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The noise simulation facility at DRDC Toronto

Room acoustics and system analysis

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Defence R&D Canada – Toronto
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Abstract

The Noise Simulation Facility and the Noise Library at DRDC Toronto are used to recreate the noise environments of various military operational settings. The Noise Simulation Facility (the Noise Lab) is a large room containing an array of speakers that enables the production of noise levels as high as 130 dB. The Noise Library is a collection of digital audio tapes containing recordings of noise that were made in various Canadian Forces land vehicles, aircraft and other operational settings. The acoustical characteristics of the Noise Lab and the quality of the digital audio tape recordings that have been modified for playback are largely unknown. To gain a better understanding of the accuracy to which the operational noise environments are modeled in the Noise Lab, the acoustical response at several different positions in the Noise Lab was measured, and spectral analyses of the noise recordings were performed. The presence of objects in the room was found to decrease the reverberation time at all frequencies compared to their absence. It was determined from the measurements that the over-amplification of low frequencies governed by the geometry of the Noise Lab could be reduced by adjusting the settings of a graphic equalizer and by moving the measurement location to an area where the effects of standing waves were minimized. Recommendations are made with regard to field measurement procedures that can help to improve the quality of the noise recordings and ensure accurate playback of levels in the Noise Lab.

Résumé

L’installation de simulation de bruit et la bandothèque d’enregistrements de bruit de RDDC Toronto permettent de reproduire les conditions de bruit de divers contextes opérationnels militaires. L’installation de simulation de bruit (laboratoire de simulation de bruit) consiste en une grande salle comprenant un réseau de haut-parleurs qui permettent de générer des niveaux de bruit allant jusqu'à 130 dB. La bandothèque comprend une collection de bandes audionumériques de bruits enregistrés dans divers véhicules terrestres et aéronefs des Forces canadiennes, ainsi que dans d’autres contextes opérationnels. En grande partie, les caractéristiques acoustiques du laboratoire de simulation et la qualité des enregistrements sur bande audionumérique, qui ont été modifiés pour l’écoute, demeurent inconnues. On a mesuré la réponse acoustique à différents emplacements dans le laboratoire afin de mieux connaître la précision de la simulation des environnements acoustiques opérationnels. Des analyses spectrales des enregistrements de bruit ont aussi été effectuées. On a constaté que la présence d’objets dans la salle diminuait le temps de réverbération pour toutes les fréquences. Les mesures prises ont permis de déterminer que la suramplification des basses fréquences, déterminée par la géométrie du laboratoire, pouvait être diminuée en modifiant les réglages de l’égalisateur graphique et en déplaçant le capteur à un endroit où les effets des ondes stationnaires sont réduits. Des recommandations sont présentées en ce qui concerne les procédures de mesure sur le terrain, qui sont censées améliorer la qualité des enregistrements de bruit et assurer une reproduction fidèle des niveaux dans le laboratoire.

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Executive summary

The Noise Simulation Facility (the Noise Lab) at DRDC Toronto was developed to model operational environments so that the effect of noise on communications and the benefits and drawbacks of hearing protective devices can be assessed under controlled conditions. A collection of tapes containing noise recordings of various military operational environments (the Noise Library) is available for playback in the Noise Lab. Although the Noise Lab is used extensively, the acoustical characteristics of the room are largely unknown. In addition, there is no documentation available for many of the Noise Library tapes, which raises concerns about the fidelity of the modeled operational environment. In this work, the acoustical response at several different positions in the Noise Lab was measured, and the Noise Library recordings were analyzed to determine their suitability for modeling real-world environments in the Noise Lab.

Pink noise was used to measure the frequency response at four previously designated measurement locations in the Noise Lab. Pink noise was chosen because it is characterized as having equal energy per octave band. At the four locations, the overall A-weighted levels were found to be quite similar; however, major differences were found between the measured sound pressure levels in 1/3 octave bands at certain frequencies, particularly the low frequencies. These differences were likely the result of the standing waves and primary modes of vibration that are associated with the dimensions of the Noise Lab. The major effect of these primary modes was to create an excess of low frequency energy in the 16 Hz and 31.5 to 63 Hz bands.

Another important parameter in room acoustics is the reverberation time (RT). The International Standard (ISO 3382 [1997]) defines a standard method for measuring and calculating the RT of a room. Following this method, both the RT and the early decay time (EDT) were calculated. The results indicate that the Noise Lab is not fully reverberant, and the presence of objects in the room decreases the RT.

Digital audio tapes contained in the Noise Library tapes were typically created from field recordings that were edited by computer. Short segments were looped to create a continuous two-hour recording. Generally speaking, the loop tapes seemed to provide a fairly accurate reproduction of the original noise environments with regard to the frequency content. However, the correct playback level for some of the tapes could not be determined because the overall noise levels that were recorded in the field were unknown due to the indirect calibration methods that were used.

Based on the measurements made, it was determined that modifications to the settings of the Graphical Equalizer (GEQ) component of the Noise Lab sound system, and a new measurement location at the node of the 16 Hz standing wave could be used to minimize the effect of room acoustics on measurements conducted in the Noise Lab. This would create a flatter frequency response and reduce the impact of the excessive low frequency energy due to the primary modes of vibration of the room. Recommendations are also made concerning the Noise Library, specifically with regard to documentation and field measurement procedures

that will ensure that any new recordings will be easy to edit and calibrate for accurate playback in the Noise Lab.

Nakashima, A.M., Borland, M.J. 2005. The Noise Simulation Facility at DRDC Toronto. TR 2005-095 DRDC Toronto.

Sommaire

L’installation de simulation de bruit (laboratoire de simulation de bruit) de RDDC Toronto a été développée pour modéliser les conditions opérationnelles afin de pouvoir évaluer, dans un milieu contrôlé, l’effet du bruit sur les communications, ainsi que les avantages et inconvénients de l’utilisation des protecteurs d’oreille. Une collection de bandes d’enregistrements de bruits provenant de divers contextes opérationnels militaires (bandothèque d’enregistrements de bruit) est disponible aux fins d’écoute dans le laboratoire de simulation. Bien que le laboratoire de simulation de bruit soit très utilisé, les caractéristiques acoustiques de la salle du laboratoire en tant que telle sont en grande partie inconnues. En outre, le manque de documentation disponible pour de nombreuses bandes de la bandothèque soulève certaines craintes en ce qui a trait à la fidélité du contexte opérationnel modélisé. Les travaux effectués portent sur la mesure de la réponse acoustique à différents emplacements dans le laboratoire de simulation, et l’analyse des enregistrements de la bandothèque afin de déterminer leur adéquation pour la modélisation de contextes réels.

On a utilisé le bruit rose pour mesurer la réponse en fréquence à quatre emplacements de mesure présélectionnés dans le laboratoire de simulation. Le bruit rose a été choisi parce qu’il s’agit d’un signal caractérisé par une énergie égale dans chaque bande d’octave. On a obtenu des niveaux pondérés A globaux très semblables aux quatre emplacements. Cependant, d’importantes différences ont été décelées entre les niveaux de pression acoustique mesurés dans des bandes de 1/3 d’octave à certaines fréquences, particulièrement les basses fréquences. Ces différences étaient probablement dues aux ondes stationnaires et aux modes de vibration principaux associés aux dimensions du laboratoire. Le plus grand effet de ces modes principaux a été de créer un excédent d’énergie dans les basses fréquences, plus précisément dans les bandes 16 Hz et 31,5 à 63 Hz.

Le temps de réverbération (TR) est un autre paramètre important en acoustique des salles. La norme internationale (ISO 3382 [1997]) définit une méthode standard pour mesurer et pour calculer le TR d’une salle. Le TR et le temps de décroissance précoce (EDT pour *early decay time*) ont été calculés selon cette méthode. Les résultats indiquent que le laboratoire de simulation n’est pas entièrement réverbérant et que la présence d’objets dans la salle diminue le TR.

Les bandes audionumériques de la bandothèque ont été créées généralement à partir d’enregistrements faits sur le terrain, qui ont ensuite été modifiés par ordinateur. De courts segments ont été mis en boucle pour obtenir un enregistrement continu de deux heures. Règle générale, les bandes de segments mis en boucle semblent donner une reproduction assez précise des milieux acoustiques originaux relativement au contenu fréquentiel. Le niveau de lecture adéquat pour certaines des bandes n’a toutefois pas pu être déterminé, parce que les niveaux de bruit globaux enregistrés sur le terrain étaient inconnus en raison des méthodes d’étalonnage indirectes utilisées.

Compte tenu des mesures effectuées, on a conclu que la modification des réglages de l’élément égalisateur graphique du système de son du laboratoire et un nouvel emplacement de mesure coïncidant avec le nœud de l’onde stationnaire de 16 Hz pourraient réduire l’effet de l’acoustique de la salle sur les mesures effectuées dans le laboratoire. Ceci permettrait d’obtenir une réponse en fréquence plus uniforme et réduirait l’impact de l’excédent d’énergie dans les basses fréquences dû aux modes de vibration principaux qui caractérisent la salle. De plus, des recommandations sont présentées concernant la bandothèque, particulièrement en ce qui concerne les procédures de documentation et de mesure sur le terrain. Le but de ces recommandations est de faire en sorte que tous les nouveaux enregistrements soient faciles à modifier et à étalonner pour obtenir une lecture précise dans le laboratoire.

Nakashima, A.M., Borland, M.J. 2005. The Noise Simulation Facility at DRDC Toronto (L’installation de simulation de bruit à RDDC Toronto). TR 2005-095 RDDC Toronto.

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List of Acronyms

Noise Lab	Noise Simulation Facility
DRDC Toronto	Defence Research and Development Canada – Toronto
SPL	Sound Pressure Level
CF	Canadian Forces
DAT	Digital Audio Tape
GEQ	Graphic Equalizer
DEQ	Digital Equalizer
ISO	International Organization for Standardization
RT	Reverberation Time
T_{20}	Conventional Reverberation Time
EDT	Early Decay Time
dB SPL, dBL	Unweighted (Linear) Sound Pressure Level
dBA	A-weighted Sound Pressure Level
B&K	Brüel and Kjaer Company
ELF	Extended Low Frequencies
NASO	Non-Acoustic Sensor Operator
SENSO	Sensor Operator
ANR	Active Noise Reduction

Introduction

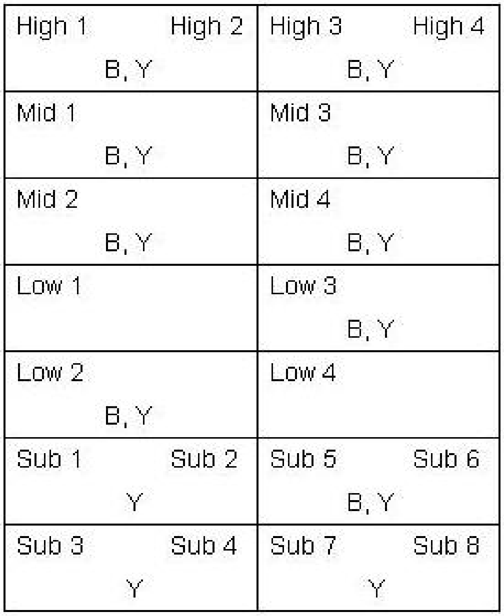
The Noise Simulation Facility (hereafter referred to as the Noise Lab) at Defence Research and Development Canada – Toronto (DRDC Toronto) is used to study the effects of high-noise environments on hearing, communication and task performance. The room was designed for the simulation of noise environments that are typical of military operations. To meet such objectives, the surfaces of the room are reflective to create a semi-reverberant effect, enabling the production of sound pressure levels (SPL) as high as 130 dB. A selection of military noise environments, recorded inside various Canadian Forces (CF) vehicles (hereafter referred to as the Noise Library), is available on digital audio tape (DAT).

The dimensions of the Noise Lab are 10.55m long, by 6.10m wide, by 3.05m high. An array of loudspeakers is placed at one end of the length of the room, consisting of 8 sub-low (Gane G218), 2 low (ServoDrive BassTech 7), 4 mid (ElectroVoice), and 4 high frequency speakers (ElectroVoice), powered by 12 Bryston amplifiers (stereo model 4B and mono model 7B). The input signal is filtered with a Yamaha GQ1031BII Graphic Equalizer (GEQ) and a Yamaha DEQ7 Digital Equalizer (DEQ) before being passed to the amplifiers. The low frequency sounds are also divided by a BAG END/Modular Systems Inc. ELF-1 (ELF, extended low frequencies). A schematic of the amplifier rack is shown in Figure 1. The amplifiers in Figure 1 are labelled as high, mid, low and sub to indicate which speakers they power. Two amplifier combinations are used. The first power configuration uses the amplifiers labelled “B, Y” and “Y” in Figure 1, and is used for noise that contains a lot of low-frequency energy. The second configuration uses only the “B, Y” amplifiers. Two of the amplifiers (Low 1 and Low 4) are not currently used, and are thus not labelled. Hereafter, the amplifier configurations will be referred to as C1 (“B, Y” and “Y” amplifiers) and C2 (“B, Y” amplifiers only).

The components of the sound system and the frequency spectra of the various noise recordings have been documented (Dunn, 2004). However, little is known about the acoustical characteristics of the room. In general, it is very difficult to re-create the environment in which the noise was recorded, unless an anechoic chamber is used. An anechoic chamber is a room with highly absorptive surfaces, designed to simulate free-field conditions. In any other type of room, playback of recorded noise will be altered by the reflection, absorption and scattering of the sound waves from the surfaces and objects in the room. There are some acoustical characteristics that can be derived from the geometry of the room. Standing waves will occur at sound frequencies for which a room dimension is an integer multiple of the half-wavelength. The wavelength is given by $\lambda = \frac{c}{f}$, where c is the speed of sound (typically 340 m/s) and f is the frequency. Standing waves will thus occur when $d = \frac{n\lambda}{2}$, where d is the dimension (height, width or length) and n is any integer number. For example, the length of the room is 10.55 m, meaning that standing waves will occur at 16 Hz, 32 Hz, 48 Hz, etc. Standing waves in the width of the room will occur at 28 Hz, 56 Hz, 84 Hz, etc. The presence of standing waves will cause the SPL at those frequencies to change dramatically with position in the room. This is particularly a problem at very low frequencies, which are strongly reflected by the room surfaces and are not readily absorbed or scattered.

The detailed acoustical response of the room, called the frequency response, can be extracted from its impulse response. An impulse response is defined as “a plot as a function of time of the sound pressure received in a room as a result of excitation of the room by a Dirac delta function (ISO 3382 [1997]).” A Dirac delta function is a spike of infinite amplitude occurring in an infinitesimally short period of time. It can be approximated acoustically by a highly impulsive sound such as a gunshot. One of the most important acoustical parameters in rooms, which can be determined from the impulse response, is called the reverberation time (RT). Given an initial noise disturbance, the RT is the time required for the SPL to drop by 60 dB. The International Organization for Standardization document for measurement of RT in rooms, ISO 3382 (1997), defines two different reverberation times:

- T_{20}, the conventional reverberation time (in seconds), which is measured from the slope of the sound decay curve between –5dB and –25dB below the maximum initial level; and
- EDT, the early decay time, which is determined from the slope of the initial 10 dB of decay below the maximum initial level (ISO 3382 [1997]).



High 1 High 2 B, Y	High 3 High 4 B, Y
Mid 1 B, Y	Mid 3 B, Y
Mid 2 B, Y	Mid 4 B, Y
Low 1	Low 3 B, Y
Low 2 B, Y	Low 4
Sub 1 Sub 2 Y	Sub 5 Sub 6 B, Y
Sub 3 Sub 4 Y	Sub 7 Sub 8 Y

Figure 1. Schematic of the amplifier rack in the Noise Lab. The amplifiers labelled “B, Y” represent one power configuration (C2), while the addition of the “Y” amplifiers represents an extra low-frequency power configuration (C1).

In addition to the RT, a number of other room acoustics parameters can be determined from the impulse response of the room. These additional parameters are indicators of speech clarity and sound quality in the room. Since the main purpose of the Noise Lab is to produce very high levels of noise, a detailed analysis of the acoustical characteristics is likely not needed. However, it is of interest to know: (1) the reverberation times, T_{20} and EDT, (2) the frequency response at the positions in the room where the subjects have been positioned in previous studies, and (3) the frequency response at other positions in the room, to determine if there is an “optimal” position for the placement of subjects, in terms of minimizing the room effects. The equipment that is required for measuring the impulse response is not available at DRDC Toronto. However, for the applications for which the room is used, it should be sufficient to simply measure the spectra at different positions in the room when equal-energy-per-octave broadband noise is played (i.e., pink noise). In addition, it is of interest to know the comparative levels at different positions by frequency, which can be thought of as the directivity of the speaker array.

Room acoustics of the Noise Simulation Facility

A series of measurements were made to quantify some of the acoustic parameters of the Noise Lab. Historically, subjects have been tested at one of four positions in the room that were considered to be “acoustically equivalent.” The four positions are equidistant from the ElectroVoice (mid and high frequency) speaker array, and were thus assumed to be acoustically equivalent in terms of the amount of sound energy received. However, there is no documentation of the acoustical characteristics of these four positions. Thus, the measurement of the frequency spectra at four locations and the reverberation time of the room were the main priorities in this study. An important factor in both measurements was the effect of the objects that are normally present in the room. To determine the impact of the objects in the room on its acoustical response, measurements were made with the room in its normal (“full”) state and in its “empty” state.

Broadband noise testing: Pink noise source

Pink noise is a random noise similar to white noise. The difference between the two is that pink noise, when examined on a logarithmic scale, produces a consistent and flat level. Another way to say this is that pink noise has equal amounts of energy per octave. Using a pink noise source for testing purposes is very useful because it allows the signal and room acoustics to be tested against a flat reference response. In an ideal situation, with perfect signal reproduction through the speakers into an anechoic chamber, the measured SPL would be the same at all frequencies. In a real room, any deviation from this flat response is due to the effect of the acoustical properties of the room (and to a lesser extent, the distortion that is introduced by the sound system). With this approach in mind, pink noise was played over the speaker array, without equalization, and measurements were taken at the four locations shown in Figure 2. In physical terms, Locations 1 and 4 are at a distance of 4.25 m from the speaker array and Locations 2 and 3 are at a distance of 4.7 m. These four locations were identified for the purpose of testing four subjects simultaneously. Historically, Location 2 has been predominantly used when only one testing position is required, and the simultaneous testing of multiple subjects has not been done in the Noise Lab. The four locations are identified in the room by small red circles painted on the floor.

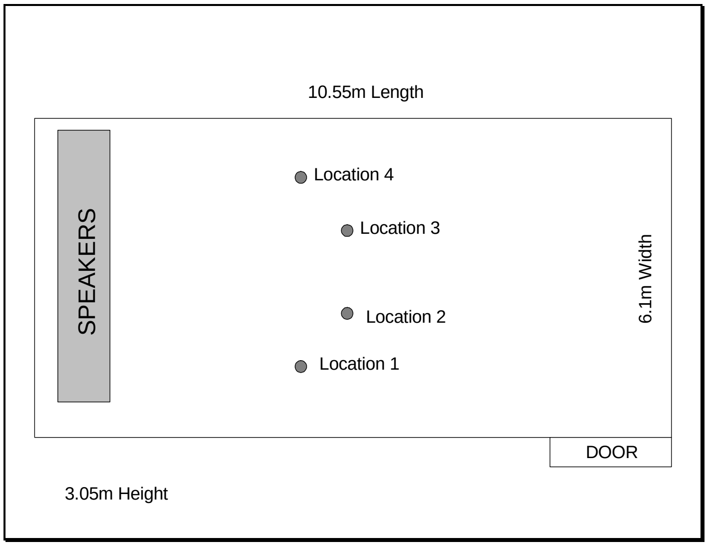


Figure 2. Noise room locations

To conduct the tests, a B&K Noise Generator (Type 1049) was used to produce a pink noise signal from 20 Hz to 20 kHz with an output level of 1.25 V. The digital equalizer (DEQ) was bypassed, and the ELF (a component that splits the low frequency bands into low and sub-low ranges) was set at 22 Hz (i.e., 8, 4, 2 switches in the up position, which are added to the base 8 Hz cutoff to give a total value of 22 Hz.), and the C1 amplifier configuration was used (see Figure 1). With the ventilation system turned off, the background noise of the room with the amplifiers on was measured to be 54 dBA. A microphone was connected to the B&K 2133 frequency analyser and an averaging time of 32 seconds was used to calculate the SPL (labelled as dBL in the figures) in 1/3 octave bands. A sound level meter (Quest 1900) was also used to verify the accuracy of the B&K 2133. The frequency analyser and sound level meter were found to give consistent results (see Appendix, Figure A1).

