Acoustic Analysis: Report

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INTRODUCTION

The following is a report on small room acoustics via theoretical calculations utilising spreadsheet software and physical measurement analysis using *FuzzMeasure,* a signal analysis software. Room dimensions are provided along with specifications for its construction materials and respective absorption coefficient data. Theoretical calculations are initially performed and are tallied and plotted. It is then analysed and compared with the impulse response analysis data from *FuzzMeasure* for validity and accuracy. Acoustic behaviour is predicted in accordance with the findings from both methods.

ROOM DETAILS

DIMENSIONS

Room Dimensions. Length = 2.6m, Width = 2.06m, Height = 2.63m

Glass Window 1. Width = 1.88m, Height = 1.345m

Glass Window 2. Width = 1.33m, Height = 0.95m

Glass Window 3. Width = 1.33m, Height = 0.365m

Door Dimensions. Width = 0.82m, Height = 2.04m

ROOM MATERIALS

Floors are carpeted and laid on concrete.

Walls are made of plasterboard on studs.

Roof is made of acoustic tiling.

Windows are made of glass.

Door is of solid wood panel.

ABSORPTION COEFFICIENT DATA

Floor

125Hz	250Hz	500Hz	1kHz	2kHz	4kHz
0.02	0.06	0.14	0.37	0.60	0.65

Walls

125Hz	250Hz	500Hz	1kHz	2kHz	4kHz
0.29	0.10	0.05	0.04	0.07	0.09

Roof

125Hz	250Hz	500Hz	1kHz	2kHz	4kHz
0.07	0.21	0.66	0.75	0.62	0.49

Windows

125Hz	250Hz	500Hz	1kHz	2kHz	4kHz
0.35	0.25	0.18	0.12	0.07	0.04

Door

125Hz	250Hz	500Hz	1kHz	2kHz	4kHz
0.10	0.07	0.05	0.04	0.04	0.04

BOLT RATIO

CALCULATION

1:X:Y

Shortest dimension (1) = width 2.06m

x-axis = length 2.6m

y-axis = height 2.63m

Ratio of **1:1.26:1.28**

PLOTTING

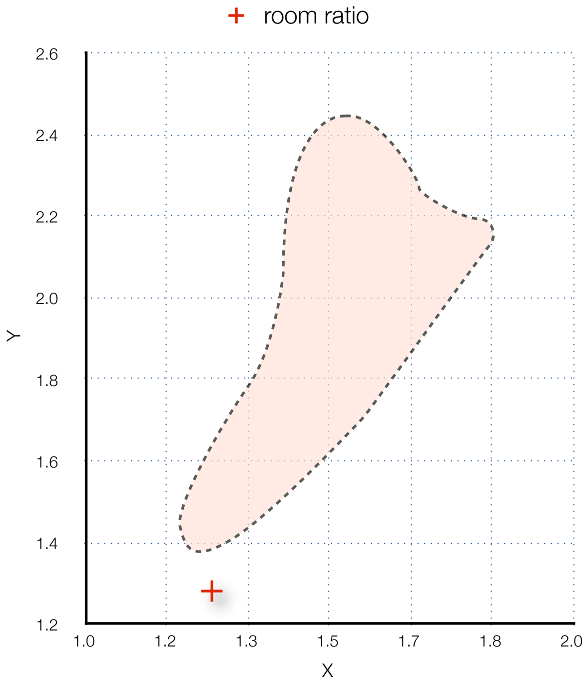


Figure 1 - *Bolt ratio*

ANALYSIS

Bolt theorises favourable room dimension ratios as indicated by the coloured area in the above graph (Everest & Pohlmann, 2009, p.248). A resulting room ratio of **1:1.26:1.28** fall well outside "Bolt's area" of optimal room ratios. This initially suggests that the room in question may contain problematic convergences with poor modal distribution. However further analysis is needed to verify this result.

BONELLO CRITERION

CALCULATION

No. of modes in 1/3 octave bands.

Lowest axial mode frequency = 65.34Hz

The table below shows the number of modes per 1/3 octave calculated by using **Modal Calculator Template** (Appendix 1).

