The Doppler Effect

How does the Doppler Effect affect sound emitted from a source travelling in a circular motion?

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1 Introduction

As a hobby musician, I find the physics behind music and sound in general to be extremely fascinating. Upon discovering the Doppler Effect, I was intrigued by its possible effect on music, hence this report.

I will be analysing the effect of the Doppler Effect on a sound source undergoing circular motion.

2 Experiment Setup

Here's a little diagram of the experiment setup:

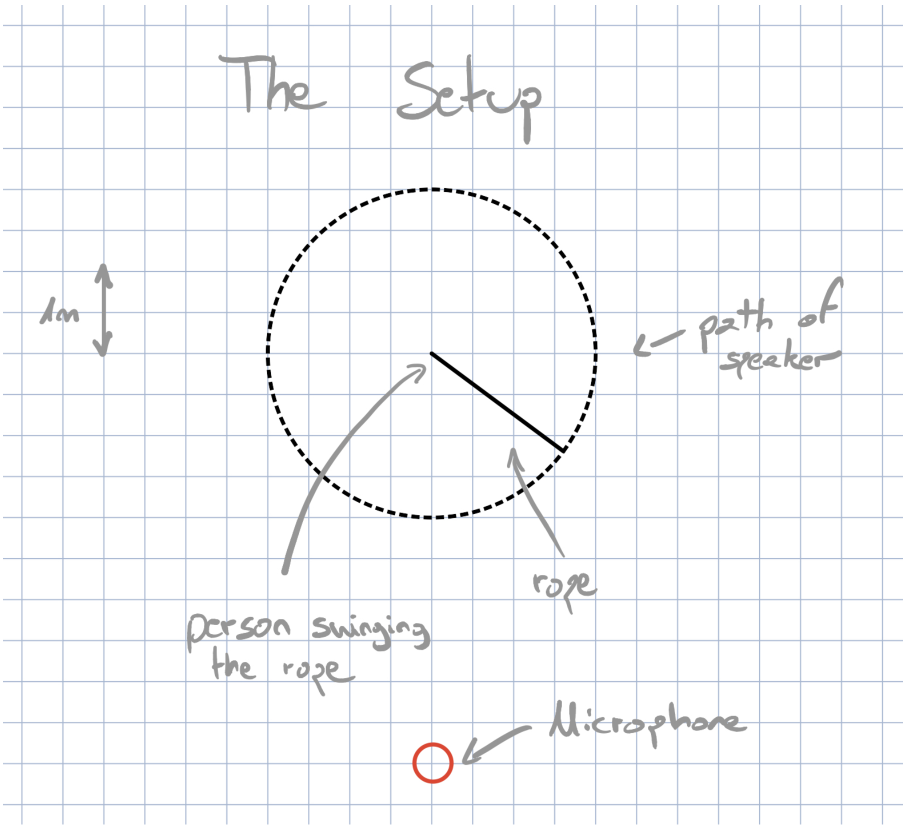

Figure 1: The setup of the experiment

A speaker is attached to the end of a rope of variable length. The rope is held by a person standing exactly 5 metres away from a microphone.

3 Predictions

This is the equation of the effect of the doppler effect on a sound emitted from a source traveling towards the observation point:

$$f' = \frac{v}{v - v'} f \tag{1}$$

v here is the speed of sound in air. Since the air temperature at the time of the experiment was 14.7 degrees celsius, the speed of sound in air is approximately $340ms^{-1}$. This gives the following:

$$f' = \frac{340ms^{-1}}{340ms^{-1} - v'} f \tag{2}$$

We also know the frequency of the wave since it was set at the beginning of the experiment: 300Hz. Thus we get the following:

$$f' = \frac{340ms^{-1}}{340ms^{-1} - v'} * 300Hz \tag{3}$$

Since the motion of our object is circular, some modifications have to be made. v' can be rewritten as follows:

$$v' = l * 2\pi\omega \tag{4}$$

- ω being the rotational frequency of the swinging motion and
- l being the length of the rope.

This is, however, only the maximum frequency. The minimum frequency would be the negative of the value.

