Suzie Chung

PHYS 406

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An Acoustical Study on 190 ESB

Introduction

Room acoustics is an important factor of consideration when it comes to designing a room. The sounds that one hears can either make an experience very memorable and exciting, or very horrendous and painful to listen to. I made my research topic focused on room acoustics because I wish to build concert halls and auditoriums in the future. The beautiful music and sounds that enthrall us has made me interested in building places where others can experience the same fascinating experiences I have one day.

Acoustical Elements of 190ESB

Initially, I had desired to do a study of a facility with great acoustical properties, like the Foellinger Great Hall or the Wesley Foundation chapel, places that are great for musical properties. However, access to these places proved difficult, and thus the lecture auditorium 190ESB was chosen instead for study.

The auditorium room 190 Engineering Sciences Building was designed to be a conference / lecture room, intended for public use. Because its purpose is intended for speakers and presentations, a “dead” sound is more desired, as opposed to a “lively” one, the reason being that speech intelligibility is more important than musical harmonics and echoes.

The room 190ESB is a lecture hall that is rounded, with rows of seats in middle, left, and right section. The rows of seats consist of several levels that slope downwards from the back of the room towards the front, to the lecture floor. The side walls are angled inwards towards the front, making the front more tapered than the back. Because of the side walls being angled in, the walls are “winged” off.

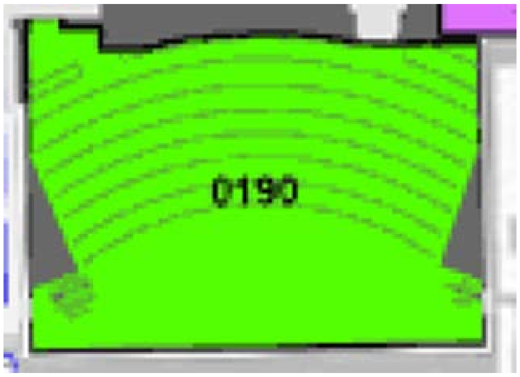


Figure 1 Blueprint layout of 190ESB

The front walls are consisted of concrete masonry covered with paint, with wooden panels attached on the lower half, while the middle is covered by whiteboards for lecturing purposes, and the top is also covered with wooden panels. The purpose for this design is to help absorb sound and to dampen whatever sound waves are trapped between the front and back walls.

Figure 2 Wooden panels are placed along the front wall of 190ESB

Figure 3 A close-up of a wooden panel.

The side walls are covered with long, wooden boards attached vertically on both side walls, which are built of brick masonry. The wooden boards make a rectangular profile along the walls, so that the sound can be diffused or trapped.

Figure 4 The wooden boards attached vertically to the walls to entrap and/or diffuse sound

The majority of the auditorium floor is covered in carpet, with the exception of the floor path leading from the back to the front, as well as the floor by the back entranceway, which are composed of tile. The carpet helps to muffle the sound of footsteps, as well as to absorb sound that propagates into the floor.

Figure 5 The floor is carpeted with exception to the tile paths

The ceiling of the auditorium is made of a shell-like, reflective hard surface, with a saw-tooth-shaped profile. The ceiling is angled toward the front, where light fixtures and sound is directed toward the speaker.

Figure 6 The ceiling has a saw-tooth profile, angled to reflect towards the speaker

On the back side of the auditorium, panels are attached to the brick masonry. These acoustical panels are made of tightly-woven hardened fabric, in order to absorb sound along the back wall.

Figure 7 Acoustical panel along back walls for sound absorption

The seats of the auditorium are made of hard plastic, and there are around 200 seats in the auditorium.

Figure 8 One of the many, hard plastic seats of the auditorium

Experiment: Sound Recording

The analysis performed of the room consists of recording the sound that dissipates when a sound source is abruptly turned off after the room is filled with noise. Measurements were taken by recording the sound at the center of the room, and as well as recordings taken at the middle of the house right section of the seats.

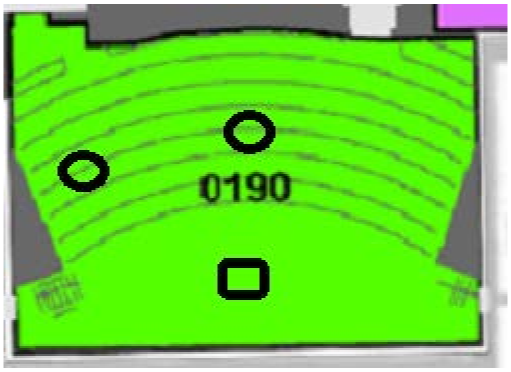


Figure 9 The ovals are where the microphones were placed for recording purposes. The rectangle is where the speaker and amplifier were positioned.

To take sound recordings of the auditorium 190, a microphone (consisting of microphones that measure both pressure and particle velocity) was set up, at first in the middle and the second time at the house right seats. A large speaker was set up in the middle of the "stage", pointed directly towards the center of the middle auditorium seats. The speaker was hooked up to an Agilent 33220A function generator and a Marantz Model 510 power amplifier to generate very loud noise. Loud noise was generated until it filled up the whole entire room, then the sound was turned off by reducing the volume very quickly. Three sound recordings were taken for each microphone position, so three recordings for the microphone placed in the center, and another three recordings for the microphone placed in the middle of the stage left side.

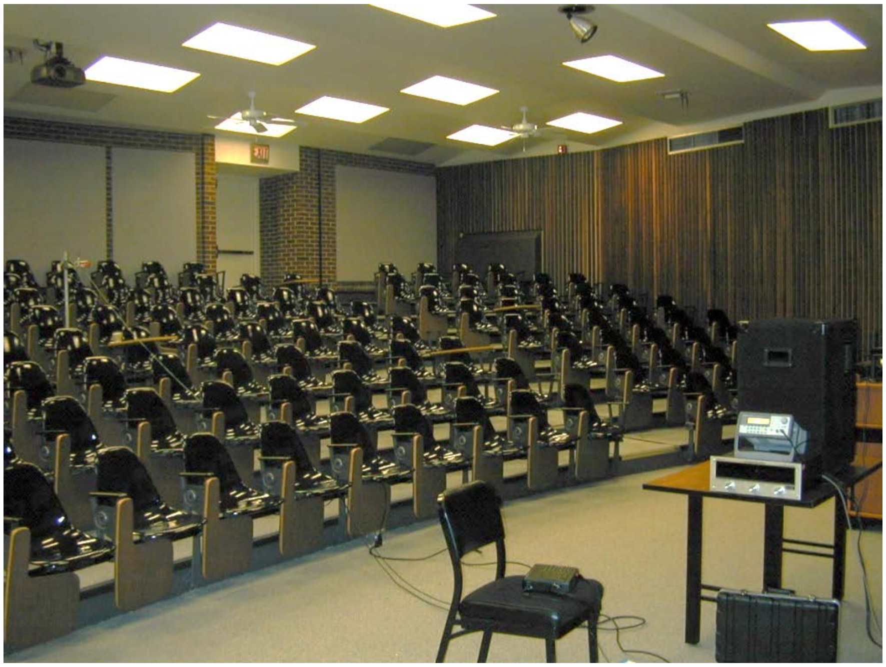


Figure 10 The speaker is pointed toward the middle and the back. The microphones are faced directly perpendicular from the speaker

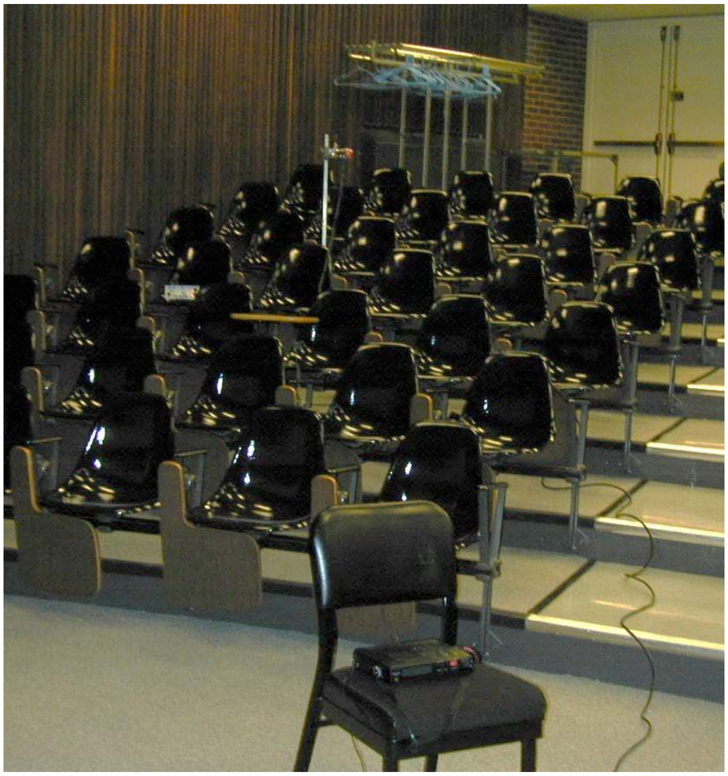


Figure 11 The microphones were also placed in the house right middle section of the seats, pointed toward the speaker.

