TEACHING CONCEPTS OF ACOUSTICAL WAVES IN AIR, PART 2

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1 Introduction

This paper has been written to participate in the "Teaching Acoustics" session at the 2023 Acoustics Week in Canada. It builds on Part 1 which was presented at the 2022 Acoustics week in Canada and contains materials from 30 years of teaching Architects at the University of Waterloo and Dalhousie University. The goal is to provide teachers with practical demonstrations to enhance learning. "Hands on" teaching methods can engage multiple senses to be effective using sight and sound as well as written material.

Part 1 dealt primarily with sound propagation in air and the concepts of longitudinal wave motion, speed, frequency and wavelength and related effects which relate to what we perceive as pitch. Part 2 expands on those concepts by discussing superposition, identifying the concept of source path and receiver, and introducing the definition of sound pressure, decibels and the decibel scale which correlate with loudness. If time permits, or perhaps in a third installment, we will examine the hearing mechanism to discern how we physically perceive pitch and loudness.

2 Principle of Superposition

While waves do interfere (combine their pressure) at a point in space, they successfully pass through each other without changing. That is why a sound maintains its character in the presence of other sounds as in Figure 1.

Figure 1: Principle of Superposition [1].

3 Source, Path and Receiver

An acoustical situation comprises three basic éléments as shown in Figure 2. If a sound is desirable, favourable conditions are provided for its production, transmission and reception and the listener relieved of distractions like competing noise.

If sound is undesirable, unfavourable conditions are provided for its the production, transmission and reception. These measures belong to the realm of noise control.

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Figure 2: Source, Path, Receiver [2].

4 Sound Pressure

Of all the quantities which could be used to characterize the "strength" of a sound wave (particle velocity, displacement, intensity, power, etc) the most amenable to measurement is sound pressure.

The variation in pressure caused by speech, music or noise is shown in the following figure. Most sounds in the everyday world are complex (Figure 3) consisting of a variety of pressures of different frequencies which vary with time.

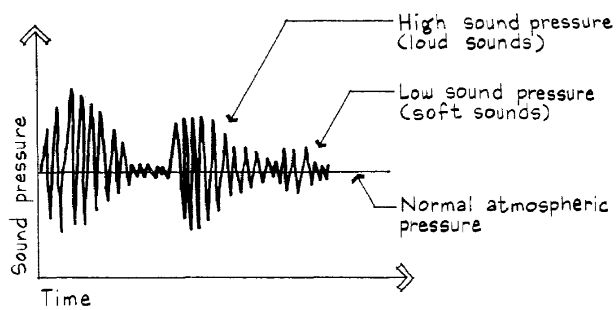

Figure 3: Complex Sounds [2].

The range of audible sound pressures is 20 micro-Pascals to 100 Pascals. Atmospheric pressure is approximately 100,000 Pascals. The quietest sound a normal hearing individual can hear is approximately 20 μPascals (0.00002 Pascals).

5 The Decibel Scale

The decibel scale is a logarithmic scale used to describe sound levels. It was named after its inventor, Alexander Graham Bell. We define the Sound Pressure Level (SPL) in decibels (tenths of a Bell) to be:

$$\mathrm{SPL} = 20\log_{10}(p/p_{\mathrm{ref}}) \quad \mathrm{(dB)}, \qquad (1)$$

where the reference pressure is

$$p_{\mathrm{ref}} = 20\mu\,\mathrm{Pa} = 20\cdot 10^{-6}\,\mathrm{Pa} = 2\cdot 10^{-5}\,\mathrm{Pa}. \qquad (2)$$

The range of audible sound pressures (20 μ Pascals to 100 Pascals) is a ratio of 5 million to one. If a bathroom scale had the same sensitivity range as the human ear, it would be able to weigh both a human hair and a building. The decibel scale compresses this range of audible sound pressures into a

