TEACHING CONCEPTS OF ACOUSTICAL WAVES IN AIR PART 3, REVERBERATION

William J. Gastmeier *1
[1]HGC Engineering, Mississauga, Ontario,

1 Introduction

This paper has been written to participate in the Education in Acoustics session at the 2024 joint conference of the Canadian Acoustical Association and the Acoustical Society of America. It is written to build on Parts 1 and 2 of this series and contains materials extracted from 30 years of teaching to Architects at the University of Waterloo and Dalhousie University in Halifax.

Part 1 dealt with sound propagation in air and the concepts of longitudinal wave motion, speed, frequency and wavelength which relate to what we perceive as pitch.

Part 2 examined superposition, sound pressure, decibels and the decibel scale, and how to manage decibels; all of which we perceive as loudness.

Part 3 deals with reverberation, which is an important aspect of sound in indoor spaces. It affects both our ability to communicate and how we experience and perceive the quality of the acoustical environment.

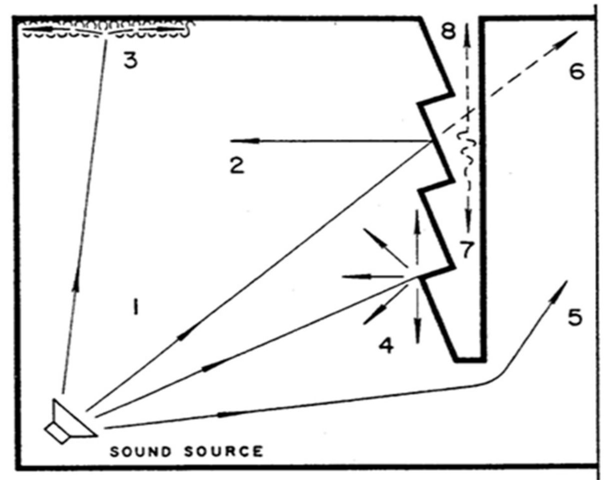

Figure 1: Acoustical Phenomena in Enclosed Spaces

2 Behaviour of Sound in Rooms

Several new concepts describe how sound behaves in rooms. 1 Direct Sound, 2 Reflected Sound, 3 Absorption, 4 Diffusion, 5 Diffraction, 6 Transmission through Partitions, 7 and 8 Structureborne Sound. In previous parts of this series, we learned that when a sound is made, it travels outwards as a spherical longitudinal wave at a speed of 344 m/s.

Figure 1 shows how the path a sound wave follows in a room can be described by geometric or "ray" acoustics. Geometric acoustics assumes that sound can be visualized as rays which travel perpendicular to the advancing longitudinal wavefront and reflect from flat surfaces with an angle of reflection equal to the angle of incidence, like light reflecting from a mirror. This concept generally holds true if the dimensions of a room are large compared to the wavelength of the sound. In typical rooms this is the case for frequencies above approximately 300 Hz. (Wavelengths of less than ~1 m).

3 First Reflections

A valuable sound is an “impulse” like a single handclap or a bursting balloon. That impulse “excites” all the possible ways sound can interact with the room surfaces during its travels until it loses its energy.

Figure 2 illustrates what happens after a handclap. Some surfaces are reflective, some are absorptive, some are diffusive, and some are diffracting, and they all modify the sound which reaches our ears. But our auditory system is not easily fooled.

*bgastmeier@hgcengineering.com

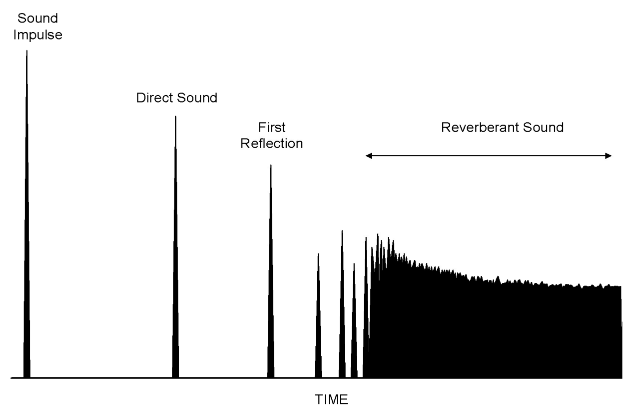

Figure 2: Reflections of an Impulse as Heard by a Listener.

Humans have evolved the capability of listening very closely to what happens during the first ~30 milliseconds (ms) of the arrival of a direct sound as that early arriving sound contains the really good information. It is almost like our ears act like open windows to let in the initial sound and the other good reflections and then close to suppress the interfering reverberation.

To put this in perspective, 30ms is roughly one thirtieth of a second, a timeframe in which we cannot physically react or even think. We can’t put up our hands and answer the teacher in 30ms. We can’t do much of anything at all in 30ms, so our brain does it for us. In a way that discovers our surroundings, like an early warning system.

