ACS 597: Noise Control Applications
Ducts, mufflers, and silencers

1 Cut-on frequencies in ducts and pipes

The lowest cut-on frequency for a rectangular duct is

$$f_{\mathrm{co}} = 0.5\frac{c}{L} \tag{1}$$

where c is the speed of sound, and L is the largest cross-section dimension. For a circular duct (or pipe) of diameter d, the lowest cut-on frequency is

$$f_{\mathrm{co}} = 0.568\frac{c}{d} \tag{2}$$

(a) What is the lowest cut-on frequency for a rectangular duct in air with $c = 343\,\mathrm{m/s}$ and dimensions $L_x = 12\,\mathrm{cm}$ and $L_y = 20\,\mathrm{cm}$?

(b) What is the lowest cut-on frequency for a circular duct in air with the same cross-sectional area as the rectangular duct in part (a)?

(c) What is the lowest cut-on frequency for the same circular duct as in part (b) if the duct is instead filled with water, with $c = 1500\,\mathrm{m/s}$?

(d) The speed of sound in air can be calculated by

$$c = \sqrt{\gamma R T_k} \tag{3}$$

where $\gamma = 1.4$ is the ratio of specific heats and $R = 287\,\mathrm{J/kg{\cdot}K}$ is the gas constant and T_k is the absolute temperature in kelvin. For a circular pipe of diameter 5 cm, generate a plot showing how the lowest cut-on frequency changes as the air heats up from 0 °C to 500 °C.

(e) Based on your above responses, are cut-on frequencies higher for circular or rectangular ducts for a given cross-sectional area? What about in air versus water? What about cold versus hot air?

2 Muffler design comparison

You are tasked with designing a muffler that must fit in a chamber that is 10 in. in diameter and 18 in. long. The inlet and outlet pipes are 2 in. in diameter. The inlet pipe is 6 ft long, and the outlet pipe is 1 ft long and unflanged. The objective is to reduce noise in the range of 0–5000 Hz. Plot the transmission loss for the following designs, assuming no resistive terms and no flow:

(a) Simple expansion chamber: transition from the inlet pipe to the full diameter, then back to the outlet pipe.

(b) Double-tuned expansion chamber: extend both the inlet and outlet pipes 3 in. into the expension chamber.

(c) Cascaded double-tuned expansion chamber: divide the double-tuned expansion chamber into two halfs, each 9 in. long, connected by a pipe extending 3 in. into each chamber.

Compare your results for the first three designs. Experiment with the relative lengths of the two chambers and pipes for part c, keeping the total length to 18 in. Comment on how the different variations can be used to affect the transmission loss curves.

3 Bugle recorder

"Bugle calls" are short tunes designed to be played with a bugle, a brass instrument without any valves. Bugle calls only have four notes, but can be used to signal that it is time to wake up ("Reveille"), go to sleep ("Taps"), or charge ("Charge"). You want to design a recorder that can be used in place of a bugle. That is, it can only play four notes. The five notes are:

Note name	Frequency
C5	523 Hz
F5	698 Hz
A5	880 Hz
C6	1046 Hz

Different notes on a recorder are played by covering and uncovering holes drilled in a length of pipe attached to the mouthpiece. The mouthpiece is 90 mm long, measured from the source (which can be assumed to be high-impedance) to the pipe connection. Assume there is no mean flow through the recorder.

The inner diameter of the pipe will be a constant cross-section of 9 mm, the wall thickness is 4 mm, and the end will be unflanged. Four holes, each 6 mm in diameter, will be drilled along a length of pipe attached to the end of the mouthpiece.

(a) With all of the holes covered, the recorder acts as one long pipe with constant cross-section. How long should the pipe be to produce the lowest note?

(b) Where should the holes be drilled to produce the other notes?

4 Intake duct

An intake duct consists of a 1 in. diameter pipe that is 6 in. long connected to a 4 in. diameter pipe that is 5 in. long. The 4 in. pipe is flanged. The volumetric flow rate of the system is $37\,\mathrm{ft^3/min}$.

(a) Calculate the Mach number of the flow in both pipe sections. Note that since it is an intake system, the Mach numbers will be negative.

(b) Plot the transmission loss from 0–2500 Hz for the intake system if there is no flow in the system.

(c) Calculate the transmission loss with the Mach numbers you calculated. How does the flow affect the TL curve?

