Acoustic Metamaterials: Investigation of Extraordinary Transmission

Emmanuel Zeta
School of Physics and Astronomy
University of Nottingham

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Abstract

The aim of this experiment was to test the idea of extraordinary acoustic transmission through a variety of membranes and baffle sizes at specific frequencies. Due to time constraints only one membrane, made out Nitrile glove, was tested for. Another aim was to simulate this phenomenon with an electrical circuit. This idea was explored through the utilisation of Lock-in detection to record voltage data which represented the transmission of acoustic waves and electrical signals. Data acquisition was automated using MATLAB. An extraordinary transmission of 77% occurred near 830Hz when the membrane was stretched over a baffle with a hole of diameter 18.7mm. This phenomenon also occurred at near 1023 and 646Hz when the membrane was stretched over baffles, each with a hole diameter of 15.6mm and 11mm, resulting in transmissions of 65% and 88% respectively.

Contents

1 COVID-19 Statement

Due to the COVID-19 pandemic, my lab partner and I were unable to work together in person to minimise the chances of contracting COVID from each other. This, in turn, made our work flow much slower and has led to some inconveniences which has limited how much we could do. Even though we could not test this phenomena for other materials, we were still able to showcase and explore it in detail for one material.

2 Introduction

A metamaterial is one which is able to achieve effects which seem to defy the laws of physics which requires odd concepts such as negative density or negative compressibility to explain the phenomena [1]. There are many different types of acoustic metamaterials which can be potentially used for a variety of applications such as low-frequency noise reduction and energy tunneling [2]. One type of acoustic metamaterial is a membrane-type acoustic metamaterials (MAMs). Membrane-type acoustic metamaterials are thin pieces of a material which under certain conditions can allow for attenuation of sound [3] but can also for extraordinary transmission of sound waves. When an acoustic metamaterial has a negative dynamic mass density, the attenuation of sound occurs [4]. This occurs because there is an energy loss occurring when sound waves interact with the metamaterial. By minimising this energy loss, acoustic coupling is achievable, allowing for the extraordinary transmission sound waves. Extraordinary transmission at specific frequencies occur due to small subwavelength apertures in the chosen membrane which is a phenomenon based on its local resonances [5]. Interestingly even though this phenomenon was first shown for electromagnetic waves as demonstrated by Ebbesen et al [6], the same phenomenon for acoustic waves was also shown with even lower energy losses and higher transmission percentages [5]. It was proposed by Park et al that extraordinary transmission can occur by utilising a thin membrane to make the effective mass of the air column zero [7]. The membrane has a resonant frequency dependent on its geometry and the material it is made out of. When the membrane is subjected to vibrations equal to or similar to its resonant frequency, resonance occurs and therefore allows extraordinary transmission of the sound waves. A circular membrane attached to a rigid copper barrier was used for this experiment meaning that we can model the membrane as an idealised drumhead [8]. As a membrane can have an infinite number of normal modes, the focus of this experiment is on the fundamental mode ie, the mode which occurs at the lowest frequency. These simple concepts form the basis for the experiment outlined by this report. Through the utilisation of MATLAB and an experimental setup which will be described, this idea of extraordinary transmission has been discussed in this report.

3 Methodology

In order to showcase this idea of extraordinary transmission when a membrane is present within the tube, a data set which represents the transmission of sound waves through an empty tube and another data set which represented the corresponding phase first needed to be collected. Then another data set which represents the transmission of sound waves through the tube with a membrane under specific conditions also needed to be collected: in this case, a membrane stretched over a baffle with a hole of diameter 18.7mm, 15.6mm and 11mm. Finally a data set which represents the transmission of sound waves through the tube with just the baffles also needed to be collected. This was done through the use of the experimental setup shown by Figure 1.

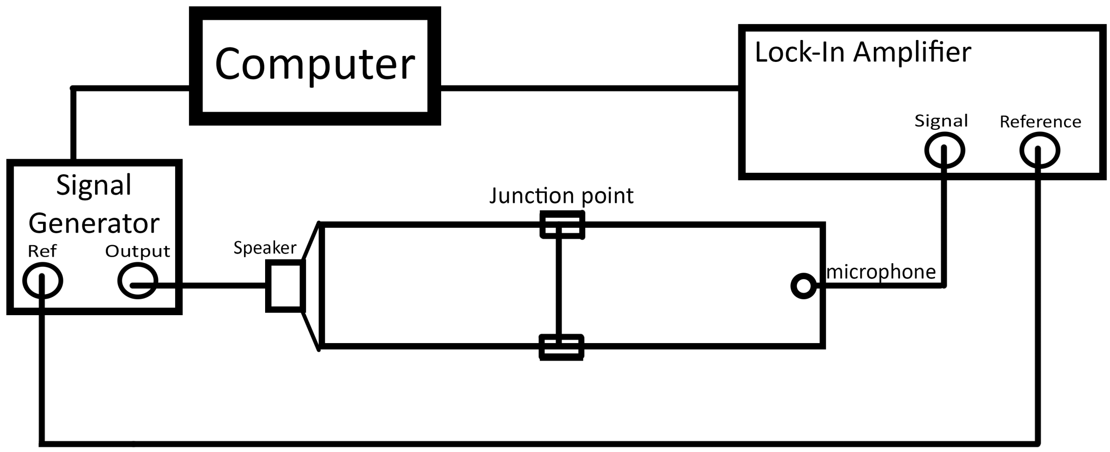

Figure 1: A diagram of the experimental setup which measures the transmission of sound waves.

A signal generator was used to generate sine waves of a frequency range of 100Hz to 2000Hz which was outputted through a speaker attached to one end of a tube of length 1m. Frequency was increased in steps of 9.5Hz allowing for 200 data points to be collected and each frequency was outputted for a 1.5 seconds at a time. These pulses of sound travelled through the tube and through the junction point where baffles could be placed. The junction point was made from a short tube of slightly larger diameter and a screw in clamp. It was constructed this way in order to allow a baffle to be placed in the junction but to acoustically seal the junction too. The sound waves then travelled through another 1m tube where a microphone was positioned. The microphone was placed in dampening material in order to acoustically seal the tube. The microphone detected the sound waves and converted the intensities into voltages which was stored by the computer. The signal generator was connected to a lock-in amplifier and was used as a reference signal which ensured that the microphone collected data for a specific frequency at a given time. The lock-in amplifier had its amplitude set to 1.352V, its time constant set to 0.333 seconds and itss sensitivity set to millivolts. This process was automated using MATLAB. Once data had been collected for the empty tube, a set of data which represented the transmission of sound waves through the tube with a membrane present and another set which represented the phase of the sound waves needed to be recorded. This was done by stretching a piece of Nitrile glove over a baffle with a hole of diameter 18.7mm. A copper rod was pressed into the baffle and a rubber band was used to keep the membrane as tight as possible without ripping it. The surface tension of the Nitrile glove then had to be measured first before placing it in the junction point so this was done by utilising a clamp stand, ball bearings and a travelling microscope. The boundary of the membrane was aligned with the scale on the travelling microscope as shown below in figure 2. Eight ball bearings, each of mass 4.1g were placed on the inner surface of the membrane in intervals, and the deflection of the outer surface was measured using the travelling microscope. The deflection of the outer surface of the membrane was then visible in the eye piece of the microscope as shown in Figure 2.

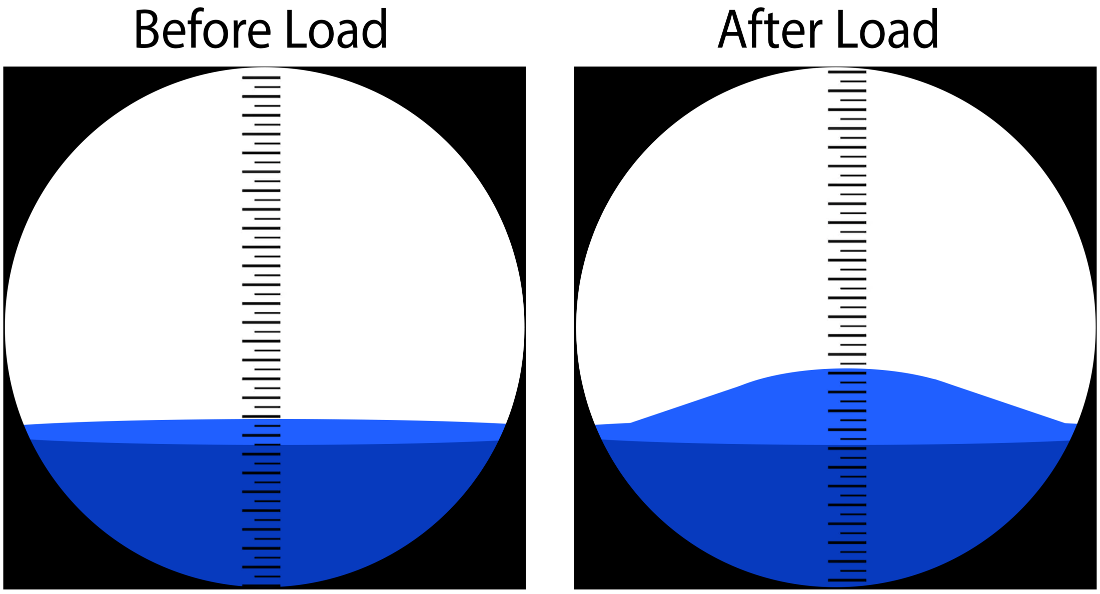

Figure 2: Diagram which show the alignment of the boundary of the membrane with the scale in the eyepiece.

