International Baccalaureate

Extended Essay: Physics High Level

The effect of the frequency of a sound wave and the thickness of the obstacle it passes through on Sound Transmission Loss

Word Count:3922

MAY, 2019

Content:

1. Introduction:

I have always wondered why when my neighbors play music loudly I can only hear the bass guitar and the drum sound but not the singer's voice. Thus, one day I started to investigate the factors that may have caused this difference. I realized that the frequency was one of the main elements and may be the answer to my initial question, but during my research I also found out that the properties of the obstacle between the receiver and the source also drastically affect the transmission of sound. This made me think about soundproofing and the ways it may affect sound transmission. Therefore, I also wanted to experiment on different thicknesses of the same material to determine if the effect of frequency on Sound Transmission Loss changes with the thickness of the obstacle as well. This curiosity led me to my research question: *"How does the frequency of the sound wave affect the Sound Transmission Loss while passing through obstacles of different thicknesses?"* Thus, my extended essay will focus on an experiment where I will study the effect of different frequencies on the sound wave intensity while varying the thickness of the obstacle.

2. Background Information and Literature:

a) Nature of Sound:

Sound is a mechanical wave because it is a disturbance that is transported through a medium via the mechanism of particle-to-particle interaction[1]. This vibration of the sound wave in air can be described as longitudinal because the motion direction of the individual particles of the medium and the direction of energy transport are parallel as seen in Fig 1. Because of this motion, air particles are compressed and spread away. The region where they are compressed is called compression whereas the region where they are separated is called rarefaction.

[1] https://www.physicsclassroom.com/class/sound/Lesson-1/Sound-is-a-Mechanical-Wave

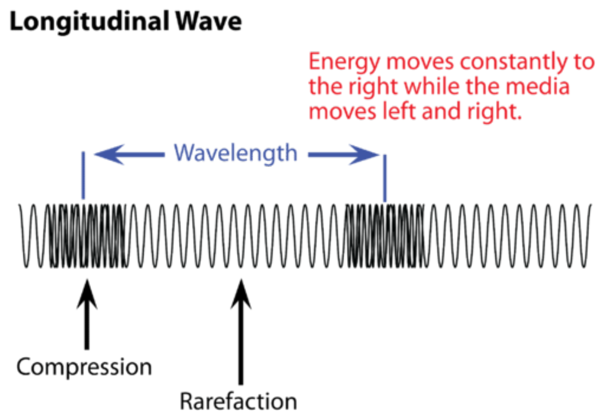

Fig 1: Visual representation of the motion of a longitudinal wave[2]

Since the sound wave consists of high pressure and low-pressure regions, it can also be called as a pressure wave. Therefore, it can be perceived by the human ear and can be observed by using a detecting device.

b) Properties of Sound and Their Perception:

As the sound vibrates back and forth, the frequency of the wave refers to how often the particles of the medium vibrate when a wave passes through it in one second. The common unit for frequency is Hertz (Hz). Hence;

$$1\ Hertz = 1\ vibration/second$$

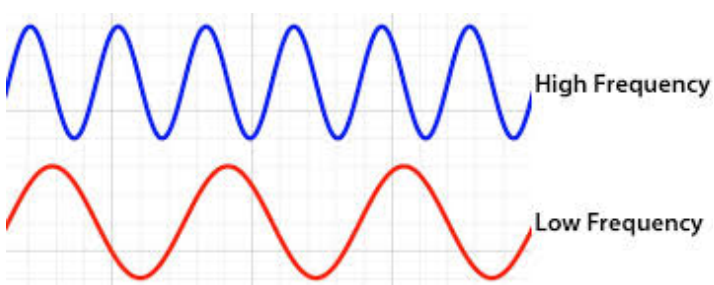

Fig 2: The comparison of high and low frequency waves[3]

[2] https://www.ck12.org/physics/longitudinal-wave/lesson/Longitudinal-Waves-PHYS/
[3] https://blog.zzounds.com/2017/05/24/headphones-produce-bass-frequencies/

Frequency can also be referred to as pitch. High pitch indicates high frequency and low pitch indicates low frequency.

The intensity of the sound wave is the amount of energy transported through a given area of the medium per unit time. The square of the amplitude of the wave is directly proportional to the intensity of the wave because the greater the amplitude of vibrations of the particles of the medium, the greater the rate at which energy is transported through it, and the more intense that the sound wave is[4]. Thus;

$$Intensity^{5} = \frac{Energy}{Time\ x\ Area}$$

As energy/time equals to power;

$$Intensity^{6} = \frac{Power}{Area}\ \frac{Watts}{Meter^{2}}$$ Equation 1

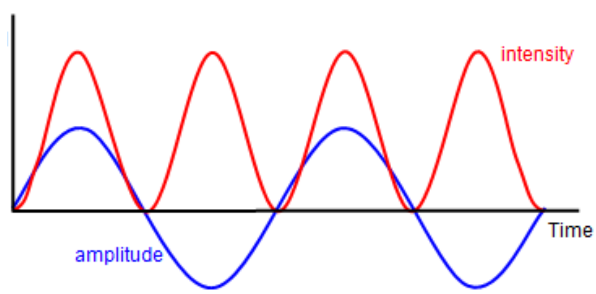

Fig 3: Intensity and amplitude versus time graph[7]

Human ears are very sensitive and are capable of detecting sound waves as low as 1×10^{-12} W/m^2 and this level corresponds to a pressure wave in which a compression of air particles have only 0.3 billionth of an atmosphere[8]. The lowest sound wave intensity a human ear can hear is referred to

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[4] https://www.physicsclassroom.com/class/sound/Lesson-2/Intensity-and-the-Decibel-Scale
[5] http://www.insula.com.au/physics/1279/L14.html
[6] http://www.insula.com.au/physics/1279/L14.html
[7] http://www.schoolphysics.co.uk/age16-19/Wave%20properties/Wave%20properties/text/Intensity_and_amplitude/index.html
[8] https://www.mwit.ac.th/~physicslab/applet_04/physics_classroom/Class/sound/u11l2b.html

as the threshold of hearing (TOH). Moreover, the highest sound wave intensity a human ear can detect without any damage is almost as one billion times more intense than the TOH. Because the intensity range is large, the scale used in physics to measure the intensity is based on powers of 10 which can also be referred to as the logarithmic or decibel scale. TOH which has an intensity of 1×10^{-12} W/m^2 corresponds to a level of 0 decibels (dB).

Intensity of a sound is an objective quantity which is measured with detective instruments whereas the loudness of a sound is more subjective to the receiver. Loudness can be different to individuals who are older than who are younger. Moreover, two sound waves that have the same intensity with different frequencies will be perceived differently. Although loudness and intensity are two different concepts, it can be said that the more intense the sound wave, the loudest it is.

c) Behavior of Sound:

When a sound wave travels between two mediums, there are two possible outcomes when it reaches the boundary. It can undergo reflection and absorption either completely or partially. Absorption of a sound wave means that the material or object takes in the sound energy and when the dissimilarity between the objects is higher, the absorption ability is higher. Therefore, in concert halls, foam which is more similar to the air medium is more preferable in order to absorb more sound. Reflection of a sound wave refers to when the material does not take in the wave but scatter it away. Therefore, considering the transmission of sound from a source afar to the receiver with obstacles between, the traveling sound wave may be both reflected and absorbed.

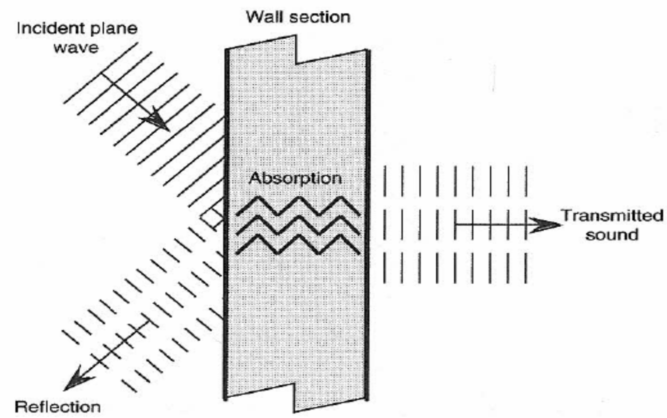


Figure 5: Transmission of a sound wave[9]

The sound wave creates vibrations which means a pressure wave in the air. Therefore, when the wave is transmitted, as air particles vibrate, the materials along the way also vibrate to pass on the wave. However, with each step, the energy is lost so the intensity decreases. This also corresponds to a decrease in dB and loudness. In addition, some materials can vibrate more easily than other because of a physical property called natural frequency. When the incident frequency of the sound wave matches with the natural frequency of the object, the energy loss is lower because the object starts vibrating more easily. In order to find the loss during sound transmission, transmission coefficient (τ) of materials, which is frequency dependent, is used. Transmission coefficient is found by;

$$\tau^{10} = \frac{I_{Transmitted}}{I_{Incident}} \qquad \text{Equation 2}$$

Thus, the Sound Transmission Loss (STL) can be found by the log ratio of the incident energy to the transmitted energy of the wave[11].

