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Frequency of Sound Produced by a Straw Oboe

Aditya Garg[1] and Gyaneshwaran Gomathinayagam[2]

[1]High School Student, The Doon School, Dehradun
[2]Department of Physics, The Doon School, Dehradun
E-mail: [1]aditya.84.2020@doonschool.com, [2]gya@doonschool.com

Abstract—*A straw oboe is a simple drinking straw with one end cut into a wedge shape. The demonstration of how the straw oboe produces sounds of higher frequency when it is cut into smaller lengths intrigued me. The standard explanation is that the drinking straw is an air column open at both ends. So when the flaps vibrate, stationary sound waves are set in the air column that has resonant frequencies based on the length of the straw. However, when the sound frequencies produced by the straw were measured and compared with the expected resonant frequencies, they were found to be 15 times lower. This set me thinking as we conducted a thorough investigation by taking five trials for each length and measured the first four harmonic frequencies (using 'plot spectrum' feature of AUDACITY software) for 26 different lengths of the straw. The data provides comprehensive proof that the current accepted belief is wrong. The lower frequency can be explained by considering the sound to be produced by the vibration of the flaps in the wedge directly, and not by the stationary wave setup. The flaps vibrate at around 15 times lower frequency than the corresponding resonant frequency for the length of the straw. The 'correction factor', found to be 15 in our case, is expected to depend on the material properties of the flap-like the size, shape and stiffness of the flap.*

1. INTRODUCTION

The current theory found in textbooks and internet sources [1-5] state that the frequency of the sound produced by the vibrating straw should match with the resonant frequencies possible for stationary waves set in an air column of length equal to that of the straw, which is open at both ends. However, the preliminary investigation showed a considerable difference between the measured frequency and the frequency predicted by current theory. So, through this research, we want to establish a new and correct model to predict the frequencies of sound emitted by the straw oboe for different lengths. The research summarizes accurate data (measured sound frequency for each length for five different trials) over a wide range of the independent variable (26 different lengths of the straw).

2. LITERATURE REVIEW

A straw oboe vibrates due to the following reason. When air is blown into the reed-end of the straw oboe, a region high pressure is created inside our mouth. Air rushes into the straw as it the only region it is allowed to move. Now, we know that the only way air can speed up is by moving from a region of high pressure to a region of low pressure. This implies that, since the air is moving from our mouth (high-pressure) to the inner column of the straw, the inner column of the straw must be low-pressure. The pressure gradient surrounding the straw oboe (Stage 1) and the reeds are shown below.

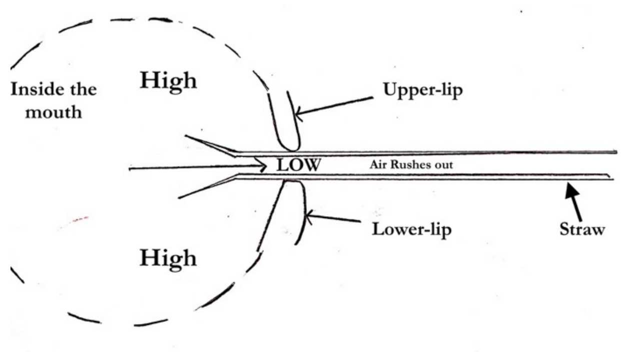

Figure 1: Demonstration of why reeds flutter (hand-drawn) (Stage 1)

The pressure between the two reed is lower than the atmospheric pressure. The high pressure outside pushes the reeds together, causing them to close.

Now, as the reeds close the airway, the pressure inside them gradually equalizes itself with the atmospheric pressure. This leads them to spring back to their initial position again. This causing the reeds to flutter (repeated opening and closing action).

