Applet Exercise 3: End Correction for a 1-D Open-Closed Tube

Objectives:

1. Measure the effect of the end correction at the open end of a tube and see how it depends on the width of the tube.
2. Understand and know how to use the concept of an "effective" length as opposed to the physical length.
3. Learn how to use the "scan" option in the Virtual Lab.

Preface:

In this lab, we will focus on the open-closed tube in order to understand the end correction. In a 1-D tube, there is a pressure antinode at the closed end and a node at the open end. However, as you will see in the simulation, the pressure does not go to zero right at the end of the tube. Rather it reaches zero a small distance beyond the end of the tube. This is called the "End correction", because our simple picture of the tube is not quite right. Taking this effect into account is called a "correction." Essentially, the tube will behave as though it is slightly longer than its actual length. This gets confusing, so we will call the actual tube length the "physical length" or L_{phys}. This is the length you would get if you measured the tube with a ruler. We can account for the end correction by saying that the tube effectively behaves like a perfect tube which is slightly longer. We will call this the "effective" length of the tube, or L_{eff}. This is a useful approach, in that we can use all of the formulas we have developed for tubes, but instead of using the physical length, we use the effective length. This may seem like a lot of effort, but if you create a wind or brass instrument without understanding the end correction, the instrument will be very out-of-tune. A flute designed without the end correction will be about a quarter step off in pitch.

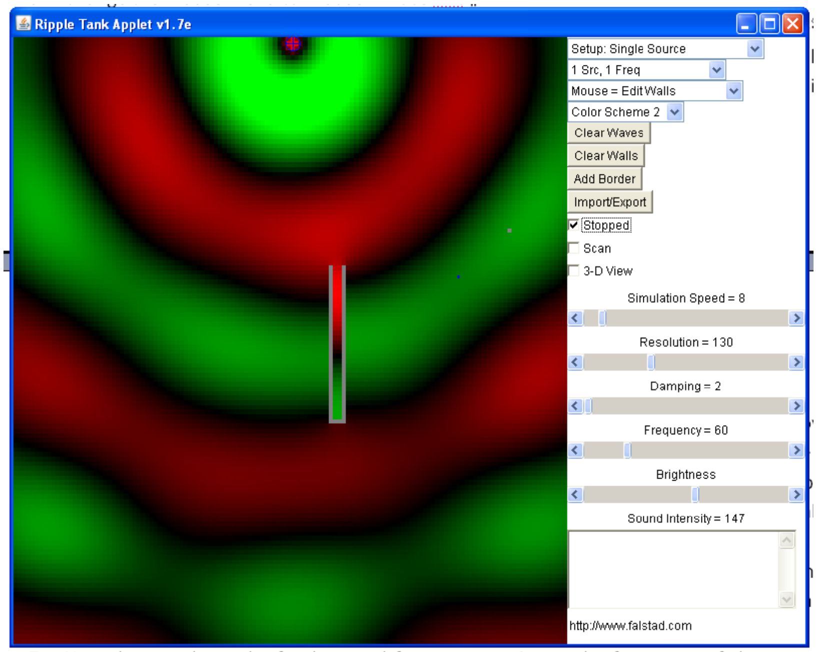
It turns out that the end correction becomes larger as the diameter of the tube increases. This makes sense, as the pressure at the end of the tube will be harder to control as the opening gets bigger. We can write this as $L_{eff} = L_{phys} + a*(\text{diameter of the tube})$. Here, "a" tells us how important the end correction really is. "a" is roughly equal to 0.3 for a 3-D cylindrical tube. Again, you can see that the tube "effectively" acts like it is a bit longer than you would think.

As in the other Virtual Labs, things are a little different in 2-D, but we also have more control over the experiment. Here, the tubes will have a width "w" and the end correction will depend on w: $L_{eff} = L_{phys} + a*w$. We will measure the resonance of an open-closed tube for 3 different values of w. From this, we can find the value of "a".

Finally, we will introduce a new method to find the resonance of the tube. It is the same as in the previous lab, but now the computer does most of the work. It is not faster, but it is automated and this usually leads to more accurate results. Also, this method will be necessary in the next lab, so it is important to understand it in this lab, first.

Instructions:

1. Initial settings: Simulation speed = 8, Resolution = 130, Damping = 2, Frequency = 100.
2. In the upper right part of the Applet, there is a Mouse selection drop-down menu. Choose Mouse = Edit Walls. Draw two vertical parallel lines with two pixels between them. Make them between 30 and 40 units long and close the bottom. (As before, you can draw lines by clicking and dragging. If you start the line on a spot that has no wall, you will add a wall wherever you go. If you start on a spot with a wall, you will erase the wall wherever you go. This allows you to fix errors.) You're screen will look something like this:



3. Change the mouse menu to Mouse = Place Mic and place the microphone at the closed end of the tube.
4. We are going to record the value of the second mode (remember, for an open-closed tube, the second mode has a value of 3f, where f is the fundamental). Based on the length you drew for the tube, calculate the frequency of the second mode, not worrying about the end correction. The speed of sound in these simulations is $1000\pi = 3141.6$.
5. We are going to use a more precise technique to find the frequency of the second mode. The Virtual Lab applet will scan the frequency and record the sound intensity of the microphone. As you scan through a resonance, the intensity will go up and down and by finding the peak, you will find the frequency of the mode. Set the frequency slider to a value 15 less than you found in Part 4 above. Then, set the simulation speed to the maximum value. The sound waves will look a bit strange, but it speeds up the lab a lot.
6. Clear the waves, make sure the simulation is running (uncheck the "Stopped" box) and then check the "Scan" box. The simulation will now automatically scan the frequency, increasing the frequency by one each time. The program will wait a few seconds for the waves to settle down at the new frequency and then record the value for the microphone. You can watch the progress in the text

box at the lower right-hand corner. You will see the frequency and the value of the microphone for that frequency. It will take 10-20 seconds per point, depending on your computer. You should see the intensity go up and then down. When you see that the frequency has clearly passed through the resonance, you can stop the scan by unchecking the "Scan" box. Note, the frequency slider will not update during the scan, but don't worry about that.