[9] http://proaudioencyclopedia.com/acoustical-fundamentals/
[10] http://pcfarina.eng.unipr.it/Public/Acoustics-Course/Penn-State-Course/9_trans.pdf
[11]http://pcfarina.eng.unipr.it/Public/Acoustics-Course/Penn-State-Course/9_trans.pdf

$$Sound\ Transmission\ Loss^{12} = 10\log\frac{1}{\tau} \qquad \text{Equation 3}$$

I am expecting to have results that support the incident that incited this experiment. Therefore, I believe that the lower frequencies will result in a lower Sound Transmission Loss. Referring to the nature of sound waves, it is also plausible to assert this assumption. As the higher frequency sound wave vibrates more rapidly, it creates more wavelengths per unit time. Thus, it has a higher velocity value, so it loses more energy in the same travel distance when compared to a lower frequency sound wave. Therefore, I believe my hypothesis which is supported by both a theoretical explanation and real-life situation will be justified by my experiment as well.

[12]http://pcfarina.eng.unipr.it/Public/Acoustics-Course/Penn-State-Course/9_trans.pdf

3. Experiment:

a) Variables:

I. Independent Variables:

i. Frequency of the sound wave generated by using a smartphone application, Tone Generator: Audio Sound Hz and sent through the obstacle

ii. Thickness of the obstacle, controlled by using a ruler to measure the thickness of the obstacle

II. Dependent Variable:

i. Intensity of the sound after passing through an obstacle, measured by using a smartphone application, Decibel X

III. Controlled Variables:

i. Temperature of the medium, measured by a digital thermometer: The temperature can affect the movement of the gas particles, thus impacting the speed of the sound wave.

ii. Medium in which the experiment is conducted, controlled by doing the experiments in the same medium: There may be sound waves in the medium that cannot be eliminated but conducting the experiment in the same environ can prevent the fluctuations in the data.

iii. The material of the obstacle in front of the frequency generator, controlled by using foam as the material for all the obstacles used in the experiment: Materials transmit sound waves differently, thus it is important to use the same material in the trials.

iv. Distance of the obstacle from the frequency generator and the intensity detector, controlled by using a ruler to measure the distances in each trial: Sound waves lose their energy while traveling, so the distance in which they hit the obstacle and detected by the detector carry high importance.

b) Material List:

1. Smartphone which has the frequency generating application “Tone Generator: Audio Sound Hz” installed
2. Smartphone which has the decibel measuring application “Decibel X” installed
3. Speaker that can be connected to the smartphone through Bluetooth.
4. 3 foam and closed boxes with dimensions 30 cm x 30 cm x 30 cm and thicknesses 5.0 cm, 10.0 cm and 15.0 (± 0.5) cm.
5. Ruler with a range 100 (± 0.5) cm.
6. Thermometer with a range -38.0 – 50.0 (± 0.5) °C.

c) Procedure:

1. The application Tone Generator: Audio Sound Hz is downloaded to a smartphone.
2. The application Decibel X is downloaded to a smartphone.
3. The phone with the Tone Generator: Audio Sound Hz application is connected to a speaker for better audio.
4. The frequency of the generator is adjusted to 100 Hz from the application Tone Generator: Audio Sound Hz.
5. The smartphone with the application Decibel X installed is put 15 cm away from the speaker.
6. The intensity of the sound wave with Decibel X is measured and recorded when the value stabilizes.
7. The speaker is put into foam box with 5 cm thickness.
8. The foam box is placed 15 cm away from the speaker.
9. The intensity of the sound is measured and recorded with the application Decibel X.
10. Steps 6-8 are repeated for 4 more trials, thus having data for 5 trials in total.

11. Steps 4-10 for 200, 300, 400, 500, 600, 700, 800, 900 and 1000 Hz are repeated with an obstacle that has 10 cm in thickness.
12. Steps 4-10 for 200, 300, 400, 500, 600, 700, 800, 900 and 1000 Hz are repeated with an obstacle that has 15 cm in thickness.

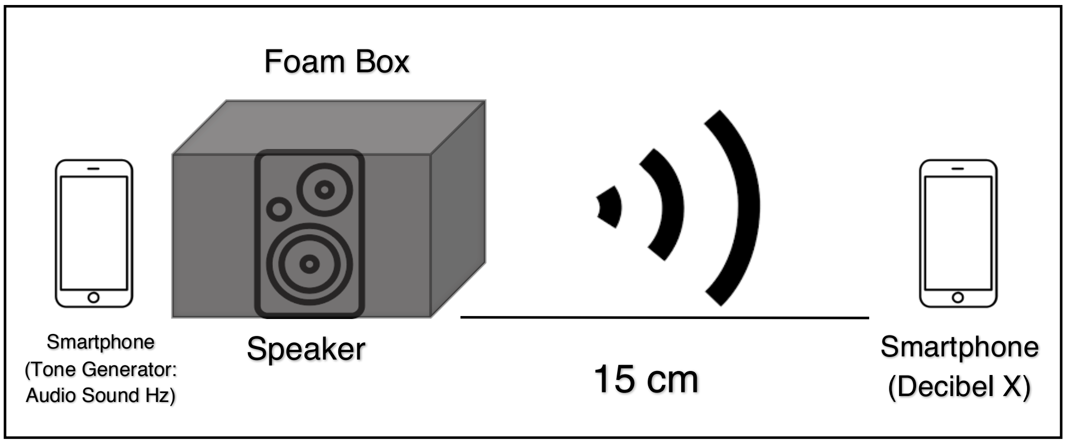


Diagram 1: Experimental Setup

d) Raw Data:

➢ For the obstacle with 5 cm thickness:

	Trials	Incident Intensity of the Sound (dB ± 0.01)	Transmitted Intensity of the Sound (dB ± 0.01)
100 Hertz	Trial 1	36.20	35.40
	Trial 2	36.50	35.50
	Trial 3	33.40	32.20
	Trial 4	35.80	34.60
	Trial 5	36.30	35.10
200 Hertz	Trial 1	42.10	40.10
	Trial 2	43.00	41.70
	Trial 3	42.60	40.30
	Trial 4	42.40	40.20
	Trial 5	42.90	39.90
300 Hertz	Trial 1	45.60	42.30
	Trial 2	46.30	42.90
	Trial 3	45.80	42.00
	Trial 4	45.60	42.90
	Trial 5	46.10	44.00
400 Hertz	Trial 1	54.20	49.00
	Trial 2	55.00	50.80
	Trial 3	54.60	50.30
	Trial 4	53.90	49.80
	Trial 5	54.70	50.10
500 Hertz	Trial 1	53.80	46.20
	Trial 2	54.80	47.90
	Trial 3	52.90	48.20
	Trial 4	53.60	47.20

	Trial 5	55.00	48.10
600 Hertz	**Trial 1**	58.30	50.70
	Trial 2	57.60	48.90
	Trial 3	58.70	50.40
	Trial 4	58.90	50.70
	Trial 5	57.90	47.80
700 Hertz	**Trial 1**	63.50	53.80
	Trial 2	62.80	51.50
	Trial 3	64.60	53.70
	Trial 4	63.60	52.30
	Trial 5	62.90	51.80
800 Hertz	**Trial 1**	65.60	53.20
	Trial 2	63.90	50.90
	Trial 3	64.80	51.70
	Trial 4	64.90	52.50
	Trial 5	65.20	53.90
900 Hertz	**Trial 1**	73.70	62.10
	Trial 2	74.30	62.90
	Trial 3	73.90	61.60
	Trial 4	74.50	61.70
	Trial 5	73.20	62.80
1000 Hertz	**Trial 1**	80.60	63.40
	Trial 2	80.90	62.90
	Trial 3	82.40	64.80
	Trial 4	83.80	66.80
	Trial 5	83.90	65.30

Table 1: Initial and transmitted intensities of a sound wave with frequencies 100-1000 Hz through an obstacle that is 5 cm in thickness

- For the obstacle with 10 cm thickness:

	Trials	Incident Intensity of the Sound (dB ± 0.01)	Transmitted Intensity of the Sound (dB ± 0.01)
100 Hertz	Trial 1	35.20	34.80
	Trial 2	36.30	35.80
	Trial 3	35.30	34.20
	Trial 4	34.80	33.50
	Trial 5	35.70	34.60
200 Hertz	Trial 1	42.50	40.10
	Trial 2	42.60	40.40
	Trial 3	43.10	39.90
	Trial 4	42.70	40.20
	Trial 5	42.40	39.90
300 Hertz	Trial 1	46.40	42.10
	Trial 2	45.70	41.30
	Trial 3	46.30	42.60
	Trial 4	47.10	43.50
	Trial 5	45.90	41.80
400 Hertz	Trial 1	53.80	47.90
	Trial 2	54.50	48.80
	Trial 3	55.10	48.70
	Trial 4	55.00	49.60
	Trial 5	53.90	48.10
500 Hertz	Trial 1	54.80	47.30
	Trial 2	54.90	47.40
	Trial 3	55.00	48.20
	Trial 4	54.60	46.30
	Trial 5	54.70	47.40

600 Hertz	**Trial 1**	57.50	48.90
	Trial 2	58.30	52.60
	Trial 3	58.60	47.40
	Trial 4	56.90	47.80
	Trial 5	57.80	48.30
700 Hertz	**Trial 1**	62.90	52.60
	Trial 2	63.70	51.40
	Trial 3	61.50	51.80
	Trial 4	63.50	50.30
	Trial 5	62.30	51.60
800 Hertz	**Trial 1**	66.00	55.20
	Trial 2	65.90	53.70
	Trial 3	65.40	53.30
	Trial 4	66.20	55.50
	Trial 5	65.90	52.90
900 Hertz	**Trial 1**	74.90	60.10
	Trial 2	74.40	61.90
	Trial 3	74.50	60.70
	Trial 4	74.90	63.70
	Trial 5	75.60	62.60
1000 Hertz	**Trial 1**	81.80	65.50
	Trial 2	81.40	64.60
	Trial 3	82.30	61.90
	Trial 4	82.20	66.30
	Trial 5	81.70	61.40

Table 2: Initial and transmitted intensities of a sound wave with frequencies 100-1000 Hz through an obstacle that is 10 cm in thickness

➢ For the obstacle with 15 cm thickness:

	Trials	Incident Intensity of the Sound (dB ± 0.01)	Transmitted Intensity of the Sound (dB ± 0.01)
100 Hertz	Trial 1	36.20	32.40
	Trial 2	35.80	31.40
	Trial 3	36.30	31.90
	Trial 4	35.50	31.60
	Trial 5	35.70	30.60
200 Hertz	Trial 1	41.50	36.70
	Trial 2	42.40	38.70
	Trial 3	41.80	35.90
	Trial 4	42.50	37.40
	Trial 5	41.90	35.80
300 Hertz	Trial 1	45.40	39.30
	Trial 2	45.80	39.60
	Trial 3	45.90	38.90
	Trial 4	46.50	41.50
	Trial 5	46.40	40.30
400 Hertz	Trial 1	54.10	46.30
	Trial 2	54.90	47.20
	Trial 3	55.20	47.90
	Trial 4	54.80	47.60
	Trial 5	55.30	49.10
500 Hertz	Trial 1	56.40	46.20
	Trial 2	57.80	48.30
	Trial 3	54.30	45.50
	Trial 4	56.20	44.80
	Trial 5	55.80	45.30

600 Hertz	**Trial 1**	58.20	47.60
	Trial 2	59.10	49.50
	Trial 3	56.60	48.10
	Trial 4	59.30	48.80
	Trial 5	58.80	47.50
700 Hertz	**Trial 1**	61.90	50.60
	Trial 2	62.40	51.70
	Trial 3	63.60	51.60
	Trial 4	62.60	51.20
	Trial 5	63.20	50.90
800 Hertz	**Trial 1**	66.20	51.70
	Trial 2	65.90	50.40
	Trial 3	65.60	51.10
	Trial 4	65.70	50.00
	Trial 5	66.00	51.20
900 Hertz	**Trial 1**	75.10	58.70
	Trial 2	75.20	59.20
	Trial 3	73.90	57.70
	Trial 4	74.80	58.60
	Trial 5	74.70	60.50
1000 Hertz	**Trial 1**	80.80	60.40
	Trial 2	83.00	62.80
	Trial 3	82.60	64.50
	Trial 4	81.90	61.20
	Trial 5	82.40	61.90

Table 3: Initial and transmitted intensities of a sound wave with frequencies 100-1000 Hz through an obstacle that is 15 cm in thickness

e) Data Calculations:

In order to evaluate the average values of collected data, mean values of 5 trials for each frequency in 3 different obstacles are calculated by using the equation:

$$Mean^{13} = \frac{\sum x}{n}$$

The uncertainty is calculated by the formula:

$$Uncertainty^{14} = \frac{Maximum\ value - Minimum\ value}{2}$$

Example mean and uncertainty calculation for the incident intensity of the sound with the 5cm obstacle for 5 trials:

$$\frac{36.2 + 36.5 + 33.4 + 35.8 + 36.3}{5} \pm \frac{36.5 - 33.4}{2} = 35.6 \pm 1.55\ dB$$

[13] https://www.purplemath.com/modules/meanmode.htm
[14] https://www.bellevuecollege.edu/physics/resources/measure-sigfigsintro/f-uncert-percent/

	Mean of the Incident Intensity of the Sound with the 5 cm-obstacle (dB)	Mean of the Transmitted Intensity of the Sound with the 5 cm-obstacle (dB)	Mean of the Incident Intensity of the Sound with the 10 cm-obstacle (dB)	Mean of the Transmitted Intensity of the Sound with the 10 cm-obstacle (dB)	Mean of the Incident Intensity of the Sound with the 15 cm-obstacle (dB)	Mean of the Transmitted Intensity of the Sound with the 15 cm-obstacle (dB)
100 Hertz	35.60 ± 1.55	34.60 ± 1.65	35.50 ± 0.75	34.60 ± 1.15	35.90 ± 0.40	31.60 ± 0.90
200 Hertz	42.60 ± 0.45	40.40 ± 0.90	42.70 ± 0.35	40.10 ± 0.25	42.00 ± 0.50	36.90 ± 1.45
300 Hertz	45.90 ± 0.35	42.80 ± 1.00	46.30 ± 0.70	42.30 ± 1.10	46.00 ± 0.55	39.90 ± 1.30
400 Hertz	54.50 ± 0.55	50.00 ± 0.90	54.50 ± 0.65	48.60 ± 0.85	54.90 ± 0.60	47.60 ± 1.40
500 Hertz	54.00 ± 1.55	47.50 ± 1.00	54.80 ± 0.20	47.30 ± 0.95	56.10 ± 1.75	46.00 ± 1.75
600 Hertz	58.30 ± 0.65	49.70 ± 1.45	57.80 ± 0.85	49.00 ± 2.60	58.40 ± 1.35	48.30 ± 1.00
700 Hertz	63.50 ± 0.90	52.60 ± 1.15	62.80 ± 1.10	51.50 ± 1.15	62.80 ± 0.85	51.20 ± 0.55
800 Hertz	64.90 ± 0.85	52.40 ± 1.50	65.90 ± 0.40	54.10 ± 1.30	65.90 ± 0.30	50.90 ± 0.85
900 Hertz	73.90 ± 0.65	62.20 ± 0.65	74.90 ± 0.60	61.80 ± 1.80	74.70 ± 0.65	58.90 ± 1.40
1000 Hertz	82.30 ± 1.65	64.60 ± 1.95	81.90 ± 1.30	63.90 ± 2.45	82.10 ± 1.10	62.70 ± 1.95

Table 4: Means of the initial and transmitted intensities of a sound wave with frequencies 100-1000 Hz through obstacles that are 5, 10 and 15 cm in thickness