Using these values, a Force-Displacement graph was created in MATLAB. The gradient and therefore the spring constant and its error was found using MATLAB's built-in curve fitting tool. The ball bearings were then removed from the baffle and the baffle with the membrane was placed at the junction point between the two tubes. The process for data collection mentioned before was used to collect data. The transmission data for the 18.7mm baffle and for the empty tube were then plotted on the same graph. This was to make it clear to see at which frequency the extraordinary transmission occurred. The data acquisition process for sound wave transmission was repeated but with a frequency range focused about this point of extraordinary transmission. Instead of collecting 200 pieces of data, 100 pieces of data was collected since this would have been enough to show give a smooth graph without being excessive. The membrane was then cut out of the baffle. The mass of the circular membrane piece was recorded and was used in combination with the spring constant found earlier to estimate a frequency at which the resonant frequency would be. This was done by modelling the membrane as a spring oscillating vertically. This works under the assumption that the force acts on the membrane on one point. This was done using the following equation:

$$\omega_0 = 2\pi f_0 = \sqrt{\frac{k}{(M_{air} + M_{membrane})}} \tag{1}$$

where ω_0 is the resonant angular frequency, f_0 is the resonant frequency, k is the spring constant, M_{air} is the mass of air and $M_{membrane}$ is the mass of the membrane. The mass of air was approximated to be 0 since the mass of the membrane had a much larger value and the equation was rearranged to make the resonant frequency the subject of the equation giving

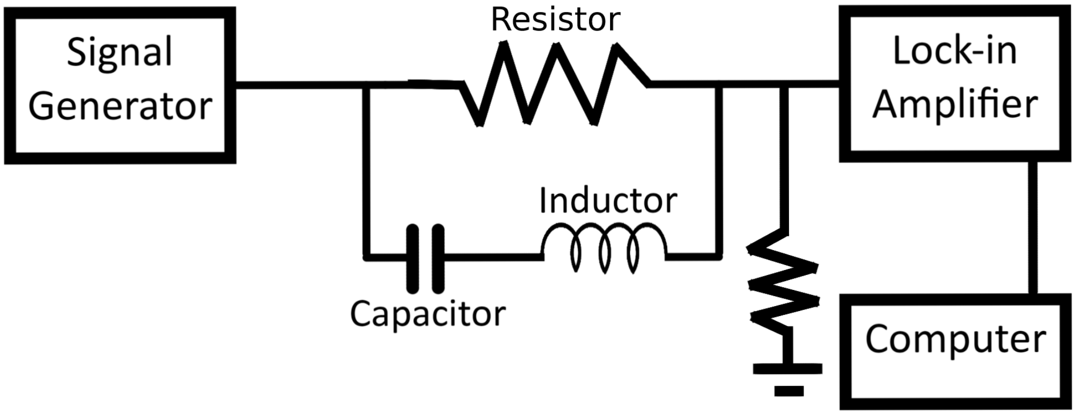

Figure 3: A diagram of the experimental setup for the electrical simulation.

the following equation:

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{k}{M_{membrane}}} \tag{2}$$

Error of the resonant frequency was determined using the standard error propagation equations. The membrane was then cut out of the rigid copper tube and was placed in the junction point of the experimental setup. Data was then collected for when just the baffle and copper rod was present using the same method outlined before with a frequency range of 100 to 2000Hz. This set of data was either plotted on its own graph with the empty tube data or with the graph with the data for the empty tube and for when the membrane was present. This was done because midway through conducting the experiment, some factor changed which we could not identify which caused the maximum amplitude for some of the data to be different. The data acquisition process outlined previously was then repeated for baffles with a hole of diameter 15.6mm and 11mm. For the 15.6mm baffle, 4.1g ball bearings were also used in order to calculate the spring constant however for the 11mm baffle, 1g ball bearings were used instead. This was done in order to prevent plastic deformation or ripping of the nitrile glove membrane but also because the 4.1g ball bearings were too big.

An electrical circuit was also constructed to simulate the phenomenon of extraordinary transmission occurring at a resonant frequency. In order to simulate the transmission of sound waves through an empty tube, a low ohm resistor was used. To simulate the transmission of sound waves through just the baffle, a high ohm resistor was used. Finally to simulate the transmission of sound waves through a membrane, the resistor-inductor combination was used. The data sets required to showcase the phenomenon of extraordinary transmission occurring at a resonant frequency was collected using the experimental setup shown in Figure 3.

Similarly to the Acoustic experiment, a signal generator was used to generate a signal however, the frequency range used was from 10Hz to 100,000Hz. This range was selected since it covered the entire range of the lock-in amplifier. To simulate the case for with the baffle with membrane stretched over it, the signal was passed through a parallel circuit with either the high ohm or low ohm resistor on one channel and a capacitor and inductor on the other channel. The capacitor had a capacitance of 0.1 μF and the inductor had an inductance of 0.1μH. The high ohm resistor had a resistance of 1MΩ and the low ohm resistor had a resistance of 47Ω. The capacitor and inductor combination represents the membrane, the high ohm resistor represents just the baffle and the low ohm resistor represents the empty tube. The signal was then passed through a lock-in amplifier where the transmission data sent to the computer and was recorded. This process was also repeated for each of the resistors, without the capacitor and inductor combination, to simulate the phenomenon for when just the baffle is present and for the empty tube.

4 Results

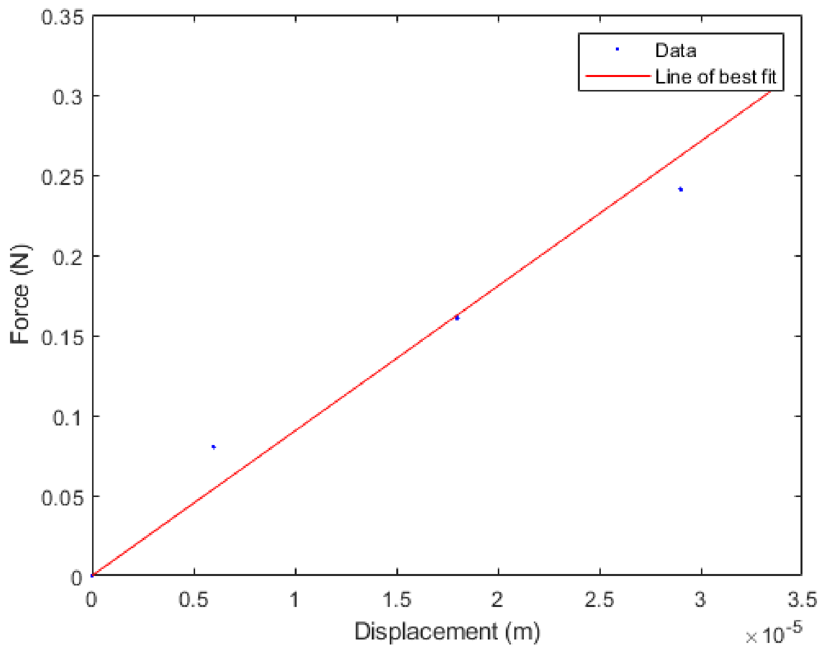

Figure 4: Force against Displacement graph for the membrane stretched over an 18.7mm baffle. The gradient and therefore the spring constant was found to be $(9.0 \pm 0.5) \times 10^3$N m^{-1}.