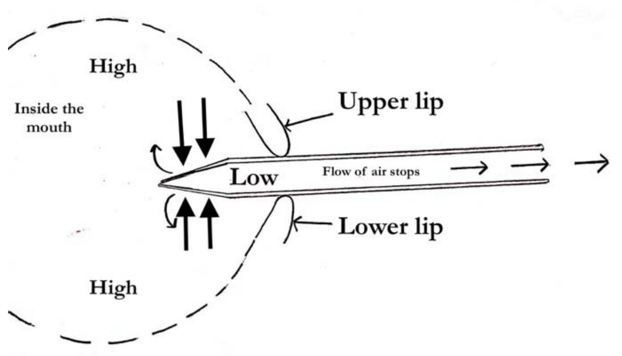

Figure 2: Demonstration of why reed flutter [Stage 2]

When this happens, air puffs created at regular intervals travel up and down, reflecting from both ends. During this process, a particular frequency of these vibrations (air puffs) is supported by the length of the air column. This particular frequency is termed as the resonant frequency, which depends on the length of the oboe. According to the current literature, this should also be equal to the frequency of the sound heard.

In order to determine the value of this resonant frequency, it was also determined that the straw oboe acts like a displacement antinode-antinode air column. This sets the condition, as the fundamental wavelength is twice the length of the air column:

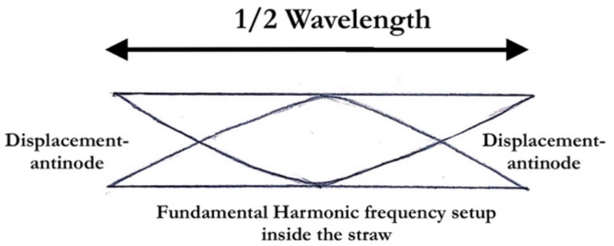

Figure 3: Diagrammatic (Hand-drawn) Depiction of fundamental harmonic setup inside the straw.

Since the length of our straw was 23cm (0.23m), the expected 1st harmonic wavelength was expected to be 0.56m, and the frequency of sound was expected to be 758.69Hz. (considering the speed of the sound to be $346ms^{-1}$ at 25 degrees Celsius). The expected frequency vs length of the straw graph would be produced as follows:

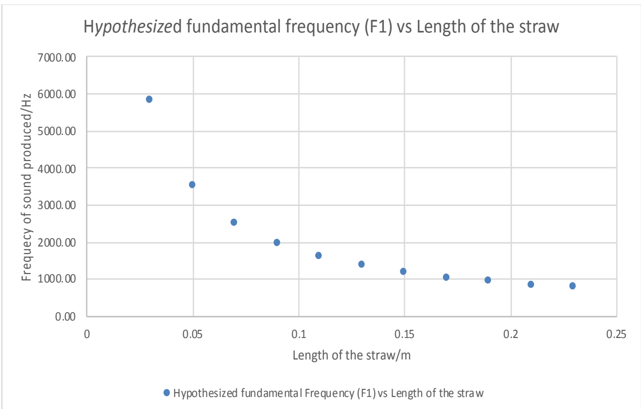

Figure 4: Frequency vs Length of straw relation as suggested by existing literature

3. METHODOLOGY

3.1 Preliminary Investigation

For the preliminary investigation, an ordinary 23cm long drinking straw was used. For each length, the air was blown into the straw three-times, and the distinctive 'buzzing' sound produced was recorded by a laptop's microphone. The sound recording was done inside a quiet room of the physics lab to minimize ambient noises. The same straw was snipped by 2cm each time until it was reduced to just 3cm.

Through this procedure, sound recordings for 11 different lengths of the straw were procured. Also, for each length, a total of 3 trials were conducted, so that a mean frequency approximation for each length could be produced.

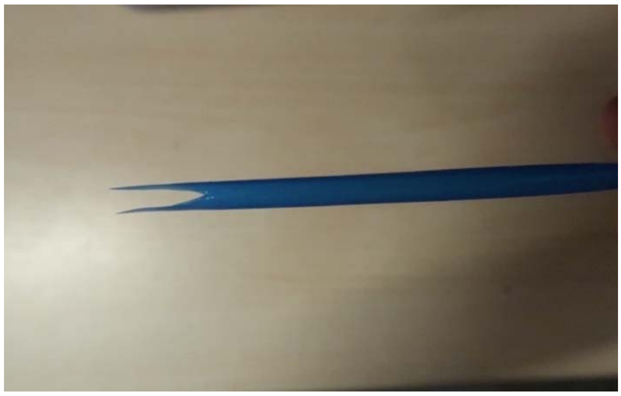

Figure 5: Straw used for preliminary investigation

3.1.1 Use of AUDACITY Software

Plot Spectrum feature of the AUDACITY Software was utilized to analyze the component frequencies of the 'buzzing' sound of the oboe. The peaks in the plot spectrum represented frequency harmonics.