The transmission coefficient is calculated by using Equation 2 to find the Sound Transmission Loss of the frequencies through the obstacles with different thicknesses. The uncertainty of the transmission coefficient is found by converting the absolute uncertainties to percentage, adding them together and converting them to absolute uncertainty by using the formula:

$$Percentage\ Uncertainty^{15} = \frac{Absolute\ Uncertainty\ x\ 100}{Value}$$

Example calculation for the percentage uncertainty of the mean of the incident and transmitted intensity of the sound with the 5 cm-obstacle:

$$Percentage\ Uncertainty = \frac{1.55\ x\ 100}{35.60} = 4.35$$

[15] https://www.bellevuecollege.edu/physics/resources/measure-sigfigsintro/f-uncert-percent/

$$Percentage\ Uncertainty = \frac{1.65\ x\ 100}{34.60} = 4.76$$

$$Total\ Pecentage\ Uncertainty = 4.76 + 4.35 = 9.12\ \%$$

Example calculation for the transmission coefficient value in 100 Hz with the 5 cm-obstacle:

$$\tau = \frac{34.6}{35.6} = 0.97$$

$$Absolute\ Uncertainty = \frac{9.12}{100} x\ 0.97 = 0.06$$

Therefore, the transmission coefficient of the obstacle with 5 cm thickness is:

$$\tau = 0.97 \pm 0.06$$

	Transmission Coefficient of the 5 cm-obstacle	**Transmission Coefficient of the 10 cm-obstacle**	**Transmission Coefficient of the 15 cm-obstacle**
100 Hertz	0.97 ± 0.06	0.96 ± 0.04	0.88 ± 0.03
200 Hertz	0.95 ± 0.02	0.94 ± 0.01	0.88 ± 0.04
300 Hertz	0.93 ± 0.02	0.91 ± 0.03	0.87 ± 0.03
400 Hertz	0.92 ± 0.03	0.89 ± 0.02	0.87 ± 0.03
500 Hertz	0.88 ± 0.03	0.86 ± 0.02	0.82 ± 0.04
600 Hertz	0.86 ± 0.03	0.85 ± 0.05	0.83 ± 0.03
700 Hertz	0.83 ± 0.02	0.82 ± 0.02	0.81 ± 0.01
800 Hertz	0.81 ± 0.03	0.81 ± 0.02	0.77 ± 0.01
900 Hertz	0.84 ± 0.01	0.83 ± 0.02	0.79 ± 0.02
1000 Hertz	0.79 ± 0.03	0.78 ± 0.03	0.76 ± 0.03

Table 5: Transmission coefficients of the sound waves with frequencies 100-1000 Hz through obstacles that are 5, 10 and 15 cm in thickness

It can be seen from Table 5 that the lower frequencies generally result in higher transmission coefficients. Therefore, it can be assumed that the higher values will have a lower STL due to

Equation 3 which takes the logarithm of the transmission coefficients. By using the transmission coefficient and Equation 3, the Sound Transmission Loss is calculated. The uncertainty is calculated by using the formula:

$$For\ y = \log a(\pm S_a);$$

$$S_y{}^{16} = 0.434\ x\ \frac{S_a}{a}$$

Example calculation for the STL value for the 100 Hertz sound wave traveling through the 5 cm-obstacle:

$$Sound\ Transmission\ Loss = \ 10 \log \frac{1}{0.97} \pm 0.434\ x\ \frac{0.06}{0.97} = 0.13\ dB\ \pm 0.03$$

	Sound Transmission Loss of the 5 cm-obstacle (dB)	**Sound Transmission Loss of the 10 cm-obstacle (dB)**	**Sound Transmission Loss of the 15 cm-obstacle (dB)**
100 Hertz	0.13 ± 0.03	0.18 ± 0.02	0.56 ± 0.01
200 Hertz	0.22 ± 0.01	0.27 ± 0.01	0.56 ± 0.02
300 Hertz	0.32 ± 0.01	0.41 ± 0.01	0.60 ± 0.01
400 Hertz	0.36 ± 0.01	0.51 ± 0.01	0.60 ± 0.01
500 Hertz	0.56 ± 0.01	0.66 ± 0.01	0.86 ± 0.01
600 Hertz	0.66 ±0.01	0.71 ± 0.02	0.81 ± 0.01
700 Hertz	0.81 ± 0.01	0.86 ± 0.01	0.91 ± 0.01
800 Hertz	0.92 ± 0.01	0.92 ± 0.01	1.14 ± 0.01
900 Hertz	0.76 ± 0.04	0.81 ± 0.01	1.02 ± 0.01
1000 Hertz	1.02 ± 0.01	1.08 ± 0.01	1.19 ± 0.01

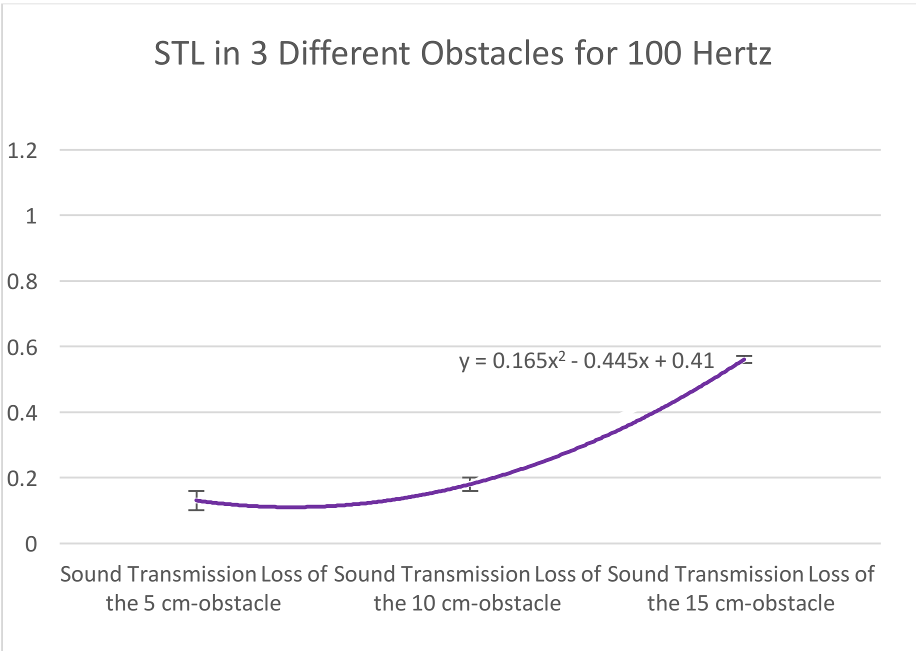
Table 6: Sound Transmission Loss values for the sound waves with frequencies 100-1000 Hz through obstacles that are 5, 10 and 15 cm in thickness

[16] http://chemistry.oregonstate.edu/courses/ch361-464/ch361/Propagation.htm

4. **Analysis:**

a) Comparison in Regards to the Frequencies of the Sound Waves:

- 100 Hertz Sound Wave:

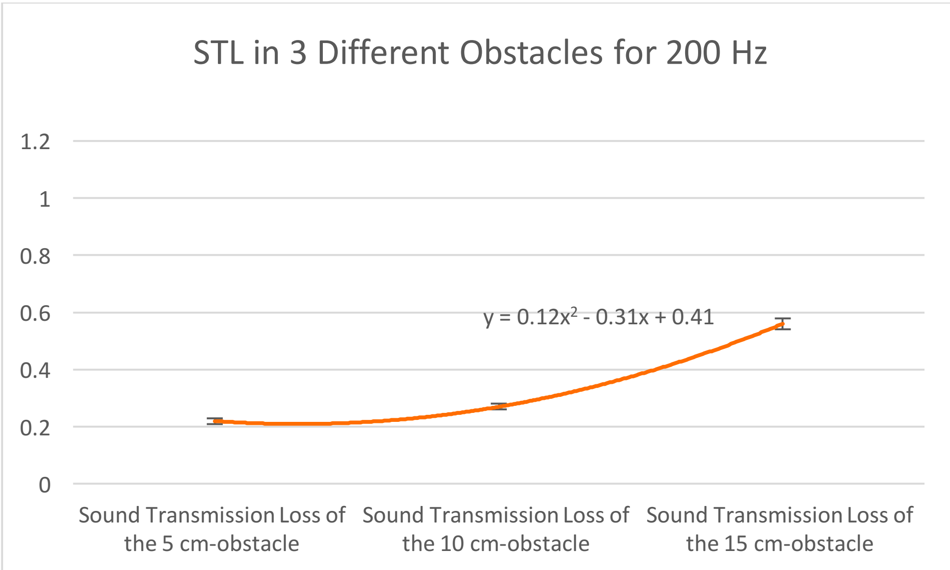


Graph 1: Sound Transmission Loss values for the 100 Hertz sound wave through obstacles that are 5, 10 and 15 cm in thickness

The Graph 1 shows the best-fit line suggested by Microsoft Excel for the STL data of the 100 Hertz sound wave in obstacles 5, 10 and 15 cm thicknesses. As it can be clearly seen from Graph 1 and its equation, for the 100 Hertz sound wave, the relation between the STL and the thickness of the obstacle is increasing concave up. Therefore, the STL increases as the thickness of the obstacle also increases. The error bars for the graph are based on the specific uncertainties each data has, which are given in Table 6.

