IA Trumpet and frequency

Introduction

I’ve been playing the trumpet for a long time, so I really wanted my physics IA to have something to do with that. I have always known that there is a lot of different physics-topics to explore related so musical instrument and after some thinking I decided to analyze the different between the length of the trumpet and the frequency. I wanted to see how accurate the length of the valves was and how the frequency changed when I adjusted the length slightly. The reason behind why I chose this is that I wanted to explore the physics behind something I don’t really think about and just know unconsciously. I knew I was going to learn a lot about frequency and wavelength during this experiment, but I also knew that I was going to get really annoyed playing the trumpet out of tune all the time. I had to think about the physics around my experience rather than how pretty it sounded. I decided recorded the sound and analyzes the different frequencies afterwards.

Research question

What is the relationship between the length of the trumpet pipe and the frequency?

Independent variable: Length of trumpet

Dependent variable: Frequency

Controlled variables:

Speed of sound is 345 m/s

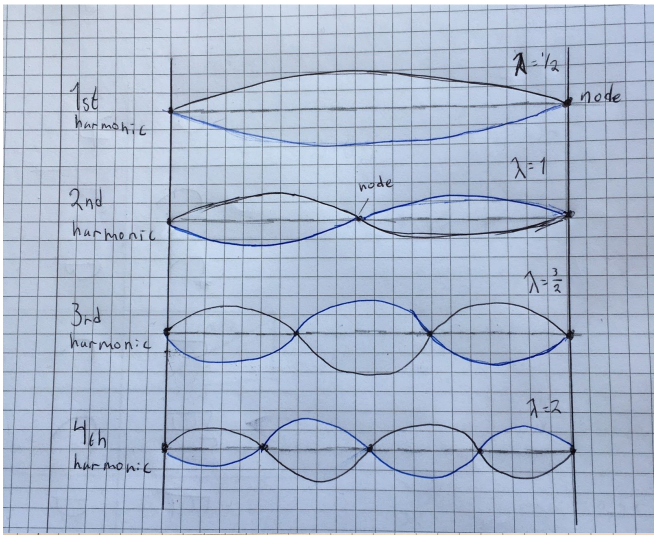
Temperature

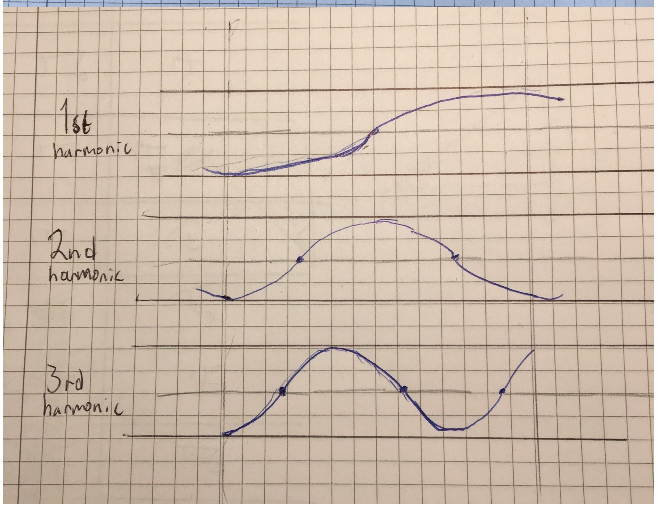
Same trumpet

Trumpet played by same person

Theory

Standing waves in open tubes





Standing waves are waves that has boundaries. When the waves meet the boundaries, they reflect. We talk about standing wave because there are only particular frequencies and wavelengths that can form these standing waves. The soundscape will therefore become dominated by these standing waves. The points where the waves crosses become nodes and all the other points become antinodes. The number of nodes in a length decides the harmonic. The formula for the wavelength in each harmonic is given with:

$$\lambda_n = \frac{2(L)}{n}$$

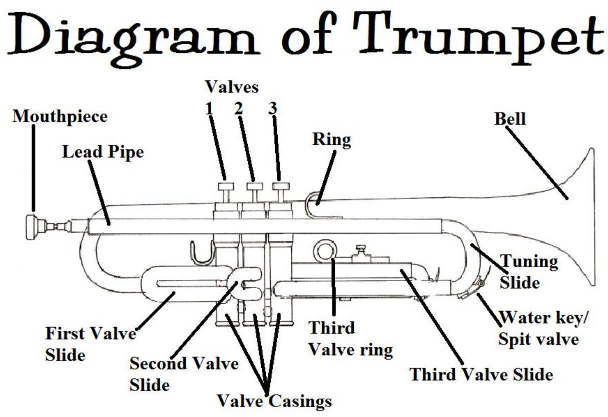
with n being the harmonic and L being the length of the tube.

When we have standing waves on a string we have nodes on the ends but standing waves in an open tube have antinodes on the ends. *Figure 1* shows standing waves on strings for four harmonics and their reflection. *Figure 2* shows standing waves in an open tube.

Trumpet

Before we start explaining how the trumpet works. let us establish some definition.

- Frequency is the number of waves per second. The unit for frequency is Hertz(Hz)
- A note is the frequency we write or read
- A tone is the frequency we hear
- A pitch is the frequency we play



The instrument I am using is a Bb trumpet which means it is a brass instrument tunes in Bb. I, as the player, can select the pitch and therefore the harmonic I am playing. I played a G which is the third harmonics. Blowing air through closed lips into the mouthpiece makes standing waves vibration in the lead pipe which is what makes the sound. The air goes through the lead pipe and out the bell. Of you press down the valves, the air goes through the valve slides as well. The length of the instrument is 143 cm. However, small inaccuracies due to the bending of the instrument and damages to the instrument. The different valves make the instrument longer. The longer the instrument gets, the lower the tone get. And the lower the tone gets, the lower the frequency gets. The first valve slide is 18 cm long and makes the instrument and pitch one whole tone lower, the second valve slide is 8,5 cm long and makes the instrument and pitch half a tone lower and the third valve slide is 27 cm long and makes the instrument and pitch one and a half tone lower. The valve slides can be adjusted and the lengths I have mentioned is there original and minimal length.

Formulas

The formula for frequency is:

$$f = \frac{v}{\lambda}$$

So, if we put the wavelength formula for the third harmonic into the formula for the frequency we get:

$$f = \frac{3v}{2L}$$

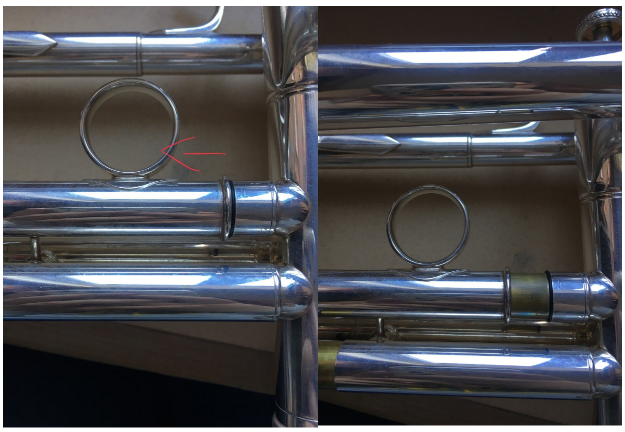
with v being the velocity of the air (speed of sound, 345 m/s) and L being the length of the trumpet.

Hypothesis

The longer the instrument gets the smaller the frequency gets. I expect the frequency to be inversely proportional to the length of the trumpet.