	65-85Hz	86-107Hz	108-130Hz	131-173Hz	173-216Hz
No. of modes	3	3	2	8	13

Table 1 - *1/3 octave band mode occurrences*

PLOTTING

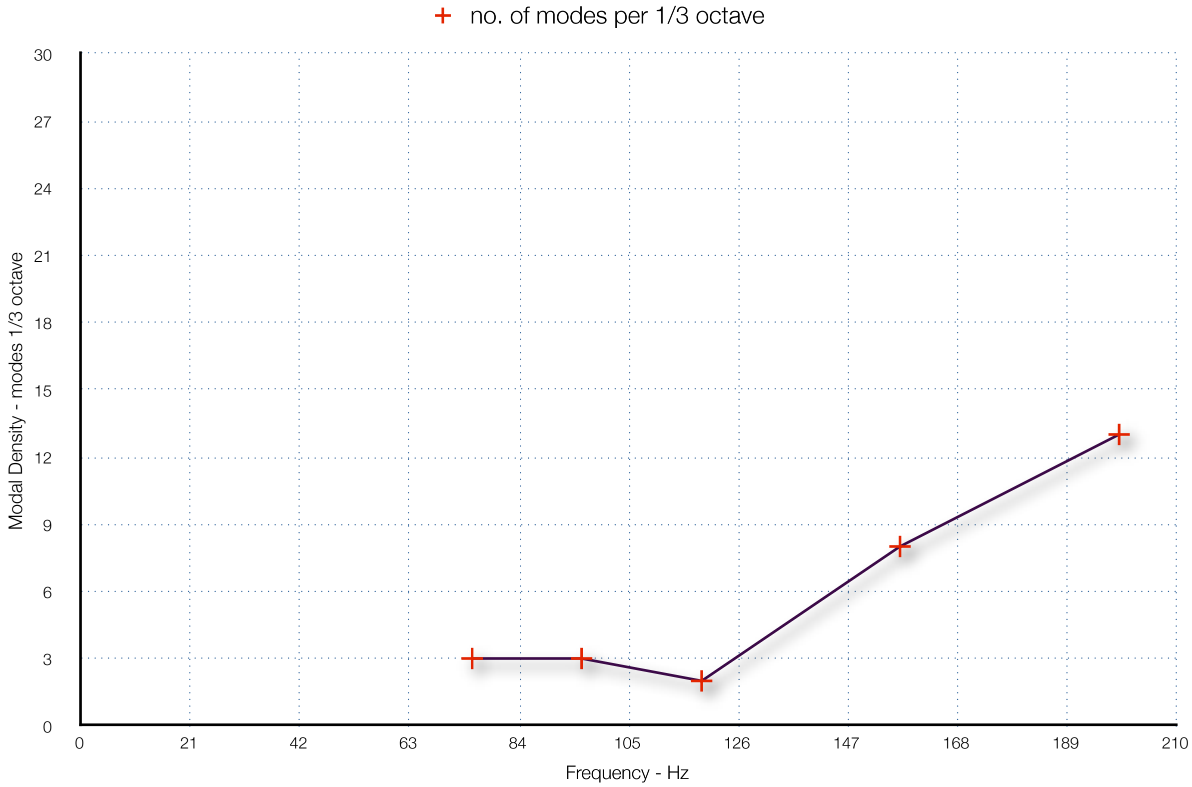


Figure 2 - *Bonello's criteria*

ANALYSIS

The plot graph above suggests a steady rise in modal frequencies with a slight dip between the 108-130Hz range. This suggest that modes maybe poorly distributed within this frequency range. This also mean that this room does not meet Bonello's criteria of each 1/3 band having more (or equal amount) modal frequencies than the previous band to achieve "acoustical desirability" (Everest & Pohlmann, 2009, p.250).

SINGLE MODE ANALYSIS

AXIAL MODES CALCULATIONS

Standing Wave Formula:

$$SW = \frac{v}{(2d)}$$

Where *SW* = Standing Wave (Hz)
v = speed of sound (m/s)
d = distance between walls (m)

Where v 343.71 m/s

Length Dimension Calculations:

Length Dimension = 2.6m

First SW (Hz) = 343.71 / (2 x 2.6)
= 343.71 / 5.2
= 66.10Hz

Second SW (Hz) = 66.10 x 2
= 132.20Hz

Third SW (Hz) = 66.10 x 3
= 198.29Hz

Fourth SW (Hz) = 66.10 x 4
= 264.39Hz

Fifth SW (Hz) = 66.10 x 5
= 330.49Hz

* calculations cease at ≈ 300Hz

A **Modal Calculator Template** was used to calculate for the remaining axial modes for the *width* and *height* dimensions. Results are tallied and shown in the table below.

Table 2 - *axial modes*

Modal Number	Length = 2.6	Width = 2.06	Height = 2.63
1	66.10	83.42	65.34
2	132.20	166.85	130.69
3	198.29	250.27	196.03
4	264.39	333.70	261.38
5	330.49	417.12	326.72

AXIAL MODES PLOTTING

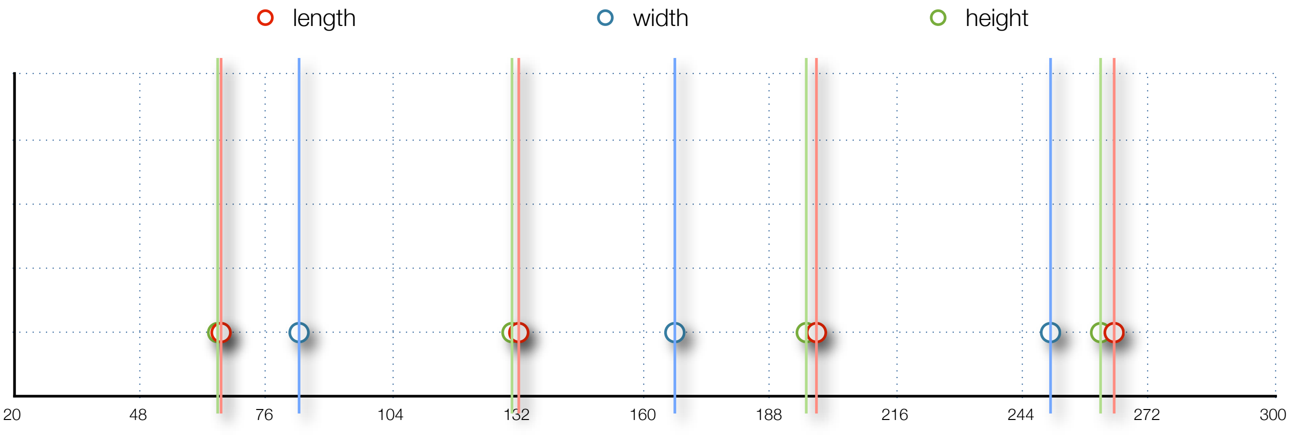


Figure 3 - *axial modes plot graph*

AXIAL MODES ANALYSIS

Axial modes are standing wave frequencies between parallel room surfaces (White, 1998). These can become problematic below 300Hz as they are usually not distributed evenly enough to create a smooth response within a small room. They are especially troublesome if there are any *convergences* which are frequency modes emphasised due to their close proximity to one other (within 3Hz). Table 1 shows that similar modal frequencies occur between the length and height dimensions of the room due to their identical measurements. This is further illustrated in Fig. 3 where the length (red) and height (green) modes are almost on top of one another. These convergences will cause the room to emphasise bass frequencies.

