

Anomalous Acoustics in Crawley Forum: An Introductory Acoustical Analysis of Crawley Forum

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The objectives for the Fall 2013 semester were to identify the ramifications of the 2004 renovations of Crawley Forum, show that the structural modifications made to Crawley Forum negatively effected its acoustic properties, assess the frequency-dependent reverberation times for the space, and generate potential solutions for the acoustical space. These objectives were pursued using CARA (Computer Aided Room Acoustics), to model and test the acoustics of Crawley Forum. The reverberation times of Crawley Forum were also tested using the RT20 method. By the end of the semester, it was determined that the 2004 renovations negatively altered the acoustical properties of Crawley Forum. Also, the reverberation time of the space was measured to be 1.39 seconds at 250 Hz, 1.212 seconds at 500 Hz, and 1.35 seconds at 1250 Hz. When compared to the reverberation times of the space calculated by CARA, these measurements had discrepancies of 21%, 7%, and 2% respectively. It was determined that structural modifications to Crawley Forum were not efficient due to their poor effect to cost ratio; however, temporary acoustical treatments, such as heavy drapery, acoustic foam and wooden panels, were effective in lowering the reverberation time to a suitable value for lecture hall settings. This research will be a foray into more involved and conclusive research for the following year.

INTRODUCTION

Crawley Forum was built in 1984 and renovated in 2004. Prior to the 2004 renovations, the space was considered to be a great space for chamber music. Jim Kidd quote? However, after the renovations, it was believed that the acoustics of Crawley Forum had been altered. Now, the space is considered to have "dead spots" in the listening section. David Salvage, a fine arts professor at H-SC, stated that "It matters where you sit in Crawley... different seating areas have different 'sounds.'" The acoustics of Crawley Forum seemed to have been considerably altered. The renovation of Crawley Forum involved modifying the structure of the back wall of the main hall to add a handicap accessible ramp. This modification resulted in an asymmetrical (sloping downward) back reflecting wall when compared to the original symmetrical (no slope) wall.

The main focus of modeling Crawley Forum was to determine whether the renovations of Crawley Forum actually created more dead spots in the listening area, and if those dead spots were significant enough to alter the listening experience. Dead spots in a room are created from the complete destructive interference of two or more sound waves. Sound waves destructively interfere when they combine out of phase. There is complete destructive interference when two sound waves combine and are 180° out of phase. In terms of antinodes, dead spots are created

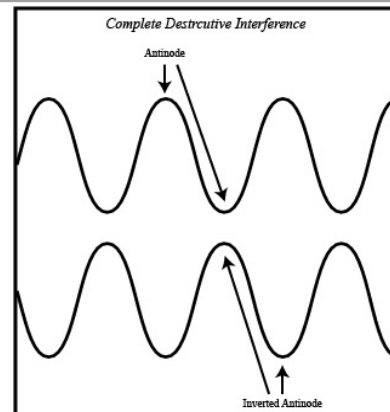


Figure 1. Illustration of Complete Destructive Interference

when the antinodes of one wave match up with the inverted antinodes of another wave. From this perspective, it is clear that the more antinodes that exist in a given area, the more probable it is that there will be dead spots in that area due to the higher probability of antinodes of sound waves overlapping. This is supported by the equation,

$$\lambda = \frac{v}{f}, \text{ where } v = 343 \text{ m/s}$$

So, as the frequency (f) of a sound wave increases the wavelength (λ) decreases. This implies that the same sound wave is able to have more antinodes in a given area than it was at a lower frequency. The increased availability of antinodes implies that there is a higher probability for more dead spots. Therefore, as the frequency of a projected sound increases, the probability of dead spots and the amount of dead spots increases.

EXPERIMENTAL PROCEDURE

In order to determine whether the acoustics of Crawley Forum had been altered by the 2004 renovations, Crawley had to first be modeled using the CARA software. Crawley Forum was modeled based on the renovation plans, which included floor plans of the space before and after the renovation, from the Buildings and Ground department of H-SC. Once the before and after spaces were modeled, calculations were run using the CARA software. The following parameters were used for the calculations,

Room Temp (°C)	22
Rel. Humidity (%)	50
Max Reflection Order	3
Locating Time (ms)	1
Wall Impedances	Real
Sampling Rate (kHz)	44.1

With the sound fields for the models calculated, the coloration and frequency fields were analyzed to find any significant changes.

