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Reverberation Time Measurements in the NASA Langley Exterior Effects Room (EER)

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June 2006

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INTRODUCTION

The exterior effects room (EER) is being considered to serve as a subjective test area for acoustic simulation using a vector based panning algorithm. Modifications to the room are anticipated to allow an acoustically convincing setting including video capabilities. The purpose of the current measurements is to characterize the room in terms of the background noise, the reverberation times and the related overall acoustic absorption.

EXTERIOR EFFECTS ROOM

The exterior effects room (EER) (Figures 1-3) is a four-row, thirty-nine seat test room in which subjects can be exposed to the types of noises that would be experienced outdoors where aircraft speed, altitude, flight direction, and lateral position can influence the character of the observed noise signatures[1]. The EER is located in the Acoustics Research Laboratory (ARL), Building 1208 at the NASA Langley Research Center. The room features stadium seating and the chairs have fold-away writing surfaces for subjects to make notes and complete surveys. The test noises are presented through a system of ten loudspeakers, two of which (L1 and L2) are integrated into the corners of the front wall (Figure 4), two (L3 and L4) in the rear wall corners (Figure 5), and six (L5-L8) are mounted in the ceiling (Figure 6). Specifics of the facility are presented in Reference 1. The loudspeakers are Altec 604E models, which have a continuous power rating of 50 watts and a usable frequency range from 20 Hz to 20,000 Hz. By properly phasing sound signals to the speakers, the noise signatures can represent an aircraft flying in a particular direction, and at a particular altitude and offset distance, either with or without 'neighborhood' background noise superimposed. The layout of the EER is presented in Figure 7. Dimensions of the room are nominally 8.2 m long (left to right in the drawing of Figure 7), 8.2 m wide and 4.4 m high. The volume of the room is about 293 m^3 with a total surface area of approximately 275 m^2. The ceiling and the floor are of reinforced concrete and the walls consist of double-plastered 8-inch cinder block with specially designed acoustic doors.[1] A nominal transmission loss of 40 dB is provided by the walls to minimize possible disturbances to the testing environment within the room due to activities outside and vice versa. [1] Acoustical absorptive treatment of the interior surfaces is concentrated on the walls which have a perforated vinyl septum covering 5-inch thick fiberglass blankets with 5 inches of backup air space.[1] A close up of the perforated wall is depicted in Figure 8. Some absorption is also provided by the cushioned carpeting and by the upholstered chairs. The ceiling is a smooth cement plaster on expanded metal lathe. It is suspended from the reinforced concrete structure on a metal suspension system.[1]

MEASUREMENTS

Background Noise Levels

The background noise levels were measured with a Brüel & Kjær Type 4134 ½ inch random incidence condenser microphone, conditioned by a Brüel & Kjær Type 2619 preamplifier and analyzed by a Brüel & Kjær Type 2131 digital frequency analyzer (32 seconds exponential averaging). A description of the equipment and the instrumentation used in the current measurements is listed in Table 1 along with the manufacturer, the model/type, the serial number, the NASA ECN/Calibration number, the calibration dates and relevant notes. The microphone measuring the background noise was positioned at Location 1 (Figure 7) where it was mounted on a tripod 1.3 m above the floor. The measured background noise levels and their A-weighted equivalents are tabulated in Table 2 for the 50-20,000 Hz one-third octave bands. The Overall Sound Pressure Level (OASPL) for the background noise was calculated to be 49.8 dB. This amounts to an A-weighted OASPL of 31.6 dBA, which is approximately NC-24 on the Noise Criteria scale.

Reverberation Time Measurements

The EER had been calibrated post acoustical modifications in 1979. The modifications were made to reduce reverberation times and background noise levels. Reference 2 reports the measurement results from four octave band reverberation time measurements at each of three seating locations. One location was at the Location 1 in Figure 7 and the other two locations were in front of the two outer seats in the same row. The report also includes the sound pressure level distribution over twenty distributed seating locations from pink noise input through the ceiling loudspeakers, with and without an equalizer to smooth the spectra. The octave band reverberation time results published in Reference 2 will be compared with the one-third octave band data acquired by the current measurements. In the present study, two different one-third octave band reverberation time measurement methods were used to acquire the room decay curves, the sound pressure level decays as function of time after the source of the sound has ceased. The Integrated Impulse Response Method[3] (proposed by Schröder[4]) obtains the decay curves by reverse-time integration of squared impulse responses. The Interrupted Noise Method[3] acquires the decay curves by the direct recording of the sound pressure level decay after exciting the room with a broadband or band limited noise.

Measurement Locations

Reverberation time measurements were conducted for three microphone locations in the EER as indicated in Figure 7. Location 1 is in front of the center seat in the third row from the room entrance. Location 2 is in front of the end seat at the start of the second row when one enters the room. Location 3 is in the center of the space in front of the first row of seats. All microphones were positioned 1.3 m above the floor (Table 3), satisfying, for frequencies equal or higher than the 80 Hz one-third octave band center frequency, the International Organization for Standardization (ISO) requirement[3] of at least one-quarter wavelength. The calculated wavelength for each one-third octave band center frequency is listed in Table 2. The distances between each of the three microphones (Table 3) satisfy the requirement[3] of being at least half a wavelength apart for the 80 Hz and higher one-third octave bands. The speaker box (Table 1) was located in the corner near the entrance of the room to excite most of the room modes in the frequency region of interest (100-8,000 Hz). Table 3 also lists the distances between the speaker box and each of the three microphones. To avoid the effects from the direct radiated sound, the distance between the sound source and any microphone position should exceed a minimum distance d_{min}, which can be approximated by the equation[3]

$$d_{\min} = 2 * \sqrt{\frac{V}{cT}}$$

where V is the volume [m^3] of the room, c is the speed of sound [m/s], and T is the reverberation time [s]. The distances 5.5, 4.0 and 3.7 m between the speaker box and the microphone locations (Table 3) are sufficient for minimum reverberation times of 0.11, 0.21 and 0.25 seconds, respectively. To allow somewhat shorter reverberation times at the higher frequencies, the loudspeaker boxes were pointed towards the room wall service under a 45 degree angle shielding the direct sound path.

Integrated Impulse Response Method

A Brüel & Kjær Modular Precision Sound Level Meter Type 2231 with a Type BZ 7108 Reverberation Processor (Table 1 and Figure 9) was used to compute the reverberation times from the response of the room to gated band-limited noise bursts. Using the integrated impulse or noise burst method[5] a noise burst signal was generated by the sound level meter in the specified, lowest one-third octave frequency band (100 Hz) in the frequency range of interest. This was sent from the sound level meter through the Kenwood Integrated Amplifier (Table 1) to the three-way loudspeaker box. The sound level meter sampled the sound decay in the room and calculated the reverberation times. Then, a noise burst in the next one-third octave band was transmitted and sampled, and the reverberation times again were calculated. This procedure was repeated to include all 100-8,000 Hz one-third octave bands. The process was software-controlled to obtain automated, reproducible and accurate results. Four records were obtained for each location. The calculated reverberation times included the Early Decay Time (EDT), the T(20) and the T(30). The EDT is the estimated time required for a 60 dB decay in sound pressure level (SPL) based on the SPL decay between 0 dB and -10 dB. The T(20) and T(30) parameters indicate the estimated times required for a 60 dB SPL decrease based on the SPL decays between -5 dB and -25 dB and -35 dB, respectively. The four EDT reverberation time records (M1-M4) measured at Microphone Location 1 (Figure 7) are tabulated in Table 4 along with the mean value and standard deviation for each one-third octave band. The mean reverberation time is calculated from the reverberation time decay rates

$$\overline{T} = \frac{N}{\frac{1}{T_1} + \frac{1}{T_2} + \ldots + \frac{1}{T_N}}$$

