Lab #6 – Room Acoustics

EQUIPMENT

- Tape measures
- Noise making devices (pieces of wood for clappers).
- Microphones, stands, preamps connected to computers.
- Extra XLR microphone cables so the microphones can reach the padded closet and hallway.
- Key to the infamous *padded* closet

INTRODUCTION

One important application of the study of sound is in the area of acoustics. The acoustic properties of a room are important for rooms such as lecture halls, auditoriums, libraries and theatres. In this lab we will record and measure the properties of impulsive sounds in different rooms. There are three rooms we can easily study near the lab: the lab itself, the "anechoic" chamber (i.e. padded closet across the hall, B+L417C, that isn't anechoic) and the hallway (that has noticeable echoes). Anechoic means no echoes. An anechoic chamber is a room built specifically with walls that absorb sound. Such a room should be considerably quieter than a normal room. Step into the padded closet and snap your fingers and speak a few words. The sound should be muffled. For those of us living in Rochester this will not be a new sensation as freshly fallen snow absorbs sound well. If you close your eyes you could almost imagine that you are outside in the snow (except for the warmth, and bizarre smell in there).

The reverberant sound in an auditorium dies away with time as the sound energy is absorbed by multiple interactions with the surfaces of the room. In a more reflective room, it will take longer for the sound to die away and the room is said to be 'live'. In a very absorbent room, the sound will die away quickly and the room will be described as acoustically 'dead'. The time for reverberation to completely die away will depend upon how loud the sound was to begin with, and will also depend upon the acuity of the hearing of the observer and the ambient noise level of the room. In order to provide a reproducible parameter, a standard reverberation time has been defined as the time for the sound to die away to a level 60 decibels below its original level. The reverberation time, RT_{60}, is the time to drop 60 dB below the original level of the sound. The reverberation time can be measured using a sharp loud impulsive sound such as a gunshot, balloon popping or a clap.

Why use 60dB to measure the reverberation time? The reverberation time is perceived as the time for the sound to die away after the sound source ceases, but that depends upon the intensity of the sound. To have a parameter to characterize a room that is independent of the intensity of the test sound, it is necessary to define a standard reverberation time in terms of the drop in intensity from the original level, i.e., to define it in terms of a relative intensity. The choice of the size of the relative intensity drop to use is arbitrary, but there is a rationale for using 60 dB since the loudest crescendo for most orchestral music is about 100 dB and a typical room background level for a good music-making area is about 40 dB. Thus the standard reverberation time is seen to be about the time for the loudest crescendo of the orchestra to die away to the level of the room background. The 60 dB range is about the range of dynamic levels for orchestral music.

What is a good reverberation time for a room? If you are using the room for lectures (speech) then a long reverberation time makes it difficult for the audience to understand words as the echoes interfere. However a long reverberation time adds character to spaces such as churches where organ music is played. Reflective surfaces lengthen the reverberation time whereas absorption surfaces shorten it. A larger room usually has a longer reverberation time because it takes longer for the sound to travel between reflections. Rooms that are good for both speech and music typically have reverberation times between 1.5 and 2 seconds. The reverberation time is influenced by the absorption coefficients of the surfaces in a room, but it also depends upon the volume of the room. A small room would not have a long reverberation time.

An example of a large room with reflective surfaces that has a long reverb time (and so is constantly unpleasantly noisy) would be Wilson commons. Although it is visually striking this building is atrocious acoustically. It would be possible to improve the acoustics of this space by hanging artwork made of absorptive materials. The new biomedical and optics building (Georgen) has a similar problem -- all those beautiful glass surfaces are highly reflective acoustically (and so you can hear the growl of the espresso machine from the coffee shop everywhere in the building). It seems that some recently built buildings on campus are designed by architects who have neglected the acoustics of the spaces. I suspect that it might be possible to compensate for visually striking but acoustically reflective building materials with cleverly placed acoustic absorbers hidden in the ceilings behind the lights or boldly in the open as 3D structures on opaque walls.

Predicting the reverberation time and Sabine's formula.

Sabine is credited with modeling the reverberation time with the simple relationship which is called the Sabine formula:

$$RT_{60} = (0.16\,\mathrm{sec/\,m})\frac{V}{S_e} = (0.049\,\mathrm{sec/\,ft})\frac{V}{S_e} \qquad \text{(Equation 1)}$$

This formula relates the reverberation time, RT_{60}, to room volume and an effective area. You use the 0.16 sec/m coefficient if you are working in meters. You use the 0.049 sec/foot coefficient if you are working in ft. Here V is the volume of the room and S_e is an effective area. The effective area is calculated as follows

