Estimation of Room Characteristics Through Comparison to the Known

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I. Background and Purpose

Often times an acoustician, or musician, will walk into a space and need to judge its qualities in a quick and efficient manner. In situations involving performances or live sound reinforcement, the individual will not necessarily have time to perform empirical measurements, or complete extensive tests. Being able to estimate the response of a room by its composition and features of its construction can prove to be a useful tool in these situations. By building upon experience and using a somewhat scientific approach, a musician, live sound person, acoustician, or a casual listener trying to discover the venues whose sound is "the best" could all apply these processes.

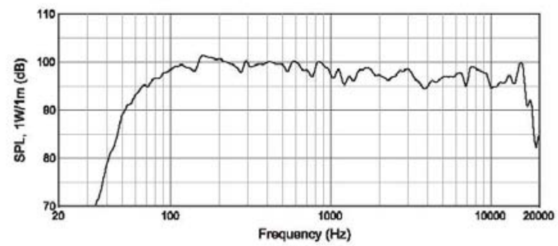
In order to gain a better understanding of the variables that shape the overall sound of a given space, three rooms were objectively measured for overall reverb time (RT_{60}), frequency dependent reverb time, and a set of physical measurements and estimations using absorption coefficients and surface area. An audio sample was then played in a room and examined subjectively. These subjectively drawn descriptions were then compared with the empirical measurements and estimations of the room to give the author a sense of what the numbers on paper mean in terms of perception of audio events. In order to judge how effective these measurements were and to see if the data on paper correlated consistently with the subjective response, a fourth room was measured empirically and a prediction was made as to what the resulting subjective sound would be.

II. The Experiment

EQUIPMENT AND PROCEDURE:

A fixed playback and recording system was used with consistent settings in each space that was to be evaluated. The playback system consisted of a JBL Eon 15; the unit is a two-way, self powered loudspeaker which has a fairly flat frequency response, as displayed in **FIG 1. [1]** In each space, the speaker was placed so that the front of the unit was 33" from the wall, on a tripod mount approximately 66" from the ground to center of the woofers speaker cone. The sounds output were consistently measured between 100-102 db on the "A"-Weighted scale.

FIG 1.



The microphone utilized to record the test sounds was an AKG 414. Both pads and roll-off were set to zero, and the pickup pattern was set to Omni-directional mode. As is displayed in **FIG 2 [2]**, the microphone has near ideal equal response across the frequencies the experiment will primarily deal with when used in Omni-directional mode. Also, without any pads or roll-off on, in a similar manner to the JBL Eon, the microphone has an almost ideal (flat) frequency response in the region of concern for this experiment. **FIG 3[2]** The microphone was placed on a boom stand with the center of its diaphragm approximately 60" from the ground. The distance from microphone to speaker varies, as will be discussed individually with each studio as a factor of critical distance and ensuring it is placed in the reverberant field.

FIG 2.

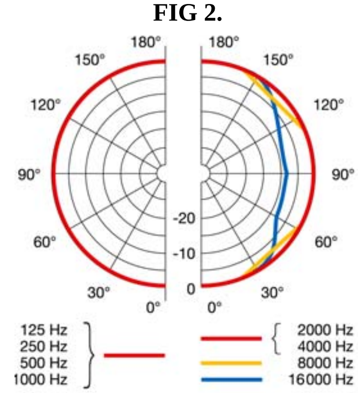
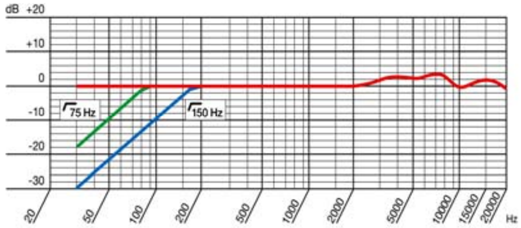


FIG 3



All samples and test tones were recorded and played back using a Digi-Design M-Box operating at a sampling rate of 44.1 kHz at 24 bits. In order to lower the ambient noise in the spaces, all air conditioning units and other devices which produced noise, or audible hum, were powered off. Even with major devices off, the ambient noise levels in most of the measured spaces were between 50 and 60 decibels ("A" - Weighted). As the procedure is discussed, it becomes evident that this level of noise proved to make portions of the testing difficult.