The standard deviation SD of the reverberation times is defined by[6]

$$SD = \sqrt{\frac{\left(T_1 - \overline{T}\right)^2 + \left(T_2 - \overline{T}\right)^2 + \ldots + \left(T_N - \overline{T}\right)^2}{N - 1}}$$

The results of the T(20) and T(30) reverberation times for Microphone Location 1 are listed in Table 5 and Table 6. The repeatability of the measurements using the integrated impulse response method is of the same order of magnitude as the comparable repeatability of an average ten runs with the interrupted noise method.[3] The relationship between the measurement repeatability, r, in accordance with Reference 7 and the number of averages N can be estimated for T(20) by[3]

$$r_{20} = \frac{370}{\sqrt{BNT_{20}}}$$

where N=10 and the bandwidth B is given as a fraction of the one-third octave band center frequency

$$B = 0.23 f_c$$

The repeatability for the T(30) reverberation time measurements is defined by[3]

$$r_{30} = \frac{200}{\sqrt{BNT_{30}}}$$

The r_{20} and r_{30} as function of the one-third octave band center frequency are also listed in Table 5 and Table 6, respectively. Tables 7-9 list the EDT, the T(20), and the T(30), including the mean value, the standard deviation and the measurement repeatability for four measurements at Location 2, while the results for the Location 3 measurements and calculations are listed in Tables 10-12. Reliable measurements could not be obtained for some of the lowest frequency bands. This may be due to one or more spikes in the impulse response. Since a spike has a very narrow time window it contributes little to the reverse-integrated curve and the calculation fails.[5] Also, when more than one reverberation decay is present at low frequencies, the dynamic range of the reverse-integrated decay is reduced. [5] The results show that the EDT reverberation times differ from the T(20) and T(30) reverberation times, which are largely the same. In a perfectly diffuse acoustic field, EDT would yield the same values as the T(20) and the T(30) reverberation times. However, if the sound field is not entirely diffuse the EDT is more dependent on the geometry of the room and on the measurement position.[8] The standard deviation for the EDT, T(20) and T(30) reverberation times in Tables 4-12 were mostly 0.01 seconds or less (0.02 seconds in only a few instances), showing that the results of repeated measurements were very consistent. For a certain number of averages, the measurement repeatability is inversely dependent on the reverberation time and, as shown in Tables 5, 6, 8, 9, 11 and 12, is lower for the higher frequency bands. For the same number of averages and reverberation times the measurement repeatability for the T(30) is lower than for the T(20) measurements. Table 13 lists the calculated mean EDT, T(20), and T(30) reverberation times averaged over the three locations, along with the standard deviation and the measurement repeatability. The standard deviation for the EDT reverberation times is higher than the standard deviation for the mean T(20) and T(30) measurements for the 400 Hz and higher one-third octave bands showing that the T(20) and T(30) measurement times averaged over the three locations are more consistent at those frequencies. Table 13 also shows that the three-location measurement repeatability is lower for the T(30) reverberations time measurements than for the T(20) based tests.

Room Diffusivity

The geometry of the room determines the acoustic modal response. To simplify calculations of the modal frequencies the EER has been modeled as a rectangular room with approximately the same volume, surface area and edge length as the physical room. These dimensions are summarized in Table 14. The normal mode frequencies of the room are given by[9]

$$f_n = \frac{c}{2}\sqrt{\left(\frac{n_x}{l}\right)^2 + \left(\frac{n_y}{w}\right)^2 + \left(\frac{n_z}{h}\right)^2}$$

where l, w and h are the length [m], the width [m] and the height [m] of the room, and n_x, n_y and n_z are the respective mode numbers in those directions. Thirty-eight modal frequencies were calculated in the simplified EER model for the 80 Hz and lower one-third octave bands. The mode numbers, modal frequencies, mode spacing and number of modes in the band are summarized in Table 15. The modal density is defined by[9]

$$\frac{dM}{df} = \frac{4\pi f^2 V}{c^3} + \frac{\pi f S}{2c^2} + \frac{L}{8c}$$

where M is the number of modes in the room, f is the one-third octave band center frequency [Hz], V is the volume [m^3], S is the total wall surface area [m^2] and L is the total edge length [m]. The modal densities were calculated and the results are listed in

Table ***16***. In a diffuse sound field the average energy density is the same throughout the room and all directions of propagation are equally probable. The lowest frequency at which the modal density is sufficient to constitute a diffuse field is given by the Schröder cut-off frequency f_S[9]

$$f_S = \sqrt{\frac{c^3}{4\ln 10}} * \sqrt{\frac{T}{V}}$$

where c is the speed of sound [m/s], T is the reverberation time of the room [s] and V is the volume of the room [m^3]. The Schröder frequencies for the T(20) reverberation times are tabulated in Table 17. Below these frequencies the room acoustic pressure responses are dominated by individual room modes. Statistical consideration of the sound field in a room is only valid when the sound field is diffuse. The minimum distance d_{min} between source and measurement locations are included in Table 17 for the T(20) reverberation times. It is concluded that the minimum source microphone distances for these measurements (Table 3) are according to the requirements in Reference 3 except for 5000 Hz and higher one-third octave bands for the Microphone Location 2 and the 3150 Hz and higher one-third octave bands for Microphone Location 3.

Room Absorption

The absorption of the room may be calculated assuming that the sound field is diffuse. The equivalent sound absorption area A is defined by[10]

$$A = \frac{55.3V}{cT} - 4Vm$$

where T is the reverberation time [s] and m is power attenuation coefficient [1/m]. The value of m is dependent on the temperature, relative humidity and atmospheric pressure and can be calculated from the attenuation coefficient [dB/m] for atmospheric absorption[11]. The power attenuation coefficient is assumed to be negligible for the measurements in the EER, as the absorption by the boundaries in the room is much greater than the atmospheric absorption of the sound while traveling between these boundaries. The average Sabine absorption coefficient $\overline{\alpha}$ is calculated by dividing the equivalent sound absorption area by the total surface area of the room

$$\overline{\alpha} = \frac{A}{S}$$

Table 18 lists the mean (three locations) integrated impulse response EDT, T(20) and T(30) reverberation times, the equivalent sound absorption areas and the averaged Sabine absorption coefficients. The averaged Sabine absorption coefficients based on the T(20) and T(30) measurements are in reasonable agreement with each other (within less than 9%). However, the average absorptions coefficients based on the EDT differ from the T(20) and T(30) by as much as 42%. The average absorption coefficients in the table are not accurate for a non-diffuse field below the Schröder frequencies (Table 17).

