Bio-Inspired Sound Absorbing Building Facades

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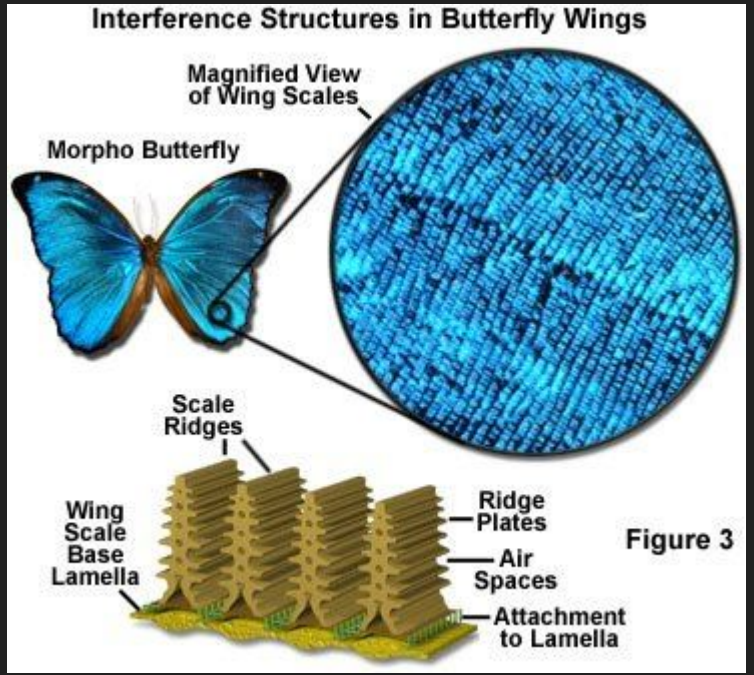
Final Project

Bio-Inspiration

- Diffraction grating present in butterfly wing scales
- Nanostructure composed of “arrays of vertically aligned net-like skeleton structures”



Highway sound barrier
https://www.soundfighter.com/applications/roads-and-highways/

Motivation and Application

Can we extend the analogy from light to sound?

If we can selectively absorb certain wavelengths,
then we can engineer more effective sound barriers.

Sound Absorption

- past and current research focuses on:
  - sound absorption by flexible/porous material
  - sound diffusion off of hard surfaces of different geometries to improve sound quality
  - macro-scale shape and height of sound barrier walls along highways

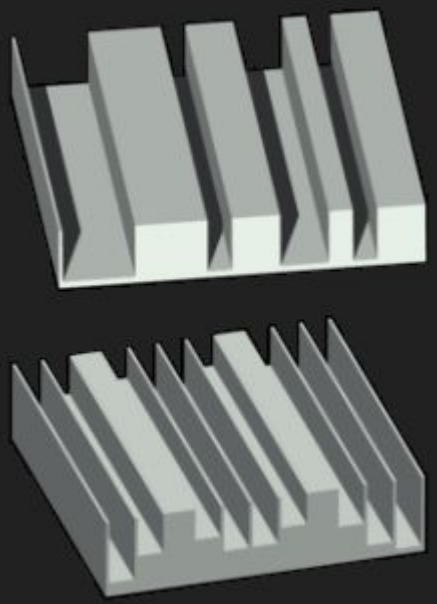


Figure XXX: Examples of maximum length sequence (MLS) acoustic diffusor pattern [left] and Quadratic-residue acoustic diffusor pattern [right]

Hypothesis

If we design a specimen with lengths that correspond to a certain frequency, we will observe greater sound absorption at that frequency.