TANGENTIAL MODES CALCULATIONS

Rayleigh's Equation:

$$Hz = \frac{v}{2}\sqrt{\left(\frac{p^2}{L^2}+\frac{q^2}{W^2}+\frac{r^2}{H^2}\right)}$$

Where p = modal no. for length dimension
q = modal no. for width dimension
r = modal no. for height dimension
L = length dimension (m)
W = width dimension (m)
H = height dimension (m)
v = speed of sound (m/s)

Where v 343.71 m/s

A **Modal Calculator Template** using Rayleigh's equation was used to calculate for tangential modes between length & width, length & height and width & height. Results are shown in the table below.

Table 3 - *tangential modes*

Length & Width	Length & Height	Width & Height
106.44	92.95	105.97
156.32	146.45	155.05
179.47	147.46	179.19
212.87	185.89	211.94
215.13	206.88	213.05
258.86	208.78	257.42
259.15	236.44	258.66
277.24	237.49	274.37
283.04	269.60	282.34
312.64	272.35	310.09
319.31	278.84	317.91

TANGENTIAL MODES PLOTTING

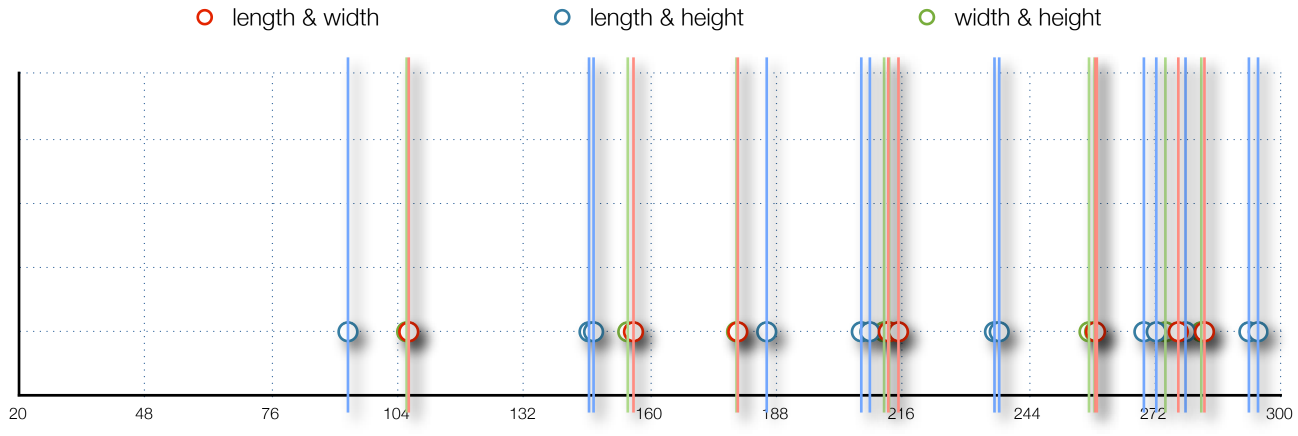


Figure 4 - *tangential modes plot graph*

TANGENTIAL MODES ANALYSIS

Tangential modes are created by sound energy reflecting from four walls (Everest & Pohlmann, 2009, p.256). They contain only half of the energy of axial modes. Table 2 tallies the tangential modes contained in the room with the red frequencies indicating convergences within 3Hz. As indicated in Table 3, almost all of the modal frequencies are within close proximity of another. This data is better exemplified in Fig. 4 where convergences are shown to be especially dense in the 200-216Hz range and within 270-285Hz. The next set of analysis should assist in clarifying an overall modal frequency impression of the room.

OBLIQUE MODES CALCULATIONS

A **Modal Calculator Template** using Rayleigh's equation was used to calculate for oblique modes between the length, width & height dimensions (Appendix 1). Convergent frequencies and their occurrences are tallied in the table below.

Frequency Range (Hz)	Occurrences
168-169	2
222-224	4
249-251	3
265-267	3
282-284	2
289-291	5