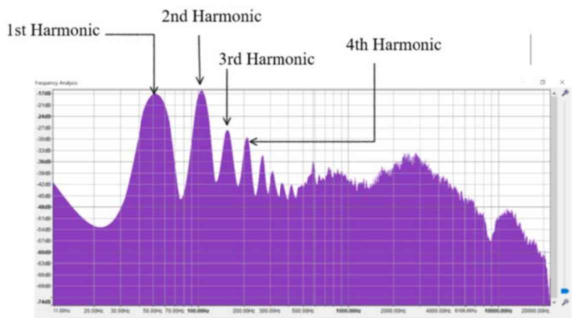

Figure 6: Screenshot of 'plot-spectrum' analysis in AUDACITY software

The experimental data in the preliminary investigation indicated the mean first harmonic frequency at 0.23cm to be 81Hz. This was very different from the fundamental frequency for first harmonic hypnotized for that length: 758.69Hz. It prompted me to explore the relationship in greater depth by collecting data for a broader range of the independent variable (length).

3.2 Final Data Collection

To increase the range of independent variable, a straw longer than 23cm was needed. After a quick market-search, we realized that straws longer than 23cm were not readily available. Still, to procure a longer straw, two identical straws were connected by sliding into one another (for a small length only) and by being fixed with a transparent cello tape. Doing this, the range of independent variable (length of straw) more than doubled (23cm to 53cm).

Figure 7: Straw used for the final data collection (52cm)

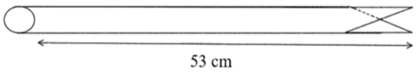

Figure 8: Diagrammatic representation of the straw

3.2.1 Important precautions and measures

- A mark was put on the reed-end of the straw to ensure that the distance between the point of contact of the lip to the straw and the fluttering portion of reeds remained controlled. The mark helped to ensure that the same length of straw was placed inside the mouth for each trial.
- For each of the trials, air was blown into the straw with the same force. Since the air was still blown through the mouth, subtle variation in forces was unavoidable. However, it should be noted that these subtle variations would not have a significant impact on the pitch, as the jump was only noticed above a significant increase in air pressure.
- A finger was placed on the father-edge of the straw as a support to keep the straw horizontal. This was done instead of holding the straw tightly from any one point. This prevented the unintended alteration of the air column in which the stationary wave was set.
- Finally, since slight variations in the frequencies of sound were noticed, even for the same length of the straw, the number of trials was increased from 3 to 5, in hope for a better mean approximation.
- Laptop's microphone settings for ambient noise reduction was enabled, so as to eliminate any possible background noise and disturbance which could provide faulty evidence in plot spectrum AUDACITY.

4. RESULTS AND DISCUSSION

Using the data collected from the final collection, (data for the first two harmonics can be accessed in the Appendix) the dependent variable (frequency) was plotted against the independent variable (length). As hypothesized, all four frequency harmonics increased with decrease in the length of the straw. The graph is shown below.

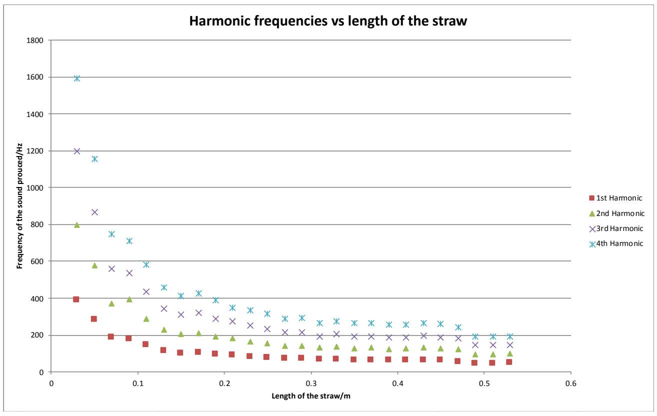

Figure 9:

However, when an attempt was made to compare the expected 1st Harmonic frequency, calculated using the speed of air as 349m/s (because the speed of air was 25^{O} Celsius), with the actual frequency, a mismatch was found again.

