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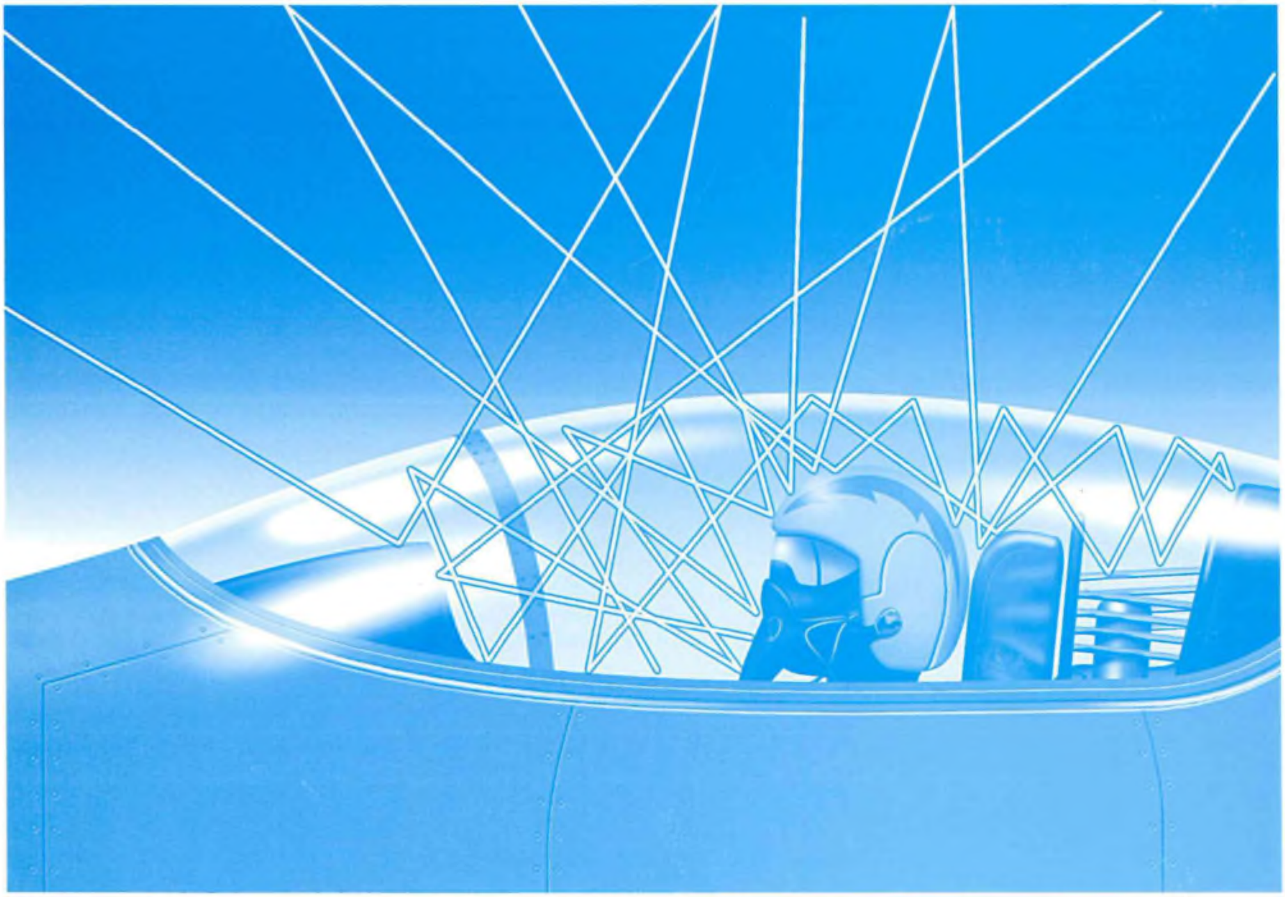

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EDITORIAL / ÉDITORIAL

The many ideas that were probed over the last year are slowly being incorporated in the journal. However, the success of these endeavours is still dependent on the full involvement of our membership. We would like to outline potential areas where your cooperation would have immediate benefits to the well being of the journal.

Francine Desharnais, our News Editor, has been attempting, valiantly I might add, to provide tit-bits that would be of interest to the Canadian readers. She is having difficulty in obtaining information. She has to call upon her contacts to supply the necessary information. Her efforts have produced information in the area of underwater acoustics. I am sure similar happenings could be found across the acoustical spectrum in this vast land of ours. Get your stories out and send them to Francine at your earliest convenience.

Finally, we had started to report on the graduate research done by future acousticians and presented the abstract of a Ph. D. student from the University of Sherbrooke. Once again, we are sure that at least a few graduate (both MS and Ph. D) degrees are awarded every year by the many universities in Canada. We request the many professors to report on the success of their students by sending us the summary of the theses after their oral defense by the students.

Recently, the Journal of Acoustical Society of America, JASA 106 (6), December 1999, pp 3048, reported on the confusing status acquired by the oft-maligned dB (decibel) rating in the field of acoustics. I refer our readers to 'Noise Control and SI Units' by Robert Hickling and request them to read the short item. I invite all of you to send in your opinions and thoughts (I will be contacting a few of you personally) on the use of the 'decibel.' I am interested in providing a reader's column on this in the June issue of the journal.

Les nombreuses idées qui ont été proposées au cours de la dernière année sont lentement incorporées dans le journal. Cependant, le succès de ces dernières motivations dépend toujours de la participation totale de nos membres. Nous voudrions citer des domaines potentiels où votre coopération serait bénéfique au journal dans l'immédiat.

Francine Desharnais, notre éditeur des nouvelles, avait essayé, vaillamment si je peux ajouter, de fournir des informations qui seraient d'intérêt aux lecteurs canadiens. Elle a des difficultés à obtenir de l'information. Elle doit rappeler à chaque fois ses contacts pour acquérir l'information nécessaire. Ses efforts ont finit par nous procurer des nouvelles dans le domaine de l'acoustique sous-marine. Je suis sûr que des faits semblables pourraient être reproduits dans d'autres domaines de l'acoustique à travers cette vaste terre qui est la notre. Envoyez vos nouvelles à Francine dans les meilleurs délais.

En conclusion, nous avons commencé à informer nos lecteurs des travaux effectués par de futurs acousticiens en publiant le résumé de thèse d'un étudiant en Doctorat de l'université de Sherbrooke. De cette façon, nous savons au moins que des diplômes (MS et Ph.D.) sont attribués chaque année par les nombreuses universités du Canada. Nous invitons les nombreux professeurs à rendre compte du succès de leurs étudiants en nous envoyant les résumés des thèses après leurs soutenances.

Récemment, 'The Journal of Acoustical Society of America', JASA 106 (6), décembre 1999, pp 3048, a publié un article sur le caractère embrouillant saisi par l'estimation diffamatoire du dB (décibel) dans le domaine de l'acoustique. J'invite donc nos lecteurs à lire l'article publié par Robert Hickling dans 'Noise Control and SI Units'. J'en courage tout le monde à envoyer ses opinions et ses avis sur l'utilisation du 'décibel' (je contacterai quelques-uns d'entres vous personnellement). Je suis résolu à consacrer une colonne sur ce sujet dans l'édition du journal de mois de juin prochain.

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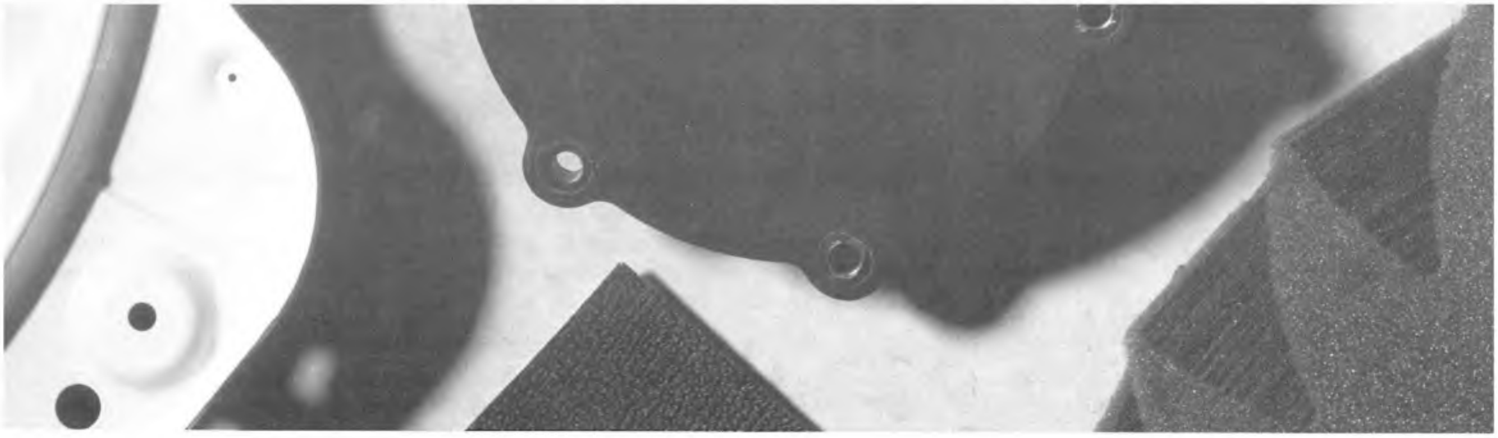
Francine Desharnais, DREA Ocean Acoustics, P.O. Box 1012, Dartmouth NS, Email: desharnais@drea.dnd.ca



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Review article / Article de revue

BINAURAL TECHNOLOGY FOR APPLICATION TO ACTIVE NOISE REDUCTION COMMUNICATION HEADSETS: DESIGN CONSIDERATIONS

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SUMMARY

This article examines the fundamental basis and the technical aspects involved in integrating two emerging technologies in the design of communication headsets for use in noisy environments. The first technology, active noise reduction (ANR), can improve signal detection and speech intelligibility by reducing the amount of interfering noise from the environment. The second technology, known as binaural technology, allows the creation of 3D auditory displays, which can improve signal detection and speech intelligibility in noise, and situational awareness, over monaural listening. For an optimal integration of binaural technology into ANR headsets, digital devices are preferred over analog devices. The complexity of the integrated system, particularly the features of the binaural simulation, is found to be largely dependent on the specific demands of the application targeted. Two extreme cases relevant to an aircraft cockpit environment are analyzed. The greatest benefit is likely to be found in situations of divided attention listening in relatively low signal-to-noise environments.

SOMMAIRE

Cet article examine les principes de base et les aspects techniques nécessaires à l'intégration de deux technologies émergentes dans la conception de casques d'écoute pour les milieux bruyants. La première technologie, le contrôle actif du bruit, permet d'améliorer la détection de signaux et l'intelligibilité de la parole en réduisant l'interférence causée par le bruit environnant. La deuxième technologie, la technologie binaurale, permet de créer un environnement d'écoute 3D, ce qui en retour permet d'améliorer la détection de signaux et l'intelligibilité de la parole dans le bruit, ainsi que la vigilance en situation d'écoute, par rapport à l'écoute monaurale. L'utilisation de casques actifs numériques est préférable aux casques actifs analogiques pour assurer une intégration optimale avec la technologie binaurale. La complexité du système total, tout particulièrement les caractéristiques de la simulation d'écoute binaurale, dépend en grande partie des exigences de l'application ciblée. Deux situations extrêmes appliquées à un environnement de cockpit d'avion sont analysées. L'avantage d'appliquer la technologie binaurale aux casques actifs sera le plus important en situation d'écoute où l'attention doit être partagée entre plusieurs signaux dans des milieux dont le rapport signal au bruit est faible.

1.0 INTRODUCTION

This study was undertaken to evaluate the feasibility of applying binaural technology to the design of active noise reduction (ANR) communication headsets. The long-term objectives of combining both technologies are the improvement of the intelligibility of competing spoken messages presented simultaneously in the presence of noise, and the enhancement of situational awareness in complex auditory listening environments. ANR technology (Steeneken and Verhave, 1996) can improve speech intelligibility by reducing the amount of interfering noise from the environment. This is accomplished by electronic sound wave cancellation of the environmental noise inside the earcups of the device. Binaural technology (Moller, 1992), on the other hand, allows the transfer of coincident messages to different virtual spatial positions by filtering the incoming communication signals with the head-related transfer functions of the user. This processing generates interaural time difference (ITD) and interaural level difference (ILD) cues for each message. Variation in these cues normally signifies real-world differences in spatial location (Blauert, 1997), and impacts on the intelligibility of speech in noise (Bronkhorst and Plomp, 1988).

In this article, we begin by reviewing the fundamental research on binaural speech intelligibility in noise and binaural technology. The practical aspects involved in the creation of directional audio signals through ANR headsets are then discussed in terms of the required technical characteristics of the devices, and the application requirements. The process of integrating binaural technology into ANR headsets is illustrated through two different listening scenarios relevant to an aircraft cockpit environment. The potential benefits are assessed.

2.0 Binaural Signal Detection And Speech Intelligibility in Noise

Incident acoustic signals are transformed by the complex geometry of the human torso, head and external ear (Shaw, 1974). This filtering produces direction-dependent sound spectra at the ears, and encodes time and level differences in the sound across the left and right ears. Binaural analysis of these cues provides the basis for localizing sound sources in space (Blauert, 1997).

In addition, the detection, discrimination and recognition of a sound signal in the presence of other signals or noises can sometimes be markedly improved when listening binaurally rather than monaurally (Yost, 1997). It has long been suggested that the binaural hearing cues could play a major role in separating sound sources perceptually (Cherry, 1953). Data on the benefits of binaural over monaural listening have been collected over the past decades.

2.1 Headphone studies

A representative early study was conducted by Levitt and Rabiner (1967a). They presented speech signals interaurally out-of-phase over headphones in the presence of a broadband white noise masker interaurally in-phase (S_pN_o). They found a masked threshold for speech detection about 13 dB lower than if both signal and noise were presented interaurally in-phase (S_oN_o). Further experiments showed that this release from masking for detection was determined primarily by interaural phase opposition in the low-frequency region of the speech signal, typically below 0.5 kHz. In contrast, the maximum binaural gain at the 50% intelligibility level, i.e., the maximal decrease in speech reception threshold (SRT) with respect to the S_oN_o condition, was about 6 dB and required interaural signal phase opposition over a wide frequency region. Presenting the speech signal in-phase with an interaurally uncorrelated noise masker (S_oN_u) led to a small decrease of about 3 dB in the masked detection threshold, but no advantage for speech intelligibility. In all conditions investigated, the binaural gain was substantially lower than the corresponding decrease in masked threshold. Levitt and Rabiner (1967b) predicted that even lower binaural gains could be expected for reference intelligibility levels greater than 50%.

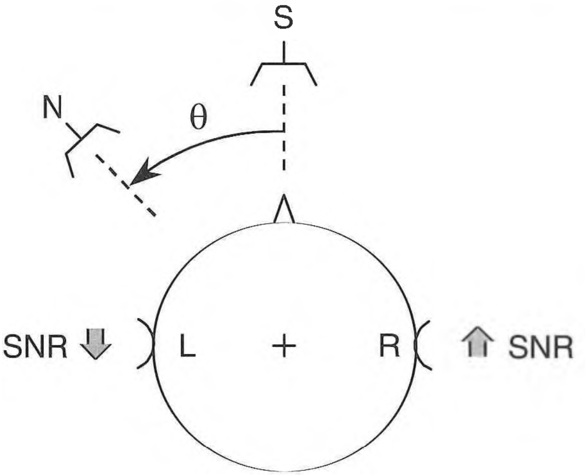

Figure 1: Schematic representation of binaural listening in sound field. L: left ear, R: right ear, S: signal source, N: noise source, θ: azimuth angle, SNR: signal-to-noise ratio.

2.2 Sound-field studies

Binaural speech intelligibility has also been investigated in rooms using spatially-separated loudspeakers for signal and noise sources (Figure 1). For example, Plomp and Mimpen (1981) measured the SRT for normal listeners in an anechoic room for a frontal speech signal, as a function of the azimuthal position q of a speech noise masker. They found a general decrease in the SRT when the noise source was displaced from frontal to lateral positions. A maximal decrease in SRT, or binaural gain, of about 9-11 dB was found for a noise azimuth close to q=90°.

Santon (1986) performed a similar experiment and found a maximal decrease in SRT of about 8 dB when a broadband white noise masker of moderate level was displaced from a frontal to a lateral position. If the broadband masker was divided into two noise bands, above and below 1.4 kHz, then the maximal decrease in SRT for each band was limited to 3 dB. Further experiments (Santon, 1987) showed that the variations in SRT for low (0.125-0.8 kHz) or mid (1-2 kHz) frequency noise bands were smaller than the corresponding variations in detection threshold for pure tones near the centre frequency of the bands, but followed the same trends as a function of noise azimuth. In the case of a high-frequency (2.5-6.3 kHz) noise band masker, the variations in SRT were also smaller than the corresponding variations in detection threshold, but the trends as a function of noise azimuth differed.

Januška (1983) measured speech intelligibility for a frontal speech signal as a function of the level and spatial location (frontal, lateral, behind, above) of different noise maskers.

Data were obtained for broadband white noise and octave bands of noise centred on 0.125 kHz to 8 kHz. The effect of varying the reverberation time of the listening space (anechoic, 0.4 s and 2.0 s) was also investigated. A coincident position of speech and noise sources was always the most unfavourable condition. Both the masking effect and the benefit of displacing the masker away from the frontal position were always greater for the broadband than the octave-band noises. Speech intelligibility gains were found for all conditions of the listening space, but were most evident in the anechoic environment. Typically, for broadband white noise, the maximum binaural gain at the 50% speech intelligibility level was about 14 dB in the anechoic environment, and 8 dB and 6 dB in the rooms with reverberation times of 0.4 s and 2.0 s respectively.