In addition to the before and after renovation models, an acoustically treated model was created to analyze the effects of acoustical treatment on reverberation times (RT). The RTs of the current Crawley Forum (post 2004 renovation) were compared to the RTs of the treated space to determine the treatment's effectiveness.

The RTs were also calculated in three different methods to validate CARA's calculations. The first two methods utilized the iPhone app, Rev Meter Pro. The RT20 impulse method used with the app involved allowing the app to read the ambient noise of the room, creating an pulse of at least 20 dB louder than the ambient noise of the room, and letting the app run its calculations. A white noise method was also used with the app, which involved allowing the app to measure the ambient noise level, playing a white noise sample from the app, and measuring the broadband RTs with the apps calculations. The third method was a manual RT20 method in which an oscilloscope, loudspeaker, amplifier, microphone, function generator, and SPL meter were used. The function generator supplied a constant, pure sine wave of variable frequency to the loudspeaker (amplified by the amplifier). Then, the output volume was set to 73 dB by adjusting the amplifier and monitoring the levels with the SPL meter. The oscilloscope was calibrated to view the resulting sine wave via the input from the microphone. Then, the signal was further amplified to 93 dB. Once this level was seen on the oscilloscope, the signal was

terminated and the time interval for the reverberated tone to drop 20 dB was determined from the time scale on the oscilloscope. The 20 dB drop was measured from 93 dB to 73 dB because the 73 dB mark was more easily discernible than the ambient level (about 40 dB).

ANALYSIS

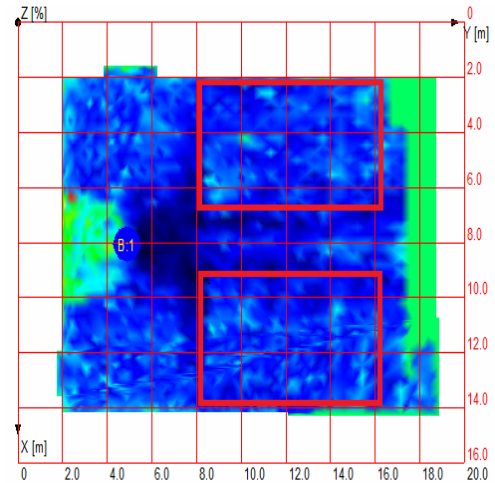


Figure 2. Coloration Sound Field (pre renovation)

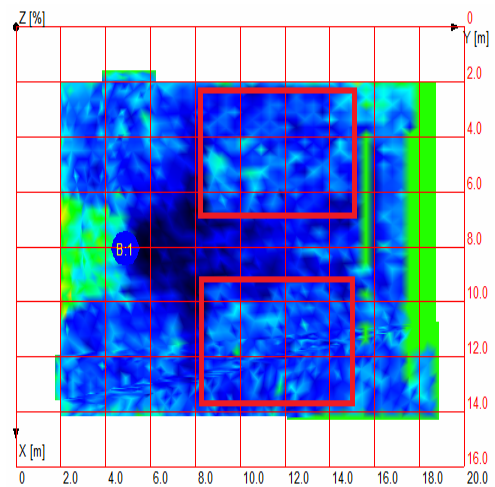


Figure 3. Coloration Sound Field (post renovation)

The scale of the coloration field is measured in terms of color warmth (i.e. the warmer a color is the more intense the coloration). The areas boxed in red are the listening areas (the areas of primary concern). The major difference between the two areas is the amount of coloration. After the renovation, the listening area of Crawley Forum had a significant amount more of coloration.

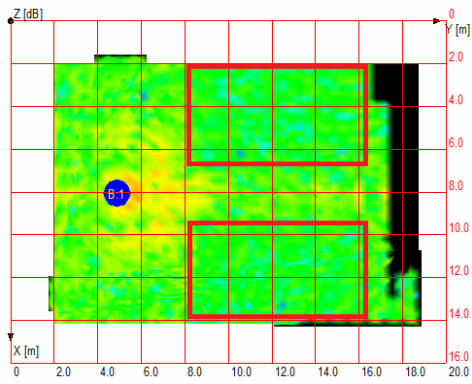


Figure 4. Frequency Sound Field- 746 Hz (pre renovation)

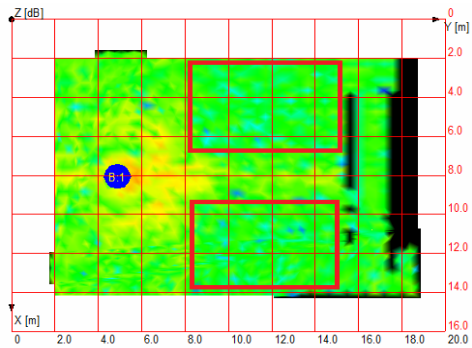


Figure 5. Frequency Field- 746 Hz (post renovation)

