Speed of Sound

I believe the use of noise to make music will increase until we reach a music produced through the aid of electrical instruments which will make available for musical purposes any and all sounds that can be heard.

composer John Cage, 1937

1 Introduction

There are many ways to determine the speed of sound. The method we will use in this lab is both fairly straight forward and the equipment needed is fairly minimal. We will be creating sounds and recording them with two microphones. We will measure the difference in distance between the paths the sounds take from going to the two microphones. We will then study the recorded signals of the sound to see the time difference between how long the sound took to get to each microphone. Our measurement of the speed of sound will be the result of dividing the difference in distance by the difference in time.

1.1 Theory

Sound is a vibrational wave that travels through a medium. The speed of sound in a medium depends on how quickly the energy of the vibration can be transferred across the medium. While the details of the equations that are used to find the speed of sound will vary depending on the state of the medium, the basic equation

$$\frac{\partial^2 u}{\partial t^2} = c^2 \nabla^2 u \tag{1}$$

describes the wave where u describes the medium the wave is moving through, and c is the speed of the wave [**?**].

In a sound wave, the general method to find the speed is from

$$v_s = \sqrt{\frac{\partial p}{\partial \rho}} \tag{2}$$

where p is the pressure and ρ is the mass density [**?**]. In fluids, the speed can be recast in terms of the bulk modulus, B,

$$v_s = \sqrt{\frac{B}{\rho}} \tag{3}$$

which describes the change in volume undergone by a medium when the pressure changes [**?**]. Similarly, in a solid the sound speed depends on the Young's modulus, Y,

$$v_s = \sqrt{\frac{Y}{\rho}} \tag{4}$$

which describes the stress divided by the strain.

For gases, the bulk modulus is not always easy deal with, since it will in general vary with temperature, pressure, and density. So the speed of sound equation is often recast using the terms of ideal gases:

$$v_s = \sqrt{\frac{\gamma k T}{m}} \tag{5}$$

where γ is adiabatic index (which is equivalent to the specific heat at constant pressure divided by the specific heat at constant volume), k is Boltzmann's constant, T is the temperature and m is the molecular mass [?]. For dry air we will take $\gamma = 1.4$ and $m = 28.9645$ u. Unfortunately, air is not a perfectly ideal gas, so to determine the speed of sound more exactly pressure and humidity must be considered. Consideration of these effects does not lead to simple equations, though, so in practice tables or numerical approximations are typically used.

2 Procedure

2.1 The Speed of Sound in Air

In this lab we will be using the program **audacity** on a Linux computer to record sounds received by two microphones. Using the provided adapters you will save one microphones sound as the left track of a stereo recording and one as the right track. For all of the measurements that you make below, be sure to establish reasonable uncertainties and to make notes in your lab notebook about why you picked the uncertainties that you used.

Record the air temperature, pressure and humidity for the time of your measurements. Currently we have 1 device that will make all three measurements.

Your first order of business is to figure out how you need to use the provided adapters and cords to hook up the microphones to the computer. Once you believe that you have the cords set up right, open up audacity and configure that program to receive stereo input. Then test each microphone separately, to be sure that they are providing signals to the correct channel. Once you are convinced that each microphone is working correctly, try both microphones at the same time. Play with causing a sound closer to one microphone or the other and see if your recorded signals make sense.

Once you are convinced that your setup is correctly recording the signals to both microphones, take several sets of data that you can use to find the speed of sound. Remember that the distance that will go into your calculations is the *difference* in the path length traveled by the sound to each microphone.

For the time difference between how long it takes the sounds to get to each microphone, first use **audacity** directly. Zoom in on your recordings, pick notable locations in the sound waves, and read off the time difference between when those portions of the wave appear in the left and the right channels. Be sure to assign an uncertainty to the time difference. Be sure to bf print off at least one set of sample signals from audacity and use the plots when explaining your method. You may need to create a screenshot in order to extract plots from audacity.

Mathematica can be used to increase the precision of your measurements of the time delays. A file called sound_analysis.nb shows examples using some of the commands below.

You should save your files as .wav files from audacity, using Export.

Then open them in Mathematica using:

```
sdata= Import["filename", "Data"]
c1 = sdata[[{1}]]
c2= sdata[[[{2}]]
ListPlot[c2, PlotRange -> {{1500, 1550}, {-.1, .2}}]
```

Repeat this process for at least five different path length differences for the sound's travel to the two microphones. Be sure to have your path difference use the entire range of possible values allowed by the supplied equipment. Plot your results as path length difference versus time delay and fit the line to find a value for the speed of sound in air.

2.2 The Speed of Sound in Some Other Material

In this section of the lab you are in charge. Use the techniques that you learned in the previous section to find the speed of sound in some material other than air. In your lab notebook describe in detail what you do on this portion. Note that you should be very careful to consider the fact that the sound may travel both through the material that you are attempting to test and the air. Think carefully how to best use the equipment available to measure the speed of sound in the material.

3 Conclusions

1. Find online or in a book a source for the speed of sound in air that considers temperature, humidity, and pressure. This source may have equations, tables, or web forms that give the speed of sound. Cite your source. Find the speed of sound using equation 5 and your source and compare. Also, try slightly varying the temperature, pressure, and humidity that you use and see how the results change. Variations in which parameters make the most difference here? Why? Use these values to come up with a theoretical value of the speed of sound in air with uncertainty for the time of your measurements. Explain how you decided on your value.

2. How do your results for the speed of sound in air compare to the published values? Are the values consistent to within their uncertainties?

3. What is the published value for the speed of sound in the other material that you tested and what is your source for the speed? (`http://www.engineeringtoolbox.com/sound-speed-solids-d_713.html` and `http://piano-tuners.org/sound.html` have some values.)

   How do your results compare to the published values? Are the values consistent to within their uncertainties?

4. How could this lab be improved to increase the precision and accuracy of the measurements of the speed of sound for air or for other materials?