Andrew Conner
Trevor Figge
Logan Anderson
PHY 2010.01
Dr. Scott Hawley

Room Tuning

Abstract

For this project we took an in-depth look at room tuning and various methods of absorption to target problem room modes. Through using room analysis software and manipulating absorption equations we went through the process of analyzing and acoustically treating a room. Our physical measurements were to analyze the room's reverb time and dimensions, while our theoretical treatment focused on creating a plan consisting of specifications of absorbers and diffusers that would address room modes.

Introduction

For our project, we used Andrew's bedroom for our measurements and hypothetical dimensions. The objective of the project was to control the various problem frequencies present in a home studio (bedroom) and flatten the room's frequency response. We approached the project hoping to better our understanding of room tuning and the various things that can be done in order to change an average bedroom into a bedroom/mixing studio - a problem which many audio students encounter both during and after college.

We came in with remedial knowledge of room modes, reverberation and how to target room modes with various types of absorption. Most of this knowledge was gained through reading The Physics of Sound, by Richard Berg and David C. Stork, and Master Handbook of

Acoustics, by F. Alton Everest. This reading was complemented by doing various homework problems dealing with room modes, reverberation, and absorption.

We began by measuring the room's dimensions along the x, y, and z axes. After that we input the x, y and z values into the following equation:

$$f_{n_1 n_2 n_3} = \frac{V_s}{2}\sqrt{\frac{n_1^2}{L^2} + \frac{n_2^2}{W^2} + \frac{n_3^2}{H^2}}$$

(Fig. 1: room mode calculation equation)

In this equation the L, W, H values represent the rooms dimensions along the x, y and z axes. Next, we simply input the speed of sound, which is 1140 ft/s for Vs. After this we applied the values for n_1, n_2, and n_3 from the table shown below in Figure 2. By doing this we calculated room modes and the axes on which they occur.

Mode Sum	nx	ny	nz	Freq. (Hz)	Graph Y
1	0	0	1	63.6	1
1	0	1	0	37.3	1
1	1	0	0	39.5	1
2	0	0	2	127.2	1
2	0	1	1	73.7	1
2	0	2	0	74.6	1
2	1	0	1	74.9	1
2	1	1	0	54.3	1
2	2	0	0	79.1	1
3	0	0	3	190.8	1
3	0	1	2	132.6	1
3	0	2	1	98.0	1
3	0	3	0	111.8	1
3	1	1	1	83.7	1
3	1	0	2	133.2	1
3	1	2	0	84.4	1
3	2	0	1	101.5	1
3	2	1	0	87.4	1
3	3	0	0	118.6	1
4	0	0	4	254.5	1
4	0	1	3	194.5	1
4	0	2	2	147.5	1
4	0	3	1	128.7	1
4	0	4	0	149.1	1
4	1	1	2	138.3	1
4	1	2	1	105.7	1

(Fig 2: room mode calculation chart)

We also calculated the room's reverb time. This was done using the Sabine equation (in order to deduce rough numbers) as well as SHAART. We used SHAART to measure the room's reverb time by creating impulse responses by slamming a book on the floor five times. We then measured the reverb times in SHAART. Once this was done we were also able to detect the frequencies that were causing a longer reverberation time and the frequencies that were dissipating quickly.

After the initial measurements were taken and we had found the frequencies we wanted to target, we went about selecting the absorption methods that we would use. We choose to use perforated panel absorbers (for bass frequencies), diaphragmatic panel absorbers (for bass frequencies), porous absorption (for treble frequencies) and quadratic residue diffusers.

It is important to note the following: porous absorbers work by converting a sound source's acoustic wave energy into heat, which is done through friction. Also, soft porous materials are useful for damping high frequencies because air can move through them; but the moving air suffers multiple collisions with the foamy material.