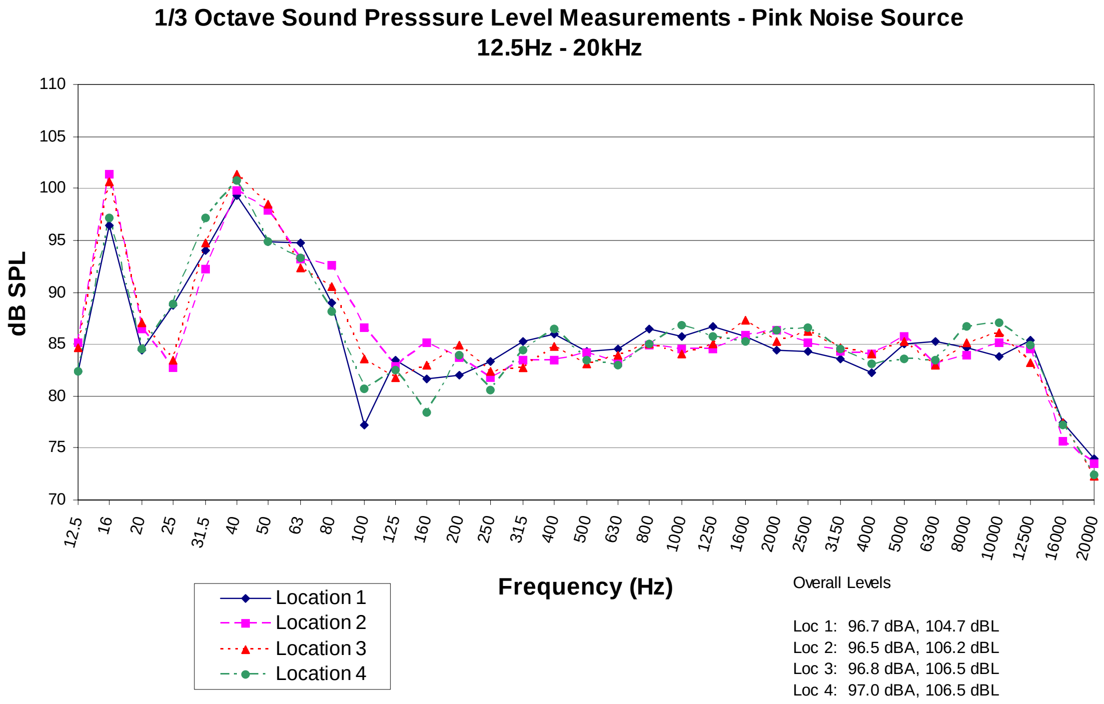


Figure 3. Pink noise spectra at the four locations -– Room full.

The frequency responses for pink noise at the four locations with the room “full” are shown in Figure 3. At the four locations, the total A-weighted levels were 96.7, 96.5, 96.8 and 97.0 dBA, respectively. At frequencies above 250 Hz, the differences in the measured SPL between the four locations are fairly insignificant when pink noise was used to excite the room. On average, the differences are approximately ±1 dB. The same cannot be said for the frequencies below 250 Hz, where differences as great as 9 dB were noted. In particular at 100 Hz, there was a difference of 9 dB between Locations 1 and 2, even though they are separated by a distance of only 1.2 m. The distance of the measurement positions from the speaker array also had a large effect at low frequencies. As shown in Figure 2, Locations 1 and 4 are 4.25 m and Locations 2 and 3 are 4.7 m from the speaker array. At 25 Hz, the SPLs at Locations 1 and 4 were about 6 dB greater than at Locations 2 and 3, but at 16 Hz, the SPLs at Locations 2 and 3 were greater by about 4 dB. These differences at the low frequency bands are likely due to the effect of the room geometry, which emphasizes certain modes of vibration and creates standing waves. Another item of significance is the dramatic increase in SPL that was seen in these low frequency bands, particularly in the 16 Hz and 31.5 to 63 Hz regions of the frequency spectrum. The primary frequency of excitation (resonance) of the Noise Room along its length is 16 Hz. Examining the height and width of the room reveals primary frequencies of excitation of 56 Hz and 28 Hz, respectively. Combined with the harmonics of the 16 Hz standing wave, the primary modes of excitation offer an explanation for the high levels at the 16 Hz and 31.5 to 63 Hz bands. It is clear that room geometry will have a significant impact on the SPL measured at low frequency levels; however, it may not be the only cause of the excess amount of low frequency energy that is present in the room. The signal equalization and amplification system may also have an impact and will be examined later in this document.

Table 1 shows a comparison of mean SPL for two frequency ranges. The mean values and standard deviation over a given bandwidth were fairly consistent across the measurement locations. The mean SPL across the entire range of frequencies measured (12.5 Hz to 20 kHz) and between 250 Hz to 12.5 kHz were calculated to illustrate the large variations in SPL at low frequencies, and the drop-off at high frequencies. As can be seen, for the 12.5 Hz to 20 kHz bandwidth, the standard deviation values were relatively larger than those calculated for the 250 Hz to 12.5 kHz bandwidth. This is explained by the large variations in SPL at the low frequency bands.

Table 1. *Mean SPL at the four locations*

Measurement Position	**Mean SPL ± One Standard Deviation** (12.5 Hz to 20 kHz, dB)	**Mean SPL ± One Standard Deviation** (250 Hz to 12.5 kHz, dB)
Location 1	85.6 ± 5.4	84.8 ± 1.1
Location 2	86.0 ± 5.8	84.3 ± 1.1
Location 3	86.0 ± 5.9	84.5 ± 1.3
Location 4	85.7 ± 5.8	84.8 ± 1.7

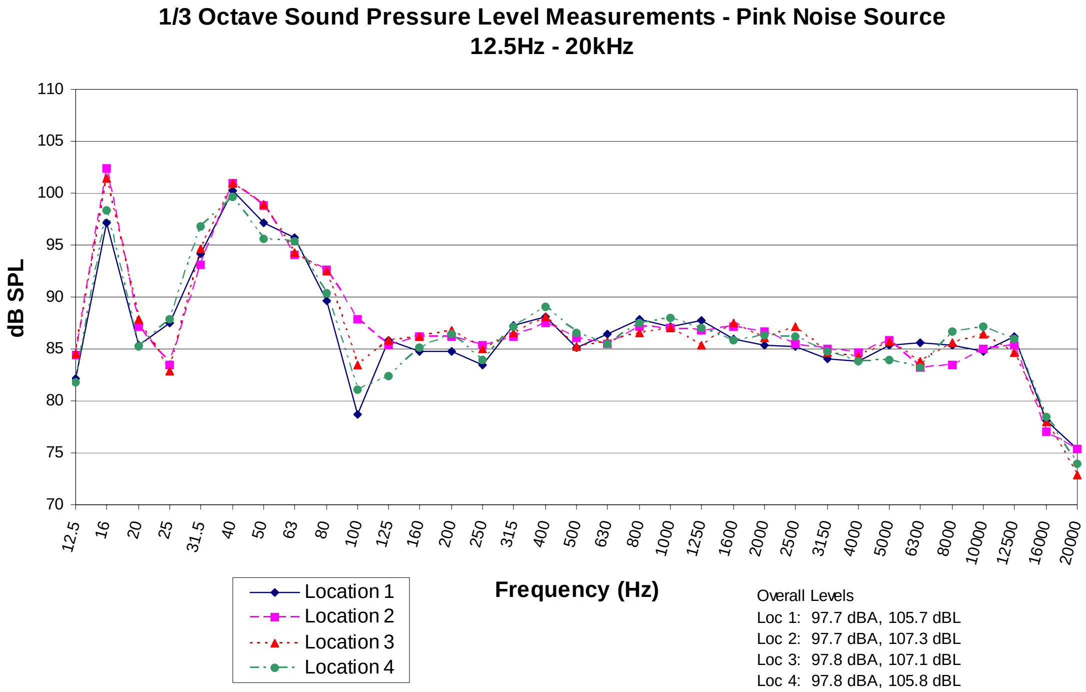


Figure 4. Pink noise spectra at the four locations -- Room empty.

To investigate the impact of objects in the room on the noise spectra, the measurements were repeated with the room empty. The results are shown in Figure 4. The spectra at all four of the locations were similar to those with the room "full"(Figure 3). Above 250 Hz, the spectra of the four locations were similar while below 250 Hz, some large differences were seen. The only major difference between the two cases, "empty" vs. "full", was an overall increase in both the linear and A-weighted SPL (about 1 dB).

A comparison between "full" and "empty" spectra at Location 2 is shown in Figure 5. The SPL at low frequencies were unaffected by the objects in the room, but the levels between 63 Hz and 2 kHz were slightly higher in the empty room. Above 2 kHz, the measurements were similar. The increase in level is expected, given that there were fewer objects in the room to absorb energy from the sound waves. It is likely that at low frequencies, the room furnishings absorb very little energy and thus there is practically no difference in SPL between the room empty and full states. A similar trend was found at the other 3 locations; the results are shown in the Appendix (Figures A2 to A4).

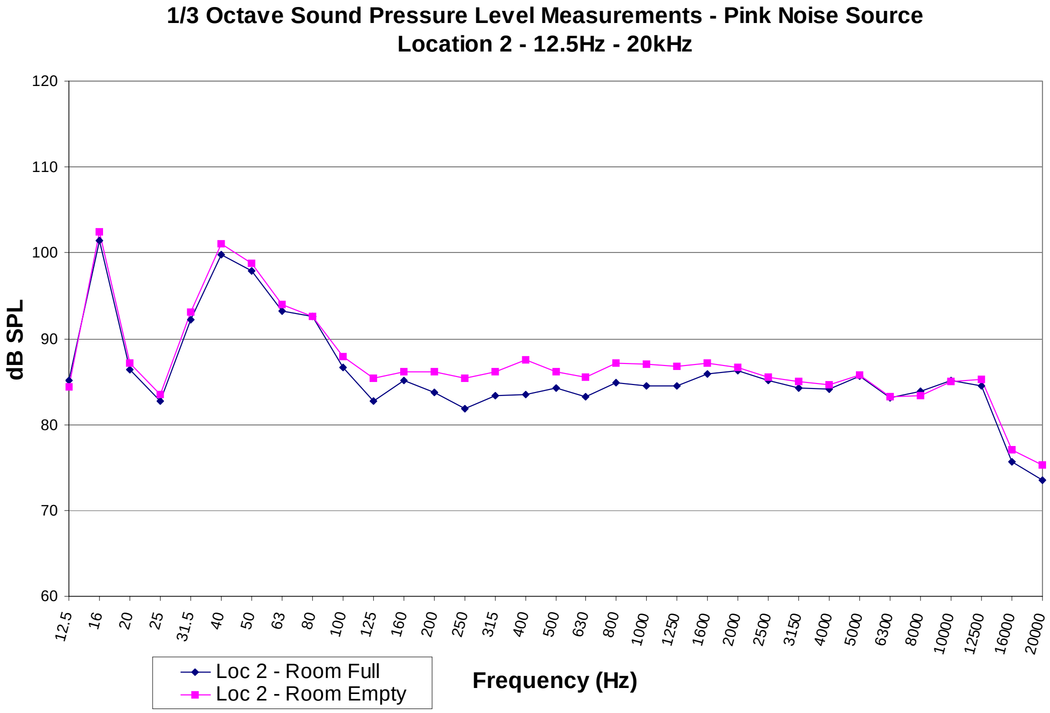


Figure 5. Pink noise spectra at Location 2 -- Room empty vs. full.

By exciting the Noise Lab with pink noise and measuring the spectra from 12.5 Hz to 20 kHz at different locations in the room, some general properties of the room acoustics were discovered. Of greatest importance is the acoustical equivalence of the four measurement locations. For frequencies above 250 Hz, it was found that, although there were slight differences between the measured SPL at the four locations, they were typically less than 2 dB. In this regard, the locations can be thought of as acoustically equivalent. The same cannot be said for frequencies below 250 Hz, as standing waves and room effects caused large differences in the SPL at each of the four locations. It is important to keep in mind that these results only examine the impact of random noise; in the next section, it will be seen that the room responds dramatically differently to tonal noise sources. It also should be noted that the analysis of the frequency response shown in Table 1 indicated little difference across the four locations. Location 2 has been most commonly used for previous studies in the Noise Lab, and it was also shown to be the best of the four locations in terms of minimal deviation from a flat frequency response across the 12.5 Hz to 20 kHz bandwidth. For this reason, several of the more time consuming tests that will be discussed later in this document were only conducted at Location 2.

Narrow band noise testing: Pure tone noise source

To investigate the effect of standing waves on the frequency response at the four locations, a series of measurements were taken using tonal noise as the source. This was done using the B&K Noise generator to produce pure tone signals corresponding to the centre frequencies of the standard 1/3 octave bands (tonal noise). Figure 6 shows the 1/3 octave band measurements of tonal noise taken at each of the four locations.

Compared to the results of the pink noise tests, pure tones produced large spectral and spatial variations in SPL, even at high frequencies. The measurements were also repeated with the room empty, but as before, there were no significant differences from the room "full" results (these results can be found in the Appendix). The results shown in Figure 6 indicate that the four positions cannot be considered as "acoustically equivalent" in terms of modal response.

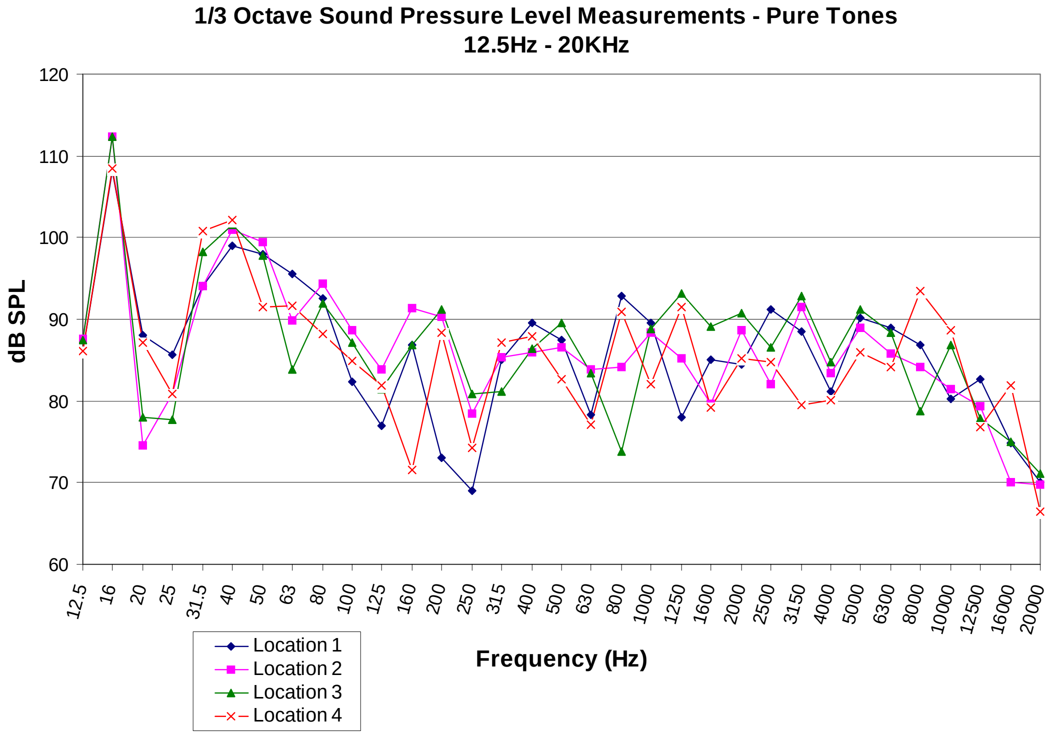


Figure 6. Pure tone noise spectra at the four locations – Room full.

Directivity plots

The directivity of a sound source is the extent to which the radiated sound is focussed in a particular direction. A sound source is said to be omnidirectional if it radiates energy equally in all directions. In order to create a uniform sound field in any room, the speaker or speaker array must be as omnidirectional as possible. The directivity of a sound source is frequency dependent. In general, a source radiates energy more omnidirectionally when the wavelength of sound is large compared to the dimensions of the source. That is, it is easy to achieve omnidirectional radiation for low frequencies, but difficult for high frequencies. The true directivity of the speaker array used in the Noise Lab cannot be measured without moving the array into a large anechoic chamber. However, it is of interest to present the pink noise measurements discussed earlier as pseudo-directivity plots to show the SPL at the four measurement locations by 1/3 octave band. A sample plot showing the "directivity" at 100 Hz is shown in Figure 7. The full range of 1/3 octave band directivity plots from 12.5 Hz to 20 kHz can be found in the Appendix. For orientation purposes, the speaker system should be considered to be at the centre of the plot and Locations 1 through 4 to be located approximately equidistant along the appropriately labelled lines. It is likely that most of the SPL differences on these plots are attributable to: 1) room effects and 2) interference patterns of the sounds waves that are emitted from each speaker in the array. While the plots do not represent the true directivity, they provide a good visualisation of the differences in SPL between the four locations.

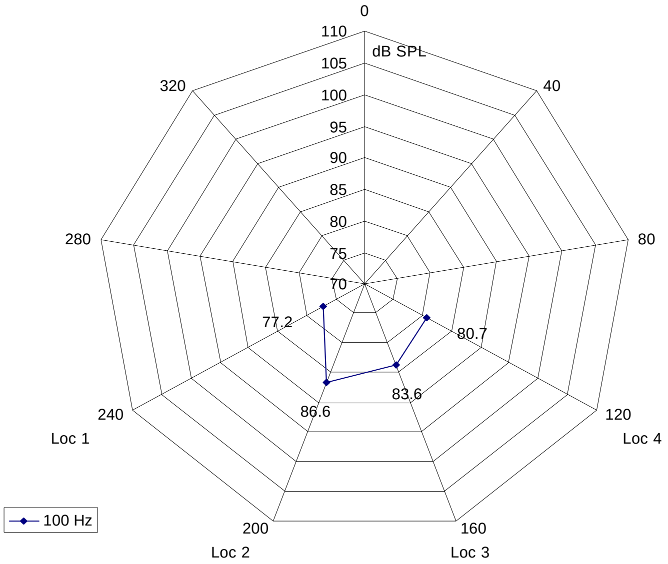


Figure 7. Directivity of the Noise Lab speaker array at the 100 Hz 1/3 octave band.

Room reverberation characteristics

The RT of a room can have a significant impact on auditory perception and is particularly important to speech intelligibility. However, there are many different ways of measuring, expressing, and reporting RT. The reverberation time T_{30} is the time "that would be required for the sound pressure level to decrease by 60 dB, at a rate of decay given by the least-squares regression of the measured decay curve from a level 5 dB below the initial level to 35 dB below" (ISO 3382 [1997]). Alternatively, the decay between 5 dB and 25 dB below the initial level can be used; RT calculated in this way is to be labelled T_{20}. The EDT is defined in a similar way as the RT of a room, except that it is obtained from the slope of the initial 10 dB of decay. A key difference between EDT and T_{20} is that the "EDT is subjectively more important and related to perceived reverberance, while T is related to the physical properties [of the room]" (ISO 3382 [1997]).

To conduct the measurements, the Ivie Electronics IE-17A System, a specialized integrating sound level meter, was used to record the decaying SPL found in the room after it had been excited with pink noise. This is called the interrupted noise method as described in ISO 3382 (1997). RT is a frequency-dependent value that will vary depending on the location in the room. All measurements were conducted at Location 2 and were repeated with both the room "empty" and "full". The IE-17A meter was used in combination with the B&K Noise Generator. The C1 amplifier configuration (see Figure 1) was used, and the digital equalizer (DEQ) was set to the Pink Noise program (see Dunn, 2004). The microphone was positioned 1.2 m above the ground at Location 2, and the ventilation system was turned off. With the pink noise turned on, the level was approximately 94 dB. The IE-17A meter was set up according to the instructions given in the manual except for the weighting factor, which was set to Flat, not A as indicated by the manual (note: measurements taken with the weighting factor set to A produced unreasonable values for RT). The meter reference level was set to 90 dB and a 5 second measurement time was used. Five measurements were made at successive octave bands with center frequencies from 31.5 Hz to 16 kHz. Reported values are the average of the 5 measurements at each octave band.

The IE-17A system measures each 5 dB of decay down to 30 dB below the original level. The RTs are then calculated from the 5, 10, 15 or 30 dB decay increments. For example, the RT given as "1-5" is calculated from the first 5 dB of decay, the RT given as "4-5" is calculated from the fourth 5 dB of decay, and the RT given as "2-15" is calculated from the second 15 dB of decay. The EDT can thus be estimated by averaging the IE-17A readings given as "2-5" and "3-5", and T_{20} can be estimated by averaging the values "2-5" through "5-5." The results are listed in Table 2. Measurements were taken only at Location 2 because, as discussed in the previous sections, it has proven to be the "best" location and is typically the only one used when conducting noise tests in the room. There will be differences in the measured T_{20} and EDT at other locations in the room; however, these were not investigated as a part of this study. The T_{20} and EDT are compared to the measurements performed by Dunn (Dunn, 2004) in Figure 8 and Figure 9. A good correlation was seen between the two sets of measurements.

Table 2. Reverberation time measurements.

