REVERBERATION ROOMS AND SPATIAL UNIFORMITY

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1. INTRODUCTION

Reverberation rooms are special test rooms used to evaluate the sound power level of sources as well as to qualify space bound hardware such as antennae and satellites to a high intensity noise environment with levels and spectral content representative of the acoustic environment present during launch. Combinations of reverberation rooms are used to evaluate transmission properties of building materials as well as absorption characteristics of noise control products. A number of standards are available that prescribe minimum requirements of reverberation rooms [1, 2].

The main characteristics of the reverberation rooms are: i) Adequate volume; ii) Suitable shape or diffusing elements or both; iii) Suitably small sound absorption over the frequency of interest; and iv) Sufficiently low background noise levels. [1, 2].

The volume of the chamber needs to be adequate as it determines the low-frequency limit of the room. Above the low-frequency limit, the room responds to bands of noise uniformly thus assuring spatial constancy of the sound levels. There are different methods to determine the low-frequency limit. One such limit is the Schroeder frequency and is given by [3],

$$f_c = 2000\sqrt{\frac{T_{60}}{V}} \tag{1}$$

where, T_{60} is the chamber's reverberation time, sec. And V is the volume of the chamber in cubic meters.

The above limit is quite restrictive and when the sound levels are bands of noise, the volume can be lower and one can still maintain adequate spatial uniformity. The results of sound levels, from both single sinusoidal tones as well as bands of noise, measured in two reverberation chambers are presented in this paper to determine the adequacy of chamber volume.

2. CHAMBER VOLUME

Eq. (1) has provided a low-frequency limit which has been adopted by many standards and based on that requirement, the volume of the chamber has to be determined. As mentioned earlier, Schroeder requirement is quite restrictive.

Another empirical approach is to impose a norm of at least 20 modes per octave for acceptable uniformity. Slingerland, Elfstorm and Grün applied 20 modes/octave criterion and derived the following relationship for the cut-off frequency [4],

$$f_c = \frac{c}{\sqrt[3]{V}} \tag{2}$$

where, c is the speed of sound.

The two different approaches produce different limits and the most commonly used Schroeder limit is too restrictive. Field measurements were conducted in two different chambers to determine the most reasonable limit that is practical and can be easily implemented. The description of the two chambers is presented next.

3. THE REVERBERATION CHAMBERS

Two chambers were used to determine the spatial uniformity of the chamber as well as the low-frequency cut-off limit of the chamber. The two chambers are located in Montreal and Ottawa respectively.

2.1 Chamber 1 – Concordia University

The smaller of the two chambers is located in the engineering building of Concordia University, Montreal and is used by the Building, Civil and Environmental Engineering Department (BCEE). The characteristics of the chamber are:
Length, L = 6.13 m; Width = 6.96 m; Height = 3.56 m; Chamber Volume = 152.3 cu.m.

The RT_{60} varied between 0.8 sec to 3 sec. across the frequency band. The cut-off frequency as per Eq. (1) is 188 Hz and as per Eq. 2 is 64 Hz.

2.2 Chamber 2 – National Research Council of Canada

The larger of the two chambers is located at the Structures, and Material Performance Laboratory (SMPL) of the National Research Council's Institute for Aerospace Research in Ottawa, Canada. The characteristics of the chamber are:
Length, L = 7.01 m; Width = 7.93 m; Height = 9.75 m; Chamber Volume = 542 cu.m.

The RT_{60} varied between 5 sec to 10 sec. across the frequency band. The cut-off frequency as per Eq. (1) is 272 Hz and as per Eq. 2 is 42 Hz.

2.3 Modal Compositions of the two chambers

The two chambers are rectangular in shape and the standing wave frequencies can easily be determined from basic descriptions [5] and are given by,

$$f_n = \frac{c}{2}\sqrt{\left[\frac{n_x}{L_x}\right]^2 + \left[\frac{n_y}{L_y}\right]^2 + \left[\frac{n_z}{L_z}\right]^2} \tag{3}$$

The number of modes in each octave band was enumerated from the above equation and the results for the two chambers are given in Tables 1 and 2 respectively.