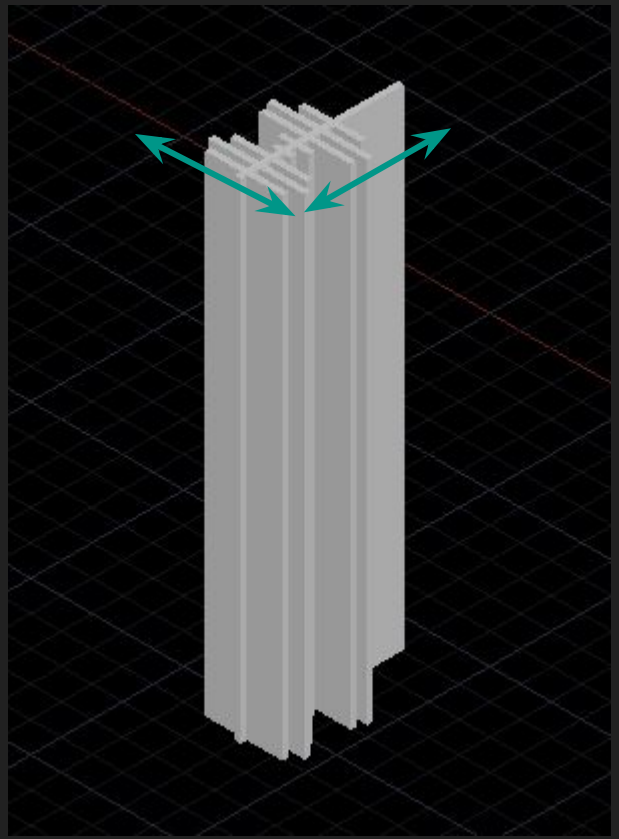
Project Design: Specimen

-characteristic length: 1.7cm

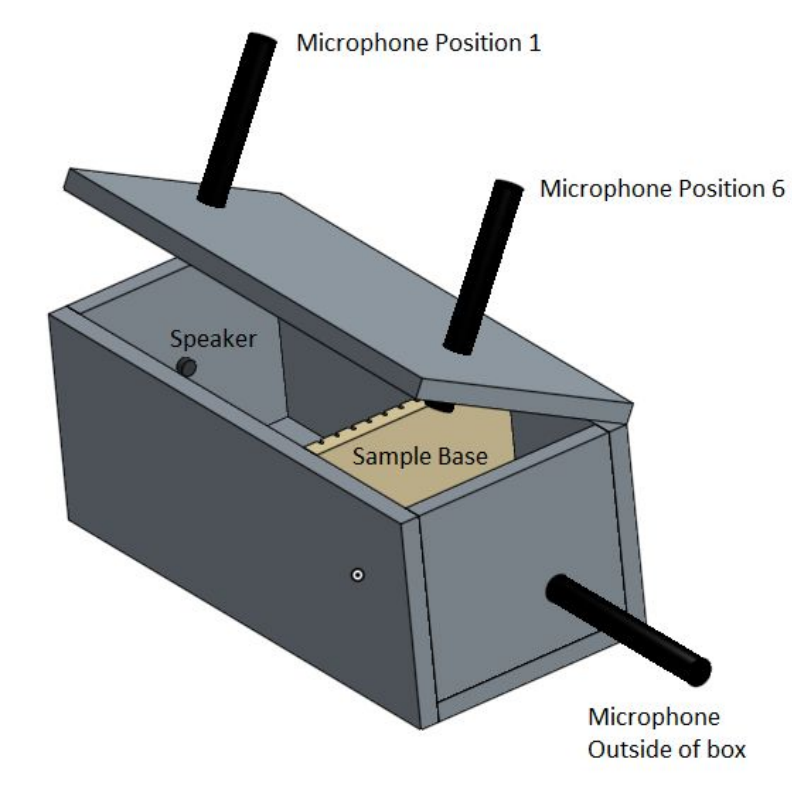
-wavelength of a 10kHz soundwave

-sine curve like structure with the branches

-based off the nanostructure of the Morpho butterfly



Project Design: Testing Chamber