Figure 12 Agilent 33220A Wavefunction generator and a Marantz Model 510 power amplifier used to generate very loud noise.

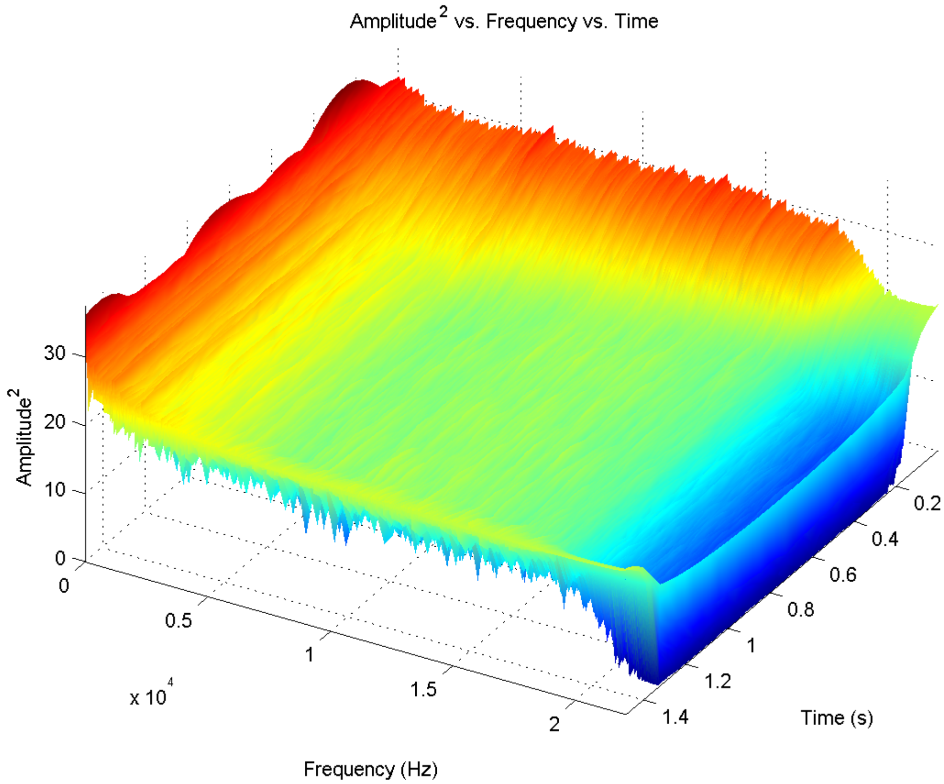
Figure 13 Speaker is placed in middle, facing towards back wall. Digital Sound Recorder is on the floor on bottom right

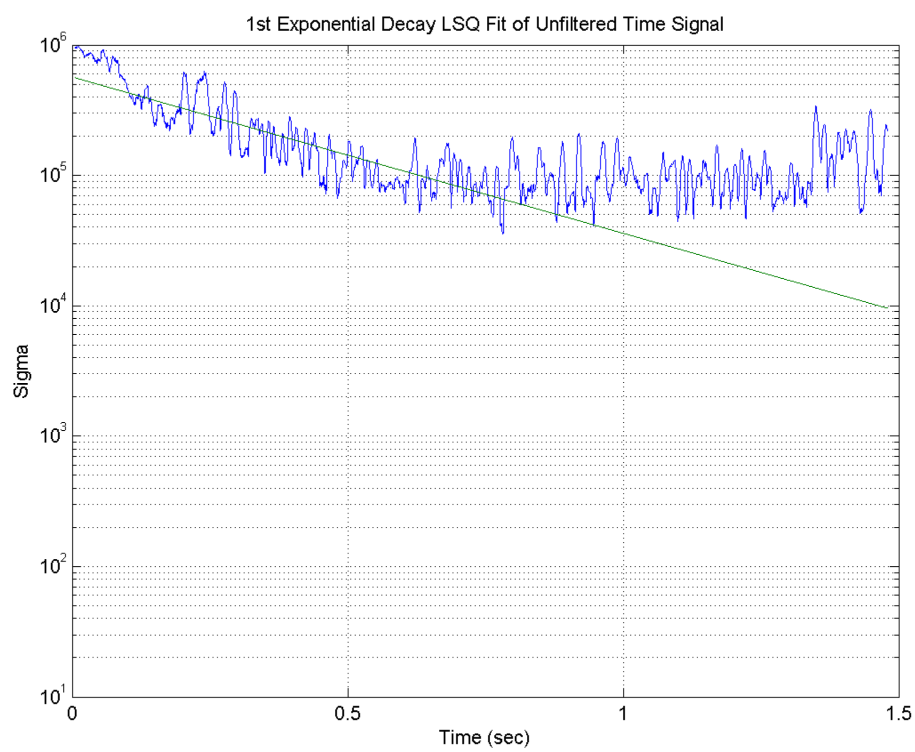
Figure 14 The pressure and particle velocity microphone is placed together, facing towards the speaker in front

<u>Results</u>

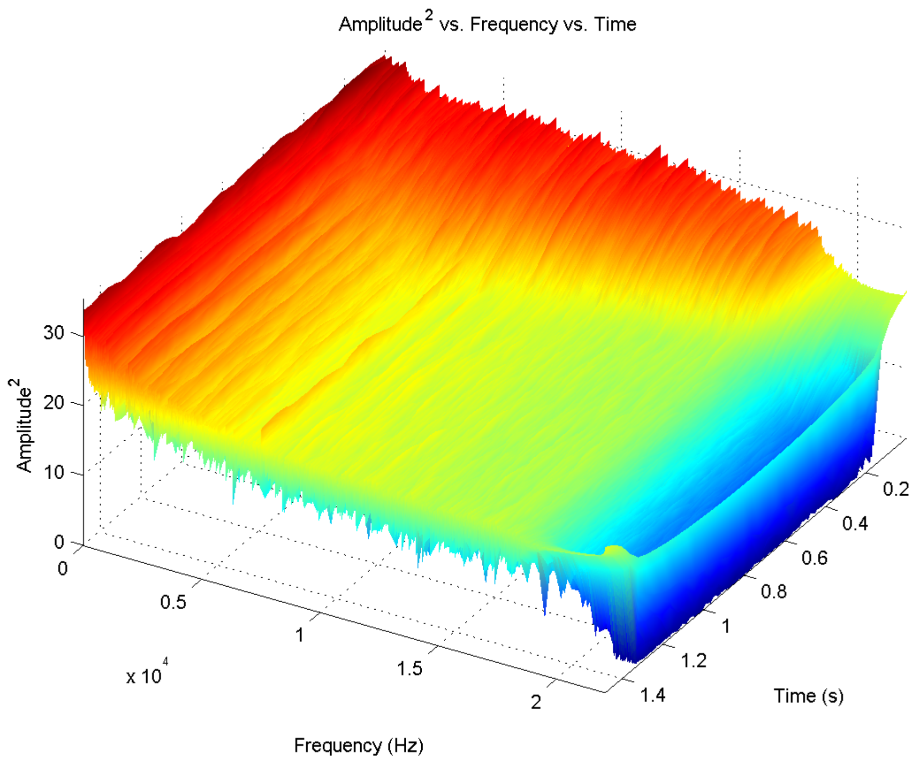
From the sound recordings, a Matlab program was used to analyze the decaying sounds. Four cases were studied for the sound analysis: pressure at the center, pressure at the house right area, particle velocity at the center, and particle velocity at house right. Three recordings were ran for each position (center and house right), and for all the data the third recording of each case was analyzed. A separate Matlab code was adjusted for just the pressure microphone and just the particle velocity microphone. For each case, a 3D graph was produced, showing the relationship of how the amplitude of each frequency decays with time. The 2D graph that follows shows the relation between sigma values and time, its purpose being to convert the exponential decay of the signal into a linear fit so that a decay rate can be shown and compared.