2.3 Simulated sound-field studies

In the sound-field studies discussed above, the speech and noise levels were defined with respect to the free field, typically at the head position in absence of the listener. Due to the direction-dependent transfer function of the external ear (Shaw, 1974), the actual signal-to-noise ratio (SNR) at the listener's ears will vary when the speech signal and/or noise sources are spatially displaced, and will be different across the two ears. For example, in Figure 1, when the noise source is displaced laterally, the noise level increases in the ipsilateral ear (SNR decreases) and decreases in the contralateral ear (SNR increases). Thus, the speech intelligibility benefit of spatially separating signal and noise sources from a common position may include a monaural contribution from the ear with the best SNR, as well as the contribution from binaural processing per se. Also, interaural time and level differences cannot be independently controlled in sound-field experiments, and thus their respective roles cannot be separated in the interpretation of speech intelligibility results.

To address these questions, Bronkhorst and Plomp (1988) simulated free-field conditions over headphones by presenting speech and noise signals recorded a-priori on a KEMAR manikin in an anechoic room. The speech signal recordings corresponded in all conditions to a frontal sound incidence. The noise recordings were made at several azimuth angles q in the horizontal plane, and from each recording two additional noise signals were derived by computer processing, one containing only ITDs and one containing only ILDs. The results for normal-hearing listeners showed, as in Plomp and Mimpen (1981), a gain of about 10 dB in SRT, when the noise containing both ITDs and ILDs was presented laterally relative to the frontal position. In the same conditions, the noise containing ITDs alone provided a gain of about 5 dB, and the noise containing ILDs alone provided a gain of about 7 dB. Thus, the effects of ITDs and ILDs were not additive. The benefit of the ITD cues was essentially unaffected by simulating a one-sided attenuation of 20 dB at either ear. Also, the effect of the ILD cues was entirely dependent on monaural processing and not on binaural processing per se, since the same gain in intelligibility could be obtained by listening only through the ear with the best SNR. Overall, for a frontal speech signal and a lateral noise masker, the minimum and maximum gains observed for binaural listening compared to monaural listening were 2.5 dB and 13.2 dB respectively. The higher value is the binaural gain compared to monaural listening through the ear with the worst SNR, and the lower value is the binaural gain against the ear with the best SNR.

Bronkhorst and Plomp (1989) extended their experiments to hearing-impaired listeners. These listeners had a 2.5 dB higher SRT than normal-hearing listeners when the speech signal and noise masker were presented from the front, and a 2.6-5.1 dB smaller binaural intelligibility gain when the noise masker was displaced laterally depending on the configuration of the hearing loss. The shortfall in binaural gain for hearing-impaired listeners was mainly due to an inability to take full advantage of ILD cues. This was especially pronounced for listeners with asymmetrical high-frequency hearing losses when the noise source was displaced contralaterally to their best ear. In contrast, the gain in speech intelligibility due to ITD cues was less affected by hearing impairment. It was about 4-5 dB for normal-hearing listeners and listeners with symmetrical losses, but 2.5 dB for listeners with asymmetrical losses. When ITD cues were introduced in a noise already containing ILD cues, the resulting gain was 2-2.5 dB for both groups of hearing-impaired listeners.

Bronkhorst and Plomp (1992) further investigated binaural speech intelligibility in simulated free-field conditions with a frontal speech signal source in the presence of one to six mutually-uncorrelated noise sources located in the horizontal plane in various configurations. Over all conditions, the hearing-impaired listeners needed a 4.2-10 dB better SNR than normal listeners for equal intelligibility. The binaural advantage arising when the noise maskers were displaced from the frontal position to symmetrical or asymmetrical spatial configurations around the listeners varied from 1.5 to 8 dB for normal listeners, and from 1 to 6.5 dB for hearing-impaired listeners. The higher value corresponds to a single masker moved laterally to the side of the listeners, and the lower value corresponds to a configuration of six maskers located symmetrically around the listeners at 60° intervals. Comparison of binaural listening with monaural listening results through the best ear showed a fairly constant binaural advantage of about 3 dB across noise masker configurations and listener groups.

In summary:

- the advantage of binaural over monaural listening in noise is greater for detection than intelligibility tasks;

- only the ITD cues provide a true benefit for speech intelligibility in noise;
- the effects of ILD cues can be fully accounted by monaural SNR considerations alone;
- the maximum speech intelligibility benefit derived from binaural listening over monaural listening through the ear with the best SNR is limited to 4-6 dB under the most favourable conditions (anechoic environment, normal hearing or symmetrical hearing loss, single noise source spatially separated from the speech signal, broadband noise, low overall SNR); and
- the benefit of binaural hearing decreases with increasing signal level above masked threshold, and is very small when the signal is relatively easy to detect (Yost, 1997).

Most experiments described to date have been devoted to measures of selective attention, where the listener is asked to focus on a particular signal source and ignore all others (Yost, 1997). There is very little information on situations of divided attention, where the listener must attend to several or all the sound sources in the environment.

3.0 BINAURAL TECHNOLOGY

The input signals to the hearing system are the sound pressure waves inside the left and right ear canals. Three-dimensional auditory environments or displays could thus be simulated through headphones if the directional transfer functions of the human head and external ears were known. The methods and techniques necessary to create virtual auditory environments are together referred to as binaural technology (e.g., Moller, 1992; Blauert, 1997).

3.1 General methodology

There are two main steps involved in a typical binaural technology application (Moller, 1992). The first is the derivation of the head-related transfer functions (HRTFs) of the listener from binaural measurements. The second is the creation of binaural signals by filtering the desired acoustic source input with the HRTFs, and the playback of these signals to the listener using headphones.

HRTFs measurements:

An important aspect to consider in the derivation of the HRTFs is the selection of a reference position for the binaural measurements. The reference position should allow the recording of all the spatial information available to the ear. Moller (1992) investigated three possible positions: at the eardrum, at the entrance to the open ear canal, and at the entrance to the blocked ear canal. The entrance to the blocked ear canal offered several advantages (Moller, 1992; Moller et al., 1995b). Firstly, the blocked ear canal method is easier to implement because it is less prone to microphone fitting and stability problems, measurement noise, sound field interference and other artifacts. Secondly, recordings at the blocked ear canal entrance are free from individual subject differences in ear canal transmission that are not related to the spatial characteristics of the ear as such. HRTFs derived from the blocked ear canal method possess less interindividual variation than other reference positions. This was demonstrated theoretically (Moller et al., 1996) and verified experimentally (Moller et al., 1995b). In the latter study, blocked ear canal HRTFs measured in 40 human subjects showed a clear common structure with small interindividual variations up to about 8 kHz.

Headphone equalization:

In a practical application, the derivation of HRTFs is not an end in itself. Binaural signals must be created by convolution or filtering with the HRTFs and they must be played back to the listener. However, the electroacoustic transfer function of the headphones contributes to the total sound transmission to the ear, and thus require equalization for the correct playback of binaural signals.

Moller (1992) examined the correction functions required in the headphone equalization step. The first correction compensates for the electroacoustical pressure transfer function of the headphone (or PTF in the terminology of Moller et al., 1995a) from the electrical input terminals of the heaphone to the sound pressure at the reference position. There is no other correction needed when a location in the open ear canal is chosen for the reference position. When the blocked ear canal is used as the reference position, the equalization step also requires an extra correction to account for the different acoustical source impedance loading of the ear when listening through headphones instead in the free-field. This correction term is referred to as the pressure division ratio (PDR) (Moller et al., 1995a). It reduces to unity if the radiation impedance looking outwards from the ear canal entrance is unchanged by fitting of the headphone, or if this impedance is much smaller than the input impedance looking inwards from the ear canal entrance (Moller, 1992). In this case, the headphone is said to provide a free-air equivalent coupling (FEC) to the ear.

Moller et al. (1995a) measured the PTF and PDR functions of 14 commercial headphones at the blocked ear entrance of 40 human subjects. The PTF functions were found to be far from flat for all headphones and, in general, none of the headphones tested was deemed suitable for the playback of binaural signals without proper equalization. All PTF functions also showed considerable interindividual variations, especially above 8 kHz. A blocked ear canal reference position led to smaller interindividual variations than a position in the open ear canal, and was easier to implement from a methodological standpoint. The PDR functions were found to be much smaller than the PTFs for all headphones. In general, headphone constructions closely mounted to the ear canal had larger PDF functions than those mounted further away. Up to 2 kHz, all headphones gave flat PDR functions close to 0 dB. Above 2 kHz, the PDRs showed fluctuations with some degree of interindividual variations but with a common structure for each headphone.

__Individualized versus generic binaural signals__:

Perfect reproduction of the binaural signals can only be guaranteed only if binaural measurements and headphone equalization steps are realized with the target listener's own ears. Thus, the question of the possible errors introduced by using another subject, or artificial head, in either or both steps of the binaural technique must be considered. Moller et al. (1996) conducted an error analysis of the reproduced binaural signals, and compared the sensitivity of different reference positions to the use of non-individualized binaural measurements and/or headphone equalization. For the smallest possible error, they proposed: (1) a blocked ear canal reference position for the binaural measurements, (2) the use of an FEC headphone, and (3) the use of individualized PTF headphone equalization whether the binaural measurements were individualized or not.

3.2 Psychoacoustical evaluation

Wightman and Kistler (1989) studied the localization performance of 8 subjects over a set of 72 source directions for broadband white noise bursts presented either by loudspeakers in the free field or by headphones. The headphone stimuli were derived from individualized HRTFs and were individually equalized using a reference position at the eardrum of the open ear canal. Overall, the localization performance with headphone stimuli was nearly identical to that of the reference condition in the free field for each subject. The only noticeable differences that emerged were a greater percentage of front/back confusions (almost double) and a slightly poorer perception of elevation in the headphone condition than in the free field.

Moller et al. (1996) studied the localization performance of 8 subjects over 19 source directions and distances for speech stimuli presented either by loudspeakers in a listening room with reverberation time of 0.4 s or by headphones. The headphone conditions were meant to reproduce binaural recordings made in the same room with the same loudspeaker arrangement. These recordings were made at the blocked ear canal of several subjects. Subjects listened to their own recordings (i.e., individualized), or to those of another subject or a mixture of subjects (i.e., generic). The headphones were always individually equalized to the target listener for the localization experiment. The results for the loudspeaker condition and the headphone condition with individualized recordings were not significantly different. However, the headphone condition with generic recordings led to a significantly greater percentage of errors for sources in the median plane (approximately double), including front/back confusions, and a slight increase in the number of distance errors. Out-of-cone errors were very rare in all conditions tested. None of the subjects reported in-the-head perception of localization in any of the headphone conditions, regardless of whether or not the recordings had been individualized.

In the headphone experiments above, the binaural signals were not synchronized with the head movements of the subjects. Subjects were instructed to keep their heads fixed. Head movements may reduce localization ambiguities, especially front/back confusions and within cone-of-confusion errors (Wallach, 1940; Wightman and Kistler, 1999), and may facilitate the perception of externalization (Durlach et al., 1992). Head movements can be taken into account in a binaural technology application by using a head-tracking device to update the location of the source(s) with respect to the listener's head coordinate system (Blauert, 1997). The externalization of signals, and distance perception, may also be greatly facilitated by reflections and reverberant energy in the listening room (Durlach et al., 1992). The simulation of room acoustics for binaural technology applications requires sound-field modelling (Blauert, 1997).

4.0 INTEGRATING ACTIVE NOISE REDUCTION AND BINAURAL TECHNOLOGIES

4.1 General concept

Communication headsets with sound attenuation capabilities are often used in situations where an individual must be in contact with others at a remote location while operating in a noisy environment. The most common design is based on a passive circumaural hearing protection device fitted with earphones inside the earcups and a boom microphone in front of the mouth. ANR communication headsets can provide a significantly higher amount of low-frequency attenuation compared to passive headsets. The potential benefits of this additional attenuation are a reduced noise exposure for the user, and improvements in speech intelligibility and signal detection through the communication channels. If the speech signals are spatialized and separated from the environmental noise using binaural technology (Section 3), further improvements in intelligibility and signal detection can be expected (Section 2). In addition, virtual auditory displays and 3D models of the listening space can be created through binaural technology, which can greatly facilitate the monitoring and interpretation of the various sources of information presented to the listener (Begault, 1993; McKinley et al., 1994; Bronkhorst et al., 1996).

Figure 2 illustrates the main components in a complete system integrating binaural technology to ANR communication headsets. A typical use of such a system would be inside a noisy aircraft cockpit. The different communication signals are individually spatialized on the basis of the HRTFs of the target listener, the desired spatial position q_S of each signal source, and the current head position q_H. The coordinates q_S express the virtual display model to be created for the particular listening task. The right and left ear signals from each spatialized source are then scaled in level to compensate for head movement effects, as appropriate. The signals are then mixed to sum all left and right components. The resulting two signals are equalized for headphone sound transmission, and fed into the left and right communication channels of the ANR headset. The ANR headset, itself, reduces the external noise from the environment with little or no effect on the transmission of the communication signals.

There are several aspects to consider when combining ANR and binaural technologies as in Figure 2. Firstly, there is the hearing protection performance of the ANR device for the given environmental noise conditions. Secondly, there are the electroacoustical characteristics of the communication channels of the device that would be necessary for an adequate reproduction of binaural signals. Thirdly, there are the requirements of the application itself, which determine the complexity of the binaural simulation, and the design of a suitable virtual auditory display.

4.2 ANR devices for hearing protection and speech transmission

ANR technology provides a means of increasing the low-frequency attenuation in communication headsets or hearing protectors for use in high-level environmental noise (Casali and Berger, 1996). A miniature microphone housed within the earcup samples the incoming waveform. An inverted copy is created and added to the original for the purpose of cancellation. Components of the two waveforms that are out-of-phase will cancel, thereby reducing the overall sound pressure inside the earcup. ANR systems mounted on earmuffs are currently limited to frequencies below 0.5-1 kHz, where they add to the passive attenuation provided by the earcup (McKinley et al., 1996). Attenuation at higher frequencies is achieved by passive means only. Maximum active low-frequency attenuation in the order of 10-20 dB has been measured around 0.125-0.25 kHz over the passive mode (McKinley et al., 1996; Abel and Spencer, 1997; Abel and Giguère, 1997).

The additional low-frequency noise reduction achieved by ANR headsets over passive devices points to improvements in auditory perception for signals transmitted through the communication channels. Objective predictions based on the Articulation Index (Nixon et al., 1992) and the Speech Transmission Index (Steeneken and Verhave, 1996) procedures have demonstrated the speech intelligibility gains that can be realized. However, this has not always been achieved in practice (Gower and Casali, 1994). The frequency response of the communication channels and the effects of the ANR circuitry on the speech transmission quality are important determinants of intelligibility (Steeneken and Verhave, 1996). Several studies have also shown that ANR devices fail to operate when noise levels saturate the ANR circuitry, typically in the range of 120-135 dBA (Brammer et al., 1994). Other characteristics of the device affecting performance are the presence of transients or shut down periods after overload, and the comfort during use (Crabtree, 1996; Steeneken and Verhave, 1996).

4.3 ANR devices for binaural technology

Previous work:

ANR headsets have not been used extensively in binaural technology applications. Ericson and McKinley (1997) from the Armstrong Laboratory at the Wright-Patterson AFB (Ohio) reported a virtual audio presentation of speech communication signals over a Bose AH-1A headset, an ANR headset, configured for binaural operation. The HRTFs from the KEMAR manikin were measured at a 1° spacing in azimuth angle and used to simulate the virtual audio sources. The elevation angle of the sources was maintained fixed in the horizontal plane and distance cues were essentially absent. A head-tracking system measured the orientation of the listener's head and was used to maintain the virtual sources fixed in space.

Currently, the research group at the Armstrong Laboratory is utilizing the blocked ear canal method to derive the HRTFs and headphone equalization functions with the microphone inserted about 2-3 mm inside the canal entrance (McKinley, 1997). The critical factor is the repeatability of the microphone/plug location during the measurements. However, once a consistent fitting of the headset and microphone/plug assembly can be ascertained, they find no particular problems in equalizing their ANR headsets. To facilitate the equalization process, they choose headsets with matched left/right earphone drivers, typically within 2 dB in sensitivity. Tracking and integrating the head movements of the listener into the binaural simulation is found important for the perception of externalization of signals, and to maintain the highest possible speech intelligibility (McKinley, 1997).

Design criteria:

Commercial ANR headsets have not been specifically designed for binaural technology applications. The following criteria are proposed for the selection or design of a suitable ANR headset for experimentation with virtual audio signals. A minimal set of recommended electroacoustic specifications is given.

Listening mode ¾ The ANR headset must support stereo communication signals for dichotic listening as a pre-condition to a binaural technology application.

Volume control ¾ Headsets equipped with a single knob to control the signal volume under both earcups are preferred over headsets equipped with dual controls to independently adjust the volume in the left and right ears. Independent volume control interferes with the correct reproduction of ILDs from the virtual audio sources.

Cross-talk attenuation ¾ The amount of cross-talk attenuation between the left and right communication channels should exceed the maximum possible ILD in the free field plus a safety margin of about 10 dB. The maximum ILD arises for lateral incidence, and is typically 20-25 dB around 5 kHz and in excess of 30-35 dB above 8 kHz (Moller et al., 1995a; Wightman and Kistler, 1997).

Earphone linearity ¾ The earphone frequency response from the electrical input of the communication channel to the sound pressure output in the earcup must be linear over the full dynamic range of signal levels, and must be insensitive to environmental noise conditions. Two conditions are to be met: (1) the sound pressure output of the signal must grow linearly with the electrical input signal under constant environmental noise presented at different levels, and (2) the sound pressure output of the signal must remain constant for a constant electrical input signal under variable environmental noise levels.

Earphone frequency response ¾ The earphone frequency response must be as uniform and smooth as possible to simplify the headphone equalization procedure. The upper frequency limit depends on the location of the virtual audio sources in the intended application. In the case of virtual sources positioned in the horizontal plane and frontally, an upper frequency limit of 4-5 kHz may be adequate. In the case of sources distributed both in front and at the back, in the median plane, or elevated from the horizontal plane, an upper frequency limit of 8 kHz or more may be required.

Coupling to the ear ¾ The headset selected should provide a free-air equivalent coupling (FEC) to the ear, as defined in Moller et al. (1995a), to simplify the headphone equalization process when the blocked ear canal method is used. This could be verified by measuring the pressure difference ratio (PDR) of the headsets (Moller et al., 1995a), or by measuring the radiation impedance looking outwards from the ear canal using an artificial head with and without headset fitted (Schroeter and Poesselt, 1986).