Room Full

Category	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	16 kHz
1-5	3.00	1.75	1.09	1.28	1.35	1.37	0.87	0.75	0.66	0.60
2-5	2.87	0.96	0.54	0.90	1.02	0.98	0.87	0.63	0.59	0.55
3-5	1.67	0.88	1.00	1.25	1.06	1.18	0.87	0.64	0.52	0.53
4-5	1.57	1.03	0.81	0.82	1.31	0.96	0.97	0.65	0.60	0.50
5-5	3.87	0.87	1.36	1.06	0.96	1.19	1.05	0.65	0.57	0.48
6-5	2.06	0.94	0.81	0.53	1.17	1.10	0.91	0.62	0.57	0.49
1-10	2.93	1.35	0.82	1.09	1.19	1.18	0.87	0.69	0.62	0.58
2-10	1.62	0.96	0.90	1.03	1.19	1.07	0.92	0.64	0.56	0.51
3-10	2.96	0.91	1.09	0.79	1.06	1.14	0.98	0.64	0.57	0.48
1-15	2.51	1.20	0.88	1.14	1.14	1.18	0.87	0.67	0.59	0.56
2-15	2.50	0.95	0.99	0.80	1.14	1.08	0.98	0.64	0.58	0.49
1-20	2.28	1.15	0.86	1.06	1.19	1.12	0.90	0.67	0.59	0.55
1-30	2.51	1.07	0.94	0.97	1.14	1.13	0.93	0.66	0.59	0.52
T20	2.50	0.94	0.93	1.01	1.09	1.08	0.94	0.64	0.57	0.52
EDT	2.93	1.35	0.82	1.09	1.19	1.18	0.87	0.69	0.62	0.58

Table values are units of Time in seconds

Room Empty

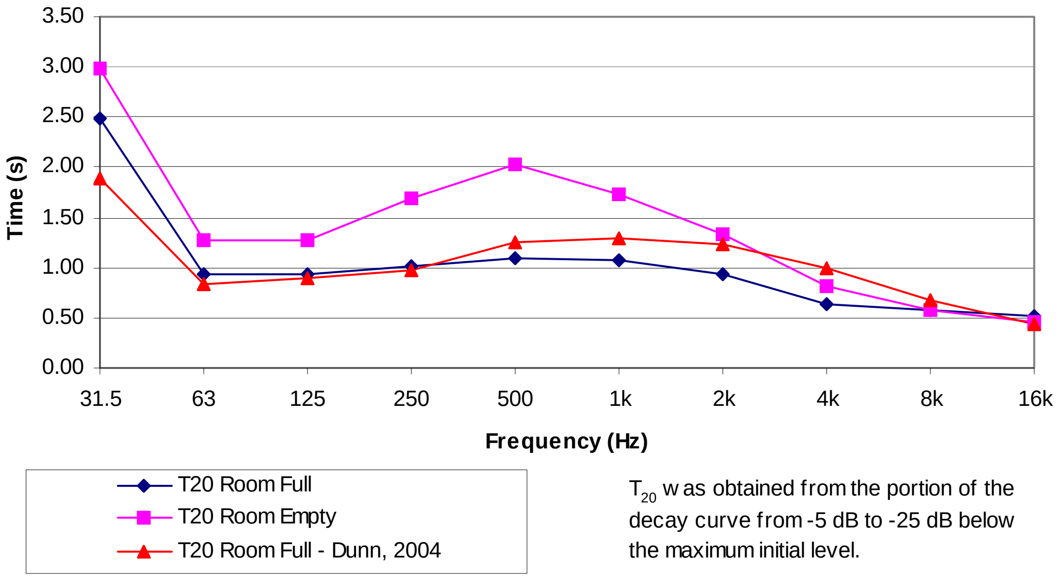
Category	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	16 kHz
1-5	3.81	1.87	1.40	1.95	1.78	1.54	1.15	0.78	0.59	0.61
2-5	3.93	1.04	1.26	1.46	2.46	1.54	1.20	0.79	0.59	0.46
3-5	2.00	1.03	1.14	2.08	1.75	1.50	1.33	0.82	0.55	0.46
4-5	3.99	1.71	1.68	2.00	2.05	1.86	1.39	0.82	0.57	0.46
5-5	2.00	1.31	1.00	1.19	1.82	2.05	1.41	0.84	0.56	0.41
6-5	4.12	1.22	2.04	1.55	1.69	1.56	1.35	0.69	0.53	0.59
1-10	3.87	1.46	1.33	1.71	2.12	1.54	1.18	0.78	0.59	0.54
2-10	3.00	1.37	1.41	2.04	1.90	1.68	1.36	0.82	0.56	0.46
3-10	3.06	1.27	1.52	1.37	1.76	1.80	1.38	0.76	0.54	0.50
1-15	3.24	1.31	1.27	1.83	2.00	1.53	1.23	0.80	0.58	0.51
2-15	3.39	1.41	1.57	1.58	1.85	1.82	1.39	0.78	0.55	0.49
1-20	3.43	1.41	1.37	1.87	2.01	1.61	1.27	0.80	0.57	0.50
1-30	3.31	1.36	1.42	1.71	1.93	1.67	1.31	0.79	0.56	0.50
T20	2.98	1.27	1.27	1.68	2.02	1.74	1.33	0.82	0.57	0.45
EDT	3.87	1.46	1.33	1.71	2.12	1.54	1.18	0.78	0.59	0.54

Table values are units of Time in seconds

T20 was obtained from the portion of the decay curve from -5 dB to -25 dB below the maximum initial level.

EDT was obtained from the initial 10 dB of decay from the decay curve.

Category 1-5 corresponds to the first 5 dB portion of the decay curve, 2-5: the second 5 dB portion of the decay curve, etc



T_{20} was obtained from the portion of the decay curve from -5 dB to -25 dB below the maximum initial level.

Figure 8. Reverberation time measurements (T_{20}).

Both figures clearly illustrate that with the room full, the measured values of T_{20} and EDT are more consistent over the different octave bands. It can also be seen that in all cases, the room "full" situation produced shorter reverberation times than those measured when the room was empty. With more objects in the room, there is more surface area by which the energy of the sound waves can be absorbed. More absorption means a faster reduction in SPL and a shorter reverberation time. The range of optimal RT for most speech and music applications would be between approximately 0.5 and 1.0 seconds at 500 Hz for a room with the same volume as the Noise Lab (Irwin and Graf, 1979). Even with the room empty, the T_{20} and EDT are less than 2.1 seconds, indicating that the Noise Lab cannot be considered to be reverberant. This is especially true since the Noise Lab is normally used in the "full" state in which the RT are even shorter.

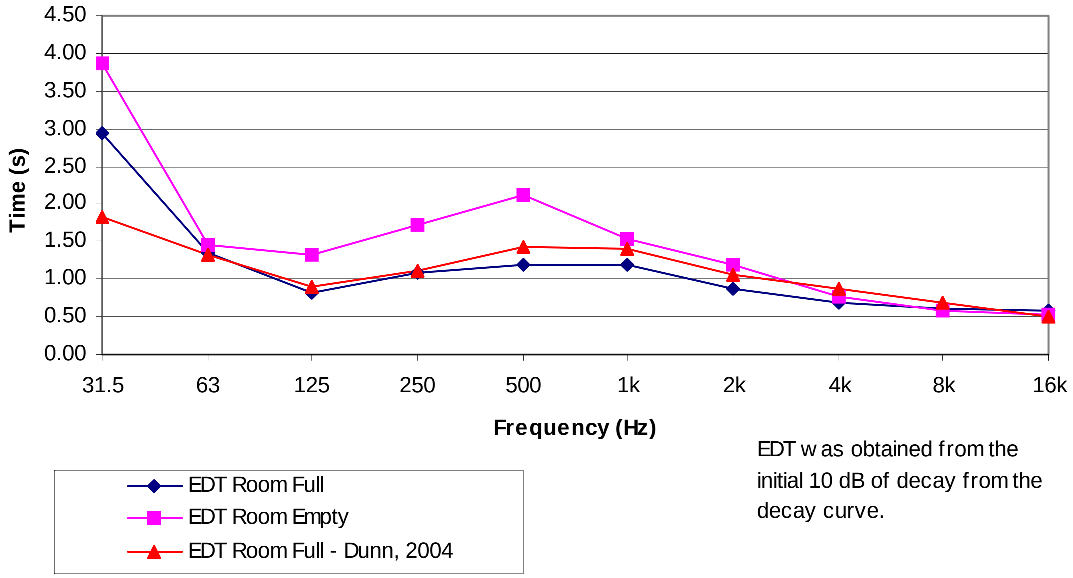


Figure 9. Reverberation time measurements (EDT).

Miscellaneous tests and results

Some miscellaneous tests and measurements were undertaken to provide data that could be used to correct for the acoustical response of the noise room. Examples of these modifications include adjusting the equalization of the signal that is fed to the speaker array or finding an ideal measurement location at which the room effects on the noise spectrum are minimal.

The input signal is modified in two steps: 1) filtering of the signal by the graphic equalizer (GEQ) and the digital equalizer (DEQ), and 2) division of the signal for transmission to the separate amplifiers and speakers. The GEQ is a 31-band equalizer that was set up originally to modify the signal so that a flat response would be heard at Location 2. The settings are given in the report by Dunn (Dunn, 2004). Further modifications to the signal are obtained by changing the settings of the DEQ. The DEQ has been pre-programmed for a number of recordings of operational environments contained in the Noise Lab's Noise Library, and is chiefly used to match the spectrum that is heard in the Noise Lab to the original spectrum recorded at the source. The effectiveness and inherent difficulties with regard to the reproduction of noise measured in the field will be discussed in the next section.

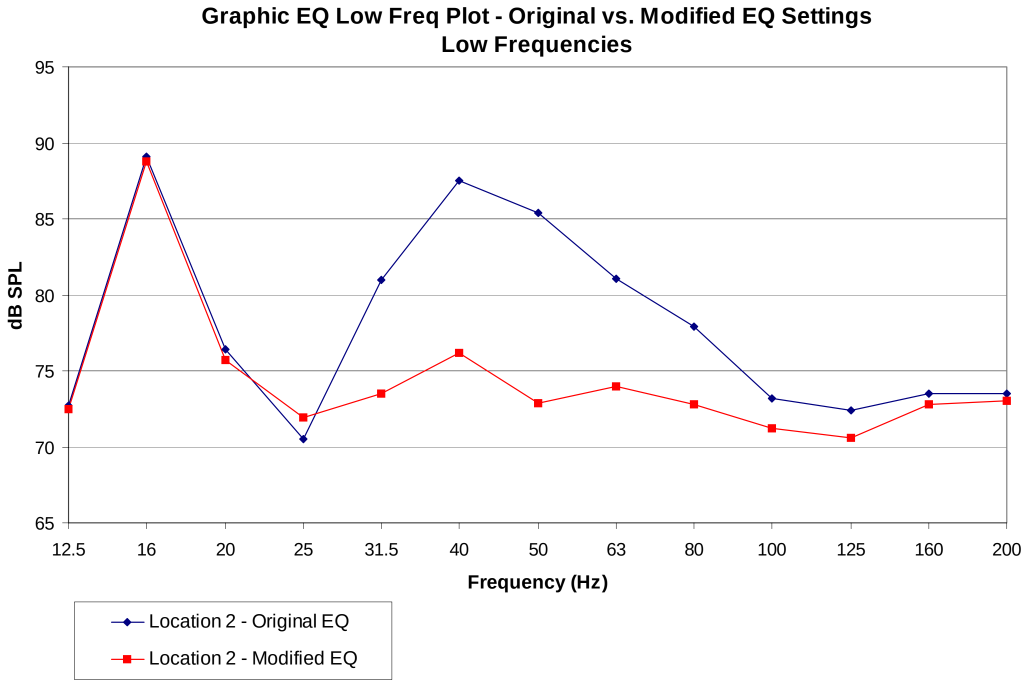


Figure 10. Pink noise spectra at Location 2 with the original and modified GEQ settings.

As mentioned previously, the major issue of the Noise Lab is an excess of energy present in both the 16 Hz 1/3 octave band and the 31.5 to 63 Hz bands. It would be desirable to eliminate this excess energy and produce a flatter room response. In a first attempt to flatten the response, the settings of the GEQ were adjusted and pink noise measurements were made at Location 2. The impact these modified settings have on the response curve can be seen in Figure 10.

By adjusting the settings on the GEQ, a flatter response was obtained for the 31.5 to 63 Hz bands; however, the response at 16 Hz was unchanged (the original and modified settings are given in the Appendix [Table A1]). A negligible effect at 16 Hz was expected since the lower limit of the GEQ is 20 Hz. The ELF cutoff was set at 22 Hz for these tests. The main purpose of the ELF is to enhance the low and sub-low frequencies, while limiting the lowest frequencies that are sent to the speaker elements. Thus, even the small amount of energy that was transmitted into the Noise Lab at 16 Hz was still enough to create a peak in SPL in this 1/3 octave band.

Without the possibility of flattening the16 Hz bump by equalization methods, a different approach is required. Several alternatives such as bass traps and acoustical screens were considered to improve this low frequency problem by absorbing the excess energy, but in the end proved impractical (sample calculations for a bass trap that would need to be 6 m long are included in the Appendix [Figure A41]). A more practical way to reduce the impact of the 16 Hz standing wave is to locate a position in the room that falls in its node (minimal sound pressure). Measurements were taken along the length of the room in line with Location 2 to identify this region of reduced sound pressure. Figure 11 shows the results of these measurements in octave bands from 16 to 125 Hz (a version of the same graph in 1/3 octave bands can be found in the Appendix). Location 2 is located at the zero position, with the positive abscissa values being between Location 2 and the speaker array, and the negative values being between Location 2 and the back wall of the room.

The node of the 16 Hz standing wave was clearly identified about 1 m in front of Location 2, closer to the speaker array. At this position, the sound pressure was dramatically reduced and the impact of the standing wave was minimized. When combined with adjustments to the GEQ settings, the frequency response at this position should be reasonably flat. A sample measurement at this new location with the GEQ settings adjusted was made; these adjustments can be found in the Appendix. This was done to illustrate the impact that both these changes could have on creating an “ideal” measurement position (i.e. with a flat frequency response). Pink noise was played into the room with the DEQ bypassed and the C1 amplifier configuration was used (see Figure 1). The results are shown in Figure 12.

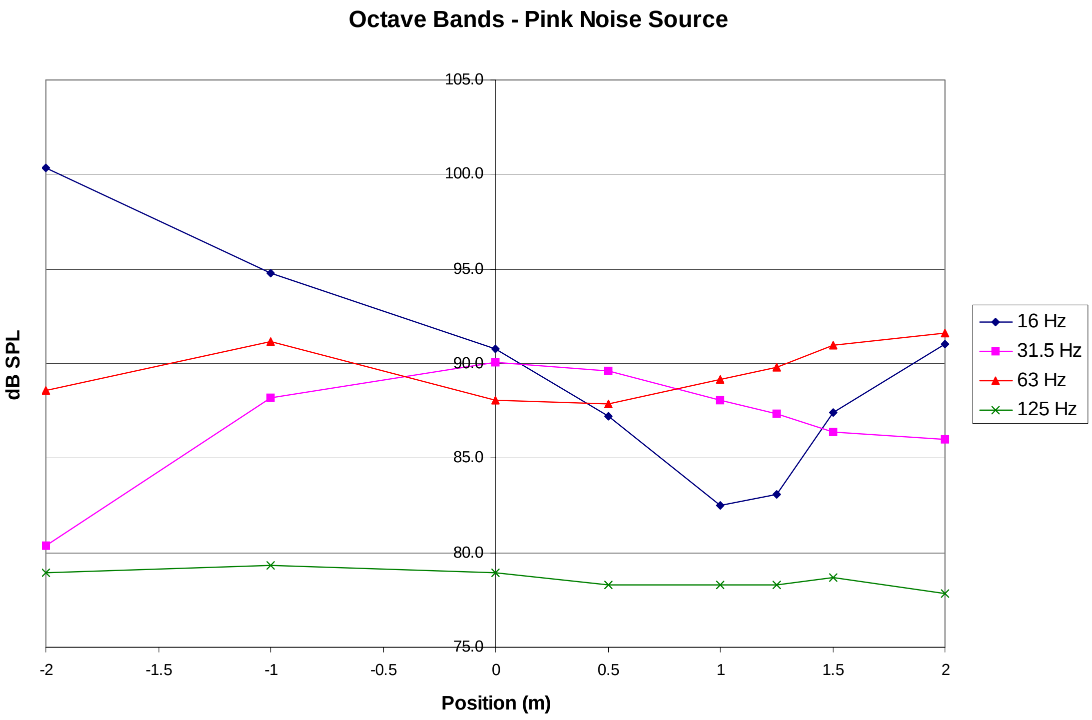


Figure 11. Sound pressure levels along the length of the Noise Lab in octave bands.

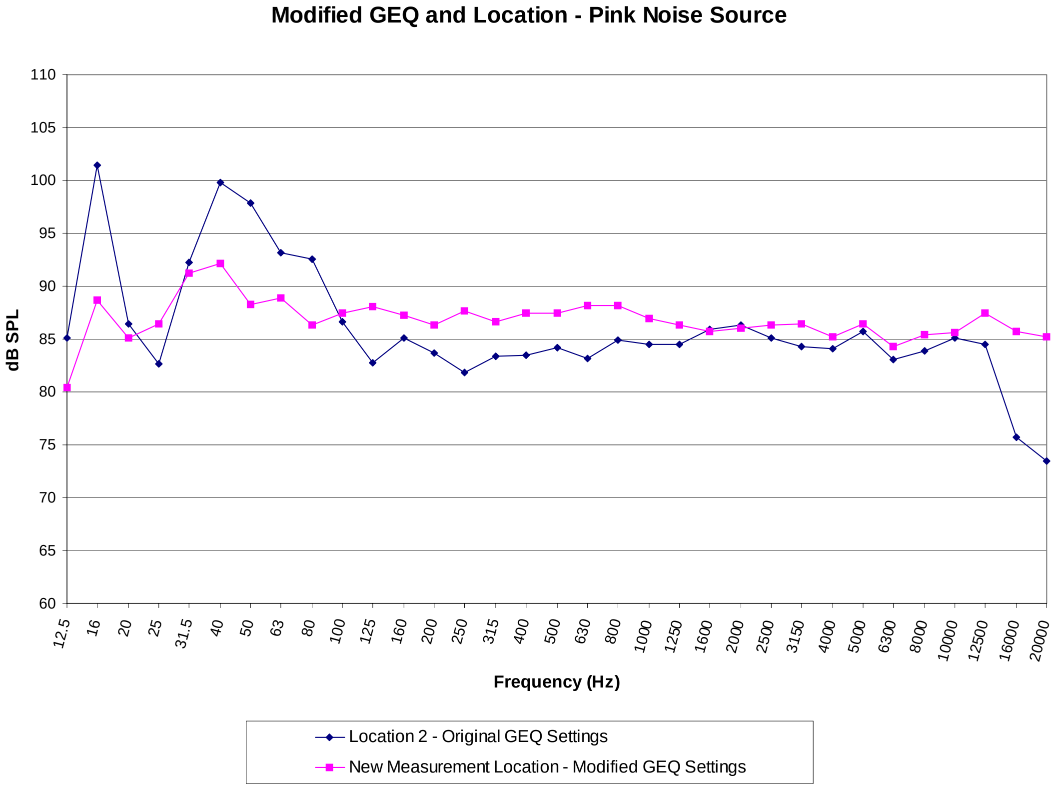


Figure 12. Comparison of spectra at Location 2 and new location with modified settings.

By moving the measurement location 1 m in front of Location 2 and modifying the GEQ settings, a significant reduction in both the 16 Hz and 31.5 to 63 Hz boosts was realized. The low frequency response has been greatly improved, and the average SPL from 12.5 Hz to 20 kHz is 86.8 ± 2.0 dB (compared to 86.0 ± 5.8 dB at Location 2 with the original GEQ settings).

One final method that was employed to reduce the amount of low frequency energy being produced in the room was to simply turn off some of the amplifiers responsible for the low and sub-low frequencies. Measurements were conducted with the three different amplifier combinations to illustrate this effect. Figure 12 shows the pink noise measurements at Location 2 with: 1) all amplifiers on, 2) C1 amplifier configuration, and 3) C2 configuration (see Figure 1).

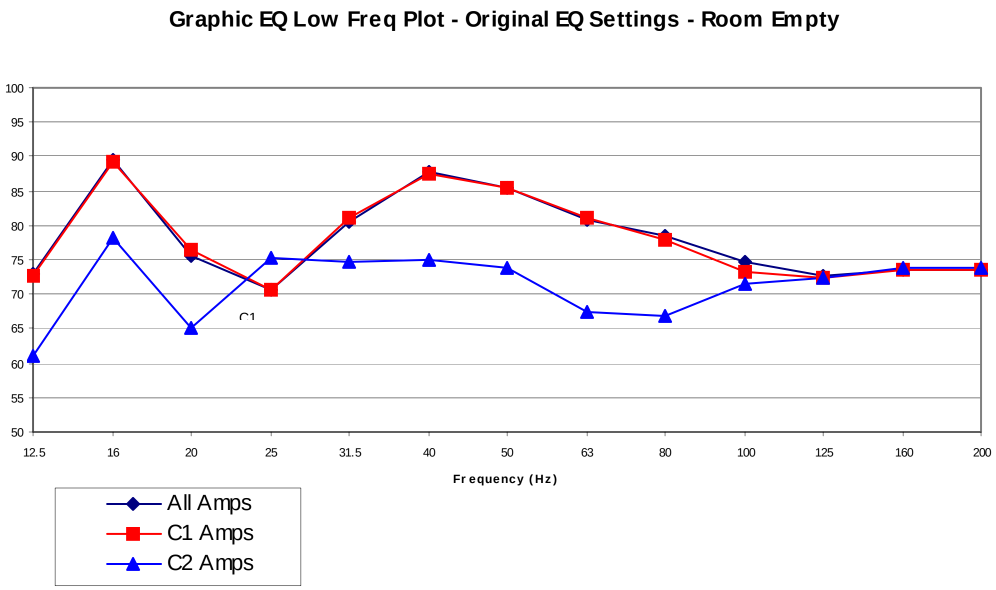


Figure 13. Pink noise measurements at Location 2 for different amplifier combinations.