The procedure followed a number of simple steps. An RT_{60} time was determined using an impulse .0453 milliseconds long, which was played over the loudspeaker. The RT_{60} time was calculated and the microphone's position was adjusted to ensure it was beyond the critical distance and contained within the reverberant field. The critical distance was determined using a simplified formula provided by NYU Professor Langdon Crawford : **[3]**

$$\text{Critical distance} = .057 * \sqrt{(\text{Volume}(m^3)/RT_{60})}$$

Once a final microphone placement was determined sine tones at 125, 250, 500, 1k, 2k, and 4kHz were played in order to calculate frequency dependent RT60's within the space. These frequencies were chosen based on the fact that the absorption coefficient charts utilized had measurements for these frequencies. Estimated absorption charts for each room are attached to this document in **Appendix 1.** Doors and windows were consistently kept closed during all tests.

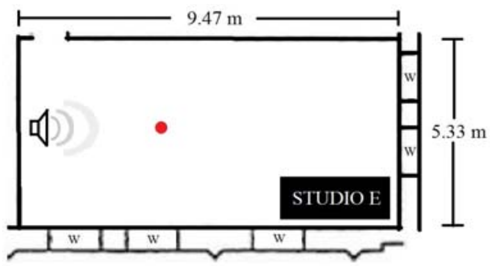
The problem that arose was in determining the RT_{60} times and involved the ambient noise. With noise levels that were only as quiet sometimes as 60 db, it would take a 120 db reference signal in order to observe the reverberation dropping by 60 decibels and still not being intermixed with the ambient noise. Although the author had ear plugs, the individual assisting in measuring did not and it was determined that playback at such a level would be unsafe - if even possible. The solution decided upon was to measure 40db worth of change instead. In the graphs of all predicted reverb times for each of the respective spaces, there is a drastic difference which is partially caused by this difference in reverberation time. The second major factor is that there a number of complex variables unique to each space created by the number and types of objects it contains. This will be generally discussed verbally, rather than through additional complex computation in the absorption coefficients of the space.

After each room was measured objectively, a subjective test was run by playing the song "Superstition" by Stevie Wonder over the playback system in the space. The song was summed to mono and qualities such as clarity, boominess, and other subjective descriptions were used to evaluate the space as a listening environment. There are obvious differences between recorded music and other forms of sound in a space such as speech, or live instruments, but in general the wide band content of this song gives a good indicator of the overall "sound" of the space. With each individual space measured, and subjective observation, clues began to develop as to why rooms behave in the manner they do.

STUDIO E

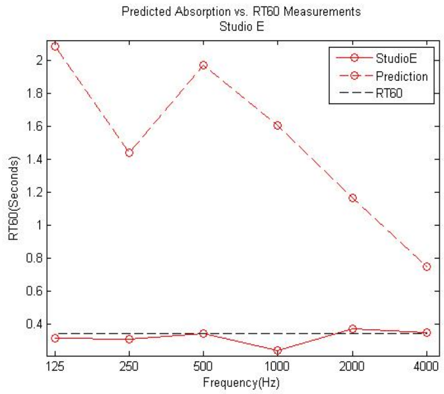
The first studio tested is called "Studio E." Studio E has a rectangular construction with two sets of parallel walls. **FIG 4,** The floor is covered with a thin carpeting over a cement floor, and the walls appear to be paint over cement. The ceiling is plywood covered in sheetrock and painted, with a hollow airspace above it. There are a five windows with shades and all of these factors were accounted for in absorption. There are however, a number of other surfaces which come into play in this room. There are "ports" or traps in the ceiling, approximately 30 hard plastic chairs scattered around the edges of the room, and a number of tables, desks, and benches with various computer and electronic equipment on them. The last notes to make are that there is an upright piano against one wall, and a stack of soft cases from the floor to nearly the ceiling occupying approximately 5 m^3 of surface area occupying the rear, lower corner of the room.