Method

I measured the length of the instrument and each pipe by have a tread follow the pipe and afterwards measure the tread. The measurements were checked online, and they were right. I started by warming up the instrument to get the most accurate measurements. I chose to play the note G because it is an easy pitch to keep steady. The first tone I recorded was the original G without any adjustments. After that I adjusted the length of the instrument by first pressing down the first valve and thereafter adjusting the valve slide with an additional two cm for each tone I recorded. The measuring of the additional length happened with a ruler. I did the same thing with the third



valve slide. Each tone was played for about three seconds so I could measure the frequency with a tuner in different part of the tone. I chose the hold one tone longer rather than playing it many times because it would make the controlled values for each tone more equal. I recorded one tone for each measurement with audacity and measured the frequency with a tuner on my phone. I assumed the speed of sound in the room was 345 m/s.

When I measured the frequency with audacity by marking to note and analyzing the spectrum, I looked at the first peak. When I measured the frequency with a tuner I replayed the note and my phone recognized the frequency.

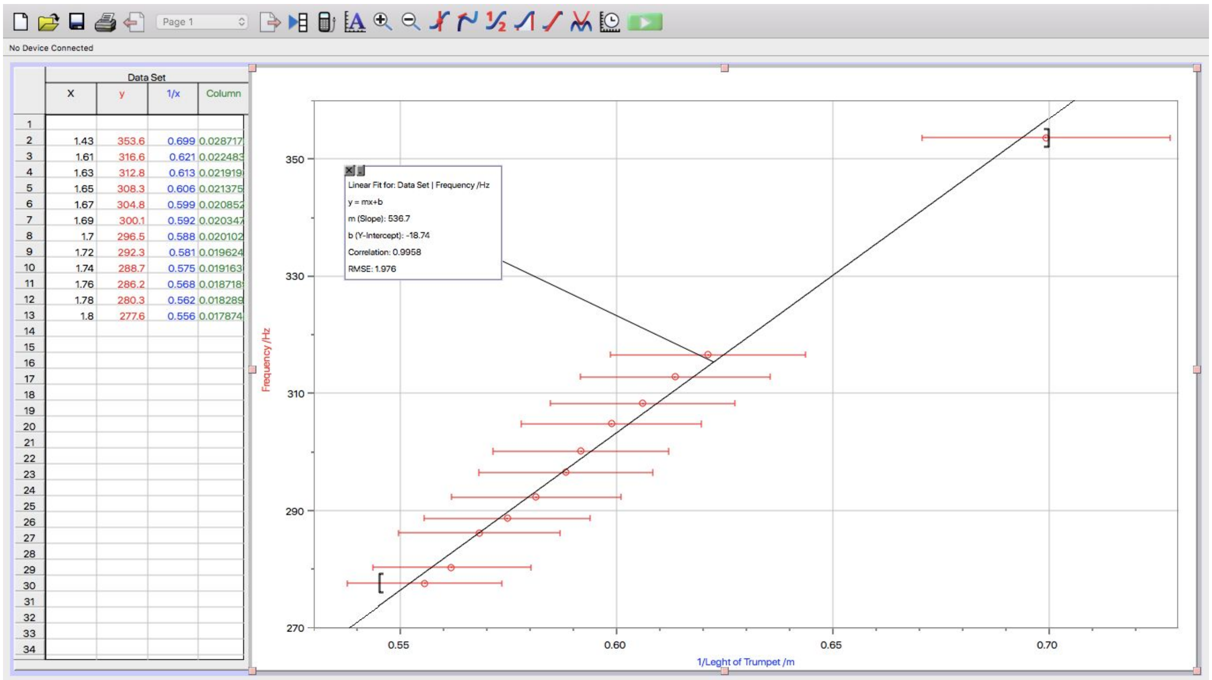
Results

Length in m ±0.01m	1/Length of trumpet /m	Frequency in Hz from analysing spectrum	Frequency from tuner /Hz
1,43	0,70	357	353,6
1,61	0,62	318	316,6
1,63	0,61	315	312,8
1,65	0,61	313	308,3
1,67	0,60	311	304,8
1,69	0,59	308	300,1
1,70	0,59	295	296,5
1,72	0,58	293	292,3
1,74	0,57	287	288,7
1,76	0,57	284	286,2
1,78	0,56	279	280,3
1,80	0,56	277	277,6

The red values are with no extra valve slides, the green values are with the first valve slide and the blue values are with the third valve slide.