The fewest number of amplifiers are on when the C2 configuration is used, and a corresponding drop in SPL across the low frequencies can be seen in Figure 13. Not only did the overall level drop when C2 was used, but it also had the effect of somewhat flattening the response between 31.5 and 63 Hz. These measurements also illustrated that there was no significant difference between using the C1 amplifier configuration and having all the amplifiers turned on. In both cases, the characteristic 16 Hz and 31.5 to 63 Hz boosts were present and the spectra were practically identical.

The demands placed on the Noise Lab are quite unique. It is often used to reproduce audio signals with large amounts of low frequency content, as typically encountered in helicopters, aircrafts, and armoured vehicles. To produce very high SPL at these low frequencies requires a large amount of power. The number of amplifiers and drivers currently being used to reproduce the low and sub-low frequencies makes this clear. Attempting to flatten the response by adjusting the GEQ settings and relocating the measurement position to the node of the 16 Hz standing wave had the effect of minimizing the natural low frequency boosts that are caused by the acoustical properties of the room; however, this may not be desirable. At times, it may be necessary to take advantage of these boosts to produce the significant sound pressure required to properly simulate the acoustic environment of an aircraft or a tank.

Noise Library analysis

The main purpose of the Noise Lab is to be able to recreate the noise conditions that CF personnel encounter as a part of their duties, in a controlled setting. Over the years, the noise in many different vehicles and operational situations has been recorded onto Digital Audio Tape (DAT) for playback in the Noise Lab. Each noise recording has been analyzed and recorded in loops to create a continuous recording that plays for approximately two hours without pauses or significant changes in level. A sample procedure for creating these loop tapes can be found in Dunn (2004). In order to recreate the noise environment with as much fidelity as possible (i.e., minimize the acoustical effects of the Noise Lab), custom equalization settings have been programmed into the DEQ for each DAT recording. By selecting the appropriate program on the DEQ, the noise being produced in the room should be quite similar to the noise originally recorded in the field. A detailed explanation of the creation of these DEQ programs and measurements of the playback levels in the room are given in Dunn (2004). The report also provides some information about the source of the loop tapes and details how to set up the amplification system for each of the different noises. The original results of the noise measurements found in Dunn's (2004) report are shown with the new results presented in this report for comparison. All new measurements were conducted at Location 2 at a height of 1.2 m. The measurement location and the system set up were chosen to replicate the original measurement conditions.

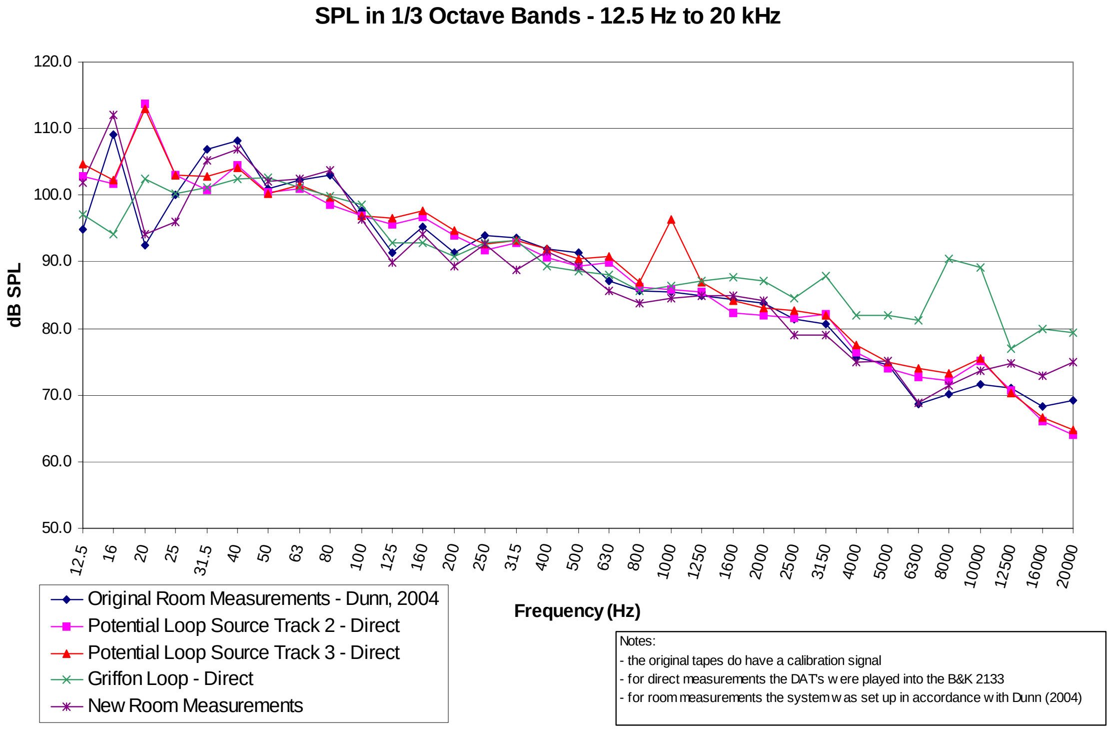
Measurements were taken to characterize the noise recordings as played in the Noise Lab, and to validate the spectra shown in Dunn (2004). The noises that were investigated fall into three main categories: 1) loop tapes created from documented source tapes with field recorded calibration signals or measured sound pressure levels, 2) loop tapes without documented source tapes or field recorded calibration signals, and 3) equalized pink noise generated from the B&K noise generator that is passed through the DEQ.

Documented loop tapes

Most of the loop tapes were produced from source tapes that were recorded in the field many years ago, with the original source tape often containing several different recordings of the vehicle or situation in various modes of operation. A segment of one of these sections was then used to create a loop tape for playback in the Noise Lab. Ideally, a calibration signal would be recorded on the source tape to establish the reference level for both editing and playback of the sound. If there is no calibration signal on the source tapes, it is not possible to establish the correct sensitivity setting for the frequency analyzer, and the actual SPL levels cannot be determined. In this case, the noise recordings can only be calibrated by comparison to SPL measurements taken with a sound level meter at the time of recording. In all cases, detailed field notes and documentation will make the analysis and reproduction of the various noise environments much easier and more accurate. Of all the loop tapes in the noise library, source tapes and detailed documentation were only found for two of the tapes. For the present study, the room measurements were conducted with a microphone placed at Location 2 and the amplification system set up in accordance with instructions provided by Dunn (2004). The results, measured with the B&K analyser, are discussed below. For each of the loop tapes, several different spectra are presented: 1) Original Room Measurements, taken from Dunn (2004), 2) Potential Loop Source – Direct, the original recording played directly into the analyzer, 3) Loop – Direct, the loop tape played directly into the analyzer, and 4) New Room Measurements, the loop tape played and measured inside the Noise Room.

Griffon loop

The Griffon loop was recorded at the co-pilot position of a Griffon helicopter flying at 120 knots and an altitude of 1500 feet. The original source tapes and the accompanying field notes are well documented and identified two possible sections of the original recordings that could have been used in the creation of the Griffon loop. Calibration signals found on the source tapes were used to establish the sensitivity level of the frequency analyser for the direct DAT measurements. Room measurements were also conducted with the system set up as indicated in Dunn's (2004) report. The results can be seen in Figure 14.



Notes:
- the original tapes do have a calibration signal
- for direct measurements the DAT's were played into the B&K 2133
- for room measurements the system was set up in accordance with Dunn (2004)

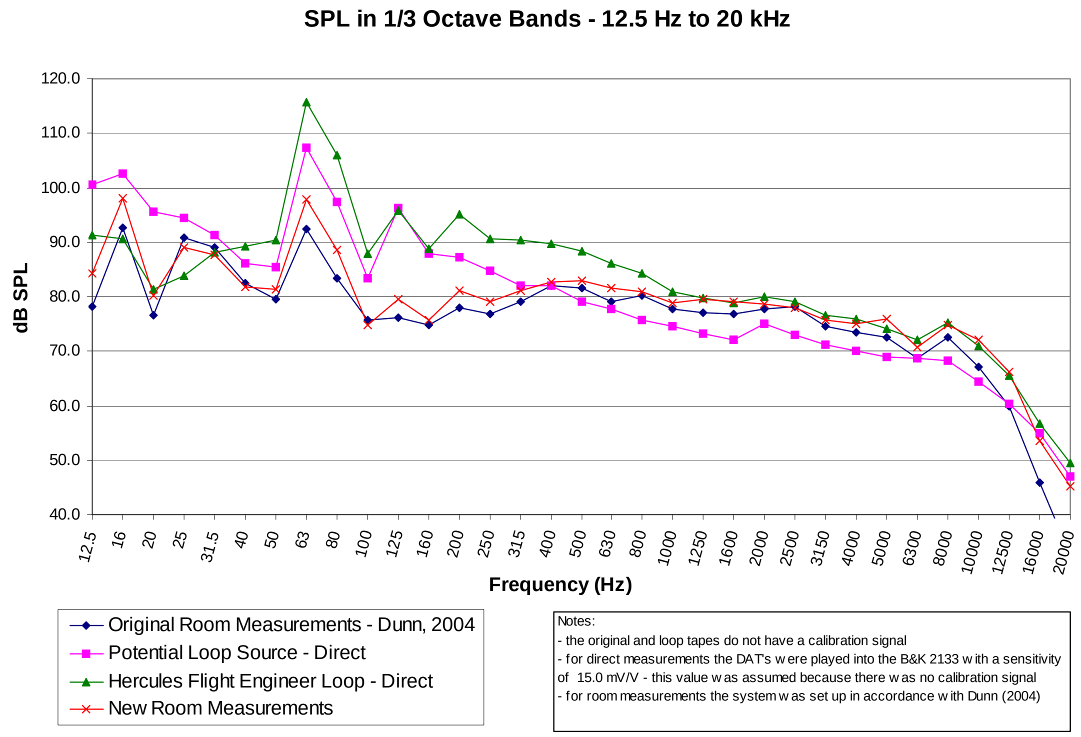
Figure 14. Griffin loop noise spectra.

From 50 Hz to 1000 Hz, a strong similarity was seen between all the results. Below 50 Hz, the response of the Noise Lab caused a peak in the 16 Hz band and a reduced level in the 20 Hz band. The difference in SPL was greater than 10 dB in the 16 Hz band. Above 1000 Hz, the direct measurement of the loop tape (tape played directly into the analyzer) showed an increase in level that is not found in the other measurements. Where this extra high frequency energy came from is not clear, but one possibility is that it is an artefact of the editing process used to create the loop. However, as shown in Figure 14, the increased levels did not change the spectrum of the noise as measured in the Noise Lab. Aside from the problems below 50 Hz, the noise environment of the Griffon helicopter can be accurately reproduced in the Noise Lab.

Hercules loops

Noise loops for two positions in the Hercules aircraft are available in the Noise Lab's Noise Library. The field notes indicated that the original recordings, from which the loop tapes were created, were made in the Flight Engineer and Load Master positions while the aircraft was flying at 240 knots at 8000 feet. However, calibration signals could not be recorded with the microphones that were used. Instead, the noise levels were logged with a sound level meter in 1/3 octave bands. The analysis of these source tapes, the loop tapes, and the room measurements are shown in Figure 15 and Figure 16.

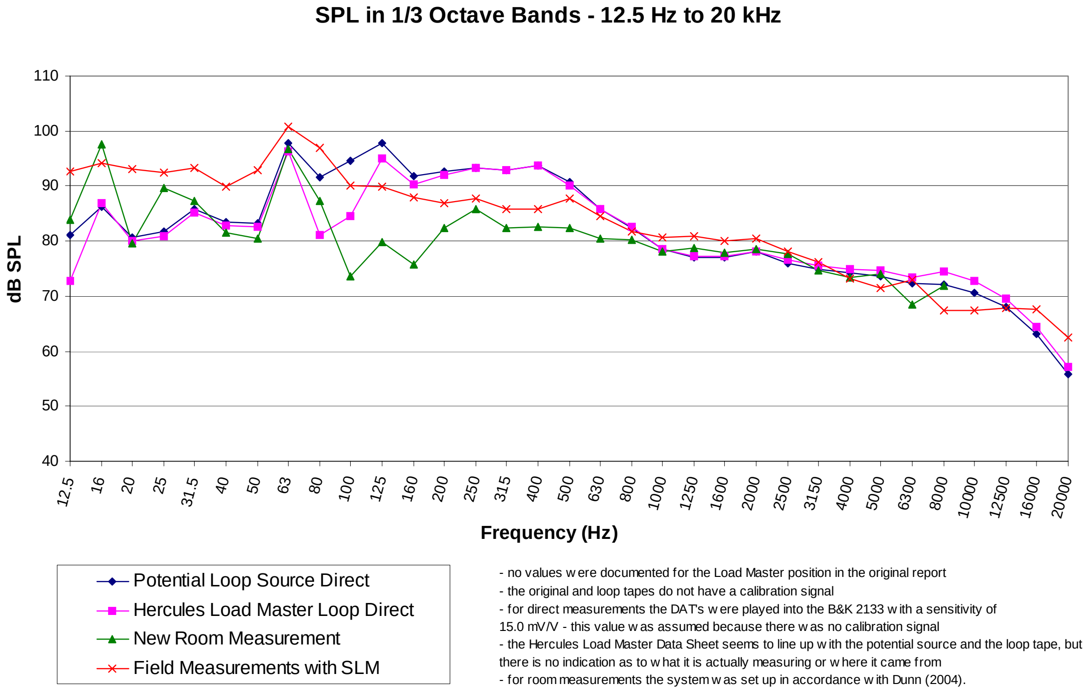
Compared to the original measurements of the Flight Engineer loop, the new measurements made in the Noise Lab were found to be quite similar. The characteristic 16 Hz peak was present, and above 100 Hz, the spectrum was relatively flat. Because neither the loop tape nor the possible source tape had a calibration signal, the actual overall levels could not be determined directly. The results of field measurements made with a sound level meter are available, but because the notes contain data from several different tests, it is unknown as to which result corresponds to the recording that was ultimately used to produce the loop tape. Without more detailed information about the ambient noise levels in the aircraft when the original recordings were conducted, it is difficult to comment on the accuracy of reproduction in the Noise Lab. Large differences in SPL were seen between the room measurements and the possible source tape at frequencies below 250 Hz.



Notes:
- the original and loop tapes do not have a calibration signal
- for direct measurements the DAT's were played into the B&K 2133 with a sensitivity of 15.0 mV/V - this value was assumed because there was no calibration signal
- for room measurements the system was set up in accordance with Dunn (2004)

Figure 15. Hercules noise spectra: Flight engineer position.

The good agreement between the direct measurements of the Load Master Loop (Figure 15) and the possible source tape indicate that the loop tape is of good quality. The impact that the room acoustics and the DEQ program had on the SPL measured in the room was significant for the frequencies below 1000 Hz. When compared to the sound level meter measurements conducted in the field, the room measurements were often 10 dB lower for these frequencies. If the original field measurements with the sound level meter are accurate, then the level of the low frequencies being produced in the room is much too low and the noise environment of the Load Master position is not being accurately reproduced. However, as stated above for the Flight Engineer position, it is difficult to comment on the accuracy of the noise reproduction in the Noise Lab with the available information regarding the field measurements.



- no values were documented for the Load Master position in the original report
- the original and loop tapes do not have a calibration signal
- for direct measurements the DAT's were played into the B&K 2133 with a sensitivity of 15.0 mV/V - this value was assumed because there was no calibration signal
- the Hercules Load Master Data Sheet seems to line up with the potential source and the loop tape, but there is no indication as to what it is actually measuring or where it came from
- for room measurements the system was set up in accordance with Dunn (2004).

Figure 16. Hercules noise spectra: Load master position.

Undocumented loop tapes

Without detailed field notes and calibration signals, the analysis and proper playback of the loop tapes is much more difficult. Determining the reference level of the signal becomes guesswork, and there can be no certainty that original levels measured in the field will be reproduced accurately in the Noise Lab. Without source tapes, the impact that the editing process had on the signal is impossible to establish and any noise that may have been introduced cannot be quantified. The lack of reference signals and source tapes also makes it difficult to “tune” the Noise Lab, placing a degree of uncertainty on the settings programmed into the DEQ. Because of these difficulties, the analysis of the remaining noise tapes discussed in this report was limited to playing the loop tapes directly into the frequency analyser and then playing them into the room and comparing the two spectra. The sensitivity of the frequency analyser was set to an assumed value for the direct analysis of the loop tapes from the DAT recorder, but as mentioned before, this will affect the overall SPL levels. By altering the sensitivity of the frequency analyser the levels can be increased or decreased by any amount desired. The room measurements were conducted with the amplification system set up in accordance with the instructions provided in Dunn’s report (Dunn, 2004), with a microphone placed at Location 2 and connected to the frequency analyser.

Operations room loop

The Operations (Ops) room loop is intended to reproduce the operations room of a Halifax Class frigate and was made from a recording of a simulated war game. The measurement results are presented in Figure 17. At some frequency bands, there were significant differences between the direct measurements and room measurements, but overall a fairly good match was seen for this loop. The major discrepancies occurred at the low frequencies, particularly at 20 Hz.

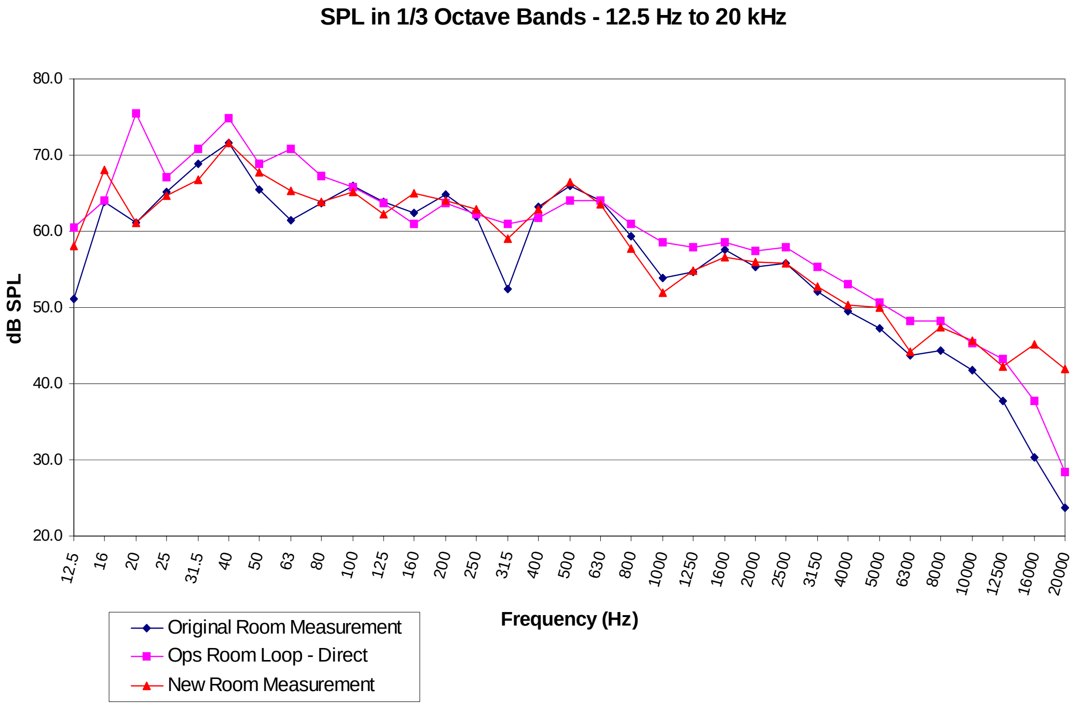


Figure 17. Ops room loop noise spectra.

Aurora loop

Originally recorded with a Nagra tape recorder in 1981, the Aurora loop represents the noise environment found at the NASO (non-acoustic sensor operator) position of the aircraft. The results are presented in Figure 18. A close match was seen between the original room measurements and the new room measurements. In both, however, the 16 Hz energy boost was quite obvious and had a large effect on the measured levels in this 1/3 octave band. At the higher frequencies, the direct measurement and the room measurements lined up fairly well. Overall, the Noise Lab seems to produce a fairly accurate reproduction of the Aurora noise environment captured in the original recording.