FIG 4



The critical distance of Studio E is 1.11 m, and the microphone was placed almost 4 meters from the sound source. Although adding this distance does drop the source signals initial level as it strikes the diaphragm of the microphone, it does ensure that nature of the reverberant field is being captured. The idealized version of the room versus the actual measurements were drastic. The hard plastic chairs are most likely reflecting energy, while things like the pile of soft cases are absorbing a significant amount of sound energy. **FIG 5** When the sample was played in the room it could be described as muddy, boomy, or unclear. Individual notes of the bass guitar lacked definition and attack, while the hi-hat was "tinny" and bright in a harsh sounding way. When the vocals entered although they still seemed present, they meshed in with the remainder of the instruments. Many of the instrumental parts blended together in an unnatural sounding manner.

FIG 5



STUDIO B

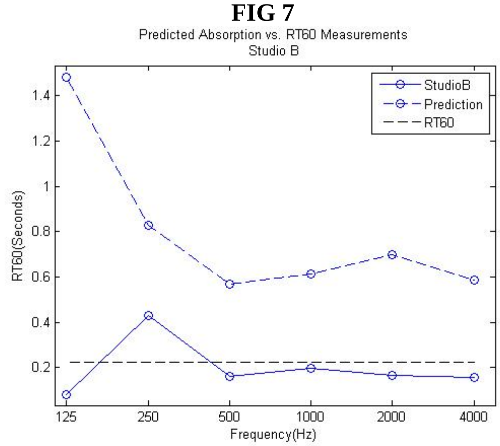
The second studio tested was Studio "B." Studio B is much smaller in relation to Studio E, and is shaped very differently. Although the diagram provided by NYU **FIG 6** shows this room as having one slanted side, the reality is that left side of the room also has a slight bow inward.Although the floor is carpeted, the ceiling does not meet the walls at a right angle, rather a trapezoidal pattern that resembles a curvature. The rear wall of the room is covered with thin wooden boards spaced 1" apart in groups of 5, which are 3 inches deep.

An interesting component of this studio is that almost 50% of the wall surface area is covered in modular and other synthesizers. These units almost all have slanted faces and have a number of materials contained within each unit. Some of these units are contained within wooden cases but have plastic keyboards, and almost all have large amounts of knobs and jacks which are essentially miniature windows, or traps. What is also interesting is that what appears to be a window at the top of the diagram is actually a "cubby hole" or storage space, which essentially acts as a window. There was also a pile of various material approximately 2.5 m^3 occupying the lower right hand corner.

FIG 6

The critical distance of Studio B is .758 m, and the microphone was placed almost 1.778 meters from the sound source. Due to the cramped nature of this studio, there weren't many options for microphone placement. The idealized version of the room versus the actual measurements were drastic. The sheer amount of material in this room, coupled with the "window" effect of the opening to the storage space drastically drops the response on the low end of the spectrum. **FIG 7** When the sample was played in the room it could be described as defined and clear. Individual notes of the bass guitar were very prominent with definition and attack, and the hi-hat was bright, yet natural sounding. When the vocals entered they were present and articulation was clear. The instrumental parts were easily separated and the room did very little overall to color the sound in any negative way.

FIG 7



STUDIO C

The third studio tested was Studio "C." Studio C represent a unique challenge in multiple ways; it is the first studio tested without a carpeted floor but rather has wood flooring. There is a curtain on the wall, and the angled portion of the room is mostly glass. This is also the only room tested which was not rectangular. The ceiling was also covered with acoustic tiles to treat, as well as a fabric covered trap. There is a large desk complete with mixing console which occupies the floor space between where the speker and microphone were placed. There were approximately 20 hard plastic chairs, 3 upholstered computer chairs, and a small window between this studio space and the smaller adjacent studio accessed through the aforementioned glass doors.