7. Increase the width of the tube to 4 units, making sure not to change the length of the tube. Reset the frequency slider to the value you chose above and perform another scan. The program will append the new data to the old data – it will not over-write the data you already have.
8. Repeat this process for widths of 6 and 8 units.
9. Finally, enter the resonant frequencies into Table 1. You can enter the frequency with the highest intensity. However, if two frequencies are similar, you can enter a number halfway in between. For example, if you numbers are:

   61 0.286071
   62 0.45844337
   63 0.8063784
   64 1.6039487
   65 2.3539882
   66 1.8505212
   67 0.8602444

   you would enter 65 as the resonant frequency. However, if your numbers are:

   58 0.31851947
   59 0.40419456
   60 0.504841
   61 0.560298
   62 0.54056907
   63 0.46947357

   You would enter 61.5 for the resonant frequency.

Table 1

Tube width, w	Measured frequency of 2nd mode, f_2
2	
4	
6	
8	

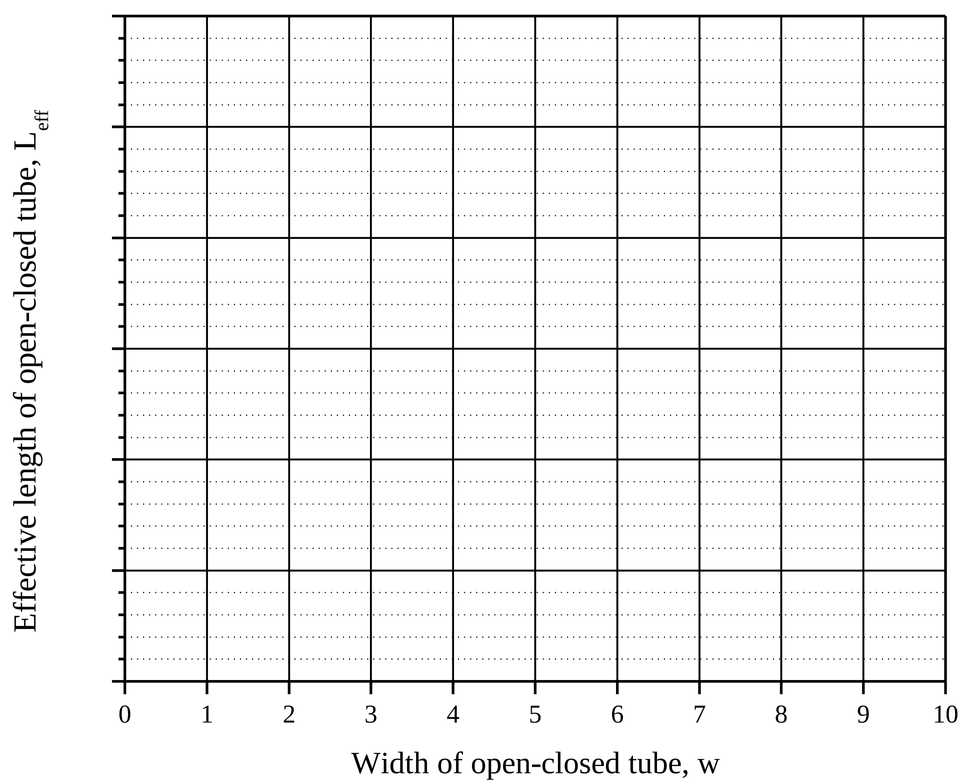
Questions

A. Fill in Table 2 with the effective length of the tube calculated from your *measured* resonant frequencies from Table 1. Remember the formula for the second mode of an open-closed tube: $f_2 = 3v/(4L_{eff})$. From this, you can calculate $L_{eff} = 3v/(4f_2(\text{measured}))$.

Table 2

Tube width, w	Effective length, L_{eff}
2	
4	
6	
8	

B. Plot the value of L_{eff} as a function of w and draw a straight line through the points.



C. What is the slope of the line? To determine the slope take two points, one at each end of the line. Then the slope is the change in the y-value of the two points divided by the change in the x-value. This gives you the value for "a". What is the intercept of the line? The intercept is the value of y when w=0. Does this correspond to the physical length? Should it correspond to the physical length?

Slope =

Intecept =

D. Go back to the Virtual Lab and the tube with a width of 4 units. Run the simulation at the resonant frequency for the second mode of this tube that you found from the scan. Set the simulation speed to 8. Look closely at the open end. Can you see how the wave kind of "spills out" of the tube? This is why there is an end correction. How far out does the wave go before it seems to disappear? Does this match up to the effective length that you found from the resonance?