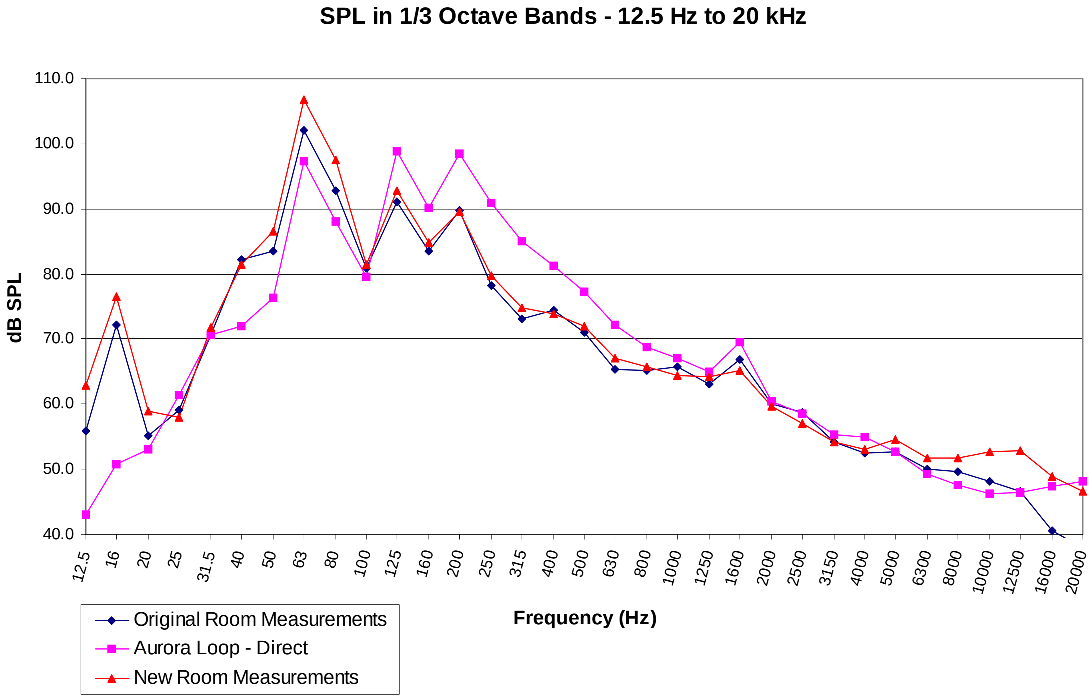


Figure 18. Aurora loop noise spectra.

Sea King loop

The Sea King loop was created from a recording of the SENSO (sensor operator) position while the helicopter was hovering. The measurement results are presented in Figure 19. The direct measurements and the room measurements of this loop tape lined up quite well at low frequencies. The Noise Lab was designed to reproduce the high level at 16 Hz caused by the blade-passing frequency of the Sea King helicopter. The differences between the original and new room measurements around 200 Hz indicate that the DEQ settings may have to be modified to reproduce the noise environment more accurately.

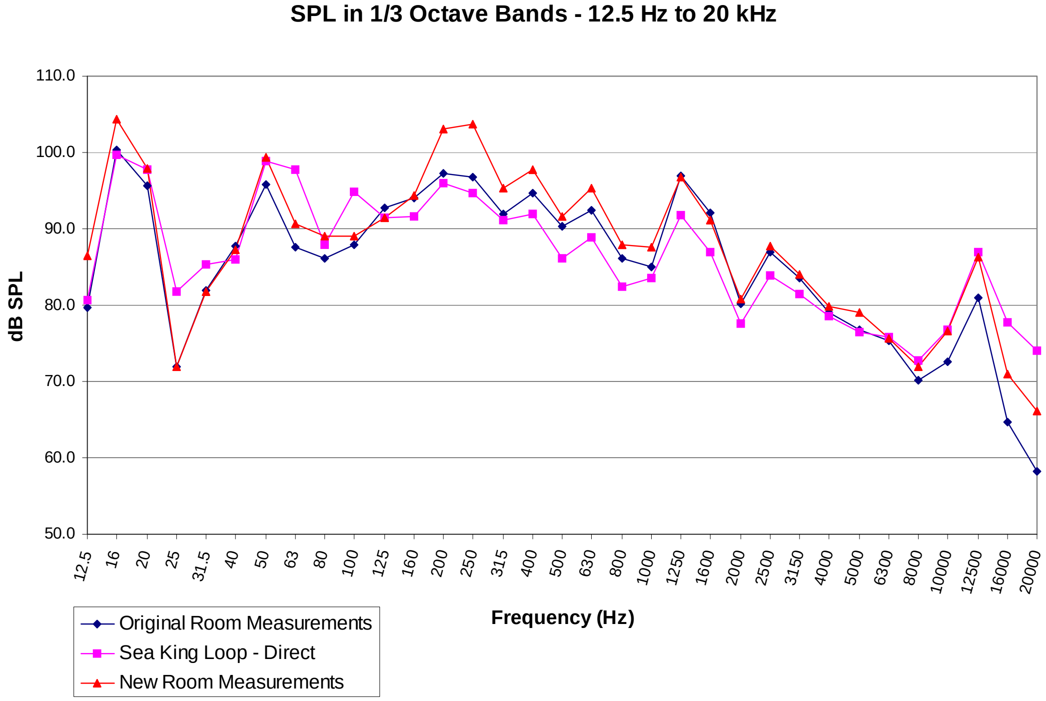


Figure 19. Sea King loop noise spectra.

Leopard tank loop

The Leopard tank loop is probably the poorest quality loop in the library. It is only about four seconds in length and the loop point is quite audible. Also, there were two tapes labelled as Leopard Loops. They seemed to contain the same audio program, except that one was recorded at a slightly higher level. The source tape for this loop did appear to exist and the label indicates that there was a calibration signal recorded, but unfortunately the tape was broken and could not be played back without causing further damage. In this investigation, the DAT labelled “Leopard Cruise Loop – 2 Hour Loop” was used and the results are presented in Figure 20. The direct measurements were similar to the room measurements only in the range of 31.5 to 100 Hz. This was likely due in part to the room acoustics and a problem encountered with the amplification and playback of the audio program. The effect of the room acoustics have already been discussed, but the second problem was only encountered with the Leopard tank loop. When the system is configured, according to the instructions provided in Dunn (2004), the left output of the DEQ clips quite harshly. Because of this, and to err on the side of safety, the attenuator was not turned up to full volume during the new room measurements. As a result, the levels measured were lower than they should be. The levels shown in Figure 20 have been scaled up by 6 dB for easier comparison with the previous measurements.

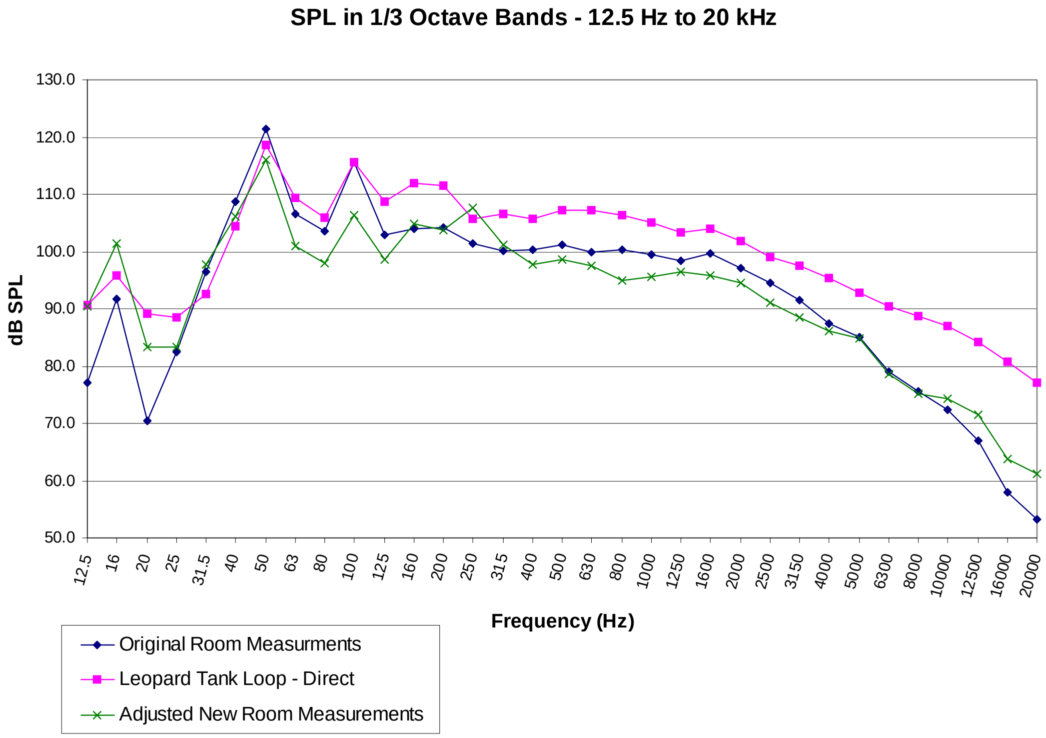


Figure 20. Leopard tank loop noise spectra.

Equalized pink noise programs

Four of the audio programs used in the Noise Lab are simply pink noise that has been filtered by the DEQ. As mentioned earlier, two major problems with the noise library are:
1) determining the sensitivity level for analysis with the frequency analyzer, and 2) determining the level at which the source should be played back into the room. For pink noise, the playback level is easy to establish as the B&K Noise Generator has an adjustable output level that should be set at the maximum position, 1.25 V. Unlike some of the loop tapes, however, it is not clear what level the sensitivity of the frequency analyser should be set when analysing the pink noise source directly. In the following figures, the direct pink noise signal is presented along with the measured levels in the room to illustrate the effects that the DEQ, the signal path, and the room have on the original signal. In all cases, the levels of the direct pink noise signal were adjusted to allow a better visual analysis of the data being presented.

Speech Noise

This noise was used to test active noise reduction headsets as a part of the round-robin testing performed in the Noise Lab. The measurement results are presented below in Figure 21. In most frequency bands, a close match was found between the original measurements and the new measurements taken in the Noise Lab. The figure illustrates that speech noise is characterized by a general reduction of both the high and low frequencies, with a peak in level at approximately 315 Hz.

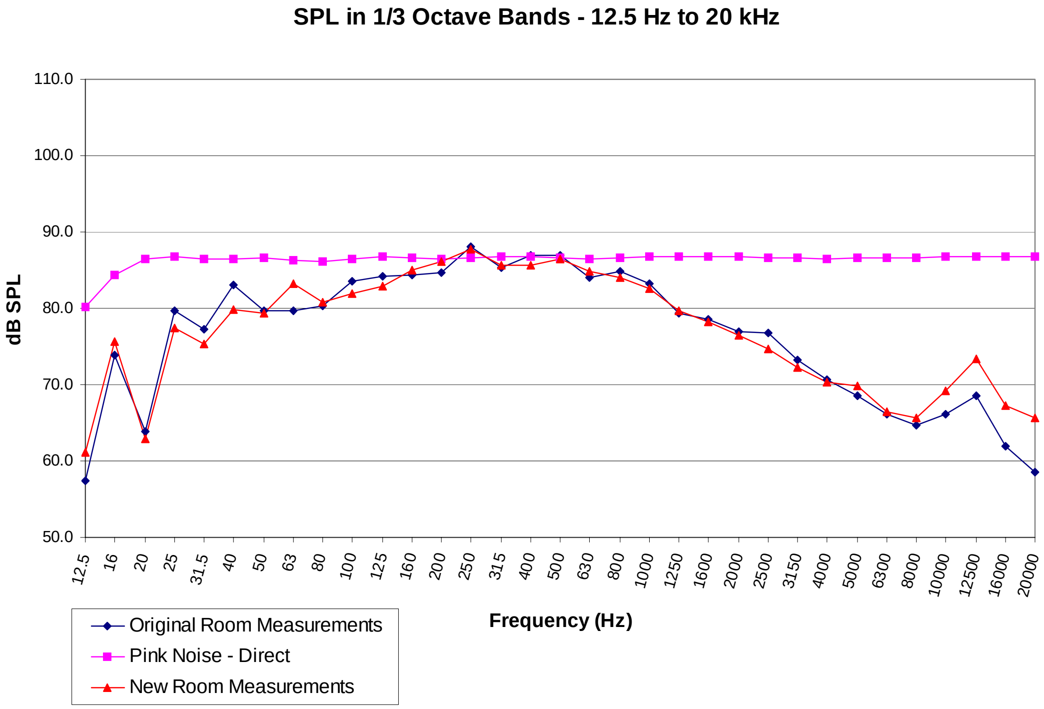


Figure 21. Speech noise spectra.

Pink noise

Pink noise should ideally produce the same SPL across all octave bands. In an attempt to minimize the impact that the room acoustics have on the SPL, the system configuration (detailed in Dunn (2004)) uses the DEQ to filter the signal to produce a flatter response. Two separate DEQ programs are used to produce the two different levels of pink noise, 80 dB and 86 dB. A comparison of the spectra can be seen in Figures 22 and 23.

Above 200 Hz, the measured SPL was quite consistent around the 80 dB level and indicates that for these frequencies this system configuration did provide a good approximation of pink noise. Below 200 Hz, there were large fluctuations in the SPL caused by the room geometry, as discussed before. Thus, although the DEQ was programmed to produce a flat frequency response, the equalization settings did not compensate for the low frequency response of the room.

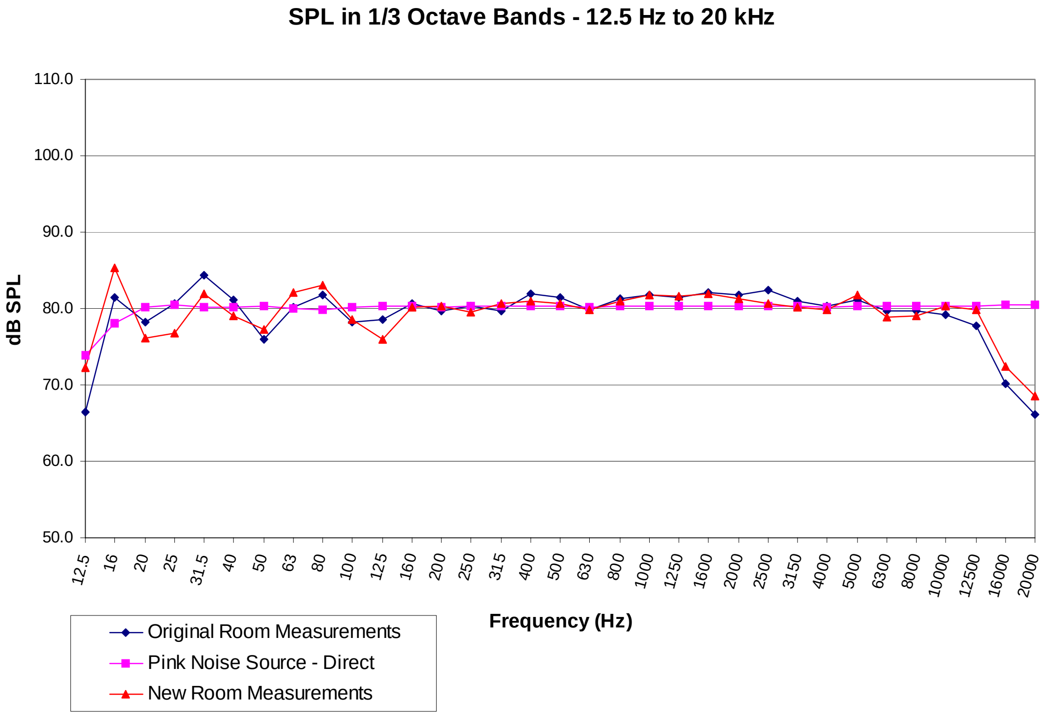


Figure 22. Pink noise, 80 dB.

The DEQ settings originally chosen for 86 dB pink noise were completely different than those used for 80 dB pink noise, which was surprising considering that they were meant to produce similar spectra. This was especially clear at the low frequencies where dramatic non-linearities occur that were not present in the 80 dB spectra. These non-linearities make it a poor approximation of pink noise at low frequencies. However, for the frequencies above 200 Hz, a fairly consistent level of 86 dB was measured and indicates that this program does provide a good approximation of pink noise (flat response) over the higher frequency bands.

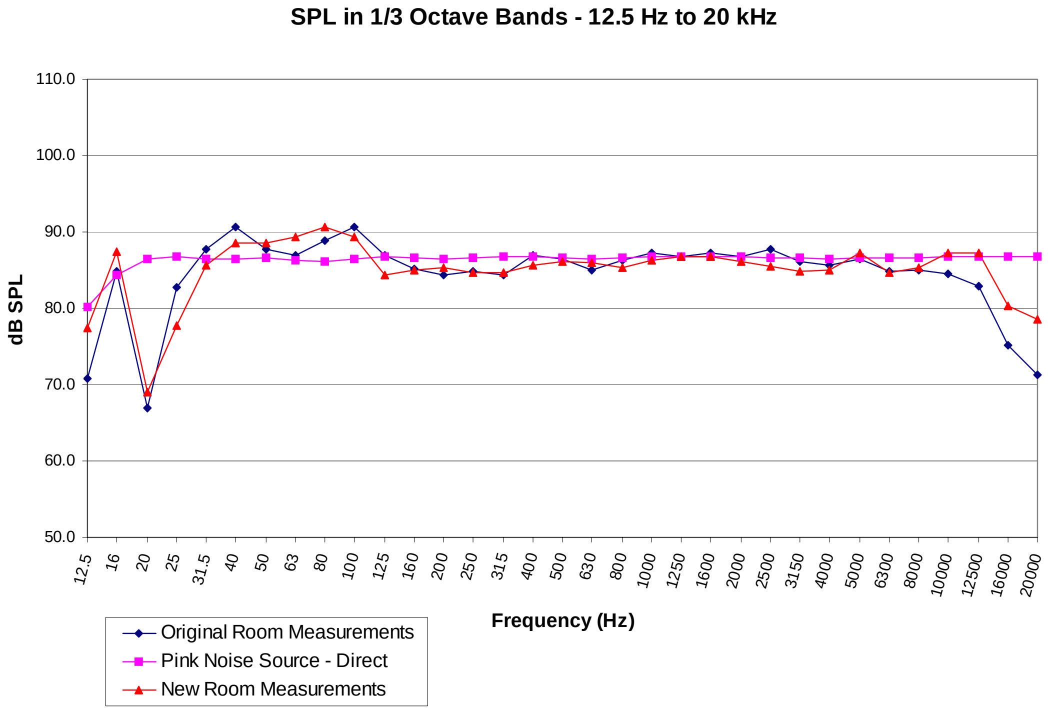


Figure 23. Pink noise spectra, 86 dB.

Mauve noise

Mauve noise was originally used to study the performance of active noise reduction (ANR) headsets in the Noise Lab. For frequencies up to 1 kHz, mauve noise is identical to pink noise, and from 1 kHz to 20 kHz it is identical to white noise. The resulting spectrum contains equal energy per octave band below 1 kHz, and equal energy per unit frequency above 1 kHz. The results of the room measurements are shown in Figure 24. For this noise, a question arose with respect to the system settings given in Dunn (2004). The settings indicate that the DEQ input level should be set to 3.5; however, as shown in Figure 24, the power output was too low when this setting was used. When the DEQ input was set to 6.5, the spectrum was similar to the original measurements found in Dunn (2004). The previously discussed room effects were seen again in these measurements, but despite this, the noise being produced can be considered a reasonably accurate simulation of mauve noise.

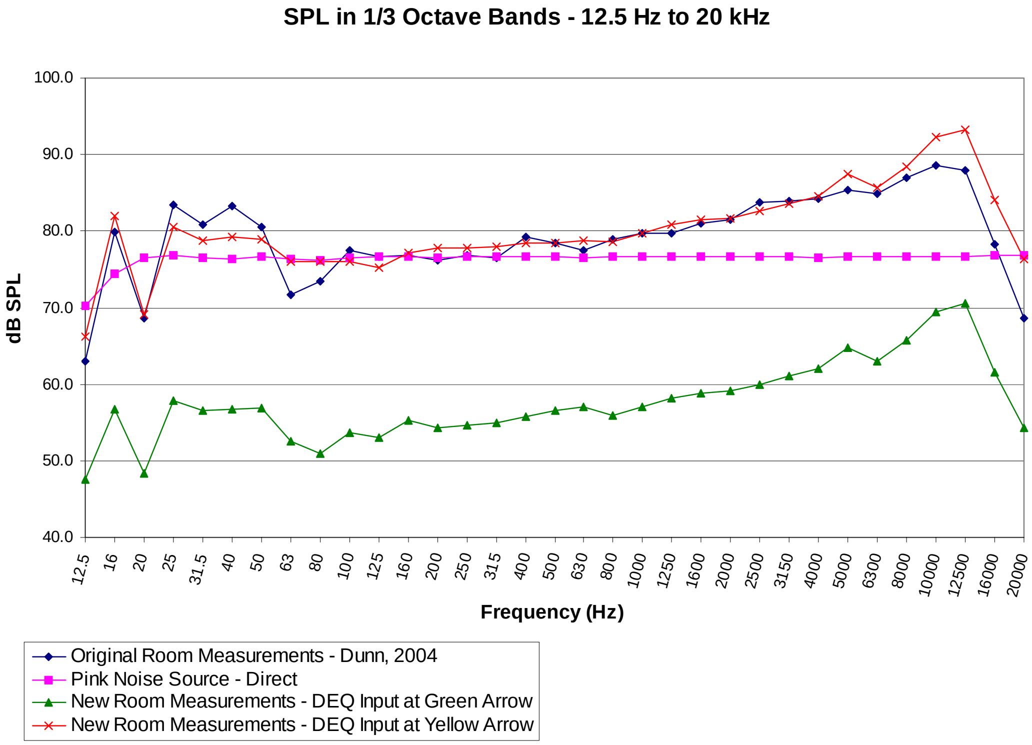


Figure 24. Mauve noise spectra.