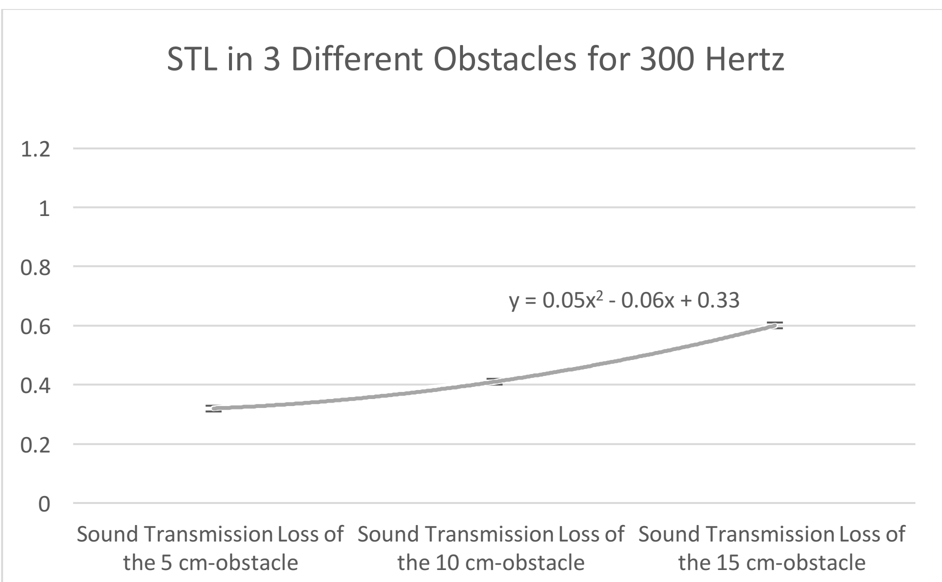
Similar results are obtained from other frequencies as well which can be seen in the graphs given below. All of the graphs display a polynomial trend as increasing concave up, except Graph 4 which showcases increasing concave down and Graph 7 which showcases a linearly increasing relation.

- 200 Hertz Sound Wave:



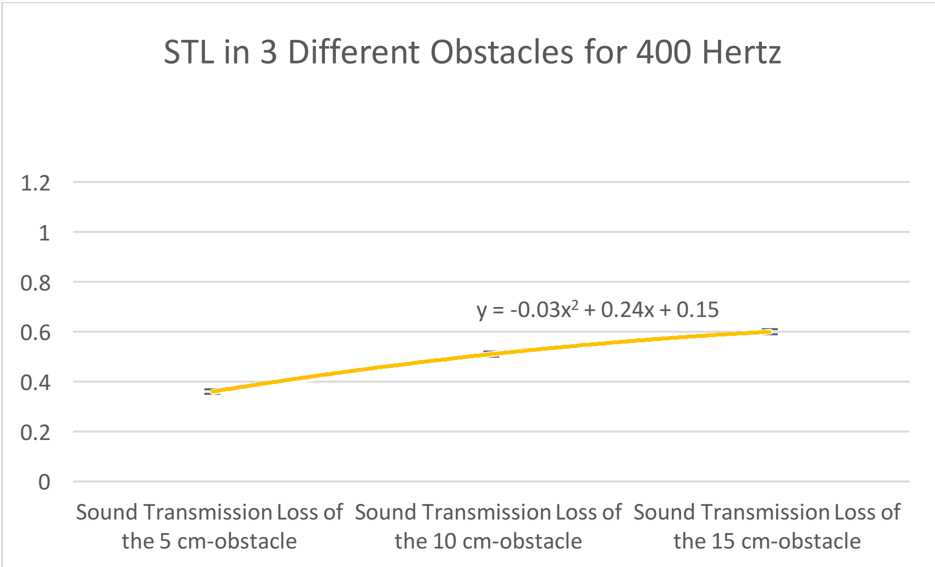
Graph 2: Sound Transmission Loss values for the 200 Hertz sound wave through obstacles that are 5, 10 and 15 cm in thickness

- 300 Hertz Sound Wave:



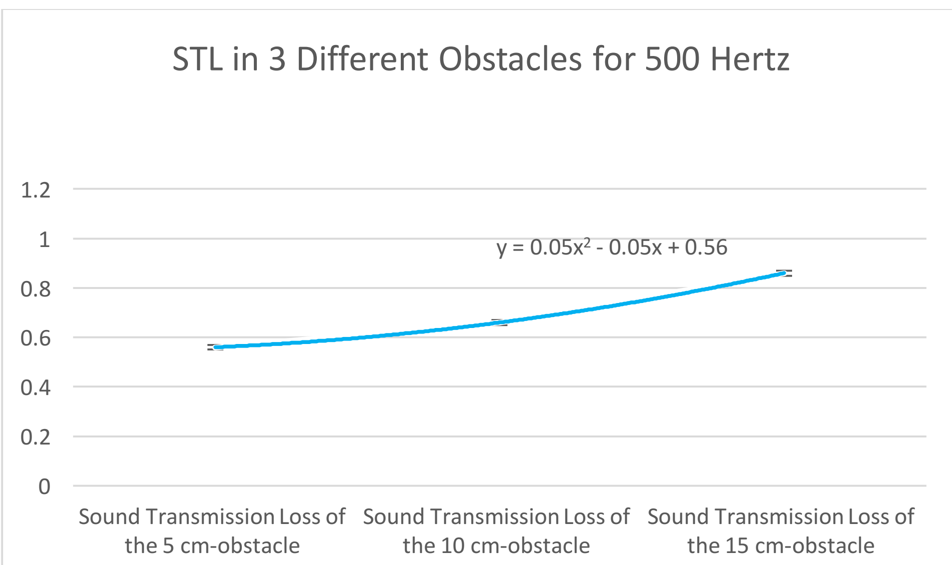
Graph 3: Sound Transmission Loss values for the 300 Hertz sound wave through obstacles that are 5, 10 and 15 cm in thickness (the error bars are too small for the graph to show clearly)

- 400 Hertz Sound Wave:



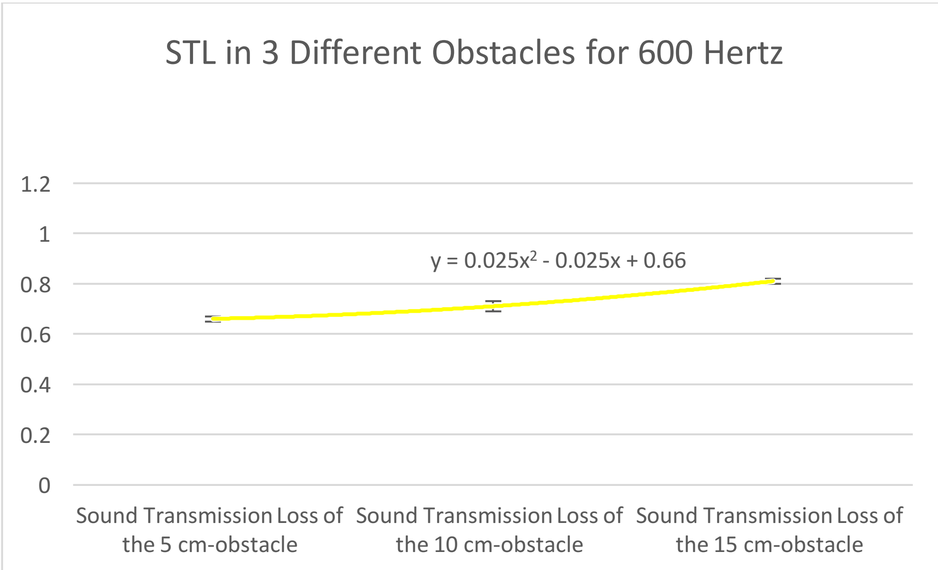
Graph 4: Sound Transmission Loss values for the 400 Hertz sound wave through obstacles that are 5, 10 and 15 cm in thickness (the error bars are too small for the graph to show clearly)

- 500 Hertz Sound Wave:



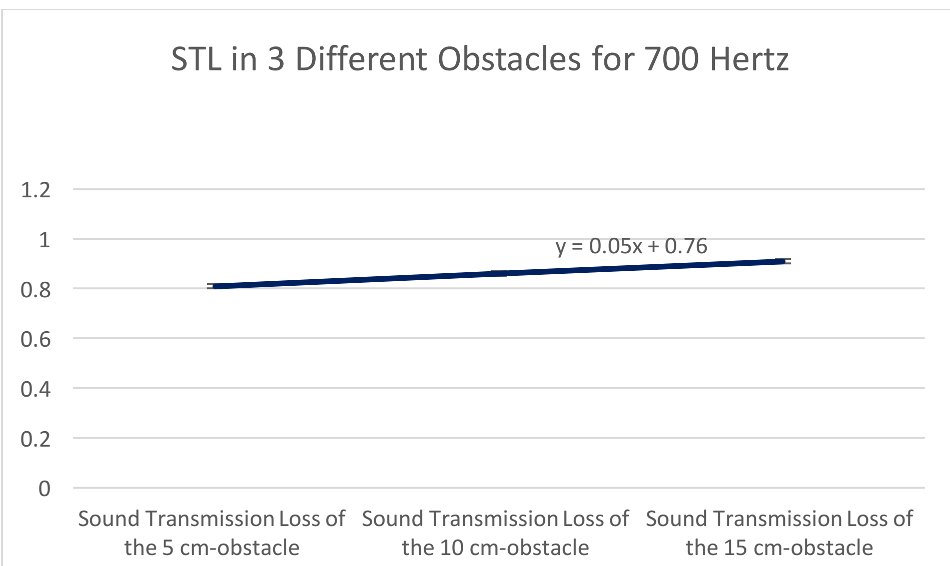
Graph 5: Sound Transmission Loss values for the 500 Hertz sound wave through obstacles that are 5, 10 and 15 cm in thickness (the error bars are too small for the graph to show clearly)

