Bio-inspired Sound Absorbing Building Facades

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I. Introduction

Butterfly wings appear iridescent due to the nanoscale, teethed structures on their wings. Since the distance of the gaps between each protrusion are equal to the wavelength of certain frequencies of visible light, that particular color of light is diffused or absorbed. A similar concept could be applied to sound but at a macroscopic scale. Sound waves are considerable longer in wavelength than light waves, and correspond to lengths and dimensions of architectural features. In that way, a building facade or interior wall could be sound-absorbing just based on its inherent geometry rather than a material property or porosity.

1.1 Motivation

The motivation for our project comes from the need to design interesting, yet practical bio-inspired materials. Our main focus in this was in how we could apply nanostructures designed to reflect and refract light waves, to sound waves. The nanostructures we sought inspiration from also had specific lengths and parts that corresponded to certain wavelengths of light. If we could figure out a sample that would be able to absorb specific sound wavelengths, we would be able to revolutionize the architecture industry; specifically for buildings that have to filter out a lot of sound, such as airports and factories.

1.2 Bio-inspiration: Butterfly wing selective light absorption

The nanostructure of butterfly wings, particularly that of the *Morpho* species of butterfly, is such that it allows for a specific diffraction and absorption of certain light waves, which in turn, gives the butterfly wing iridescent properties. Although chemical components from the wing played a role in the displayed color, a significant factor in the displayed color was the physical nanostructure of the wing. The wing is comprised of periodical submicrometer structures, specifically described as arrays of vertically aligned net-like skeleton structures. Small changes in thickness, to an atomic scale, greatly influenced the color that was shown. In addition, in the *Papilio blumei* species of butterfly, the nanostructure consists of ridges and cross ribs that form frames, which create a pattern that is suitable for nonplanar specular reflection. With this specific nanostructure, the color shown greatly varied with the angle of incidence of light directed at the specimen. Using these biological nanostructures as a base for our design, we sought to translate this concept from a diffraction and absorption of light, to the absorption and reflection of sound.

1.3 Sound absorption and diffusion

There is already extensive research in the areas of sound absorption for soundproofing applications, sound diffusion for recording and other applications requiring high acoustic quality, and selective sound absorption as an application of geometry and number theory.

Acoustic absorption results in sound energy being removed from the system and instead, converted to heat or transmitted through matter. Flexible or porous materials, like foam, absorb sound very well. Acoustic anechoic chambers are closed spaces designed to maximize sound absorption by making the walls of absorptive materials like foam and with a geometry that re-directs any sound deflection.
Cite: https://en.wikipedia.org/wiki/Absorption_(acoustics)

Figure 1.1. Example anechoic chamber ("Absorpotion (acoustics)", 2017).

Acoustic diffusors re-direct the sound waves to change the sound quality, unlike acoustic absorbers, which remove sound energy from the system. They are often designed as a 1D or 2D matrix of protrusions and cavities along a flat, rigid surface, where the widths and the depths of the protrusions and cavities correspond to the half-wavelength of the desired sound frequency. Thus, acoustic absorbers are most effective at diffusing sound at specific frequencies. Depending on the complexity of the design, acoustic diffusers may be effective at diffusing sound at a limited range of frequencies. ("Diffusion (acoustics)", 2017)

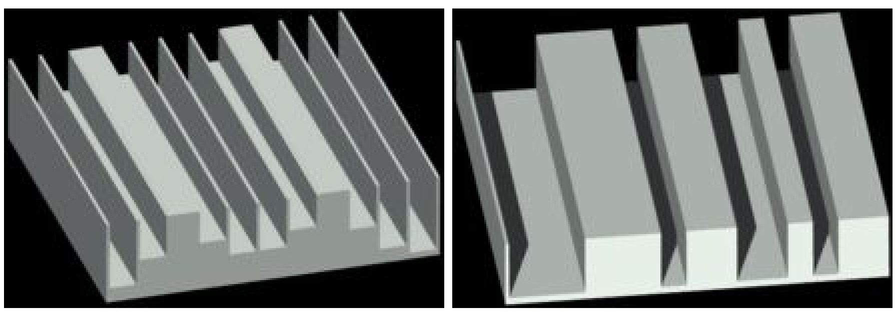

Figure 1.2: Examples of maximum length sequence (MLS) acoustic diffusor pattern [left] and Quadratic-residue acoustic diffusor pattern [right] ("Diffusion (acoustics)", 2017).

In addition, there has been some research in recent decades for engineering sound barrier walls for blocking highway traffic or construction noise. However, much of this research has focused on the macro-scale general shape (e.g. T-shape, Y-shape) or optimal height of such a barrier, rather than small-scale patterns on the surface of the sound barrier. According to the Federal Highway Authority, a sound absorbing barrier needs to be rigid and of a density of at least 20 kilograms per meter squared for it to effectively lower sound intensity across the barrier (Federal Highway Administration, 2017). Without any further attempts to optimize or improve efficiency of sound absorption, they instead design highway sound barrier walls with the main goal of material and cost reduction.