Consequently, we get the following equation:

$$f' = \frac{340ms^{-1}}{340ms^{-1} - l * 2\pi\omega} * 300Hz \tag{5}$$

3.1 2 metre rope

- For the string at distance 2 metres, the following predictions can be made:

$$\begin{aligned} f' &= \frac{340ms^{-1}}{340ms^{-1} - l * 2\pi\omega} * 300Hz \\ &= \frac{340ms^{-1}}{340ms^{-1} - 2m * 2\pi\frac{4}{5}} * 300Hz \\ &= \frac{340ms^{-1}}{340ms^{-1} - 2m * 5.03} * 300Hz \\ &= \frac{340ms^{-1}}{340ms^{-1} - 10.06ms^{-1}} * 300Hz \\ &= \frac{340ms^{-1}}{329.94ms^{-1}} * 300Hz \\ &= 1.03 * 300Hz \\ &= 309Hz \end{aligned} \tag{6}$$

If we look at both figures 2 and 3, we can see that the maximum frequency is in fact around 309 - 310Hz, a surprisingly accurate result

3.2 3 metre rope

For a string of length 3 metres, we get the following:

$$\begin{aligned} f' &= \frac{340ms^{-1}}{340ms^{-1} - l * 2\pi\omega s^{-1}} * 300Hz \\ &= \frac{340ms^{-1}}{340ms^{-1} - 3m * 2\pi\frac{7}{5}s^{-1}} * 300Hz \\ &= \frac{340ms^{-1}}{340ms^{-1} - 3m * 8.80s^{-1}} * 300Hz \\ &= \frac{340ms^{-1}}{340ms^{-1} - 26.4ms^{-1}} * 300Hz \\ &= \frac{340ms^{-1}}{313.6ms^{-1}} * 300Hz \\ &= 1.08 * 300Hz \\ &= 324Hz \end{aligned} \tag{7}$$

4 Data

4.1 2 metre rope

Figures 2 and 3 plot the data points I collected when the radius of the string was 2 metres long.