Interrupted Noise Method

The Larson Davis System 824 precision sound level meter and real time analyzer (Table 1 and Figure 10) was used with the interrupted noise method to verify the results obtained from the Brüel & Kjær impulse response based measurements. The interrupted noise method calculates the reverberation times from the decay slopes after pink noise injected into the room is abruptly stopped. The pink noise was produced by a General Radio random noise generator, amplified by the Kenwood integrated amplifier, and fed into the three-way loudspeaker box. The pink noise level in the room was first measured by the Brüel & Kjær digital frequency analyzer so that the level could be adjusted to have a dynamic range of at least 40 dB above previously measured background noise for all one-third octave band frequencies of interest (50-16,000 Hz). The results are summarized in Table 19. The real time analyzer function in the Larson Davis System 824 was set up to perform one-third octave band reverberation time analysis based on T(20). The System 824 pre-trigger function was set to keep a circular buffer of the most recent 400 samples, which were reset for each new measurement run. The autostore function was enabled to automatically store measurement results and basic information in a record after the measurement was ended by the triggering setup. The triggering was set for the 630 Hz one-third octave band, which band has a high pink noise level and a high dynamic range

(Table 19). All other frequency bands were then triggered at the same instant. The System 824 was armed when the sound pressure level in the 630 Hz band exceeded 75.0 dB. The real time analyzer was triggered at 64.0 dB and was ended 2 seconds later. The measurements included thirty-seven runs for Location 1, eleven runs for Location 2 and also eleven runs for Location 3. The data was transferred to a personal computer for post-processing. The frequency spectrum of the pink noise played into the room was fluctuating with, of course, no correlation between one-third octave bands. When triggering the 630 Hz one-third octave band, some bands were at decidedly lower sound pressure levels at the instant of the trigger, affecting the dynamic range and the decay rate, and causing the reverberation times in some of the bands to be well outside the expected range. Rather than manually identifying and removing these values, a statistical procedure was applied to all records and all frequency bands to yield median and mode values more representative of the true reverberation times. The median value constitutes the value below which 50% of the cases fall. The mode value is the most frequently observed data value in the record. In case of a tie, the smallest value was selected. The median and mode T(20) reverberation times for Locations 1-3 are tabulated in Table 20 along with the measurement repeatability r_{20}[3] for N number of runs.

Results Comparison

The comparison between the one-third octave band median and mode interrupted noise reverberation times (Larson Davis), the integrated impulse response reverberation times (Brüel & Kjær) and the octave band reverberation times from Reference 2 are shown, for Location 1, in Table 21. Included in the table are the deviations (in percentages) from the mean T(20) integrated impulse response reverberation times. The deviations of the octave band reverberation times reported in Reference 2 are taken with respect to the longest T(20) of the three one-third octave bands in the octave band. As shown previously, the T(30) and T(20) impulse response reverberation times were in close agreement. Reasonable agreement was obtained between the median and mode interrupted reverberation times and the reference T(20). The mode reverberation time was generally closer than the median results except for frequencies in the 3150 Hz one-third octave band and higher for which there was no difference. The Reference 2 octave band reverberation time showed deviations up to 38% which was still considered acceptable considering different acoustic source locations, different instrumentation and equipment, and room material properties that might have changed in the twenty-seven years between measurements.

CONCLUSIONS

One-third octave band background noise and reverberation time measurements were conducted in the Exterior Effect Room (EER) at the NASA Langley Research Center. The related overall acoustic absorption of the room was calculated. The acoustic field in the room was characterized. Reverberation time measurements were performed using the integrated impulse response method. The results were compared with independent measurements using the interrupted noise reverberation time method and different instrumentation. Reasonable agreement was obtained between the reverberation times of the two methods. The agreement with twenty seven year old octave band reverberation time data was judged acceptable.

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TABLES

Table 1. Equipment and instrumentation.

Description	Manufacturer	Model/ Type	Serial Number	ECN/ Calibration	Calibration		Notes
					Date	Due	
½-inch Random Incidence Condenser Microphone	Brüel & Kjær	4134	478911	A014662	12/28/04	12/28/05	
Microphone Preamplifier	Brüel & Kjær	2619	593981	A004356	05/13/04	05/13/05	
Digital Frequency Analyzer	Brüel & Kjær	2131	945145	469104			
Class 1 Acoustical Calibrator	Brüel & Kjær	4231	2242298	A029504	7/6/05	4/6/06	94dB SPL 1000Hz
Modular Precision Sound Level Meter	Brüel & Kjær	2231	1413682	060034/ A038138	12/27/04	12/27/05	
1/3-1/1 Octave Filter	Brüel & Kjær	1625	1418440	060034/ A033054	12/27/04	12/27/05	
Reverberation Processor Module	Brüel & Kjær	BZ 7108					
Input Stage	Brüel & Kjær	ZC0020					
BNC to Mini Cable	Brüel & Kjær	AO173					
Random Noise Generator	General Radio Company	1382	01793	M094274	7/12/04	7/12/07	20Hz-50kHz
Integrated Amplifier	Kenwood	KA-52B	42K70641				Stereo 185W
Three-way Speaker Box	In-house						14-in Woofer 6-in Mid 2-in Tweeter
Class 1 Precision Sound Level Meter and Real Time Analyzer	Larson Davis	System 824A	824A3232	1639117	9/8/05	10/8/06	
Microphone Preamplifier	Larson Davis	PRM902					
½-inch Random Incidence Condenser Microphone	Larson Davis	377A60	1062				Externally polarized 15-146 dB(A) 3.15-10,000 Hz, ±2 dB

Table 2. Background noise levels measured at Location1 (Figure 7) in the Exterior Effects Room (EER) with the Brüel & Kjær Type 2131 Digital Frequency Analyzer.

One-third Octave Band Number	One-third Octave Band Center Frequency	Background Noise Level	A-weighted Background Noise Level	Wavelength (c=343 m/s)
[-]	[Hz]	[dB]	[dBA]	[m]
7	50	47.2	17.0	6.86
8	63	43.0	16.8	5.44
9	80	39.6	17.1	4.29
10	100	36.6	17.5	3.43
11	125	35.8	19.7	2.74
12	160	31.6	18.2	2.14
13	200	31.3	20.4	1.72
14	250	26.5	17.9	1.37
15	315	25.1	18.5	1.09
16	400	25.3	20.5	0.86
17	500	21.5	17.8	0.69
18	630	21.2	19.3	0.54
19	800	21.6	20.8	0.43
20	1000	20.4	20.4	0.34
21	1250	16.8	17.1	0.27
22	1600	15.4	16.4	0.21
23	2000	14.6	15.6	0.17
24	2500	14.5	15.3	0.14
25	3150	14.0	15.2	0.11
26	4000	15.1	16.1	0.09
27	5000	14.8	15.3	0.07
28	6300	15.1	15.0	0.05
29	8000	15.1	14.0	0.04
30	10000	15.7	13.2	0.03
31	12500	16.7	12.4	0.03
32	16000	19.6	13.0	0.02
33	20000	18.4	9.1	0.02
	OASPL	49.8	31.6	

Table 3. Distances from the loudspeaker source to the three microphone locations.

	Distance
	[m]
Microphone 1 - Floor	1.3
Microphone 2 - Floor	1.3
Microphone 3 - Floor	1.3
Microphone 1 - Microphone 2	2.7
Microphone 2 - Microphone 3	3.5
Microphone 1 - Microphone 3	3.7
Speaker Box - Microphone 1	5.5
Speaker Box - Microphone 2	4.0
Speaker Box - Microphone 3	3.7

Table 4. Measured EDT integrated impulse response reverberation times at Location 1.

One-third Octave Band Center Frequency	Early Decay Time (EDT)					
	M1	M2	M3	M4	Mean	SD
[Hz]	[s]	[s]	[s]	[s]	[s]	[s]
100	0.32	0.31	0.31	0.31	0.31	0.01
125	0.36	0.38	0.37	0.37	0.37	0.01
160	0.55	0.58	0.58	0.60	0.58	0.02
200	0.31	0.31	0.31	0.32	0.31	0.01
250	0.28	0.29	0.27	0.28	0.28	0.01
315	0.31	0.31	0.34	0.33	0.32	0.02
400	0.39	0.39	0.39	0.39	0.39	0.00
500	0.30	0.30	0.31	0.29	0.30	0.01
630	0.23	0.23	0.22	0.22	0.22	0.01
800	0.20	0.20	0.19	0.19	0.19	0.01
1000	0.19	0.19	0.19	0.19	0.19	0.00
1250	0.24	0.23	0.24	0.24	0.24	0.01
1600	0.21	0.21	0.21	0.21	0.21	0.00
2000	0.21	0.21	0.21	0.22	0.21	0.01
2500	0.22	0.21	0.21	0.22	0.21	0.01
3150	0.21	0.20	0.19	0.20	0.20	0.01
4000	0.19	0.18	0.18	0.18	0.18	0.01
5000	0.17	0.17	0.17	0.17	0.17	0.00
6300	0.16	0.16	0.16	0.16	0.16	0.00
8000	0.17	0.16	0.16	0.16	0.16	0.01

Table 5. Measured T(20) integrated impulse response reverberation times at Location 1.