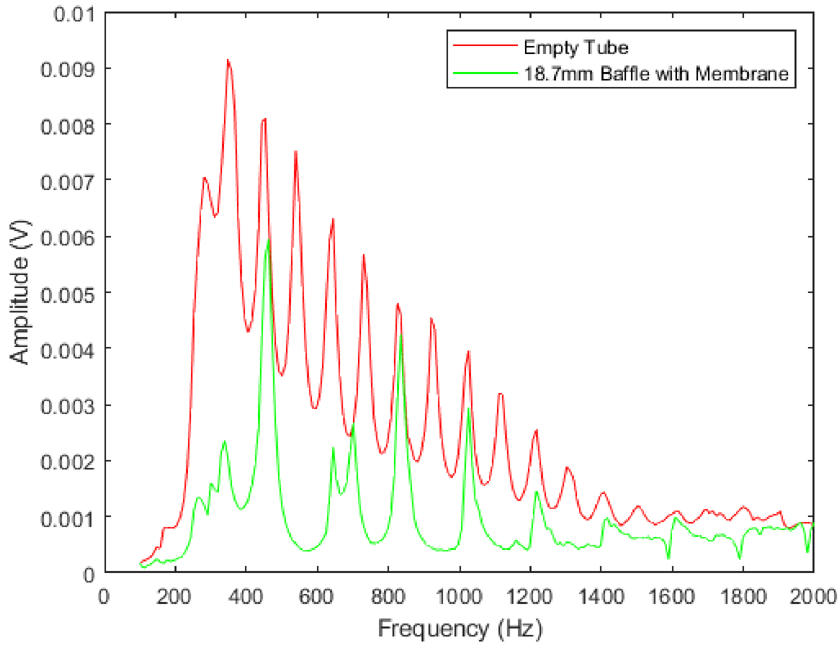

Figure 5: The transmission of sound waves across a frequency range of 100 to 2000Hz for the membrane stretched over a baffle with a hole of diameter 18.7mm. Extraordinary transmission occurs at the 800 to 950Hz range.

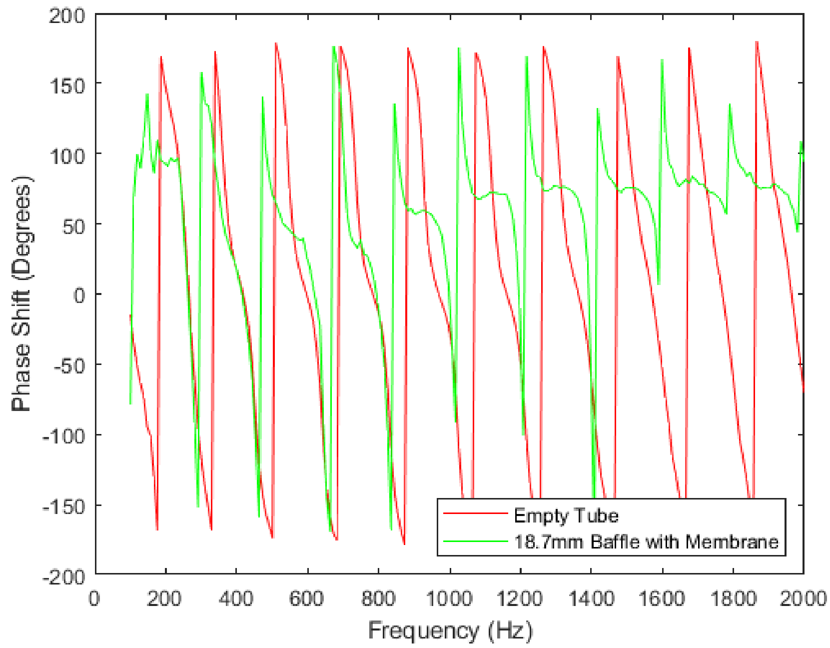

Figure 6: The corresponding phase of the sound waves across the 100 to 2000Hz frequency range for the membrane stretched over a baffle with a hole of diameter 18.7mm, compared to that for an empty tube.

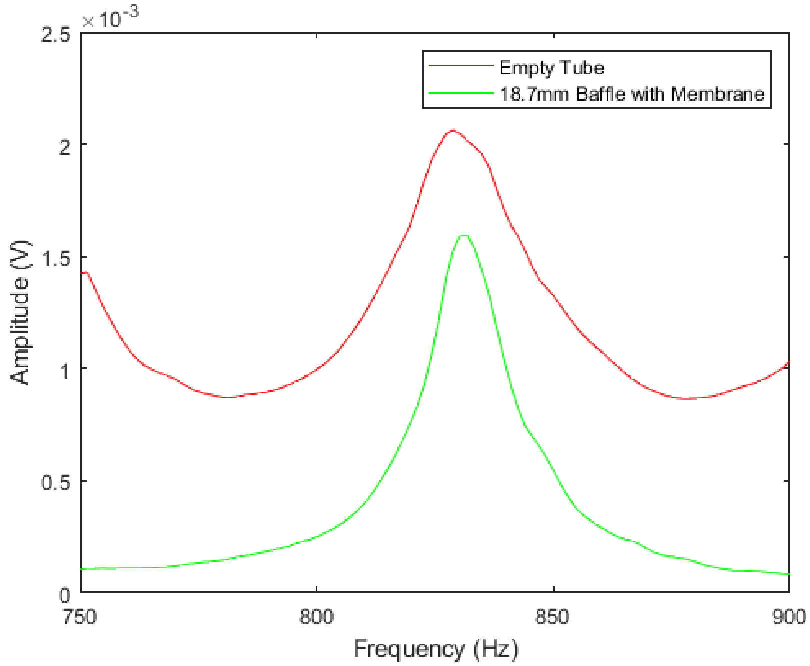

Figure 7: The transmission of sound waves across a frequency range of 750 to 900Hz for the membrane stretched over a baffle with a hole of diameter 18.7mm, compared to that for an empty tube. Extraordinary transmission occurs 830.3Hz.

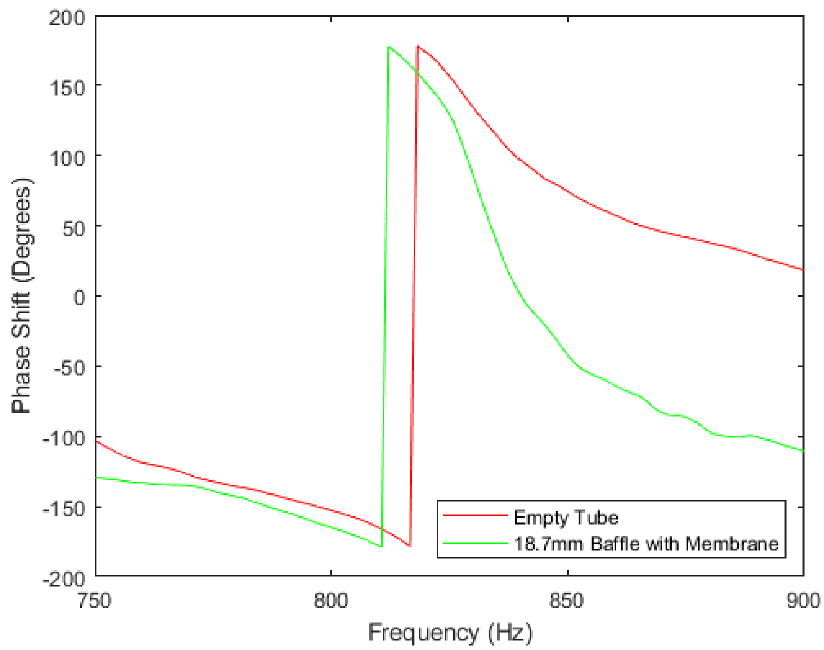

Figure 8: The corresponding phase of the sound waves across a frequency range of 750 to 950Hz for the membrane stretched over a baffle with a hole of diameter 18.7mm, compared to that for an empty tube.

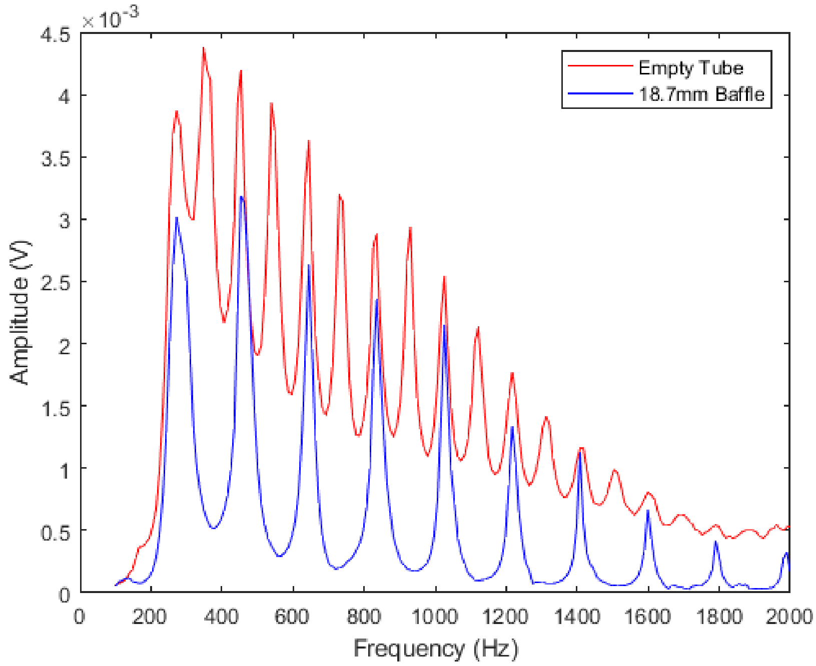

Figure 9: The transmission of sound waves across a frequency range of 100 to 2000Hz for just the baffle with a hole of diameter 18.7mm with the copper rod inserted, compared to that for an empty tube.