II. Methodology

2.1 Project design

We design and 3D print a hard plastic specimen whose dimensions correspond to a characteristic wavelength. We then test the acoustic diffraction and absorption effects of the designed sample by creating a soundproof testing chamber and projecting sound at the specimen and measure subsequent sound intensity.

2.1.1 Specimen design

We propose to scale the optic diffraction effects found in butterfly wings at the nano-scale up to a scale where the target frequency associated with the characteristic length of our sample is audible. We are also constrained by the manufacturing methods available for the scope of this project (3D printing). To this end, we choose 10 kHz as our target frequency both because it is an audible frequency, and because the length associated with this frequency (1.7 cm) is of a magnitude that can quickly and easily be constructed in a 3D printer.

We take direct inspiration from the nanostructure of *Morpho* butterfly wings, and design our structure with branches that approximate a sinusoidal curve, with a central "stem" cutting through. An image of the 3D model for our specimen is presented in **Figure 2.1.** We print several of these specimens from a hard plastic (VeroBlack) and arrange them in a plywood substrate by slotting each "stem" into a channel cut out from the wood. The final specimen arrangement is presented in **Figure 2.2.**

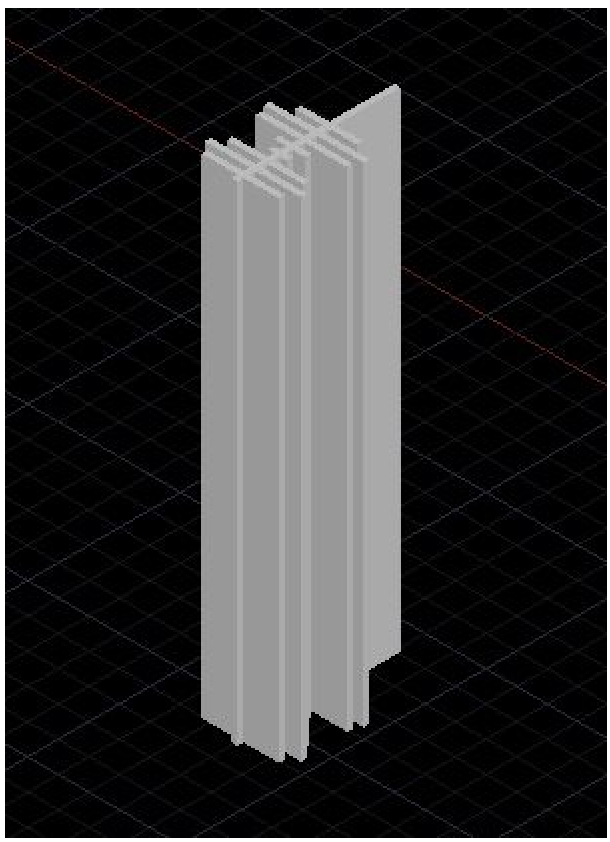

Figure 2.1. CAD model of Specimen.