One-third Octave Band Center Frequency	T(20)						
	M1	M2	M3	M4	Mean	SD	r_{20}
[Hz]	[s]	[s]	[s]	[s]	[s]	[s]	[%]
100	0.60	0.61	0.60	0.59	0.60	0.01	31.5
125	0.40	0.40	0.40	0.40	0.40	0.00	34.5
160	0.43	0.44	0.42	0.43	0.43	0.01	29.4
200	0.40	0.41	0.40	0.39	0.40	0.01	27.3
250	0.31	0.30	0.31	0.31	0.31	0.01	27.8
315	0.40	0.40	0.42	0.40	0.40	0.01	21.6
400	0.33	0.33	0.33	0.33	0.33	0.00	21.2
500	0.30	0.30	0.30	0.30	0.30	0.00	19.9
630	0.32	0.31	0.32	0.31	0.31	0.01	17.3
800	0.26	0.25	0.26	0.26	0.26	0.01	17.0
1000	0.28	0.28	0.28	0.28	0.28	0.00	14.6
1250	0.26	0.26	0.27	0.27	0.26	0.01	13.4
1600	0.28	0.28	0.28	0.28	0.28	0.00	11.5
2000	0.26	0.26	0.26	0.26	0.26	0.00	10.7
2500	0.25	0.25	0.26	0.26	0.25	0.01	9.7
3150	0.23	0.23	0.23	0.23	0.23	0.00	9.1
4000	0.22	0.23	0.22	0.22	0.22	0.01	8.2
5000	0.20	0.20	0.20	0.20	0.20	0.00	7.7
6300	0.19	0.19	0.19	0.19	0.19	0.00	7.1
8000	0.18	0.18	0.17	0.18	0.18	0.01	6.5

Table 6. Measured T(30) integrated impulse response reverberation times at Location 1.

One-third Octave Band Center Frequency	T(30)						
	M1	M2	M3	M4	Mean	SD	r_{30}
[Hz]	[s]	[s]	[s]	[s]	[s]	[s]	[%]
100	0.61	0.59	0.58	0.57	0.59	0.02	17.2
125	0.41	0.42	0.42	0.41	0.41	0.01	18.3
160	0.47	0.51	0.51	0.51	0.50	0.02	14.8
200	0.35	0.36	0.36	0.36	0.36	0.01	15.6
250	0.31	0.32	0.32	0.31	0.31	0.01	14.9
315	0.41	0.42	0.42	0.42	0.43	0.01	11.5
400	0.30	0.30	0.30	0.30	0.30	0.00	12.0
500	0.28	0.29	0.29	0.29	0.29	0.01	11.0
630	0.29	0.29	0.29	0.29	0.29	0.00	9.8
800	0.30	0.30	0.30	0.31	0.30	0.01	8.5
1000	0.28	0.29	0.29	0.29	0.29	0.01	7.8
1250	0.26	0.26	0.26	0.26	0.26	0.00	7.3
1600	0.27	0.26	0.27	0.27	0.27	0.01	6.4
2000	0.25	0.25	0.25	0.25	0.25	0.00	5.9
2500	0.25	0.26	0.28	0.28	0.27	0.02	5.1
3150	0.24	0.23	0.24	0.24	0.24	0.01	4.8
4000	0.24	0.26	0.24	0.24	0.24	0.01	4.2
5000	0.20	0.21	0.21	0.21	0.21	0.01	4.1
6300	0.20	0.21	0.20	0.20	0.20	0.01	3.7
8000	0.19	0.19	0.18	0.18	0.19	0.01	3.4

Table 7. Measured EDT integrated impulse response reverberation times at Location 2.

One-third Octave Band Center Frequency	Early Decay Time (EDT)					
	M1	M2	M3	M4	Mean	SD
[Hz]	[s]	[s]	[s]	[s]	[s]	[s]
100	0.51	0.53	0.50	0.50	0.51	0.01
125	0.41	0.40	0.40	0.40	0.40	0.01
160	0.38	0.39	0.39	0.39	0.39	0.01
200	0.32	0.35	0.35	0.35	0.34	0.02
250	0.24	0.23	0.23	0.23	0.23	0.01
315	0.31	0.30	0.30	0.30	0.30	0.01
400	0.35	0.36	0.35	0.35	0.35	0.01
500	0.41	0.40	0.41	0.41	0.41	0.01
630	0.29	0.28	0.28	0.29	0.28	0.01
800	0.28	0.28	0.28	0.28	0.28	0.00
1000	0.24	0.24	0.24	0.24	0.24	0.00
1250	0.27	0.27	0.27	0.27	0.27	0.00
1600	0.30	0.31	0.31	0.31	0.31	0.01
2000	0.24	0.24	0.24	0.24	0.24	0.00
2500	0.20	0.19	0.20	0.20	0.20	0.01
3150	0.15	0.16	0.16	0.15	0.15	0.01
4000	0.16	0.16	0.15	0.16	0.16	0.01
5000	0.13	0.14	0.13	0.13	0.13	0.01
6300	0.16	0.15	0.15	0.16	0.15	0.01
8000	0.16	0.17	0.16	0.18	0.17	0.01

Table 8. Measured T(20) integrated impulse response reverberation times at Location 2.

One-third Octave Band Center Frequency	T(20)						
	M1	M2	M3	M4	Mean	SD	r_{20}
[Hz]	[s]	[s]	[s]	[s]	[s]	[s]	[%]
100	0.35	0.35	0.36	0.35	0.35	0.01	41.1
125	0.42	0.42	0.42	0.42	0.42	0.00	33.7
160	0.49	0.50	0.52	0.50	0.50	0.01	27.2
200	0.33	0.31	0.32	0.32	0.32	0.01	30.5
250	0.33	0.33	0.33	0.33	0.33	0.00	26.9
315	0.41	0.42	0.43	0.43	0.42	0.01	21.2
400	0.30	0.31	0.31	0.31	0.31	0.01	22.0
500	0.34	0.34	0.35	0.34	0.34	0.01	18.6
630	0.29	0.30	0.29	0.29	0.29	0.01	18.0
800	0.27	0.28	0.28	0.28	0.28	0.01	16.4
1000	0.27	0.28	0.28	0.28	0.28	0.01	14.6
1250	0.28	0.28	0.28	0.28	0.28	0.00	13.0
1600	0.25	0.25	0.26	0.25	0.25	0.01	12.1
2000	0.28	0.27	0.27	0.27	0.27	0.01	10.5
2500	0.26	0.27	0.26	0.27	0.26	0.01	9.5
3150	0.23	0.23	0.23	0.23	0.23	0.00	9.1
4000	0.24	0.24	0.25	0.24	0.24	0.01	7.8
5000	0.20	0.20	0.21	0.21	0.20	0.01	7.6
6300	0.17	0.17	0.17	0.17	0.17	0.00	7.5
8000	0.17	0.18	0.17	0.17	0.17	0.01	6.6

Table 9. Measured T(30) integrated impulse response reverberation times at Location 2.

