24 (7)

The Relationship between Frequency and Sound Absorption

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12/7/2015

Database/Sim

#1

Introduction

A couple months ago, I worked as a sound mixer for a student musical theatre production. This means I controlled the microphones, sound effects, and overall soundscape of the production. Some of the most important things were making sure the orchestra and singers were balanced and that it wasn't too loud or too quiet overall. One thing I noticed while doing this was the difference of sound level during a rehearsal, when the majority of the seats were empty, and during a performance, when the majority of the seats were full. I became interested in sound absorption. The purpose of this investigation is to determine what factors affect the amount of sound that gets absorbed.

When a wave, such as a sound wave, encounters a barrier (a change in medium), some of the wave reflects off of the barrier and bounces back in the direction it came from, while some gets absorbed by the medium. The amount which gets reflected versus the amount that gets absorbed depends on things such as the materials, angle of impacts, and frequency of the wave (Homer 2014).
Sound absorption coefficients represent the percentage of the sound that is absorbed by the material, and are numbers between 0 and 1. The higher the number, the more of the sound is absorbed. For example, a coefficient of 0.65 means that 65% of the sound is absorbed and 35% is reflected. Absorption coefficients are unique for every surface and material, and also depend on factors such as frequency and angle of incident.
The sound absorption coefficient is most commonly used in the Sabine formula, which is as follows:

$$RT_{60} = \underset{\text{for dimensions in meters}}{(0.16\ \text{s/m})} \frac{V}{S_e} = \underset{\text{for dimensions in feet}}{(0.049\ \text{s/ft})} \frac{V}{S_e}$$

$$S_e = \textit{effective absorbing area}$$

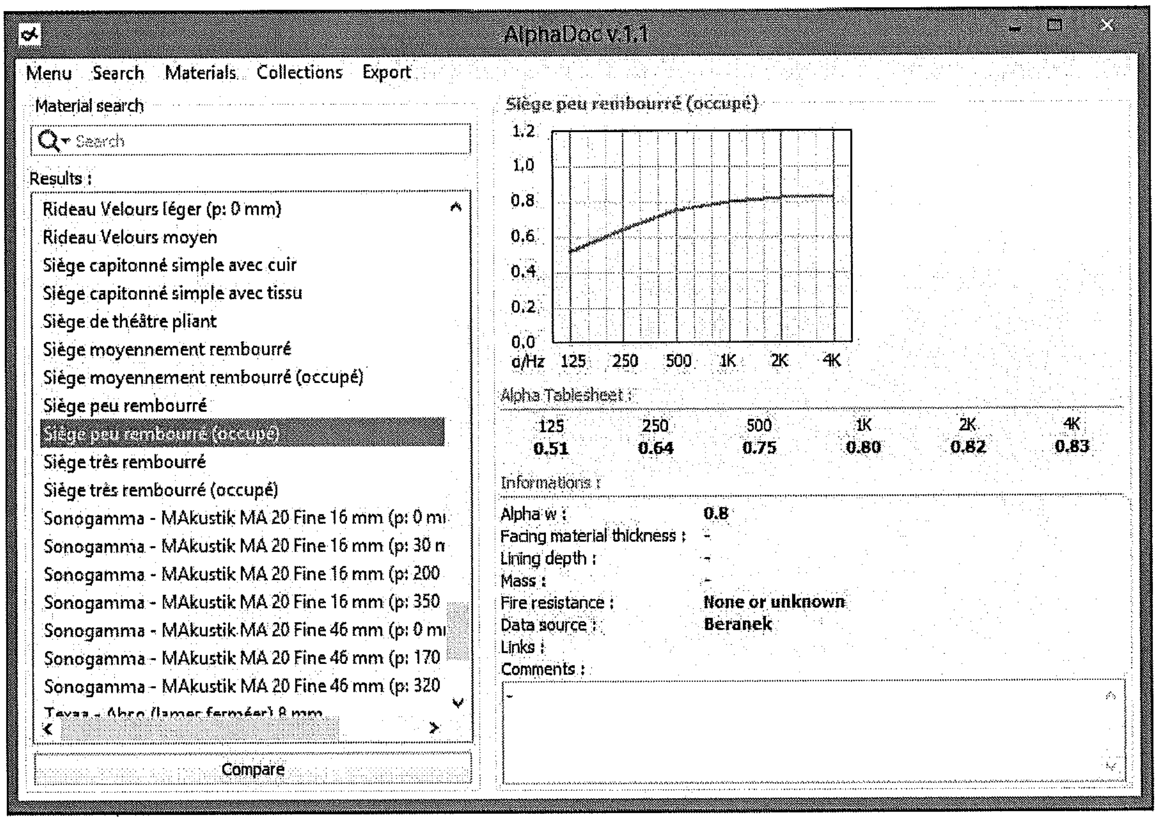
$$S_e = a_1 S_1 + a_2 S_2 + a_3 S_3 + \ldots$$