Table 4 - *oblique mode convergences*

OBLIQUE MODES PLOTTING

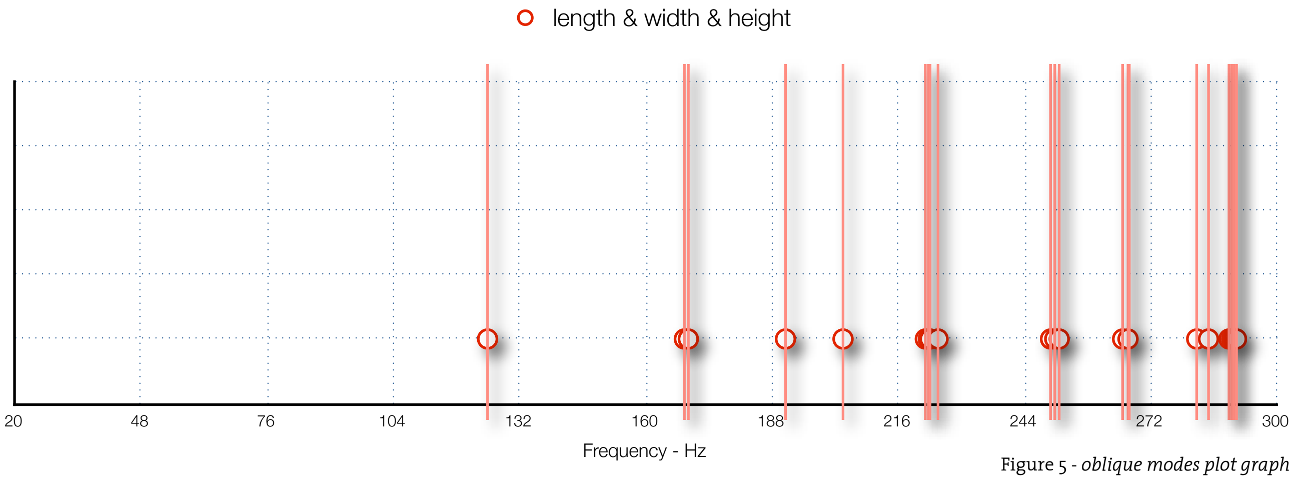


Figure 5 - *oblique modes plot graph*

OBLIQUE MODES ANALYSIS

Oblique modes are created by soundwaves reflecting from all six surfaces within a room (Everest & Pohlmann, 2009, p.256). They contain only half of the strength of a tangential mode and only a quarter of an axial mode, making them less obtrusive. Table 3 indicate that converging oblique modes from 222Hz onwards with five occurrences between 289-291Hz. This is further illustrated in Fig. 5 above where there is evident density within the same frequency region. On their own, oblique modes may not present a real problem but will certainly contribute to the overall colouration of the room when in convergence with several others or when in convergence with axial and/or tangential modes.

ALL MODES ANALYSIS

ALL MODES CALCULATIONS

Standing Wave Formula:

$$Hz = \frac{v}{2}\sqrt{\left(\frac{p^2}{L^2}+\frac{q^2}{W^2}+\frac{r^2}{H^2}\right)}$$

Where p = modal no. for length dimension
q = modal no. for width dimension
r = modal no. for height dimension
L = length dimension (m)
W = width dimension (m)
H = height dimension (m)
v = speed of sound (m/s)

Where v 343.71 m/s

A **Modal Calculator Template** using Rayleigh's equation was used to calculate for all axial, tangential and oblique modes (Appendix 1). Convergent frequencies and their occurrences are tallied in the table below.

Table 5 - *all modes convergences*

Frequency Range (Hz)	Occurrences
65-66	2
105-106	2
130-132	2
146-147	2
155-156	2
166-169	3
179-179	2
196-198	2
203-215	7
222-237	6
249-251	4
257-278	14
282-284	4
289-294	7

ALL MODES PLOTTING

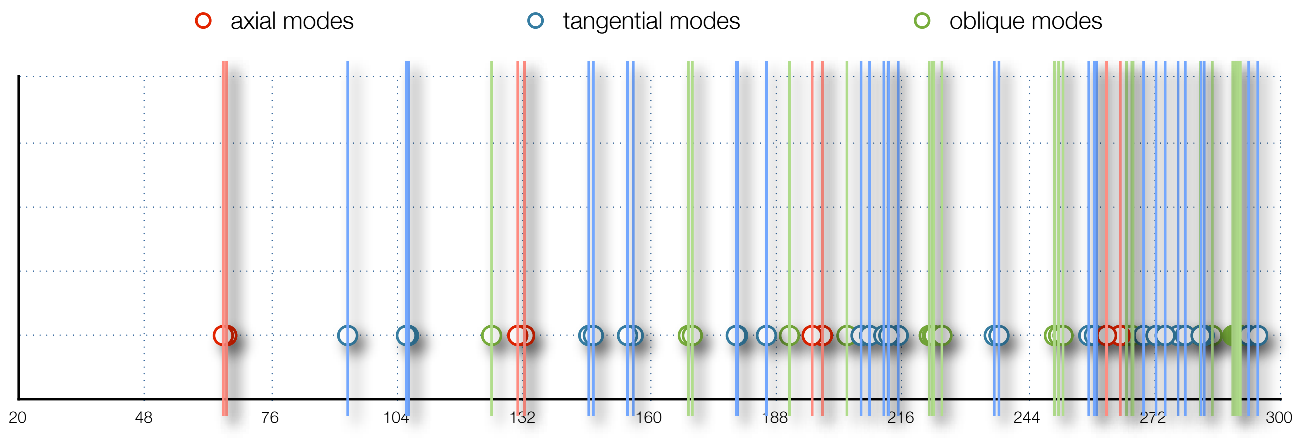


Figure 6 - *all modes plot graph*

ALL MODES ANALYSIS

In analysing all the modes together it becomes evident that this room has several problematic convergences from 203Hz onwards with fourteen occurrences within the 257-278Hz range as indicated in Table 5. This is further illustrated in the plot graph above (Fig. 6) where modes, especially of a tangential nature, are shown to be quite dense within this range. There are also significant axial convergent pairings, the lowest being at 65Hz, which will most likely be audibly prominent due to their combined strength and isolation. This early analysis indicate a room that may contain significant low end frequency resonances where sounds that are recorded or monitored in the space may have its low end dramatically emphasised.