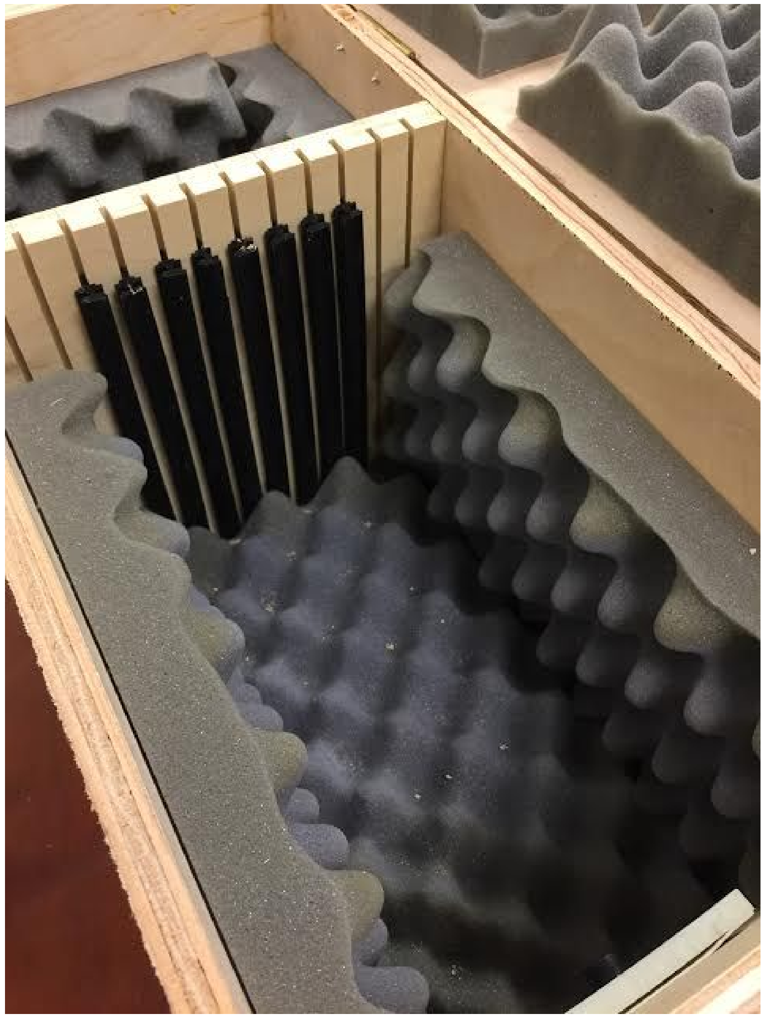

Figure 2.2. Specimens arranged in wood substrate.

2.1.2 Acoustic testing chamber

In order to effectively test the diffraction and absorption capabilities of our specimen, we construct a table-top testing chamber from plywood box lined with egg crate foam as sound insulation. We drill 1″ and 17/16″ holes in the top of the box as locations for the microphone to collect sound data, and 1/8″ holes in the side for the speaker wiring to go through. We designate two separate positions for the microphones receiving sound in order to test for diffraction and absorption effects. A CAD model of our chamber design is presented in **Figure 2.3.**

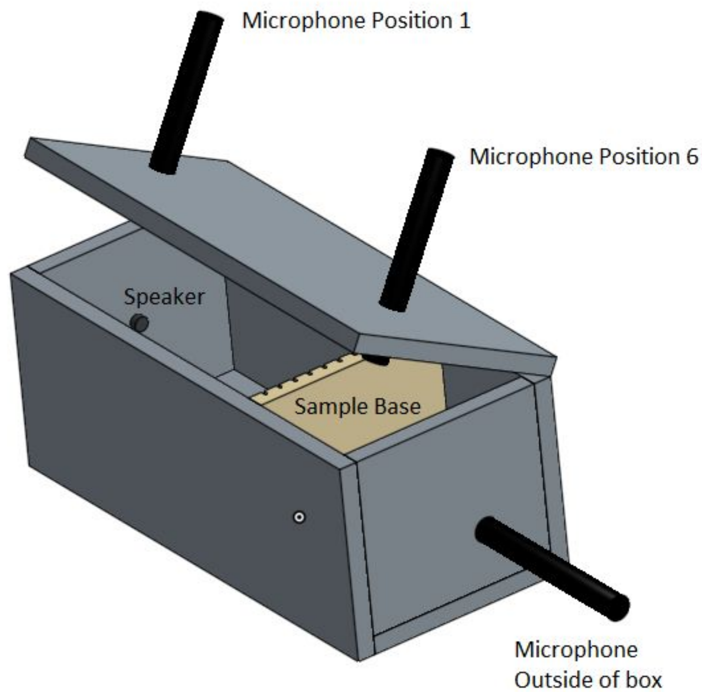

Figure 2.3: 3D CAD model of the texting box (without the foam)

2.2 Experimental setup

In order to run our experiment, we design a system that transmits sound into the box and then receives the diffracted sound to compare intensity.

2.2.1 Experiment

The experiment was run five times per frequency (2 kHz, 6kHz, 8kHz, 10kHz, and 12 kHz), per condition (control, foam and sample), and for each combination, we measured sound at three locations (in front of the sample base, behind the sample base, and outside of the testing box). A third microphone was placed outside of the box opposite from the speaker to monitor the ambient sound.

2.2.2 Sound generation

An 8 Ohm Magnetic Speaker (CVS-1508, Manufacturer Part Number: CVS-1508, Digi-Key Part Number: 102-2498-ND) controlled by an Arduino Uno microcontroller were used to as a sound generator. Although this speaker is rated to produce a strong tone at a wide range of frequencies from approximately 2 kHz to 20 kHz, the intensity of the sound falters and the sound distorts as the speaker begins emitting sound near the top of its range. The frequency response of the speaker is presented in **Figure 2.4** below.