(d) Design a lossy Helmholtz resonator to target the first dip in the transmission loss curve (which should be between 100–200 Hz), and plot the transmission loss of the combined system. Assume the resonator is immmediately adjacent to the pipe transition, attached to the smaller pipe section. How much additional attenuation does the resonator achieve?

5 Intake duct silencer

With the combined system from Problem 4, there will be a dip in the transmission loss curve between 500–1000 Hz. If 1.5 in. thick acoustic wrapping can be added on the inside of the 4 in. diameter pipe, what should the flow resistivity, R_1, of the material be such that the total transmission loss of the system at this frequency is 0 dB?

(a) Calculate the total attenuation required. Using Figure 1, compute the the total attenuation of the lining. Divide this number by the duct segment length to get the needed attenuation rate, in $^{\mathrm{dB}}/_{\mathrm{m}}$.

(b) Calculate the parameters l (liner thickness) and h (liner half width) based on the geometry of the duct and liner. l is simply the thickness of the liner itself, and $2h = \sqrt{\pi}a_{\text{open}}$, where a_{open} is the radius of the duct after subtracting the liner thickness.

(c) Calculate the liner thickness ratio, l/h, and the normalized frequency, $2h/\lambda$, where λ is the wavelength at the frequency of interest.

(d) Use Figure 2 to determine the resistivity parameter, $R_1 l/\rho c$. The thickness ratio determines which curve number (1–5) to use. Note that these curves are for rectangular ducts lined on two walls. The resulting attenuation rate is doubled for fully-lined circular ducts, so you will need to divide the attenuation rate you calculated in part (a) by 2. The sub plot with the curve closest to the needed attenuation rate will determine the resistivity parameter.

(e) Finally, compute R_1, the flow resistivity. This value is a property of the material itself. For fibrous materials, it is related to the material size and bulk density, and will generally be between 10^3 and 10^6 $^{\mathrm{kg}}/_{\mathrm{m^3 \cdot s}}$.

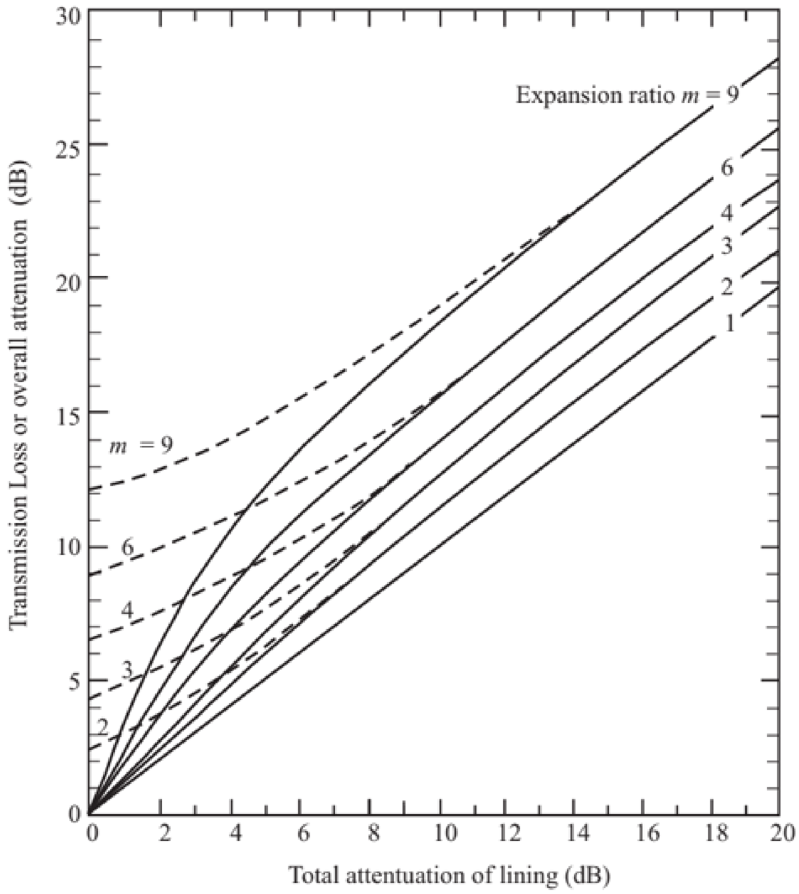

FIGURE 8.37 Transmission loss (TL) of a lined expansion chamber as a function of the area expansion ratio, m, and the total attenuation of the lining. The solid curves show TL for $kL = 0, \pi, \ldots, n\pi$, and the dashed curves show TL for $kL = \pi/2, 3\pi/2, \ldots, (2n+1)\pi/2$. The quantity, k, is the wavenumber and L is the length of the expansion chamber.