The results of Table 1 show that that the Chamber 1 can be comfortably used from the 125 Hz octave band to achieve acceptable spatial uniformity. This is borne out by the cut-off frequency of 64 Hz calculated from Eq. 2. The Schroeder limit for Chamber 1 is 188 Hz (from Eq. 1) which is very restrictive.

Table 1. Modal Composition of Chamber 1

Band No.	Lower Limit	Centre Frequency	Upper Limit	Number of Modes
1	22	31.5	44	2
2	44	63	88	12
3	88	125	177	44
4	177	250	355	165

Table 2. Modal Composition of Chamber 2

Band No.	Lower Limit	Centre Frequency	Upper Limit	Number of Modes
1	22	31.5	44	5
2	44	63	88	38
3	88	125	177	210
4	177	250	355	340

The results of Table 2 show that that the Chamber 2 can be comfortably used from the 63 Hz octave band to achieve acceptable spatial uniformity. This is borne out by the cut-off frequency of 42 Hz calculated from Eq. 2. The Schroeder limit for Chamber 1 is 272 Hz (from Eq. 1) which is very restrictive.

The validity of these limiting frequencies is confirmed through measurements and is presented next.

4. THE EXPERIMENT

Two chambers were used to determine the spatial uniformity of the chamber as well as the low-frequency cut-off limit of the chamber. Simple speakers (both low-frequency speakers and a bank of high frequency tweeters) were used to generate the sound. Both pink noise and sinusoidal tones (100, 150, 200, 250, 300, 400, 500 Hz) were generated and the resulting noise levels were measured at a number of locations, - between 48 and 54. The locations were chosen randomly at two different heights.

High intense sound were generated in the second chamber through hydraulically powered airstream modulators driven by high pressure air (150 to 200 psi) and connected to two exponential horns (25 Hz and 100 Hz). The resulting sound pressure levels were measured at eight locations at three different heights inside the chamber.

5. RESULTS

The results for Chamber 1 are presented for both broad-bands and sinusoids in Tables 3 and 4 below. Similarly, the results for the broad-band sound sources for Chamber 2 are shown in Table 5 below.

The ISO Standard 3741 [2] requires a minimum of 200 cu. m. as per the Schroeder limit of 125 Hz Octave band and the maximum allowable standard deviation is 1.5 dB. The results of Tables 4 and 6 show that even if one cannot meet the minimum volume requirement, the spatial uniformity of the chamber sound levels can be satisfied for broadband sound levels. For pure sinusoids, even though the volume requirements are satisfied, the results of Table 5 indicate that the spatial uniformity cannot be assured.

Table 4. Sound Levels in Chamber 1 (Broadband, 36 Locations)

1/3 Octave Band Centre Frequency, Hz	Average SPL, dB	Range dB	Standard Deviation, dB
50	87.7	12.4	3.7
63	89.3	10.7	2.8
80	93.9	6.6	1.7
100	99.7	5.0	1.1
125	97.1	5.5	1.2

Table 5. Sound Levels in Chamber 1 (Tones, 36 Locations)

Tones, Hz	No. of modes ± 5 Hz	Average SPL, dB	Range dB	Standard Deviation, dB
300	9	94.4	31.4	7.4
400	11	96.3	29.8	7.8
500	11	100.7	32.6	8.4

Table 6. Sound Levels in Chamber 2 (Broadband, 28 Samples)

1/3 Octave Band Centre Frequency, Hz	Average SPL, dB	Range dB	Standard Deviation, dB
50	145.4	10.0	3.8
63	146.1	8.3	2.6
80	144.9	7.1	2.6
100	144.2	3.9	1.4
125	144.2	4.0	1.4

REFERENCES

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