One-third Octave Band Center Frequency	T(30)						
	M1	M2	M3	M4	Mean	SD	r_{30}
[Hz]	[s]	[s]	[s]	[s]	[s]	[s]	[%]
100	0.38	0.37	0.40	0.38	0.38	0.01	21.3
125	0.37	0.36	0.37	0.37	0.37	0.01	19.5
160	0.53	0.53	0.54	0.53	0.53	0.01	14.3
200	0.33	0.32	0.33	0.33	0.33	0.01	16.3
250	0.29	0.28	0.29	0.29	0.29	0.01	15.6
315	0.42	0.43	0.43	0.43	0.43	0.01	11.4
400	0.30	0.32	0.32	0.32	0.31	0.01	11.8
500	0.34	0.34	0.36	0.34	0.34	0.01	10.0
630	0.27	0.27	0.28	0.27	0.27	0.01	10.1
800	0.27	0.28	0.27	0.27	0.27	0.01	8.9
1000	0.27	0.28	0.28	0.27	0.27	0.01	8.0
1250	0.26	0.26	0.27	0.27	0.26	0.01	7.2
1600	0.24	0.25	0.25	0.25	0.25	0.01	6.6
2000	0.27	0.27	0.27	0.27	0.27	0.00	5.7
2500	0.27	0.28	0.28	0.28	0.28	0.01	5.0
3150	0.23	0.22	0.22	0.22	0.22	0.01	5.0
4000	0.24	0.24	0.24	0.24	0.24	0.00	4.3
5000	0.22	0.21	0.21	0.20	0.21	0.01	4.1
6300	0.18	0.17	0.18	0.18	0.18	0.01	3.9
8000	0.19	0.20	0.19	0.19	0.19	0.01	3.4

Table 10. Measured EDT integrated impulse response reverberation times at Location 3.

One-third Octave Band Center Frequency	Early Decay Time (EDT)					
	M1	M2	M3	M4	Mean	SD
[Hz]	[s]	[s]	[s]	[s]	[s]	[s]
100	0.27	0.27	0.27	0.27	0.27	0.00
125	0.35	0.35	0.35	0.35	0.35	0.00
160	0.25	0.25	0.26	0.26	0.25	0.01
200	0.30	0.3	0.31	0.31	0.30	0.01
250	0.32	0.33	0.32	0.33	0.32	0.01
315	0.22	0.24	0.24	0.23	0.23	0.01
400	0.35	0.35	0.35	0.35	0.35	0.00
500	0.33	0.34	0.33	0.33	0.33	0.01
630	0.31	0.32	0.32	0.32	0.32	0.01
800	0.32	0.33	0.32	0.31	0.32	0.01
1000	0.24	0.24	0.24	0.23	0.24	0.01
1250	0.30	0.3	0.30	0.31	0.30	0.01
1600	0.30	0.31	0.31	0.31	0.31	0.01
2000	0.32	0.33	0.32	0.33	0.32	0.01
2500	0.31	0.31	0.31	0.31	0.31	0.00
3150	0.33	0.32	0.33	0.32	0.32	0.01
4000	0.31	0.31	0.31	0.31	0.31	0.00
5000	0.27	0.27	0.27	0.27	0.27	0.00
6300	0.27	0.27	0.27	0.27	0.27	0.00
8000	0.26	0.26	0.26	0.26	0.26	0.00

Table 11. Measured T(20) integrated impulse response reverberation times at Location 3.

One-third Octave Band Center Frequency	T(20)						
	M1	M2	M3	M4	Mean	SD	r_{20}
[Hz]	[s]	[s]	[s]	[s]	[s]	[s]	[%]
100	0.27	0.27	0.27	0.26	0.27	0.01	66.7
125	0.43	0.44	0.43	0.43	0.43	0.01	33.2
160	0.48	0.48	0.49	0.47	0.48	0.01	27.8
200	0.28	0.28	0.28	0.27	0.28	0.01	32.8
250	0.31	0.31	0.31	0.31	0.31	0.00	27.7
315	0.30	0.31	0.31	0.31	0.31	0.01	24.8
400	0.33	0.33	0.34	0.34	0.33	0.01	21.1
500	0.28	0.28	0.28	0.28	0.28	0.00	20.6
630	0.30	0.29	0.29	0.29	0.29	0.01	18.0
800	0.28	0.29	0.28	0.29	0.28	0.01	16.2
1000	0.25	0.25	0.25	0.25	0.25	0.00	15.4
1250	0.27	0.27	0.27	0.27	0.27	0.00	13.3
1600	0.27	0.27	0.27	0.27	0.27	0.00	11.7
2000	0.27	0.28	0.28	0.27	0.27	0.01	10.4
2500	0.26	0.27	0.26	0.27	0.26	0.01	9.5
3150	0.21	0.21	0.21	0.21	0.21	0.00	9.5
4000	0.21	0.21	0.21	0.21	0.21	0.00	8.4
5000	0.22	0.22	0.22	0.21	0.22	0.01	7.4
6300	0.18	0.18	0.18	0.18	0.18	0.00	7.2
8000	0.18	0.18	0.17	0.17	0.17	0.01	6.5

Table 12. Measured T(30) integrated impulse response reverberation times at Location 3.

One-third Octave Band Center Frequency	T(30)						
	M1	M2	M3	M4	Mean	SD	r_{30}
[Hz]	[s]	[s]	[s]	[s]	[s]	[s]	[%]
100	0.25	0.25	0.25	0.25	0.25	0.00	37.3
125			0.55		0.55		
160							
200	0.29	0.29	0.29	0.29	0.29	0.00	17.3
250	0.26	0.27	0.27	0.27	0.27	0.01	16.1
315	0.33	0.33	0.32	0.32	0.32	0.01	13.0
400	0.30	0.31	0.31	0.31	0.31	0.01	11.9
500	0.28	0.28	0.28	0.28	0.28	0.00	11.1
630	0.28	0.28	0.28	0.28	0.28	0.00	9.9
800	0.26	0.26	0.26	0.29	0.27	0.02	9.0
1000	0.29	0.29	0.29	0.29	0.29	0.00	7.7
1250	0.28	0.28	0.29	0.28	0.28	0.01	7.0
1600	0.27	0.26	0.27	0.27	0.27	0.01	6.4
2000	0.28	0.28	0.29	0.28	0.28	0.01	5.5
2500	0.25	0.25	0.25	0.25	0.25	0.00	5.3
3150	0.21	0.21	0.21	0.21	0.21	0.00	5.1
4000	0.22	0.21	0.21	0.21	0.21	0.01	4.5
5000	0.22	0.23	0.22	0.21	0.22	0.01	4.0
6300	0.19	0.20	0.19	0.20	0.19	0.01	3.8
8000	0.18	0.18	0.18	0.17	0.18	0.01	3.5

Table 13. Mean (three locations) reverberation times, standard deviation and measurement repeatability.