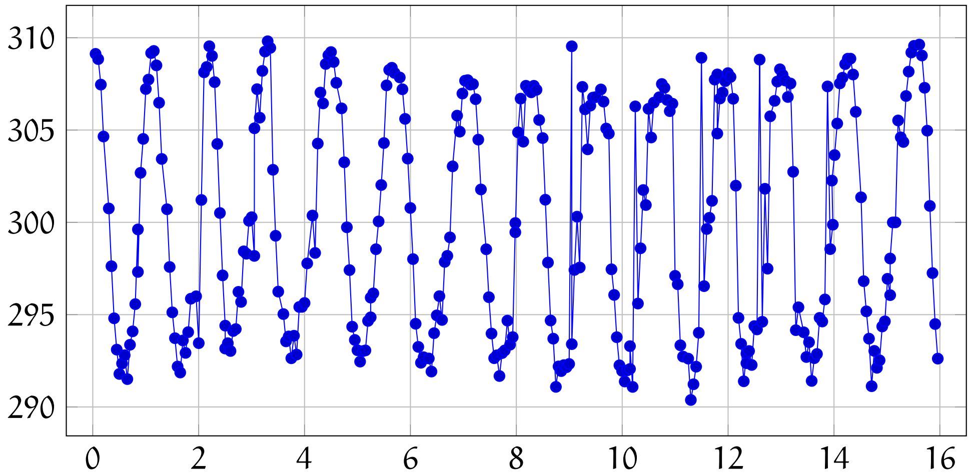

Figure 2: The variation of a 300Hz sound at radius 2m - 1st try

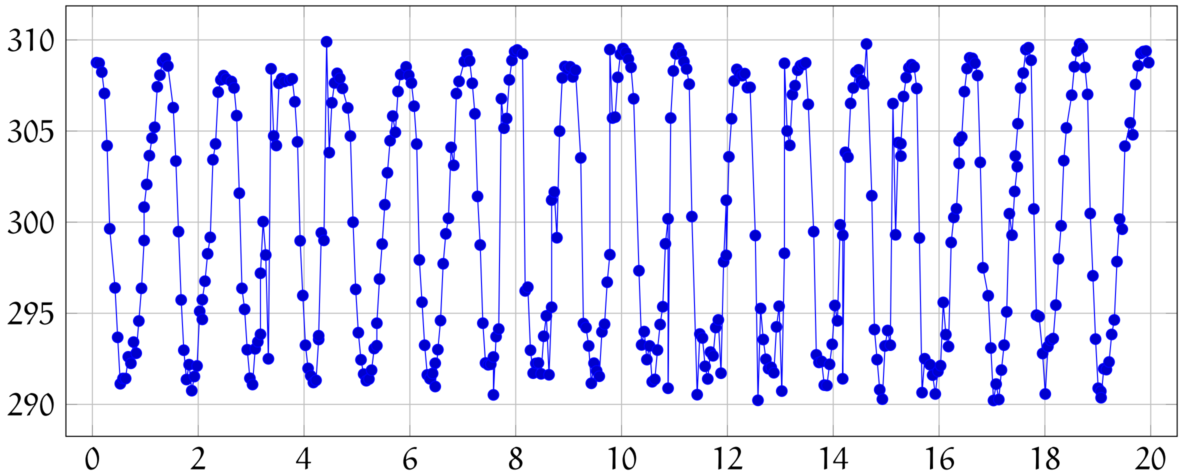

Figure 3: The variation of a 300Hz sound at radius 2m - 2nd try

4.2 3 metre rope

Figures 4, 5 and 6 plot the data points I collected when the radius of the string was 3 metres long.