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

Here each area S_i has an absorption coefficient a_i. The effective area is a sum of areas, S_i , each with its own absorption coefficient a_i. These areas are the surfaces in the room (ceiling, walls, floor, seats, people, etc…). Another way to write the effective area is with a sum

$$S_e = \sum_{\text{surfaces } i} a_i S_i$$

Note you must put the areas (S_i) in the same units as the volume V (meter^2 for area and meter^3 for volume or ft^2 for area and ft^3 for volume). When a sound wave in a room strikes a surface, a certain fraction of it is absorbed, and a certain amount is transmitted into the surface. Both of these amounts are lost from the room, and the fractional loss is characterized by an absorption coefficient, a, which can take values between 0 and 1, 1 being a perfect absorber and 0 being a perfect reflector. Absorption coefficients are unitless. The absorption coefficient is the fraction of the power absorbed in one reflection. Absorption coefficients for some common materials are given below. The absorption coefficient of a surface can depend on the frequency of sound used to measure it. For example, carpet is quit absorptive at high frequencies but not at low frequencies. A perfectly absorptive room would have an effective area that is equal to the total surface area of its walls, ceiling and floor. A highly reflective room would have an effective area that is smaller than its total surface area.

The Sabine formula works reasonably well for medium sized auditoriums but is not always an accurate predictor of the reverb time. The Sabine formula neglects air absorption, which can be significant for large auditoriums. It also tends to overestimate the reverberation times for enclosures with high absorption coefficients.

The reverberation time is not the only important acoustic parameter of a concert hall or auditorium. Another measurement used to characterize a performance space is the based on the time of the first echo. Consider an impulsive sound produced on a stage and a position in the audience. One can measure the time between the arrival of the direct sound (travelling directly between source and audience position) and the arrival time of the first strong echo. Prior to renovation, the Eastman theatre, due to its very high ceiling was criticized because the first echo time in the center of the audience (high priced seats) was considered too long. During renovation, the volume of the theatre was reduced to improve the acoustics of the space.

Other descriptive acoustical characteristics to consider are:

- Liveness – This just refers to the length of the reverberation time. The longer the reverberation time, the more "live" the room is.
- Intimacy – This refers to how close the performing group sounds to the listener.
- Fullness – This refers to the amount of reflected sound intensity relative to the intensity of the direct sound. The more reflected sound, the more fullness the room will have.
- Clarity – This is the opposite of fullness. In general, greater clarity implies a shorter reverberation time.

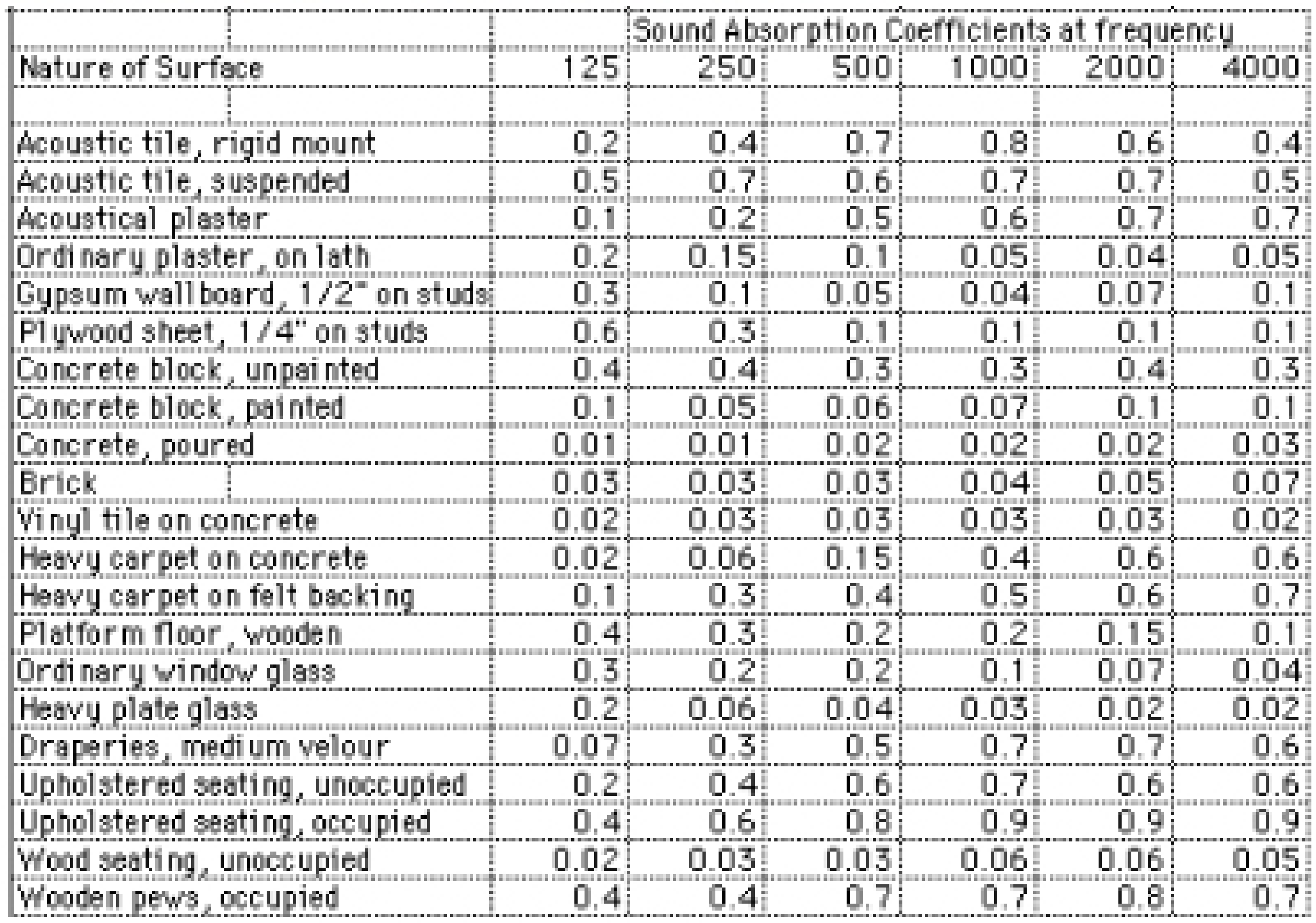
- Warmth – This is obtained when the reverberation time for low-frequency sounds is somewhat greater than the reverberation time for high frequencies.
- Brilliance – This is the opposite of warmth.
- Texture – This refers to the time structure of the pattern in which the reflections reach the listener. The first reflection should quickly follow the direct sound.
- Blend – This refers to how well the mixing of sound occurs between all of the instruments playing.
- Ensemble – This refers to the ability of the members of the performing group to hear each other during the performance.