Interaural earphone matching ¾ The interaural amplitude and phase matching in the earphone frequency response is obtained by equalizing independently the left and right sides at the headset. In cases where a single generalized equalization function is required, the left and right earphone transmission should be closely matched in frequency response and sensitivity.

Device selection:

The characteristics of nine commercial ANR headsets were assessed against the proposed design criteria (Abel and Giguère, 1997). The devices surveyed are listed in Table I. The manufacturers differ greatly in their methods of presenting the communication signals through the devices. For example, the Bose Aviation approach (Gauger, 1995) is based on the conventional feedback servosystem where the output, the sound pressure wave inside the earcup, is tracking a desired input, the electrical communication signal, while minimizing interfering noise. Thus, the effect of the ANR feedback loop on the communication signal must be compensated for by an equalization filter to flatten the transmission response. The communication signal of the Telex ANR Headset System is injected electronically just before the earphone transducer, but is subtracted from the sensing microphone output. The communication signal is in effect removed from the ANR feedback loop and its transmission becomes essentially insensitive to the operation of the ANR circuitry. A similar approach is used in the Sennheiser NoiseGard (Crabtree, 1997). The David Clark H1013X uses two earphone transducers, one for the communication signal and one for the ANR cancellation procedure (Crabtree, 1997).

Table I: Analog ANR communication headsets surveyed

Peltor ANR Aviation Headset
Sennheiser NoiseGard
Bose Aviation Headset
Bose Aviation Series II
David Clark DCNC Headset
David Clark H1013X
Telex ANR Headset System
Telex ANR 4000
TechnoFirst NoiseMaster

The survey showed that the most likely candidates for binaural technology applications are the Peltor, Sennheiser and TechnoFirst devices (see Abel and Giguère (1997) for additional technical details). They all support stereophonic listening, have a single control knob for volume control in both earcups, and provide good sound attenuation properties. Unfortunately, the manufacturers' specifications do not provide sufficient information to assess adequately all the technical characteristics necessary for binaural technology on any device. In particular, the amount of cross-talk attenuation, interaural earphone matching and type of coupling to the ear are essentially unspecified. In practice, earmuff-type ANR devices are likely to behave as FEC or near-FEC headphones because of their relatively large earcup volumes that are necessary for good low-frequency passive attenuation. Indeed, Schroeter and Poesselt (1986) found that the radiation impedance looking outwards from the ear canal is essentially unchanged above 0.4 kHz by fitting an earmuff-type hearing protector. Below 0.4 kHz, these hearing protectors do affect the radiation impedance of the ear, but then, this impedance is much smaller than the impedance looking into the ear canal. Under these conditions (Moller, 1992), earmuff-type ANR headsets could be considered FEC.

The commercial devices surveyed in Table I were all based on analog ANR technology. Prototype ANR devices based on digital technology have been tested in research laboratories in the past few years (Pan et al., 1995), and the first commercial digital ANR headsets have been recently introduced (e.g. Telex ANR-1D). Since binaural technology applications are also based on digital signal processing, digital ANR headsets could lead to more completely integrated and compact ANR-binaural systems than analog ANR headsets would allow. A particularly attractive digital ANR design for use with binaural technology is based on adaptive feedforward noise control. The feedforward control structure does not perturb the communication signals, and so offers the potential for higher fidelity reproduction than the commonly used feedback control structure (Brammer and Pan, 1998)

4.4 Aircraft cockpit application

The complexity of the binaural simulation depends on the requirements of the application at hand. In an aircraft cockpit application, very different listening situations could arise. Two extreme scenarios are detailed below.

Simple selective attention task:

In this task, the pilot must focus on the speech of one and only one speaker through the communication channel of the headset, in the presence of the environmental noise in the cockpit. Using binaural technology, the speech communication signal could be externalized and positioned in space to provide an angular separation with the environmental noise. The goal would be either to (1) maximize the speech intelligibility score for a given signal level, or (2) minimize the signal level for a given speech intelligibility score. For listeners with normal hearing or symmetrical hearing losses, a gain at the 50% speech intelligibility level up to about 4-6 dB with respect to diotic listening can be expected under the most favourable noise conditions (Section 2). Under conditions of reverberation, band-limited noise, or multiple noise sources, the speech intelligibility gain will be smaller. For listeners with asymmetrical hearing losses, the speech intelligibility gain due to ITDs is typically half that of normal-hearing listeners. Nonetheless, given the very steep slope of the intelligibility function near the 50% level, typically 15% per dB for sentence material, a gain of only a few decibels could give rise to substantial intelligibility improvements for all classes of listeners, but only in communication systems with low signal-to-noise ratios. It is also under conditions of low SNRs that the greatest benefits of ANR over passive communication headsets are anticipated for speech intelligibility.

In the simple listening application above, there is no localization task involved per se. Thus, the design of the binaural system could be simplified by the use of generic HRTFs (Section 3), particularly if a direction of incidence in the horizontal plane is selected for the virtual speech signals. Likewise, the benefits of synchronizing the binaural signal simulation with the head movements of the user may be minimal in this application, so the binaural signal procesing could be further simplified.

The selection of an optimal direction of incidence for the spatialized communication signal will depend on the characteristics of the environmental noise sound field at the location of the pilot's head. Cockpit noise spectra and levels are dependent on the type of aircraft, and the speed and altitude of the aircraft, among other factors (Rood, 1988). To achieve the maximal binaural speech intelligibility gain, the speech signal should be spatially separated from the noise by about 45° or more. However, several difficulties can arise because there are in general more than one source of noise in an aircraft, and the noise field in a typical cockpit is not free field. Another problem is that earmuff-type devices can severely disrupt the localization cues from external sounds (Abel and Hay, 1996). In practice, the sources of noise are large and distributed in typical aircrafts, and there is minimal or no acoustical treatment in the cockpit. Under these conditions, the environmental noise at the pilot's head could be classified as diffuse or quasi-diffuse, and thus the selection of a speech signal incidence would not be too critical.

An important related aspect to consider is the scaling of the binaural signal level at the ears. In a system where the HRTFs are synchronized with the head movements of the user, the sound exposure arising from the communication signal will vary with the selected direction of incidence. Moreover, if at any time the speech incidence lies outside the median plane, exposure from the speech signal will be asymmetric across the two ears, typically larger on the ipsilateral ear than the contralateral ear. A possible solution to maintain a constant and symmetric exposure is to scale the HRTFs with a direction-dependent gain so that the total speech energy becomes independent of sound incidence and equal in each ear. Another possibility, suggested by Bronkhorst and Plomp's (1988) experiments, is to scale the amplitude spectrum of each HRTF to a common reference amplitude spectrum, such as that corresponding to a frontal incidence, while keeping the phase spectrum intact. These solutions are based on the observation that it is the ITDs alone that provide a true binaural benefit for speech intelligibility (Section 2), and that accurate localization of the speech signal is secondary in this task.

Complex divided attention task:

At the other extreme, in a complex divided attention task, the pilot must attend to several speakers (e.g., co-pilot, pilots in other aircrafts, ground crew, etc.) through the communication channel of the headset, in the presence of cockpit noise. The pilot may also need to be alert to various visual targets in his/her environment that are cued to characteristic warning sounds. In this case, the speech signals from the different speakers and the other sounds to attend to would be externalized using binaural technology and positioned in space on the basis of ergonomic considerations. The goal would be to provide the user with a model of his/her complex acoustic environment in order to facilitate the interpretation of the various sources of information (Figure 2). The actual display design would depend on the specific demands placed on the user (Mack et al., 1998).

Localization errors, particularly elevation errors and front/back confusions, would be very detrimental in this application, because of the need to maintain a consistent spatial model of the environment. To maximize localization performance, this application would likely require individualized HRTFs and headphone equalization. It would also be highly desirable for ergonomic considerations and for optimizing accuracy in sound localization to track the head movements of the user and update the binaural simulation synchronously, so that the acoustic sources of information remained fixed in space. Because of the localization needs, both the ITD and ILD binaural cues are important in this task. This prevents manipulations of the amplitude spectrum of the HRTFs, other than applying a direction-dependent gain to each pair of left/right HRTFs.

5.0 CONCLUSIONS

This article reviewed the fundamental research and several practical aspects relevant to the integration of ANR and binaural technologies in the design of improved communication headsets, with particular attention to an aircraft cockpit application. ANR technology can reduces the interfering noise from the environment. Binaural technology allows the creation of 3D auditory displays to transfer coincident messages to different spatial positions.

In a simple selective attention task, the requirements of the binaural simulation are not very stringent as far as localization performance and the tracking of head movements are concerned, but careful consideration must be given to the direction of incidence of the environmental noise and to the scaling of the binaural signal levels. Under the most favorable conditions, a speech intelligibility improvement equivalent to a gain of 4-6 dB in SNR can be expected for this task with a ANR-binaural headset system over a system with ANR capabilities alone.

In a complex divided attention task, the binaural simulation system must provide for accurate sound localization performance, but the scaling of the binaural signals is less critical. The greatest benefits of 3D virtual auditory displays may well be found for this type of task, when there are more than two speakers or signals to attend to simultaneously (Ericson and McKinley, 1997). However, more fundamental research is needed to quantify the real advantage gained in terms of improved speech intelligibility, total information transfer, increased situational awareness or reduced workload fatigue (Begault, 1993; McKinley et al., 1994; Bronkhorst et al., 1996)

Commercial analog ANR communication headsets are not designed for binaural applications and would require extensive testing before making firm recommendations on specific devices. A list of features relevant to binaural technology includes the listening mode and volume control options, the cross-talk attenuation across the two channels, the earphone linearity, the earphone frequency response and degree of interaural matching, and the type of coupling to the ear. Newly developped digital ANR headsets may faciltate the integration with binaural technology.

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7.0 REFERENCES

Abel, S.M. and Hay, V.H. (1996). "Sound localization: The interactive effects of aging, hearing loss and hearing protection," Scand. Audiol. 25, 3-12.

Abel, S.M. and Giguère, C. (1997). "A review of the effect of hearing protective devices on auditory perception: The integration of active noise reduction and binaural technologies," Contract Report No. W7711-6-7316/001 SRV, Defence and Civil Institute of Environmental Medicine, Department of National Defence (Canada), 50 pp.

Abel, S.M. and Spencer, D.L. (1997). "Active noise reduction vs. conventional hearing protection: The relative benefits for normal-hearing and impaired listeners," Scand. Audiol. 26, 155-167.

Begault, D.R. (1993).). "Head-up auditory displays for traffic collision avoidance system advisories: A preliminary investigation," Human Factors 35(4), 707-717.

Blauert, J. (1997). Spatial Hearing: The Psychophysics of Human Sound Localization, Revised Edition (MIT Press, Cambridge).

Brammer, A.J., Ryan, J.G., Zera, J. and Pan, G.J. (1994). "Attenuation of active noise reducing headset at high sound pressure." Vth Int. Symposium on the Effects of Noise on Hearing, Gothenburg, Sweden (May).

Brammer, A.J. and Pan, G.J. (1998). "Opportunities for active noise control in communication headsets," Canadian Acoustics 26(3), 32-33.

Bronkhorst, A.W. and Plomp, R. (1988). "The effect of head-induced interaural time and level differences on speech intelligibility in noise," J. Acoust. Soc. Am. 83, 1508-1516.

Bronkhorst, A.W. and Plomp, R. (1989). "Binaural speech intelligibility in noise for hearing-impaired listeners," J. Acoust. Soc. Am. 86, 1374-1383.

Bronkhorst, A.W. and Plomp, R. (1992). "Effect of multiple speechlike maskers on binaural speech recognition in normal and impaired hearing," J. Acoust. Soc. Am. 92, 3132-3139.

Bronkhorst, A.W. Veltman, J.A. and van Breda, L. (1996). "Application of a three-dimensional auditory display in a flight task," Human Factors 38(1), 23-33.

Casali, J.G. and Berger, E.H. (1996). "Technology advancements in hearing protection circa 1995: Active noise reduction, frequency/amplitude-sensitivity, and uniform attenuation," Am. Ind. Hyg. Assoc. J. 57, 175-185.

Cherry, E.C. (1953). "Some experiments on the recognition of speech, with one and with two ears," J. Acoust. Soc. Am. 25, 975-979.

Crabtree, R.B. (1996). "Constraints in the application of personal active noise reduction systems." Proceedings of the 82nd AGARD Meeting, Copenhagen, Denmark (October).

Crabtree, R.B. (1997). Personal communication.

Durlach, N.I., Rigopulos, A., Pang, X.D., Woods, W.S., Kulkarni, A., Colburn, H.S. and Wenzel, E.M. (1992). "On the externalization of auditory images," Presence 1, 251-257.

Ericson, M.A. and McKinley, R.L. (1997). "The intelligibility of multiple talkers separated spatially in noise," In: Binaural and Spatial Hearing in Real and Virtual Environments, edited by R.H. Gilkey and T.R. Anderson (Erlbaum, Mahwah, NJ), pp. 701-724.

Gauger, D. (1995). "Active noise cancellation for military aircraft and vehicles." Military Med. 19, 2-7.

Gower, D.W. Jr., and Casali, J.G. (1994). "Speech intelligibility and protective effectiveness of selected active noise reduction and conventional communication headsets," Human Factors 36(2), 350-367.

Januška, I. (1983). "Influence of the mutual position of speech and noise sources on speech intelligibility in noise," In: Proceedings of the 11th Int. Congress on Acoustics, Paris, France, Vol. 4, pp. 53-56.

Levitt, H. and Rabiner, L.R. (1967a). "Binaural release from masking for speech and gain in intelligibility," J. Acoust. Soc. Am. 42, 601-608.

Levitt, H. and Rabiner, L.R. (1967b). "Predicting binaural gain in intelligibility and release from masking for speech," J. Acoust. Soc. Am. 42, 820-829.

Mack, C.I., Churchill, L.L. and Arrabito, G.R. (1998). "Results of a survey on audio and visual warning systems for military helicopters, " Canadian Acoustics 26(3), 42-43.

McKinley, R.L, Erickson, M.A. and D'Angelo, W.R. (1994). "3-Dimensional auditory displays: Development, Applications, and Performance," Aviation, Space, and Environmental Medecine, May, A31-A38.

McKinley, R.L., Steuver, J.W. and Nixon, C.W. (1996). "Estimated reductions in noise-induced hearing loss by application of ANR headsets," In: Scientific Basis of Noise-Induced Hearing Loss, edited by A. Axelsson, H. Borchgrevink, R.P. Hamernik, P.-A. Hellstrom, D. Henderson and R.J. Salvi (Thieme, New York), pp. 347-360.

McKinley, R.L. (1997). Personal communication.

Moller, H. (1992). "Fundamentals of binaural hearing," Appl. Acoust. 36, 171-218.

Moller, H., Hammershoi, D., Jensen, C.B. and Sorensen, M.F. (1995a). "Transfer characteristics of headphones measured on human ears," J. Audio Eng. Soc. 43, 203-217.

Moller, H., Sorensen, M.F., Hammershoi, D. and Jensen, C.B. (1995b). "Head-related transfer functions of human subjects," J. Audio Eng. Soc. 43, 300-321.

Moller, H., Sorensen, M.F., Jensen, C.B. and Hammershoi, D. (1996). "Binaural technique: Do we need individual recordings?" J. Audio Eng. Soc. 44, 451-469.

Nixon, C.W., McKinley, R.L., and Steuver, J.W. (1992). "Performance of active noise reduction headsets," In: Noise-Induced Hearing Loss, edited by A.L. Dancer, D. Henderson, R.J.

Salvi, and R.P. Hammernik (Mosby, St. Louis), pp. 389-400.

Pan, G.J., Brammer, A.J., Zera, J. and Goubran, R. (1995). "Application of adaptive feed-forward active noise control to a circumaural hearing protector," In: Proceedings of Active 95, Newport Beach, California (July), pp. 1319-1326.

Plomp, R. and Mimpen, A.M. (1981). "Effect of the orientation of the speaker's head and the azimuth of a noise source on the speech-reception threshold for sentences," Acustica 48, 325-328.

Rood, G.M. (1988). "Noise and communication", In: Aviation Medicine, 2nd ed., edited by J. Ernstig, and P. King (Butterworths, London), pp. 353-382.

Santon, F. (1986). "Intelligibilité, de la parole masquée et rôle de la direction de la source masquante," Acustica 61, 67-74.

Santon, F. (1987). "Détection d'un son pur dans un bruit masquant suivant l'angle d'incidence du bruit. Relation avec le seuil de réception de la parole," Acustica 63, 222-228.

Schroeter, J. and Poesselt, C. (1986). "The use of acoustical test fixtures for the measurement of hearing protector attenuation. Part II: Modeling the external ear, simulating bone conduction, and comparing test fixture and real-ear data," J. Acoust. Soc. Am. 80, 505-527.

Shaw, E.A.G. (1974). "Transformation of sound pressure level from the free field to the eardrum presented in the horizontal plane," J. Acoust. Soc. Am. 56, 1848-1861.

Steeneken, H.J.M. and Verhave, J.A. (1996). "Personal active noise reduction with integrated speech communication devices: development and assessment," Proceedings of the 82nd AGARD Meeting, Copenhagen, Denmark (October).

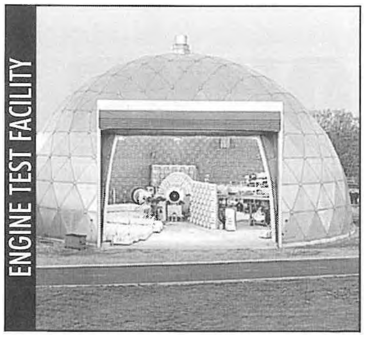
Wallach, H. (1940). "The role of head movements and vestibular and visual cues in sound localization," J. Exp. Psychol. 27, 339-368.

Wightman, F.L. and Kistler, D.J. (1989). "Headphone simulation of free-field listening. II: Psychophysical validation," J. Acoust. Soc. Am. 85, 868-878.

Wightman, F.L. and Kistler, D.J. (1997). "Factors affecting the relative salience of sound localization cues," In: Binaural and Spatial Hearing in Real and Virtual Environments, edited by R.H. Gilkey, and T.R. Anderson (Erlbaum, Mahwah, NJ), pp. 1-23.