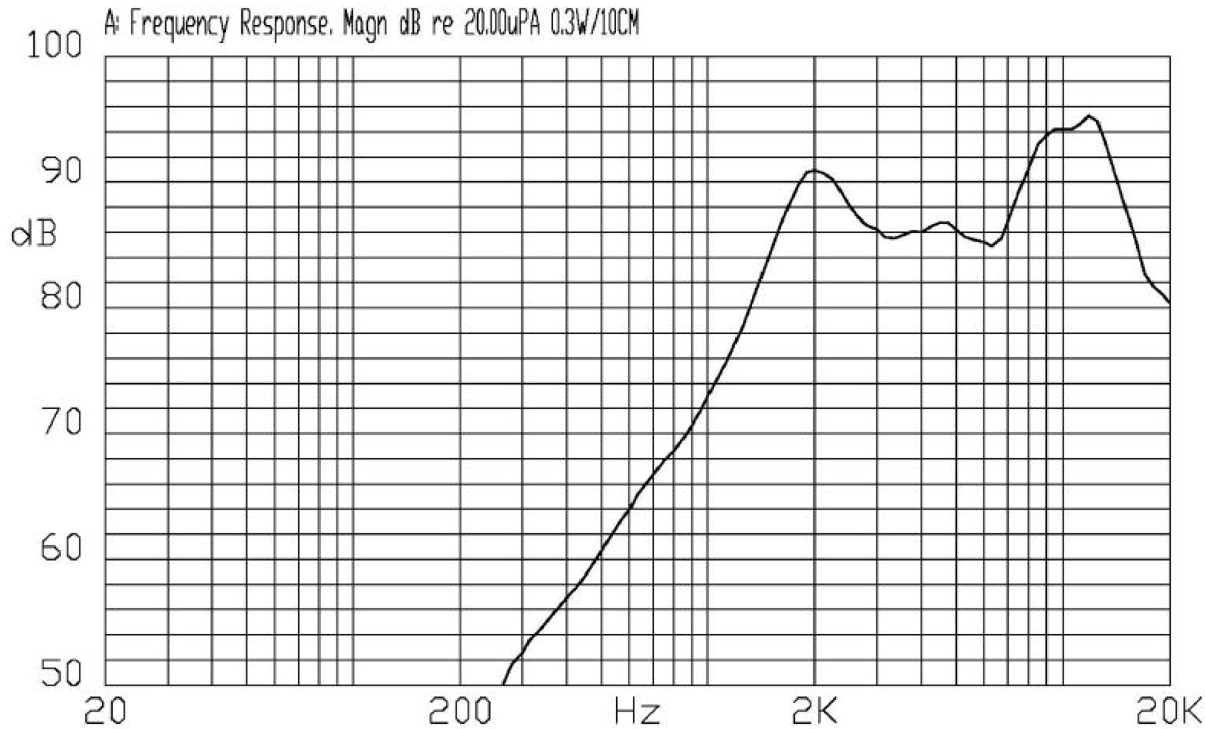

Figure 2.4: Frequency response graph for the CVS-1508 speaker

2.2.3 Microphone Calibration

Vernier microphones were calibrated at a reference sound pressure level of 94dB.

2.2.4 Data collection

Vernier Microphones (Product Code: MCA-BTA) were used to collect sound pressure data. The sound waves were recorded using Logger Pro software over a time period of 2 seconds at a sampling rate of 10000 samples per second, and the standard deviation of each soundwave was calculated to determine the amplitude of the soundwave and the level of the sound. We scaled our data by a calibration constant to determine the sound pressure in Pascals.

See Appendix for detailed instructions on set-up.

III. Results

For each combination of setting and frequency, we ran the experiment 5 times and averaged the sound level determined under those settings. The full table of sound pressure results is outlined in the Appendix. **Table 2.1** presents a summary of the percent increase or decrease from the sound intensity with our control (¾ inch plywood) to the sound intensity from either the foam or sample at positions 1 and 6.

Upon inspection, we can see that all of the sound intensities are within 8% of the sound intensity measured with the control, making the reductions marginal at best. Most of the data actually shows an average percent increase as high as 8% when we used our sound absorbing materials (foam and sample). Only at 6 kHz did we record a consistent decrease in intensity across the compartment divider, but even then the decrease is not significant. Furthermore, there does not appear to be any pattern regarding which frequencies are absorbed best, or whether the foam outperforms our sample. The most consistent decrease is that of going from position 1 to position 6, which is logical considering we are putting a barrier between our source and our sensor.

Table 2.1. Experiment Results

	Sound Intensity (Pos.1)		Sound Intensity (Pos. 6)	
Frequency (kHz)	**Foam**	**Sample**	**Foam**	**Sample**
2	108%	100%	99%	100%
6	101%	101%	94%	97%
8	105%	100%	102%	101%
10	101%	102%	100%	106%
12	106%	100%	101%	102%

A third microphone was placed outside of the box opposite from the speaker to monitor the ambient sound - the resulting sound intensity captured is presented in **Table 2.2**. This data is inconclusive, with no apparent trend. The variation is likely due to ambient noise (including the basement HVAC systems, general urban traffic, and a passing train).