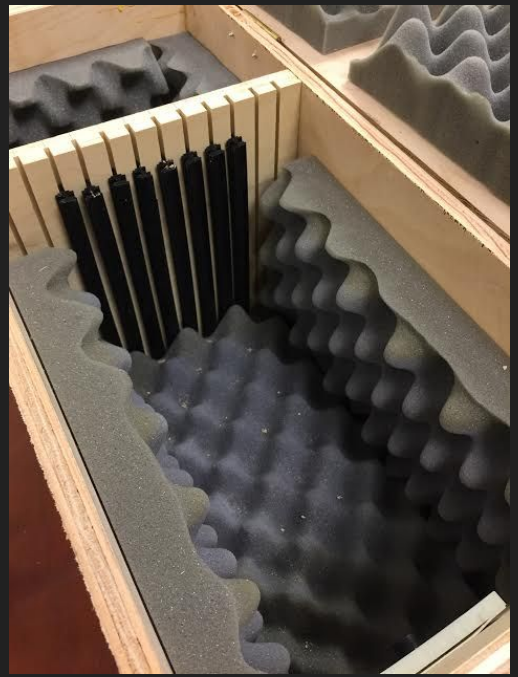
-20″ x 9″ x 9″ box made of wood

-lined with eggcrate foam

-wooden substrate to hold specimen

- two testing locations

Project Design: Testing Chamber



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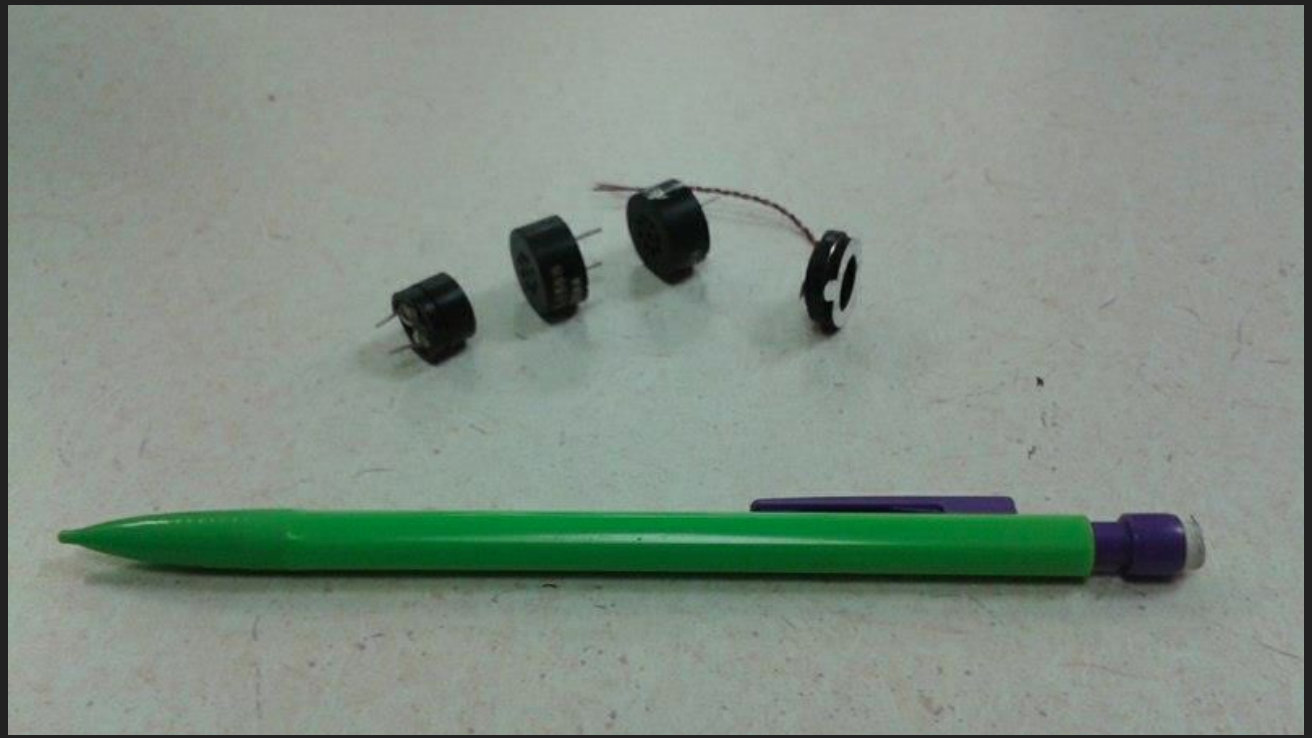
Project Design

