Lesson Outline: Build an acoustic thermometer using an iPhone (or iPad) and headset

Possible learning objectives

- Sound is a wave that travels through air at the **Speed of Sound**
- The **Speed of Sound** varies with the temperature of air
- Speed (or velocity) is distance divided by time
- How to build an **Acoustic Thermometer**

Overview

The time it takes for sound to travel between two points in air is a function of temperature; as the air temperature increases, the speed of sound increases. Therefore, by measuring the speed of sound, it is possible to calculate the (average) temperature of the air that the sound has travelled through.

Some discussion openers:

- During a thunderstorm we see lightning flash before we hear the thunder clap. Why?
- What is happening when a jet fighter creates a sonic boom?
- The tag line from the film Alien was "In space, no one can hear you scream". Why not?
- If you lived near a football stadium and you were watching a match on television, would you hear the crowd cheer first on the TV or through your open window?

Theory part 1 – Speed (or velocity) is distance divided by time

The speed of sound can be measured by timing how long it takes for a sound to travel a known distance, 'd' between two points; typically, a speaker (the source of the sound) and a microphone (the receiver of the sound). The speed can then be calculated in the usual way by dividing the distance by the time taken to cross the distance.

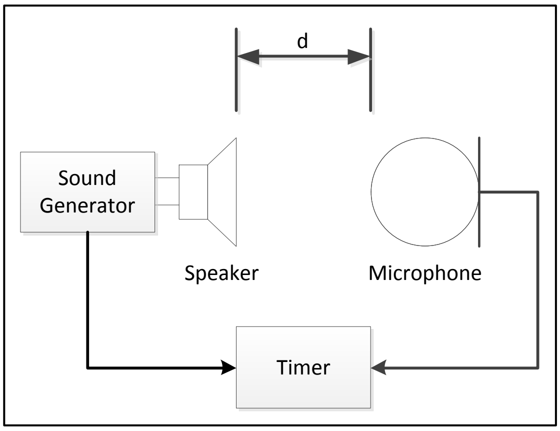

Figure 1: Typical setup for measuring the speed of sound

Questions:

Q1 – Calculate the speed of sound in the following cases:

a) Lightning strikes a tree 525m from where I am standing (a lucky escape ☺). I hear the thunderclap 1.5 seconds later.
b) I am standing 100 metres from a cliff. I clap my hands and then listen for the echo which arrives 0.6 seconds later.
c) I am standing at the back of the crowd at a music festival about 250 metres from the stage. The nearest speaker stack is about half way to the stage. I see the drummer hit the cymbal and 0.35 seconds later I hear the crash of the cymbal. (*What assumptions did you make in answering this question?)*

Q2– Calculate the distance in the following cases (assume that the speed of sound is 340 metres/second):

a) I see a flash of lightning and 2.5 seconds later I hear the thunderclap.
b) I see a second flash of lightning. This time it only takes 0.5 seconds before I hear the thunderclap. How much closer has the storm moved?

Q3– Calculate the time in the following cases (assume that the speed of sound is 340 metres/second):

a) A car is driving towards me at 20 metres/second. The driver sounds the horn to warn me to get out of the way. I hear the horn 0.5 seconds later. How long do I have to get out of the way?
b) I am running the 100m but have been given the outside lane which is furthest from the starter. I am in Lane 8 which is 10 metres from the starter and his starting gun. How much of a disadvantage do I have over the runner in Lane 1 that is only 2 metres from the starter.

Practical – Measure the speed of sound

You will need:

- Stopwatch
- Something to make a loud noise e.g. two wooden blocks to bang together
- 100 metre tape measure
- Another person to assist you

Find a large open area such as football pitch. Select two locations at opposite ends of the area and measure the distance between them. Position the assistant at one location with the wooden blocks and stand yourself at the opposite end. When you are ready, signal to your assistant to make a loud noise by banging the blocks overhead. When you see the blocks strike, start the stopwatch. On hearing the sound of the blocks striking, stop the stopwatch. Divide the distance between the locations by the time recorded to calculate the speed of sound. Repeat the measurement several times to improve the accuracy of the reading by taking an average (or median).

You could also try different distances and then plot a graph of distance v time – the slope of the line is the speed of sound (N.B. the intersection with the x-axis will be your response time).

