a square with 80 cm sides. The table below shows the results of the tests described above. Calculate the transmission loss of the panel at each octave band frequency. You may assume that changing between the calibration panel and the test panel does not affect the average absorption of the either room.

Table 2: Panel transmission loss data.

Frequency, Hz	Receiver room T_{60}, s	Src. room level, dB re: 20 μPa	Rec. room level, dB re: 20 μPa
125	2.0	90	50
250	2.1	95	50
500	1.8	103	46
1000	1.5	105	50
2000	1.2	100	50
4000	0.9	93	38

4 Panel transmission loss

You are tasked with predicting the transmission loss of a galvanized steel panel. The panel is a square with 80 cm sides. The manufacturer of the panel gives the following specifications:

Table 3: Panel properties.

Property	Value
Young's modulus, E	200 GPa
Density, ρ	7800 $^{kg}/_{m^3}$
Poisson's ratio, ν	0.29
Thickness, h	1.2 mm
Loss factor, η	0.001

The manufacturer has also provided measured transmission losses for the panel at octave band frequencies. These are:

Table 4: Measured panel transmission losses.

Frequency, Hz	63	125	250	500	1000	2000	4000	8000
Transmission loss, dB	9	14	21	27	32	37	43	42

Usually, it is a good idea to use manufacturer's speficiations whenever possible. Unfortunately, for your application, you also need data at 16000 Hz, so you decide to model the panel and use your model to predict the transmission loss at higher frequencies. You will model the panel in three different ways to see which model best matches the measured data.

(a) Model the panel as an infinite, rigid panel with only normal incidence sound. You will need a value for the mounting stiffness, s. Choose s such that the resonance frequency of the system is at $f_0 = \frac{\pi}{l^2}\sqrt{\frac{D}{m_s}}$, where l is the panel width and $D = \frac{Eh^3}{12(1-\nu^2)}$ is the bending stiffness. This frequency is the lowest resonance of a simply-supported square panel.

(b) Model the panel as an infinite, flexible panel with random incidence.

(i) Calculate the critical frequency and the coincidence frequency at an angle of incidence of 75°.

(ii) Calculate the transmission loss at an angle of incidence of 75° for the frequency range of interest. Verify that the coincidence frequency is where you predicted it to be.

(iii) Calculate the transmission loss at incidence angles between 0–90°.

(iv) Calculate the diffuse field transmission loss by averaging across all incidence angles,

$$\tau_d = \frac{1}{N_\phi} \sum_i \tau(\phi_i) \sin(2\phi_i) \tag{3}$$

where N_ϕ is the number of angles you calculated the transmission loss for in the previous step.

(c) Calculate the finite panel transmission loss by $\tau_r = \frac{\tau_\infty}{\eta} \left(\frac{Pc}{200 S_p f_{cr}} \right)^2$, where τ_∞ is the transmission coefficient for an infinite panel, P is the panel's perimeter, S_p is the panel's area, and f_{cr} is the critical frequency.

(d) Compare the transmission losses of the following cases, all on one common plot:

(i) Measured data

(ii) Infinite, rigid panel model

(iii) Infinite, flexible panel model with diffuse field incidence

(iv) Finite, flexible panel model

Which model matched the data best? Which model should be used to predict the transmission loss at 16000 Hz?

5 Large enclosure design

You have a machine outside with sound power levels of 105, 115, 106, 108, and 119 dB re: 1 pW in the octave bands of 250, 500, 1000, 2000, and 4000 Hz. Assume the machine's surface area is $3\,\mathrm{m}^2$ and it has a surface absorption coefficient of 0.07. Design a large enclosure for this system that reduces the sound pressure level outside of the enclosure at a distance of 10 m from the enclosure to less than 30 dB re: 20 μPa in all octave bands. Find real products on the market that you can use for your design and include the specifications for those products in your solution (hint: be careful on imperial vs. metric units for absorption!). The specification can be a screenshot from a website or a spec sheet. Assume the machine does not need any cooling, so that there are no penetrations in the enclosure.

6 Close-fitting enclosure design

In a large industrial workshop, you have an air compressor with sound power levels of 105 dB re: 1 pW at low frequency (50 Hz), and dimensions of 1 m-by-1 m-by-2 m. You need to bring the SPL in the workshop down to less than 82 dB re: 20 μPa for occupational health of your workers. The workshop has a room absorption of 40 Sabins (metric). You want to design a close-fitting enclosure using two layers of 0.75 in. thick MDF ($E = 3.6\,\text{GPa}$, $\rho = 800\,\text{kg/m}^3$, $h = 3.81\,\text{cm}$) with clamped boundary conditions. However, the compressor needs a 10 cm radius air intake inlet in the wall of the enclosure to operate properly. This leads you to believe you need to design an intake silencer to meet the requirements. What transmission loss do you need to design in the silencer to meet the specifications, based on the enclosure size of your choice? You do not need to design the silencer.