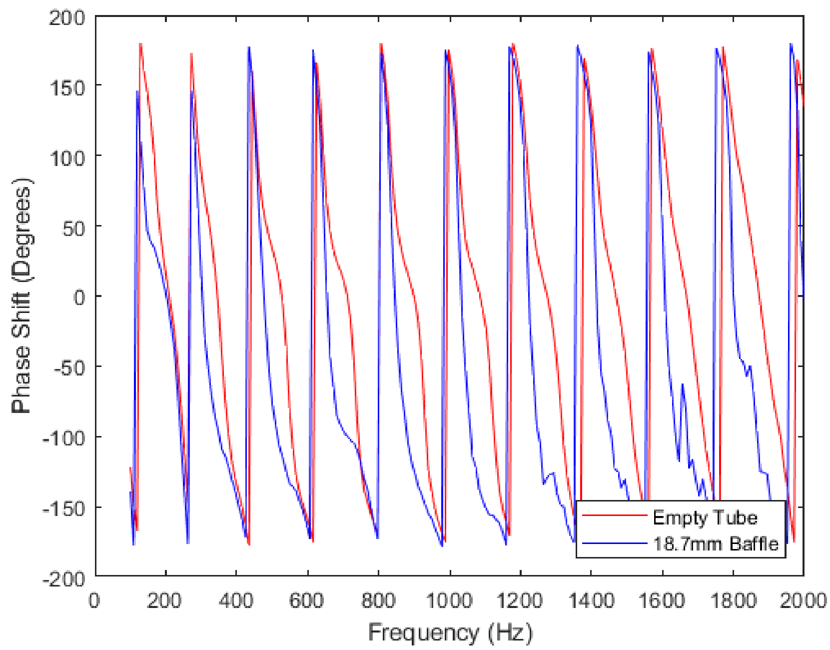

Figure 10: The corresponding phase of the sound waves across a frequency range of 100 to 2000Hz for just the baffle with a hole of diameter 18.7mm with a copper rod inserted, compared to that for an empty tube.

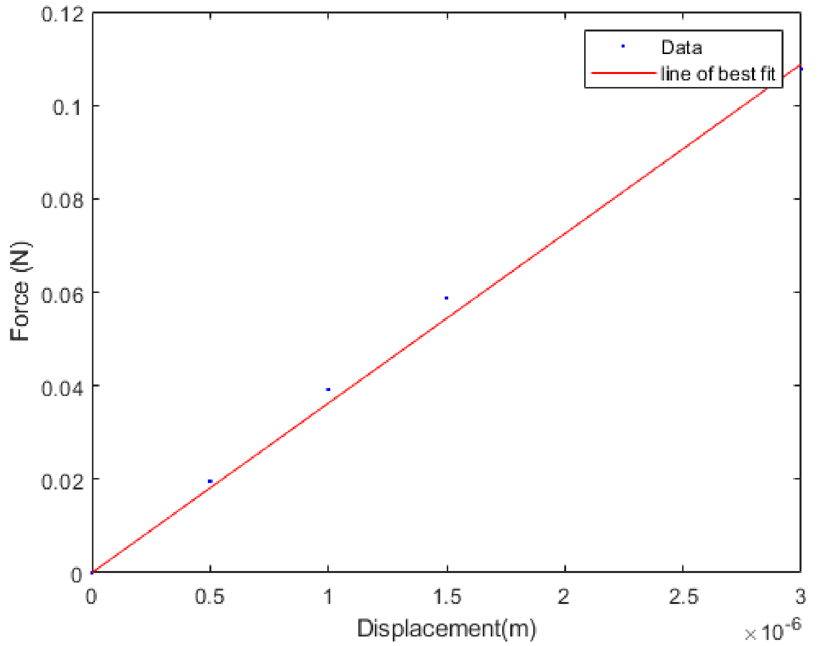

Figure 11: Force against Displacement graph for the nitrile glove membrane stretched over a 15.6mm baffle. The gradient and therefore the spring constant was found to be $(3.6 \pm 0.1) \times 10^4$N m^{-1}

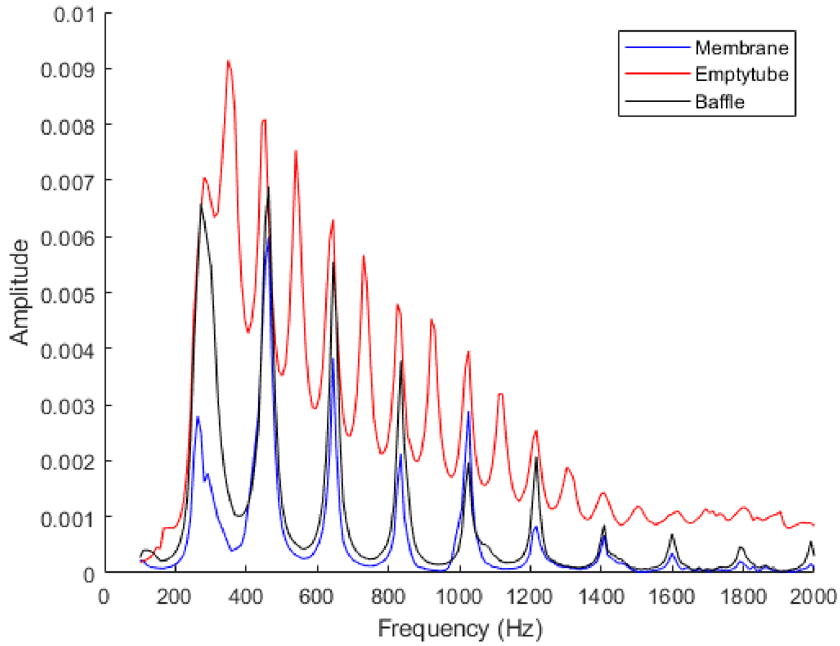

Figure 12: The transmission of sound waves across a frequency range of 100 to 2000Hz for the empty tube, the baffle with a hole of diameter 15.6mm and for the membrane stretched over the baffle hole. Extraordinary transmission occurs in the 900 to 1100Hz range.

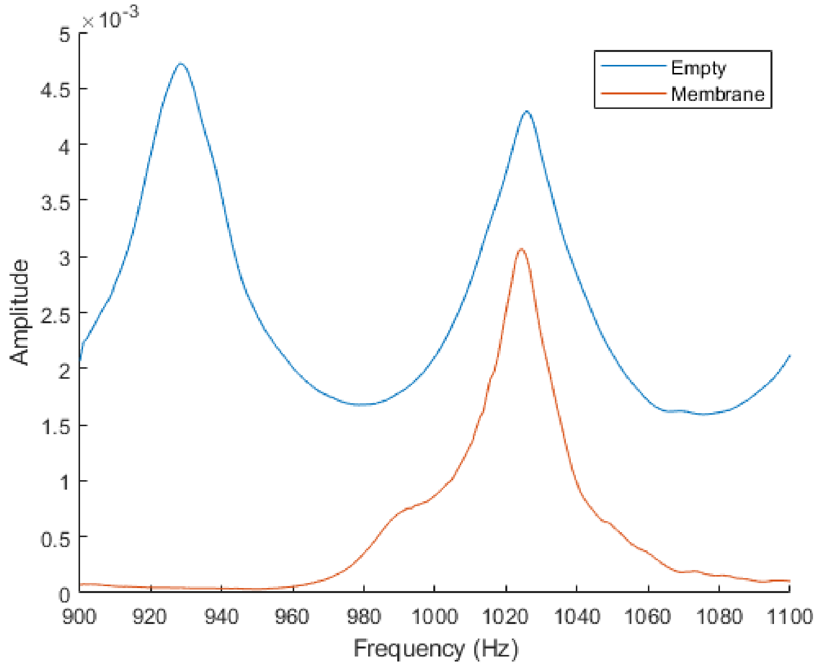

Figure 13: The transmission of sound waves across a frequency range of 900 to 1100Hz for the membrane stretched over a baffle with a hole of diameter 15.6mm, compared to that for just the baffle and for an empty tube. Extraordinary transmission occurs at 1023Hz