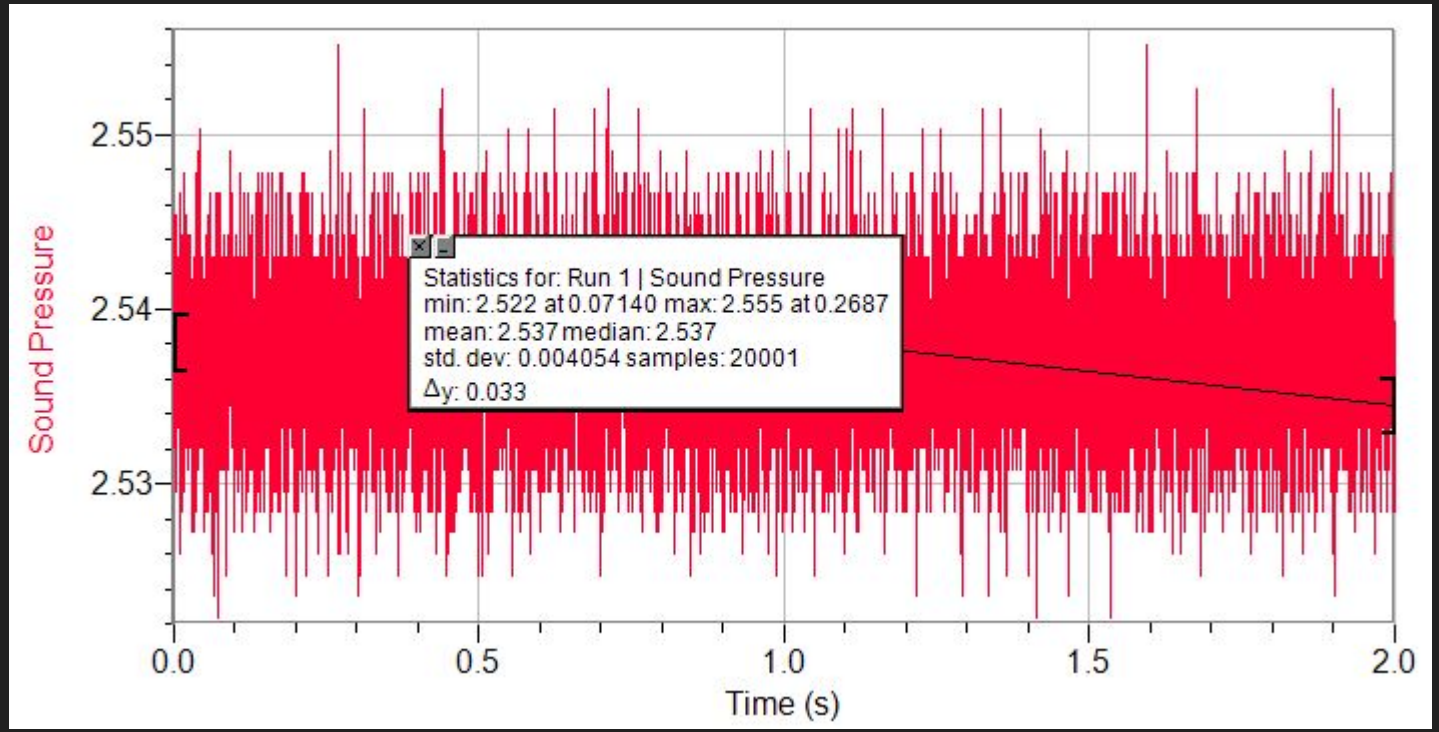
Experimental Design

Experimental Design



- 3 different models of 8Ohm Magnetic Speaker
  - SP-1504
  - CVS-1508
  - AST-01508MR-R
- ~ 1.7kHz - 20 kHz
- 80-90 dB