Wightman, F.L. and Kistler, D.J. (1999).). "Resolution of front-back ambiguity in spatial hearing by listener and source movement," J. Acoust. Soc. Am. 105, 2841-2853.

Yost, W.A. (1997). "The cocktail party problem: forty years later." In: Binaural and Spatial Hearing in Real and Virtual Environments, edited by R.H. Gilkey and T.R. Anderson (Erlbaum, Mahwah, NJ), pp. 329-347.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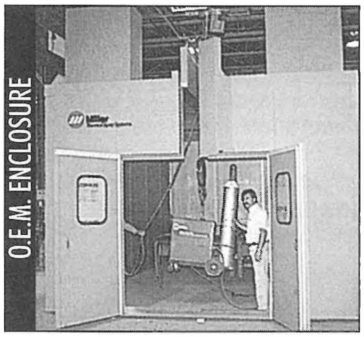
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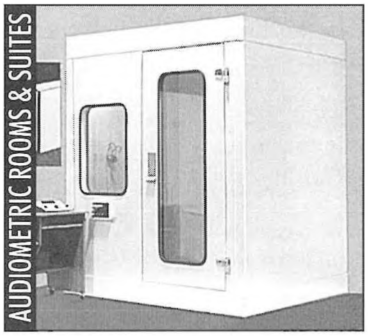
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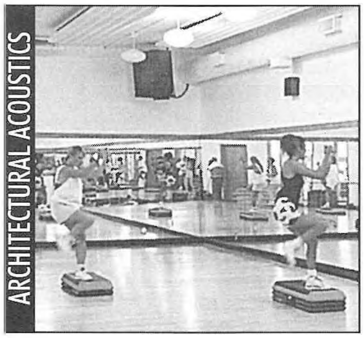
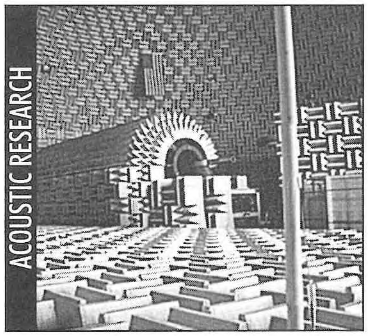
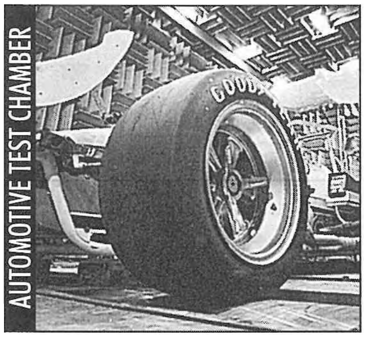

ARCHITECTURAL ACOUSTICS


ACOUSTIC RESEARCH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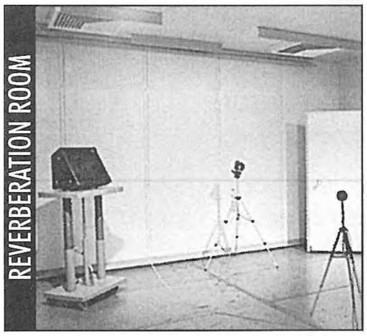
REVERBERATION ROOM

CONTROL OF BOILER NOISE IN A HIGH RISE BUILDING

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ABSTRACT

A case study is presented concerning the control of low frequency noise from gas pulse-fired hot water boilers. Basic acoustic principles of open ended pipes and of expansion chamber mufflers have been used to assist in understanding the nature of the noise problem and devising a solution.

SOMMAIRE

On présente une étude sur le contrôle aux fréquences graves du bruit généré par deux chaudières à eau chauffées par gaz plusé. Les principes acoustiques de base des tuyaux à bout ouverts et des silencieux à chambres d'expansion aident à comprendre le problème et à trouver une solution.

1.0 INTRODUCTION

This case study has a very noisy and dramatic start, and, thankfully, a peaceful and satisfactory ending. The case is interesting in that it involved an innovative approach to noise control through some basic application of muffler theory.

The boilers supplying domestic hot water to a high rise apartment building had recently been replaced by two high-efficiency pulse-fired gas hot water boilers. The boilers are located in an equipment room in the basement of the building, with both fresh air supply and exhaust being catered for through a single 300 mm diameter duct with an in-line fan. Figure 1 shows the system as it was immediately after the installation of the new boilers. The 300 mm duct with its in-line fan drew fresh air from an external vented shaft and expelled a mixture of fresh air and boiler exhaust into an underground manhole, vented to the atmosphere at grade level.

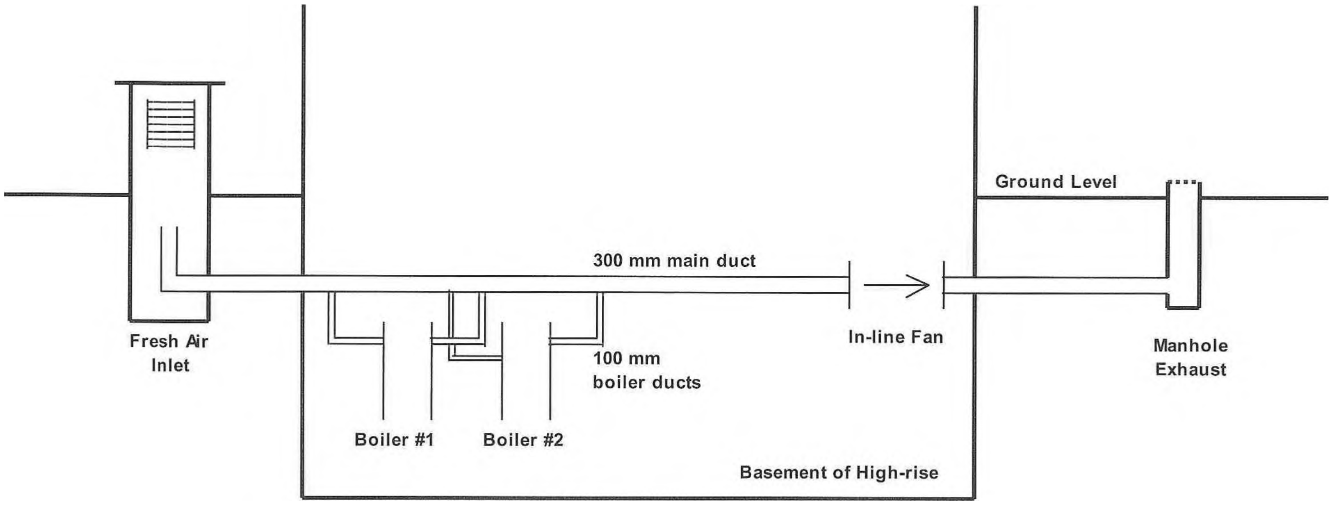
The system had operated in this configuration for some weeks without significant problems or excessive noise. However, there was a concern that, in the event of heavy rains or a blockage, high water levels could block the system outlet in the storm water manhole. It was decided that the manhole should be extended vertically to approximately 2.4 m above ground level and that the system exhaust pipe would be extended to above ground level within the extended manhole as shown in Figure 2.

It was during the construction of the extension to the manhole that events took on a very dramatic turn. The extension was to be constructed of concrete blocks. As the contractor removed the manhole cover and started to lay the concrete blocks, noise from the boilers became louder and louder. Indeed the low frequency noise was so intense that it was shaking the mortar out of the fresh blockwork. Even though it was winter, the boilers had to be shut down for several hours to allow the construction of the manhole extension to be completed. Once the mortar was sufficiently set, the boilers were turned back on, restoring the supply of hot water for the residents of the high rise. However, the noise level from the system exhaust, i.e. the extended manhole, was very high and gave rise to complaints from neighbouring residents. It was described as sounding like a trumpet, or perhaps more accurately like a sousaphone or didgeridoo since the pitch of the noise was quite low.

At this point Technical Services staff of Ottawa-Carleton Housing, who manage the building, contacted the author to seek assistance in diagnosing the problem and controlling the noise.

2.0 INITIAL INVESTIGATION AND ANALYSIS

During the initial site visit, the boilers and associated ductwork were inspected and sound pressure measurements were made at a distance of 10.4 m from the system exhaust outlet, i.e. 10.4 m horizontally from the top of the manhole. The noise had a strong low frequency tone. This is illustrated by the noise spectrum, see Figure 3, which shows strong peaks in the 40 and 50 Hz 1/3-octave bands. When both boilers were operating, the low frequency tone exhibited a distinct beating at a period of approximately 1.5 seconds. The beating did not occur when either of the boilers was operated separately. The level of the exhaust noise could be reduced



Note: Several bends in main duct not shown.

Figure 1. Schematic Diagram of Boiler System.

by about 6 dB by partially covering the opening at the top of the manhole, however the low frequency noise was still quite noticeable.

It was suspected that the source of the noise was the pulse firing of the boilers. On contacting the manufacturers of the boilers, it was found that the firing rate was indeed 44 Hz. 44 Hz is on the border between the 40 and 50 Hz 1/3-octave bands, which explains why sound levels in both bands are high.

The beating of the sound when both boilers are operating is also explained by a small difference in the firing rates of the two boilers. It immediately sprung to mind that if the boilers firing cycles could be locked 180° out of phase, then the sound could be minimised. Unfortunately, the boiler manufacturer said that this was not possible with their firing control systems.

The question still remained as to why the noise from the boilers had increased so markedly when the exhaust arrangements were altered. It seemed likely that duct system was resonating in some way and that quite likely the exhaust arrangement had something to do with this resonance. In air, 44 Hz sound waves have a wavelength, λ, of 7.8 m. The length of the extended manhole is 5.6 m, which is approximately $3\lambda/4$. This turned out to be a critical relationship as discussed below.

A pipe with one end open and the other closed has acoustic resonances at a series of frequencies which are related to the effective length of the pipe[1]. The effective length, L', is the actual length of the pipe, L, plus an end correction which for a straight pipe is $0.3D$, D being the diameter of the pipe, i.e. $L' = L + 0.3D$. For the manhole this yields the following.

$$L' = 5.6 + 0.3*0.95 = 5.9 \text{ m}$$

A series of resonances occur when the effective length of the pipe coincides with one of the following multiples of the wavelength of the sound.

$$\lambda/4,\ 3\lambda/4,\ 5\lambda/4,\ \ldots.$$

It can be seen that the effective length of the extended manhole is very near to being equal to $3\lambda/4$ or 5.85 m, which is the second in the above series of resonances for sound with a frequency of 44 Hz. Given the presence of other complicating factors, such as the entry pipe at the bottom of the manhole, it seems highly likely that this explains why the

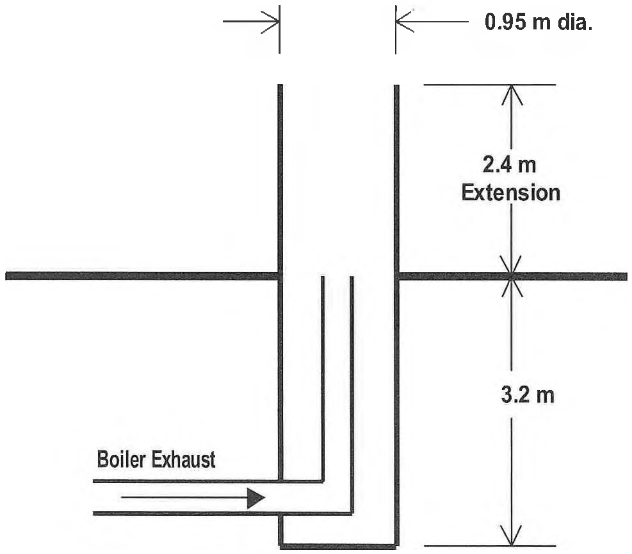


Figure 2. Initial Change to Exhaust Arrangement (manhole extended above ground)

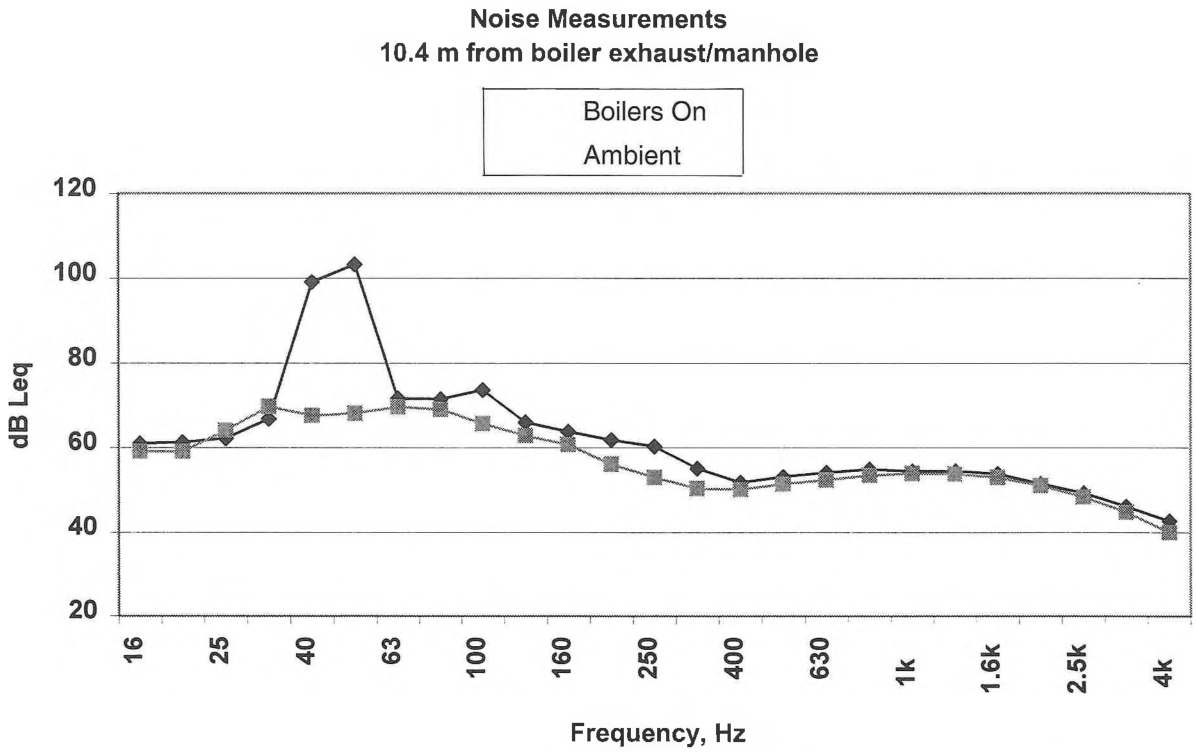


Figure 3 **Noise Spectrum, L_{EQ}, of Boiler Exhaust with Manhole Extende (Please see Figure 2).**

exhaust noise became so loud when the manhole was extended.

In simple terms it appears that a near perfect organ pipe or didgeridoo had been inadvertently created for the boilers firing at 44 Hz.

3.0 DESIGN AND TESTING OF A TEMPORARY MUFFLER

Because of the disturbance caused by the noise in the neighbourhood, something had to be done quickly. Two options were available.

Option 1, Manufacturer's Mufflers: The manufacturer of the boilers said they could supply mufflers which would fit in the 100 mm inlet and exhaust ducts which connect the boilers to the larger 300 mm duct, see Figure 1. Four mufflers would be required for the two boilers, one in each inlet duct and one in each exhaust duct. The manufacturer's mufflers were expansion chamber type mufflers, approximately 1.2 m long by 200 mm diameter with internal absorptive lining.

The author had a degree of doubt about the likely effectiveness these mufflers in this situation. The mufflers seemed rather short considering the wavelength of the sound, 7.8 m. The manufacturer of the boilers was able to supply some data on the attenuation performance of the proposed mufflers, however, the data had some inconsistencies in the frequency bands of interest and the tests had been conducted under quite different ducting arrangements.

Option 2, In-situ Muffler: It occurred to the author that it would be relatively simple to convert the manhole into an expansion chamber type muffler as shown in Figure 4.

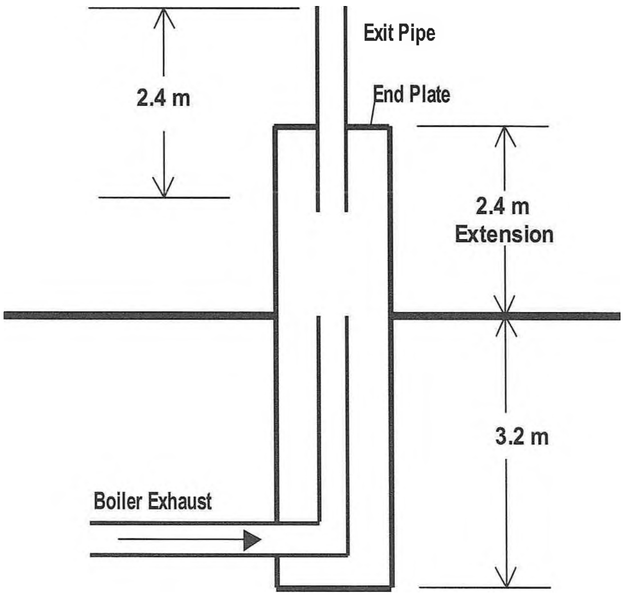


Figure 4. Temporary In-situ Muffler.

A simple theory for expansion chamber mufflers suggests that the performance is dependent on the following parameters.

A = cross sectional area of the exit pipe
l = length of the exit pipe
d = diameter of the exit pipe
l' = effective length of the exit pipe
= $l + 0.6d$
V = volume of the chamber
c = speed of sound, 344 m/s in air
f = exciting frequency, 44 Hz (firing rate)
f_o = chamber resonance frequency, Hz

$$f_o = \frac{c}{2\pi}\sqrt{\frac{A}{l'V}}$$

IL = insertion loss of muffler,

$$IL \approx 40Log_{10}\left(\frac{f}{f_o}\right) \quad \text{for} \quad f \gg f_0$$

It was decided to construct and test a temporary version of the in-situ muffler since this could be readily constructed from available materials. A 2.4 m length of 300 mm diameter PVC pipe was used as the exit pipe with a steel plate acting as an end plate, see Figure 4. Approximately half of the end pipe protruded above the end plate.