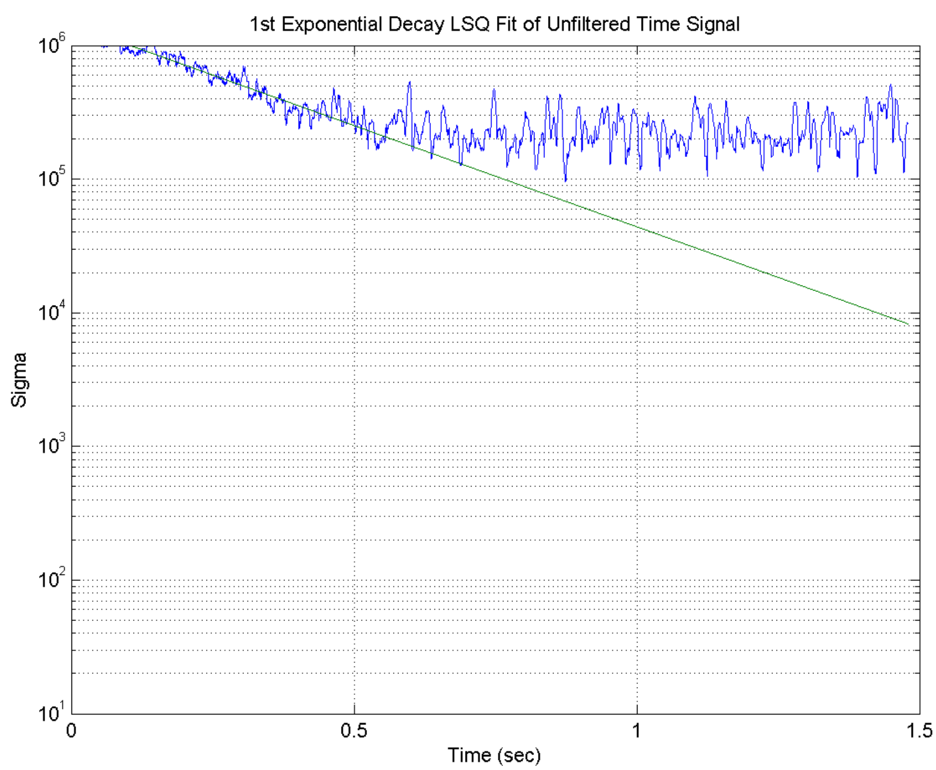
Pressure at Center



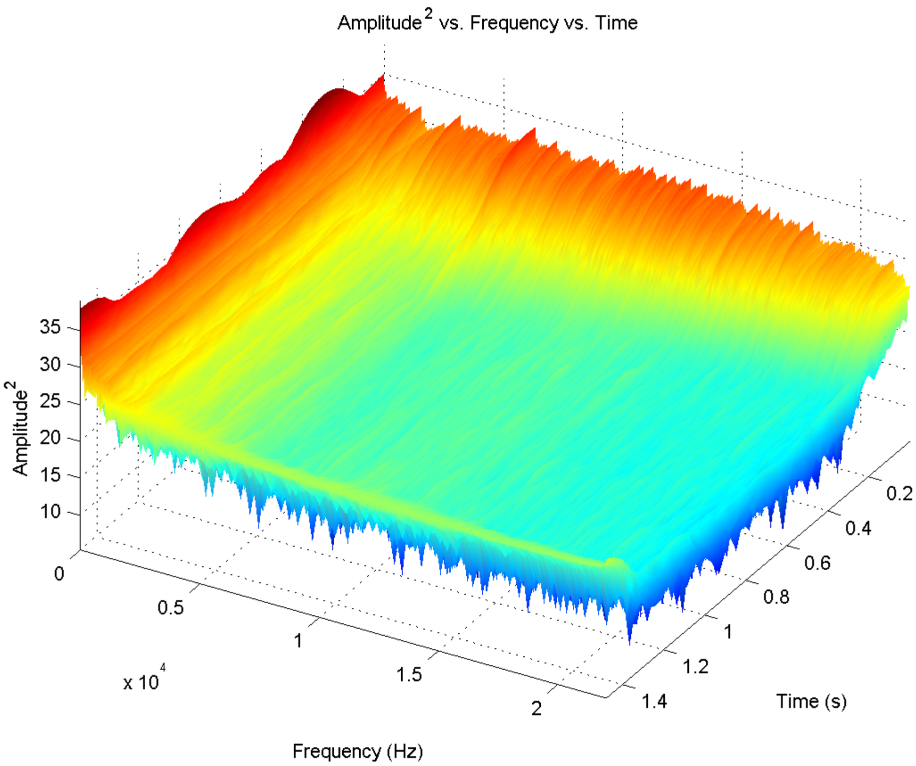


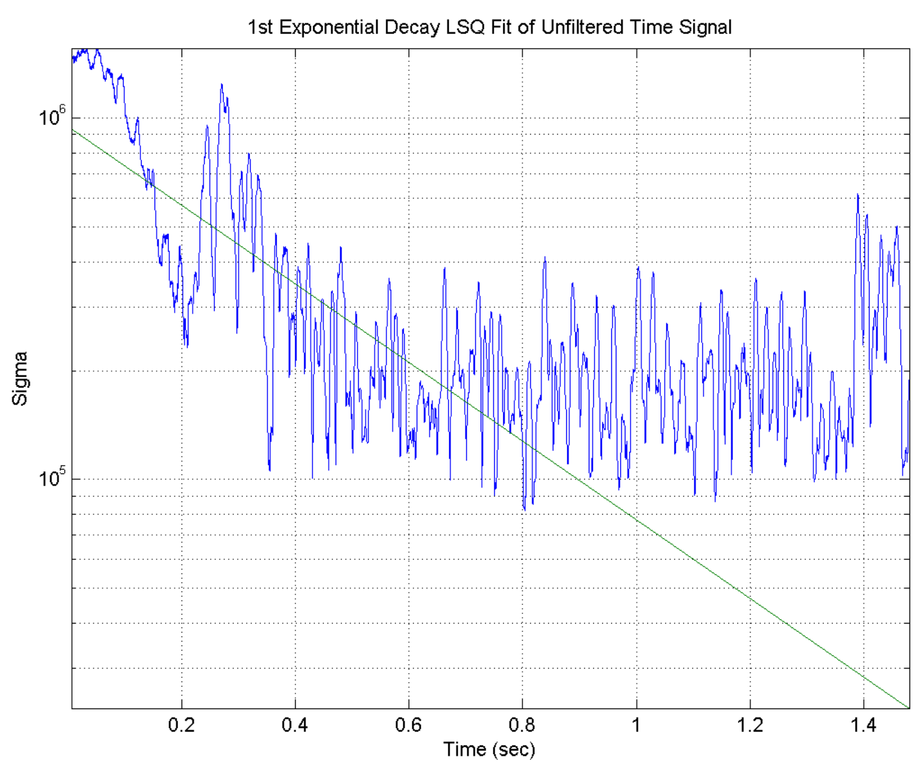
Pressure Right



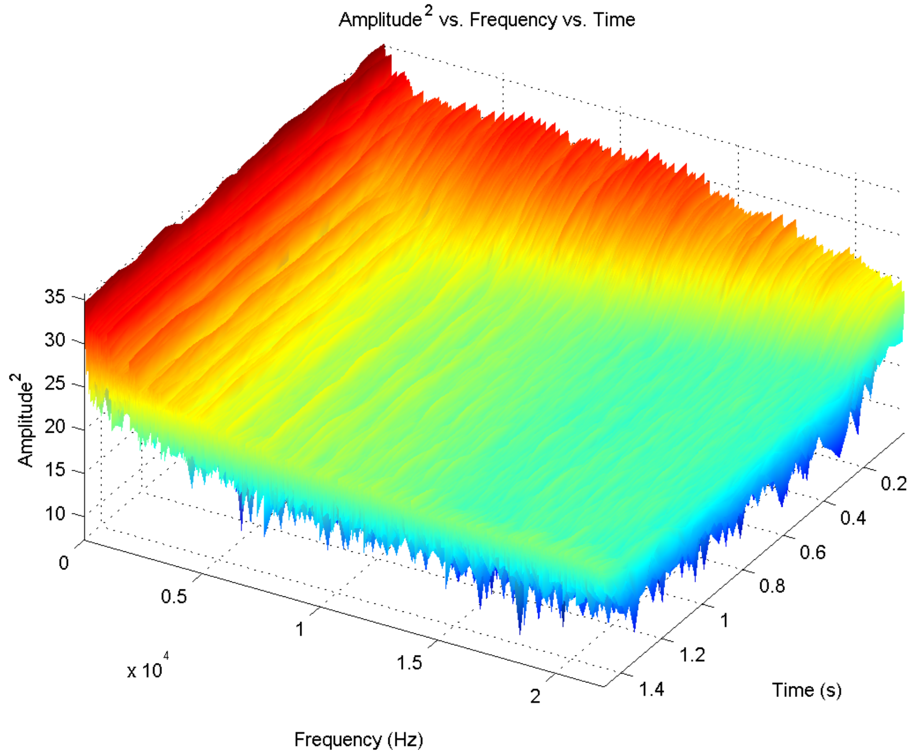


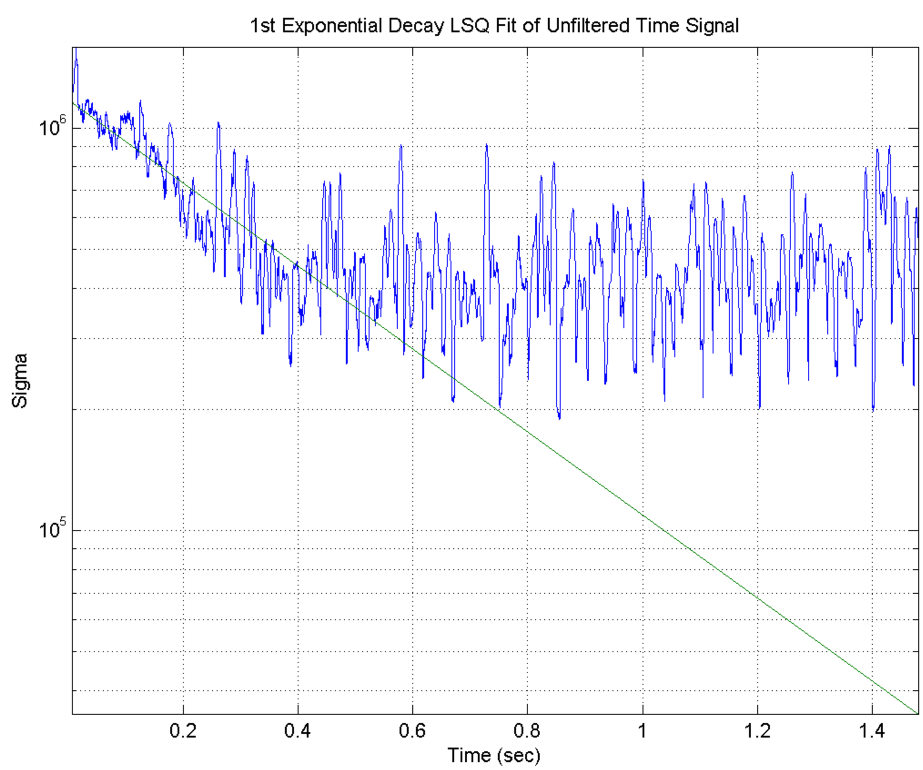
Particle Velocity Center





Particle Velocity Right





In addition to amplitudes and frequencies being graphed, the time constant τ, T30 and T60 times were generated. The T60 time is defined as the time required for sound intensity to decrease 60dB, or decreasing by a factor of 1 million. The T30 times are just half of the T60 times, as it is the time required for sound intensity to decrease 30dB. The following charts are the reverberation time data that was taken. Time constants, T30 and T60 times were recorded for each frequency octave band.

Figure 15 Pressure Center Reverberation Time Data

Trvb_Studies LSQ Fit Results
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Start time of 1st exponential fit 0.100000
End time of 1st exponential fit 0.500000

Start time of 2nd exponential fit 0.500000
End time of 2nd exponential fit 1.000000

Band #	f_lo	f_ctr	f_hi	Ynts	Taus	T30s	T60s	Yntl	Taul	T30l	T60l
0	13.920292	500.000000	22000.000000	569489.619707	0.362314	1.251397	2.502793	103971.123312	19.785708	68.337856	136.675712
1	13.920292	15.625000	17.538470	60320.545820	41020.483914	141680.649390	283361.298779	16584.211286	20597.308588	71141.044131	142282.088262
2	17.538470	19.686266	22.097087	44569.031129	22116.893608	76389.538834	152779.077667	101294.961230	0.464687	1.604983	3.209966
3	22.097087	24.803141	27.840585	38560.767768	11116.539787	38395.416769	76790.833539	62794.636810	0.881927	3.046086	6.092173
4	27.840585	31.250000	35.076939	39391.659850	44000.864890	151974.587244	303949.174489	66879.007151	0.924730	3.193925	6.387850
5	35.076939	39.372533	44.194174	141809.905140	0.324264	1.119974	2.239949	18859.180630	41576.787729	143602.067139	287204.134277
6	44.194174	49.606283	55.681170	159636.983527	0.210374	0.726612	1.453224	40775.432178	1.265759	4.371805	8.743609
7	55.681170	62.500000	70.153878	96387.998791	0.740501	2.557618	5.115235	37336.691946	83078.837041	286945.995255	573891.990510
8	70.153878	78.745066	88.388348	99414.880014	0.432289	1.493082	2.986165	30983.503438	1.810334	6.252712	12.505423
9	88.388348	99.212566	111.362340	184565.705709	0.309171	1.067846	2.135692	86900.998107	0.581327	2.007846	4.015692
10	111.362340	125.000000	140.307756	62835.880694	0.893678	3.086676	6.173352	59923.857537	2.222805	7.677347	15.354694
11	140.307756	157.490131	176.776695	51333.213073	0.420544	1.452517	2.905034	12421.102084	7.246219	25.027716	50.055433