Figure 1: Expansion chamber transmission loss for lined chambers. From Bies, Hansen, and Howard, *Engineering Noise Control*, fifth edition, Fig. 8.37.

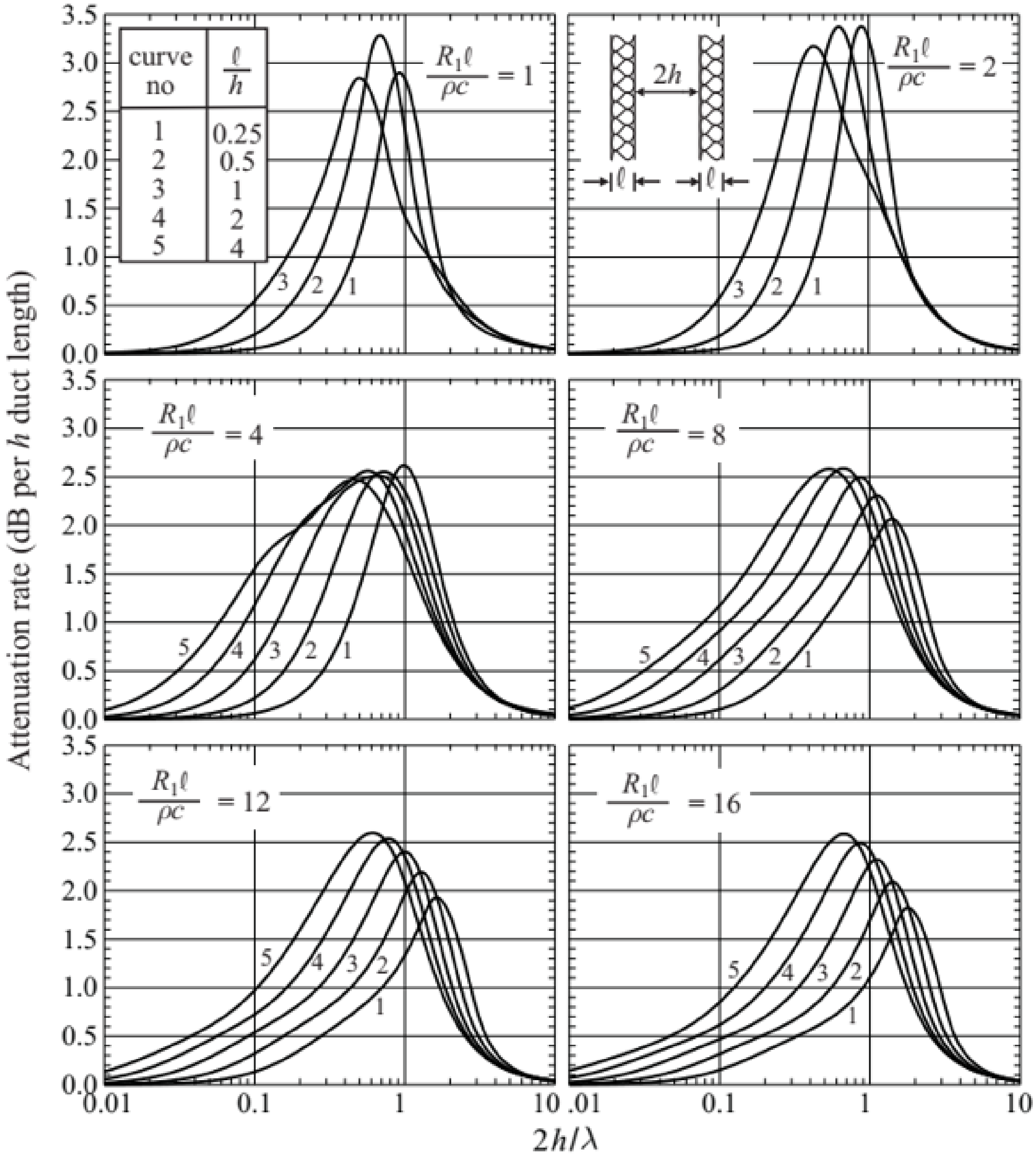

Figure 2: Attenuation rate curves. From Bies, Hansen, and Howard, *Engineering Noise Control*, fifth edition, Fig. 8.29.