Next we began calculating the specifications for diaphragmatic panel absorbers using the following formula:

$$F = \frac{170}{\sqrt{md}}$$

(Fig. 3 Diaphragmatic absorber equation: resonant frequency of a certain depth)

In this instance m equals the surface density in lbs/ft^2 and d is the air gap in inches. We then plugged our numbers into this equation.

Once we solved for the diaphragmatic panel absorbers, we moved onto consider perforated panel absorbers. We determined the specifications for these very similarly to the way

$$F = 200\sqrt{\frac{P}{td}}$$

[1]

that we determined those for diaphragmatic panel absorbers, but used the following equation:

(Fig 4: Equation used to solve for perforated panel absorbers)

In this instance P stands for the perforation percentage, which is $\frac{\text{the area of holes}}{\text{the area of panel}} \text{ X } 100$.

On the other hand t = t + 1.6L, and yet again d is equal to the air gap.

Another important room treatment method to consider is diffusion. Diffusion is used to spread the sound around the room rather than letting it sit in one area and build up energy. There are a few things to keep in mind when building a diffuser. Two of are well width and diffuser bandwidth (set by the highest and lowest frequencies in that the diffuser will affect).

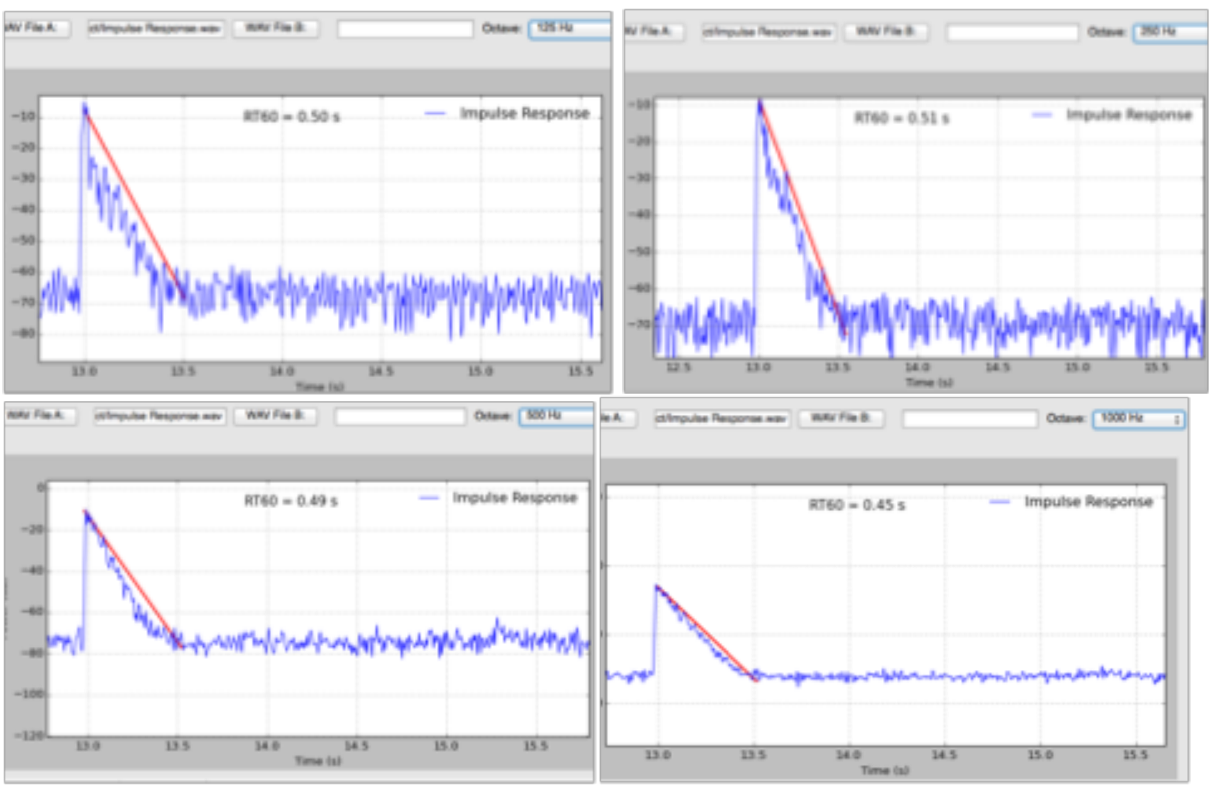
Procedure

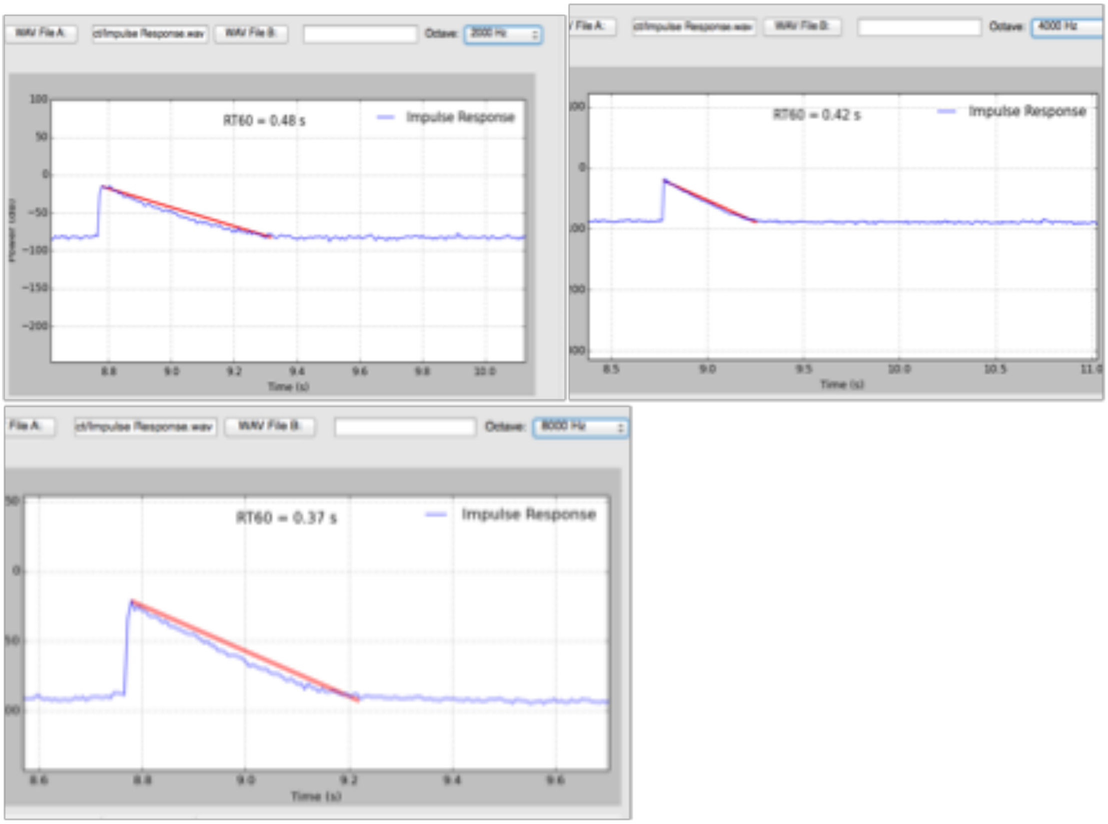
The equipment used in this experiment consisted of a MacBook Pro (OSX 10.9) running Logic X using its built in oscillator. Two loudspeakers were used (both Alesis M1 Active 520s) and an omni-directional measurement microphone (Audix TR40A Test Microphone). The speakers were six feet apart from the microphone and we performed multiple tests on the room. These included a sine wave sweep, white noise signal bursts, pink noise signal bursts and impulse responses (done by slamming a text book on the floor).