Using the above relationships, this configuration gives the following theoretical results.

f_o = 4.55 Hz
IL = 39.4 dB

The results of sound level measurements made with and without the in-situ muffler in place are shown in Table 1. It can be see that with the in-situ muffler in place, the sound has been attenuated by 25 to 30 dB, i.e. very close to background levels. Background levels are quite high because the high-rise building is located adjacent to a busy urban road.

	1/3 octave band	
	40 Hz	**50 Hz**
No Muffler (as per Figure 2)	99 dB	103 dB
In-situ Muffler (as per Figure 3)	74 dB	72 dB

Table 1 Measured Sound Pressure Level, L_{eq}
(10.4 m from manhole)

It was not expected that the insertion loss calculated by the above simple theory would be directly applicable to the boiler exhaust system. The construction of the temporary muffler is in effect a replacement of a resonant end pipe with a muffler. If anything one might expect a better performance than the calculated insertion loss.

The above temporary in-situ muffler was left in place for a number of weeks until a longer term solution to the problem could be put in place. This simple arrangement could not be a permanent solution because condensation in the boiler exhaust soaked the concrete blocks in the manhole. With the freezing and thawing cycles of the Ottawa winters, all this moisture would eventually fracture the walls of the manhole.

4.0 A LONGER TERM SOLUTION

Either of the above two options could have been pursued as longer term solutions. If the in-situ muffler was to last in the long term, it would need to be made of more durable materials. One suggestion was to construct the in-situ muffler from PVC pipes of various sizes, making it just small enough to fit within the existing manhole.

It was decided instead to try the boiler manufacturer's mufflers. If these worked satisfactorily, then they had the advantage of being off-the-shelf items, which would be housed in the equipment room within the high-rise building.

One inlet muffler and one exhaust muffler were first tested on one of the boilers. Despite the author's doubt about the effectiveness of these mufflers, they performed well.

Manufacturer's mufflers were then fitted to both boilers and at the same time, the 300 mm exhaust pipe was extended completely through the manhole to a height of approximately 1.5 m above the end plate. With both boilers operating, this arrangement led to sound pressure levels of 76 and 78 dB in the 40 and 50 Hz 1/3-octave bands respectively. Although this performance is not quite as good as the temporary in-situ muffler, the attenuation is still enough to prevent complaints from neighbours.

5.0 CONCLUSIONS

The case study did have a satisfactory ending in that noise from the boilers was controlled and the neighbours satisfied. It was also pleasing to find that basic acoustical principles of pipe resonances and of expansion chamber mufflers could be successfully applied.

The case study also illustrates that simple prediction methods should be applied with caution. Although the theoretical results discussed above predicted the general trends, the detailed results were not accurately predicted.

6.0 ACKNOWLEDGEMENTS

The author wishes to thank George Kinnear, Director of Technical Services, Ottawa-Carleton Housing, for his support and permission to publish this case study. The important roles of the following people in carrying out the project is also gratefully acknowledged: Roger Tuttle and Andy Mutch of Ottawa-Carleton Housing and Walter Liston of Baxtec Mechanical Services.

7.0 REFERENCES

N. Fletcher, “The Didjeridu (Didgeridoo)”, Acoustics Australia, Vol. 24, No. 1, pp. 11-15, 1996.

D. A. Bies and C. H. Hansen, “Engineering Noise Control”, Unwin Hyman, 1988.

ACOUSTICAL RENOVATION OF THE ORPHEUM, VANCOUVER

I. MEASUREMENTS PRIOR TO RENOVATION

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2 - National Research Council of Canada, Ottawa, Ontario

ABSTRACT

This paper reports measurements and analyses of acoustical conditions in The Orpheum, the home of the Vancouver Symphony. These measurements were made prior to renovations to the hall and were an integral part of designing those renovations. The measurements were derived from impulse responses both on-stage and at audience seats in the hall and for several configurations of the hall. Average values of several common room acoustics parameters are compared to the range of values from other halls. Measurements of conditions on-stage indicate conditions were in the range of normally accepted values. The variation with distance of sound levels and decay times is seen to be different at locations under the balcony than on the balcony. The existing over-stage reflectors were found to be useful on-stage. The large balcony overhang leads to reduced late arriving sound levels at seats under the balcony.

SOMMAIRE

Cet article présente les mesures et analyses des conditions acoustiques dans L'Orpheum, la salle de concert de l'Orchestre Symphonique de Vancouver. Ces mesures ont été prises préalablement à la rénovation de la salle et ont été une partie integrante du projet de rénovation. Les mesures ont été dérivées des réponses impulsionelles sur-scène ainsi qu'aux sièges des spectateurs dans la salle, et pour quelques configurations de la salle. Les valeurs moyennes de quelques paramètres acoustiques sont comparées aux valeurs des autres salles. Les mesures des conditions sur-scène indiquent que les conditions sont dans la portée des valeurs acceptables. La variation des niveaux sonores et la durée de décroissance du son avec distance est différent pour les endroits en dessous et sur le balcon. On a constaté que les réflecteurs existants par-dessus la scène sont utiles sur-scène. Le surplomb large du balcon réduit les niveaux des sons qui arrivent plus que 80 ms après le son direct aux sièges en-dessous du balcon.

1.0 INTRODUCTION

The Orpheum Theatre is a 2800 seat vaudeville house that was renovated for the Vancouver Symphony in the 1970s. The acousticians responsible for the work were Bolt Beranek and Newman of Cambridge, USA in collaboration with Barron and Associates of Vancouver. The project leaders for the respective firms were Ted Shultz and Ken Barron. Funds ran out prior to completion and some problematic conditions remained for the following fifteen years. Although The Orpheum is the principal home of a symphonic orchestra, it is not a concert hall in the classical 19th century sense. It is, rather, a modification of a proscenium arch vaudeville theatre that is now often used as a concert hall. As such, there have been some notable acoustical short comings including: excessive room noise, a long balcony overhang that compromises sound for a significant portion of the audience seated under the balcony and a curved ceiling that has produced disturbing focussed sound and acoustical image shifts. For patrons seated in the front of the balcony, the orchestral balance was poor and it was not unusual to hear voices or instruments that appeared to be located somewhere above the ceiling. In the 1970s, some plastic reflectors had been placed over the stage. These blocked important lighting positions and their acoustical efficacy had always been in doubt. Finally, an electro-acoustic system had been installed underneath the balcony in an effort to negate the effects of the very long balcony overhang. The system had been tampered with over the years and had long since fallen into disuse.

Vancouver Civic Theatres proposed a long term renovation project to address these and other issues. The subject of this paper is to describe the measurements and analyses that were carried out in an effort to understand these various problems. It is intended that subsequent papers will describe how solutions to these problems were developed and implemented. These subsequent papers will describe (i) subjective evaluations to determine the detection thresholds of focussed reflections and (ii) acoustical scale model studies to develop design solutions and full scale tests to verify the success of the modifications to the hall.

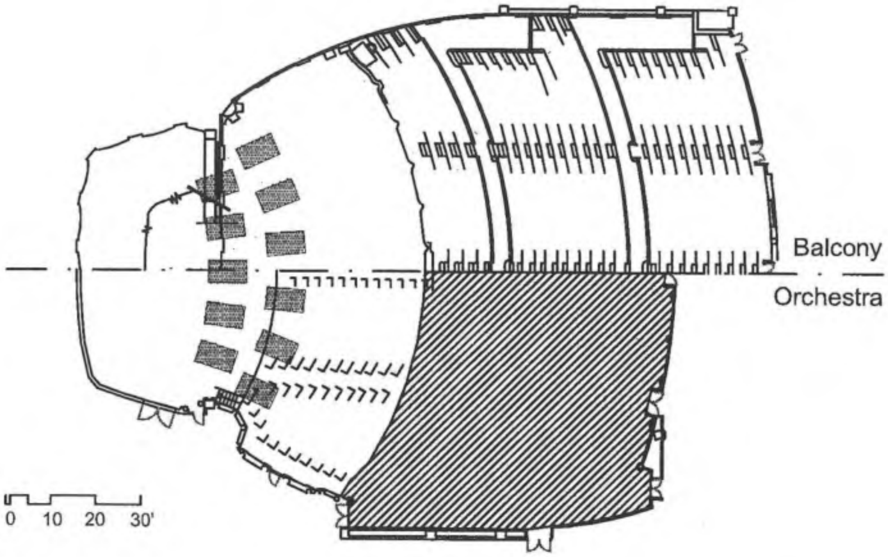

Figure 1. Schematic Details of the Orpheum Theatre, Vancouver (Plan).

It is hoped that the measurement results published in this paper will serve as a useful record of the acoustical conditions in this significant Canadian hall, as found in 1994. It is also hoped that the measurement and analysis procedures reported here represent a good example of the current state of the science of concert hall acoustics with respect to resolving practical problems in halls. Finally, the range of the acoustical problems in The Orpheum, shown in Figure 1, is quite unique and makes it possible to demonstrate a large number of problems for a single venue.

2.0 MEASUREMENT PROCEDURE

2.1 MEASUREMENTS AND MEASUREMENT SYSTEMS

All measurement results reported in this paper were obtained in 1994 before any changes were made to The Orpheum. Two different acoustical measurement systems were employed, one by Aercoustics Engineering Limited and the other by the National Research Council. For the measurements prior to the renovations (reported here) the Aercoustics system was used for stage measurements and the NRC system for the audience measurements. After the renovation, all measurements were performed with the Aercoustics system.

2.1.1 The Aercoustics System

The Aercoustics system used a Maximum Length Sequence System Analyser (MLSSA) manufactured by DRA Laboratories. Measurements were performed using a Maximum Length Sequence of order 15, i.e. 32,767 points per period. Sound was radiated by dodecahedron source with 75mm diameter loudspeakers. Responses were measured with an omni-directional Bruel & Kjaer Type 4165 microphone, powered by a Bruel & Kjaer 2230 sound level meter.

2.1.2 The NRC System

The RAMSoft II software, developed by NRC used a larger dodecahedron loudspeaker with 105 mm drivers powered by a 400 watt Carver power amplifier. This system was also computer based and used a 15th order maximum length sequence source signal. The signals from two microphones were amplified by a Stanford Research programmable filter amplifier controlled by the program and the output was digitized by a 16 bit Analog Devices converter. For all but one parameter, a Bruel & Kjaer Type 4165 omni-directional microphone was used. For Lateral Fractions, an AKG EB414 figure-of-eight microphone was also used with the sensitive lobes pointed towards the side walls.

2.1.3 Stage Measurements

For the ease of performance, the acoustics of a good stage must satisfy a delicate balance. The stage must reflect enough energy back to a performer so that he can hear his own instrument and maintain intonation. If too much energy is returned though, the musician may not be able to hear his associates and orchestral ensemble will suffer.

Stage measurements were performed at and between five locations corresponding to typical positions of a: Soloist, Violin, Viola, Horn and Bass. Support ratios (ST_{total} and ST_{late}) were measured at a distance of 0.5 m from the dodecahedron sound source. The stage measurements were made in 1994 prior to the renovations and both with and without the plastic over-stage reflectors in place. The measurement procedure is based on the one developed by Gade (1,2,3). Gade has established correlations between ST_{total} and the subjective parameter musicians refer to as Support. Naylor (4) has referred to a similar parameter as Hearing of Self.

Gade's original work on stage acoustics measurement applied a 1.0 m source receiver distance. Naylor used a 0.5 m source receiver distance, suggesting that it is closer to the actual conditions experienced by performers on stage. Stage measurements reported here were performed at a 0.5 m source receiver distance. (There is no simple conversion factor between measurements taken at 0.5 and 1.0 m. On an empty stage a simple spherical divergence correction of 6 dB might apply. On a stage with chairs, music stands and musicians the difference is in the range of 4 dB.)

2.1.4 Audience Measurements

Measurements were performed at all combinations of fifteen different seating locations in the audience seating and 3 different source locations on the stage for a total of forty-five measurements for each of three conditions of the hall. Because the hall is laterally symmetrical, the seat locations were all on the same side of the room. Nine were on orchestra level, six were distributed evenly across the balcony and two were near the front cross-aisle of the balcony where a profound image shift was noted. The source locations were at centre stage, 2 m from the foot and 3 m to the left and right of the central location, and 1 m further back. Source and receiver heights were 1.5 m and 1.2 m respectively.

One of the first questions posed by both the owners and users of The Orpheum was the efficacy of the plastic reflectors located above and slightly in front of the stage. There were two rows of 1.5 x 2.6m reflectors, 6 in one row above the foot of the stage and 5 in a second row above the front of the audience. It was this second row that was interfering with lighting positions.

Three sets of audience measurements were performed for different conditions of the hall prior to renovations in February 1994 - Plastic reflectors removed; Plastic reflectors in place, under balcony enhancement off; and Plastic reflectors in place, under balcony enhancement on.

The purpose of these last three sets of measurements was to: (i) determine the efficacy of the plastic reflectors located over the stage and (ii) determine the efficacy of the electro-acoustics sound system installed underneath the balcony during the 1970s renovation.

	Octave Band (Hz)					
Parameter	125	250	500	1000	2000	4000
RT_{60} (sec)	3.23	2.41	1.97	1.79	1.51	1.30
EDT (sec)	3.01	2.28	1.82	1.61	1.16	1.16
C_{80} (dB)	-3.4	-1.4	0.6	2.3	2.4	3.2
G (dB)	3.4	1.5	2.1	1.8	-0.6	-2.6
LF	0.14	0.19	0.18	0.17	0.19	0.22

TABLE 1. **Orpheum Audience Measurements**

	Octave Band (Hz)				
Parameter	250	500	1000	2000	4000
ST_{total}	20.1	21.7	23.7	25.6	25.2
EDT	1.82	1.67	1.81	1.33	1.15
ST_{late}	22.0	23.6	26.4	29.0	29.2

TABLE 2. **Orpheum Stage Measurements**

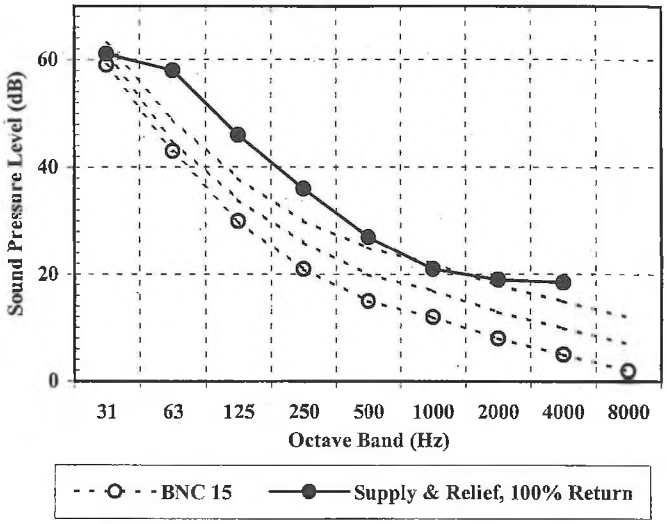

Figure 2. Balcony HVAC noise levels.

2.1.5 Dummy Head Measurements

Binaural impulse responses were obtained using a variation of the RAMSoft measurement system with a Bruel and Kjaer head and torso simulator. Measurements were repeated with and without the Plastic reflectors installed over the stage. These were used to calculate inter-aural cross correlation measures but these are not included here. The binaural impulse responses were also convolved with music for subjective evaluations of the focussed reflections observed at some balcony seat locations.

3.0 RESULTS

Average Results for the Base Case Consisting of Plastic Reflectors in Place and the Enhancement System Operating Audience Measurements are shown in Tables 1and 2.

3.1 HVAC Noise

Noise control work on The Orpheum's HVAC system was never completed during the 1970s renovation. When the money ran out, work was halted on the spot. Unfortunately, silencers and other noise control equipment were not installed. For the next twenty years, noise from the fans and pumps has remained a problem. Measured noise levels are shown in Figure 2. The dashed lines indicate the Balanced

Noise Criteria (NCB) used to assess the noise levels. Ideally a concert hall should have a NCB of 10 to 15. The measured levels on the balcony are well in excess of this and in the range of NCB 35.

3.2 Flutter Echo

Although not quantified directly in our measurements, there was an audible flutter echo in the audience chamber of The Orpheum. There was also a pronounced echo on the stage, which will be discussed in Section 3.5.

3.3 Comparisons with Other Concert Halls

Comparisons have been made between the (space) average measurement results from The Orpheum and a number of concerts halls listed in Table 3. Data associated with Table 3 is taken from the survey carried out by the Concert Hall Research Group (5).

Figures 3 to 7 compare the average measured values for audience seats in The Orpheum with the range of average values from the halls in listed in Table 3. In each figure the solid lines are the average measured values obtained in The Orpheum for the base case with the plastic stage reflectors in place. The error bars indicate the spatial standard deviation of the measured values. In Figures 3 to 7 the dashed line indicates the average measured result for the case with the plastic stage reflectors removed. The grey shaded area indicates the range of average values from the eleven halls listed in Table 3. Although we now know that the Reverberation Time is subjectively less important than the Early Decay Time (6), it does possess convenient relations to other physical properties of the hall. Figure 3 gives average measured Reverberation Times and illustrates that the spatial variation of the Reverberation Time is quite small. The average values of the Early Decay Time are found in Figure 4.

Location	Auditorium	Seats
Toronto	Massey Hall	2,500
Detroit	Orchestra Hall	2,022
Philadelphia	Academy of Music	2,984
Cleveland, Ohio	Severance Hall	1,890
Boston, Mass.	Symphony Hall	2,631
Buffalo	Kleinhans	2,839
Akron, Ohio	E.J. Thomas	2,969
Washington, DC	Kennedy Centre	2,759
Worcester, Mass.	Mechanics Hall	1,400
Baltimore	Meyerhoff Concert Hall	2,467
Troy	Music Hall	1,235

TABLE 3. **Concert Halls.**

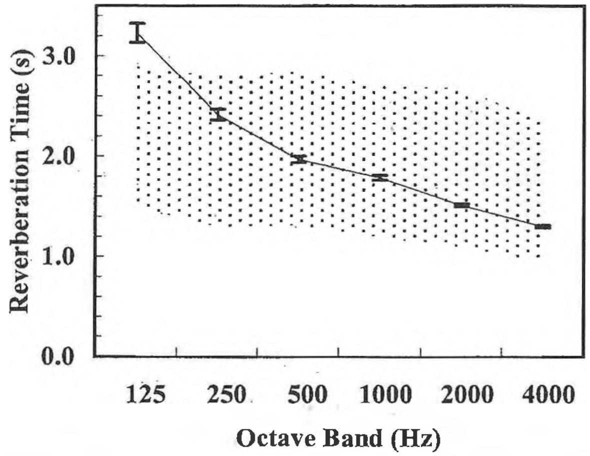

Figure 3. Comparison of Reverberation Time with North American concert halls, listed in Table 1.