RT60 CALCULATIONS

RT60 CALCULATIONS

RT60 Formula:

$$RT60 = \frac{(0.161V)}{A}$$

Where $RT60$ = Reverb Time (s)

V = Volume of room (m^3)

A = Total absorption (*Sabins*)

Where *Sabins* = Surface Area (m^2) x AbCo

Room Volume Calculations:

Dimensions Length = 2.6m

Width = 2.06m

Height = 2.63m

Room volume (m^3) = LxWxH

= 2.6m x 2.06m x 2.63m

= $14.086m^3$

Surface Area Calculations:

Floor Surface Area = LxW

= 2.6m x 2.06m

= $5.356m^2$

Ceiling Surface Area = LxW

= 2.6m x 2.06m

= $5.356m^2$

Front & Back Walls

Surface Area = WxH

= 2.06m x 2.63m

= $5.418m^2$

Side Walls

Surface Area = LxH

= 2.6m x 2.63m

= $6.838m^2$

Door Surface Area = WxH
= 0.82m x 2.04m
= $1.673m^2$

Window 1 = WxH
= 1.88m x 1.345m
= $2.529m^2$

Window 2 = WxH
= 1.33m x 0.95m
= $1.264m^2$

Window 3 = WxH
= 1.33m x 0.365m
= $0.485m^2$

∴ Total Window
Surface Area = $2.529m^2 + 1.264m^2 + 0.485m^2$
= $4.278m^2$

Sabine Calculations @ 125Hz:

Floor AbCo @ 125Hz = 0.02
∴ Floor Absorption = 5.356 x .02
= 0.107 Sabins

Ceiling Tile AbCo @ 125Hz = 0.07
∴ Ceiling Absorption = 5.356 x 0.07
= 0.375 Sabins

Plasterboard AbCo @ 125Hz = 0.29
∴ Front Wall = 5.418 x 0.29
= 1.571 Sabins

∴ Back Wall = 5.418 x 0.29
= 1.571 Sabins

∴ Side Wall 1 = 6.838 x 0.29
= 1.983 Sabins

∴ Side Wall 2 minus
Door and Windows = (6.838 - 1.673 - 4.278) x 0.29
= 0.887 x 0.29
= 0.257 Sabins

Solid Wooden Door AbCo @ 125Hz = 0.1

∴ Door Absorption = 1.673 x 0.1

= 0.167 Sabins

Glass Windows AbCo @ 125Hz = 0.35

∴ Window Absorption= 4.278 x 0.35

= 1.497 Sabins

Total Sabin Calculations @ 125Hz:

Total Sabins = 0.107 + 0.375 + 1.571 + 1.571 + 1.983 + 0.257 + 0.167 + 1.497

= 7.528 Sabins

RT60 Calculations @ 125Hz:

$$RT60 = \frac{(0.161V)}{A}$$

= (0.161 x 14.086) / 7.528

= 2.268 / 7.528

= 0.301ms

RT60 Calculations @ Different Frequencies:

An RT60 Template was used to calculate total Sabins and RT60 for octave frequencies at 250Hz, 500Hz, 1kHz, 2kHz and 4kHz (Appendix 2). Results are summarised and appropriately tallied in the table below.

Table 6 - *RT60 calculations using template*

	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz
	Total Sabines for each surface material					
Floor	0.107	0.321	0.750	1.981	3.214	3.481
Ceiling	0.375	1.125	3.535	4.017	3.321	2.624
Front Wall	1.571	0.542	0.271	0.217	0.379	0.488
Back Wall	1.571	0.542	0.271	0.217	0.379	0.488
Side Wall 1	1.983	0.684	0.342	0.274	0.479	0.615
Side Wall 2	0.257	0.089	0.044	0.035	0.062	0.080
Door	0.167	0.117	0.084	0.067	0.067	0.067
Windows	1.497	1.07	0.770	0.513	0.299	0.299
Total Sabins	7.53	4.49	6.07	7.32	8.20	8.14
RT60	0.30	0.51	0.37	0.31	0.28	0.28