12	176.776695	198.425131	222.724680	123190.229937	0.224943	0.776930	1.553859	13793.224263	82856.307962	286177.402070	572354.804139
13	222.724680	250.000000	280.615512	157303.949111	0.251515	0.868706	1.737412	21312.679094	2.697708	9.317612	18.635224
14	280.615512	314.980262	353.553391	186227.593399	0.227765	0.786678	1.573357	49113.311783	0.619418	2.139408	4.278815
15	353.553391	396.850263	445.449359	100331.151935	0.242045	0.835998	1.671996	14277.040224	164141.992138	566930.026645	1133860.053290
16	445.449359	500.000000	561.231024	90899.492810	0.289937	1.001412	2.002825	15997.454987	8.975757	31.001366	62.002731
17	561.231024	629.960525	707.106781	144356.656038	0.264187	0.912476	1.824953	30404.924149	0.950367	3.282473	6.564946
18	707.106781	793.700526	890.898718	111221.177440	0.326313	1.127053	2.254107	26795.507648	0.918248	3.171537	6.343074
19	890.898718	1000.000000	1122.462048	128403.468273	0.260143	0.898507	1.797014	29337.246104	1.132581	3.911822	7.823644
20	1122.462048	1259.921050	1414.213562	94142.617628	0.223070	0.770463	1.540926	21624.847665	1.476422	5.099414	10.198828
21	1414.213562	1587.401052	1781.797436	129629.034157	0.163009	0.563018	1.126037	11778.490899	2.192189	7.571601	15.143203
22	1781.797436	2000.000000	2244.924097	170659.311167	0.116480	0.402312	0.804624	7403.121350	22.663955	78.279034	156.558068
23	2244.924097	2519.842100	2828.427125	145581.014556	0.123795	0.427577	0.855154	7594.171778	2.505007	8.652045	17.304090
24	2828.427125	3174.802104	3563.594873	131301.387539	0.125227	0.432523	0.865046	4903.646851	4.235269	14.628194	29.256388
25	3563.594873	4000.000000	4489.848193	220596.853404	0.098150	0.339000	0.678000	3374.546734	9.050786	31.260509	62.521018
26	4489.848193	5039.684200	5656.854249	219459.412869	0.098538	0.340342	0.680684	2885.247932	3.010822	10.399077	20.798153
27	5656.854249	6349.604208	7127.189745	404187.355371	0.080940	0.279560	0.559120	1717.184010	3.143055	10.855796	21.711592
28	7127.189745	8000.000000	8979.696386	397879.297024	0.068002	0.234870	0.469741	1010.733049	184306.962267	636577.816974	1273155.633948
29	8979.696386	10079.368400	11313.708500	810103.837023	0.051035	0.176271	0.352543	1263.863028	327691.827427	1131814.802751	2263629.605502
30	11313.708500	12699.208420	14254.379490	1426944.643073	0.042411	0.146482	0.292964	1540.379897	41.338064	142.777538	285.555076
31	14254.379490	16000.000000	17959.392770	3047381.297714	0.029777	0.102848	0.205696	1394.330971	5.696710	19.675868	39.351735
32	17959.392770	20158.736800	22000.000000	423130.001222	0.033335	0.115134	0.230268	420.614808	3.745322	12.935967	25.871933