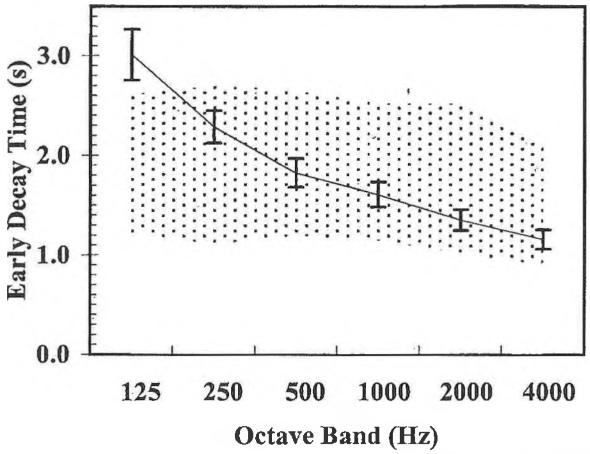

Figure 4. Comparison of Early Decay Time with North American concert halls.

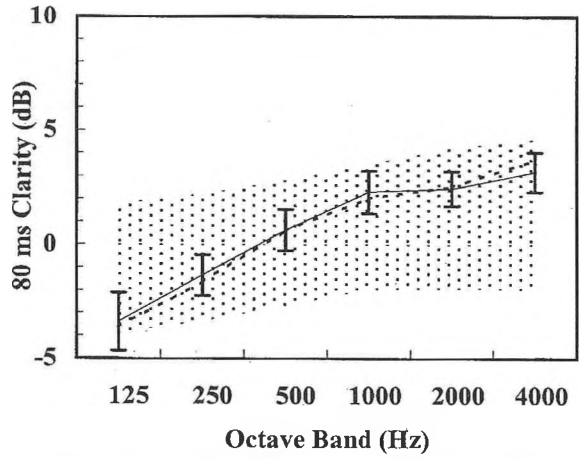

Figure 5. Comparison of musical Clarity with North American concert halls.

The preferred decay time for a concert hall is 2 seconds at middle frequencies and a little longer at lower frequencies. The Orpheum has a longer low frequency (125 Hz) decay time than any of the other eleven North American Halls. At high frequencies, the decay seems to be shorter than average.

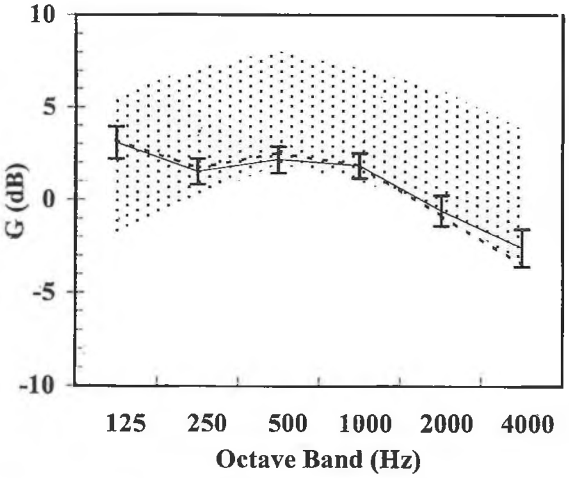

Figure 6. Comparison of Strength with North American concert halls, listed in Table 1.

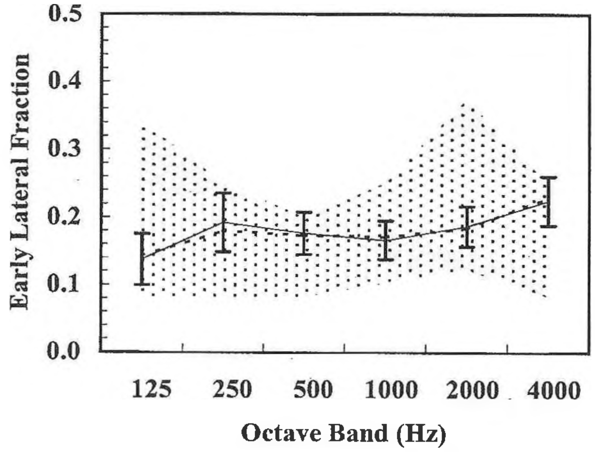

Figure 7. Comparison of Early Lateral Fraction with North American concert halls.

The mid-frequency (250 Hz to 2 kHz) average Reverberation Time is 1.92 seconds, the average Early Decay Time is 1.77 seconds. Although sound decays are often assumed to be exponential, it is quite common for the initial decay to be a little more rapid than the later decay as indicated by these mid-frequency reverberation and early decay times. In The Orpheum, as in other similar rooms, the Early Decay Time is significantly reduced underneath the long balcony overhang, while the Reverberation Time hardly changes at all.

Figure 5 compares the average measured Clarity (C80) with the average values from the other eleven halls. For mid and high-frequencies, Clarity in The Orpheum is greater than the average of the other halls. Since Clarity tends to be inversely related to Reverberance, this naturally follows from the shorter than average Early Decay Times shown in Figure 4. Strength values (G) indicate the effect of the hall on the level of sounds. The average Strength values in Figure 6 indicate that The Orpheum is close to the bottom of the range of values found in the other halls. Thus sounds will tend to appear to be weaker in The Orpheum. There are two reasons for this. First, The Orpheum, at 2800 seats is larger and Strength is inversely proportional to room volume. Second, the long balcony overhang leads to particularly low G values at seats under the balcony which, in turn, bring down the overall average G values.

In spite of this general trend, the average measured Strength in the lowest 125 Hz octave band is relatively stronger and above the average of the other halls. The Strength of low frequency sounds has been shown to relate to the perceived Strength of bass sounds in halls (7) and hence this result explains the reputation of The Orpheum to have a warm sound.

The Early Lateral Energy Fraction, ELF, is a measure of spatial impression and specifically relates to source broadening (8,9) and the ELF results are shown in Figure 7. One expects that in general Early Lateral Energy Fractions will be lower in wide halls. Compared to other concert halls, The Orpheum is very wide. Vienna's Musikvereinssaal, for example is 20 m wide, compared to 35 m in The Orpheum. In spite of its width the average measured ELF is about average, slightly less than 0.2 .

3.4 Stage Comparisons

Musicians' ability to hear themselves on stage is quantified by the acoustical parameter called Support (ST_{total})(3), shown in Figure 8. In this bar chart the optimum range is approximately -16 dB ±2 dB. At levels greater than this, the musician may not be able to hear his associates. At levels below this range, he may not be able to hear himself. With both rows of reflectors installed above the stage, Support on The Orpheum stage falls within the optimum range and is similar to values measured at Kitchener's Centre in the

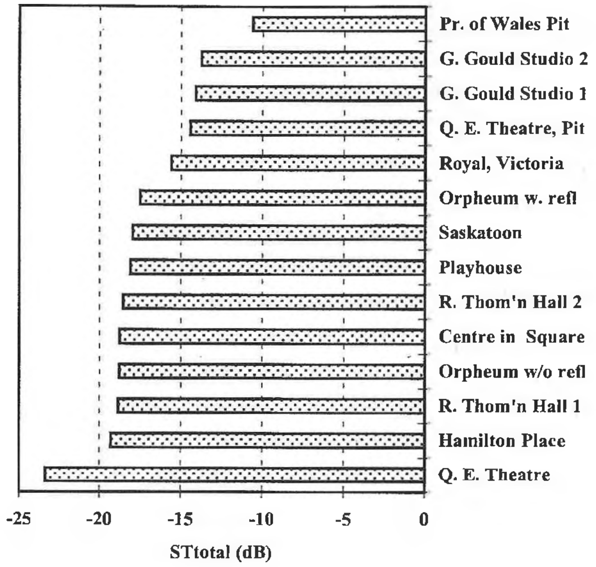

Figure 8. Comparison of Orpheum's Support (Hearing of Self) with other halls.

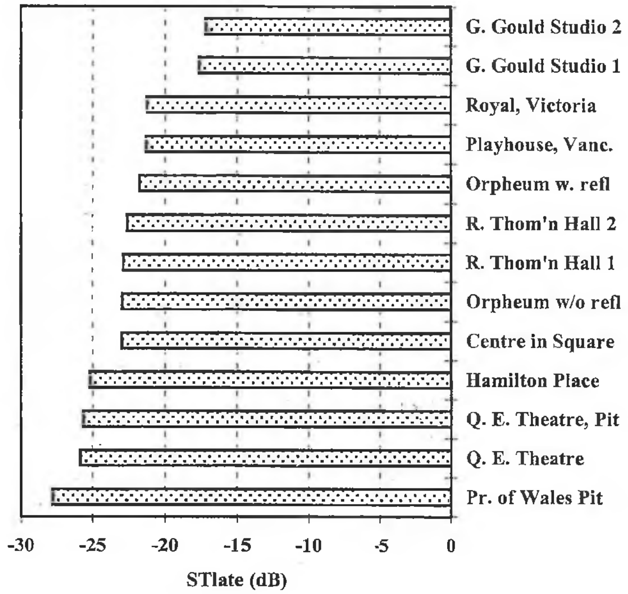

Figure 9. Comparison of Orpheum's Late Reverberant Energy with other halls.

Square and Roy Thomson Hall in Toronto. Reverberance heard by musicians on stage is quantified by ST_{late} (3). In the Orpheum it is about average and does not change when the plastic stage reflectors are removed. Please see Figure 9.

3.5 The Effect of the Plastic Reflectors

3.5.1 Audience Effects

The solid lines in Figures 3 to 7 are averaged measured values for the case with the over-stage plastic reflectors in place while the dashed lines represent levels measured when the reflectors were removed. Thus one can determine the average effects of the plastic reflectors at audience seats by comparing the dashed line and the solid line on each of Figures 3 to 7. These comparisons show that there is little or no difference in the audience chamber when the reflectors are removed. In some cases at low frequencies, there is very little difference and in these figures the dashed line is hard to see. At higher frequencies there is a slight difference but it is much less than the standard deviation indicated by the vertical bars. In other words, the effect of the reflectors is less than would be experienced by moving to a different seat. These differences are all less than the difference limen for in each of these quantities. Difference limen for Reverberance is usually taken as 0.1s (10). For Clarity, difference limen have been established at 0.67 dB (11). Although difference limen for Strength have not been determined, it is normally assumed that for most sound level measures that differences as small as 1 dB can be detected.

The effect of the plastic reflectors was also assessed subjectively. Measured binaural impulse responses were convolved with anechoic music and played back to listeners. The result was a series of fifteen second samples of Handel's Water Music and the Marriage of Figaro overture with and without the reflectors in place. The listening rig was developed by Soulodre and Stammen (12). It consists of two small loudspeakers enclosed in open ended boxes When the subject places his head between the speakers, the combination of the boxes and his head effectively eliminates the need for an anechoic space and cross-channel compensation. Back to back blind listening tests were performed informally by a four groups of listeners including the authors, the architects and members of Vancouver Opera and the Vancouver Symphony, respectively. It was very difficult to tell the difference between the two conditions and no one could express a conclusive preference for one or the other.

The conclusion drawn from this exercise is that the reflectors do not have a significant affect on listening conditions in the audience chamber.

3.5.2 Stage Effects

A three dimensional computer model study suggested that the reflectors were effective at producing on-stage reflections. In particular there were a number of reflections directed towards the front part of the stage. Figure 8 and Figure 9, above, include stage measurements with and without the reflectors in place. The reflectors appear to have a minimal affect on Support (Hearing of Self). There is a noticeable change in reverberant energy (ST_{late}) when the reflectors are removed. The change is for the worse.

The more significant stage effects however are associated with Ensemble reflections (Hearing of Other). This was probably the main reason why the over-stage reflectors were installed in the first place, although there is no way of knowing for sure. Modulation Transfer Functions (a reliable measure of Hearing of Other (4)) were significantly reduced between the Violin and Bass sections when the reflectors were removed.

In 1978, Marshall et al. (13) found that musicians are more sensitive to reflected sound arriving from above than in the horizontal plane. This suggests that, in terms of Ensemble, stage ceilings and overhead reflectors are more important than wall surfaces. The tests with the musicians also suggested that reflections that arrive between 17 and 35 ms after the direct sound are more useful than others. Using this optimum temporal window, the following parameter was devised and investigated. It is a simple ratio of the sound arriving between 17 and 35 ms to the sound that arrives between 0 and 10 ms. The latter is, for all intents and purposes, the direct sound (15).

The ensemble sound is evaluated from Equation 1. The results, calculated fron Equation 1 and presented in Figure 10 to Figure 12, show that the reflectors in The Orpheum and Centre in the Square significantly affect Ensemble

Reflections but that at Roy Thomson Hall, the change is hardly noticeable.

$$\text{Ensemble Reflections} = 10\log\frac{\int_{17}^{35\,\text{ms}} p^2(t)dt}{\int_{0}^{10} p^2(t)dt} \qquad (1)$$

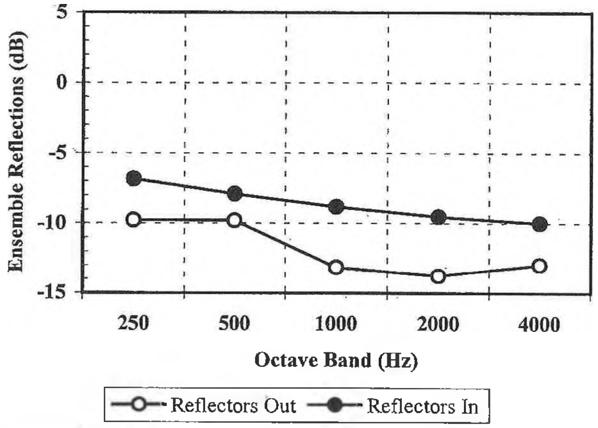

Figure 10. Direct and reflected sound in Orpheum.

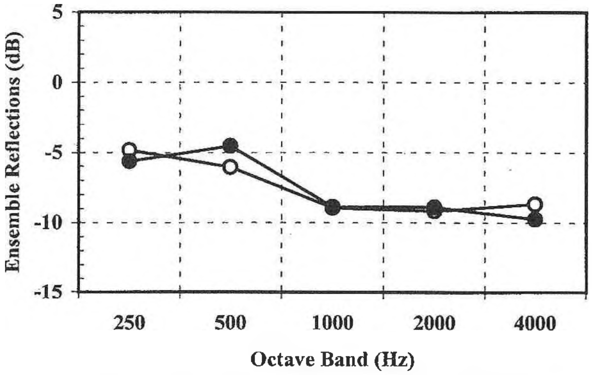

Figure 11. Direct and reflected sound in Roy Thompson Hall, Toronto.

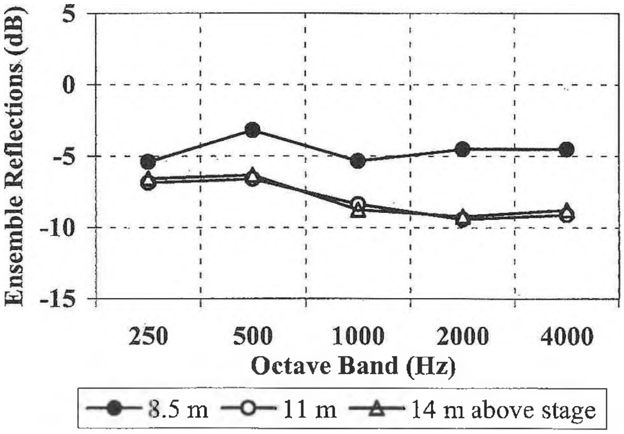

Figure 12. Direct and reflected sound in Center in the Square, Kitchener, Ontario.

An interesting comparison may be made between The Orpheum and The Centre in the Square in Kitchener, Ontario. The overhead reflectors for these two stages are profoundly different. As indicated above, only five of the small reflectors at The Orpheum actually cast reflections on the stage. Conversely, the reflector at the Centre in the Square covers almost the entire orchestra platform and weighs over 30 tons. Figure 10 and Figure 12 however suggest that the important 17 to 35 ms ensemble reflections are equally affected. It was concluded therefore that the upstage row of reflectors (the ones furthest from the audience) do in fact have significant acoustical merit and should not be removed without some form of compensation.

3.5.3 On-Stage Echo

The users of The Orpheum have identified a problem with an echo on the stage. The echo can be heard between upstage right and upstage left and appears to be coming off the back wall of the house. This is a fairly significant problem and its solution is not simple. In the test configuration, the dodecahedron loudspeaker was placed upstage right and the measurement microphone symmetrically upstage left. Figure 13 shows significant reflected energy at approximately 245 ms after the direct sound. This corresponds approximately to the time delay that one would expect for reflections off the back wall of the balcony.

A study of the frequency content of the direct and reflected components reveals further interesting information. The reflected sound is lower in amplitude at both high and low frequencies. Attenuation of the higher frequencies is to be expected. By the time the sound has returned to the stage, it has travelled some 250 ft through the air and, through absorption by the air, it losses some of its higher frequency content.

The low frequencies show evidence of "seat dip" attenuation. Evidence of seat dip in the 245 ms reflection is useful because it suggests the sound has travelled across the seating.