Conclusions and recommendations

Noise Simulation Facility

The Noise Simulation Facility at DRDC Toronto is a complex and powerful system that has the flexibility to reproduce a wide number of noise environments in a controlled setting. However, the low frequency response of the Noise Lab (12 Hz to 200 Hz) is affected by its geometry, which creates standing waves at low frequencies. It was shown that for the high frequency bands, the measured SPL was fairly consistent, but at lower frequencies there were wide variations in measured SPL from location to location and large peaks in the 16 Hz and 31.5 to 63 Hz bands.

By adjusting the GEQ and relocating the measurement location (Location 2) to the node of the 16 Hz standing wave, a flatter frequency response was achieved and the effect that the room acoustics had on the low frequency energy was reduced. However, changing the measurement location would require that the room be re-tuned for each noise library recording and the DEQ would have to be re-programmed. As well, the natural low frequency boost caused by the standing waves could no longer be used so advantageously when trying to create extremely high SPL at low frequencies. Since Location 2 has been used in many previous studies, it is recommended that it continue to be used in order to maintain consistency. However, the new measurement location could be used if high levels of low frequency energy are undesirable.

Noise Library

The collection of recordings in the noise library can reproduce a wide variety of noise environments, ranging from the operations room of a frigate to the flight engineer position of an aircraft. Recordings were typically made on location with DAT recorders. The recordings were then analysed in the Noise Lab. From the source tapes, noise loops were created so the noise could be played continuously for 2 hours. Many of the source tapes did not contain a calibration signal, making it impossible to determine the noise levels at the time of recording. Although some data taken with a sound level meter were available, the absence of field notes made it difficult to match the data with the noise recordings. It is thus difficult to comment on how accurately the noise levels are being reproduced in the Noise Lab

Unfortunately, little can be done to improve the existing noise loops. For future recordings, several recommendations can be made that will improve both the accuracy of reproduction and ease of analysis of any new measurements/recordings that will be added to the noise library in the future. The most important step in the procedure is to ensure that whenever new field recordings are being conducted, a quality calibration signal is also recorded on the same tape. This will ensure that the recording level is captured and it will be possible to analyse the recording at a later time. The level and frequency of this calibration should be noted in the field notes and documented on the DAT itself. Field notes should be as detailed as possible, listing items such as time, the equipment used, and the field conditions encountered during the recording session. It is also recommended that the original calibration signal be included on any loop tapes that are created from the field recordings. Ideally, one minute of calibration signal would be found at the beginning of both the source and loop tapes, with the calibration level and frequency being labelled directly on the tape. It would be useful to have a copy of any accompanying field notes or documentation filed in the Noise Lab. One final recommendation is that all tapes, old and new, in the Noise Library should be backed up in case of breakage with continual use. These recommendations will greatly improve the accuracy of reproduction and ease of use of the Noise Lab.

References

1. ISO 3382 (1997). Acoustics – Measurement of the reverberation time of rooms with reference to other acoustical parameters. International Organization for Standardization, Geneva, Switzerland.

2. Dunn, G. (2004). Development and documentation of the Noise Simulation Facility at DRDC Toronto. DRDC Toronto Contractor Report CR2004-074.

3. Irwin, J.D. and Graf, E.R. (1979). Industrial noise and vibration control. Prentice-Hall Inc., Englewood Cliffs, N.J., pp. 179-180.

Appendix

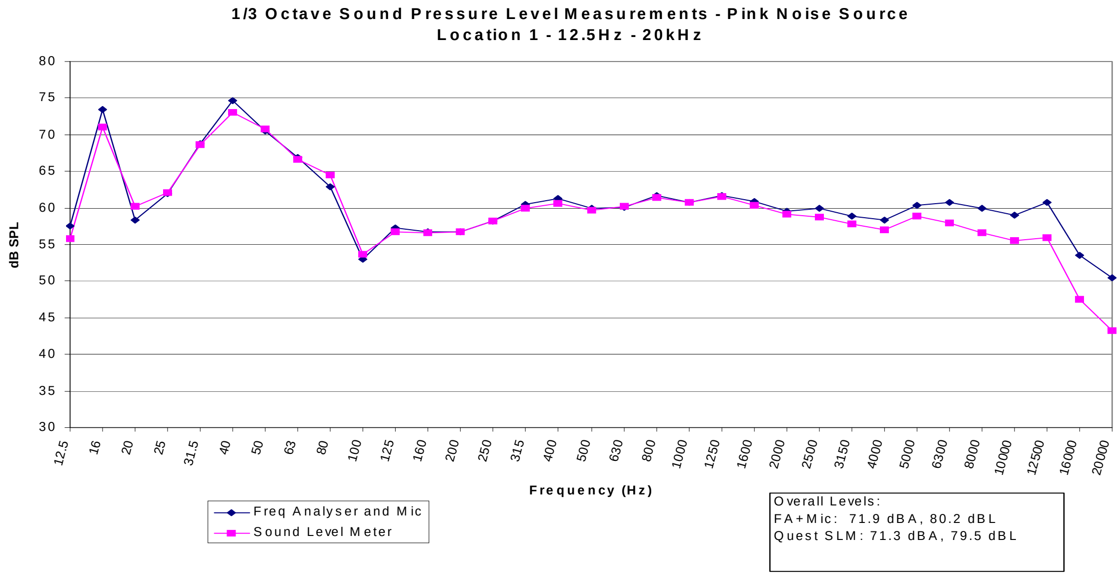


Figure A1. Comparison between sound level meter and frequency analyser results

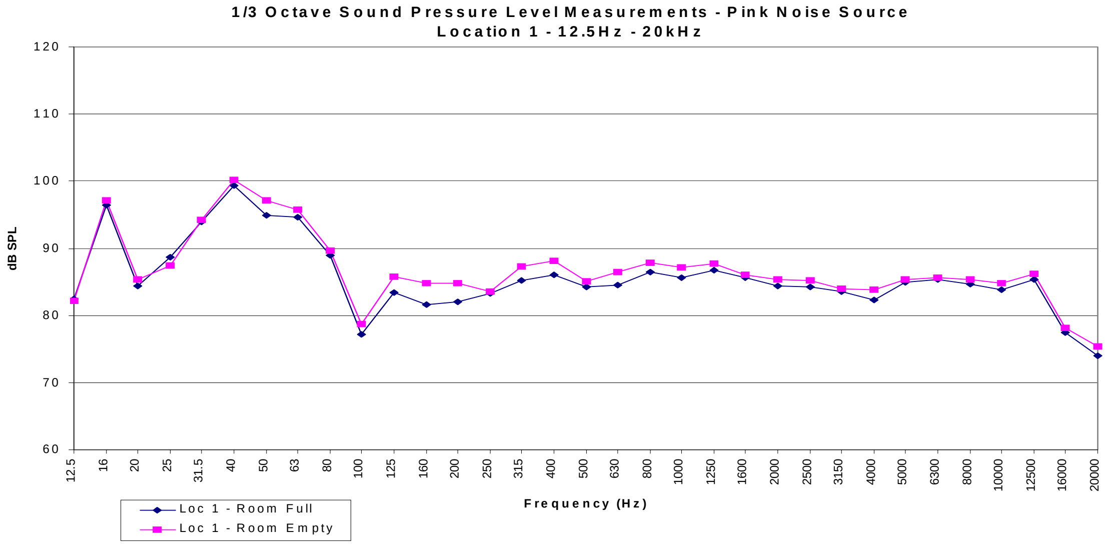


Figure A2. Pink noise spectra at Location 1 -- Room empty vs. full.

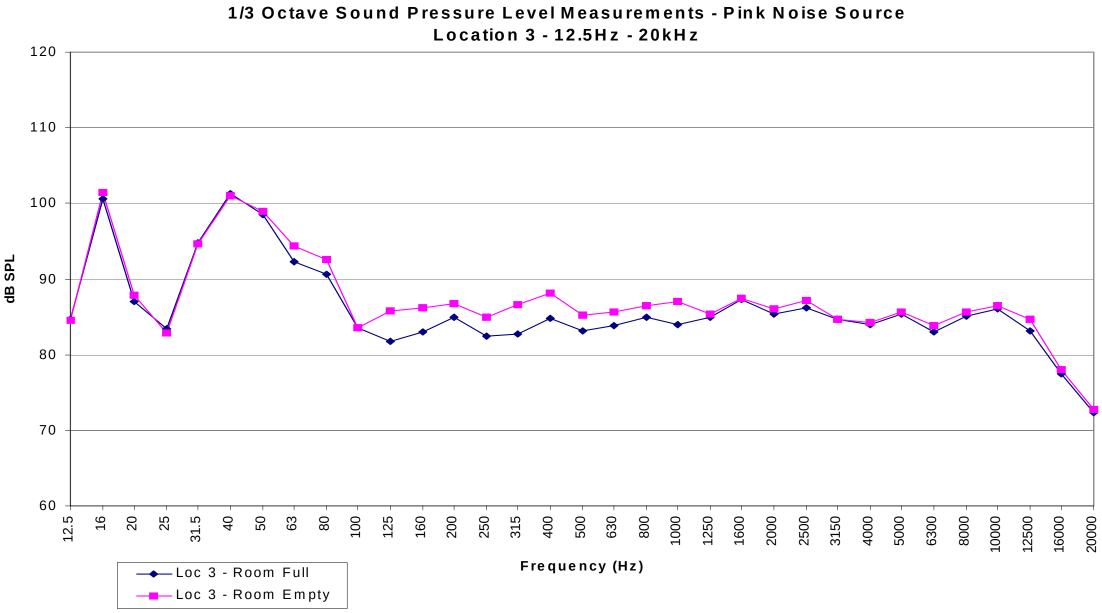


Figure A3. Pink noise spectra at Location 3 -- Room empty vs. full.

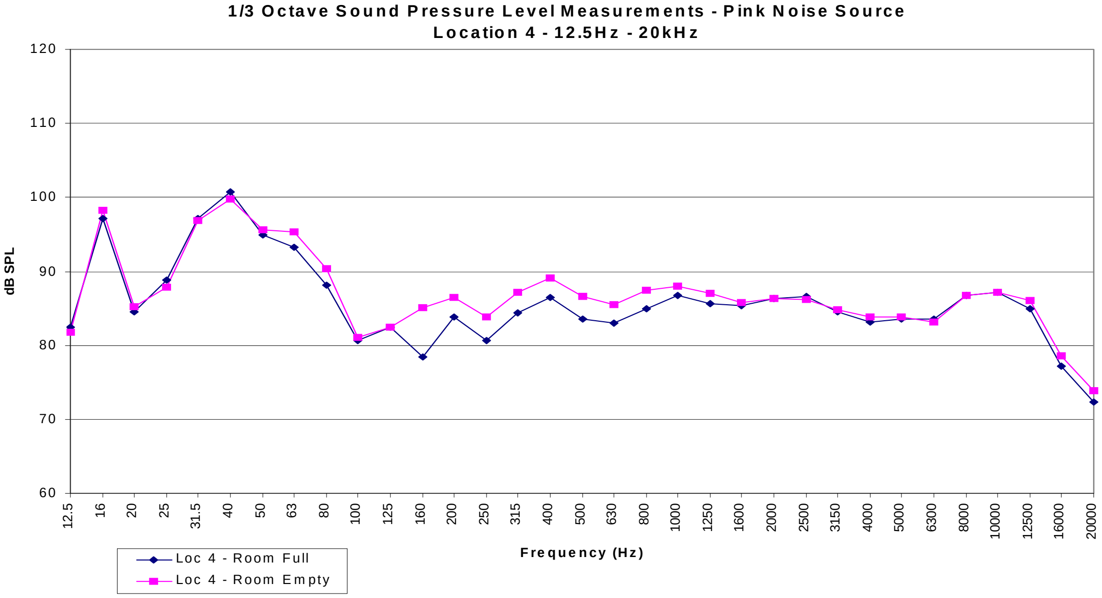


Figure A4. Pink noise spectra at Location 4 -- Room empty vs. full.

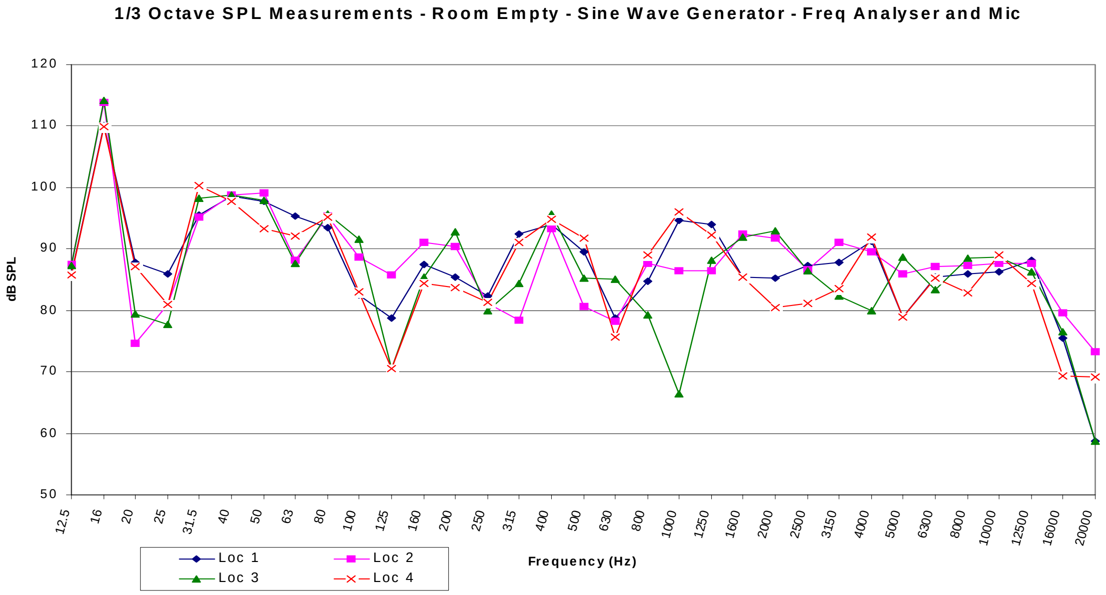


Figure A5. Pure tone noise spectra at the four locations – Room empty.

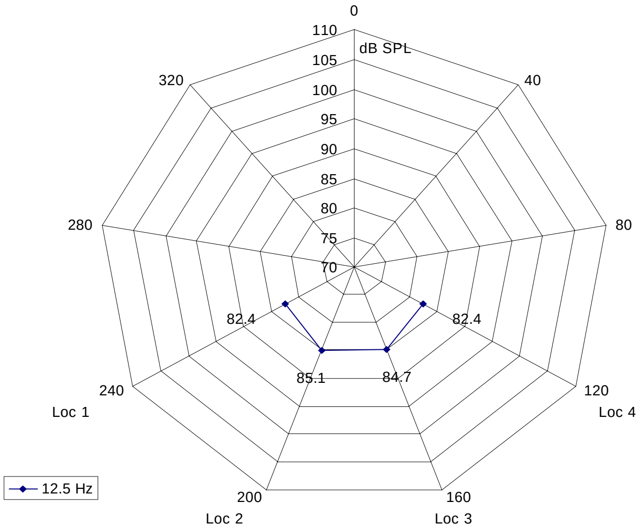


Figure A6. Directivity of the Noise Lab speaker array at the 12.5 Hz 1/3 octave band.

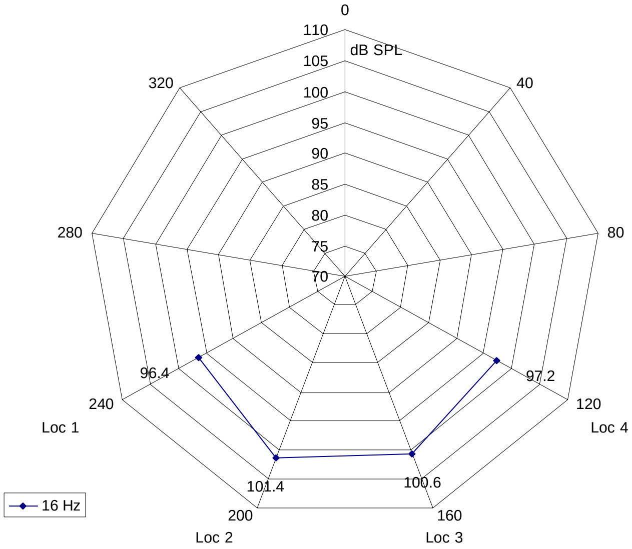


Figure A7. Directivity of the Noise Lab speaker array at the 16 Hz 1/3 octave band.

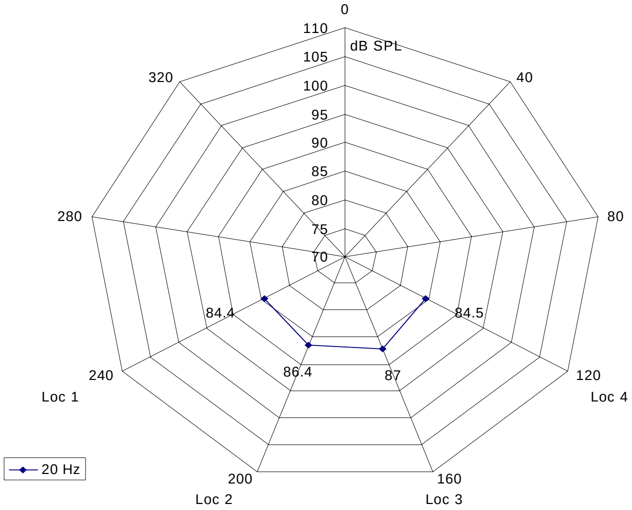


Figure A8. Directivity of the Noise Lab speaker array at the 20 Hz 1/3 octave band.

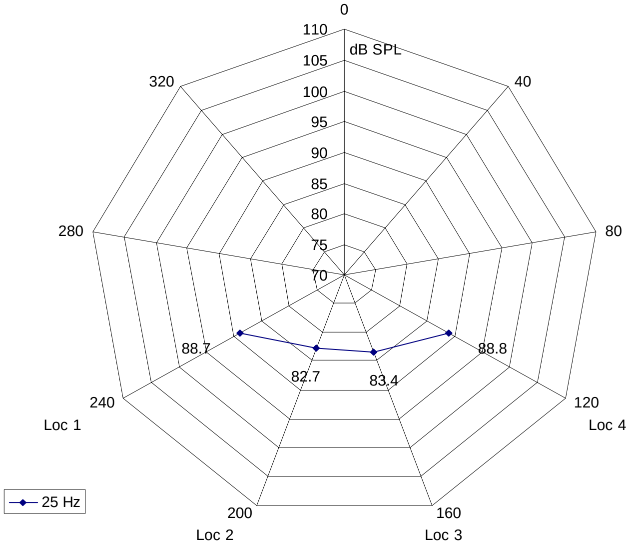


Figure A9. Directivity of the Noise Lab speaker array at the 25 Hz 1/3 octave band.

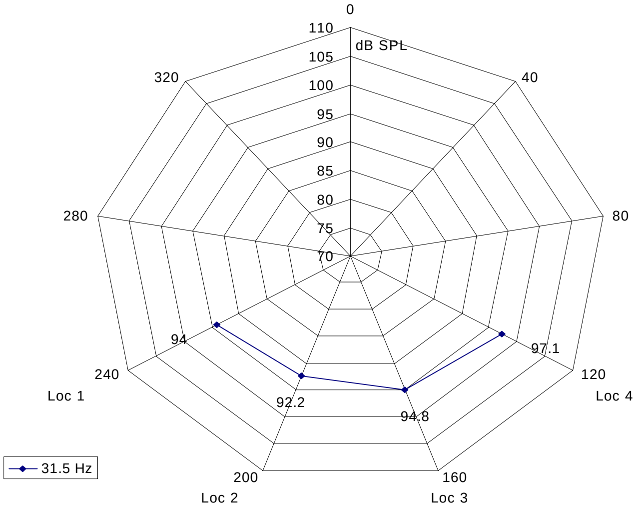


Figure A10. Directivity of the Noise Lab speaker array at the 31.5 Hz 1/3 octave band.

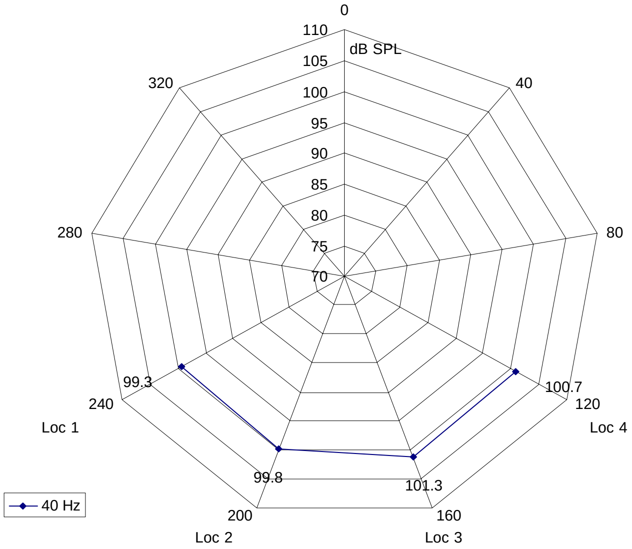


Figure A11. Directivity of the Noise Lab speaker array at the 40 Hz 1/3 octave band.