The results show the length of the trumpet for each measurement in m, 1 over the length and the frequency of the tone from both audacity with three significant figures and from a tuner with four significant figures.

Graph



The graph shows the length of the trumpet divided by 1 against the frequency with error bars for the length of the trumpet. The frequency is from the measurements with the tuner. The gradient of the slope shows 536.7. The frequency is inversely proportional to the length of the trumpet. The intercept is not 0.

Analysis

When we look at the graph we can see that the gradient is 536.7 which indicates the speed of sound is. This is not the correct number, we have to recalculate the gradient from the first harmonic to the third harmonic. We can do this with dividing the gradient by 3/2.

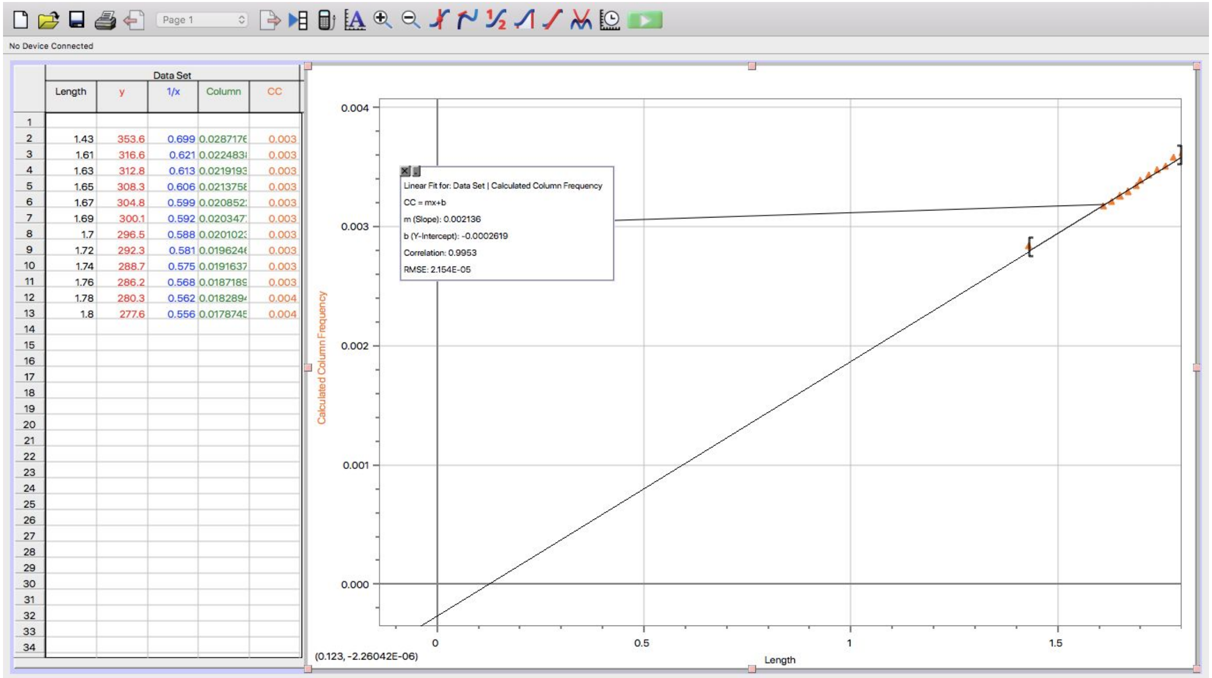
$$536.7\ m/s\ :\ 3/2\ = 357.8\ m/s$$

We can also see a different in the values when we use the first valve slide and the second valve slide. The six longest lengths I used the third valve slide and when we look at the graph we can see that the frequency values are slightly under the best fitted line. The five lengths I used with the first valve is on the graph placed slightly above the best fitted line.