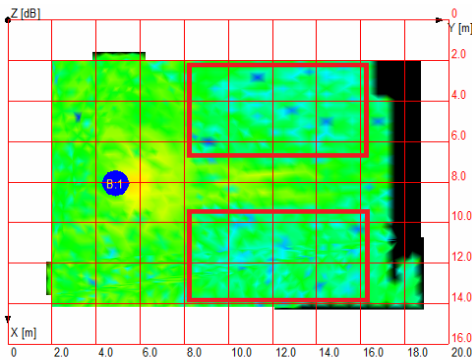


Figure 6. Frequency Field 1493 Hz (pre renovation)

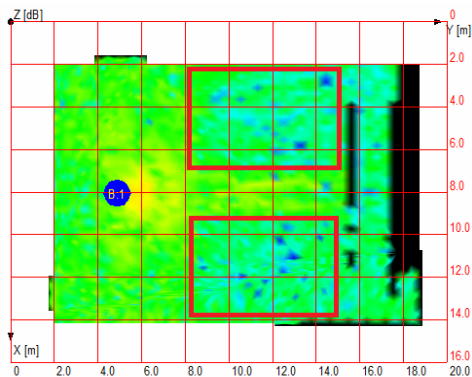


Figure 7. Frequency Field 1493 Hz (post renovation)

As with the coloration sound field, the frequency sound fields were metered in terms of color warmth. So this implies that the warmer the color, the louder (in decibels) a certain frequency is in different areas of the room. The blue spots throughout the listening areas represent the dead spots because they are severe drops in SPL (dB) and are relatively isolated from each other. It is clear that at both 746 Hz and 1493 Hz there are more dead spots and the dead spots are more severe (deeper blue). Furthermore, this shows that dead spots become more prominent as the frequency of a sound increases.

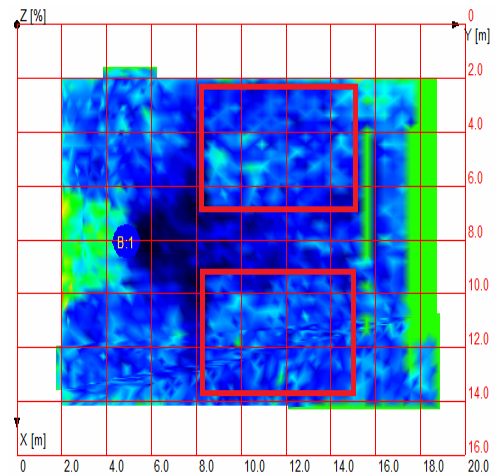


Figure 8. Coloration Field (post renovation)

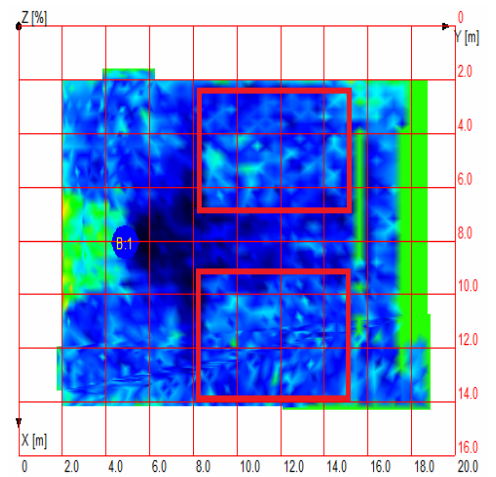


Figure 9. Coloration Field (structural change 1)

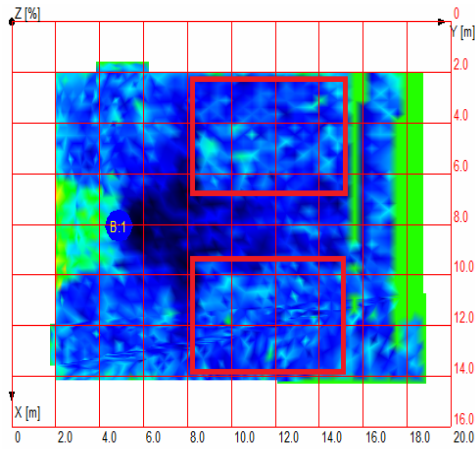


Figure 10. Coloration Field (structural change 2)

For structural change one, the sloping ramp wall built up so that it was returned to its prior symmetry. In theory this should help to alter the coloration of the sound field. However, the results from CARA proved to be inconclusive for this change as there was little to no coloration change in the sound field at the listening areas. For the second structural change, the sloping ramp wall was again built up and the stair junction at the top of the handicap ramp was removed to try and further the symmetry of the reflecting wall. However, the modification also proved to be ineffective as the sound field bowed little to no coloration change in the listening areas.