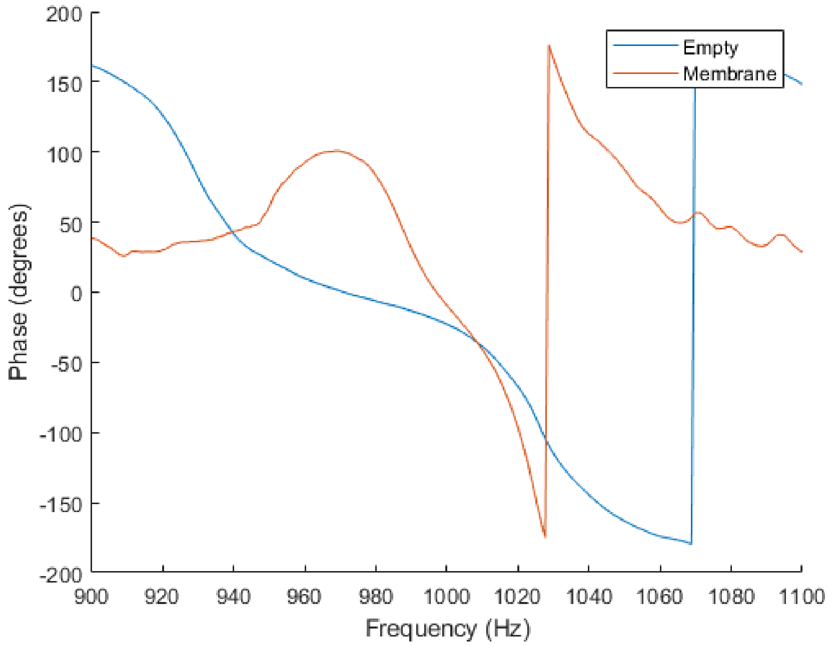

Figure 14: The corresponding phase of the sound waves across a frequency ranger of 950 to 1100Hz for the membrane stretched over a baffle with a hole of diameter 15.6mm, compared to that for an empty tube.

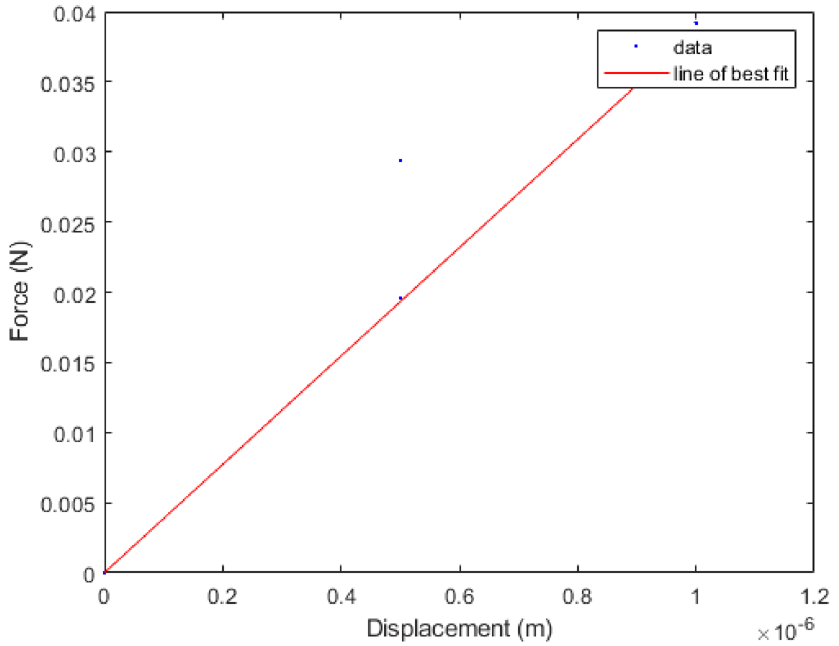

Figure 15: Force against Displacement graph for the nitrile glove membrane stretched over a baffle with a hole of diameter 11mm. The spring constant was found to be $(3.9 \pm 0.8) \times 10^4 \mathrm{N\,m^{-1}}$

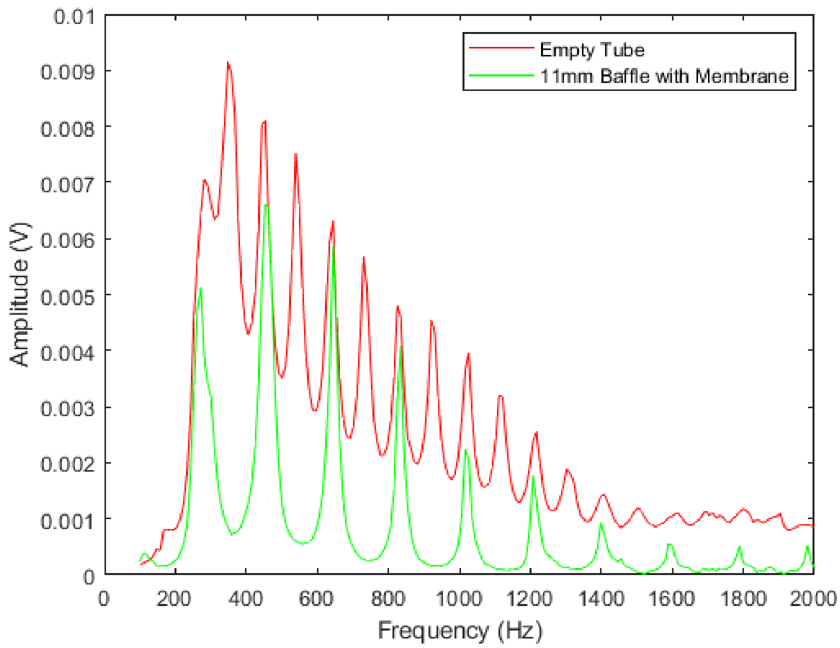

Figure 16: The transmission of sound waves across the 100 to 2000Hz frequency range for the membrane stretched over a baffle with a hole of diameter 11mm, compared to an empty tube. Extraordinary transmission seems to occur in the 600 to 700Hz and 800 to 900Hz ranges.

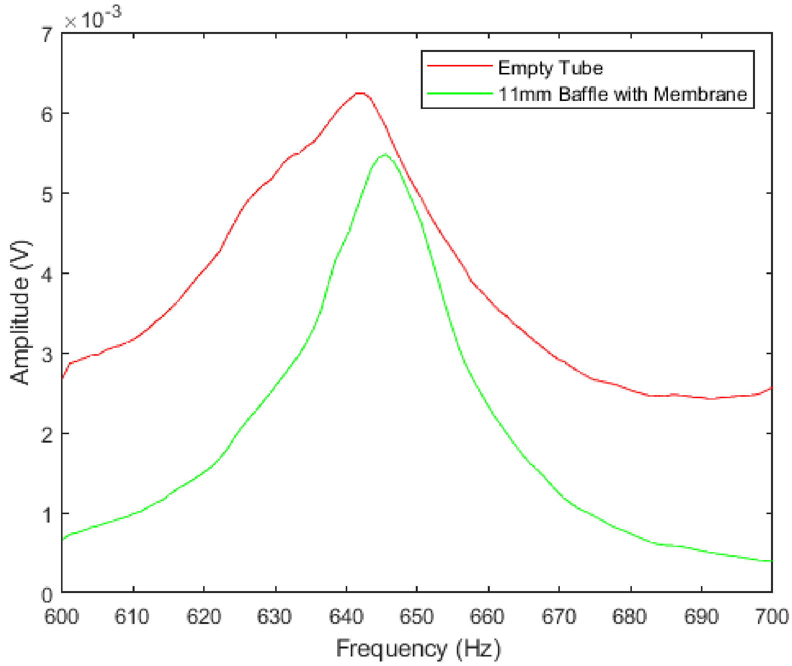

Figure 17: The transmission of sound waves across a frequency range of 600 to 700Hz for the membrane stretched over a baffle with a hole of diameter 11mm, compared to that for an empty tube. Extraordinary transmission occurs at 646Hz