- 600 Hertz Sound Wave:



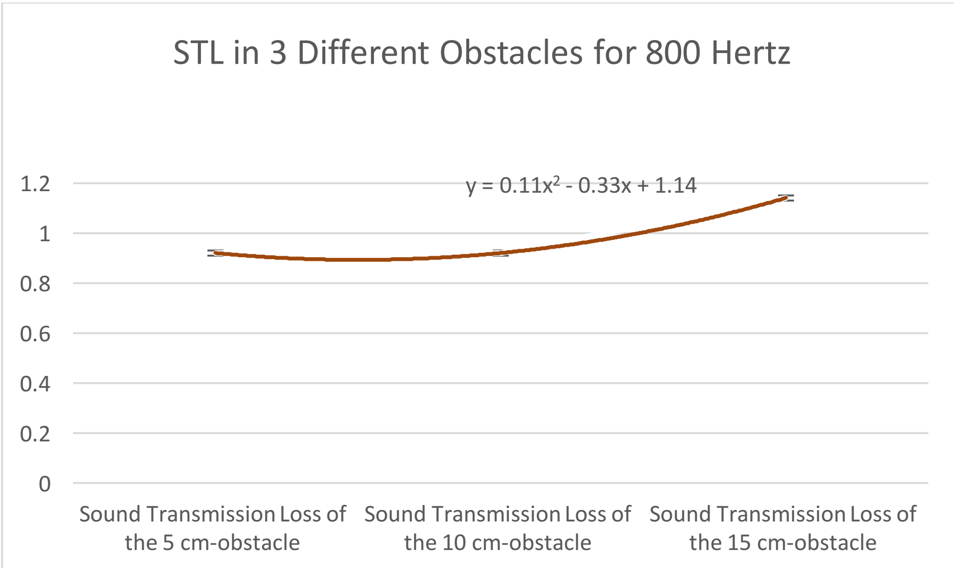
Graph 6: Sound Transmission Loss values for the 600 Hertz sound wave through obstacles that are 5, 10 and 15 cm in thickness (the error bars are too small for the graph to show clearly)

- 700 Hertz Sound Wave:



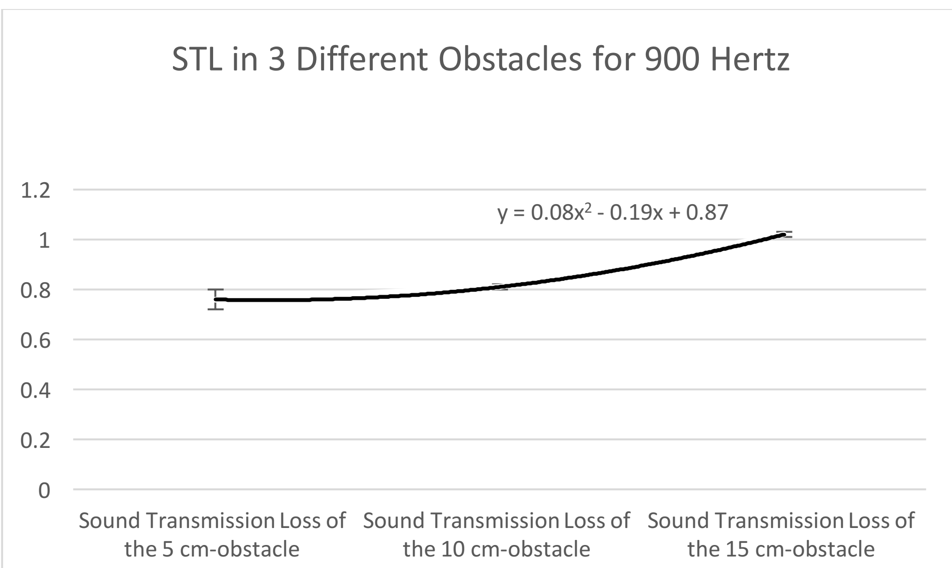
Graph 7: Sound Transmission Loss values for the 700 Hertz sound wave through obstacles that are 5, 10 and 15 cm in thickness (the error bars are too small for the graph to show clearly)

- <u>800 Hertz Sound Wave:</u>



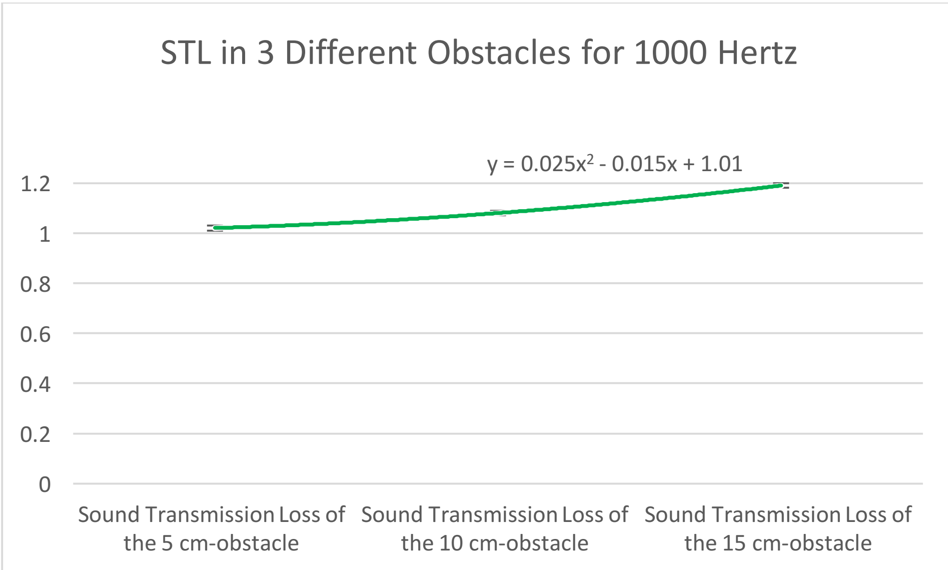
<u>Graph 8: Sound Transmission Loss values for the 800 Hertz sound wave through obstacles that are 5, 10 and 15 cm in thickness (the error bars are too small for the graph to show clearly)</u>

- <u>900 Hertz Sound Wave:</u>



<u>Graph 9: Sound Transmission Loss values for the 900 Hertz sound wave through obstacles that are 5, 10 and 15 cm in thickness (the error bars are too small for the graph to show clearly)</u>

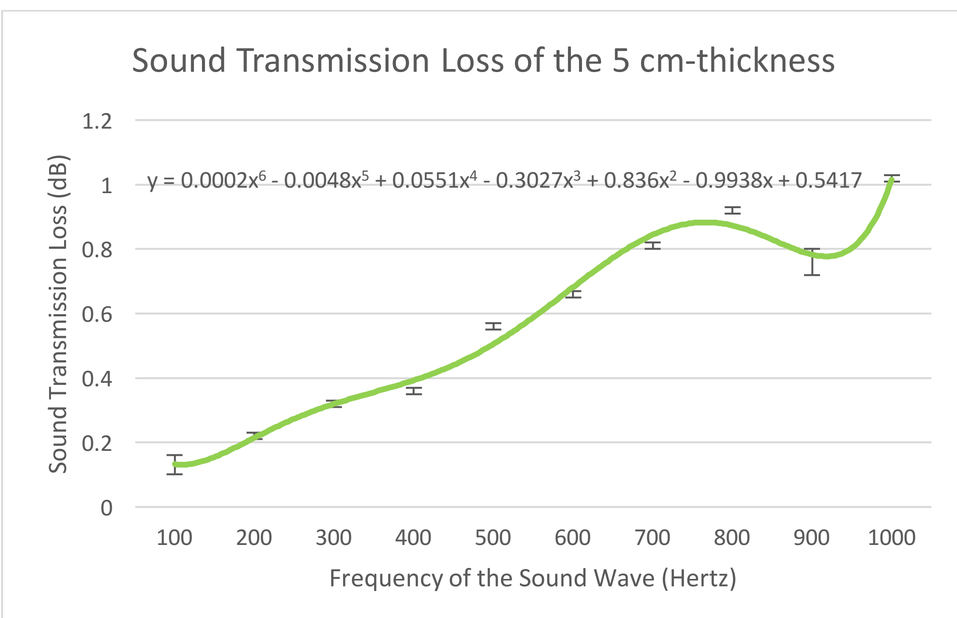
- 1000 Hertz Sound Wave:



Graph 10: Sound Transmission Loss values for the 1000 Hertz sound wave through obstacles that are 5, 10 and 15 cm in thickness (the error bars are too small for the graph to show clearly)

b) Comparison in Regards to the Thickness of the Obstacle:

- Foam Box with 5 cm Thickness:

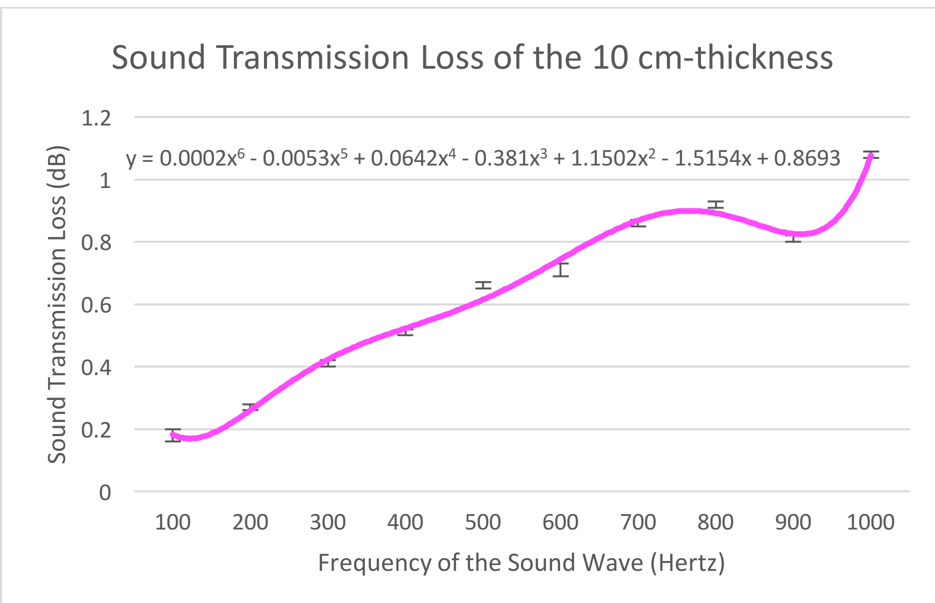


Graph 11: Sound Transmission Loss values for the 100-1000 Hertz sound wave through the obstacle with 5 cm in thickness

The Graph 11 shows the best-fit line and its equation Microsoft Excel suggested for the STL of the sound frequencies 100-1000 through an obstacle with 5-cm thickness. It can be seen that there is not a linear relation between the STL and frequency of the sound wave. However, the general trend is increasing, although it peaks in the 800 Hertz sound wave and decreases for the 900 Hertz sound wave. The error bars for the graph are based on the specific uncertainties each data has, which are given in Table 6.

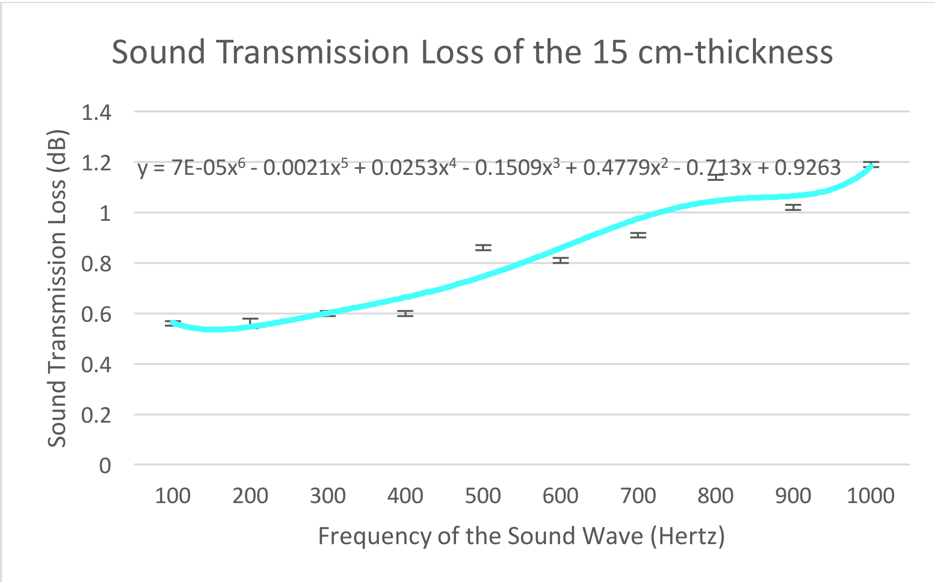
Similar behaviors are also observed in the obstacles with thicknesses 10 and 15 cm which are illustrated in Graph 12 and 13. This suggests that foam box absorbed more energy in 800 and 1000 Hertz sound waves which is linked to resonance effects.

- <u>Foam Box with 10 cm Thickness:</u>



<u>Graph 12: Sound Transmission Loss values for the 100-1000 Hertz sound wave through the obstacle with 10 cm in thickness</u>

- Foam Box with 15 cm Thickness:



Graph 13: Sound Transmission Loss values for the 100-1000 Hertz sound wave through the obstacle with 15 cm in thickness

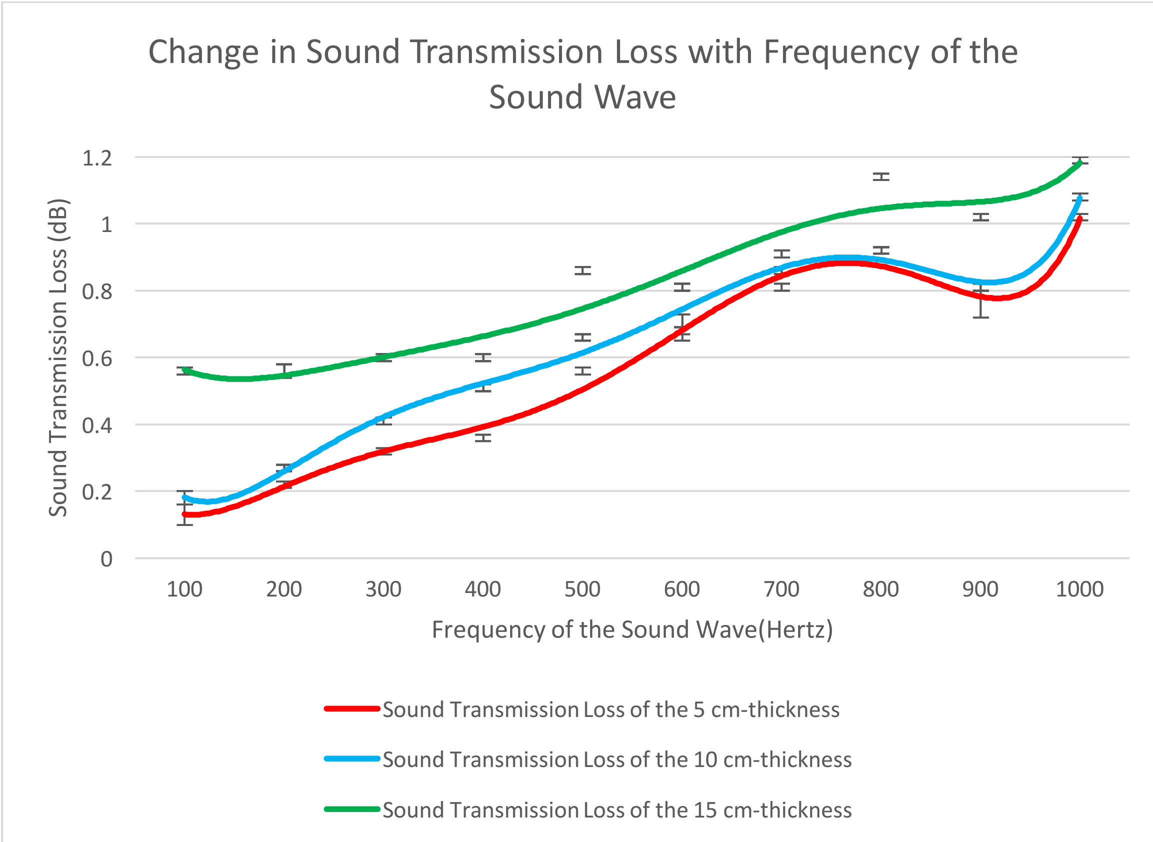
5. Conclusion, Discussion and Evaluation:

a) Results:

The aim of this experiment is to find the relation between the frequency of the sound wave and the Sound Transmission Loss through an obstacle with varying thicknesses. The frequency is generated by the application Tone Generator: Audio Sound Hz and the intensity is detected by the application Decibel X. The use of smartphones as measurement tools ensure that the experiment materials are reusable and easy so that the experiment can be repeated.