Table 2.2. Experiment Results and Ambient Sound Intensity

	Sound Intensity (Pos.1)		Sound Intensity (Pos. 6)		Ambient Sound	
Frequency (kHz)	**Foam**	**Sample**	**Foam**	**Sample**	**Foam**	**Sample**
2	108%	100%	99%	100%	108%	101%
6	101%	101%	94%	97%	84%	111%
8	105%	100%	102%	101%	110%	140%
10	101%	102%	100%	106%	80%	65%
12	106%	100%	101%	102%	108%	114%

IV. Analysis

Based on our results, we cannot conclude that our butterfly-inspired structure has any meaningful sound absorbing or diffracting capabilities. There are a number of factors that could have potentially affected our results. These range from manufacturing errors, to environmental conditions, to frequency selection. For example, due to the scope of this project, we manufactured our samples using 3D-printed plastic. While this material choice allowed us to quickly create the fine structures desired, the sample was brittle and chipped easily. A sturdier choice of material or a better manufacturing technique could have prevented damage to the specimen, at the cost of significant additional time.

Additionally, our structure was designed to selectively dampen a frequency of 10kHz. However, due to manufacturing errors, the frequencies that are dampened may have been sufficiently distant from 10kHz that we saw no discernible absorption. At this length scale, an error as small as 0.1cm would lead to a 5% increase in the frequency of the sound the structure is expected to absorb. Fluctuations in air temperature, moisture and humidity (which were not measured) could also affect the results of our experiment.

Finally, it is important to note that there was no meaningful sound absorption even when we used foam, which is an industry standard in sound absorption. It is possible that our experimental setup is not as soundproof as we had assumed. Therefore, the sound deflection off of any exposed wood may have covered-up any change in sound intensity due to absorption by the sample. Furthermore, ambient noise or even low-frequency vibrations of vehicles passing by could have affected the data collection. If these sounds are considerably more intense than our speaker sound, any dampening due to the foam or the sample could have been overpowered by these intrusive noises. In future runs, a more isolated and silent testing room may prove more meaningful results.

While it is possible that improvements can be made to our experimental setup, it is also likely that the process of optic diffraction simply does not scale up to the order of feet due to differences in the properties of sound and light waves.

V. Next Steps

To augment the results presented in this study, the experiment could be repeated with more control of possible sources of error (ambient temperature, sample precision, manufacturing quality) and with additional frequency and microphone placement settings. Furthermore, additional sample designs could be made with varied parameters and materials. Additionally, a more precise selection of frequencies (testing at intervals of 0.1 kHa, instead of 2kHz) may also produce detectable absorption.

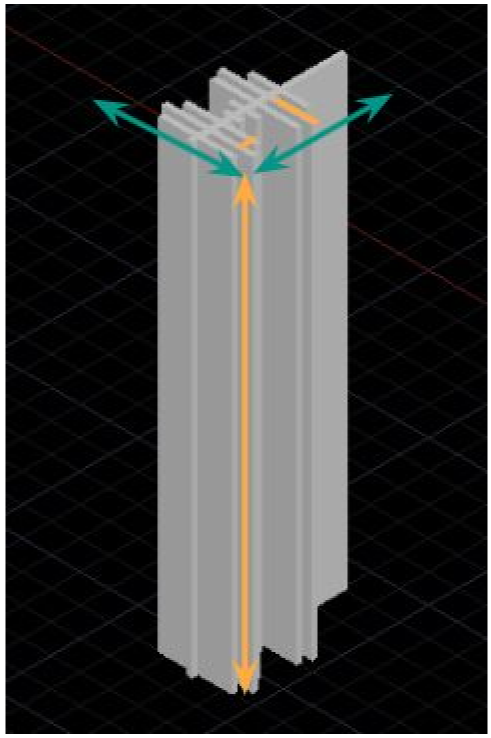

Figure 5.1: We designed our specimen with two dimensions set based on the target frequency, but future extensions of this work could test using other dimensions.

VI. Conclusion

In the course of this project, we design a structure that draws inspiration from the butterfly wing nanostructure with the purpose of serving as a targeted sound absorbing barrier. An experiment for testing the effectiveness of such a barrier was devised, and the samples and testing box for this experiment were manufactured. The samples were designed to selectively absorb frequencies of 10kHz. The samples' absorption was tested, and compared to that of foam (a common sound absorbing material) and plywood (a reflective surface, which served as our control).

When the setup was tested, we found no appreciable difference between the performance of our sample and that of the foam or our control. Therefore our results were inconclusive, and further testing is required for us to definitively determine the potential for such structures to be used as sound absorbing barriers. Potential areas of improvement include a more reliable manufacturing technique, more granular selection of frequencies, and reduction of ambient noise. We also noted that, according to the Federal Highway Authority website, designing an experiment to test at this scale may be impossible.