One-third Octave Band Center Frequency	Mean Reverberation Time (three locations)			Standard Deviation (three locations)			Measurement Repeatability (three locations)	
	EDT	T(20)	T(30)	SD(EDT)	SD(T20)	SD(T30)	r_{20}	r_{30}
[Hz]	[s]	[s]	[s]	[s]	[s]	[s]	[%]	[%]
100	0.51	0.45	0.46	0.01	0.15	0.11	34.2	19.7
125	0.37	0.42	0.43	0.02	0.01	0.06	35.7	18.3
160	0.36	0.46	0.52	0.15	0.04	0.02	32.0	15.3
200	0.32	0.32	0.32	0.02	0.05	0.03	30.5	16.4
250	0.27	0.32	0.29	0.04	0.01	0.02	29.5	14.8
315	0.28	0.37	0.38	0.04	0.05	0.05	26.0	12.2
400	0.36	0.32	0.31	0.02	0.01	0.01	20.2	11.6
500	0.34	0.31	0.30	0.05	0.03	0.03	18.7	10.7
630	0.27	0.30	0.28	0.04	0.01	0.01	18.7	9.6
800	0.25	0.27	0.28	0.06	0.01	0.02	17.1	8.9
1000	0.22	0.27	0.28	0.02	0.01	0.01	16.5	8.0
1250	0.27	0.27	0.27	0.03	0.01	0.01	13.3	7.2
1600	0.27	0.27	0.26	0.05	0.01	0.01	11.8	6.4
2000	0.25	0.27	0.27	0.05	0.01	0.01	10.9	5.7
2500	0.23	0.26	0.26	0.05	0.01	0.01	10.1	5.2
3150	0.21	0.22	0.22	0.08	0.01	0.01	9.6	5.0
4000	0.20	0.22	0.23	0.07	0.01	0.02	8.6	4.4
5000	0.18	0.21	0.21	0.06	0.01	0.01	8.2	4.1
6300	0.18	0.18	0.19	0.06	0.01	0.01	7.2	3.9
8000	0.20	0.17	0.18	0.05	0.01	0.01	6.0	3.5

Table 14. Simplified rectangular room dimensions for the EER.

		Dimension	
Length	l	[m]	8.17
Width	w	[m]	8.23
Height	h	[m]	4.36
Volume	V	[m^3]	293.2
Surface Area	S	[m^2]	277.5
Edge Length	L	[m]	83.0

Table 15. Calculated acoustic modes in the simplified rectangular EER.

One-third Octave Band Center Frequency	Length Mode n_x	Width Mode n_y	Height Mode n_z	Modal Frequency	Mode Spacing	One-third Octave Band Number	Number of Modes in Band
[Hz]				[Hz]	[Hz]		
20	0	1	0	20.8		13	2
20	1	0	0	21.0	0.2	13	2
31.5	1	1	0	29.6	8.6	15	1
40	0	0	1	39.4	9.8	16	5
40	0	2	0	41.7	2.3	16	5
40	2	0	0	42.0	0.3	16	5
40	0	1	1	44.5	2.5	16	5
40	1	0	1	44.6	0.1	16	5
50	1	2	0	46.7	2.1	17	3
50	2	1	0	46.9	0.2	17	3
50	1	1	1	49.2	2.3	17	3
63	0	2	1	57.3	8.1	18	9
63	2	0	1	57.6	0.2	18	9
63	2	2	0	59.2	1.6	18	9
63	1	2	1	61.1	1.9	18	9
63	2	1	1	61.2	0.2	18	9
63	0	3	0	62.5	1.3	18	9
63	3	0	0	63.0	0.5	18	9
63	1	3	0	66.0	3.0	18	9
63	3	1	0	66.4	0.4	18	9
80	2	2	1	71.1	4.7	19	18
80	0	3	1	73.9	2.8	19	18
80	3	0	1	74.3	0.4	19	18
80	2	3	0	75.3	1.1	19	18
80	3	2	0	75.5	0.2	19	18
80	1	3	1	76.8	1.3	19	18
80	3	1	1	77.2	0.3	19	18
80	0	0	2	78.7	1.6	19	18
80	0	1	2	81.4	2.7	19	18
80	1	0	2	81.5	0.0	19	18
80	0	4	0	83.4	1.9	19	18
80	4	0	0	84.0	0.6	19	18
80	1	1	2	84.1	0.1	19	18
80	2	3	1	85.0	0.9	19	18
80	3	2	1	85.2	0.2	19	18
80	1	4	0	86.0	0.8	19	18
80	4	1	0	86.6	0.6	19	18
80	3	3	0	88.8	2.2	19	18

Table 16. Calculated modal density in the simplified rectangular EER.

One-third Octave Band Center Frequency	Modal Density	One-third Octave Band Center Frequency	Modal Density
[Hz]	[1/Hz]	[Hz]	[1/Hz]
100	1.3	1000	94.8
125	1.9	1250	147.0
160	3.0	1600	239.2
200	4.4	2000	371.8
250	6.6	2500	578.7
315	10.2	3150	915.6
400	16.1	4000	1472.5
500	24.7	5000	2296.1
630	38.5	6300	3639.2
800	61.3	8000	5860.1

Table 17. The Schröder diffuse field cut-off frequencies and the required minimum source-microphone distances as function of the mean reverberation time.

One-third Octave Band Center Frequency	Mean Reverberation Time T(20)	Schröder Cut-off Frequency f_S	Minimum Source- Microphone Distance d_{min}
[Hz]	[s]	[Hz]	[m]
100	0.44	187.6	2.8
125	0.42	181.8	2.9
160	0.47	192.8	2.7
200	0.32	160.5	3.2
250	0.32	158.2	3.3
315	0.37	171.5	3.0
400	0.32	160.2	3.2
500	0.31	155.6	3.3
630	0.30	154.1	3.4
800	0.27	147.1	3.5
1000	0.27	145.9	3.6
1250	0.27	146.7	3.5
1600	0.27	145.5	3.6
2000	0.27	146.0	3.6
2500	0.26	144.0	3.6
3150	0.22	132.9	3.9
4000	0.22	133.3	3.9
5000	0.21	128.2	4.1
6300	0.18	119.3	4.4
8000	0.17	117.3	4.4

Table 18. Mean (three locations) integrated impulse response reverberation times, equivalent sound absorption areas and averaged Sabine absorption coefficients.

One-third Octave Band Center Frequency	Mean Reverberation Time			Equivalent Sound Absorption Area			Averaged Sabine Absorption Coefficient		
	EDT	T(20)	T(30)	A(EDT)	A(T20)	A(T30)	$\overline{\alpha}$ (EDT)	$\overline{\alpha}$ (T20)	$\overline{\alpha}$ (T30)
[Hz]	[s]	[s]	[s]	[m^2]	[m^2]	[m^2]			
100	0.51	0.45	0.46	92.7	105.2	102.0	0.34	0.39	0.38
125	0.37	0.42	0.43	126.7	113.3	109.4	0.47	0.42	0.40
160	0.36	0.46	0.52	129.7	102.0	91.7	0.48	0.37	0.34
200	0.32	0.32	0.32	148.1	145.4	146.4	0.54	0.53	0.54
250	0.27	0.32	0.29	172.5	149.7	163.7	0.63	0.55	0.60
315	0.28	0.37	0.38	168.8	127.4	123.0	0.62	0.47	0.45
400	0.36	0.32	0.31	130.0	145.9	153.7	0.48	0.54	0.57
500	0.34	0.31	0.30	138.5	154.7	156.7	0.51	0.57	0.58
630	0.27	0.30	0.28	174.9	157.7	168.3	0.64	0.58	0.62
800	0.25	0.27	0.28	186.3	173.2	168.9	0.68	0.64	0.62
1000	0.22	0.27	0.28	214.8	176.0	166.4	0.79	0.65	0.61
1250	0.27	0.27	0.27	176.7	174.0	175.8	0.65	0.64	0.65
1600	0.27	0.27	0.26	177.4	176.9	181.4	0.65	0.65	0.67
2000	0.25	0.27	0.27	188.2	175.6	177.1	0.69	0.65	0.65
2500	0.23	0.26	0.26	203.8	180.7	178.6	0.75	0.66	0.66
3150	0.21	0.22	0.22	229.0	211.9	212.1	0.84	0.78	0.78
4000	0.20	0.22	0.23	237.2	210.7	204.1	0.87	0.77	0.75
5000	0.18	0.21	0.21	269.9	228.0	222.6	0.99	0.84	0.82
6300	0.18	0.18	0.19	258.4	263.0	247.4	0.95	0.97	0.91
8000	0.20	0.17	0.18	232.2	272.1	255.9	0.85	1.00	0.94

Table 19. Dynamic range between pink noise and background noise levels in the EER measured with the Brüel & Kjær Type 2131 Digital Frequency Analyzer.