Figure 16 Pressure Right Reverberation Time Data

Trvb_Studies LSQ Fit Results
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Start time of 1st exponential fit 0.100000
End time of 1st exponential fit 0.500000

Start time of 2nd exponential fit 0.500000
End time of 2nd exponential fit 1.000000

Band #	f_lo	f_ctr	f_hi	Ynts	Taus	T30s	T60s	Yntl	Taul	T30l	T60l
0	13.920292	500.000000	22000.000000	1441833.404491	0.286805	0.990596	1.981193	252373.129013	11.819393	40.823002	81.646004
1	13.920292	15.625000	17.538470	40240.862938	41543.233690	143486.174843	286972.349685	237559.349780	0.373913	1.291457	2.582913
2	17.538470	19.686266	22.097087	33640.972519	9.201458	31.780916	63.561831	32145.065752	166047.556420	573511.655121	1147023.310241
3	22.097087	24.803141	27.840585	46247.478975	23653.362395	81696.348375	163392.696750	45394.380664	82863.278211	286201.476612	572402.953224
4	27.840585	31.250000	35.076939	75761.261028	0.879900	3.039085	6.078170	40506.051935	82665.146409	285517.149183	571034.298366
5	35.076939	39.372533	44.194174	47049.052899	11784.975529	40704.126979	81408.253958	51895.289490	165382.216557	571213.637767	1142427.275534
6	44.194174	49.606283	55.681170	81462.151600	1.779015	6.144541	12.289083	100059.557089	1.508331	5.209623	10.419246
7	55.681170	62.500000	70.153878	106213.293942	-384681.391782	-1328651.059075	-2657302.118150	113085.365189	-171874.742624	-593638.173549	-1187276.347098
8	70.153878	78.745066	88.388348	125358.666586	0.591250	2.042119	4.084238	35733.960538	83167.405357	287251.901364	574503.802728
9	88.388348	99.212566	111.362340	100081.164533	-84768.139964	-292780.678620	-585561.357241	99823.798123	0.920814	3.180400	6.360800
10	111.362340	125.000000	140.307756	98811.913263	390335.498335	1348179.777699	2696359.555399	96012.238004	82398.283968	284595.432997	569190.865994
11	140.307756	157.490131	176.776695	103863.025316	-89763.640587	-310034.638223	-620069.276445	97376.605963	0.673686	2.326846	4.653691
12	176.776695	198.425131	222.724680	92757.157218	-86856.764704	-299994.579613	-599989.159225	87060.605188	0.825225	2.850246	5.700491
13	222.724680	250.000000	280.615512	105005.562163	-199658.872434	-689601.779501	-1379203.559002	97116.002478	1.318464	4.553844	9.107689
14	280.615512	314.980262	353.553391	264405.711395	-1633426.412030	-5641691.484511	-11283382.969022	173928.791243	0.528956	1.826960	3.653921
15	353.553391	396.850263	445.449359	116699.752726	-168374.448333	-581548.507098	-1163097.014195	72571.431722	1.320685	4.561515	9.123030
16	445.449359	500.000000	561.231024	85018.123752	-172435.374693	-595574.540653	-1191149.081306	54951.025667	2.079301	7.181697	14.363394
17	561.231024	629.960525	707.106781	130911.892965	-773909.869477	-2673007.298185	-5346014.596371	94550.803144	0.963439	3.327621	6.655241
18	707.106781	793.700526	890.898718	137782.992041	-770331.160618	-2660646.795658	-5321293.591316	75828.319153	1.309616	4.523283	9.046565
19	890.898718	1000.000000	1122.462048	144595.927956	-355593.252744	-1228183.535653	-2456367.071307	70424.397135	2.806822	9.694483	19.388966
20	1122.462048	1259.921050	1414.213562	269032.783474	0.220750	0.762447	1.524895	25291.597145	4.495459	15.526866	31.053733
21	1414.213562	1587.401052	1781.797436	332592.422207	0.187688	0.648257	1.296514	30289.566933	1.287844	4.448086	8.896171
22	1781.797436	2000.000000	2244.924097	207630.883243	0.213223	0.736450	1.472900	22793.181784	20438.595197	70592.863950	141185.727901
23	2244.924097	2519.842100	2828.427125	289874.877288	0.168048	0.580420	1.160841	18423.482494	1.727315	5.965972	11.931945
24	2828.427125	3174.802104	3563.594873	340307.725338	0.150499	0.519808	1.039616	11966.813427	19.908544	68.762121	137.524242
25	3563.594873	4000.000000	4489.848193	453352.056944	0.139776	0.482773	0.965545	11536.022323	2.407239	8.314361	16.628723
26	4489.848193	5039.684200	5656.854249	579245.151963	0.117761	0.406736	0.813472	7888.294869	2.942916	10.164537	20.329073
27	5656.854249	6349.604208	7127.189745	658893.840073	0.126074	0.435446	0.870893	8530.615494	0.961881	3.322242	6.644484
28	7127.189745	8000.000000	8979.696386	433002.639678	0.126265	0.436106	0.872211	5572.900023	1.658638	5.728771	11.457543
29	8979.696386	10079.368400	11313.708500	623380.266760	0.105761	0.365286	0.730573	3067.228897	4.317457	14.912064	29.824129
30	11313.708500	12699.208420	14254.379490	741153.486517	0.091804	0.317083	0.634166	2462.222240	5.679888	19.617766	39.235532
31	14254.379490	16000.000000	17959.392770	319575.740897	0.092883	0.320807	0.641614	1704.969530	11.472199	39.623830	79.247659
32	17959.392770	20158.736800	22000.000000	84019.156922	0.084158	0.290674	0.581349	549.905255	20482.619107	70744.918134	141489.836267