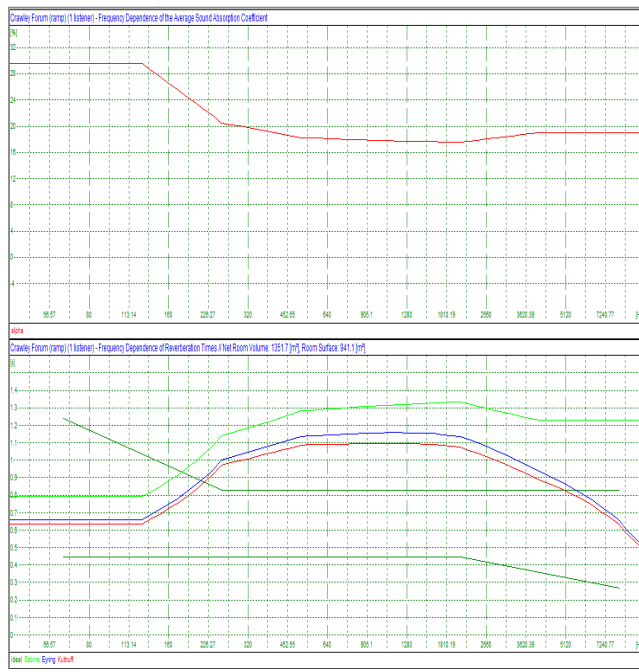


Figure 11. Reverberation Time for Crawley Forum (post renovation)

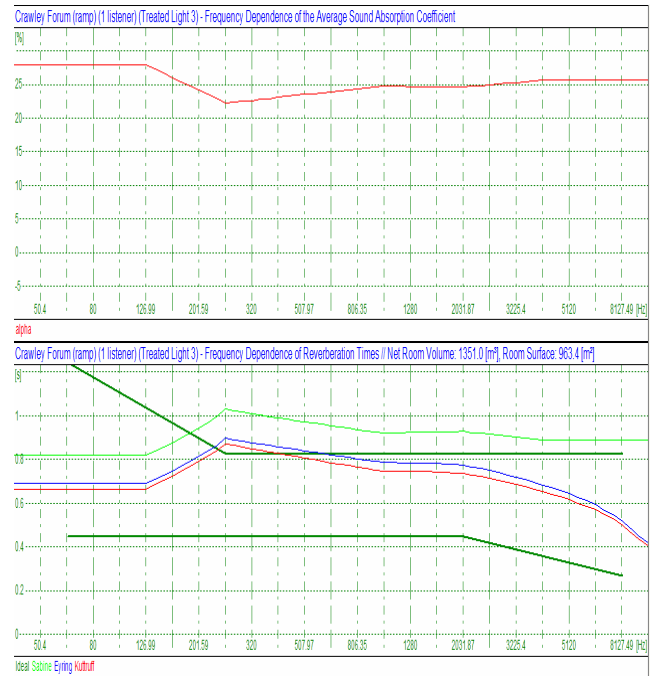


Figure 12. Reverberation Time for Crawley Forum (post treatment)

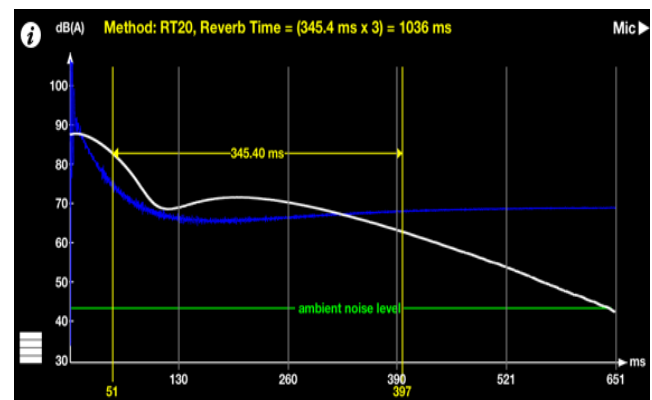


Figure 13. Rev Meter Pro (impulse RT20)