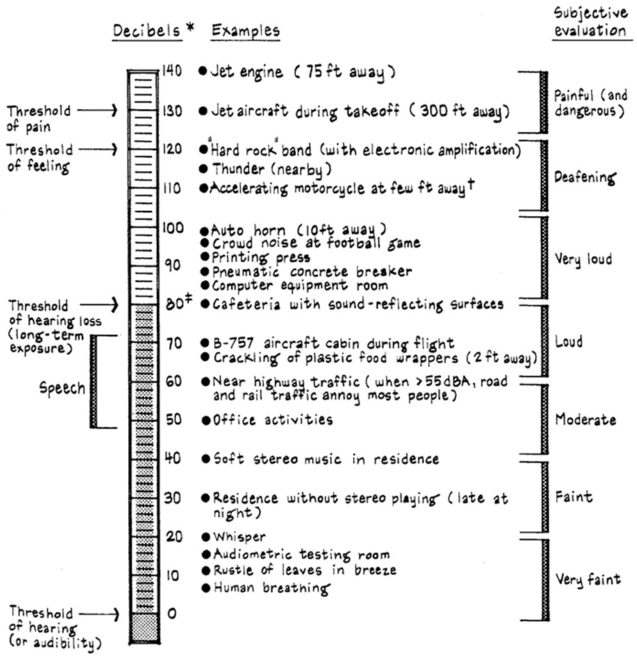

Figure 4: The Decibel Scale [2]

more intuitively understandable scale which correlates well with our perception of loudness.

The ear hears logarithmically, not arithmetically. That is why a logarithmic scale correlates closely with our perception of loudness. In other words, the ear judges louness of sounds by the ratio of their pressures, not by arithmetic addition.

1. A 1 decibel change in sound level is not perceptible to most individuals.
2. A 3 dB increase is "just perceptible".
3. A 5 dB increase is "clearly perceptible".
4. A 10 dB increase is regarded as twice as loud.
5. "0 dB" is not an absence of sound, it is a sound level equal to the reference level which was chosen to be the average threshold of hearing.
6. Decibels do not add arithmetically. They add logarithmically (Figure 5). 60 dB + 60 dB is not = 120 dB, 60 dB + 60 dB = 63 dB

$$\mathrm{SPL_{TOT}}\,(\mathrm{dB}) = \mathrm{SPL_1}(\mathrm{dB}) + 10\log_{10}(N) \qquad (1)$$

where N = # of sources of equal magnitude.

6 Audio Demonstrations

A set of Audio Demonstrations is available from the Acoustical Society of America for use in demonstrating the above concepts and related psychoacoustic phenomena. [3].

7 The Sound Level Meter

Sound levels are measured with a sound level meter compliant with IEC 61672-1:2002 consisting of:

1. A good quality microphone
2. A linear amplifier
3. An attenuator

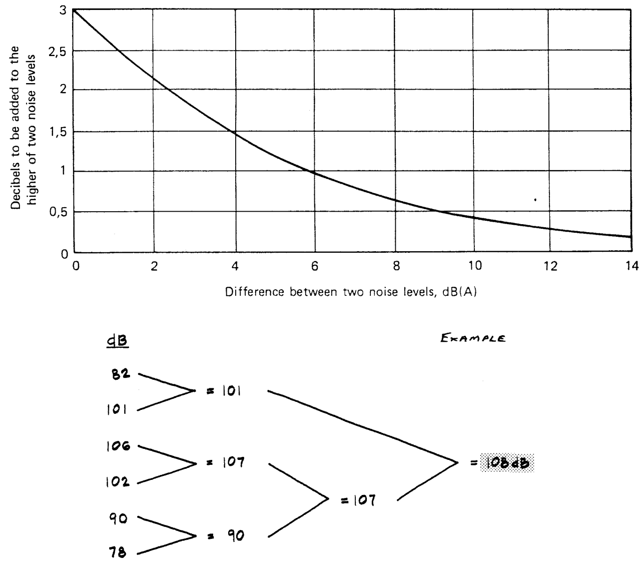

Figure 5: Decibel Addition [1, 2].

4. An indicating meter or digital display
5. A set of weighting networks to make the meter readings correspond closely to either physical pressure or perceived loudness since the ear is not equally sensitive at all frequencies.

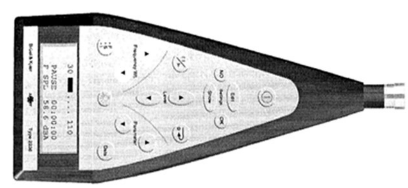

Figure 6: The Sound Level Meter [1].

8 Conclusion

Presenting visual and audible examples and demonstrations can be helpful to teachers of acoustics. Providing this kind of baseline knowledge to our communities is important as acoustical fundamentals may not always be taught in our public schools.

References

[1] Files and company seminars of HGC Engineering, Mississauga, Ontario

[2] Egan, M.D. "Architectural Acoustics" J. Ross Publishing, Originally Published by McGraw Hill Book Co., 1988

[3] "Acoustical Demonstrations – The Decibel Scale" Acoustical Society of America.