While our proposed design did not work as intended, we can envision many potential applications for successful implementation of a similar design. For example, a sound absorbing barrier could be used to reduce noise from airplanes or subway trains passing by residential neighborhoods.

VII. Acknowledgements

We would like to thank Dr. Barbara Hughey (2.671 Instructor) and Randall Briggs (2.671 TA) for their assistance on calibrating the Vernier microphones, as well as the teaching staff for 1.102.

VIII. References

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VII. Appendix

7.1 Detailed experimental set-up

1) Set-up microphone
    a) Connect LabProMini (sensor hub) to computer via USB cable
    b) Connect microphone (Note which microphone you use: MCA-8, MCA-9, or MCA-10) to LabProMini
    c) Put the microphone in the hole that you want to use for the test. Note which hole number you use: 1, 2, 3, 4, 5 for in front of sample; 6 for behind sample.
    d) Open LoggerPro 3.14 Demo
    e) in main menubar: "Experiment" > "Set Up Sensors" >
        i) Microphone should be auto-detected, but you can check here.
    f) in main menubar: "Experiment" > "Data Collection" (shortcut: CTRL + D) > Change "Duration" to 3 seconds.
        i) When microphone is auto-detected, the experiment settings should default to the correct settings, except that it defaults to 0.03 second data collection. Data should baseline at 2.5; do NOT zero!
2) Connect the Arduino Uno to the computer via USB cable
    a) Code should already be uploaded onto the board! (unless you want to edit the program)
    b) Note which frequency the speaker is programmed to emit (our target is 10kHz; range ~ 2kHz - 13 kHz).
    c) If your using same code as before, you can just press the red button on the Arduino Uno microcontroller board to re-start the program.
    d) Otherwise, to upload code to Arduino:
        i) Open the .ino file
        ii) in the main menubar: "Sketch" > "Port" > check that the selected port is correct. Arduino model and port should be auto-detected, but you can check here. Wrong port is a really common error when uploading code, so always check this.
    e) Check that the circuit is set-up correctly and that it uses the same pin as the code (pin 8).
    f) Upload
3) Set-up speaker.
    a) Just check that the wires are in the correct direction (+/-)
4) Set-up sample.
    a) Put the sample in the correct place (or put the empty board or the foam, if you are doing a control test)

7.2 Data collection

1) Note that the steps below might need to be adjusted for time/ordering, if you decide to change the code.
2) Note about file system: Files stored in folders that are organized by hole # and frequency. I have been naming files with date (YYYYMMDD format) and type (e.g. control vs sample)
3) Note which microphone you use, which hole the microphone is in, which frequency the speaker emits. <also set-up second microphone to monitor ambient sound level? extra>
4) For each of 3 types (control wood, control foam, sample), take 3-5 runs of data.
    a) Space = Shortcut to start/stop collecting a run of data

b) CTRL + L = Shortcut to save the most recent run of data

5) Remember to save file!

7.3 Data analysis

1) Save files!
2) After you've collected and stored all runs for that setting/that file:
    a) in icon bar: Statistics button (can also go to main menubar: "Analyze" > "Statistics")
    b) Select all runs
3) Read the Stdev value for each run of data and copy into spreadsheet
4) Average the Stdev values for that setting
5) Calculate and compare sound reductions (Control foam:Control wood vs Sample:Control wood. Expect ratios to be < 1)
6) Repeat with all other settings
7) Plot % sound reduction (dependent variable on y-axis) vs frequency (independent variable on x-axis) for the sample and for the control foam.
    a) Alternatively, plot % sound received
    b) *We expect control foam to have higher sound reduction than sample at all frequencies, but less so at 10kHz*
8) Also plot difference in %sound reduction vs frequency
    a) Alternatively, plot proportion of %sound reduction
    b) *We expect there to be less difference/lower reduction ratio at 10 kHz*

7.4 Raw Data

Table 7.1 Preliminary data:

	10 kHz	Pos 1	
Trial	Foam	No Foam	
1	4.77E-03	1.22E-02	
2	4.64E-03	5.55E-03	
3	4.50E-03	1.10E-02	
AVG	**0.013907**	**0.02876**	**48%**
STDEV	9.62E-05	3.87E-03	
	6.91E-03	1.35E-01	

	10 kHz			Pos 1			
Trial	Foam	Sample	Sample - t	No Foam			
1	4.77E-03	1.44E-02	6.54E-03	1.22E-02			
2	4.64E-03	6.75E-03	7.58E-03	5.55E-03			
3	4.50E-03	9.74E-03	6.77E-03	1.10E-02			
4		0.005969	6.83E-03		Foam:Con	Sample:Control	
AVG	**4.64E-03**	**9.21E-03**	**6.93E-03**	**9.59E-03**	**48%**	**96%**	
STDEV	9.62E-05	1.99E-03	4.52E-04	3.87E-03			
	2%	22%	7%	40%			