Length in m ±1	Frequency from tuner /Hz	Frequency from calculation /Hz	Difference /Hz (Calculated frequency minus tuner frequency)
1,43	353,6	361,9	8,3
1,61	316,6	321,4	4,8
1,63	312,8	317,5	4,7
1,65	308,3	313,6	5,3
1,67	304,8	309,9	5,1
1,69	300,1	306,2	6,1
1,70	296,5	304,4	7,9
1,72	292,3	300,9	8,6
1,74	288,7	297,4	8,7
1,76	286,2	294	7,8
1,78	280,3	290,7	10,4
1,80	277,6	287,5	9,9

The red values are with no extra valve slides, the green values are with the first valve slide and the blue values are with the third valve slide.

When we look at the graph we can see that the intercept is not 0. If we put the length of the trumpet against 1 over the frequency we can see that the length of the trumpet is wrong with about 12 cm. The figure under shows the graph with the length of the trumpet against 1 over the frequency and we can see that the intercept isn't 0.



Conclusion

The goal of the experiment was to see if the relationship between the length and the frequency was inversely proportional and it was. When we look at these different values we can see that the values when I used the first valve slide was the most accurate ones. The gradient is also a bit higher than it should have been. This could have been because of the assumption of the speed of sound was lower than it was or because of damages.
I set the uncertainty of the length of the trumpet as 1 cm. However, when I look at error bars it seems like this was a bit exaggerated and they could have been shorter. When I looked

closer at the graph, I noticed that the intercept wasn't 0 and that according to my measurements the length of the trumpet is approximately 12 cm too long.

Evaluation

When I looked at the graph and noticed that the intercept isn't 0, I tried to figure out how. I figured out that the graph showed the trumpet was too long. The reason my intercept isn't 0 can be because I didn't think about end correction for the bell of the trumpet. The end correction is the additional length the instrument appears to have, so the errors make sense. However, it is still a bit too long. The additional length should be approximately 0.6r and the radius of the end is 6 cm, so the instrument should only appear 3.6 cm longer. This is still a big uncertainty.

Another thing which could be the reason for an error source can be the quality of the instrument. The bell in the trumpet is the part of the trumpet which isn't the best quality, so this could be the reason for the end correction not being right. Another thing could be myself and how I played. I would say I'm a pretty accurate source, considering I've been playing for more than 10 years and it doesn't sound completely wrong when I play together with other instruments, and that my playing wasn't the biggest reason for the results errors, but it can still have been one. The instrument could also have had damages I didn't see that could have affected the results like dents or dirt inside the instrument. I used a pretty standard mouthpiece but that could also have affected the result.

People have always told me that the first valve slide is more accurate than the third valve slide and in my experience, it's true. Technically, if you press down the third valve it should make the same results as with the first and second valve together. However, when I use the first and second valve instead of the third valve the tone is cleaner. This means that the points on the graph show the difference between first and third valve slide have a reasonable reason.

Discussion

If I were to do this experiment again I would probably have used other equipment to do the measurements with. I originally used Audacity. I recorded one tone for each measurement with audacity. I analyzed the spectrum to get the frequency, but the measurements were not accurate. Because it didn't really work so I ended up using a tuner with frequency measurement from my phone which showed four significant figures. This ended up working fine but I wished I could have found another measuring equipment were the waves were visualized. The reason I didn't do it with the second valve slide was because it is almost impossible to adjust because it's so small. I will also think about the end correction of the trumpet. The aim of the experiment was to see how the length of the trumpet affected the frequency. However, in my head it was so much more. I really wanted to see how the whole instrument was put together and how one part affected all the other part. I used different valve slides because I wanted to see if the first one actually was more accurate than the third valve slide and now I have "proved" with physics that it's true and that is pretty cool. And isn't that what physics is all about, figuring out how things work? This was a cool and good learning experience.

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