The above terms can be used to describe a performance space and famous performance spaces can be ranked by performers and listeners. Researchers can measure and tabulate quantities such as reverb time, the time of the first echo and other quantities. Acoustic engineers have searched for relations between these measured quantities and the perceived quality of the performance space. These relations are now used to guide the design of performance spaces.

Some problems in acoustical design are:

- Focusing of sound – This refers to the undesirable effect that occurs when sound is much louder at one point in the room than surrounding points in the room.
- Echoes – To obtain good texture, it is desirable to avoid any particularly large single echoes.
- Shadows – These are quiet areas that can be produced when there are large overhanging balconies or other structure jutting into the room.
- Resonances – It is necessary to separate the resonances of a speaker and the box enclosure of a tuned-port system to provide the best sound.
- External noise – This refers to noise coming from outside of the room.
- Double-valued reverberation time – If a recording of a musical event is played back in a room that it was not originally recorded in, this phenomenon can result.

Absorption coefficients for common surfaces:



	Sound Absorption Coefficients at frequency					
Nature of Surface	125	250	500	1000	2000	4000
Acoustic tile, rigid mount	0.2	0.4	0.7	0.8	0.6	0.4
Acoustic tile, suspended	0.5	0.7	0.6	0.7	0.7	0.5
Acoustical plaster	0.1	0.2	0.5	0.6	0.7	0.7
Ordinary plaster, on lath	0.2	0.15	0.1	0.05	0.04	0.05
Gypsum wallboard, 1/2" on studs	0.3	0.1	0.05	0.04	0.07	0.1
Plywood sheet, 1/4" on studs	0.6	0.3	0.1	0.1	0.1	0.1
Concrete block, unpainted	0.4	0.4	0.3	0.3	0.4	0.3
Concrete block, painted	0.1	0.05	0.06	0.07	0.1	0.1
Concrete, poured	0.01	0.01	0.02	0.02	0.02	0.03
Brick	0.03	0.03	0.03	0.04	0.05	0.07
Vinyl tile on concrete	0.02	0.03	0.03	0.03	0.03	0.02
Heavy carpet on concrete	0.02	0.06	0.15	0.4	0.6	0.6
Heavy carpet on felt backing	0.1	0.3	0.4	0.5	0.6	0.7
Platform floor, wooden	0.4	0.3	0.2	0.2	0.15	0.1
Ordinary window glass	0.3	0.2	0.2	0.1	0.07	0.04
Heavy plate glass	0.2	0.06	0.04	0.03	0.02	0.02
Draperies, medium velour	0.07	0.3	0.5	0.7	0.7	0.6
Upholstered seating, unoccupied	0.2	0.4	0.6	0.7	0.6	0.6
Upholstered seating, occupied	0.4	0.6	0.8	0.9	0.9	0.9
Wood seating, unoccupied	0.02	0.03	0.03	0.06	0.06	0.05
Wooden pews, occupied	0.4	0.4	0.7	0.7	0.8	0.7

Data from Hall, 2nd. Ed, Table 15.1