RT60 PLOTTING

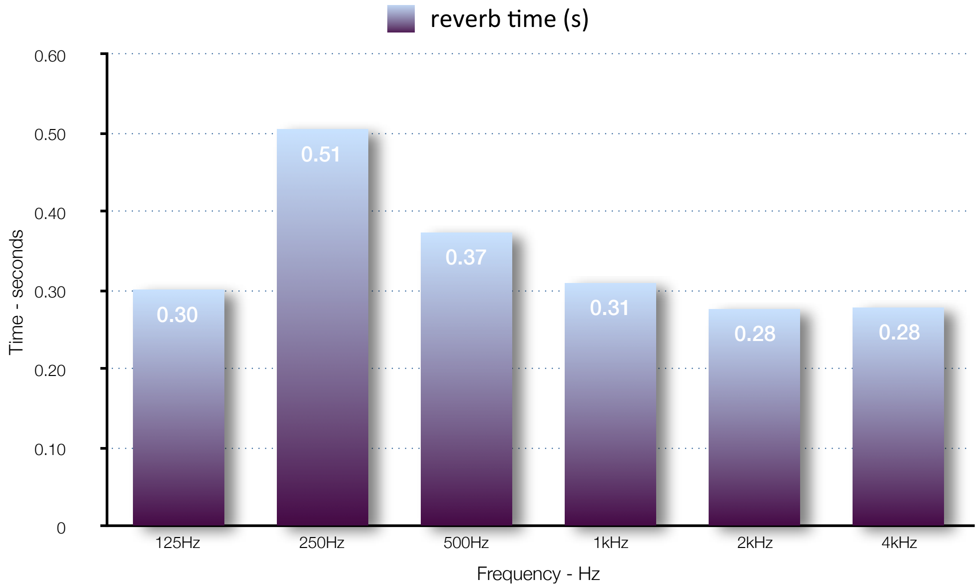


Figure 7 - *RT60 calculations using template*

RT60 ANALYSIS

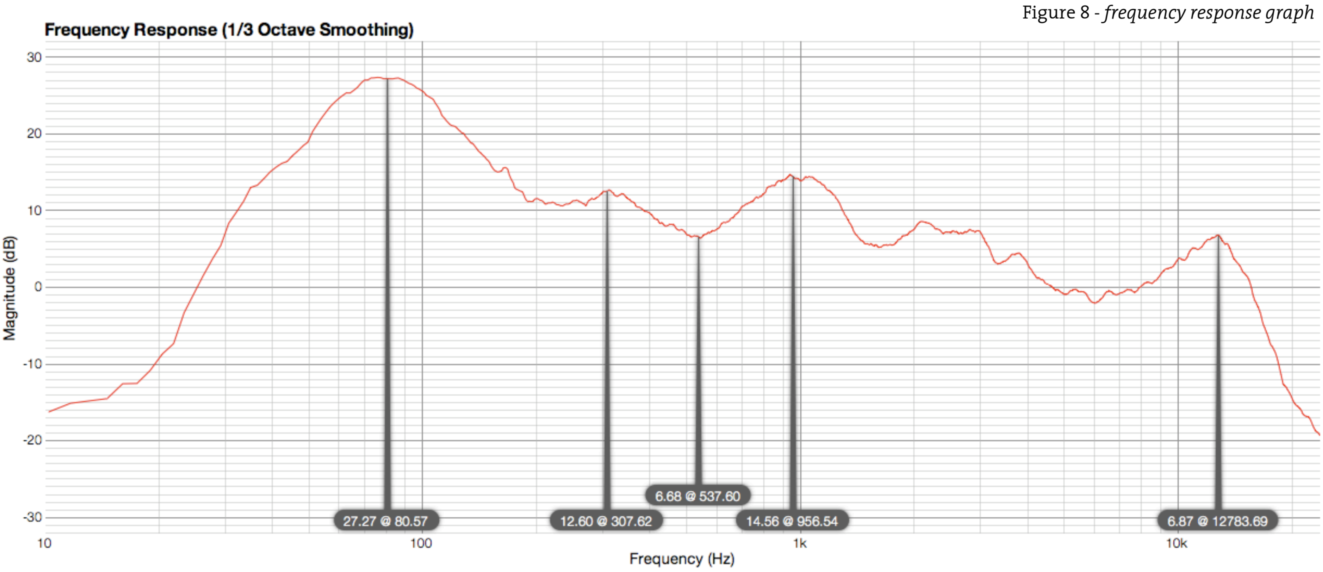
The resulting bar graph above (Fig. 7) indicate that there is persistent reverberation energy at 250Hz with a time of 500ms. 500Hz is shown to have the second longest reverb decay of 370ms. The rest of the frequency bands are averaging at 300ms. According to *Sound on Sound Magazine* (SOS) author Paul White (1998), these figures may not be entirely undesirable as “ideal reverb time varies depending on the room size and the type of material being auditioned”. A control room will generally be around 300ms and studios may have anything in between 200-500ms. The main issue however, is the uneven decay distribution of reverb across the frequency spectrum. This means that 250Hz will persist in the room much longer than all the other frequencies making it hard to monitor or capture an accurate representation of a sound.

IMPULSE RESPONSE ANALYSIS

An impulse response recording of the room was imported into a signal analysis software called *FuzzMeasure Pro 3*. The next section discusses the results for frequency response, RT60 response and waterfall plot data analysis.

FREQUENCY RESPONSE ANALYSIS

Figure 8 - *frequency response graph*



The graph above (Fig. 8) immediately shows a noticeable discrepancy with the sound energy distribution within the room. There is considerable excess pressure at ≈81Hz and at two other peaks, ≈957Hz and ≈12.8kHz. Drastic peaks and dips are to follow throughout the spectrum range with three main low pressure points at ≈ 538Hz, ≈1.7kHz and ≈6kHz. The data suggests that the room has not been ideally treated to be setup as a control room environment. As White and Robjohns state in their 2007 article for *SOS* "an untreated room can make even the best monitors sound boomy, with an ill-defined mid-range, an aggressive high end and an uneven bass response — where some notes boom out and others seem almost to vanish." Indeed at this point one can assume that the room in scrutiny has fundamental bass frequency problems as well as some troublesome specular reflections as indicated by the peak pressure located at ≈12.8kHz.

RT60 ANALYSIS

Table 7 - *RT60 calculations using FuzzMeasure*

	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz
RT60	0.184	0.524	0.402	0.400	0.296	0.155

An RT60 analysis was also performed using *FuzzMeasure's* reverberation time plugin. Table 7 above tabulates the results from the software data and shows an almost identical set to the theoretical RT60 calculations using the spreadsheet template. 250Hz still remain as having the longest reverb decay with 500ms, while the lower mids show an average decay time of 400ms. There is a significant difference with the 4kHz decay information with the plugin registering at only 150ms compared with the first set of calculations which resulted in 280ms. Differences in data may be attributed to the equipment or furnishings in the room that further influence the reverberation behaviour of the space.