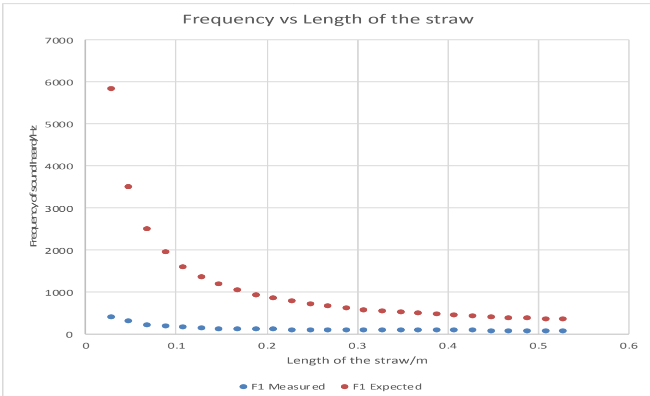

Figure 10: Comparing the measured 1st harmonic and the expected 1st harmonic.

So, to confirm the relationship between the measured frequency and the length of the straw, the graph was firstly linearized with the known hypnotized formula based on resonant frequencies

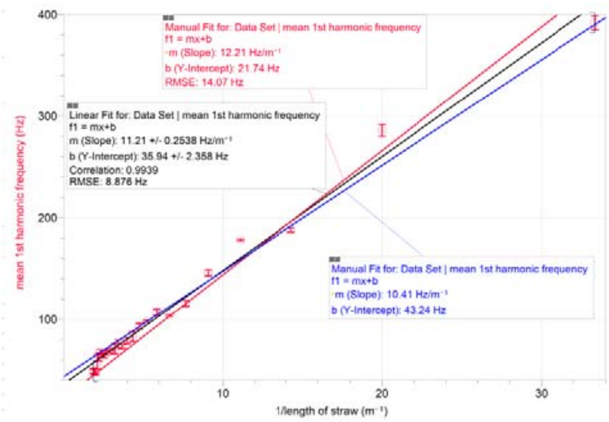

Figure 11: Mean 1st Harmonic vs 1/length of the straw.

As expected, it was a straight line, with a constant slope (v/2), passing through origin since:

$$f = \frac{v}{2} \times \frac{1}{l} \quad (1)$$

However, the value of the slope of the measured data was found to be lower than that of the expected value. The value of the slope, as can be seen in the graph above, had a value of 11.21, implying –

$$\frac{v}{2} = 11.21 \quad (2)$$

$$v = 22.41 m/s \quad (3)$$

This value was approximately 15 times lower than the actual speed of sound at the measured temperature of the air. The actual temperature of the air at 25^{O} Celsius, and thus the speed of air was 346m/s[1]. This revealed that the existing hypothesis failed to predict the correct frequencies.

Though an attempt was made to consult more literature on the subject, all the sources, including well-known physics textbooks (including IB Physics HL Textbook by Chris Hamper) provided explanations that were inconsistent with the data.

4.1 New Hypothesis

In order to explain the lower measured frequency, it is proposed that the frequency heard is the frequency of the fluttering of the reeds of the straw, and not of the stationary wave setup inside its air column. Through this explanation, it is possible to understand why the frequency of the sound measured is 15 times lower though still have a linear relationship with $1/lenght$. The fluttering reeds of the straw are not able to match the frequency of the stationary wave formed inside the air column due to their mass/inertia. Itis why when the reeds vibrate, they do so at a frequency which is 15 times lower. Thus the sound heard has the frequency 15 times lower than the expected resonant. It is reckoned that the value of this factor depends on the material of the straw and would remain a constant for all lengths for a given straw. The value of this factor, correction factor (m), could be calculated as follow:

$$m = \frac{f_{stationary\ wave}}{f_{measured}} \quad (4)$$

This value could be used to obtain the values for expected 1st harmonics of the sound heard for all lengths of the straw.

$$f_{pridicted} = \frac{f_{stationary\ wave}}{m} = \left(\frac{v}{2m}\right) \times \frac{1}{l} \quad (5)$$

The new hypothesis led to a new set of predicted frequencies. These predicted frequencies and measured frequencies are plotted on the same graph below.