Experimental Design



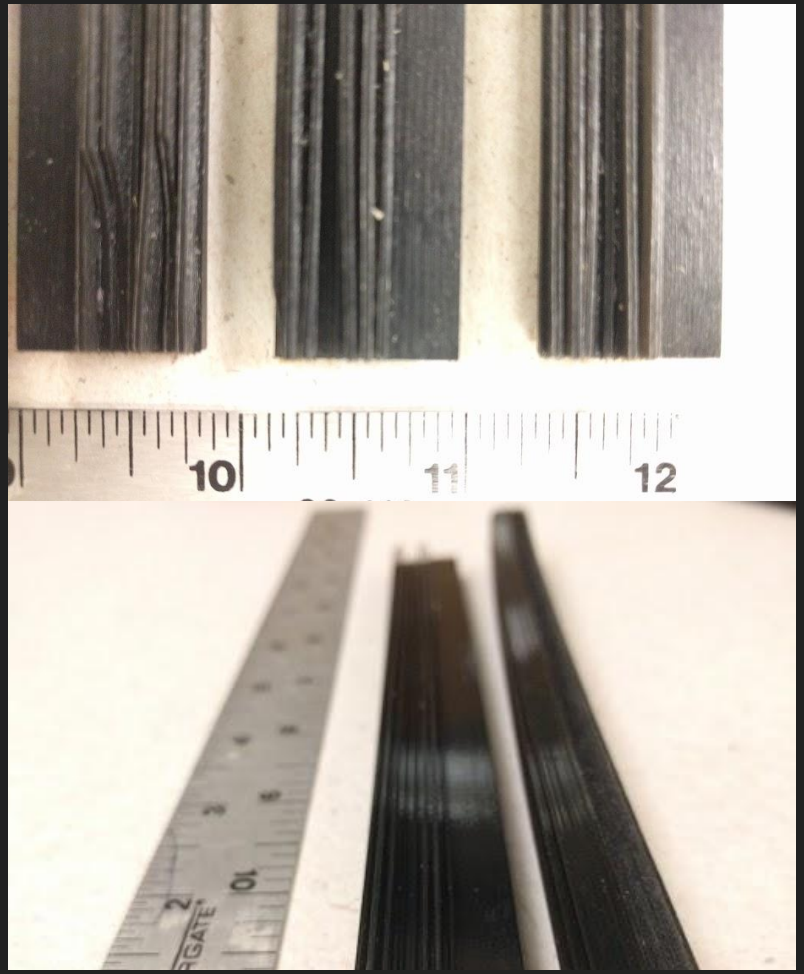
Results and Analysis

	Sound at position 1		Sound at position 6		Ambient sound	
Freq (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%

- All percent differences are within 8% of the control intensity.
- No apparent trend regarding conditions, frequencies, etc.