One-third Octave Band Center Frequency	Pink Noise Level	Background Noise Level	Dynamic Range	One-third Octave Band Center Frequency	Pink Noise Level	Background Noise Level	Dynamic Range
[Hz]	[dB]	[dB]	[dB]	[Hz]	[dB]	[dB]	[dB]
50	88.9	47.2	41.7	1000	76.8	20.4	56.4
63	83.5	43.0	40.5	1250	80.2	16.8	63.4
80	84.1	39.6	44.5	1600	80.9	15.4	65.5
100	85.1	36.6	48.5	2000	78.9	14.6	64.3
125	83.4	35.8	47.6	2500	77.5	14.5	63.0
160	82.3	31.6	50.7	3150	76.3	14.0	62.3
200	80.2	31.3	48.9	4000	74.1	15.1	59.0
250	76.7	26.5	50.2	5000	75.5	14.8	60.7
315	78.4	25.1	53.3	6300	68.7	15.1	53.6
400	79.8	25.3	54.5	8000	64.8	15.1	49.7
500	81.7	21.5	60.2	10000	66.3	15.7	50.6
630	82.1	21.2	60.9	12500	66.0	16.7	49.3
800	81.4	21.6	59.8	16000	62.4	19.6	42.8

Table 20. Median and mode T(20) reverberation times, and the measurement repeatability values for N runs of the interrupted noise measurements (Larson-Davis) at Locations 1-3.

One-third Octave Band Center Frequency	Median Reverberation Time T(20)			Mode Reverberation Time T(20)			Measurement Repeatability r_{20}		
	Loc 1	**Loc 2**	**Loc 3**	**Loc 1**	**Loc 2**	**Loc 3**	**Loc 1**	**Loc 2**	**Loc 3**
[Hz]	[s]	[s]	[s]	[s]	[s]	[s]	[%]	[%]	[%]
							N=37	N=11	N=11
50	1.62	2.24	1.40	1.43	0.99	0.90	14.1	22.0	27.8
63	1.02	0.88	0.72	0.71	0.44	0.61	15.8	31.2	34.5
80	0.64	0.56	0.49	0.61	0.40	0.39	17.7	34.8	37.2
100	0.51	0.51	0.49	0.37	0.41	0.22	17.8	32.6	33.2
125	0.56	0.44	0.45	0.36	0.36	0.38	15.6	31.4	31.0
160	0.55	0.45	0.64	0.43	0.32	0.35	13.5	27.4	23.0
200	0.40	0.35	0.50	0.36	0.22	0.50	14.4	27.8	23.3
250	0.30	0.40	0.26	0.28	0.15	0.25	14.6	23.3	28.9
315	0.53	0.31	0.41	0.34	0.25	0.38	9.8	23.5	20.5
400	0.39	0.33	0.31	0.34	0.21	0.27	10.2	20.2	20.9
500	0.34	0.37	0.37	0.31	0.28	0.28	9.7	17.1	17.1
630	0.31	0.28	0.33	0.29	0.28	0.30	9.1	17.5	16.1
800	0.32	0.30	0.31	0.27	0.26	0.31	7.9	15.0	14.8
1000	0.28	0.26	0.29	0.24	0.26	0.27	7.6	14.4	13.7
1250	0.30	0.26	0.28	0.28	0.24	0.28	6.5	12.9	12.4
1600	0.26	0.27	0.28	0.25	0.27	0.27	6.2	11.2	11.0
2000	0.27	0.23	0.26	0.25	0.22	0.26	5.5	10.8	10.2
2500	0.25	0.21	0.26	0.24	0.21	0.25	5.1	10.2	9.1
3150	0.24	0.20	0.24	0.24	0.21	0.23	4.6	9.3	8.5
4000	0.22	0.18	0.23	0.22	0.18	0.23	4.3	8.7	7.7
5000	0.21	0.17	0.21	0.21	0.16	0.21	3.9	8.0	7.2
6300	0.21	0.14	0.19	0.21	0.14	0.19	3.5	7.8	6.7
8000	0.18	0.16	0.18	0.18	0.16	0.18	3.3	6.5	6.1
10000	0.16	0.14	0.18	0.16	0.14	0.18	3.2	6.2	5.5
12500	0.16	0.13	0.16	0.16	0.13	0.16	2.8	5.8	5.2
16000	0.18	0.12	0.16	0.18	0.12	0.16	2.4	5.3	4.6
20000		0.11			0.11			5.0	

Table 21. Location 1 comparison between the median and mode interrupted noise reverberation times (Larson Davis), the integrated impulse response reverberation times (Brüel & Kjær), and the octave band reverberation times from Reference 2.

One-third Octave Band Center Frequency	Median T(20) Interrupted Pink Noise (Larson Davis)		Mode T(20) Interrupted Pink Noise (Larson Davis)		Mean T(20) Integrated Impulse Response (Brüel & Kjær)	Mean T(30) Integrated Impulse Response (Brüel & Kjær)		Octave Band Interrupted Pink Noise (Ref. 2)	
[Hz]	[s]	([%])	[s]	([%])	[s]	[s]	([%])	[s]	([%])
50	1.62		1.43						
63	1.02		0.71						
80	0.64		0.61						
100	0.51	(13.3)	0.37	(-17.8)	0.45	0.46	(2.2)		
125	0.56	(33.3)	0.36	(-14.3)	0.42	0.43	(2.4)	0.45	(-2.2)
160	0.55	(19.6)	0.43	(-6.5)	0.46	0.52	(13.0)		
200	0.40	(25.0)	0.36	(12.5)	0.32	0.32	(0.0)		
250	0.30	(-6.3)	0.28	(-12.5)	0.32	0.29	(-9.4)	0.23	(-37.8)
315	0.53	(43.2)	0.34	(-8.1)	0.37	0.39	(5.4)		
400	0.39	(21.9)	0.34	(6.3)	0.32	0.31	(-3.1)		
500	0.34	(9.7)	0.31	(0.0)	0.31	0.30	(-3.2)	0.29	(-9.4)
630	0.31	(3.3)	0.29	(-3.3)	0.30	0.28	(-6.7)		
800	0.32	(18.5)	0.27	(0.0)	0.27	0.28	(3.7)		
1000	0.28	(3.7)	0.24	(-11.1)	0.27	0.28	(3.7)	0.31	(14.8)
1250	0.30	(11.1)	0.28	(3.7)	0.27	0.27	(0.0)		
1600	0.26	(-3.7)	0.25	(-7.4)	0.27	0.26	(-3.7)		
2000	0.27	(0.0)	0.25	(-7.4)	0.27	0.27	(0.0)	0.28	(3.7)
2500	0.25	(-3.8)	0.24	(-7.7)	0.26	0.26	(0.0)		
3150	0.24	(9.1)	0.24	(9.1)	0.22	0.22	(0.0)		
4000	0.22	(0.0)	0.22	(0.0)	0.22	0.23	(4.5)	0.26	(18.2)
5000	0.21	(0.0)	0.21	(0.0)	0.21	0.21	(0.0)		
6300	0.21	(16.7)	0.21	(16.7)	0.18	0.19	(5.6)		
8000	0.18	(5.9)	0.18	(5.9)	0.17	0.18	(5.9)	0.20	(11.1)
10000	0.16		0.16						
12500	0.16		0.16						
16000	0.18		0.18						

FIGURES

Figure 1. EER viewed from the main room entrance.

Figure 2. EER viewed from a location opposite the main entrance door.

Figure 3. EER viewed from second floor room entrance.