The critical distance of Studio C is .941 m, and the microphone was placed 3.2 meters from the sound source. A slow walkthrough of this room with a sample playing reveals that the reverberant field actually drastically changes as one crosses the plane of the dotted line displayed in **FIG 8**. The idealized version of the room versus the actual measurements were even more drastically different than either of the other rooms. **FIG 9** When the sample was played in the room it could be described as slightly muddy, with better definition than Studio E, but not nearly the clarity provided by studio B. The position of the desk probably contributes to absorbing a significant amount of low frequency energy and the result is a flat spectrum that lacks the appearance presence. The vocals were clear, but still lacked strong articulation. The remaining fact is that this was the only room whose measurements included an increase in RT60 between 2k and 4k; although the hi-hat did not sound tinny as it had in Studio F, it had thin, nasal quality to its sustaining period, or when it would be opened.

FIG 8

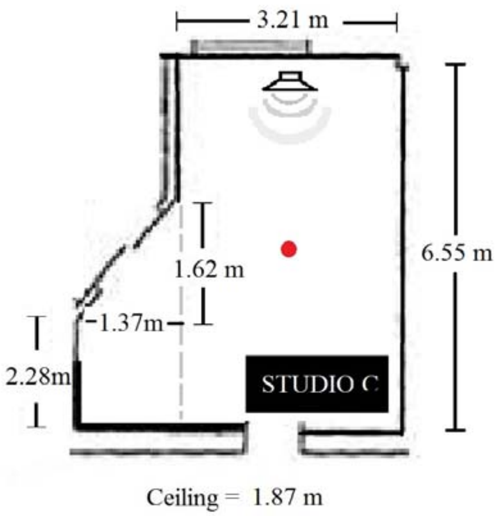
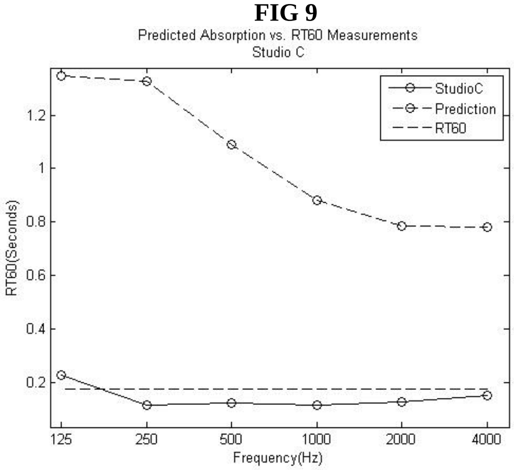