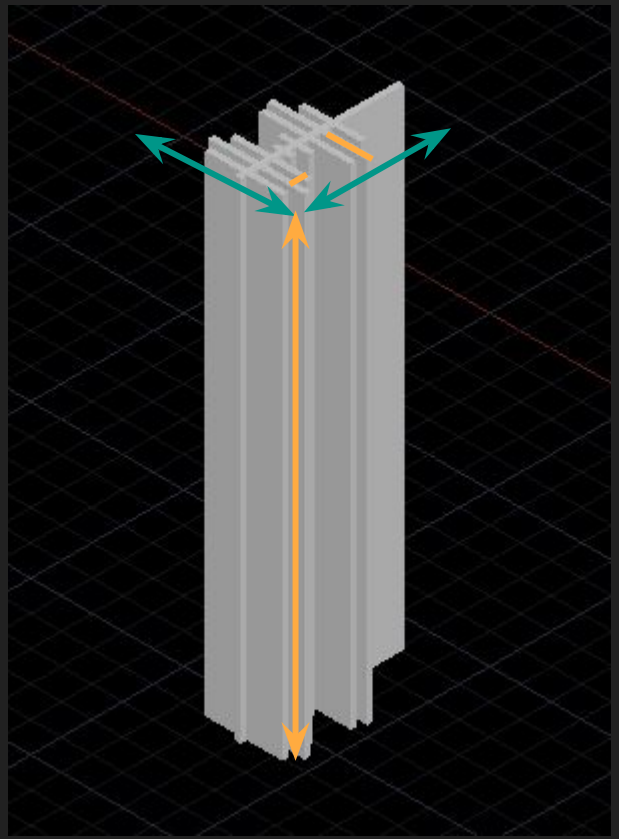
Sources of Error

- Manufacturing
  - samples chipped off at end in some cases
  - imperfect sample alignment
  - backing material remaining in samples
  - variation between samples
- Air characteristics
  - temperature
  - moisture
  - humidity
- Soundproofing
- Scalability



Next Steps

- Additional testing:
  - other frequencies
  - new dimensions
  - reduce manufacturing errors
- Improve testing environment:
  - acoustic anechoic chamber



References

Li, Q., Zeng, Q., Shi, L., Zhang, X., & Zhang, K. (2016). Bio-inspired sensors based on photonic structures of Morpho butterfly wings: a review. *J. Mater. Chem. C, 4*(9), 1752-1763. doi:10.1039/c5tc04029a

Huang, Jingyun, Wang, Xudong, and Lin Wang, Zhong. (2006), Controlled Replication of Butterfly Wings for Achieving Tunable Photonic Properties, Nano Letters Vol. 6:2325- 2331

Ingram, A. L., Lousse, V., Parker, A. R., & Vigneron, J. P. (2008). Dual gratings interspersed on a single butterfly scale. *Journal of The Royal Society Interface, 5*(28), 1387-1390. doi:10.1098/rsif.2008.0227

Federal Highway Administration. (2017, March 27). Highway Traffic Noise Barriers at a Glance. Retrieved May 17, 2017, from https://www.fhwa.dot.gov/environment/noise/noise_barriers/design_construction/keepdown.cfm

Acknowledgements

- 2.671 Teaching Staff:
  - Dr. Barbara Hughey (instructor)
  - Randall Briggs (TA)
- 1.102 Teaching Staff
- Butterflies!

Any questions?

Experimental Design

Sound level equations used to calibrate microphone and scale data from sound pressure (AU) to sound pressure (Pa) and sound level (dB)

$$K = \frac{P_{rms}}{\sigma_{mic}}$$

$$P_{rms} = P_{ref} 10^{\frac{SPL}{20}}$$

Preliminary Results

	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				10 kHz		Pos 3				10 kHz		Pos 5		
Trial	Foam	Sample	Sample - t	No Foam				Foam	Samples	No Foam				Foam	Sample	No Foam		
1	4.77E-03	1.44E-02	6.54E-03	1.22E-02				0.006784	0.006768	0.006828				0.006298	0.006252	0.005966		
2	4.64E-03	6.75E-03	7.58E-03	5.55E-03				0.006126	0.006027	0.006181				0.00579	0.005673	0.00717		
3	4.50E-03	9.74E-03	6.77E-03	1.10E-02				0.007006	0.005694	0.006659				0.005719	0.005767	0.005832		
4		0.005969	6.83E-03		Foam:Con	Sample:Control		0.006495	0.005921	0.005902	Foam:Con	Sample:Control		0.00595	0.005612	0.005528	Foam:Con	Sample:Co
AVG	**4.64E-03**	**9.21E-03**	**6.93E-03**	**9.59E-03**	**48%**	**96%**		**6.60E-03**	**6.10E-03**	**6.39E-03**	**103%**	**95%**		**5.94E-03**	**5.83E-03**	**6.12E-03**	**97%**	**95%**
STDEV	9.62E-05	1.99E-03	4.52E-04	3.87E-03				4.42E-04	1.70E-04	3.83E-04				1.18E-04		8.74E-04		
	2%	22%	7%	40%				7%	3%	6%				2%		14%		

- Preliminary tests suggested that at position 1, up to a 50% sound reduction could be achieved with the foam control,
- Expected to see the proportion of sound detected with the sample decrease from the control (a flat piece of wood) - i.e. expected