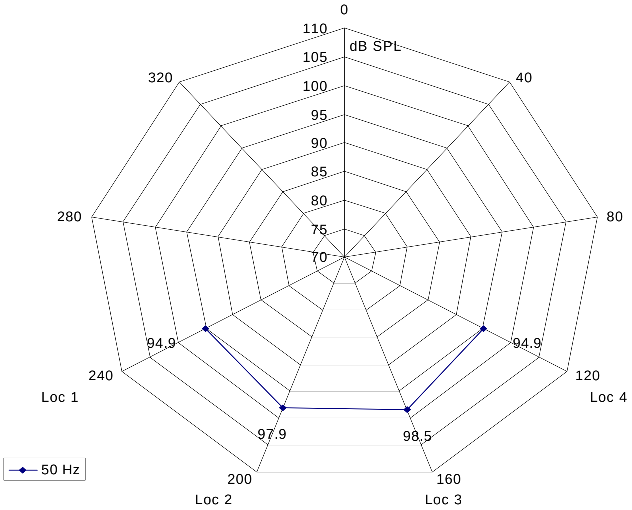


Figure A12. Directivity of the Noise Lab speaker array at the 50 Hz 1/3 octave band.

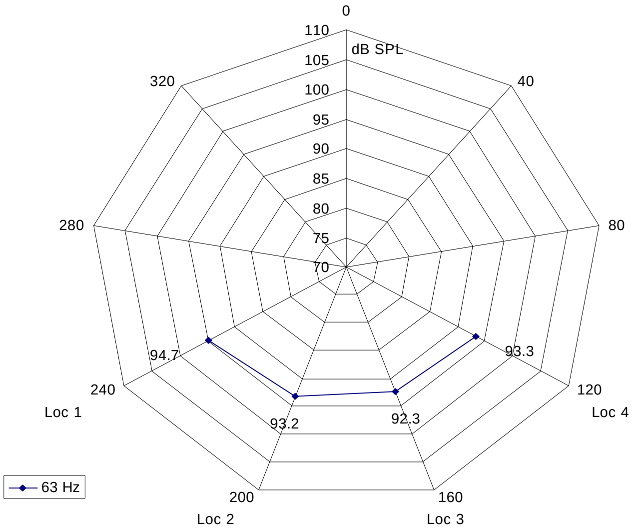


Figure A13. Directivity of the Noise Lab speaker array at the 63 Hz 1/3 octave band.

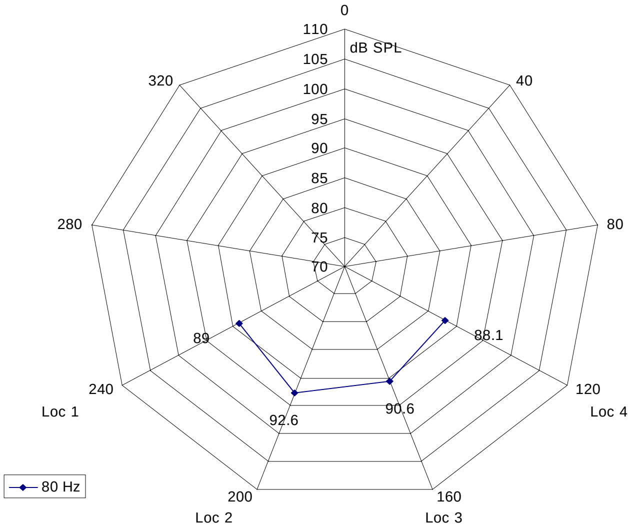


Figure A14. Directivity of the Noise Lab speaker array at the 80 Hz 1/3 octave band.

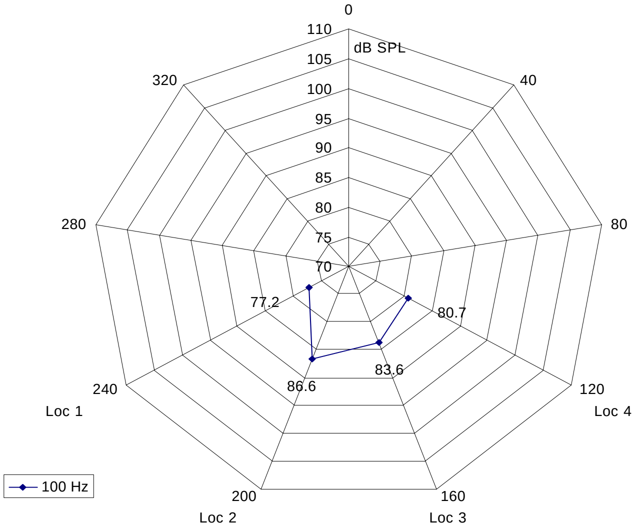


Figure A15. Directivity of the Noise Lab speaker array at the 100 Hz 1/3 octave band.

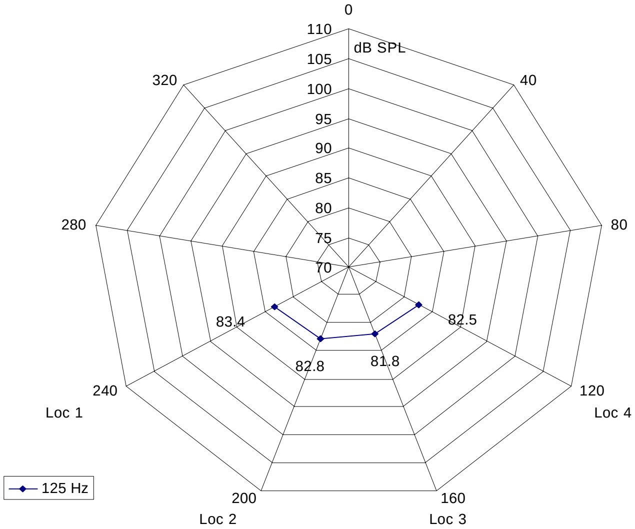


Figure A16. Directivity of the Noise Lab speaker array at the 125 Hz 1/3 octave band.

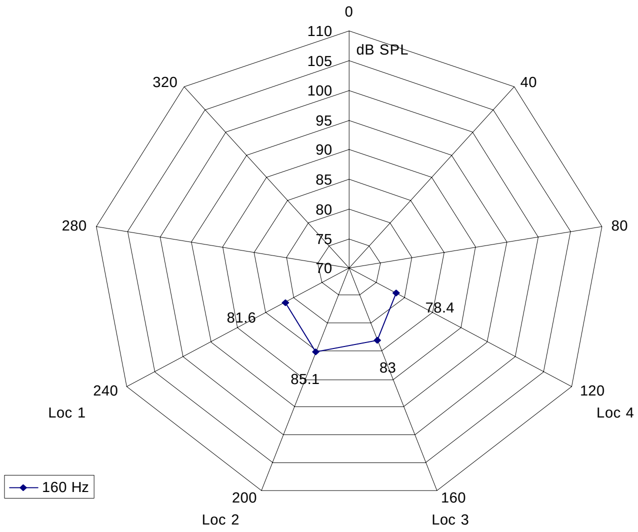


Figure A17. Directivity of the Noise Lab speaker array at the 160 Hz 1/3 octave band.

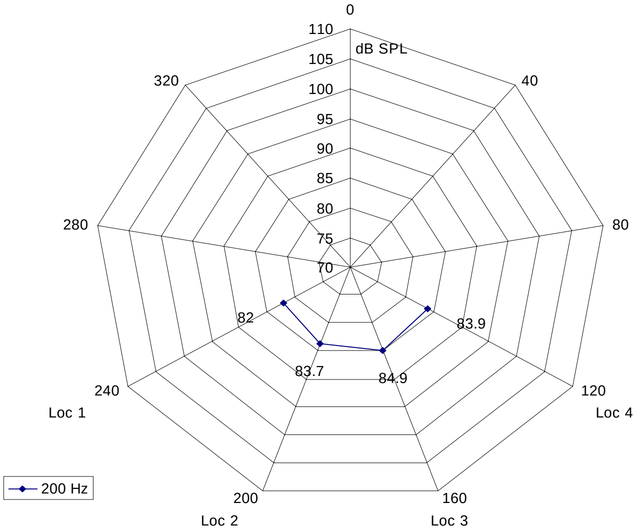


Figure A18. Directivity of the Noise Lab speaker array at the 200 Hz 1/3 octave band.

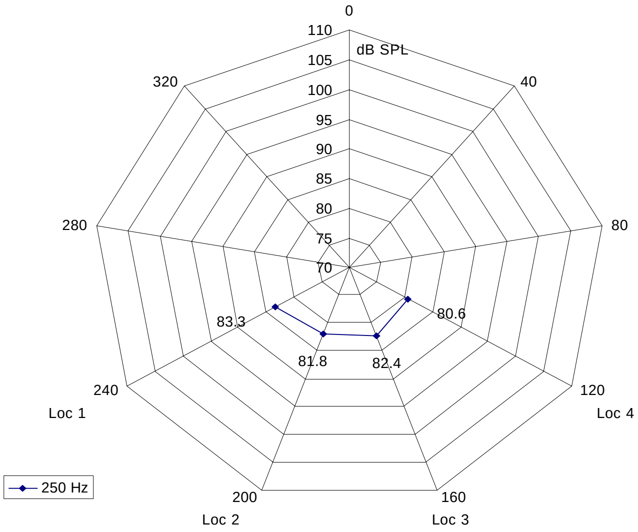


Figure A19. Directivity of the Noise Lab speaker array at the 250 Hz 1/3 octave band.

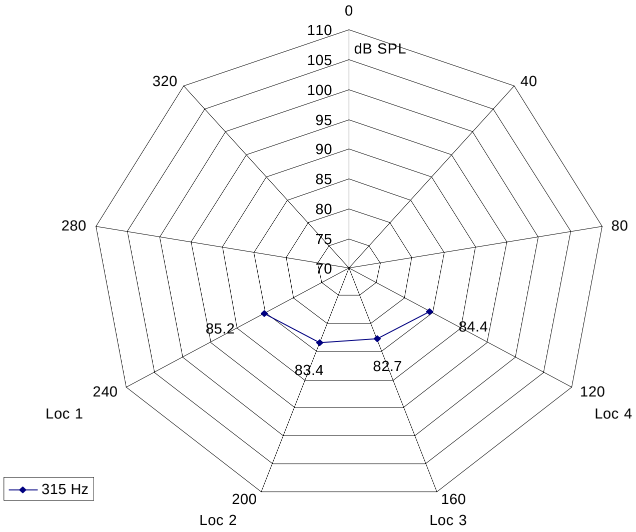


Figure A20. Directivity of the Noise Lab speaker array at the 315 Hz 1/3 octave band.

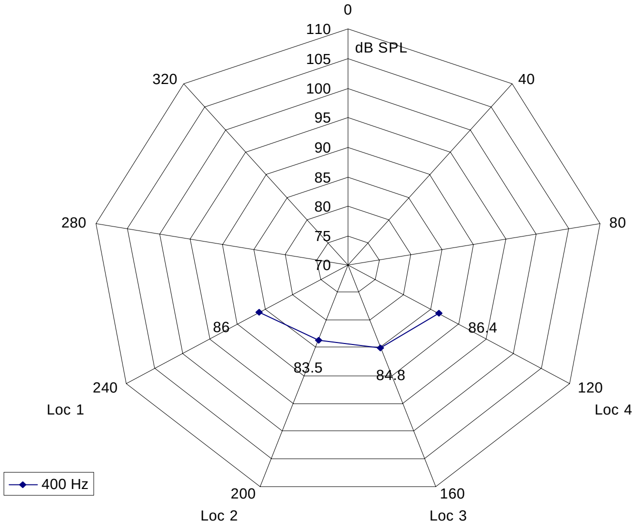


Figure A21. Directivity of the Noise Lab speaker array at the 400 Hz 1/3 octave band.

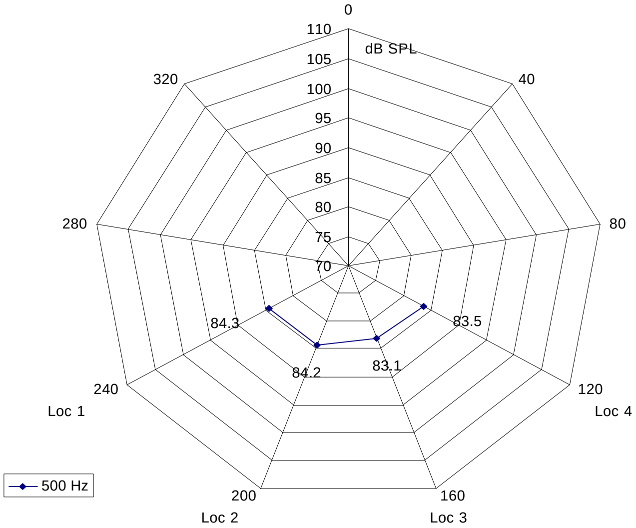


Figure A22. Directivity of the Noise Lab speaker array at the 500 Hz 1/3 octave band.

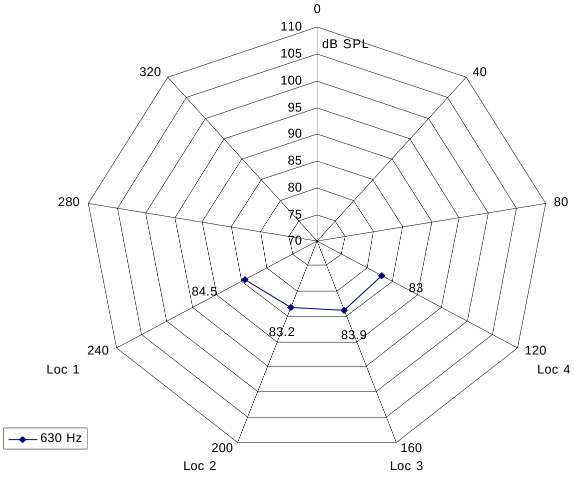


Figure A23. Directivity of the Noise Lab speaker array at the 630 Hz 1/3 octave band.

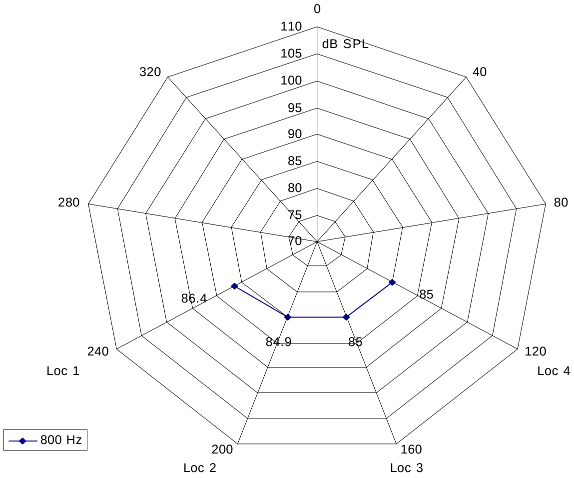


Figure A24. Directivity of the Noise Lab speaker array at the 800 Hz 1/3 octave band.

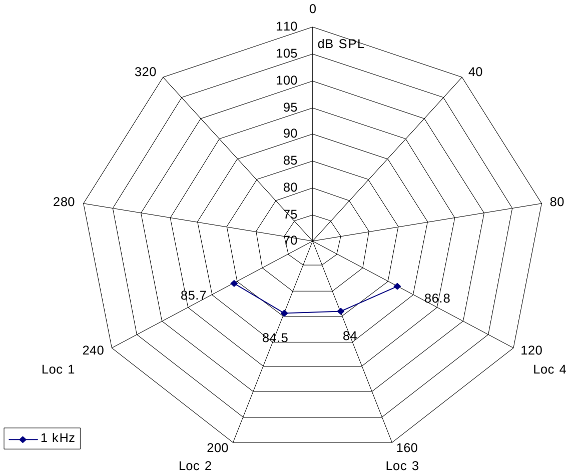


Figure A25. Directivity of the Noise Lab speaker array at the 1 kHz 1/3 octave band.

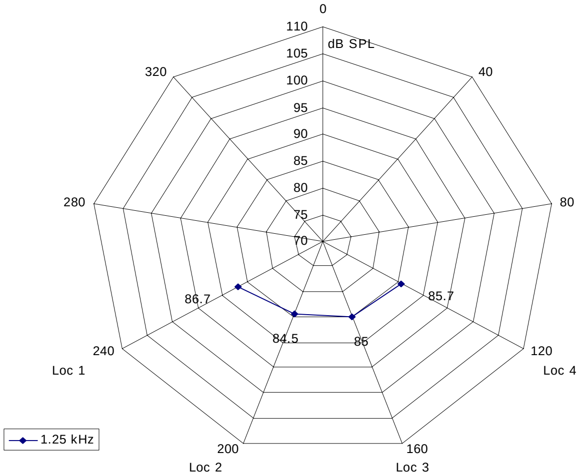


Figure A26. Directivity of the Noise Lab speaker array at the 1.25 kHz 1/3 octave band.

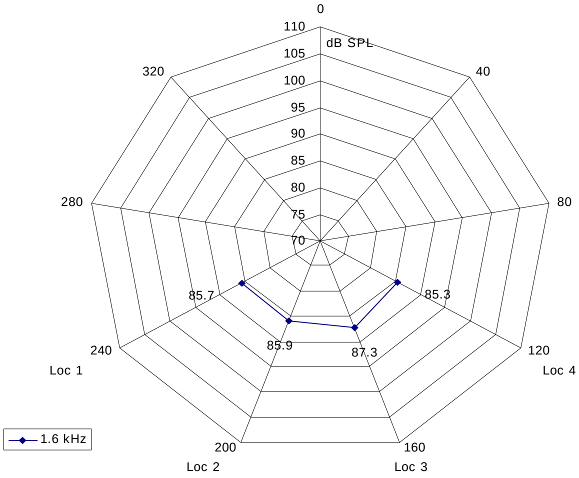


Figure A27. Directivity of the Noise Lab speaker array at the 1.6 kHz 1/3 octave band.

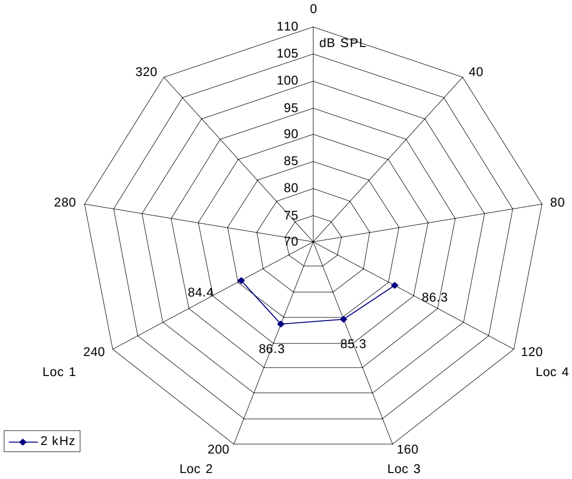


Figure A28. Directivity of the Noise Lab speaker array at the 2 kHz 1/3 octave band.

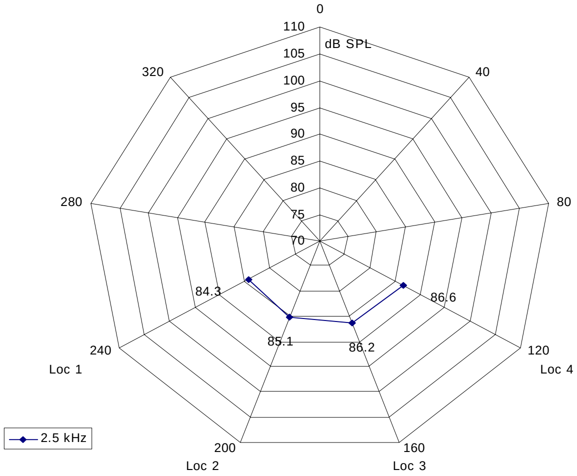


Figure A29. Directivity of the Noise Lab speaker array at the 2.5 kHz 1/3 octave band.

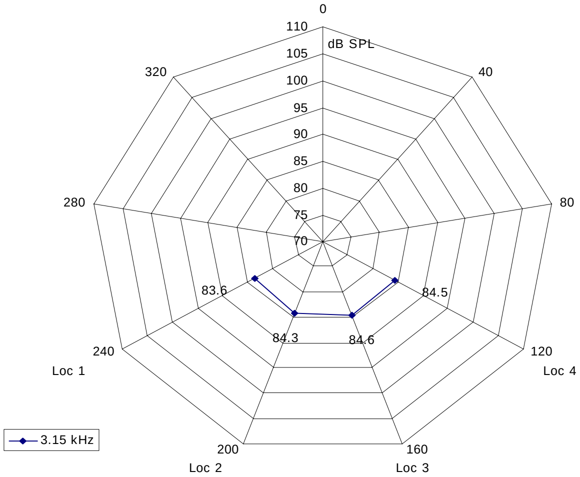


Figure A30. Directivity of the Noise Lab speaker array at the 3.15 kHz 1/3 octave band.