RT60=reverberation time; V=volume; a=sound absorption coefficient; S=area (various surfaces)

The effective absorbing area has a unit of sabins, but the sound absorption coefficient itself does not have a unit. ("Modeling" 2012)

Methodology

At first, I thought a simulation experiment would be best. However, when I found an excellent simulator, called ODEON Room Acoustics Software, I ran into difficulties while trying to download it on my computer. After looking a bit further, I came across a database that could give me the information I needed and, more importantly, I was able to download. The database is called AlphaDoc, downloaded from the website Free Acoustics. Once I could see exactly what kind of information I would be getting, I could develop my focused research question: How does frequency affect the sound absorption coefficient of an occupied theater seat? I hypothesized that as frequency increased, sound absorption increased as well, because higher frequencies produce smaller waves, so more of them could be absorbed by the same surface.
I chose an occupied theater seat as my surface due to my interest in theater acoustics.
From there I searched the database to obtain my data.



The frequency of a wave, measured in hertz (hz), is essentially the speed of a wave. It measures how many cycles the wave goes through per second, and is related to how long or short the waves are. For sound waves, frequency determines pitch. A higher-pitched sound has a higher frequency, and a lower-pitched sound has a lower frequency. One commonly known frequency, at least for musicians, is A440, the tuning pitch. It's the A above Middle C, and has a frequency of 440 hz, meaning that 440 waves cycle through every second (Homer 2014).

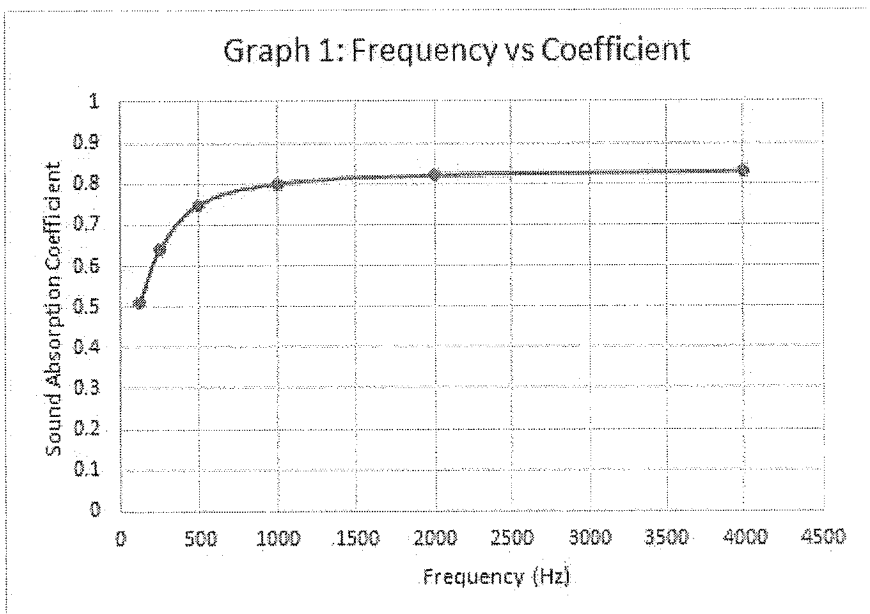
Results and Analysis

The database supplied the following information:

Table 1: Frequency vs Coefficient

frequency (hz)	125	250	500	1,000	2,000	4,000
absorption coefficient of an occupied theater seat	0.51	0.64	0.75	0.80	0.82	0.83

Margin of error is not presented because it was not provided in the database.
The information is presented in a graph below:



This is not a direct relationship because the graph is not linear. At first I thought the relationship might be a power relationship or a natural log relationship, but those graphs were not linear either. I then concluded that this could possibly be a double-inverse relationship, with an asymptotic boundary of y=1. Since the percent absorption cannot be over 100%, the y value cannot exceed 1.