With these measurements we obtained the room mode frequencies and the reverb time of Andrew's room. The room modes were discovered by using the equation from Figure 1. The reverb time samples that were taken from the white noise signal bursts can be seen in Figure 6. We used SHAART to analyze the recorded audio from the room and averaged the results of the each instance to give us a better approximation of the signal we analyzed. This, however, should be taken as an approximation due to simple human error with regards to tracing the T_{R60}. We then took this data that was found and crafted a digital scale model of Andrew's room in SketchUp (shown in Figure 10). This allowed us to create a visual representation of how we would acoustically treat this room with various kinds of absorbers. Figure 7 illustrates the room frequencies that we were trying to treat with diaphragmatic panel absorbers and the distance from the wall to be mounted. Figure 8 provides information on the hypothetical perforated panel absorbers that would be used in the room to target those specific frequencies. Lastly, the porous absorber data is seen in Figure 9 in which we would use Aurelex StudioFoam to hang from the ceiling. Treating a room within a program allowed us to properly analyze and accurately place our various absorbers, diffusers, and to treat the desired room modes.

Results

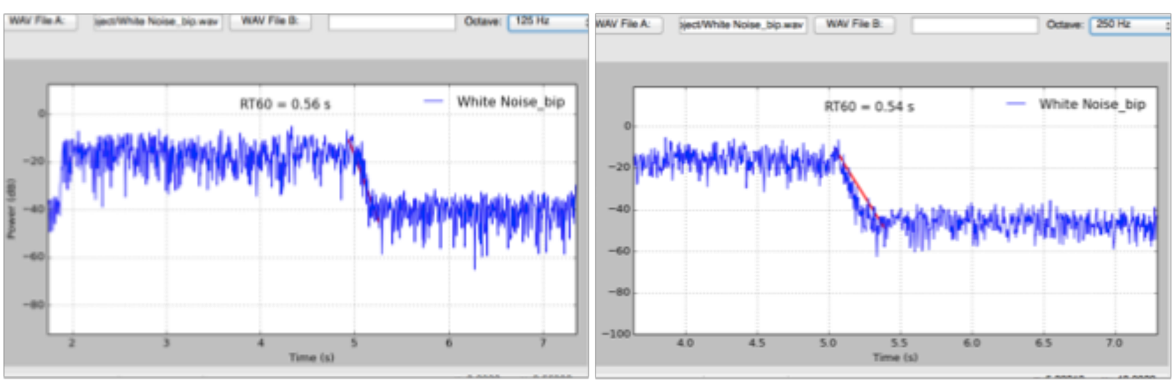
The following graph show our room's reverb time using amplitude over time graphs of impulse responses done in SHAART. The reverb times for seven different octave bands are shown:

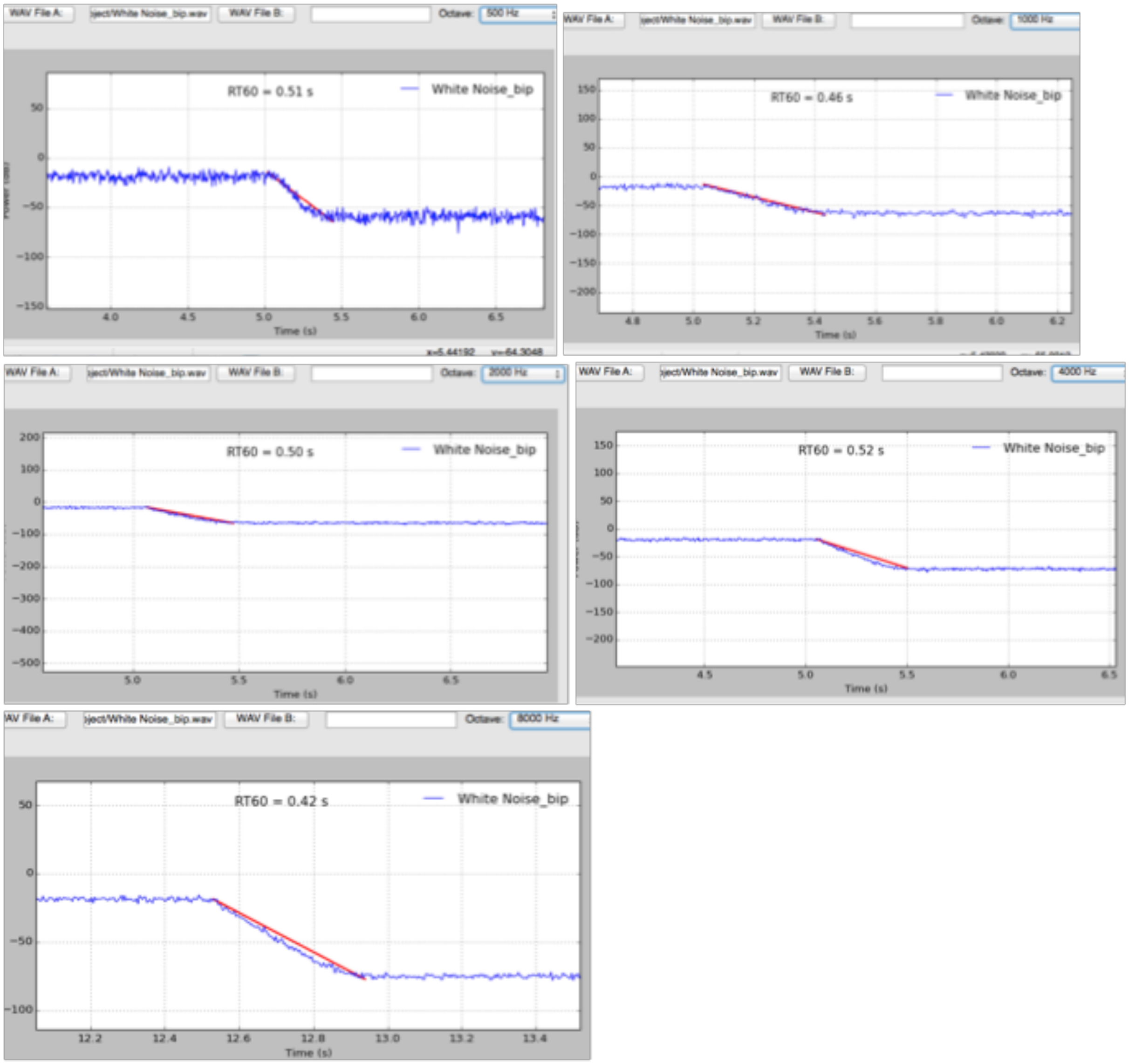




(Fig. 5: Room's reverb time for seven octave bands calculated by measuring impulse responses)

The following graph show our room's reverb time using amplitude over time graphs of white noise measurements done in SHAART. The reverb time for seven different octave bands are shown:





(Fig. 6: Room's reverb time for seven octave bands calculated by measuring impulse responses)

Additionally, we took measurements frequency sweeps in the same manner. Unfortunately, we did not understand how to use this method. What we actually ended up doing was measuring the reverb time of the frequency at the end of the sweep.

For our hypothetical diaphragmatic panel absorber designs we decided to use 3/4 inch plywood, the thickest standard width of plywood. It has a density of 2.13 lbs/sq.in. With the density already determined, plugging in our problem frequencies gave us the air gap that would be needed to target each respective frequency. In our plan, we used diaphragmatic panel absorbers to target the following frequencies: 74.9Hz, 101.5Hz, 37.3Hz and 54.3Hz. The following graphs show the air gaps required to address some of our lowest problem frequencies:

frequency	distance (in.)
37.5	9.752
39.5	8.696
54.3	4.602
63.6	3.354
73.7	2.498
74.6	2.438
74.9	2.419
79.1	2.169
83.7	1.937
84.4	1.905
87.4	1.776
98	1.413

frequency	distance (in.)
101.5	1.317
105.7	1.214
108.1	1.161
108.7	1.148
111.8	1.086
111.8	0.965
124.3	0.878
125.9	0.856
127.2	0.839
128.7	0.819
132.6	0.772
133.2	0.765
134.6	0.749