	10 kHz		Pos 3			
Trial	Foam	Samples	No Foam			
1	0.006784	0.006768	0.006828			
2	0.006126	0.006027	0.006181			
3	0.007006	0.005694	0.006659			
4	0.006495	0.005921	0.005902	Foam:Con	Sample:Control	
AVG	**6.60E-03**	**6.10E-03**	**6.39E-03**	**103%**	**95%**	
STDEV	4.42E-04	1.70E-04	3.83E-04			
	7%	3%	6%			

	10 kHz		Pos 5		
Trial	Foam	Sample	No Foam		
1	0.006298	0.006252	0.005966		
2	0.00579	0.005673	0.00717		
3	0.005719	0.005767	0.005832		
4	0.00595	0.005612	0.005528	Foam:Con	Sample:Co
AVG	**5.94E-03**	**5.83E-03**	**6.12E-03**	**97%**	**95%**
STDEV	1.18E-04		8.74E-04		
	2%		14%		

Table 7.2. Full sound pressure (AU) data at position 1:

	2kHz		Pos 1		
Trial	Foam	Sample	Control		
1	0.00518	0.00405	0.00409		
2	0.00416	0.00409	0.0041		
3	0.00408	0.00411	0.00406		
4	0.00414	0.00407	0.00403		
5	0.00417	0.00404	0.00411	Foam: Control	Sample: Control
AVG	**4.39E-03**	**4.08E-03**	**4.07E-03**	**108%**	**100%**
STDEV	3.92E-05	2.05E-05	3.76E-05		
	8.94E-03	5.02E-03	9.24E-03		
	6kHz		Pos 1		
Trial	Foam	Sample	Control		
1	0.00406	0.00409	0.00421		
2	0.00404	0.00412	0.00406		
3	0.00413	0.00412	0.00403		
4	0.00419	0.00414	0.00402		
5	0.00411	0.00418	0.00404	Foam: Control	Sample: Control
AVG	**4.11E-03**	**4.12E-03**	**4.08E-03**	**101%**	**101%**
STDEV	7.92E-05	9.54E-06	2.10E-05		
	1.93E-02	2.32E-03	5.14E-03		
	8kHz		Pos 1		
Trial	Foam	Sample	Control		
1	0.00451	0.00406	0.00403		
2	0.0042	0.00406	0.00409		
3	0.00424	0.00402	0.00404		
4	0.00406	0.00404	0.00403		
5	0.00405	0.00405	0.00401	Foam: Control	Sample: Control
AVG	**4.25E-03**	**4.04E-03**	**4.05E-03**	**105%**	**100%**
STDEV	9.71E-05	2.08E-05	3.20E-05		
	2.28E-02	5.15E-03	7.90E-03		
	10kHz		Pos 1		
Trial	Foam	Sample	Control		
Run	0.00406	0.00404	0.00407		
Run	0.00403	0.00409	0.00401		
Run	0.00406	0.0041	0.00399		
Run	0.00405	0.0041	0.00401		
Run	0.00409	0.00408	0.00396	Foam: Control	Sample: Control
AVG	0.00406	0.00408	0.00401	**101%**	**102%**
STDEV	1.55E-05	6.43E-06	1.36E-05		
	3.82E-03	1.58E-03	3.38E-03		
	12kHz		Pos 1		
Trial	Foam	Sample	Control		
1	0.00401	0.00407	0.0041		
2	0.00445	0.00406	0.00412		
3	0.00406	0.00411	0.00403		
4	0.00479	0.00401	0.00405		
5	0.00403	0.00406	0.00405	Foam: Control	Sample: Control
AVG	**4.33E-03**	**4.06E-03**	**4.08E-03**	**106%**	**100%**
STDEV	3.63E-04	5.06E-05	4.69E-05		
	8.40E-02	1.24E-02	1.15E-02		

Table 7.3. Full sound pressure (AU) data at position 6:

	2kHz		Pos 6		
Trial	Foam	Samples	Control		
1	0.00402	0.00409	0.00459		
2	0.00417	0.0042	0.00412		
3	0.00408	0.00412	0.00419		
4	0.00441	0.00454	0.00398		
5	0.00435	0.00403	0.00424	Foam: Control	Sample: Control
AVG	**4.17E-03**	**4.24E-03**	**4.22E-03**	**99%**	**100%**
STDEV	1.68E-04	2.27E-04	1.02E-04		
	4.03E-02	5.35E-02	2.42E-02		
	6kHz		Pos 6		
Trial	Foam	Samples	Control		
1	0.00391	0.00394	0.00481		
2	0.00392	0.00421	0.00413		
3	0.00401	0.00427	0.00411		
4	0.00422	0.00415	0.00407		
5	0.004	0.0043	0.00414	Foam: Control	Sample: Control
AVG	**4.01E-03**	**4.14E-03**	**4.28E-03**	**94%**	**97%**
STDEV	1.54E-04	6.20E-05	3.34E-05		
	3.84E-02	1.50E-02	7.81E-03		
	8kHz		Pos 6		
Trial	Foam	Samples	Control		
1	0.00419	0.00412	0.00405		
2	0.00399	0.00414	0.00408		
3	0.00404	0.00392	0.00414		
4	0.00427	0.00417	0.00397		
5	0.00409	0.004	0.00398	Foam: Control	Sample: Control
AVG	**4.12E-03**	**4.09E-03**	**4.06E-03**	**102%**	**101%**
STDEV	1.48E-04	1.35E-04	8.74E-05		
	3.60E-02	3.29E-02	2.15E-02		
	10kHz		Pos 6		
Trial	Foam	Sample	Control		
Run	0.00415	0.00424	0.00419		
Run	0.00401	0.00421	0.00398		
Run	0.00409	0.00438	0.00404		
Run	0.004	0.00439	0.00404		
Run	0.00408	0.00432	0.00398	Foam: Control	Sample: Control
AVG	0.00406	0.00431	0.00405	**100%**	**106%**
STDEV	5.01E-05	9.84E-05	3.84E-05		
	1.23E-02	2.29E-02	9.49E-03		
	12kHz		Pos 6		
Trial	Foam	Samples	Control		
1	0.00404	0.00412	0.00429		
2	0.00413	0.00406	0.00409		
3	0.00407	0.0043	0.00391		
4	0.00424	0.00409	0.00402		
5	0.00408	0.00417	0.00413	Foam: Control	Sample: Control
AVG	**4.12E-03**	**4.14E-03**	**4.08E-03**	**101%**	**102%**
STDEV	8.21E-05	1.28E-04	9.24E-05		
	1.99E-02	3.09E-02	2.27E-02		

Table 7.4 Full sound pressure (AU) data outside of the box:

	2kHz		outside box		
Trial	Foam	Sample	Control		
1	0.05464	0.04624	0.05432		
2	0.05694	0.05716	0.04911		
3	0.05768	0.05321	0.04858		
4	0.05562	0.05392	0.05609		
5	0.05365	0.05692	0.0505	Foam: Control	Sample: Control
AVG	**5.62E-02**	**5.26E-02**	**5.20E-02**	**108%**	**101%**
STDEV	1.04E-03		4.19E-03		
	1.86E-02		8.06E-02		
	6kHz		outside box		
Trial	Foam	Sample	Control		
1	0.02275	0.03013	0.02824		
2	0.02276	0.03046	0.02712		
3	0.02301	0.03051	0.02708		
4	0.02339	0.03034	0.02695		
5	0.02286	0.03045	0.02704	Foam: Control	Sample: Control
AVG	**2.30E-02**	**3.04E-02**	**2.73E-02**	**84%**	**111%**
STDEV	3.17E-04		8.89E-05		
	1.38E-02		3.25E-03		
	8kHz		outside box		
Trial	Foam	Sample	Control		
1	0.03732	0.04681	0.03348		
2	0.03685	0.04782	0.03378		
3	0.03695	0.04707	0.03386		
4	0.03689	0.047	0.03332		
5	0.03701	0.04745	0.03342	Foam: Control	Sample: Control
AVG	**3.70E-02**	**4.72E-02**	**3.36E-02**	**110%**	**140%**
STDEV	5.03E-05		2.91E-04		
	1.36E-03		8.67E-03		
	10kHz		outside box		
Trial	Foam	Sample	Control		
Run	0.0114	0.01042	0.01183		
Run	0.01887	0.01634	0.02239		
Run	0.01516	0.01651	0.02186		
Run	0.02648	0.01308	0.02751		
Run	0.01647	0.01546	0.02632	Foam: Control	Sample: Control
AVG	0.01768	0.01436	0.02198	**80%**	**65%**
STDEV	5.77E-03		3.12E-03		
	3.26E-01		1.42E-01		
	12kHz		outside box		
Trial	Foam	Sample	Control		
1	0.13	0.1379	0.1207		
2	0.1295	0.1373	0.1201		
3	0.1292	0.1372	0.1196		
4	0.1293	0.1369	0.1196		
5	0.1289	0.1367	0.1196	Foam: Control	Sample: Control
AVG	**1.30E-01**	**1.37E-01**	**1.20E-01**	**108%**	**114%**
STDEV	1.53E-04		2.89E-04		
	1.18E-03		2.41E-03		