Figure 4. The two loudspeakers (L1 and L2) integrated into the front wall corners.

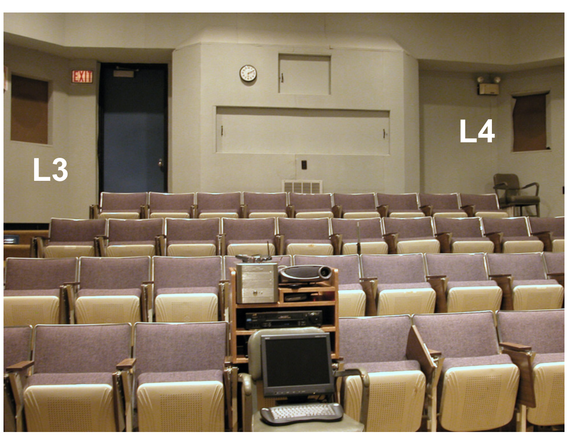

Figure 5. The two loudspeakers (L3 and L4) integrated into the back wall corners.

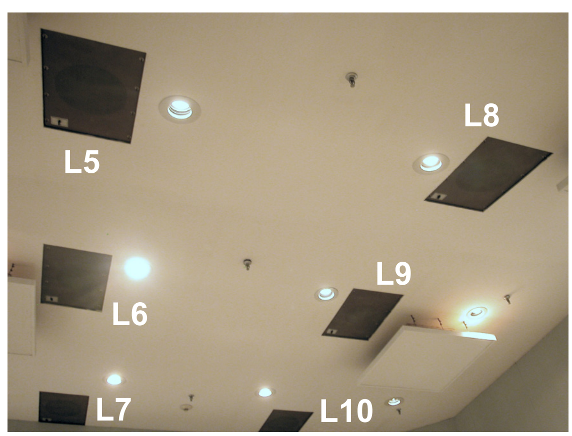

Figure 6. The six integrated ceiling loudspeakers (L5-L11).

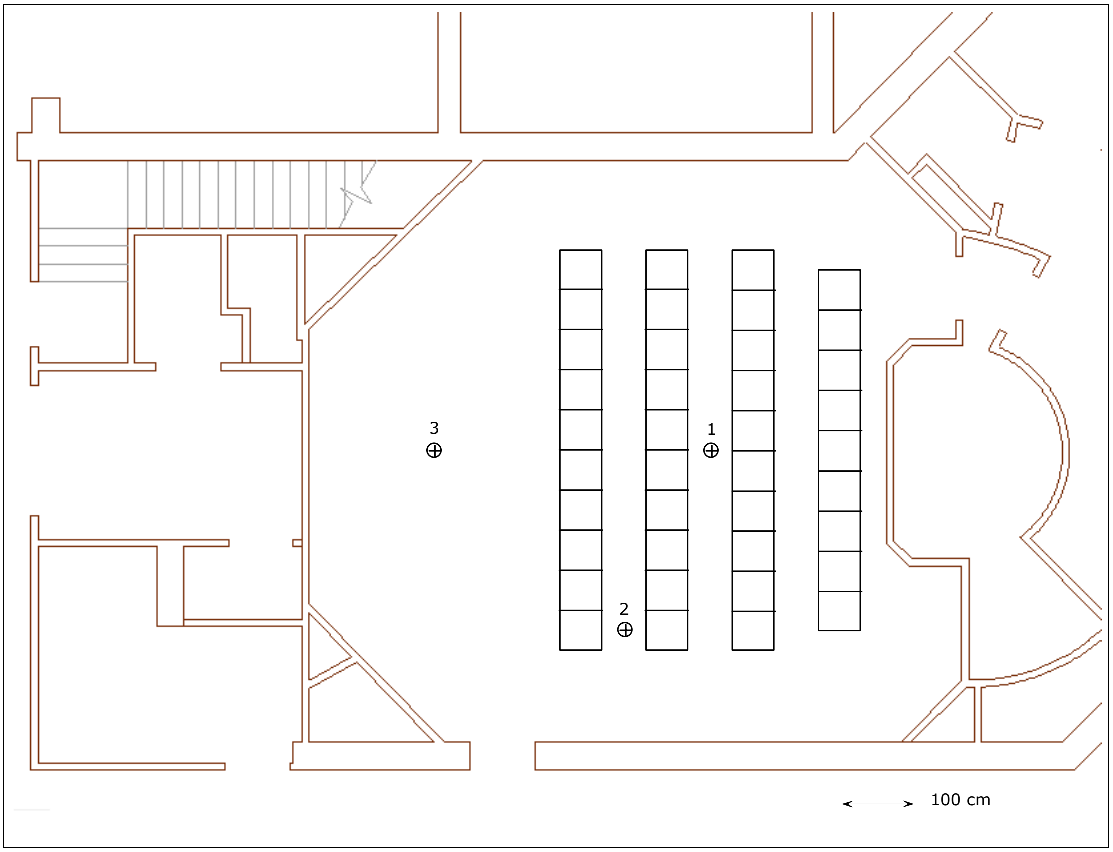

Figure 7. Plan form of the Exterior Effects Room (EER) showing the three reverberation time measurement locations.

Figure 8. Close up of the wall covering in the EER featuring a rough perforated surface to promote sound diffusiveness and sound absorption.

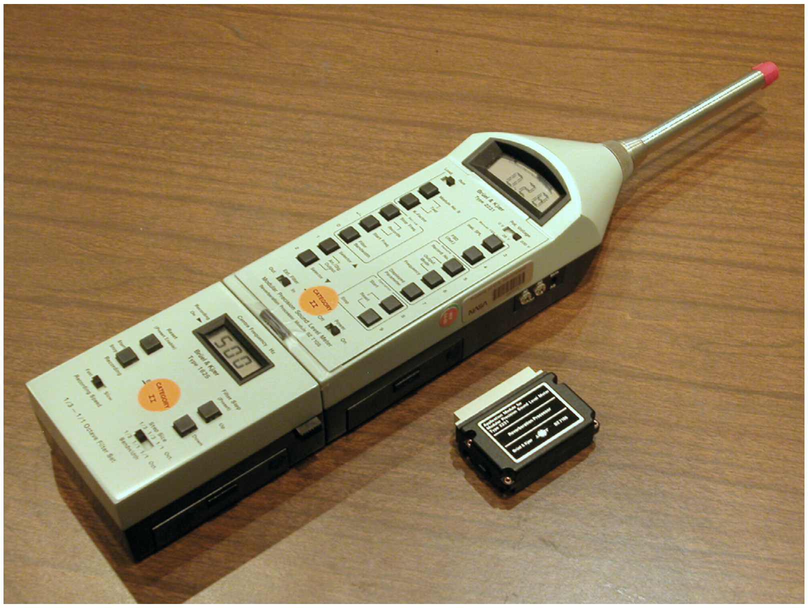

Figure 9. Brüel & Kjær Type 2231 Modular Precision Sound Level Meter with the Type 1625 1/3 Octave Filter Set and the Type BZ7108 Reverberation Processor.

Figure 10. The Larson Davis System 824A Class 1 Precision Sound level Meter and Real Time Analyzer.

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14. ABSTRACT
One-third octave band background noise and reverberation time measurements were conducted in the Exterior Effect Room (EER) at the NASA Langley Research Center. The related overall acoustic absorption of the room was calculated. The acoustic field in the room was characterized. Reverberation time measurements were performed using the integrated impulse response method. The results were compared with independent measurements using the interrupted noise reverberation time method and different instrumentation. Reasonable agreement was obtained between the reverberation times of the two methods.

15. SUBJECT TERMS
Reverberation time; acoustic absorption; integrated impulse reponse; interrupted noise;background noise; exterior effects room; EER

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