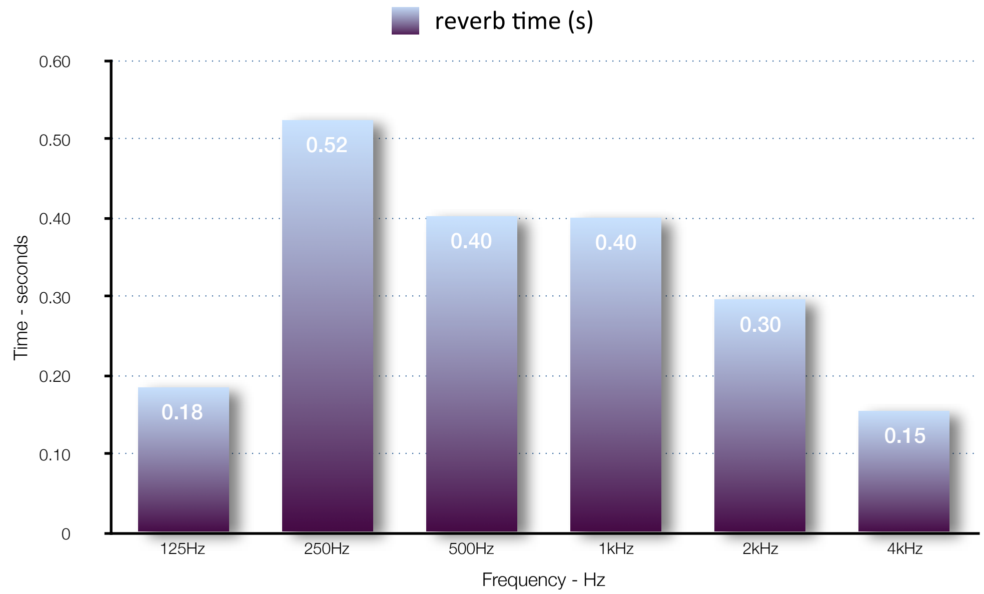


Figure 9 - *RT60 calculations using FuzzMeasure*

WATERFALL PLOT ANALYSIS

A waterfall plot data analysis was performed by using *FuzzMeasure's* waterfall plot plugin (Fig. 10). This clearly shows that low end resonances dominate the room especially at around the 30-100Hz range, with a dominant peak occurring at around 68Hz. This scenario according to Everest and Pohlmann (2009, p.165), may be undesirable as "a room that exhibits excessive reverberation time at low frequencies, [causes] poor bass clarity". The reverb response is also quite problematic with significant troughs, especially in the 1.5kHz mark, and drastic peaks at ≈200Hz and 2kHz.

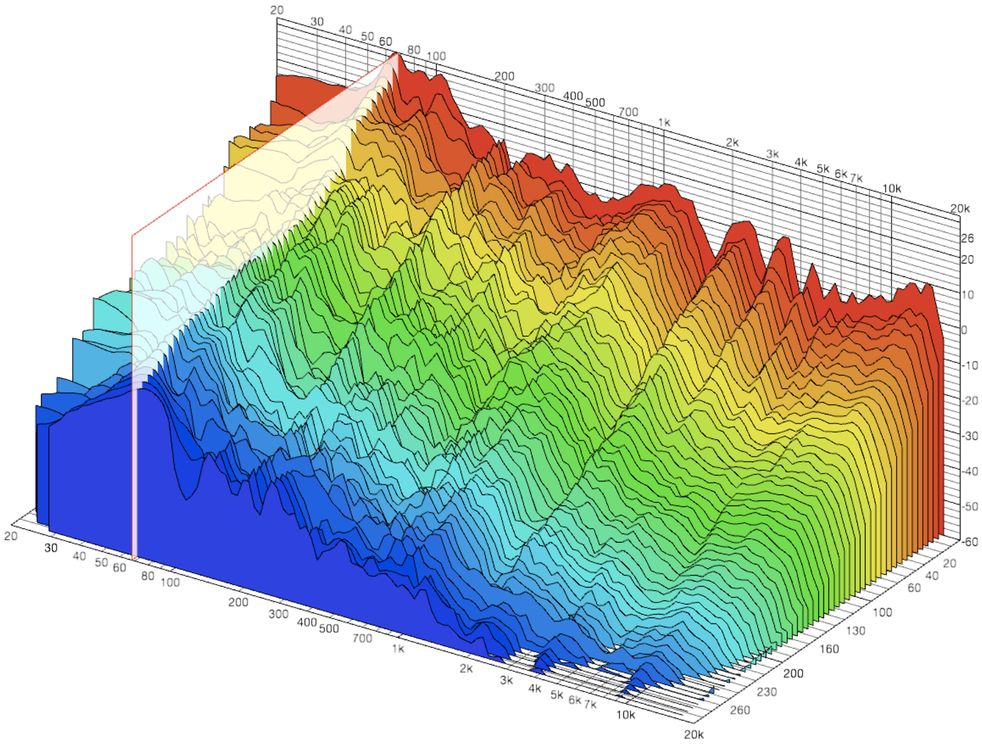


Figure 10 - *waterfall plot data using FuzzMeasure*

CONCLUDING COMPARISONS

Substantial similarities can be drawn from comparing the modal calculations with the impulse response analysis. As the frequency response graph and the waterfall plot indicate there is considerable maximum pressure occurring at ≈68Hz peak range which coincides with the lowest axial convergence in the manual calculations in Table 2 and Fig. 3. Subsequent axial convergences at ≈130Hz, ≈200Hz and ≈266Hz also match the waterfall plot (Fig.10) with peaks occurring along similar frequency ranges. The tangential and oblique convergences calculated in Table 3 and Table 4 is also reflected by the dense reverb energy around 150-300Hz as indicated by the waterfall plot.

Comparing the RT60 calculations with the impulse response of the real room however, does not generate as many similarities. The main similarity is at 250Hz, with both the manual calculations (Fig. 7) and *FuzzMeasure* calculations (Fig. 9) indicating similar decay rate of 500ms. This is also reflected by the waterfall plot graph with a significant ridge occurring along this frequency range. Manual RT60 calculations indicate that a reverb decay rate for 125Hz should be at ≈300ms, however the waterfall plot data indicate that there is still ample reverb information well past 300ms within this frequency range. Similar dissimilarities also occur for 1kHz and 2kHz with persistent reverberation occurring well past the 300ms mark.