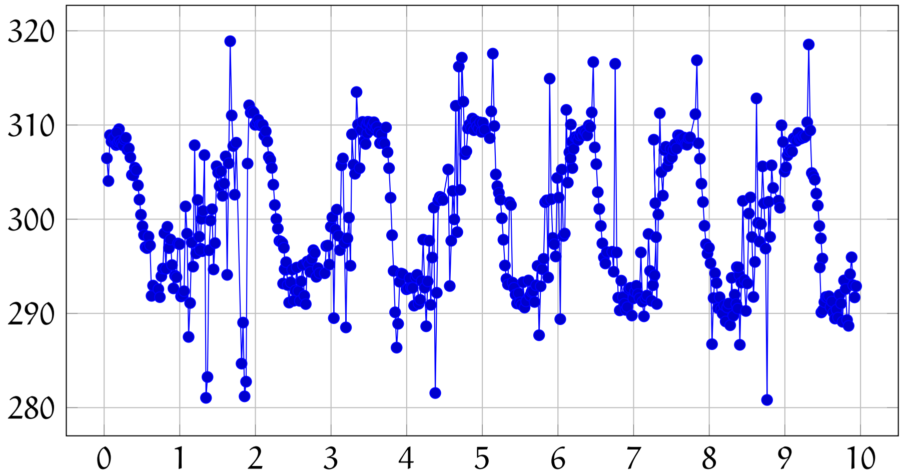

Figure 4: The variation of a 300Hz sound at radius 3m - 1st try

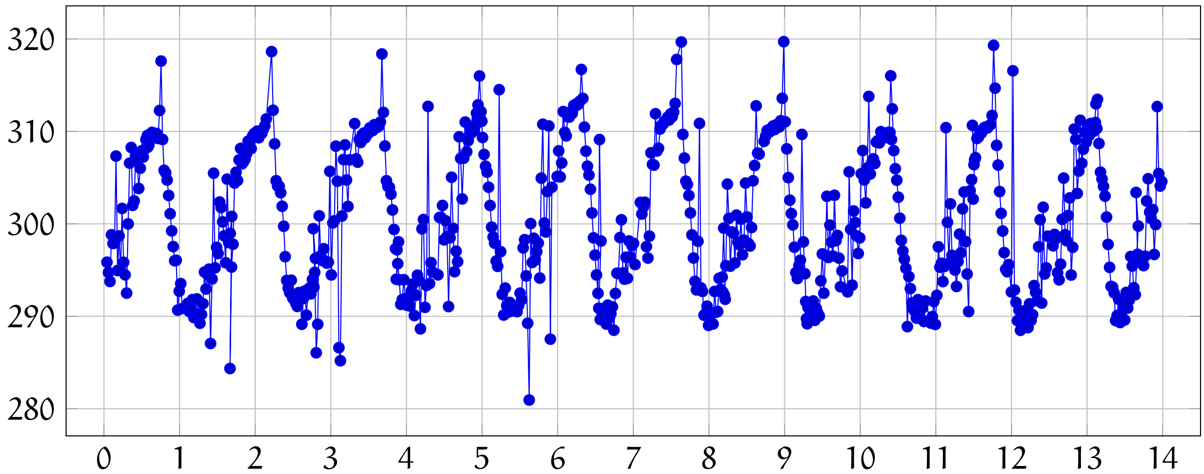

Figure 5: The variation of a 300Hz sound at radius 3m - 2nd try

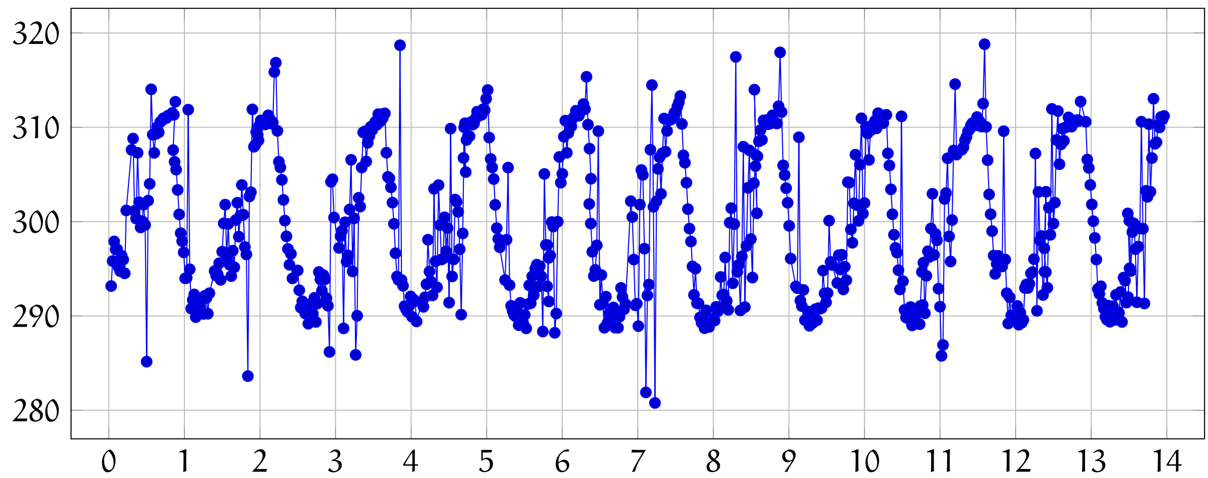

Figure 6: The variation of a 300Hz sound at radius 3m - 3rd try

5 Results

If we look at both figures 4, 5 and 6, we can see that the maximum frequency is in fact around 314Hz, which is quite far off the prediction of 324Hz.

6 Error Discussion

6.1 Error sources

There were a few potential sources of error during the experiment:

- High impact
  - The person swinging the rope may not hold their arm exactly in the same place during their swing. This would lead to the results being as if length of the rope was actually longer.
- Medium impact
  - Since the experiment was performed outside, temperature may fluctuate after initial measurement

    - The distances measured such as: the distance between the circle origin and the microphone not being exactly 5 metres

- Low impact
    - The measurement method of the air temperature (error margin of the thermometer)
    - The frequency output of the speaker may not be 100% accurate (error is low compared to other factors)
    - Error margin of the phone used to measure the frequency (error is also low compared to other factors)
    - Measurements were made 20 - 50 times per second; 100 times per second may be more accurate
- Other
    - Noise pollution from surroundings (primarily responsible for extreme outliers)

6.2 Improvement possibilities

Here are some realistically possible changes to improve on the experiment: - Instead of a human swinging the rope, use a spinning device (would be difficult to start the swinging motion though) - Hold the experiment further away from any noise pollution (such as an open field outside of the city) - Take measurements more frequently (100/s instead of 50/s)

7 Conclusion

tbd after feedback

8 References

The physics textbook

Online calculator for speed of sound in air: https://keisan.casio.com/exec/system/1258121716