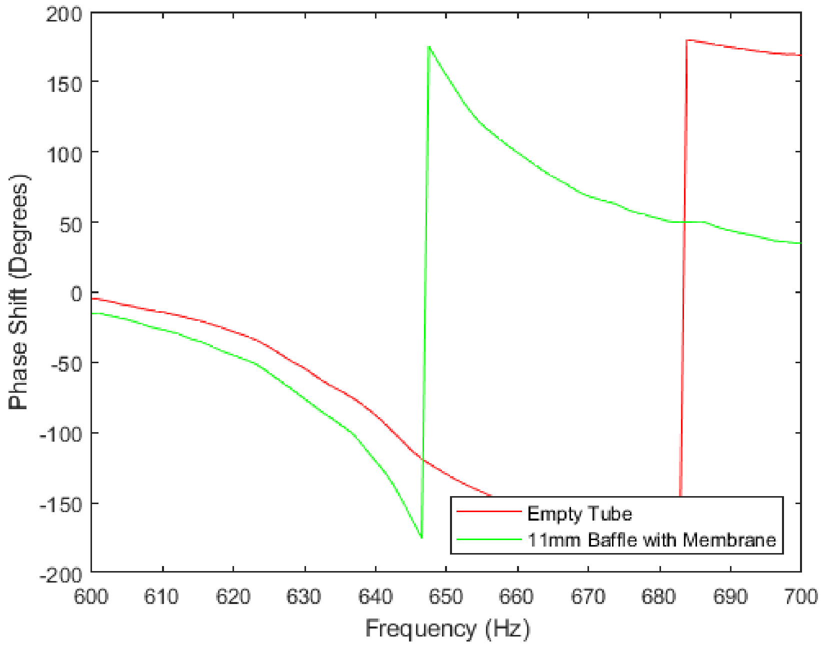

Figure 18: The corresponding phase of the sound waves across a frequency ranger of 600 to 700Hz for the membrane stretched over a baffle with a hole of diameter 11mm, compared to that for an empty tube.

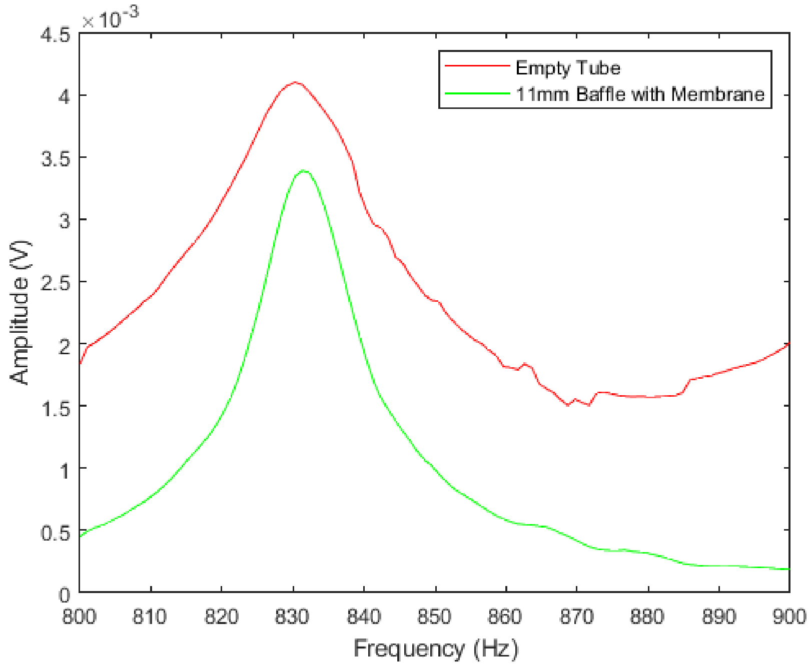

Figure 19: The transmission of sound waves across a frequency range of 800 to 900Hz for the membrane stretched over a baffle with a hole of diameter 11mm, compared to that for an empty tube. Extraordinary transmission occurs at 831Hz

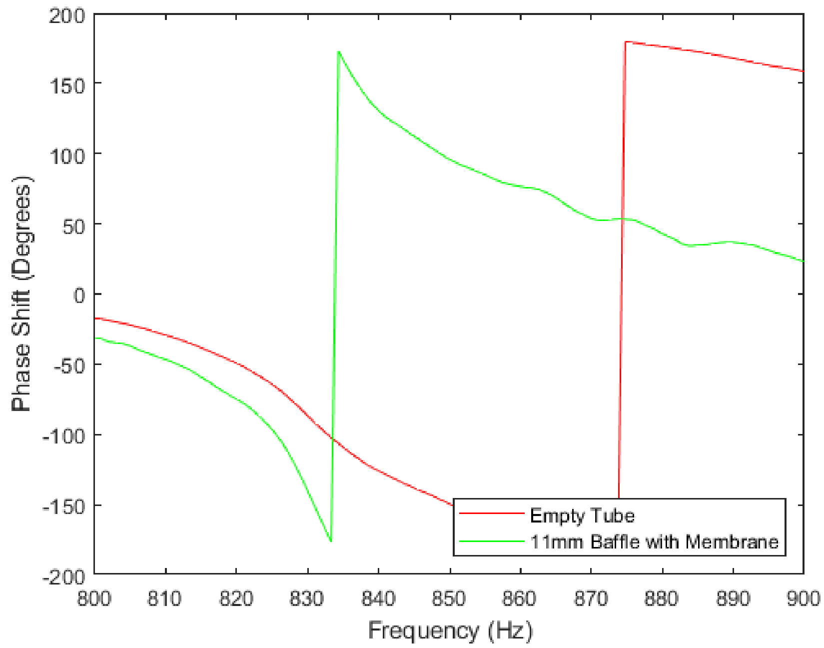

Figure 20: The corresponding phase of the sound waves across a frequency ranger of 800 to 900Hz for the membrane stretched over a baffle with a hole of diameter 11mm, compared to that for an empty tube.

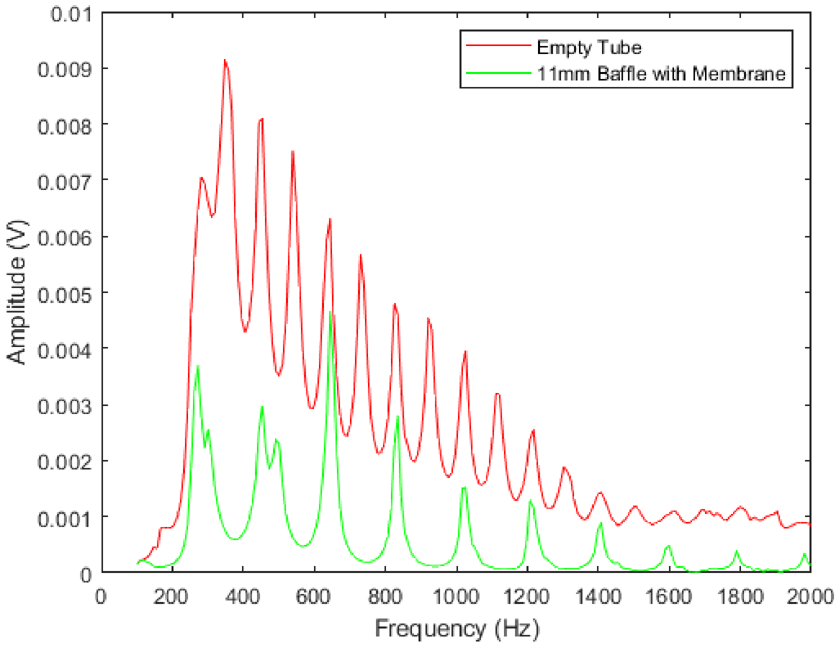

Figure 21: The transmission of sound waves across a frequency range of 100 to 2000Hz for the membrane stretched over a baffle with a hole of diameter 11mm, compared that for an empty tube. Extraordinary transmission occurs only at the 600 to 700Hz range.

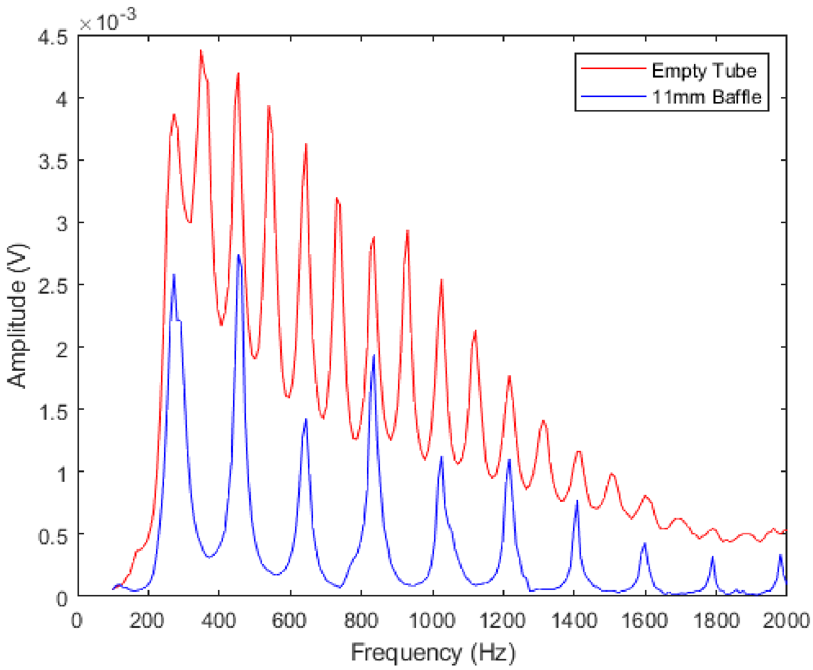

Figure 22: The transmission of sound waves across a frequency range of 100 to 2000Hz for just the baffle with a hole of diameter 11mm with the copper rod inserted, compared to that for an empty tube.