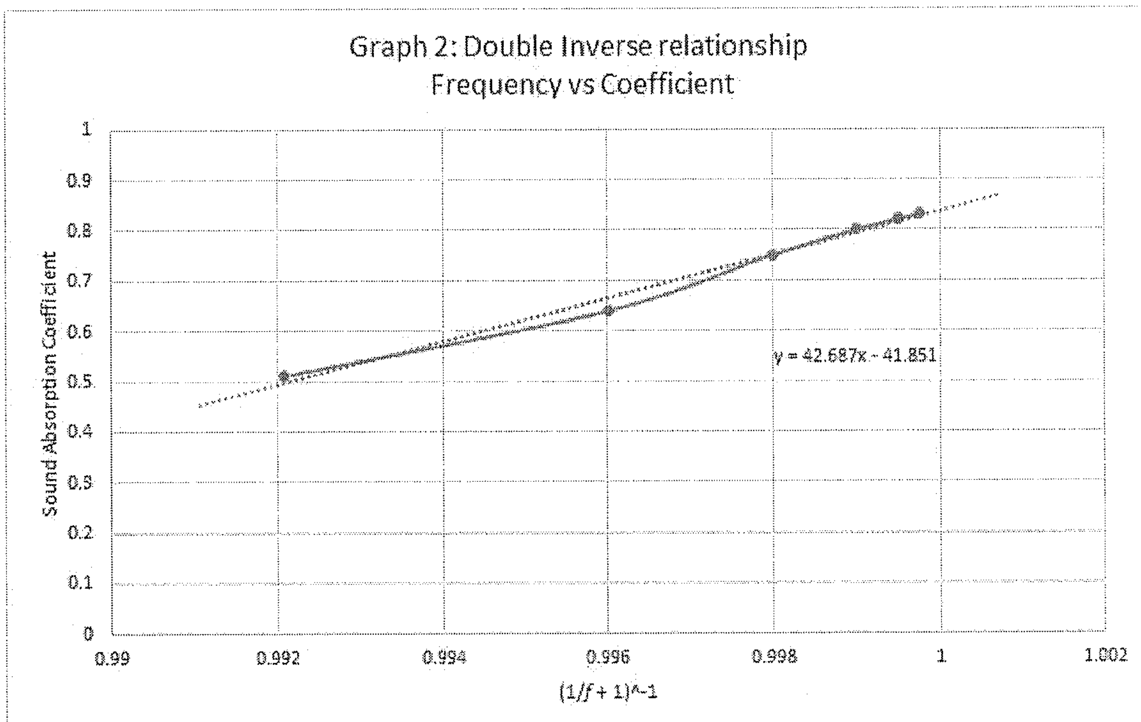
The formula for a double-inverse relationship takes the form $\frac{1}{y} = \frac{1}{x} + \frac{1}{a}$ where *a* is the asymptote. For this situation, *a*=1, so the equation would be as such: $\frac{1}{c} = \frac{1}{f} + 1$ where *c* is the sound absorption coefficient and *f* is the frequency in hertz. This can be rearranged to obtain a direct relationship by taking both sides to the power of -1, for a result of: $c = a(\frac{1}{f} + 1)^{-1} + b$ where *a* is the slope and *b* is the y-intercept.

That equation is represented in the following table:

Table 2: Double Inverse Relationship of Frequency and Coefficient

$(\frac{1}{f} + 1)^{-1}$	0.992	0.996	0.998	0.999	1.000	1.000
absorption coefficient	0.51	0.64	0.75	0.8	0.82	0.83

as well as the following graph:



Be sure to note that the *y*-boundary of the graph is not the *y*-axis due to the small range of data. This is a linear graph, so there is a direct relationship between the sound absorption coefficient and the double inverse of the frequency. The slope and y-intercept of the trend line (dotted) were calculated on the graph in terms of *y* and *x*. In terms of coefficient and frequency, the equation would be $c = 42.687(\frac{1}{f} + 1)^{-1} - 41.851$ To determine the significance of this, the fact that the inverse of frequency is period may have to be taken into account. Period is the amount of time it takes for one wave cycle to occur (Homer 2014). Perhaps the true relationship is an inverse relationship between sound absorption coefficient and period; as the period increases, the sound absorption coefficient decreases by a factor of approximately 42.687. Since the *y*-intercept value is negative, it is irrelevant, because neither frequency nor a sound absorption coefficient can be negative.

Conclusion and Evaluation

A double inverse relationship can be concluded between the frequency of sound waves and the absorption coefficient of an occupied theater seat. Since the inverse of frequency is period, there is a possible inverse relationship between sound absorption coefficient and period with a gradient of 42.687.

A strength of this investigation is the consistency. The database provided unchanging numbers, and no actual experimentation was done. This diminishes possible sources of error.

A weakness in the investigation is the lack of information from the database. While it provided the data, it did not include very much information in regards to the materials. Although something like dimensions may not have been essential to determining the sound absorption coefficient, the materials that the occupied theater seat consisted of would be useful for real life applications. Additionally, only six data points were offered. More data points would create a stronger investigation. A source of error in the investigation may be in translation: the database was downloaded in French, and I was unable to switch it into English. A simple online translator solved the problem, but it is possible there were minutia that were lost in translation.

This investigation can be applied to some other substances. A simple glance through the database of all the different materials and their sound absorption coefficients reveals that while some materials have similar data trends, others have extremely different ones. This can be explained by the different types of absorbers: pours absorbers, resonance absorbers, and single absorbers, which all have different methods of sound absorption, and therefore respond differently to frequency changes. An occupied theatre seat is a single absorber, so other single absorbers most likely have similar data trends, while pours and resonance absorbers may have radically different ones ("Sound" 2015).

Future studies could investigate the relationship between period and sound absorption coefficient in order to determine if that is an inverse relationship as predicted here. Sound absorption coefficient trends of other materials could be compared to that of the occupied theater seat. The role of people in a space would also have a relationship to theater acoustics and could be investigated.

Works Cited

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