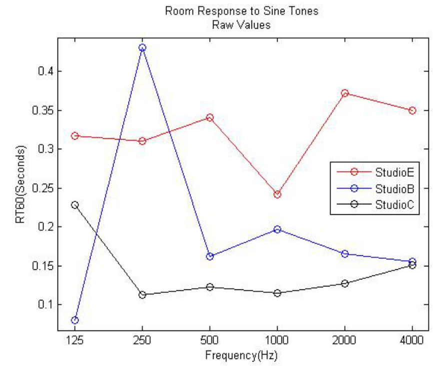
FIG 9



COMPARISON OF ROOM DATA

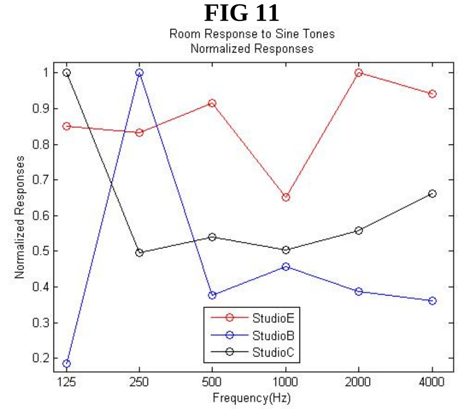
Subjectively, Studio B provided the most gratifying listening experience. In comparison it was relatively small, asymmetrically shaped, had soft transition between walls and ceiling, and window like space which absorbed a good deal of energy, particularly low frequencies radiating from the rear of the speaker cabinet. An examination of **(FIG 10),** shows the differences in all the studio but what is particularly interesting is that the room with the least bass response at 125 hz, had the most clearly defined bass guitar. Although relatively short, but longer in relation to measurements at other frequencies the second peak at 1k in Studio B may have also lead to clarity and presence in the vocal part, while maintaining a relatively flat response, and therefore the integrity, of the other instruments in the arrangement.

FIG 10



As an aside, the relative values of each of the responses were normalized to see how the rooms compared in direct relation to each other with reverberation times essentially stripped down to a maximum and subsequent relative values **FIG 11**. Studio E, which had the least pleasing sound, not only had the longest and overall flattest reverberation times, it also has a large dip at 1k, which is a portion of the region where the ears are most sensitive.

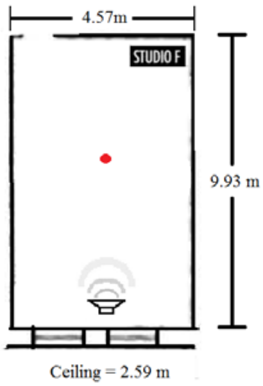
FIG 11



MEASURING FOURTH STUDIO AND PREDICTIONS

The fourth and final studio tested was Studio "F."**FIG 12** Studio F is most similar in composition to Studio E, but has slightly less volume. Although there are similar conditions with desks and workstations, the chairs contained within Studio F are spread throughout the room in a row and column fashion. There is also less area in window space. Some of the other miscellaneous material such as the soft cases, and test equipment, and piano that were in Studio E, are not in Studio F. Just on visual observation, the authors prediction would be that Studio F is going to have slightly less natural reverb time than Studio E, but because there is less material, and particularly less low frequency absorbing material, that the RT_{60} measurements in the 125, 250, and 500 hz ranges will be longer than Studio E.

FIG 12



The critical distance of Studio F is .923 m, and the microphone was placed 3.6 meters from the sound source. The idealized version of the room versus the actual measurements found drastic differences at the low end, but what now appear to be typical differences at the high end. **FIG 13** After measuring the room, and considering this room against all other rooms **FIG 14** it would be the authors prediction that the room will be boomier, lack definite bass articulation, have a medium level of clarity in vocals, but not necessarily the type of articulation experienced in studio B, and a hi-hat which will resmeble that heard in the initial tests of Studio E.

FIG 13

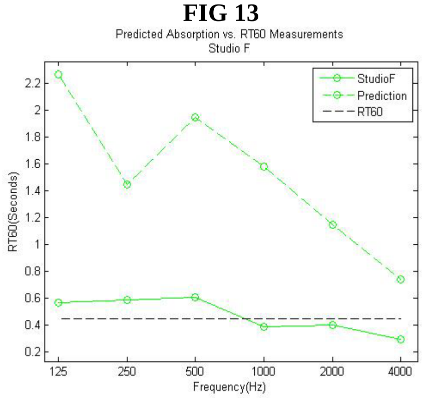
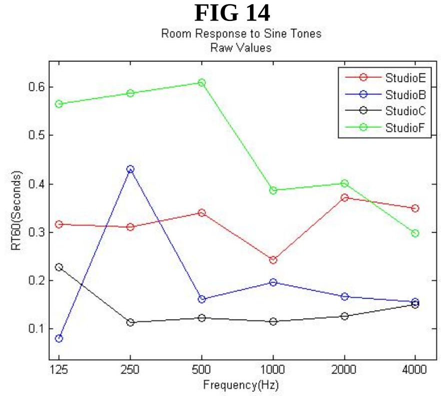


