MUSICAL ACOUSTICS
Tutorial 5: Solution Guide

1. Intensities of musical instruments

The table below is taken from the paper on "The Loudness of Musical Sounds", which can be accessed through the "Dynamic Range Project" link on the course WebCT page. It shows typical measurements of the sound power output and maximum practicable dynamic range of various orchestral instruments.

TABLE 1: SOUND POWER AND DYNAMIC RANGE OF INSTRUMENTS

Instrument	Average sound power playing forte (milliwatts)	Practical dynamic range (decibels)
Violin	0.8	35
Viola	0.5	30
Cello	1	30
Double bass	1.6	30
Flute	1.3	20
Oboe	2	30
Clarinet	2	40
Bassoon	2	30
Horn	16	40
Trumpet	13	30
Trombone	13	35
Tuba	20	30
Full orchestra (without percussion)	250	65

Use the sound power values given in the table, and the formula for the intensity of an isotropic sound source given in the lecture on "Pitch, Loudness and Timbre", to estimate the intensity (in $\mathrm{W\,m^{-2}}$) and the Sound Pressure Level (in dB) of each of the instruments listed at a distance of 10 m in the open air.

The formula for the direct sound from an isotropic sound source is

$$I_D = P/4\pi R^2$$

where P is the sound power of the source (in W) and R is the distance from the source (in m).

Instrument	Average sound power playing forte (mW)	Intensity at 10 m in open ($\mathrm{W\,m^{-2}}$)	SPL (dB)
Violin	0.8	6.37×10^{-7}	58
Viola	0.5	3.98×10^{-7}	56
Cello	1	7.96×10^{-7}	59
Double bass	1.6	1.27×10^{-6}	61
Flute	1.3	1.03×10^{-6}	60
Oboe	2	1.59×10^{-6}	62
Clarinet	2	1.59×10^{-6}	62
Bassoon	2	1.59×10^{-6}	62
Horn	16	1.27×10^{-5}	71
Trumpet	13	1.03×10^{-5}	70
Trombone	13	1.03×10^{-5}	70
Tuba	20	1.59×10^{-5}	72

2. Results of dynamic range project

Compare the values calculated above with the values which you recorded in the Dynamic Range Project, and discuss.

Note that the Dynamic Range Project results, together with a violin measurement from last year's project, are available on the course WebCT page.

Briefly, the SPL values measured show similar trends to the values calculated from the table, but the calculated values are lower because they don't take into account the contribution of the reverberation field in the lecture theatre. This is addressed in the next question.

3. Effect of reverberation on intensity

In a room, the direct sound from an instrument is supplemented by **reverberant sound**, which arrives at the listener after being reflected (perhaps several times) by the walls, ceiling and floor. This will be discussed in detail in the lectures on Architectural Acoustics. The intensity of the reverberant sound is independent of the distance from the source, but depends on how efficiently the interior surfaces of the room absorb sound. The **total absorption** A of a room is given by the formula

$$A = \sum_i \alpha_i S_i = \alpha_1 S_1 + \alpha_2 S_2 + \alpha_3 S_3 \ldots$$

where S_i is one of the surfaces of the room (for example, the ceiling), and α_i is the fraction of incident sound energy which is absorbed (the **absorption coefficient**).

Calculate the total absorption (in $\mathrm{m^2}$) of a room 20 m long, 10 m wide, and 5 m high, whose internal surfaces all have the same absorption coefficient $\alpha = 0.1$.

The ceiling and floor each have surface area $20 \times 10 = 200\mathrm{m}^2$. Each therefore contributes $20\,\mathrm{m}^2$ absorption to the total. The total wall area is $60 \times 5 = 300\mathrm{m}^2$, contributing $30\,\mathrm{m}^2$ to the absorption. So $A = 20 + 20 + 30 = 70\,\mathrm{m}^2$.

The intensity of the reverberation field is give by the formula

$$I_R = P/A,$$

where P is the sound power of the source (in W), and A is the total absorption (in m^2). Calculate the intensity of the reverberant sound field generated by a trumpet playing forte in the room described in the first part of the question, and compare this value with the direct sound heard at a distance of 10 m.

From the table in Question 1, a trumpet playing forte typically generates around 13 mW. So the reverberant intensity is

$$I_R = 13 \times 10^{-3}/70 = 1.86 \times 10^{-4}\,\mathrm{W\,m^{-2}}.$$

From Question 1, the direct sound intensity at a distance of 10 m is

$$I_D = 1.03 \times 10^{-5}\,\mathrm{W\,m^{-2}}.$$

So the reverberant sound is about 18 times more intense than the direct sound. The reverberant sound has an SPL of 83 dB, which is 13 dB greater than the direct sound.

4. The symphony orchestra

A medium size symphony orchestra has 10 first violins, 10 second violins, 10 violas, 10 cellos, 6 double basses, 2 flutes, 2 clarinets, 2 oboes, 2 bassoons, 4 horns, 2 trumpets, 3 trombones and 1 tuba.

Using the values from the table in Question 1, calculate the total sound power in (a) the string section; (b) the woodwind section; (c) the brass section; (d) the whole orchestra, when all the instruments are playing forte.

Strings:

Violins: $20 \times 0.8 = 16$ mW. Violas:$10 \times 0.5 = 5$ mW. Cellos: $10 \times 1 = 10$ mW. Double basses: $6 \times 1.6 = 9.6$ mW.

Total string section: 40.6 mW.

Woodwind:

Flutes: $2 \times 1.3 = 2.6$ mW. Oboes: $2 \times 2 = 4$ mW. Clarinets: $2 \times 2 = 4$ mW. Bassoons: $2 \times 2 = 4$ mW.

Total woodwind section: 14.6 mW.

Brass:

Horns: $4 \times 16 = 64$ mW. Trumpets: $2 \times 13 = 26$ mW. Trombones: $3 \times 13 = 39$ mW. Tuba: $1 \times 20 = 20$ mW.

Total brass section: 149 mW.

Total orchestra: 204.2 mW.

Comments: Woodwind section is relatively weak, and is oftened strengthened by having 3 or 4 of each instrument. Brass section is inherently the most powerful and if not restrained can drown the rest of the orchestra!