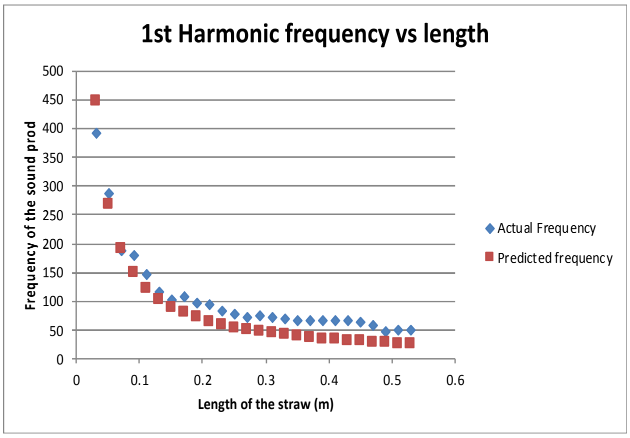

Figure 12: 1st Harmonic predicted and measured frequency vs length of the straw

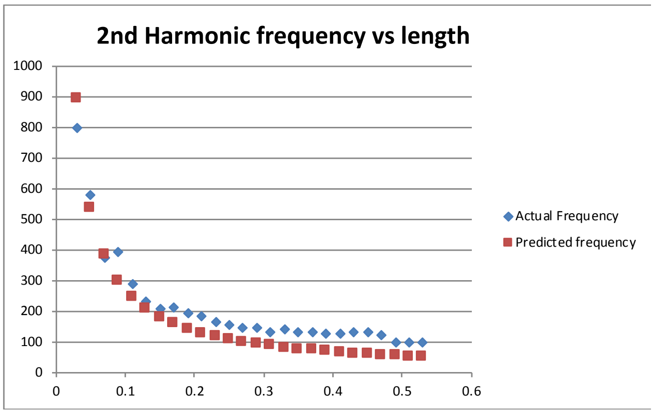

Figure 13: 2nd Harmonic predicted and measured frequency vs length of the straw

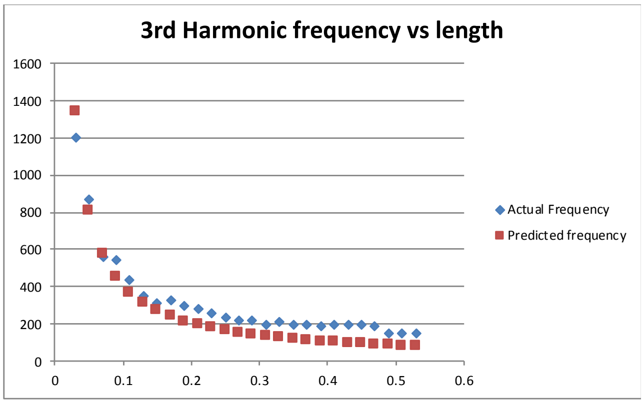

Figure 14: 3rd Harmonic predicted and measured frequency vs length of the straw

[1]https://www.weather.gov/epz/wxcalc_speedofsound

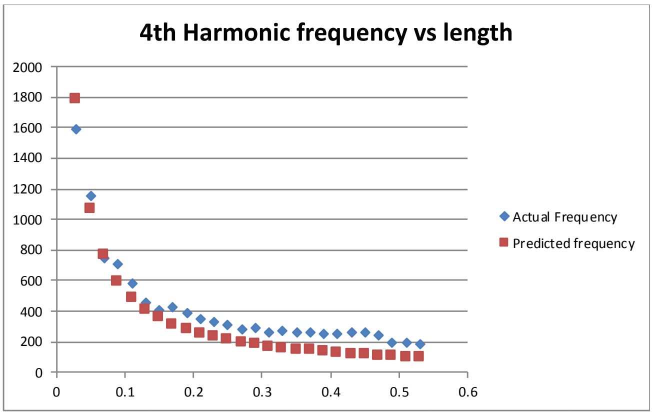

Figure 15: 4th Harmonic predicted and measured frequency vs length of the straw

As can see from the graphs above, the second hypothesis seemed to predict the frequency accurately. However, the overlap is still not perfect and could become the subject of future investigations.