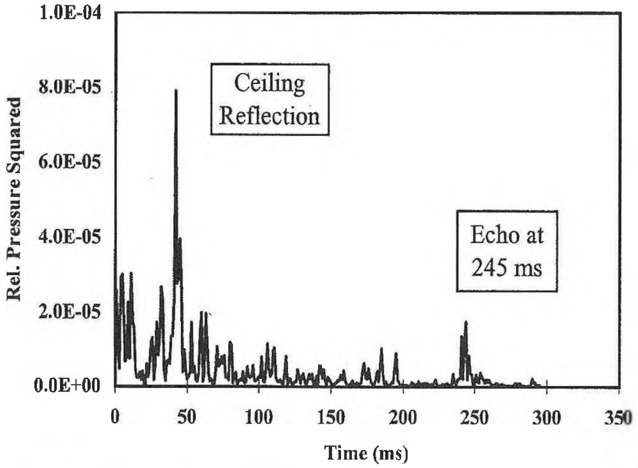

Figure 13 Measurements on The Orpheum stage sound. (strong reflections at 45 ms and 245 ms)

From this we can conclude that the path of the reflected sound is off one of the back walls and not, for example, directly off the dome located in the centre of the audience ceiling.

3.6 The Propagation of Sound in the Audience Chamber

The propagation of sound within The Orpheum was examined using linear regression plots of decays times and sound levels versus source-to-receiver distance. Figures 14 and 15 show that both reverberance and loudness decrease significantly as one moves from the front to the back of the audience chamber. One might hope that these parameters would not vary greatly with distance, but in reality this rarely happens. Research in the 1980s has shown that fan shaped rooms or rooms with too much diffusion demonstrate subjectively significant reductions in Early Decay Times and Strength (G) towards the back of the room (16). Here subjective significance can be judged in terms of two simple facts. Ideal concert halls have reverberation times in the range of 2.0 seconds, but for opera houses preferred reverberation times would be in the range of 1.2 seconds. Doubling the enclosed volume of the hall decrease levels by 3 dB.

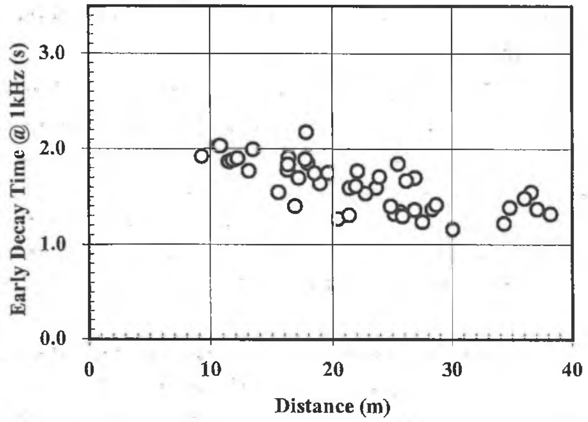

Figure 14. Variation of Early Decay Time inside the audience chamber.

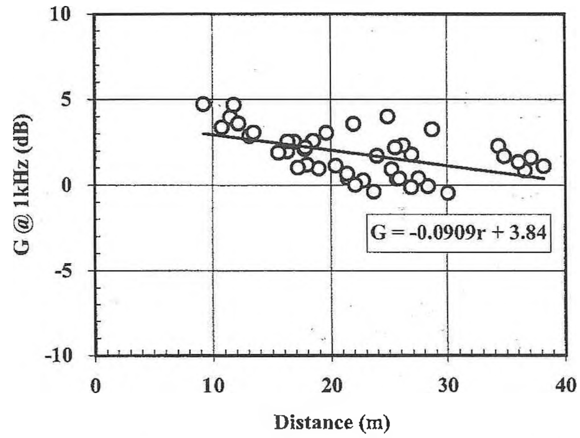

Figure 15. Variation of Strength inside the audience chamber.

Thus, Figure 14 suggests that the reverberance at 10 m from the stage is similar to what one would prefer in a concert hall but at the back of the room, the reverberance is closer to that experienced in a typical opera house. Likewise, in terms of loudness, Figure 15 shows that seats at the back will experience the sound of an orchestra sound that is "half as big" as the one heard near the front of the room (i.e. the level has decreased by 3 dB). The two preceding figures have grouped all the data for all measurement locations together. It was also desired to determine the effect of the exceptionally long balcony overhang. In the following plots the measurements obtained at seats located under the balcony are separately identified from those in the balcony.

In Figure 16 the Early Decay Times decrease quite significantly on both the orchestra and balcony levels. Decreased reverberance is to be expected on the orchestra level with its long balcony overhang but the decrease on the balcony level is surprising. It is probably due to the proximity of ceiling. Considering the Early Decay Times in isolation, one would expect that listening conditions at the back of the balcony would be less desirable. However, popular opinion suggests that these are some of the best seats in the house. The fact that the Early Decay Time is shorter than optimum only reinforces the argument that concert hall acoustics is a multidimensional experience. Other aspects of the sound near the top of the balcony must compensate for the short Early Decay Time. The two most likely candidates being Loudness and Intimacy.

In Figure 17 we see that, as expected, the loudness, as measured by G, decreases most rapidly on the orchestra level where many seats are under the balcony overhang. On the balcony, the linear regression formula shows a rate of attenuation of 0.064 dB/m. This compares favourably with other concert halls and is about the same as the Musikvereinssaal in Vienna (0.06 dB/m) (18).

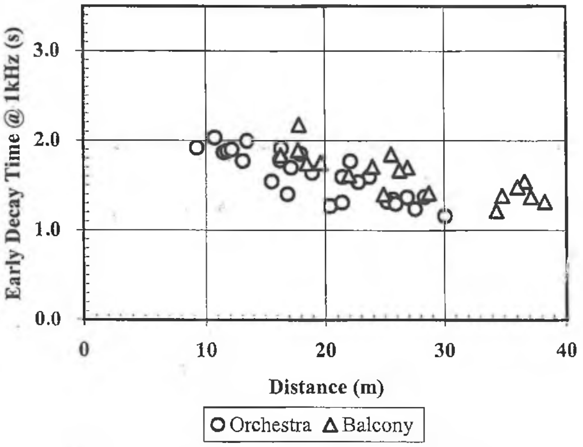

Figure 16. Variation of Early Decay Time in balcony and orchestra levels.

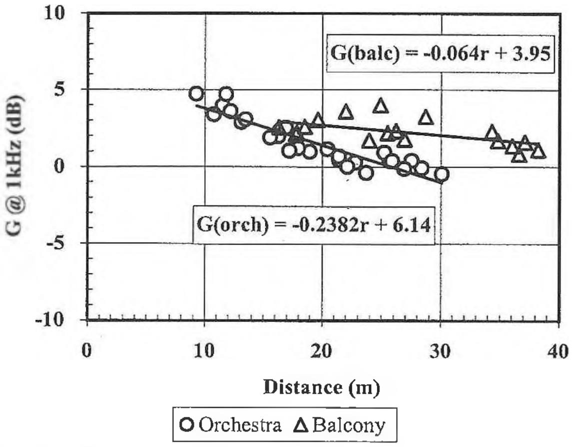

Figure 17. Variation of Strength in balcony and orchestra levels.

The early and late components of the sound were also examined. Physically, early and late components are influenced by different factors and subjectively they lead to different perceived effects. G_{80} refers to the Strength of the sound received in the first 80 ms which includes the direct sound and the important early reflections. G_{late} is the Strength of the reflected energy arriving more than 80 ms after the direct sound. Figure 18 demonstrates that early reflected energy underneath the balcony is really not much different from the levels measured on top of the balcony. Figure 19 on the other hand, shows a clear difference in late energy measured above and below the balcony.

From this we conclude that it is only the late reverberant energy that is lacking under the balcony. This is a rather interesting finding and one that has recently been confirmed in a study of British concert halls (16). It means that the enhancement system used to improve the sound under balcony seats should be designed to increase the late energy and need not enhance the sometimes difficult aspects of early reflected sound.

There is another design advantage that could be developed from this situation. Recent work by Bradley and Soulodre (10) has shown that late energy is an important aspect of spatial impression. Until their work, it was thought that good spatial impression in a room was generated by strong *early* reflections that arrive at the listeners from the side. It turns out that there are two distinct aspects of spatial impression, *apparent source width* and *listener envelopment.* Early lateral reflections generate a sensation of apparent source width (where the sound of a piano fills the stage) and late lateral energy generates a sensation of listener envelopment (where the piano fills the whole room). Bradley and Soulodre found a strong correlation between listener envelopment and the Strength of the late lateral energy (LG_{late}).

The Early Lateral Fraction, incidentally is good above and below the balcony, suggesting a good apparent source width. To summarise, the seats underneath the balcony could be improved by adding late energy and preferably late *lateral* energy. These seats already have sufficient early lateral energy.

In the 1970s, an attempt was made to introduce room reverberance underneath the balcony. Microphones were hung from the ceiling near the stage. It is not clear why they chose that position. It is possible that they were simply trying to maximise the musical signal at the microphones to minimise possible feedback problems. It is also possible that they were trying to maintain a short time delay between the direct sound and the first reflection - the so-called Initial Time Delay Gap. In hindsight and with the advantage of recent research,(12) we know that this Initial Time Delay Gap is not important in this situation. For seats under The Orpheum balcony, it now seems preferable to reduce the amount of early energy that we pick up in our microphones.

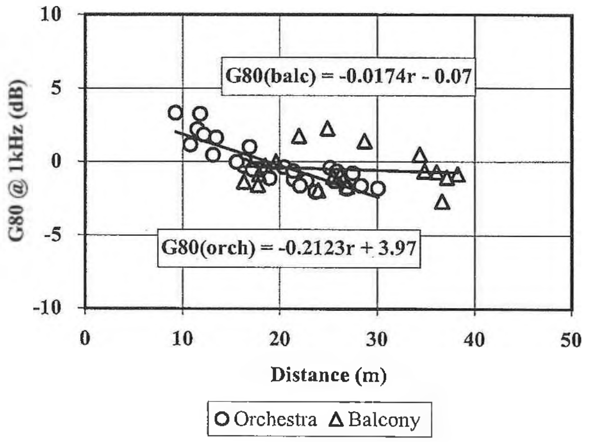

Figure 18. Variation of Early Reflected Sound in balcony and orchestra levels.

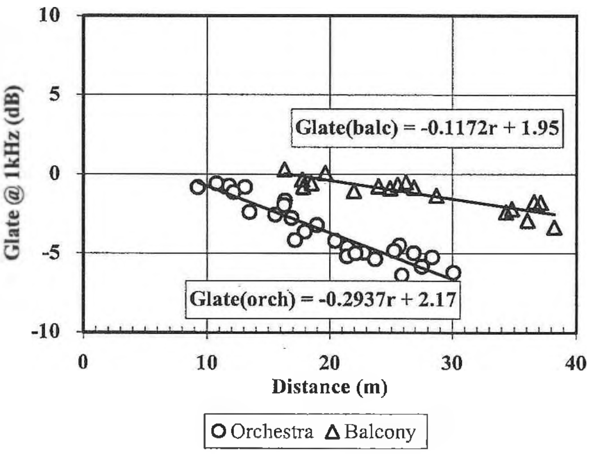

Figure 19. Variation of Later Energy Level in balcony and orchestra levels.

One solution was to move the microphone locations further back into the audience. If, in addition, a directional microphone is employed, with its sensitive lobes pointed at the side walls, it would be possible to further de-emphasise some of the frontal sound and increase the emphasis on the lateral energy. With careful selection of time delays and speaker combinations, one could easily provide listeners underneath the balcony with the late lateral energy required to promote listener envelopment.

4.0 CONCLUSIONS

A complete set of modern acoustical measurements were performed prior to a major renovation of Vancouver's Orpheum Theatre. The measured values indicated that while average mid-frequency reverberation times were close to ideal, Early Decay Times were a little bit shorter. Hence, perceived reverberance was a little less than optimum. Similarly, measured Clarity was a little greater than average. The average measured Strength was lower than many other halls and indicated that orchestral sounds would have tended to be weaker in The Orpheum. On the other hand, average measured Early Lateral Energy Fractions were comparable to those in many other halls indicating that some aspects of spatial impression were quite satisfactory.

With the plastic over-stage reflectors in place on-stage support was quite acceptable. An evaluation of the effectiveness of the over-stage plastic reflectors indicated that they had little effect at audience seat locations but they provided important benefits on stage.

Both Early Decay Times and sound levels decreased with increasing distance from the source. Early Decay Times were markedly lower at the rear of the hall suggesting that these seats would have experienced less reverberance. This decrease with distance also contributed to the average Early Decay Times being lower than the Average Reverberation Times. These decreases with distance were most noticeable at seats under the balcony. It was clearly shown that what is most lacking at under-balcony seats was later arriving sound energy. This indicates that the under-balcony enhancement system should mostly increase later arriving sound energy which would lead to an improved sense of envelopment at seats under the balcony.

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6.0 REFERENCES

1. GADE, A.C., 'Subjective Room Acoustics Experiments with Musicians', Ph. D. Thesis, Report No. 32, (Technical University of Denmark, 1982).
2. GADE, A.C., "Investigations of Musicians' Room Acoustic Conditions in Concert Halls. II Field Experiments and Synthesis of Results, Acustica, 69, pp 249-259 (1989).
3. GADE, A.C., "Practical Aspects of Room Acoustics Measurements on Orchestra Platforms", Proc. 14th ICA, Beijing, Paper F-35 (1992).
4. NAYLOR, G.M. "Modulation transfer and ensemble music performance", Acustica, 65, p 127 (1987).
5. O'KEEFE, J., "On the Sensitivity of Stage Acoustics Measurements", Proc. W.C. Sabine Centennial Symposium, pp. 223-226 (1994).
6. Bradley, J.S. "Data from 13 North American Concert Halls" Internal Report 668, July 1994 Institute for Research in Construction, National Research Council.
7. ATAL, B.S., SCHROEDER, M..R. & SESSLER, G.M., "Subjective Reverberation Time and its Relation to Sound Decay", 5th International Congress on Acoustics, Liege, Paper G32.
8. BRADLEY, J.S., SOULODRE, G.A., & NORCROSS, S., "Factors Influencing the Perception of Bass", J. Acoust. Soc. Am., Vol. 101, No. 5, Pt. 2, p.3135, (1997).
9. BARRON, M. & MARSHALL, A.H. "Spatial Impression due to early lateral reflections in concert halls: the derivation of a physical measure", J. Sound & Vib. 77, p. 211-32.
10. BRADLEY, J.S., SOULODRE, G.A. "Influence of late arriving energy on spatial impression", JASA, 97 pp.2263-2271 (1995).
11. CREMER, L & MUELLER, J (translated by SCHULTZ, T.J), "Principles and Applications of Room Acoustics, Vol. 1", Applied Science Publishers, New York, (1979).
12. COX, T.J., DAVIES, W.J. & LAM, Y.W. "The Sensitivity of Listeners to Early Sound Field Changes in Auditoria" Acustica 79, pp 27-41 (1993).

13. SOULODRE. G.A., STAMMEN, D.R., "A Binaural Simulator for Conducting Subjective Studies of Concert Hall Acoustics", Proc. W.C. Sabine Centennial Symposium, pp. 267-270 (1994).

14. MARSHALL, A.H., GOTTLOB, D. & ALRUTZ, H. 'Acoustical Conditions Preferred for ensemble', J. Acoust. Soc. Amer. 60, p. 1437 (1978).

15. O'KEEFE, J., "Acoustical Measurements On Concert And Proscenium Arch Stages", Inst. of Acoustics - Opera House & Concert Hall Symposium, February 1995.

16. BARRON, M., LEE, L.J. 'Energy relations in concert auditoriums. I', J. Acoust. Soc. Am. 84, pp 618-628 (1988).

17. BRADLEY, J.S. 'Hall Average Conditions of 10 Halls', 13th Int. Congress on Acoustics, 2, pp 199-202, Belgrade (1989).