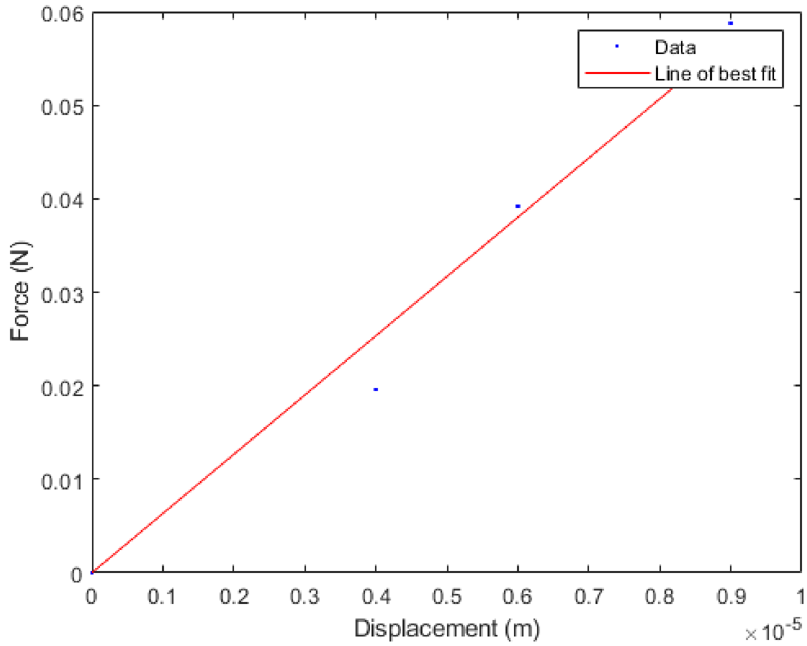

Figure 23: Force against Displacement graph for the nitrile glove membrane stretched over an 11mm baffle. The spring constant was found to be $(6.3 \pm 0.5) \times 10^3$N m^{-1}

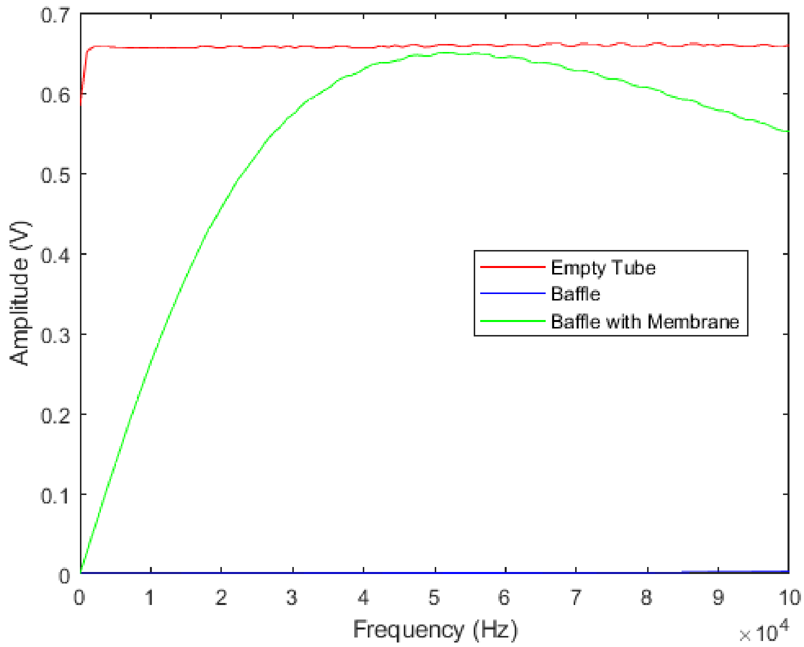

Figure 24: Voltage against frequency graph which showcases the transmission of signal for the electrical simulation.

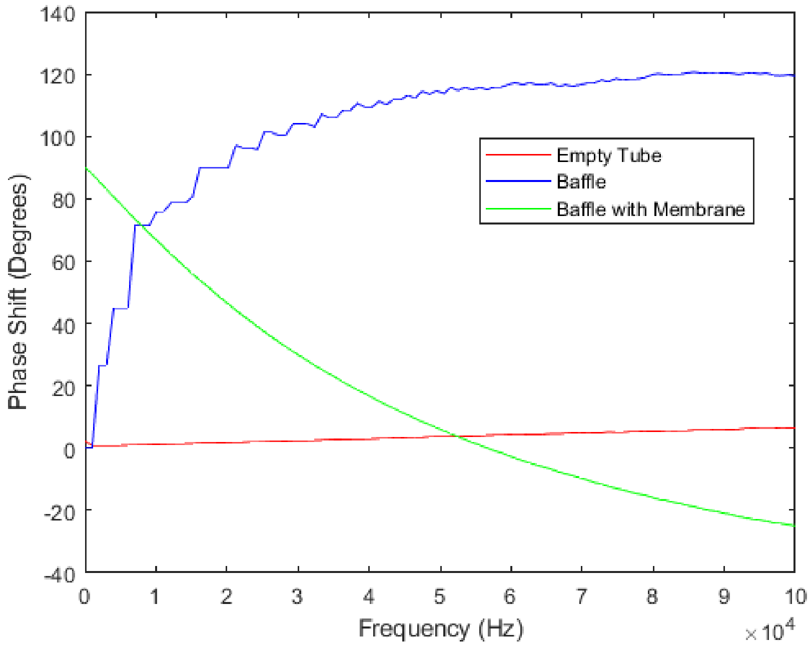

Figure 25: The corresponding phase of the signal for the transmission of signal for the electrical simulation.

5 Discussion of Results

The expected resonant frequency of the nitrile glove membrane stretched over a baffle with a hole of diameter 18.7mm was $(2.5 \pm 0.7) \times 10^3$Hz. The uncertainty is 28% of the actual value which suggests that it is somewhat of a precise measurement. This was calculated using (2) where the spring constant was found to be $k = (9.0 \pm 0.5) \times 10^3 \mathrm{N\,m^{-1}}$ as shown by figure 4 and the mass of the membrane was 0.038g. Figure 5 shows a resonant peak in the 800 to 950Hz range. This frequency range was zoomed in on as shown by figures 7 and 8. Extraordinary transmission occurs at 830Hz as seen in figure 5 meaning that the resonant frequency is near 830Hz. When examining the corresponding phase graph, figure 8, a change in phase from negative to positive does occur however, it occurs at a different frequency interval. This happened because the frequency at which extraordinary transmission occurs at is not necessarily equal to the resonant frequency but it shows that the resonant frequency is near this value. This means that when we zoom into the frequency range, it is likely that we missed the actual resonant frequency causing the phase to not line up with the transmission. Figures 9 and 10 show the transmission and corresponding phase of sound waves when just the baffle with a hole of diameter 18.7mm was placed in the junction point in comparison to the transmission of sound waves in an empty tube respectively. Figure 9 shows that by placing the baffle in the junction point, the difference in peaks changes from approx 100Hz to approx 200Hz. This happens because the length of the tube has effectively been cut in half. Figure 10 shows that the phase repeats at the same intervals but decreases at a faster rate for when the just the baffle is present in comparison to the empty tube. Furthermore, figure 9 show significant peaks throughout the frequency range which decreases in amplitude as frequency increases. Unfortunately, due to issues with the experimental setup, the maximum amplitudes of the transmission of sound waves for the empty tube in figures 5 and 9 were different meaning that transmission readings for the membrane and for just the baffle could not be plotted on the same graph since it would given off the impression that the amplitude of sound decreased much more than it actually did. Scaling of the data for just the baffle was attempted it then resulted in a graph which did not make sense because some areas had transmissions higher than for that for the empty tube. By examining comparing the trends in these graphs, it is obvious to see that the resonant frequency was near 830Hz. Interestingly, this value does not agree with the expected resonant frequency calculated however, extraordinary transmission did occur at 830Hz which suggests that the value for the expected resonant frequency was incorrect. Unfortunately, the value we found could not be compared to any secondary sources because the conditions at which this experiment was conducted was very specific however, it is safe to infer that the issue lies in the calculation of the expected resonant frequency rather than the found resonant frequency. It was decided to not include the phase plots for the 100 to 2000Hz frequency range for the other baffle sizes as it does not give much interesting information as it would not change much when the size of the hole of the baffle is changed.