The room analysed has extremely problematic modal frequencies that is most likely produced by the room's dimensions. Having similar length and height measurements mean that similar modal frequencies will be produced along these parallel walls. Given the small size of the room, bass traps positioned strategically within the corners may provide some relief to the problem. Lowering the ceiling might also help in evening out the modal frequencies and in turn minimising convergences. With the limitation of not knowing if the room is bare or if it contains equipment and furnishings, it is difficult to properly assess how to treat the room to achieve a desirable frequency response and appropriate reverberation time. Relying solely on theoretical analysis is often not enough to guarantee accurate results when assessing a room's acoustic characteristics. Physical measurements and analysis should compliment manual calculations to achieve more definitive conclusions.

APPENDIX

APPENDIX 1

Modal calculations table in order of frequencies (Hz).

Where P = Length Modal No.
Q = Width Modal No.
R = Height Modal No.

MODE	P	Q	R	Freq (Hz)	Axial	Tangential	Oblique
13	0	0	1	65.34	*		
1	1	0	0	66.10	*		
3	0	1	0	83.42	*		
14	1	0	1	92.95		*	
18	0	1	1	105.97		*	
4	1	1	0	106.44		*	
19	1	1	1	124.89			*
64	0	0	2	130.69	*		
2	2	0	0	132.20	*		
65	1	0	2	146.45		*	
17	2	0	1	147.46		*	
69	0	1	2	155.05		*	
5	2	1	0	156.32		*	
9	0	2	0	166.85	*		
70	1	1	2	168.55			*
21	2	1	1	169.43			*
29	0	2	1	179.19		*	
10	1	2	0	179.47		*	
68	2	0	2	185.89		*	
32	1	2	1	190.99			*
137	0	0	3	196.03	*		
6	3	0	0	198.29	*		
73	2	1	2	203.75			*
139	1	0	3	206.88		*	
23	3	0	1	208.78		*	
80	0	2	2	211.94		*	
12	2	2	0	212.87		*	
141	0	1	3	213.05		*	
7	3	1	0	215.13		*	

MODE	P	Q	R	Freq (Hz)	Axial	Tangential	Oblique
82	1	2	2	222.01			*
35	2	2	1	222.68			*
142	1	1	3	223.06			*
26	3	1	1	224.83			*
140	2	0	3	236.44		*	
75	3	0	2	237.49		*	
85	2	2	2	249.79			*
25	0	3	0	250.27	*		
143	2	1	3	250.73			*
78	3	1	2	251.71			*
148	0	2	3	257.42		*	
44	0	3	1	258.66		*	
27	1	3	0	258.86		*	
16	3	2	0	259.15		*	
194	0	0	4	261.38	*		
8	4	0	0	264.39	*		
149	1	2	3	265.78			*
45	1	3	1	266.98			*
38	3	2	1	267.26			*
195	1	0	4	269.60		*	
28	4	0	1	272.35		*	
197	0	1	4	274.37		*	
11	4	1	0	277.24		*	
144	3	0	3	278.84		*	
198	1	1	4	282.22			*
97	0	3	2	282.34		*	
31	2	3	0	283.04		*	
34	4	1	1	284.84			*
151	2	2	3	289.38			*
98	1	3	2	289.98			*
88	3	2	2	290.24			*
48	2	3	1	290.49			*
146	3	1	3	291.05			*
196	2	0	4	292.91		*	
79	4	0	2	294.93		*	
200	2	1	4	304.55			*
LENGTH =	2.6	**WIDTH =**	2.06	**HEIGHT =**	2.63	**VELOCITY =**	343.71

APPENDIX 2

RT60 calculations table for 125Hz, 250Hz, 500Hz, 1kHz, 2kHz and 4kHz.

Where a = Absorption Coefficient

Sa = total Sabins

Volume (m^3)	**14.086**	**125Hz**		**250Hz**		**500Hz**		**1kHz**		**2kHz**		**4kHz**	
Surface	**(m^2)**	a	Sa	a	Sa	a	Sa	a	Sa	a	Sa	a	Sa
Floor	5.356	0.02	0.1071	0.06	0.3214	0.14	0.7498	0.37	1.9817	0.6	3.2136	0.65	3.4814
Ceiling	5.356	0.07	0.3749	0.21	1.1248	0.66	3.535	0.75	4.017	0.62	3.3207	0.49	2.6244
Front Wall	5.418	0.29	1.5712	0.1	0.5418	0.05	0.2709	0.04	0.2167	0.07	0.3793	0.09	0.4876
Back Wall	5.418	0.29	1.5712	0.1	0.5418	0.05	0.2709	0.04	0.2167	0.07	0.3793	0.09	0.4876
Side Wall 1	6.838	0.29	1.983	0.1	0.6838	0.05	0.3419	0.04	0.2735	0.07	0.4787	0.09	0.6154
Side Wall 2	0.887	0.29	0.2572	0.1	0.0887	0.05	0.0444	0.04	0.0355	0.07	0.0621	0.09	0.0798
Door	1.673	0.1	0.1673	0.07	0.1171	0.05	0.0837	0.04	0.0669	0.04	0.0669	0.04	0.0669
Windows	4.278	0.35	1.4973	0.25	1.0695	0.18	0.77	0.12	0.5134	0.07	0.2995	0.07	0.2995
Total AbCo (Sabins)			7.5293		4.4888		6.0665		7.3214		8.2		8.1427
RT60 (seconds)			0.30		0.51		0.37		0.31		0.28		0.28

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