Teaching Concepts of Acoustical Waves in Air
How They Travel and Shape Acoustical Environments

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1 Introduction

This paper has been written to supplement a session in "Teaching Acoustics" at the 2022 CAA conference. It contains materials extracted from 30 years of teaching to Architects at the University of Waterloo and Dalhousie University in Halifax.

The purpose of this session is to provide teachers with practical demonstrations which can be used to enhance learning. It has always been my teaching philosophy that a teacher engages multiple senses to be effective at instilling knowledge, and what is better for architects and acousticians than using sight and sound as well as written materials.

Here are a few demonstrations I have used over the years.

1) The use of a **rope** to demonstrate our collective incorrect assumption that sound travels like waves on water and examine the speed of sound in various media.
2) The use of a **coiled flexible spring** to demonstrate the concepts of transverse and longitudinal waves. Hint: sound in air propagates as a longitudinal spherical wave modified by the directivity of the source.
3) The use of an **electronic oscillator and loudspeaker** to illustrate concepts of frequency and wavelength.
4) The use of **balloons.** Since balloons are 99% air, they are pretty much transparent to sound but they do react to sound in a manner which is instructive to our understanding of the human auditory mechanism and how sound propagates in air and through partitions.

2 Understanding Wave Propagation

There are two types of waves of interest in this regard: transverse and longitudinal.

This is our common intuition of how sound travels. Transverse waves travel on a string or on a surface and particle motion is perpendicular to the direction of propagation. **This is not how sound travels,** but the concept is useful in demonstrating the speed of sound.

2.1 Demonstration 1: The Rope

This demonstration shows the transverse nature of waves on a string as well as the relationship of the speed of sound to the elasticity of the medium. Speed is equal to distance travelled per unit time.

$$\mathbf{c = d / t} \qquad (1)$$

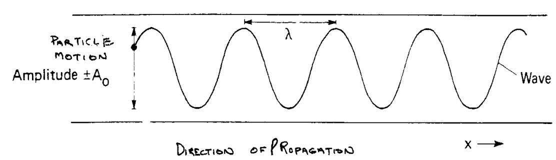

Figure 1: Transverse Waves

The speed of sound depends on elasticity, density and temperature. The relationship of the speed of sound to the elasticity and density is given by the formula $\mathbf{c} = k\sqrt{(\varepsilon/\rho)}$

Tie the rope to a solid object, hold it under some tension and puck it like a guitar string. Watch the impulse and the speed at which it propagates. Then pull harder on the rope to increase the tension (elasticity) Note that the wave propagates more quickly. You can also demonstrate reflections in this way

The speed of sound at normal atmospheric pressure and room temperature is **c = 344 m/sec.**

Equate this to a physical situation. How close to you are to the lightning strike? If you hear the thunder one second after seeing the flash it is only 344 m away!

And if you clap your hands in a living room with typical dimensions of 6 meters the sound will be reflected ~50 times in just one second. More often from the ceiling which is less than 3 m high!

Another fun concept to investigate is … does air really have mass and elasticity? We take air so for granted that it is invisible to us in those terms. The mass of air causes an atmospheric pressure of ~ 100 Millibars (weather forecast) or ~ 15 pounds (7 kg) per square inch. Massive!

Concerning elasticity, can you bounce a basketball if it is not inflated with air? The elasticity comes from the air, not the rubber.

So here is another question … Why is the speed of sound faster in water?

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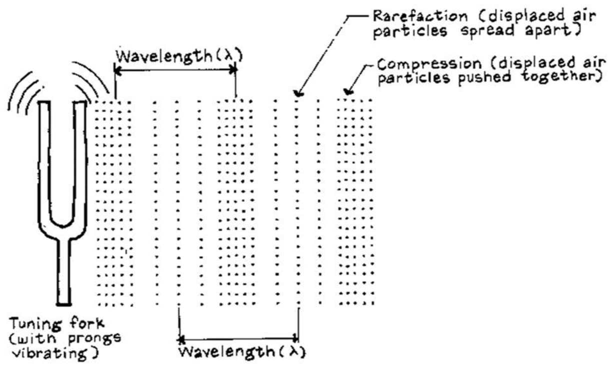

Figure 2: Longitudinal Waves

Because of the relationship of mass and elasticity. Water is more massive than air, but it is also much more elastic. It hurts much more when you belly flop into water than when you are diving through the air.

Longitudinal Waves travel in a bulk (three dimensional) medium. Particle motion is in the same direction as the direction of propagation.

This is how sound travels, although not equally in all directions.

2.2 Demonstration 2: The Coiled Spring

Use a coiled spring (Slinky) to set up longitudinal waves to illustrate the above. Firm up the concept that individual air molecules are pushing against and recoiling from each other as the energy propagates outwards from the source. Make the extension that there are a large number of slinkys connected to any noise source radiating sound in all directions, some more strongly than others (directivity) hence spherical wave propagation.

2.3 Demonstration 3: Oscillator/Speaker

Set up a loudspeaker connected to a variable frequency sinusoidal oscillator. Your laptop or smart phone will not work well for this demonstration. They may be able to produce the tones, but not visually.

Show that the speaker pushes in and out to create longitudinal waves.

Set the oscillator to 100 Hz and let them hear the bass sound. Illustrate with your body (put your arms out and walk around) how a frequency of 100 Hz results in a wavelength of 3.44 meters (~ 10 feet) …. Compression, rarefaction, compression always pushing outwards.

Set the oscillator to 1000 Hz and illustrate with your body how the wavelength has decreased to 1 foot, like the size of their heads (at least the smart ones) and then to 10,000 Hz and the wavelength is ~ 1 inch, roughly the size of their ears.

The important concept here is that our human perception is based on frequency as exhibited by wavelength and that other creatures perceive a different soundscape because of their physical size. Whales tend to communicate with lower frequency signals and bats and birds with higher frequencies.

2.4 Demonstration 4: Balloons

Balloons can be a fun part of all of this.

Have them available and have the students blow them up as they come into the classroom,

Balloons can be used to reinforce all the above concepts in a positive manner. Here are some thoughts for you.

Invite them to hod the balloon lightly with their fingertips and feel the vibration in the balloon from demonstration 3 as the frequency is changed to accommodate the balloons natural frequency of vibration.

What is causing the vibration? Areas of high and low pressure (compression and rarefaction) passing by.

Connect with how our tympanic membrane vibrates from longitudinal waves. OK, that was science speak around the entrance impedance into our middle and inner ear.

Make the extension to sound incident on a wall. Because it is a longitudinal wave, it exerts pressure against the wall which sets it in motion and causes sound to be radiated from the other side.

3 Conclusion

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

References

This material was extracted from course notes prepared for undergraduate students of Architecture at the University of Waterloo and Dalhousie University.