Theory Part 2 – The speed of sound in air varies with temperature

Acoustic thermometers rely on the principle that as air temperature varies, its density varies. The change in air density causes the speed of sound to vary according to the formula:

Speed of sound, $v = 331.3 * \sqrt{1 + \frac{t}{273}}$ m/s

where 't' is the temperature in degrees Celsius.

Plot a graph of 'Speed of Sound' in metres/second v "Temperature' in degrees Celsius and use the graph to help answer the following questions.

Q4 – Calculate the speed of sound in air for the following temperatures:

c) 20 degrees Celsius
d) Water freezing point
e) Zero degrees Fahrenheit

Q5 – What is the air temperature for the following speeds of sound:

a) 340 metres/second
b) 650 miles per hour
c) 1000 kilometres per hour

Q6 – What is the temperature change for the following cases:

a) From a speed of sound of 350 metres/second to a speed of 330 metres/second
b) From a starting temperature of 20 degrees Celsius, the speed of sound increases by 10 metres/second
c) From a starting temperature where the speed of sound is 335 metres/second, the temperature decreases to -10 degrees Celsius

Practical – Build and test an acoustic thermometer

You will need:

- iPhone or iPad with the Ondo application installed
- Apple EarPods with Lightning Connector or Jack Plug
- Method for holding the earpiece a fixed distance from the microphone (see our design guidelines at www.ondo.app/resources)
- Thermometer for calibration and comparison

Background:
Ondo is an acoustic thermometer for the iPhone or iPad utilising the standard Apple EarPods. Ondo works by transmitting a high frequency sound from the earpiece. This sound is received by the microphone positioned at a fixed distance from the earpiece. The time taken for the sound to travel between the earpiece and the microphone is very accurately measured to less than a millionth of a second. The speed of the sound and hence the temperature of the air between the earpiece and the microphone can then be calculated.

Download and install the Ondo application onto an iPhone or iPad. Follow the setup instructions to build your own acoustic thermometer (alternatively you could design your own fixture – see our design guidelines www.ondo.app/support).

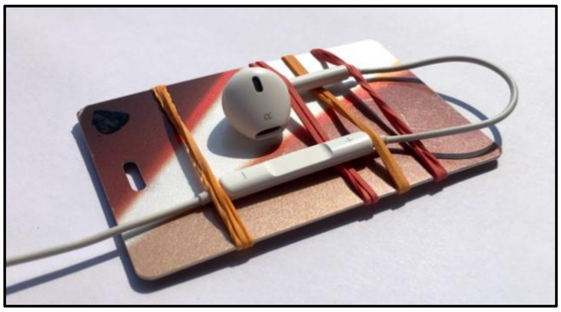

Figure 2: Example setup for holding the earpiece and microphone

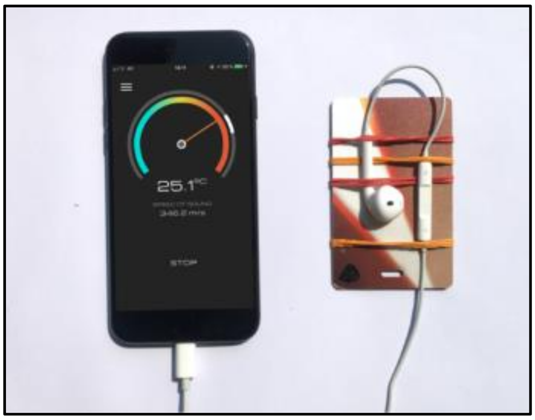

Figure 3: The Ondo application running on an iPhone

You will need to calibrate the acoustic thermometer the first time that you use it by inputting a temperature reading from the thermometer. Provided the distance between the microphone and the headset does not change, then it should not be necessary to recalibrate.

Please observe the following guidelines to get the best performance from Ondo:

1. Never put the earpieces (left or right) into your ears when Ondo is running.
2. Keep the left earpiece as far from the microphone as possible.
3. Ensure that your hands or any other objects are well clear of the microphone.

Once you have Ondo working, here are some things you can try:

- Hold the headset directly above a radiator
- Compare the indoor and outdoor temperatures
- Compare the response times of the acoustic and conventional thermometers to a change in temperature
- Measure the room temperature at floor level and at ceiling level
- Map the temperature across a large room
- Blow hot air from hair drier (take care not to overheat the headset)

We hope that you will find Ondo a fun and useful way to teach some of the theory of sound. Please send us your comments, ideas and suggestions to support@ondo.app. We would love to hear from you.