FIG 14



III. Results and Future Work

Although the composition, shape, and materials a room are constructed with matter greatly, what objects are placed into that room can have nearly the same impact in shaping the sound. Placement of these objects can also help or hinder the diffusion and absorption of waves at certain frequencies. Both the cubby hole space in Studio B, and the desk in Studio C drastically effected the actual low frequency RT60 versus ideal. The soft cases in Studio E were most likely absorbing a good deal of sound energy contained below 1k.

Although a rooms surface area can be calculated, it becomes exceptionally complex to calculate the surface area of rooms with five types of chairs, four different shaped desks made of four distinct materials, etc… There are a number of additional factors that could have been calculated numerically into the absorption coefficients which would have brought the ideal numbers closer to the actual numbers but due to time constraints this was not possible. A future study might involve completely stripping a room of all its contents and then slowly placing them back in order to observer the change that each object imparts on the character of the room. The interaction of stacked surfaces, like a curtain over a hard wall could also account for differences between ideal and actual measurements. Observing details such as calculating the surface area of the human bodies contained in the room during tests would also add a dimension of accuracy.

Ideally, the studio spaces selected would have been quieter, or a method would have been devised to use louder test sounds without damaging anyone's hearing. Overcoming this noise level using the microphone closer to sound source since may have been appropriate since it isn't levels themselves that are of interest here. The factor in question is the length of time of a level in relation to its initial state. The major problems with placing the microphone too close is having it not be in the reverberant field, and secondly if it is too close to say the sound source, the sound source could serve as a filter and block more directional frequencies from reaching the diaphragm of the microphone itself.

In terms of success as to the purpose of the experiment, it provided a very surface level way of "guesstimating" the properties of a room. After conducting this experiement hundreds of times for instance, one may be able to quickly ascertain the properties of any room by simple visualization and mental math, however after three rooms and guessing as to the nature of a fourth, it may not be currently feasible although the process to quickly obtain this information has been outlined and considered within this paper. References

[1] http://www.jblpro.com/pub/mi/eon15p-1.pdf

[2] http://www.akg.com/mediendatenbank2/psfile/datei/19/C414B_ULS4055c233c018f.pdf

[3] Crawford, Langdon. Lecture: "Acoustics of Eclosed Spaces." July 28th 2011.

[4] http://www.sae.edu/reference_material/pages/Coefficient%20Chart.htm

[5] David M. Howard and James A.S. Angus, Acoustics and Psychoacoustics, fourth ed, Burlington, MA : Focal Press, 2009.

APPENDIX 1 [4];[5]

STUDIO E

Material	**Area(m2)**	**125**		**250**		**500**	
Carpet	50.4751	0.01	0.504751	0.02	1.009502	0.06	3.028506
Window	7.8499	0.18	1.412982	0.06	0.470994	0.04	0.313996
Concrete(sealed/painted)	69.723	0.01	0.69723	0.01	0.69723	0.02	1.39446
Ceiling (Plywood over Air)	50.4751	0.15	7.571265	0.25	12.618775	0.12	6.057012
'==							
Volume (m3)	132.244	-	10.186228	-	14.796501	-	10.793974
RT60:	-	-	2.090202968	-	1.438940463	-	1.972515776

STUDIO B

Material	**Area(m2)**	**125**		**250**		**500**	
Carpet	16.17726	0.01	0.1617726	0.02	0.3235452	0.06	0.9706356
Concrete(sealed/painted)	34.656	0.01	0.34656	0.01	0.34656	0.02	0.69312
Ceiling (Plywood over Air)	16.17726	0.15	2.426589	0.25	4.044315	0.12	1.9412712
Slatboards (1")	6.896	0.08	0.55168	0.32	2.20672	0.99	6.82704
Window*(Open)	0.836	1	0.836	1	0.836	1	0.836
'==							
Volume (m3)	39.844	-	4.3226016	-	7.7571402	-	11.2680668
RT60:	-	-	1.484033134	-	0.826965071	-	0.569297655

*Studio B's window is like a cubby hole which leads to a storage area. Use an open window for the formula.