The expected resonant frequency of the nitrile glove membrane stretched over a baffle with a hole of diameter 15.6mm was $(9.5 \pm 0.1) \times 10^3$Hz. The spring constant was determined to be $k = (3.6 \pm 0.1) \times 10^4 \mathrm{N\,m^{-1}}$ using figure 11, and the mass of the membrane was 0.010g. Figure 12 shows that there was extraordinary transmission in the 900 to 1100Hz range. This is because when comparing the transmission for the membrane to that for the baffle, this point was the only point where transmission was higher. This frequency range was zoomed into as shown in figures 13 and 14. It can be seen in figure 13that extraordinary transmission occurs at 1023Hz and therefore the resonant frequency is near this value. Similarly for the membrane stretched over an 18.7mm baffle, the found resonant frequency does not fall within range of the expected resonant frequency for the reasons disclosed previously.

The expected resonant frequency of the nitrile glove membrane stretched over a baffle with a hole of diameter 11mm was $(1.1 \pm 0.1) \times 10^4$Hz. Figure 15 shows that the spring constant was $k = (3.9 \pm 0.8) \times 10^4 \mathrm{N\,m^{-1}}$. The mass of the membrane was 0.019g. There seemed to be resonant frequencies at both the 600 to 700Hz and the 800 to 900Hz range as shown in figures 16. This was very odd as only one resonant peak was expected. These frequency ranges were zoomed into as shown in figures 17,18, 19 and 20. As you can see in figure 17, extraordinary transmission occurs at 646Hz. When looking at the corresponding phase graph, figure 18, you can see that this frequency is where the switch from negative phase to positive phase occurs. In figure 19, you can see significant transmission but at 831Hz. This is also due to a switch from negative to positive phase at the same frequency as shown in figure 20. The transmission of sound waves for when the membrane was present was closer to that for the empty tube at 646Hz than it was for 831Hz but the latter peak was convincing enough so data was recollected as shown by figure 21. Here, the extraordinary transmission occurs in the 600 to 700Hz range. The shape of this graph looks more like what was expected prior but clearly something had changed. The value for the spring constant was recalculated to give a value of $(6.3 \pm 0.5) \times 10^3 \mathrm{N\,m^{-1}}$. This is significantly lower than what was used initially which suggests that the tension of the membrane had decreased as the experiment ran. This could be for a number of reasons. An example of why this could have happened is due to the actual methodology of determining the spring constant; by applying a force and measuring the deflections, the membrane might have been stretched as time passed. Another reason is when we ran the main experiment, the membrane was vibrating which would have loosened it. With this new spring constant, the new expected resonant frequency of the nitrile glove was $(4.0 \pm 0.2) \times 10^3$Hz which is closer to the extraordinary transmission we found but is still very far away. Again this suggests that there was something wrong with our methodology for estimating the spring constant and therefore the expected resonant frequency. To further understand what was going on, we ran the experiment again but with just the 11mm baffle placed in the centre of the tube. Figure 22 shows the transmission of sound waves for when just the baffle. As mentioned before, the period has doubled because by placing the baffle at the junction point, the length of the tube had been effectively cut in half. Additionally, the peak in the 800 to 900Hz range is higher than for that in the range of 600 to 700Hz. This suggests that 646Hz is indeed the correct resonant frequency since when comparing the ratio of transmissions for just the baffle in figure 22 to that for membrane stretched over the baffle in figure 16, the transmission within the range of 600 to 700Hz increased dramatically. Again, the transmission for just the baffle in figure 22 was not plotted on the same graphs as figures 16 and 21 because the amplitudes for the empty tubes for each scenario were different and by plotting this data on the same graphs, it would give off the impression that the amplitude of sound decreased much more than it actually did. The found resonant frequency does not fall within the range of the expected resonant frequency for the reasons discussed before. We expected the found resonant frequency of the membrane stretched over the baffle with a hole of diameter 11mm to be higher than that of the membrane stretched over the 15.6mm and 18.7mm baffles but we found it to be lower. This was odd because in theory, the resonant frequency should have increased as the diameter of the hole on the baffle decreased. However, it can be seen in figure 23 that the spring constant is much lower meaning that the membrane was looser, $k = (6.3 \pm 0.5) \times 10^3$N m^{-1}, which explains the lower resonant frequency.

To improve this experiment, a better method for determining the spring constant and therefore the resonant frequency of the membrane is needed. When the bearings were placed on each membrane, the deflection did not cover the entirety of the surface. Since the diameter of the ball bearings was much smaller than the diameter of the membranes, the deflection values would not have been as accurate since the force would not have been acting directly in the middle of the membrane surface which allowed for multiple deflection points on the outside surface of the membrane. Even though the methodology of determining the spring constant and therefore the resonant frequencies was flawed, it was good enough to help keep a track of the tension of the membrane relatively. We were able to see that the tension of the membrane for the 11mm baffle at the end was lower than that for both the 18.7mm and 15.6mm baffle to explain the drop in the found resonant frequency. Furthermore, since the absolute values found for the spring constants were not accurate, the estimated expected resonant frequencies are not accurate too and therefore the values resonant frequencies found can not be compared to them. However, since extraordinary transmission did occur at specific frequencies depending on the baffle size, the phenomenon of extraordinary acoustic transmission has been demonstrated. One way the method for determining the spring constant can be improved is by using ball bearings which fit the baffle hole sizes better. This would mean that the force would be acting on one point and would create one deflection rather than make multiple deflections. The experiment could be further improved by creating a way of replacing the baffles without having to take apart the entire apparatus - maybe with some kind of sliding mechanism rather than having a junction point with a screw in clamp.

This phenomenon was further backed by the electric simulation which was also conducted. Figures 24 and 25 show the transmission of electrical signal the corresponding phase shift across the frequency range of 0 to 10000Hz. As can be seen in figure 24 extraordinary transmission occurs at approximately 5×10^4Hz. This is backed by figure 25 since the phase for the membrane overlaps with the phase for the empty tube at approximately 5×10^4Hz too. Due to time constraints, the region around 5×10^4Hz was not zoomed into. From figure 24, the resonant frequency was determined to be 52530Hz. This means that at around this value, the impedance of the resistor-inductor is lower thus allowing for near maximum transmission. For the simulation of the baffle with the membrane, the 47Ω resistor was used as the high ohm resistor by mistake and unfortunately due to time constraints could not be fixed. This means that the simulation was more similar to that for just a membrane in the tube rather than the membrane stretched over a baffle. However, the phenomenon of extraordinary transmission was still showcased so it is valid to an extent. If the right resistor was used, the resonant frequency would have been different.

6 Conclusions

Normally, we would expect transmission of acoustic waves to be dampened or reflected to an extent when an object is placed in the junction point of the tube but this experiment has showcased this phenomenon of Extraordinary transmission as specific frequencies. These specific frequencies depend on the tension of the membrane, the material the membrane is made out of and the geometry of the membrane. For this experiment, a circular membrane made out a piece of nitrile glove was used with varying tensions. When the membrane was stretched over a baffle with a hole of diameter 18.7mm with spring constant $k = (8.2 \pm 2.2) \times 10^3$N m^{-1}, extraordinary transmission occurred at 830Hz with a transmission of 77% whilst when the membrane was stretched over a baffle with a hole size of diameter 15.6mm with spring constant $k = (3.6 \pm 0.1) \times 10^4$N m^{-1}, extraordinary transmission occurred at 1023Hz with a transmission of 65%. Finally, when the membrane was stretched over a baffle with a hole of diameter 11mm with spring constant starting at $k = (3.9 \pm 1.8) \times 10^4$ N m^{-1}, but ending with $k = (6.7 \pm 2.2) \times 10^3$N m^{-1}, extraordinary transmission occurred at 646Hz with a transmission of 88%. This phenomenon is further backed by the electrical simulation which was conducted. Extraordinary transmission occurred at 52530Hz with a transmission of 98% which is near full transmission. This occurred because the impedance of the resistor-inductor combination was reduced thus allowing for near maximum transmission of signal. These results clearly show that extraordinary transmission of acoustic waves occur at specific frequencies when passed through a circular membrane. Whether these specific frequencies are the resonant frequencies of the membrane hasn't been proven as our expected resonant frequency values were incorrect however, it's clear to see that these results support the idea of extraordinary transmission at certain frequencies.

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