Figure 17 Particle Velocity Center Reverberation Time Data

Trvb_Studies LSQ Fit Results
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Start time of 1st exponential fit 0.100000
End time of 1st exponential fit 0.500000

Start time of 2nd exponential fit 0.500000
End time of 2nd exponential fit 1.000000

Band #	f_lo	f_ctr	f_hi	Ynts	Taus	T30s	T60s	Ynt1	Tau1	T30l	T60l
0	13.920292	500.000000	22000.000000	947541.707875	0.399330	1.379247	2.758495	194654.090616	88.048971	304.112341	608.224681
1	13.920292	15.625000	17.538470	113185.570001	176247.404789	608740.911400	1217481.822799	43876.303649	3.034970	10.482483	20.964966
2	17.538470	19.686266	22.097087	91483.342226	91226.254469	315086.360312	630172.720624	214296.868220	0.487652	1.684300	3.368600
3	22.097087	24.803141	27.840585	67983.463177	11514.619253	39770.343438	79540.686875	140303.514051	0.888967	3.070404	6.140809
4	27.840585	31.250000	35.076939	94931.024526	1.247987	4.310423	8.620845	238187.506517	0.494728	1.708742	3.417484
5	35.076939	39.372533	44.194174	85885.481659	0.492022	1.699395	3.398790	36042.266314	5190.135184	17926.207914	35852.415827
6	44.194174	49.606283	55.681170	392140.319344	0.167218	0.577556	1.155112	110088.214208	0.923887	3.191013	6.382026
7	55.681170	62.500000	70.153878	125430.645491	-407107.753032	-1406109.468199	-2812218.936398	77364.304238	165365.008261	571154.202033	1142308.404066
8	70.153878	78.745066	88.388348	164294.790669	0.303652	1.048785	2.097570	36917.755787	1233.545410	4260.542492	8521.084984
9	88.388348	99.212566	111.362340	123804.179036	-100395.216754	-346755.039148	-693510.078296	53721.660896	2.882121	9.954556	19.909112
10	111.362340	125.000000	140.307756	67995.225349	21576.799342	74524.107249	149048.214498	82523.391865	-85158.017179	-294127.275536	-588254.551072
11	140.307756	157.490131	176.776695	43665.997301	3.380561	11.676120	23.352240	32852.352706	1.638553	5.659397	11.318793
12	176.776695	198.425131	222.724680	71172.463130	0.787518	2.720008	5.440017	30333.398828	4.285683	14.802321	29.604641
13	222.724680	250.000000	280.615512	106299.139064	0.479092	1.654734	3.309469	45376.566045	1.877262	6.483874	12.967749
14	280.615512	314.980262	353.553391	135957.331175	0.376872	1.301677	2.603354	39541.783016	1.401210	4.839638	9.679276
15	353.553391	396.850263	445.449359	92350.904341	0.384795	1.329043	2.658086	30065.750829	2603.856399	8993.459616	17986.919232
16	445.449359	500.000000	561.231024	116154.409621	0.308202	1.064498	2.128997	32276.661416	5.525611	19.084908	38.169815
17	561.231024	629.960525	707.106781	190405.709095	0.252603	0.872466	1.744932	36564.994814	2.052518	7.089193	14.178386
18	707.106781	793.700526	890.898718	109174.169858	0.386952	1.336495	2.672989	28265.425463	3.282019	11.335766	22.671531
19	890.898718	1000.000000	1122.462048	301202.401873	0.163904	0.566107	1.132214	35108.099919	3.869377	13.364442	26.728884
20	1122.462048	1259.921050	1414.213562	172518.282675	0.188927	0.652535	1.305070	34069.395270	2.506303	8.656521	17.313042
21	1414.213562	1587.401052	1781.797436	353732.554464	0.110015	0.379980	0.759960	24966.807974	1.925158	6.649303	13.298606
22	1781.797436	2000.000000	2244.924097	163212.803974	0.162874	0.562550	1.125099	14043.099157	41553.799160	143522.666919	287045.333838
23	2244.924097	2519.842100	2828.427125	264976.667806	0.110272	0.380868	0.761736	12963.525429	5.279037	18.233265	36.466531
24	2828.427125	3174.802104	3563.594873	414392.652643	0.088043	0.304090	0.608181	9253.794291	7.020515	24.248158	48.496316
25	3563.594873	4000.000000	4489.848193	740649.314204	0.076671	0.264812	0.529625	7116.160048	5.238719	18.094012	36.188024
26	4489.848193	5039.684200	5656.854249	853974.925855	0.071237	0.246044	0.492088	5234.626835	4.488959	15.504417	31.008833
27	5656.854249	6349.604208	7127.189745	2253248.308201	0.056303	0.194464	0.388928	3401.748652	2.892444	9.990213	19.980425
28	7127.189745	8000.000000	8979.696386	1467659.997318	0.061148	0.211201	0.422401	1983.541911	8.195897	28.307809	56.615618
29	8979.696386	10079.368400	11313.708500	1965924.506235	0.056133	0.193878	0.387756	2308.266938	18.444196	63.704409	127.408818
30	11313.708500	12699.208420	14254.379490	4498709.994453	0.044880	0.155011	0.310022	2572.446206	12.107688	41.818744	83.637488
31	14254.379490	16000.000000	17959.392770	3925269.998884	0.041073	0.141862	0.283723	1871.658147	8.528593	29.456906	58.913812
32	17959.392770	20158.736800	22000.000000	2011503.116075	0.039202	0.135399	0.270797	1232.906048	28.863733	99.692447	199.384894

Figure 18 Particle Velocity Right Reverberation Time Data

Trvb_Studies LSQ Fit Results
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Start time of 1st exponential fit 0.100000
End time of 1st exponential fit 0.500000

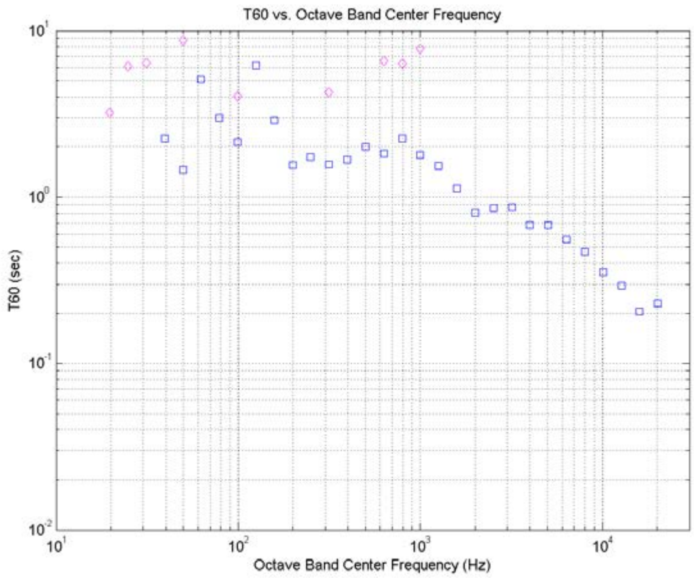
Start time of 2nd exponential fit 0.500000
End time of 2nd exponential fit 1.000000