Figure 2 is a one-dimensional picture of what reaches our ears. From which direction do those reflections originate? The walls, the ceiling, the sound system? Each of those contribute. Let’s start by looking at the horizontal and vertical planes.

These give the quality of Spaciousness, Intimacy and Localization

Sound arriving from vertical reflections (ceiling and floor) does not provide much locational information because of the "Plane of Poor Sound Source Localization" but those reflections reinforce the loudness or strength of the sound.

This is why a centrally mounted loudspeaker is good for sound reinforcement and can supply the useful ceiling reflections which may have been lost due to a skylight or large vaulted or sound absorbing ceiling.

4 Demonstration .... Plane of Poor Sound Localization.

You can use a loudspeaker and microphone to demonstrate this. Have your students close their eyes and hold their heads still and facing forward while you vary the location of the loudspeaker horizontally and vertically by approximately the same amount. Ask for their responses ...... and then them have them bend their heads over until they are as close as possible to 90 degrees still facing forwards and see what they have to say!

5 Demonstration ...Time Reversed Speech

The human auditory system has an innate ability to prefer the early sound arriving from a source (direct sound plus early reflections) and analyzes it to gain useful information about the source. ***Our auditory system suppresses the later arriving sound we call reverberation.***

A set of Audio Demonstrations is available from the Acoustical Society of America for use in demonstrating these concepts and related psychoacoustic phenomena [3]. Listening to time reversed speech makes it clear our auditory systems are intensely focussed on the early arriving energy and suppress the later reverberation which doesn't provide much helpful information and can reduce intelligibility. It does seem to help singers and musical instruments sound better ... up to a point.

These are targets selected from several references and illustrate that reverberation must be controlled to allow for good speech intelligibility and particularly for persons with some degree of hearing loss.

6 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.

7 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 Effect of Echos" Acoustical Society of America compiled by Houtsma, Rossing, and Wagenaars

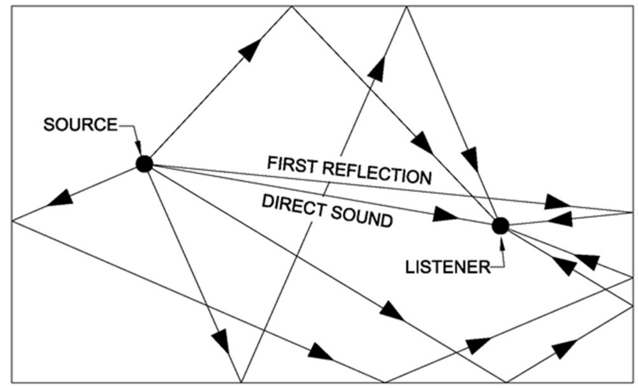

Figure 3: First Sound Reflections in the Horizontal Plane.

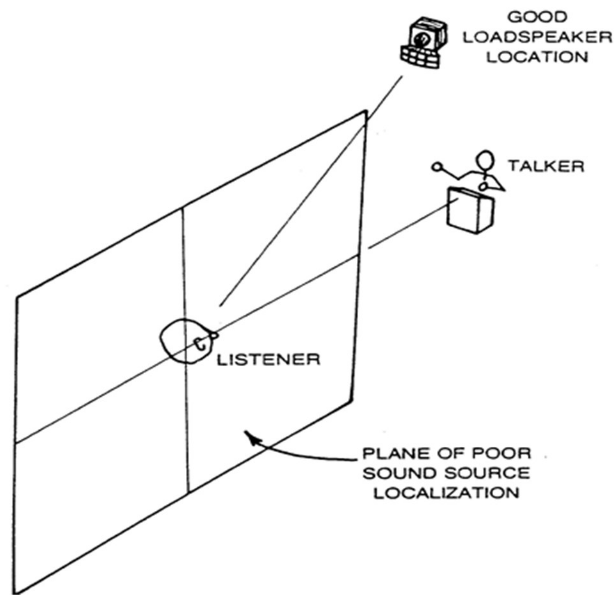

Figure 4: Vertical Reflections/Reinforcement and the Plane of Poor Sound Localization [2]

Table 1: Desired Reverberation Times [2],[4]

Performance	RT (seconds)
Traditional Organ Music	2.5 – 5.0
Symphonic Repertoire	1.8 – 2.1
Chamber Music	1.6 – 1.8
Opera	1.3 – 1.6
Modern Music	1.1 – 1.7
Live Theatre	0.9 – 1.4
Lecture or Conference	0.6 - 1.1
Broadcast, Recording Studios	0.3 – 0.7

[4] Beranek, L.L. (2004). Concert halls and opera houses. New York: Springer-Verlag.