4.2 Verification

In order to test the new hypothesis, a new experiment was such that the vibrating reeds of the straw could be captured on a high speed (high frame rate) camera. This was performed to confirm if the frequency of the sound being produced was the same as the frequency of the reeds vibrating. (a critical assumption in our new hypothesis).

A flat-bottom conical flask was taken. Two holes were made in a rubber cork that was fitted to the flask. (made airtight by a glue gun) Though one of the holes went the glass tube, while the other hole was used for the plastic straw. Now, air was blown into the conical flask through the glass tube. The air rushed out from the plastic straw, causing the reeds to vibrate.

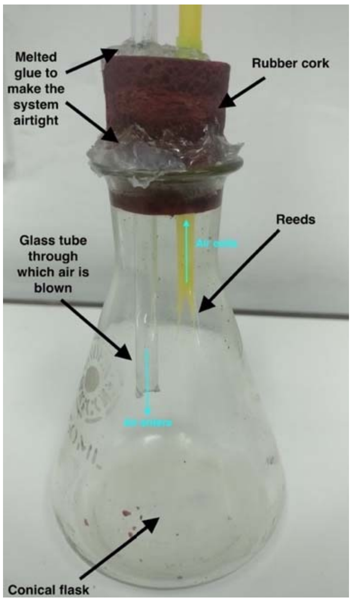

Figure 16: Apparatus for verifying new hypothesis.

The video was put into computer software called Tracker. The video was analysed frame by frame.

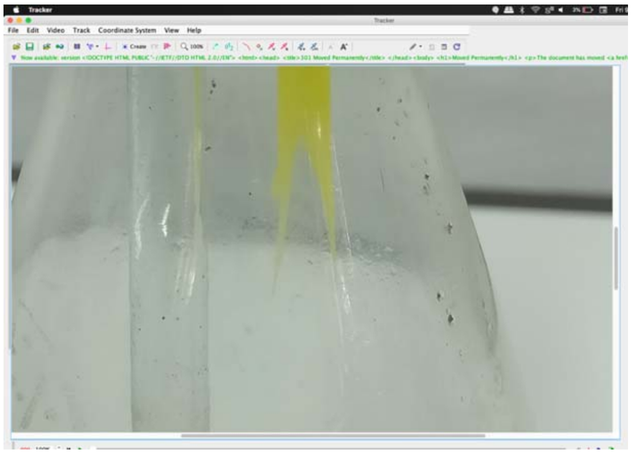

Figure 17: Screenshot from 'Tracker' Software during video analysis.

The frequency of the reeds (determined by tracker) was found to correspond the frequency of sound heard.

5. CONCLUSION

Following the verification of the new hypothesis, it can be concluded that the sound produced by blowing through the straw oboe matches the frequency of the vibrating flaps and not the stationary wave vibrations inside the straw. The sound produced by the stationary wave (predicted resonant frequency) is too weak to be heard and recorded separately. The frequency at which the reeds vibrate is exactly a numerical factor lower than the frequency of the stationary wave setup inside the air column. Our model proposes that the value of this factor that can determine the frequencies measured. It also proposes that the value of this factor depends upon its geometrical and physical properties of the reeds.

6. FURTHER INVESTIGATION

Since the frequencies predicted by the given model do not perfectly overlap with the measured frequency, the model can be improved by taking the overlap into consideration. Further investigations could factor the wear and tear of the fluttering reeds and could model the change in the correction factor as a function of the number of times air is blown into the straw. This factor would produce a dynamic value of the correction factor, instead of a constant, thereby, allowing a better prediction of the frequency of sound by the straw oboe, even when the same oboe is used again and again.

Furthermore, the geometrical and material properties (such as stiffness, mass etc.) can become the subject of another study, as we hypothesized that these are the factors affecting the value of the correction factor. Moreover, the correction factor can be modeled as a function of the length of the straw in future researches.

7. ACKNOWLEDGEMENT

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