Band #	f_lo	f_ctr	f_hi	Ynts	Taus	T30s	T60s	Ynt1	Tau1	T30l	T60l
0	13.920292	500.000000	22000.000000	1173849.080289	0.421543	1.455968	2.911937	438841.935539	24787.286284	85612.808096	171225.616192
1	13.920292	15.625000	17.538470	83244.422112	31510.157278	108832.932223	217665.864446	372379.805529	0.423934	1.464227	2.928455
2	17.538470	19.686266	22.097087	76718.031722	4.259922	14.713343	29.426686	73251.558718	84574.509360	292111.897877	584223.795754
3	22.097087	24.803141	27.840585	106773.928445	42383.754365	146389.249201	292778.498401	68207.953458	42911.385737	148211.635198	296423.270397
4	27.840585	31.250000	35.076939	112194.149221	43843.448395	151430.886410	302861.772821	69562.387073	86417.356311	298476.906963	596953.813925
5	35.076939	39.372533	44.194174	101489.161139	5.934413	20.496868	40.993737	71640.019531	83213.719372	287411.865339	574823.730679
6	44.194174	49.606283	55.681170	116019.128789	42639.786787	147273.559585	294547.119169	130188.513082	3.995825	13.801178	27.602357
7	55.681170	62.500000	70.153878	202432.224779	11519.122409	39785.896887	79571.793774	261604.137810	4.470120	15.439347	30.878695
8	70.153878	78.745066	88.388348	285661.003876	0.272279	0.940423	1.880846	75417.536664	166136.115430	573817.529085	1147635.058169
9	88.388348	99.212566	111.362340	262435.507135	0.340565	1.176279	2.352558	70716.305756	41215.666336	142354.789959	284709.579919
10	111.362340	125.000000	140.307756	223658.214978	-186580.521746	-644430.464058	-1288860.928115	205741.423680	-49568.795631	-171205.663231	-342411.326462
11	140.307756	157.490131	176.776695	264418.252405	0.254408	0.878701	1.757401	49357.790121	41296.185900	142632.896478	285265.792957
12	176.776695	198.425131	222.724680	214299.831056	0.384916	1.329462	2.658925	61139.345762	21358.930414	73771.609758	147543.219517
13	222.724680	250.000000	280.615512	139139.002435	0.839812	2.900626	5.801253	136080.635458	2.173827	7.508181	15.016361
14	280.615512	314.980262	353.553391	698594.280878	0.197995	0.683855	1.367710	59137.554533	58.629019	202.498769	404.997538
15	353.553391	396.850263	445.449359	165612.984362	0.664310	2.294460	4.588919	104311.865576	2.183809	7.542658	15.085316
16	445.449359	500.000000	561.231024	116443.609100	1.489554	5.144770	10.289540	72718.268559	112.960043	390.152694	780.305388
17	561.231024	629.960525	707.106781	112591.869413	1.646204	5.685823	11.371646	73072.276487	41228.297908	142398.418143	284796.836287
18	707.106781	793.700526	890.898718	213402.577882	0.565226	1.952233	3.904466	83476.650499	10.089283	34.847374	69.694747
19	890.898718	1000.000000	1122.462048	270557.444596	0.470060	1.623541	3.247083	105767.504810	82029.657451	283322.233871	566644.467741
20	1122.462048	1259.921050	1414.213562	186063.128029	0.279725	0.966141	1.932282	37757.199365	82169.040973	283803.650617	567607.301234
21	1414.213562	1587.401052	1781.797436	197918.455785	0.262043	0.905069	1.810139	44209.410408	2.371360	8.190439	16.380878
22	1781.797436	2000.000000	2244.924097	146000.327591	0.356523	1.231394	2.462788	44794.285727	328684.430536	1135243.154628	2270486.309255
23	2244.924097	2519.842100	2828.427125	215742.547144	0.179219	0.619004	1.238007	29115.582067	3.192943	11.028106	22.056212
24	2828.427125	3174.802104	3563.594873	302174.385301	0.153667	0.530749	1.061498	22535.138339	328266.813431	1133800.746910	2267601.493820
25	3563.594873	4000.000000	4489.848193	334905.081298	0.142791	0.493186	0.986371	17452.232884	10.387406	35.877061	71.754123
26	4489.848193	5039.684200	5656.854249	534908.355888	0.114075	0.394003	0.788005	12829.370805	6.693463	23.118553	46.237106
27	5656.854249	6349.604208	7127.189745	793993.644578	0.106915	0.369273	0.738547	8066.845784	5.572595	19.247185	38.494370
28	7127.189745	8000.000000	8979.696386	722632.665691	0.099132	0.342393	0.684785	7251.217993	3.047942	10.527288	21.054577
29	8979.696386	10079.368400	11313.708500	940990.049142	0.087115	0.300886	0.601771	4644.951692	71.151650	245.750684	491.501368
30	11313.708500	12699.208420	14254.379490	893269.317524	0.082494	0.284925	0.569849	3826.379585	43.363087	149.771768	299.543535
31	14254.379490	16000.000000	17959.392770	348902.687049	0.085549	0.295478	0.590956	2762.505554	10.609742	36.644989	73.289978
32	17959.392770	20158.736800	22000.000000	141768.219062	0.081881	0.282808	0.565616	2486.204220	39.533701	136.545449	273.090897

For analysis, the T60 times are used as reverberation times. On the following graphs, the T60 times are plotted against the octave band center frequencies. For all four T60 graphs for each case, the general shows that the T60 times decrease as frequency increases, meaning that higher frequencies dissipate faster. In the graphs, the blue squares are the data that should be considered; the pink parallelograms show data that are outliers and contribute to error.

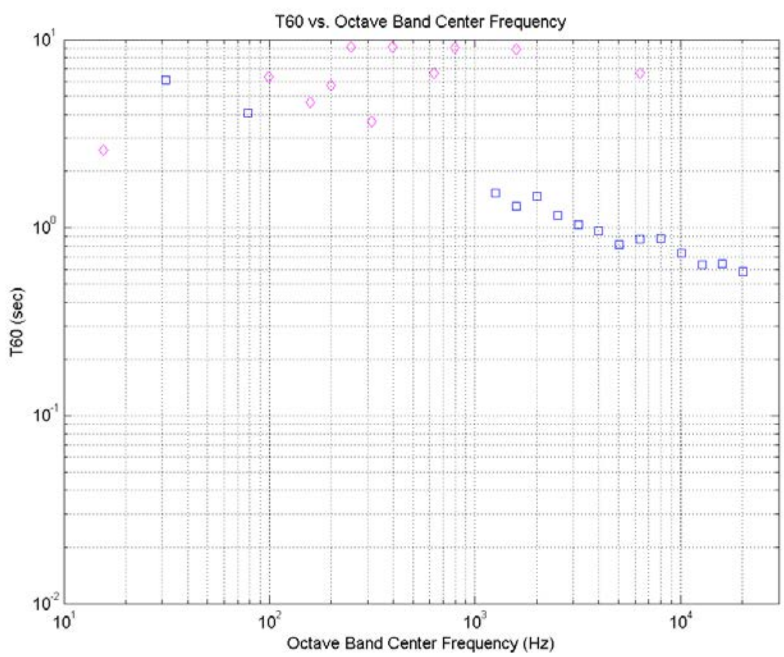
Pressure at Center

The T60 range varies from about 0.2 – 6 seconds, and the average reverberation time is at about 1.5 seconds.



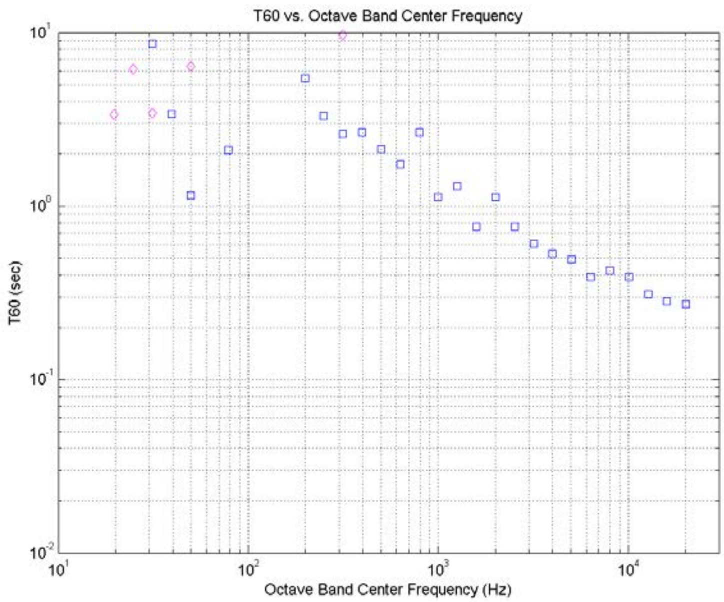
Pressure at Right

The T60 times ranged from about 0.6 – 6 seconds, averaging to around 0.9 seconds. Compared to the pressure at the center, these reverberation times are more condensed than those at the center.