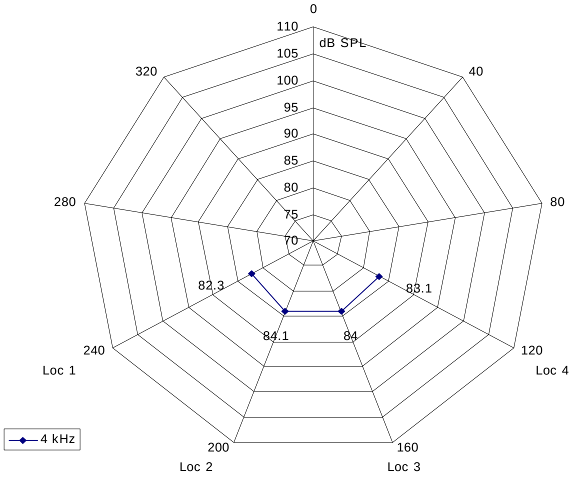


Figure A31. Directivity of the Noise Lab speaker array at the 4 kHz 1/3 octave band.

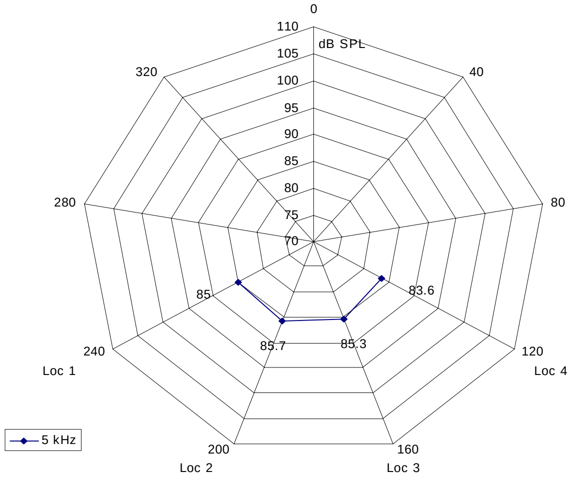


Figure A32. Directivity of the Noise Lab speaker array at the 5 kHz 1/3 octave band.

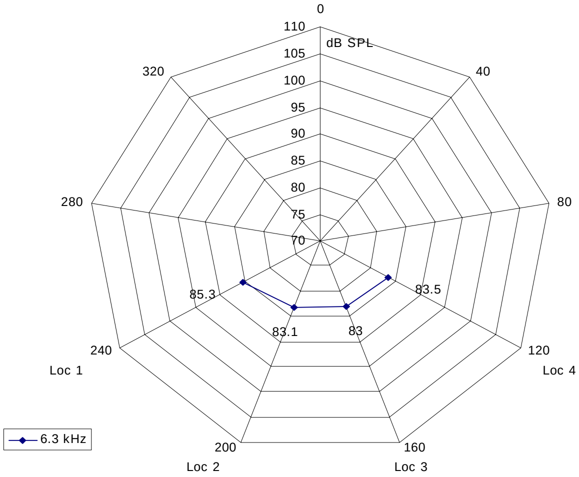


Figure A33. Directivity of the Noise Lab speaker array at the 6.3 kHz 1/3 octave band.

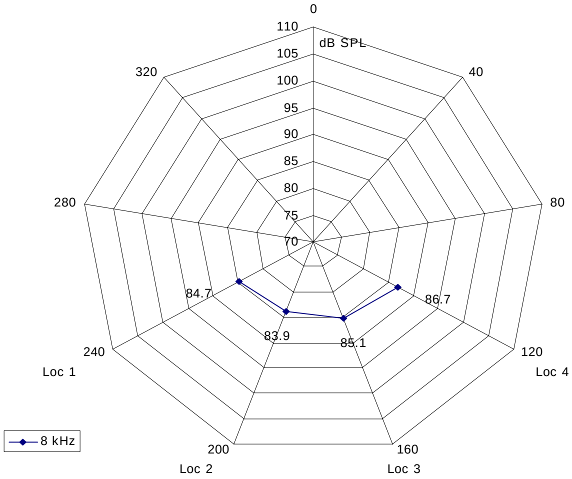


Figure A34. Directivity of the Noise Lab speaker array at the 8 kHz 1/3 octave band.

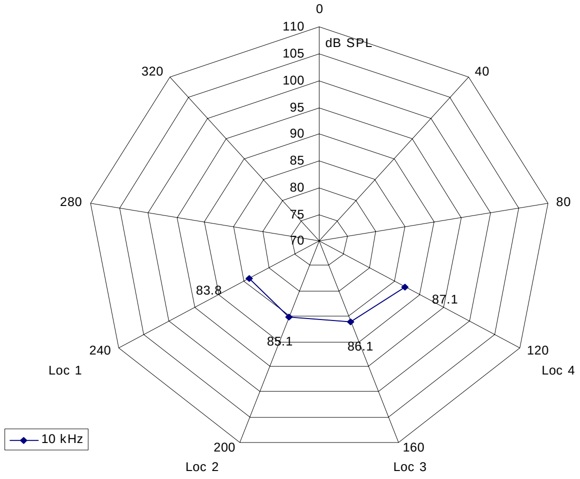


Figure A35. Directivity of the Noise Lab speaker array at the 10 kHz 1/3 octave band.

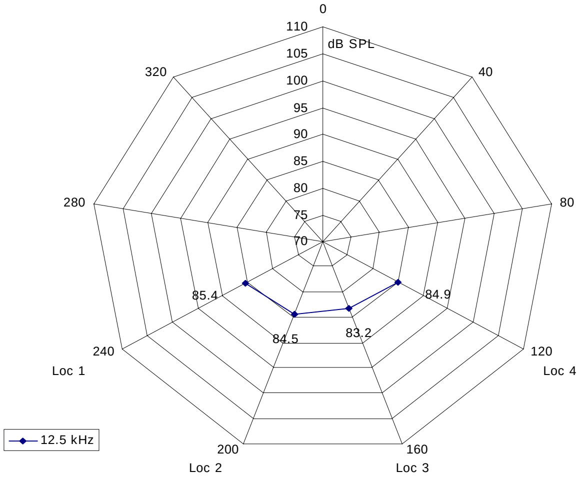


Figure A36. Directivity of the Noise Lab speaker array at the 12.5 kHz 1/3 octave band.

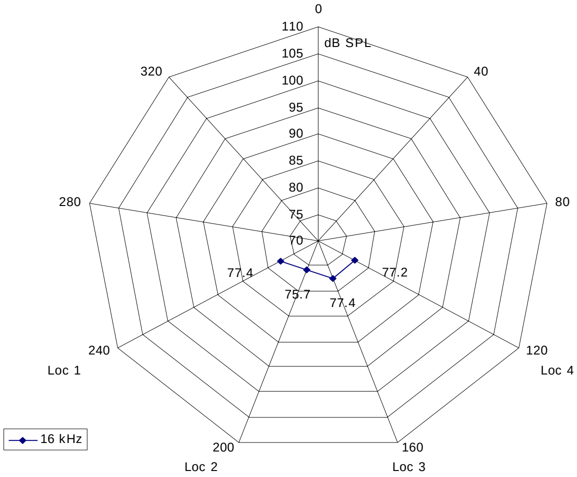


Figure A37. Directivity of the Noise Lab speaker array at the 16 kHz 1/3 octave band.

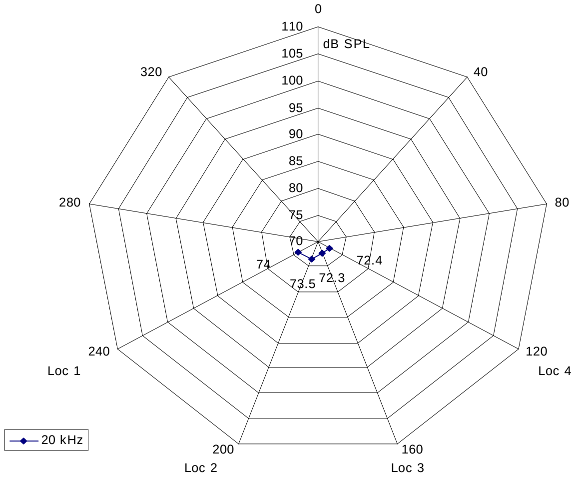


Figure A38. Directivity of the Noise Lab speaker array at the 20 kHz 1/3 octave band.

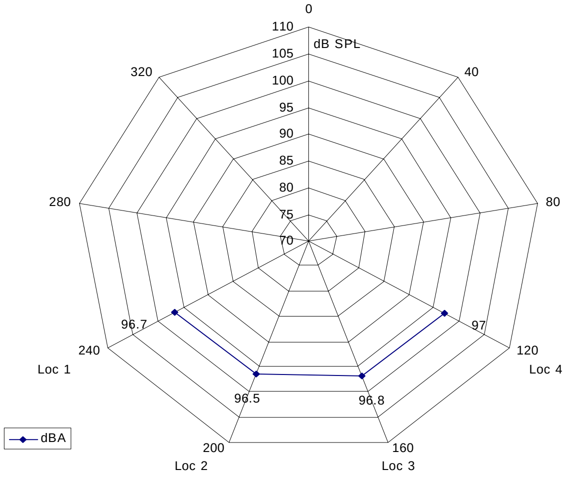


Figure A39. Overall directivity of the Noise Lab speaker array in dBA.

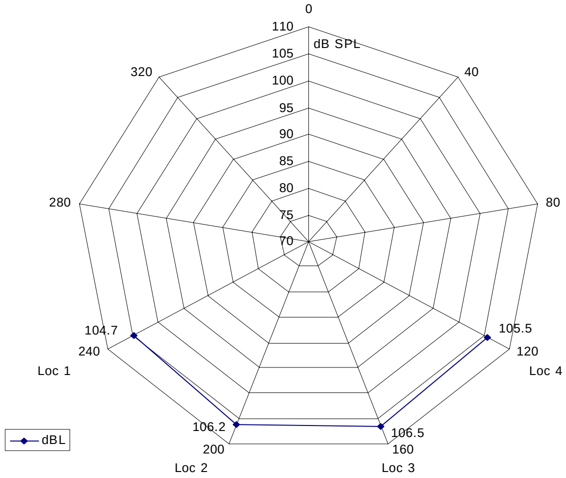
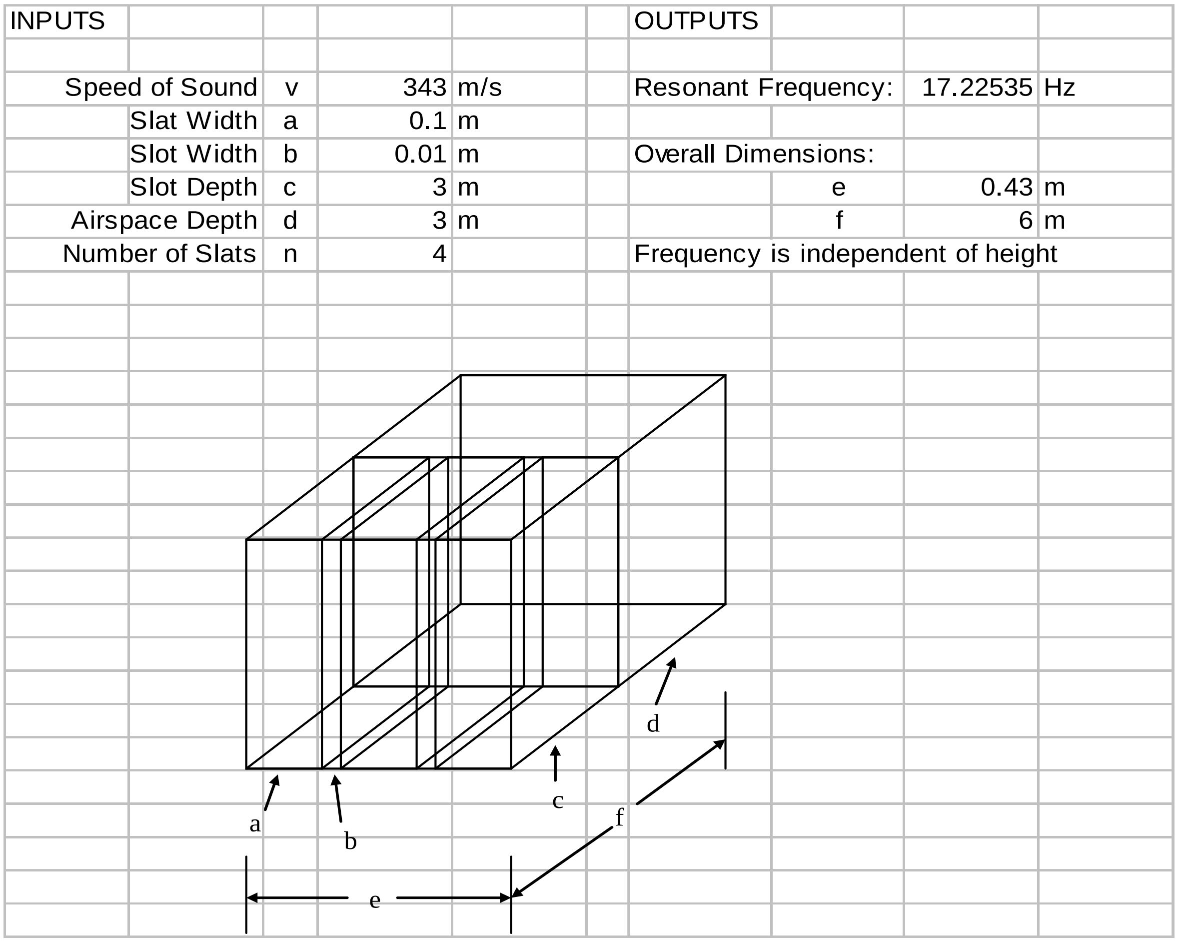


Figure A40. Overall directivity of the Noise Lab speaker array in dBL.

Table A1. *Modified GEQ settings for Location 2.*

Modified GEQ Settings Used to Flatten the Frequency Response at Location 2			
Original GEQ Settings		Modified GEQ Settings	
f (Hz)		f (Hz)	
12.5	~	12.5	~
16	~	16	~
20	+9	20	+9
25	-7.5	25	+4.5
31.5	+1	31.5	-12
40	-10	40	-12
50	+9	50	+2
63	+9	63	+5
80	+1	80	0
100	+8	100	+8
125	-5	125	-5
160	-6	160	-6
200	+2	200	+2



INPUTS					OUTPUTS			
Speed of Sound	v	343	m/s		Resonant Frequency:		17.22535	Hz
Slat Width	a	0.1	m					
Slot Width	b	0.01	m		Overall Dimensions:			
Slot Depth	c	3	m			e	0.43	m
Airspace Depth	d	3	m			f	6	m
Number of Slats	n	4			Frequency is independent of height			

Figure A41. Sample bass trap calculations.

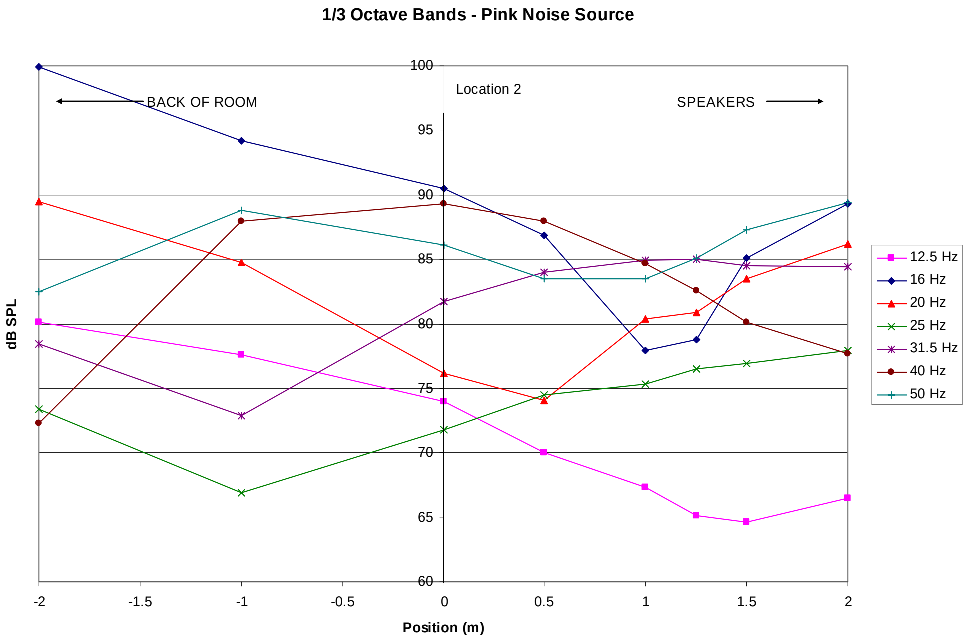


Figure A42. Sound pressure levels along the length of the Noise Lab in 1/3 octave bands.

Table A2. Modifications to the GEQ settings – New measurement location.

Modified GEQ Settings Used to Flatten the Frequency Response at the New Measurement Location

Original GEQ Settings		Modified GEQ Settings	
f (Hz)		f (Hz)	
12.5	~	12.5	~
16	~	16	~
20	+9	20	-6
25	-7.5	25	-3
31.5	+1	31.5	-12
40	-10	40	-12
50	+9	50	+8
63	+9	63	-12
80	+1	80	+12
100	+8	100	+12
125	-5	125	-4
160	-6	160	-9
200	+2	200	+4
250	-3	250	+3
315	-4.5	315	0
400	+4	400	+2
500	+2.5	500	+4
630	0	630	+5
800	+6	800	+9
1000	+9	1000	+7.5
1250	-2.5	1250	-5
1600	+4.5	1600	+1
2000	-2.5	2000	-3
2500	+6	2500	+4
3150	+4	3150	+4
4000	+2	4000	+1.5
5000	+7	5000	+7
6300	+7.5	6300	+7.5
8000	+12	8000	+9
10000	+12	10000	+7.5
12500	+7	12500	+4.5
16000	+6	16000	+10
20000	0	20000	+12

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L'installation de simulation de bruit à RDDC Toronto

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(U) The Noise Simulation Facility and the Noise Library at DRDC Toronto are used to recreate the noise environments of various military operational settings. The Noise Simulation Facility (the Noise Lab) is a large room containing an array of speakers that enables the production of noise levels as high as 130 dB. The Noise Library is a collection of digital audio tapes containing recordings of noise that were made in various Canadian Forces land vehicles, aircraft and other operational settings. The acoustical characteristics of the Noise Lab and the quality of the digital audio tape recordings that have been modified for playback are largely unknown. To gain a better understanding of the accuracy to which the operational noise environments are modeled in the Noise Lab, the acoustical response at several different positions in the Noise Lab was measured, and spectral analyses of the noise recordings were performed. The presence of objects in the room was found to decrease the reverberation time at all frequencies compared to their absence. It was determined from the measurements that the over−amplification of low frequencies governed by the geometry of the Noise Lab could be reduced by adjusting the settings of a graphic equalizer and by moving the measurement location to an area where the effects of standing waves were minimized. Recommendations are made with regard to field measurement procedures that can help to improve the quality of the noise recordings and ensure accurate playback of levels in the Noise Lab.

(U) L’installation de simulation de bruit et la bandothèque d’enregistrements de bruit de RDDC Toronto permettent de reproduire les conditions de bruit de divers contextes opérationnels militaires. L’installation de simulation de bruit (laboratoire de simulation de bruit) consiste en une grande salle comprenant un réseau de haut−parleurs qui permettent de générer des niveaux de bruit allant jusqu'à 130 dB. La bandothèque comprend une collection de bandes audionumériques de bruits enregistrés dans divers véhicules terrestres et aéronefs des Forces canadiennes, ainsi que dans d’autres contextes opérationnels. En grande partie, les caractéristiques acoustiques du laboratoire de simulation et la qualité des enregistrements sur bande audionumérique, qui ont été modifiés pour l’écoute, demeurent inconnues. On a mesuré la réponse acoustique à différents emplacements dans le laboratoire afin de mieux connaître la précision de la simulation des environnements acoustiques opérationnels. Des analyses spectrales des enregistrements de bruit ont aussi été effectuées. On a constaté que la présence d’objets dans la salle diminuait le temps de réverbération pour toutes les fréquences. Les mesures prises ont permis de déterminer que la suramplification des basses fréquences, déterminée par la géométrie du laboratoire, pouvait être diminuée en modifiant les réglages de l’égalisateur graphique et en déplaçant le capteur à un endroit où les effets des ondes stationnaires sont réduits. Des recommandations sont présentées en ce qui concerne les procédures de mesure sur le terrain, qui sont censées améliorer la qualité des enregistrements de bruit et assurer une reproduction fidèle des niveaux dans le laboratoire.

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(U) Noise simualtion facility, room acoustics, noise measurements, reverberation time, low−frequency noise

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