(Fig. 7: gaps needed to construct diaphragmatic panel absorbers and their target frequencies)

For our hypothetical perforated panel absorber designs we decided to use 2 foot by 4 foot panels with the area of perforation being that of three holes made with a 4-3/8 inch hole saw. Again, we used 3/4 inch plywood for our calculations. This gave us a perforation percentage of 3.9148468, a hole radius of 2.1875, a t prime of 4.25. By plugging our problem frequencies into the perforated panel absorber equation we were able to determine the distance from the front of the absorber to its back. The following graph shows the distances needed for some of our problem frequencies:

Frequencies	Distance (inches)
251.8	10.49668686
298.4	7.474223072
302.2	7.287436324
322.2	6.410805796
336.1	5.891510664
346.3	5.549562028
357.2	5.216038552
372.8	4.788636657
399.7	4.16577104
409.8	3.962960877

(Fig. 8: distances needed to construct perforated panel absorbers and their target frequencies)

In our plan, we used perforated panel absorbers to target 346.3Hz and 298.4Hz. We did not end up using perforated panel absorbers to target even lower because with the other variables we decided to use, the distance would have been to great to be realistic in a room the size of ours (the absorber would have taken up too much space).

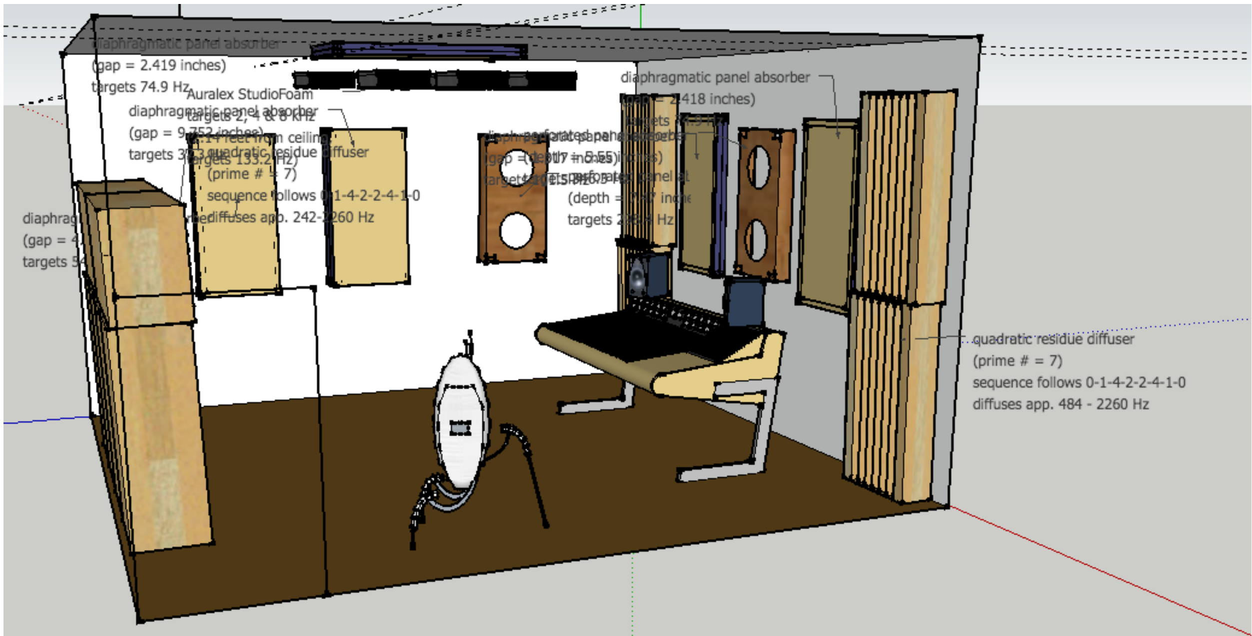
Solving for optimal positions of porous absorbers was simpler. Since porous absorbers are most effective at a quarter of a frequency's wavelength distance from the wall, we calculated the wavelengths of each of our problem frequencies and divided the result by four to find the optimal distances from the wall for porous absorbers to target our problem frequencies. The following graph shows the distances needed for some of our lowest problem frequencies:

frequency	distance (ft)	frequency	distance (ft)
37.5	7.641	101.5	2.808
39.5	7.215	105.7	2.696
54.3	5.249	108.1	2.636
63.6	4.481	108.7	2.622
73.7	3.867	111.8	2.594
74.6	3.82	118.6	2.403
74.9	3.805	124.3	2.293
79.1	3.603	125.9	2.264
83.7	3.405	127.2	2.241
84.4	3.377	128.7	2.214
87.4	3.261	132.6	2.149
98	2.908	133.2	2.14
		134.6	2.117

(Fig. 9: problem frequencies in our room and their quarter-wavelengths; the optimal place at which to target them with porous absorbers)

In our plan we used Auralex StudioFoam as our porous absorbers, which effectively absorb 2kHz, 4kHz and 8kHz. Being hung 2.14 feet from the ceiling, these absorbers also targeted 133.2Hz.

For diffusion in our room we used quadratic residue diffusers using the prime number seven. This gave us a well-depth sequence of 0-1-4-2-2-4-1-0. All our diffusers had a well-width of 3 inches. The maximum well-depth of our diffusers was either 8 inches or 16 inches, which would diffuse frequency ranges of 484Hz to 2260Hz and 242Hz to 2260Hz respectively.



(Fig 10: This is our "mock" room design using the "SketchUp" program mentioned above)

Conclusion

For our project we developed a hypothetical plan to acoustically treat a small room. We measured impulse responses and white noise to calculate the rooms reverb time. Using the dimensions of Andrew's room (14.42 ft x 15.29 ft x 8.96 ft) and equations that determine the target frequencies for diaphragmatic panel absorbers, perforated panel absorbers, porous absorbers and quadratic diffusers of different specifications, we also determined the room's problem modes and made pieces of treatment that would address problem frequencies specific to the room. The frequencies we targeted with absorbers in our plan were 37.3Hz, 54.3Hz, 74.9Hz, 101.5Hz, 133.2Hz, 242Hz, 298.4Hz, 346.3Hz, 2kHz, 4kHz and 8kHz - all problem frequencies in a room with the dimensions we used. The range of frequencies effectively diffused in our room was 242Hz to 2260Hz. For all of our absorbers we used ¾ inch plywood. If we were to revise our treatment plan or go about actually treating a room, however, it would make sense to use wood of varying thicknesses and densities to target different frequencies. For instance, using only the ¾ inch plywood, it would take a perforated panel absorber nearly 10 ½ inches deep to target 251.8Hz. To target some of our lowest frequencies the panel would have to be much deeper - far too deep to be practical in a room our size. Similarly, using less thick wood could allow us to make absorbers that could target higher frequencies without inconveniently small gaps or depths. Overall, designing specific acoustic treatment for a specific room was a beneficial exercise.

References

[1] Berg, Richard E., and David G. Stork. *The Physics of Sound*. Englewood Cliffs, NJ: Prentice-Hall, 1982. Print.

[2] Digital Audio Rock, QRD Diffuser Well Depth Calculator, http://www.digitalaudiorock.com/cgi-bin/qrd.cgi

[3] Everest, F. Alton. "Chapter 9: *Diffusion*, Chapter 11: *Reverberation*, Chapter 12: *Absorption*, Chapter: 13 *Modal Resonances*, Chapter 14: *Schroeder Diffusers*, Chapter 15: *Adjustable Acoustics*" *The Master Handbook of Acoustics*. New York: McGraw-Hill, 2001. N. pag. Print.