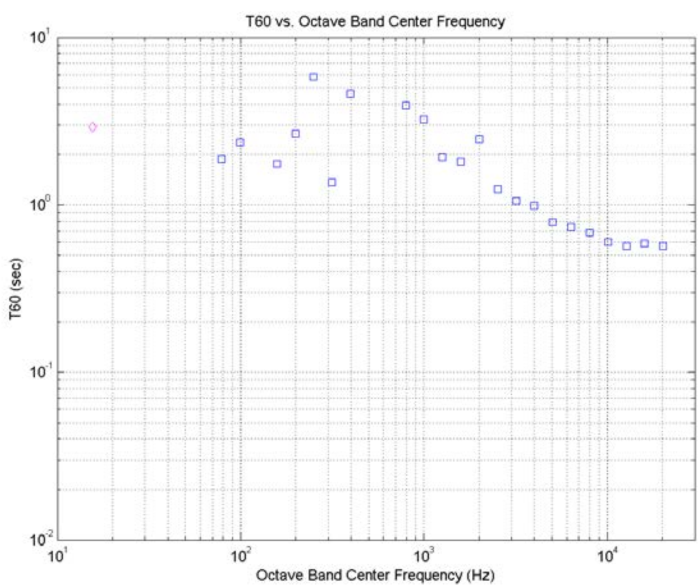
Particle Velocity at Center

The T60 times go from 0.18 – 8.5 seconds, the average being around 1.2 seconds of reverberation time.



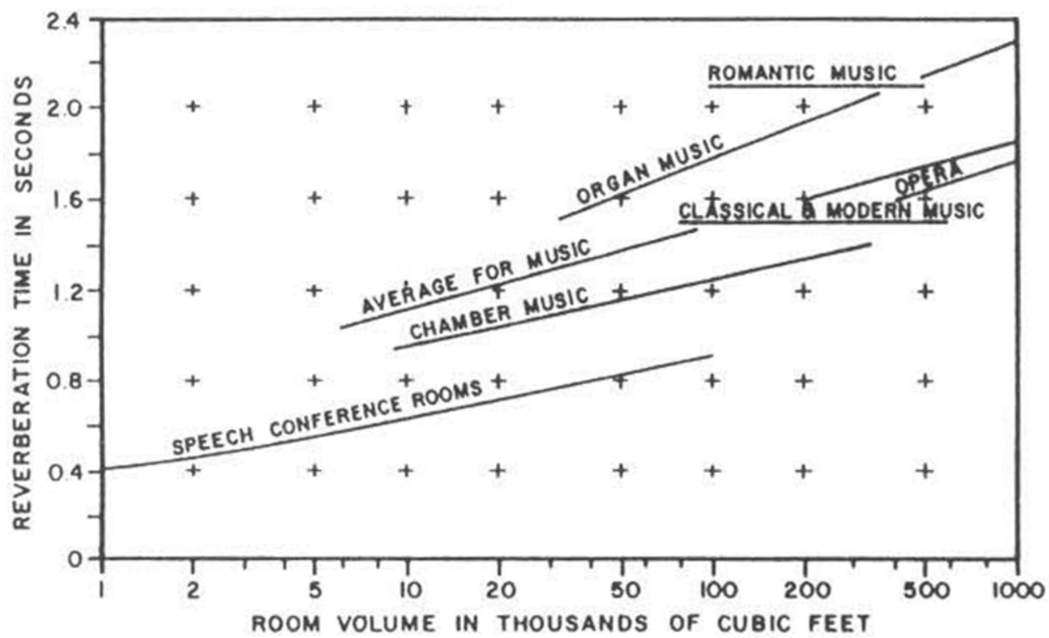
Particle Velocity at Right

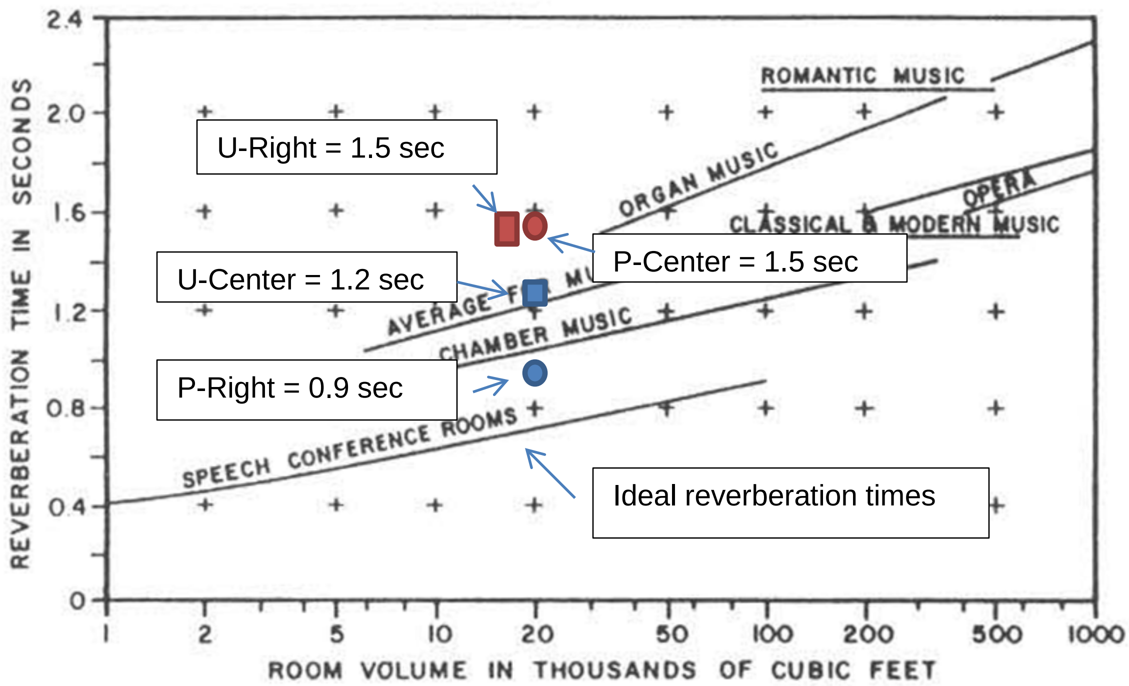
The T60 times range from 0.55 – 6 seconds, averaging around 1.5 seconds. The frequencies below 1000 Hz are more scattered than linear than that of the T60 trend of the particle velocity at center. However, the reverberation times are within a smaller range than that at the center for particle velocity.



From comparing the T60 graphs, the time measurements taken at the right side of the auditorium are more precise than those taken at the center.

Estimating the auditorium to be around 20,000 cubic feet, the average reverberation times were compared to a graph that compares optimum reverberation times for auditoriums of various sizes, listing their intended use.





From the data above, the reverberation times obtained from the right side result in a more precise reverberation time than the middle. Thus, people who sit at the sides would experience a smaller range of fluctuation between sound dissipation than it would for those who sit in the middle.

<u>Conclusion</u>

From the results of the reverberation times, 190ESB is found to be unsuitable for its purpose as a lecture room. The reverberation times are too long to be fitting for speech intelligibility, and thus the room is more suitable for listening to music instead. However, the reverberation times should be lower when the auditorium is filled with people, as opposed to the empty environment in which these measurements were taken. A more extensive analysis should be performed to find the issues that make this room undesirable for lecturing purposes, and the room should be corrected acoustically so that it may be more ideal for speech intelligibility.

In order to reduce reverberation time, more absorption is needed in the auditorium; this can be solved by using more carpeting, using seats that are cushioned, or adding more acoustical panels to increase absorption of sound and prevent prolonged reverberation.

I would like to thank Professor Errede for his extensive time and effort in assisting with the majority of this research project! I definitely would not have been able to accomplish this without this knowledge and expertise.