STUDIO C

Material	**Area(m2)**	**125**		**250**		**500**	
Wood Parquet On Concrete	16.17726	0.04	0.6470904	0.04	0.6470904	0.07	1.1324082
Glass	5.25196	0.18	0.9453528	0.06	0.3151176	0.04	0.2100784
Concrete(sealed/painted)	46.297	0.01	0.46297	0.01	0.46297	0.02	0.92594
Ceiling (Acoustic Tiles)	16.17726	0.15	2.426589	0.11	1.7794986	0.04	0.6470904
Ceiling (Baffle- estimate)	7.5	0.04	0.3	0.05	0.375	0.11	0.825
Drape(pleated 50%)	6.11	0.14	0.8554	0.35	2.1385	0.53	3.2383
'==							
Volume (m3)	47.165	-	5.6374022	-	5.7181766	-	6.978817
RT60:		-	1.346997204	-	1.327969654	-	1.088087709

STUDIO F

Material	**Area(m2)**	**125**		**250**		**500**	
Carpet	45.404532	0.01	0.45404532	0.02	0.90809064	0.06	2.72427192
Window	1.9996	0.18	0.359928	0.06	0.119976	0.04	0.079984
Concrete(sealed/painted)	73.1228	0.01	0.731228	0.01	0.731228	0.02	1.462456
Ceiling (Plywood over Air)	45.404532	0.15	6.8106798	0.25	11.351133	0.12	5.44854384
'==							
Volume (m3)	117.598	-	8.35588112	-	13.11042764	-	9.71525576
RT60:	-	-	2.265862538	-	1.444138858	-	1.948819307

1000		2000		4000	
0.15	7.571265	0.25	12.618775	0.45	22.713795
0.03	0.235497	0.02	0.156998	0.02	0.156998
0.02	1.39446	0.02	1.39446	0.02	1.39446
0.08	4.038008	0.08	4.038008	0.08	4.038008
================================					
-	13.23923	-	18.208241	-	28.303261
-	1.608196549	-	1.169321298	-	0.752255509

1000		2000		4000	
0.15	2.426589	0.25	4.044315	0.45	7.279767
0.02	0.69312	0.02	0.69312	0.02	0.69312
0.08	1.2941808	0.08	1.2941808	0.08	1.2941808
0.76	5.24096	0.34	2.34464	0.12	0.82752
1	0.836	1	0.836	1	0.836
================================					
-	10.4908498	-	9.2122558	-	10.9305878
-	0.611474201	-	0.696342366	-	0.586874569

1000		2000		4000	
0.06	0.9706356	0.06	0.9706356	0.07	1.1324082
0.03	0.1575588	0.02	0.1050392	0.02	0.1050392
0.02	0.92594	0.02	0.92594	0.02	0.92594
0.04	0.6470904	0.07	1.1324082	0.08	1.2941808
0.18	1.35	0.3	2.25	0.35	2.625
0.75	4.5825	0.7	4.277	0.6	3.666
================================					
-	8.6337248	-	9.661023	-	9.7485682
-	0.879523633	-	0.786000095	-	0.778941568

1000		2000		4000	
0.15	6.8106798	0.25	11.351133	0.45	20.4320394
0.03	0.059988	0.02	0.039992	0.02	0.039992
0.02	1.462456	0.02	1.462456	0.02	1.462456
0.08	3.63236256	0.08	3.63236256	0.08	3.63236256
================================					
-	11.96548636	-	16.48594356	-	25.56684996
-	1.582324147	-	1.148449765	-	0.740540115