The hypothesis that suggests the STL and frequency of the sound wave will increase proportionally was supported by the experiments. Although the results of the experiment and Graphs 11, 12 and 13 show that the STL increases with the frequency of the sound, it is not a linear relation. For the first experimental setup, the STL for 600 and 900 Hertz disrupt the trend line. In the dataset for the second setup, only 900 Hertz breaks the best-fit line whereas for the third experimental setup, 400 and 900 Hertz disrupt the linear form. These may be due to the random errors mentioned in "Limitations and Their Effects", but because the deviation for 900 Hertz is present in all three experiments, the reason may emerge from systematical error. Another plausible explanation for the non-linear behaviors can be the resonance quality of the foam box. Although the STL values are higher for the thickest obstacle, the fluctuations coincide at 900 Hertz. Therefore, it can be inferred that the STL values depend on the thickness of the obstacle but it is the material that determines the general trend for the STL of different frequencies.

In conclusion, as it can be seen from Graph 14, STL values generally increase with frequency for all the three obstacles. However, the 15-cm obstacle has the highest STL value and the 5-cm obstacle has the lowest STL value.



Graph 14: Change in Sound Transmission Loss values for the 100-1000 Hertz sound waves through the obstacle with 5, 10 and 15 cm in thickness

b) Comparison to Similar Experiments:

There are numerous research papers and studies done on the subject of Sound Loss Transmission, specifically in the branches of building acoustics and noise minimization. These papers usually focus on the effect of the obstacle's material on STL, thus finding the optimal conditions for canceling the noise as much as possible. The general results obtained are coherent with this investigation. For example, NRC Publications published a study where the relation between the frequency of the sound wave and the materials with different absorbing qualities are compared[17]. The results also display an increasing trend, but a constant value for frequencies between 100-400

[17] https://nrc-publications.canada.ca/eng/view/fulltext/?id=74d6f3a0-fb04-4b01-99d2-f6a24c7791fc

Hertz. This may be due to the difference in attenuation of the material that NRC Publication used and the foam box.

Another study done in British Columbia University in May, 2013 investigates the relation between the thickness of the material and the STL[18]. The results show that as thickness increases the STL generally increases, which is also consistent with this paper.

c) Accuracy of the Experimental Data:

In order to compare the accuracy of the data, the percent uncertainty is calculated by the equation:

$$\frac{Absolute\ Uncertainty}{Data} = \frac{Percent\ Uncertainty}{100}$$

Example calculation for STL of the 5 cm-obstacle:

$$\frac{0.03\ x\ 100}{0.13} = 23.08\ \%$$

The results of the other data's calculations are shown in Table 7.

[18] Angkiriwang, Patricia, and Winnie Peng. "The Walls Are Thin: Measuring Sound Transmission through Different Thicknesses of Plywood." May, 2013. Pdf Document.

	Percent Uncertainty for the Sound Transmission Loss of the 5 cm-obstacle	Percent Uncertainty for the Sound Transmission Loss of the 10 cm-obstacle	Percent Uncertainty for the Sound Transmission Loss of the 15 cm-obstacle
100 Hertz	0.23	0.11	0.02
200 Hertz	0.05	0.04	0.04
300 Hertz	0.03	0.02	0.02
400 Hertz	0.03	0.02	0.02
500 Hertz	0.02	0.02	0.01
600 Hertz	0.02	0.02	0.01
700 Hertz	0.01	0.01	0.01
800 Hertz	0.01	0.01	0.01
900 Hertz	0.05	0.01	0.01
1000 Hertz	0.01	0.01	0.01

Table 7: Percent uncertainty values for the sound waves with frequencies 100-1000 Hz through obstacles that are 5, 10 and 15 cm in thickness

It can be seen from Table 7 that the percent uncertainty data range from 0.23 to 0.01. Although generally it is low and the experiment is considered to be accurate, the percent uncertainty is relatively high for the sound waves with frequencies 100 and 200 Hertz. Therefore, it can be inferred that the experimental data are more accurate for frequencies between 300-1000 Hertz whereas they are relatively less accurate for the frequencies 100 and 200 Hertz. However, this may be a due to the lower range of data for the frequencies 100 and 200 Hertz as percentage uncertainty depends on the ratio of the uncertainty to the data.

d) Precision of the Experimental Data:

To appraise the error in this exploration and perceive the differences in the sound intensities, the sample standard deviations of the mean intensities of the incident and transmitted sound waves are calculated by using the equation:

$$\sigma = \sqrt{\frac{\sum(x_i - \mu)^2}{n}}$$

Example calculation for the standard deviation of the initials sound intensity of the 100 Hz sound wave with the 5 cm-obstacle:

$$\sqrt{\frac{(36.2-35.6)^2+(36.5-35.6)^2+(33.4-35.6)^2+(35.8-35.6)^2+(36.3-35.6)^2}{5}} = 1.14$$

	Standard Deviation of the Mean of the Incident Intensity of the Sound with the 5 cm-obstacle	**Standard Deviation of the Mean of the Transmitted Intensity of the Sound with the 5 cm-obstacle**	**Standard Deviation of the Mean of the Incident Intensity of the Sound with the 10 cm-obstacle**	**Standard Deviation of the Mean of the Transmitted Intensity of the Sound with the 10 cm-obstacle**	**Standard Deviation of the Mean of the Incident Intensity of the Sound with the 15 cm-obstacle**	**Standard Deviation of the Mean of the Transmitted Intensity of the Sound with the 15 cm-obstacle**
100 Hertz	1.14	1.22	0.57	0.84	0.30	0.59
200 Hertz	0.32	0.64	0.24	0.19	0.38	1.07
300 Hertz	0.28	0.68	0.48	0.75	0.40	0.91
400 Hertz	0.39	0.60	0.54	0.60	0.42	0.91
500 Hertz	0.78	0.75	0.14	0.60	1.12	0.91
600 Hertz	0.48	1.16	0.60	1.87	0.97	1.22
700 Hertz	0.64	0.96	0.81	0.74	0.60	0.75
800 Hertz	0.56	1.06	0.26	1.04	0.21	0.41
900 Hertz	0.46	0.54	0.42	1.29	0.46	0.60
1000 Hertz	1.39	1.39	0.33	1.95	0.76	1.41

Table 8: Standard deviations of the means of the initial and transmitted intensities of a sound wave with frequencies 100-1000 Hz through obstacles that are 5, 10 and 15 cm in thickness

To evaluate the magnitude of the standard deviations as high or low, the 30% of the means are calculated. If the standard deviation values pass that threshold, it is considered high. Referring to Table 4 and Table 8, every standard deviation data is below the threshold. Therefore, it can be said that the overall precision is high for the experimental values. However, a close investigation indicates that the frequencies that have lower data are more precise than the higher frequencies, thus leading to a more accurate value for the initial and transmitted intensities.

e) Limitations and Their Effects:

1. The medium in which the experiment is conducted is not soundproof. Therefore, the existence of different sound waves may disrupt the data. Noise canceling devices can be placed in the medium or the experiment can be conducted in a soundproof medium.
2. Smartphone applications are used for measurements, so the readings are less credible. Frequency generating and sound level measuring advanced devices can be used.
3. Limited trials may give insufficient conclusions and this experiment was done for 5 trials. Hence, the experiment can be done with more trials to increase its validity.

f) Applications:

The implications of this experiment are that the STL varies with the frequency of the sound wave and the thickness of the obstacle. It is critical to increase STL in our daily lives as it may drastically affect our productivity, communication and health. The data from the experiment suggest that while constructing a building, it can be built with the specific needs and the prominent sound qualities considered, thus minimizing the STL. As the data show, because low frequency sound waves tend to have low STL values, the places where the low frequency sound waves are prominent should be equipped with better absorbing materials. On the other hand, higher frequency sound waves do not need the extra material as they generally have a higher STL value. In addition, the experiment results and Graph 14 also implies that the thickness of the obstacle is not very significant. This means that the additional layers of equipment in soundproofing may be unnecessary and reduction in the materials used can be achieved.

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