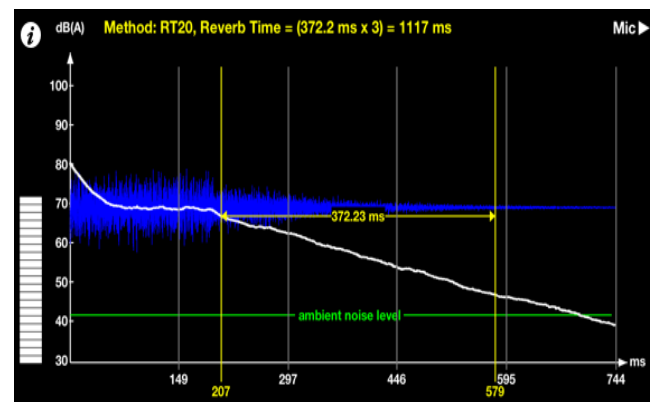


Figure 14. Rev Meter Pro (white noise RT20)

f (Hz)	t (sec)	t_f (sec)
250	0.45	1.35
250	0.46	1.38
250	0.48	1.44
	Average	1.39
	discrepancy	21%

f (Hz)	t (sec)	t_f (sec)
500	0.416	1.248
500	0.404	1.212
500	0.392	1.176
	Average	1.212
	discrepancy	7%

f (Hz)	t (sec)	t_f (sec)
1250	0.45	1.35
1250	-	-
1250	-	-
	Average	1.35
	discrepancy	2%

Figure 15. Measured RTs (RT20 method)

With the exception of the 250 Hz measurements, the measured RTs show that CARA's calculations based on the Crawley Forum model are accurate. The cause for the high discrepancy in measuring the RT for 250 Hz is likely due to equipment error as the microphones that were used were more sensitive at higher frequencies than at lower frequencies.

As for the modeled RT diagrams, CARA produces several different RT algorithms, however, the Sabine RTs are the times that were taken into consideration. There were 300 sq.ft. (in three, 10ft. x 10ft. section on walls) of heavy drapery and acoustic foam and three standing 8ft. x 4ft. x 1ft. panels added to the treated room. The heavy drapery greatly reduced the higher frequency RTs with an absorption coefficient of $\alpha = 0.45$ at 4 kHz. The acoustic foam helped to shorten the hi-mid range RTs with an absorption coefficient of $\alpha = 0.8$ at 640 Hz. The wooden panels were good for absorbing the mid rang frequencies some more with an absorption of $\alpha = 1$ at 650-750 Hz.

CONCLUSION

The purpose of this research was to determine whether the renovations of Crawley Forum had any significant impacts on the acoustics of the space, and if so, if those changes negatively affected the acoustics. Furthermore, the RT of Crawley Forum was to be determined by means of CARA's calculations, the calculations from the Phone app Rev

Meter Pro, and experimental data gathered using the RT20 method. Once it was determined that Crawley Forum's caustics did suffer from the renovations, two different structural modifications were tested to try and enhance the acoustics of the space. However, the structural modifications proved to be insufficient in enhancing the acoustics of Crawley Forum. Finally, a treated model (including heavy drapery, acoustic foam, and wooden panels) of the space was tested for its effectiveness in reducing the RTs of the space. The heavy drapery, acoustic foam, and wooden panels significantly shortened the RTs of Crawley Forum in the treated design. The shortened RTs are essential to improving the clarity of speech for a lecture hall setting. Furthermore, the treatments are temporary; thus, they can be easily removed to return the space back to its longer RTs (around 1.1-1.3 seconds), which is preferable for chamber music.

REFERENCES

1. Kidd, Dr. Jim. Personal Interview. 12 Oct. 2004.
2. Morris, John T. "Renovations to Crawley Forum." Architectural and structural drawings. *H-SC Physical Plant and Highfill & Associates* 5 May 2004. Print.
3. Rigden, John S. *Physics and The Sound of Music*. New York: Wiley & Sons, 1985. Print.
4. Salvage, Dr. David. Personal interview. 16 Nov. 2013.
5. Schorer, Matthias. *Rev Meter Pro*. Computer software. *Apple App Store*. Vers. 2.1. SchoSoft, 07. June 2013. Web. 05 Nov. 2013.
<<https://itunes.apple.com/us/app/revmeter-pro/id357421594?mt=8>>.