18. BARRON, M., "Balconies in Concert Halls", 15th International Congress on Acoustics, Trondheim, 2, p. 369-373 (1995).

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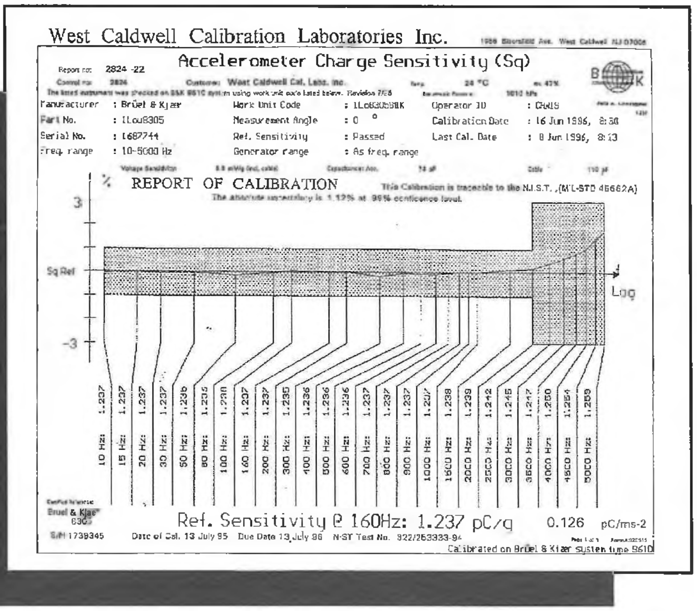

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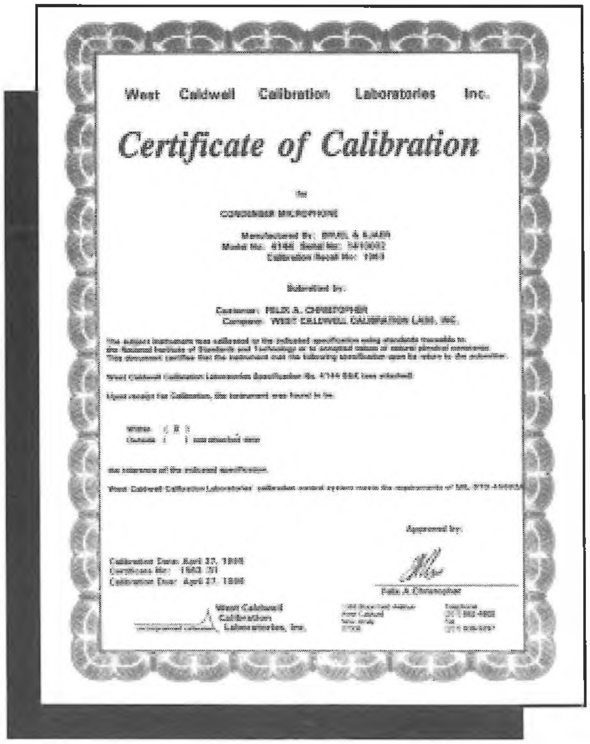

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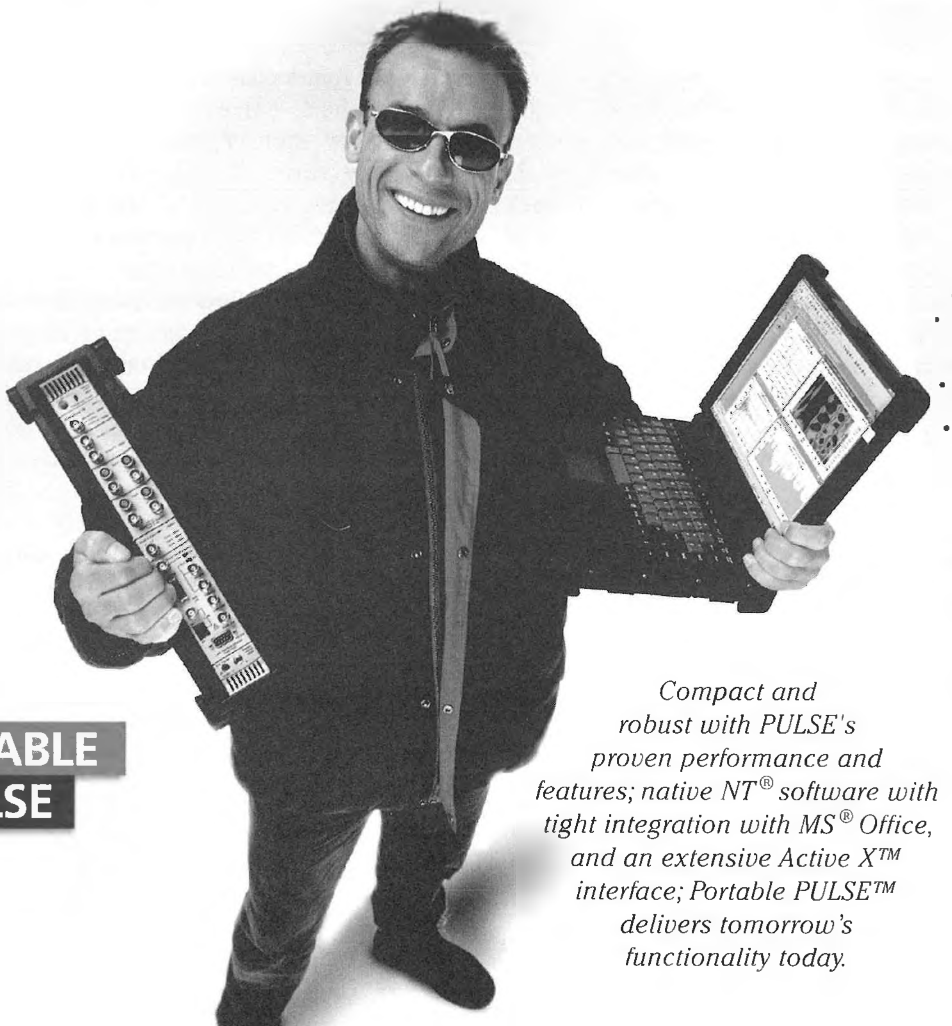

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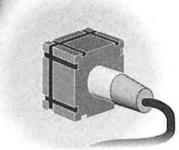

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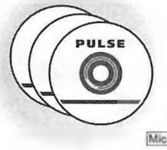

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Finland (0)9-755 950 · France (01)69906900 · Germany 06103/908-5 6 · Hong Kong 25487486 · Hungary (1)2158305 · Ireland (01)4504922
Italy (02)57604141 · Japan 03-3779-8671 · Republic of Korea (02)3473-0605 · Netherlands (0)318 559290 · Norway 66771155 · Poland (22)8409392
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Brüel & Kjær

"Computational Acoustics in Architecture," Edited by J. J. Sendra, WIT Press, Southampton. Publishers: Computational Mechanics Inc., Pages – 177, Price: US$140.00, ISBN Number – 1 85312 5571.

The title seems to suggest that the above book is a compendium of algorithms to calculate acoustical parameters useful in the field of architecture. While perusing the book, one realizes that the intentions are quite different. The book aims to present introductory materials on common physical and perceived acoustical parameters usually computed in the field of architectural acoustics. The book contains six chapters edited by J. J. Sendra of University of Seville, Spain. Each chapter is written by a set of individual specialists.

No book on architectural acoustics (at least published within the last 50 years) would be complete without some contributions from the three senior practitioners, namely L. L. Beranek, M. R. Schroeder and Y. Ando. The book under review follows that trend and includes chapters by Professors Schroeder and Ando.

The first chapter by Prof. Schroeder, deals with 'reverberation' and 'diffusion' and is adapted from a larger article in the Encyclopaedia of Electrical and Electronics Engineering published by John Wiley and Sons Inc. The chapter, very succinctly, introduces general ideas about sound rays in rooms leading to the fundamental concepts of reverberation and diffusion. The chapter does not do justice to the two major descriptors used in architectural acoustics. The editing and adaptation could have been better and even though the reviewer is familiar with these concepts, the presentation is too jagged to hold the reader's attention. A presentation similar to those in the later chapters would have enhanced it. Prof. Schroeder, who has conducted seminal work in the field of speech and communications and by extension in architectural acoustics, does not include the basic pitfalls of reverberation time computations. Even his main contribution of reverse integration procedures to calculate reverberation time has merited only a passing mention.

The second chapter titled, "Sound absorbing materials and sound absorbers in enclosures," is written by C. Diaz and A. Pedrero of the Acoustics and Vibrations Laboratory, Madrid, Spain. The chapter presents, in a systematic way, the fundamentals principles of sound absorption and sound absorbing materials. It also contains a brief description of the effect of sound absorption on speech intelligibility. Measurement procedures for sound absorption as well as introductory materials on common sound absorbers are included.

The third chapter by D. R. Begault of San Jose State University introduces the subject of sound auralization. Auralization is the process of producing a sound field from a source inside a space that represents the binaural human listening experience. Within a short span of 12 pages and through four sections, Begault is able to describe the phenomena of localization, auralization, modeling methods and the basic theory behind it. The materials are simple enough for general architects to understand the complex constructs.

The fourth chapter, "Fundamental subjective attributes of sound fields based on the model of auditory-brain system," is by Prof. Y. Ando and his colleagues at Kobe University, Japan. The chapter, in a systematic way models the subjective response of the hearing mechanism to an external source. Each portion of the hearing mechanism such as the ear-canal, ear drum, and middle ear bone chain, has been modelled through elaborate mathematical correlation functions. After elaborating on the theory for pitch, loudness and timbre based on these correlation functions, both the spatial and temporal effects of the sound fields on the subjective response of the hearing experiences are described. The main drawback of this chapter, if one is an architect or even a consultant in architectural acoustics, is the missing connection between the spatial and temporal character of the hearing mechanisms with physical parameters of the space such as reverberation time and hall sound levels, G. This drawback diminishes the usefulness of the fundamental developments presented in this chapter.

In contrast, Chapter 5, "The sound field for listeners in concert halls and auditoria," by John Bradley of the National Research Council of Canada, brings the reader down to a realistic plane and presents information that can be immediately applied by designers such as an architect-acoustician team. Two main parameters, sound levels and spatial impression, are used as guideposts to evaluate the acoustical suitabilities of auditoria. Using actual results from existing auditoria and appropriate theoretical models such as Mike Barron's, the acoustics of auditoria are evaluated with different combinations of computational parameters.

Finally, Chapter 6, written by J.J. Sendra, T. Zamarreno and J. Navarro of the University of Seville, Spain, provides a compilation of computational parameters for churches. After a detailed description of architectural and acoustics character of churches in general, the acoustics of 10 churches are described. Reverberation time, intelligibility, sound distribution and background sound levels are the basic parameters used to describe the acoustics of the 10 chosen churches. In addition, the renovations to improve the acoustics of three church spaces for different uses are also described. One can actually consider the final chapter as containing the cumulative application of the previous five chapters to actual field cases of auditoria such as churches.

Reviewed By:

Ramani Ramakrishnan
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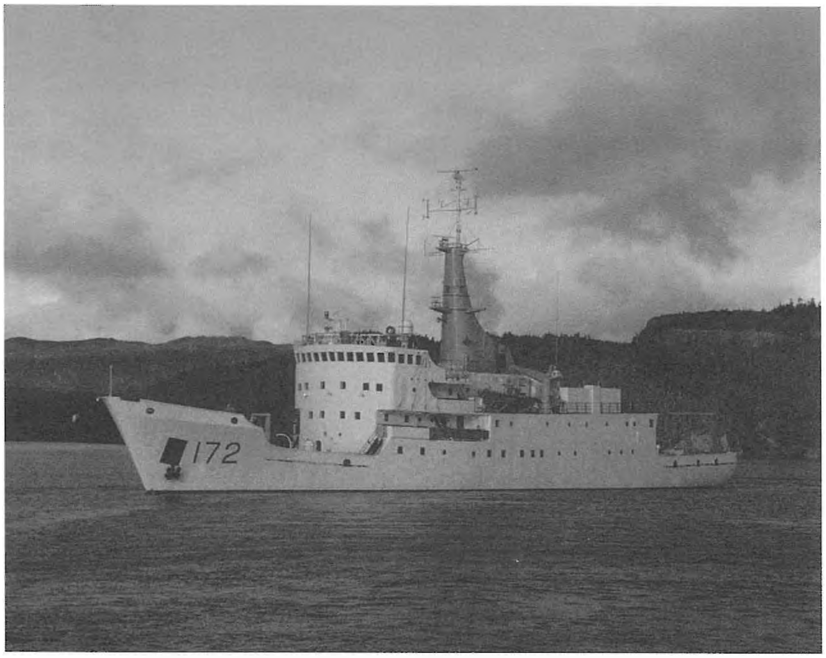

CFAV QUEST RETURNS TO SUPPORT THE NAVY'S FUTURE NEEDS

Commander Dan Parks
Canadian Forces Liaison Officer (CFLO)
Defence Research Establishment Atlantic

The picture shows Canadian Forces Auxiliary Vessel (CFAV) QUEST in Marystown, Newfoundland, shortly after completing her mid-life refit there. After more than two years undergoing extensive refit and modernization, QUEST returned to Halifax on Saturday, 30 October 1999. While in Marystown, the ship's systems were refitted and the installed scientific systems were replaced. Throughout this refit, special attention was given to maintaining her acoustic integrity and habitability. The refit extends QUEST's operating life to 2015.

CFAV QUEST has played a crucial role in DREA's research and development efforts for almost 30 years. She has a crew of 24, provided by MARLANT (QHM), and can accommodate up to 21 scientific staff. QUEST conducts 7 to 10 trials per year, spending up to 160 days at sea. These trials encompass a wide range of R&D activity, from research on the acoustic properties of the ocean and experiments on ship signatures, to the evaluation of prototype acoustic detection systems. These at sea experiments have often lead to the procurement of new systems for Canada's Maritime Forces.

This broad range of R&D activities requires a capable and versatile vessel. QUEST was designed with well laid out laboratories to accommodate experimental signal processing systems and data recording equipment. There are large working deck areas, and very capable marine cranes and specialized equipment handling systems to allow arrays and other large and cumbersome experimental equipment to be deployed and recovered. The vessel was designed with a large margin of stability and this, combined with its roll-stabilization system and constant displacement systems, makes QUEST a stable platform from which to carry out experiments, even in heavy seas. Noise must be kept to a minimum when conducting acoustic experiments at sea; thus, the single most important characteristic of QUEST is its acoustic quietness. When QUEST is configured in its "quiet state", the ship's radiated noise is reduced to virtually undetectable levels.

DREA will consider applications from external organizations to piggyback DREA cruises for a fee. For more information on QUEST's capabilities and program, please contact DREA's CFLO at 902-426-3100 ext 159 or e-mail cflo@drea.dnd.ca. Formal applications should be made to DREA's Business Development Officer, Dr.Roger Hollingshead at 902-426-3100 ext 166 or e-mail bdo@drea.dnd.ca.

Master thesis at Université de Sherbrooke
Denis Blanchet

RÉSUMÉ

Les vibrations du moteur se propageant à travers sa suspension sont souvent la source du bruit basse fréquence perçu par les occupants d'un véhicule. Au stade préliminaire du processus de conception, il est utile de connaître une façon efficace d'évaluer les paramètres adéquats de la suspension moteur car ces paramètres dictent la contribution solidienne du moteur au bruit total du véhicule. Ces propriétés sont la raideur, l'amortissement, la position, l'orientation et le nombre de supports moteurs composant la suspension. Un bon design fournira un support adéquat du moteur ainsi qu'une faible puissance transmise à la structure afin de réduire au maximum le niveau de vibration structural et l'énergie acoustique rayonnée.

L'objectif de ce mémoire est de présenter une approche efficace et directe de développement et d'optimisation d'une suspension moteur. Différentes fonctions coûts dont la force et la puissance transmise à la structure, le niveau de vibration à un point critique de la structure réceptrice ainsi que la pression acoustique au voisinage de l'oreille de l'occupant du véhicule peuvent être utilisées comme critère d'optimisation. À l'aide de Matlab^{TM} , un logiciel dédié et facile à utiliser a été développé afin d'assister et de guider le concepteur de suspension moteur. Ce logiciel hybride permet de modéliser chacune des parties du système soit par un corps rigide ou une structure flexible en utilisant des données théoriques ou expérimentales.

ABSTRACT

Engine's vibration propagating through its suspension is often responsible for low frequency noise perceived by vehicle occupants. In the design process and at early stage of development, it is useful to have an efficient way of estimating the properties of an engine suspension since these directly dictate the engine's structureborne vibration contribution to total noise of a vehicle. These properties include stiffness, position, orientation and number of engine mounts. A good design will provide adequate support of the engine as well as low power transmitted to the structure in order to reduce as much as possible the transmitted structureborne vibration and the radiated acoustic energy.

The purpose of this paper is to present an efficient and straightforward approach to develop and optimize engine suspension. Various objective functions such as transmitted forces, power flow injected in the elastic base structure, vibration levels taken at critical locations and driver ears acoustic pressure levels can be used. Using Matlab^{TM} , a dedicated and friendly user software has been developped to assist and guide suspension designers. It allows the user to model each of the different parts of the system as either rigid body or as flexible structures.

Try the Quiet Diet on Noise Awareness Day!

April 12, 2000 will mark the 5th annual International Noise Awareness Day and more than 20 countries will be participating this year. Spearheaded in New York by The League for the Hard of Hearing's Noise Centre, pro-quiet activists worldwide will try to raise the public's awareness of noise pollution's negative effects. For more details on activities in Canada and abroad, please visit NoiseWatch's website at www3.sympatico.ca/noise.

Passons une journee tranquille lors du Jour de la prise de conscience du bruit!

Le jour du 12 avril, 2000 marquera le cinquieme annuel Jour de la prise de conscience du bruit. Au dela de 20 pays vont y participer cette annee. Le League for the Hard of Hearing a New York mene cette campagne qui a comme but d'instruire le grand public a l'egard des effets nuisibles que peuvent infliger la pollution du bruit. Pour plus de details sur les activites qui auront lieux au Canada et a l'etranger, veuillez visiter le site web de NoiseWatch a www3.sympatico.ca/noise

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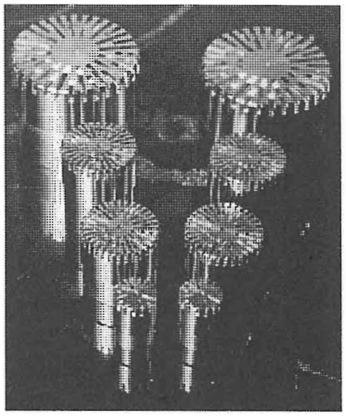

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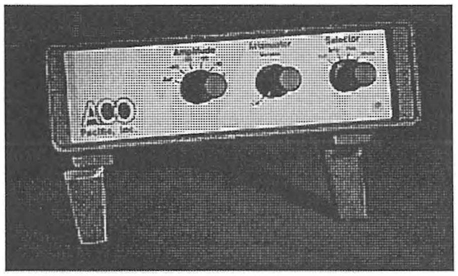

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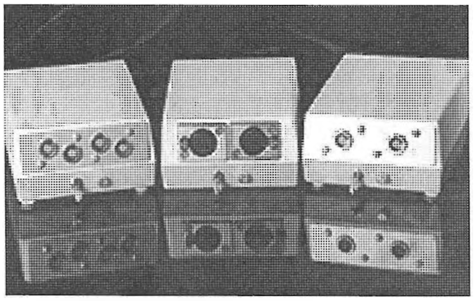

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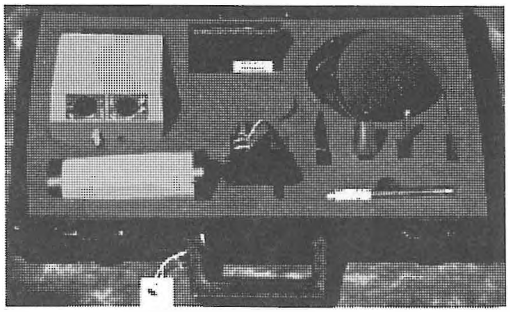

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NEWS / INFORMATIONS

CONFERENCES

The following list of conferences was mainly provided by the Acoustical Society of America. If you have any news to share with us, send them by mail or fax to the News Editor (see address on the inside cover), or via electronic mail to desharnais@drea.dnd.ca

2000

15-17 March: Acoustical Society of Japan Spring Meeting, Tokyo, Japan. Contact: Acoustical Society of Japan, Ikeda-Building, 2-7-7, Yoyogi, Shibuya-ku, Tokyo, 151-0053 Japan; Fax: +81 3 3379 1456; Email: kym05145@nifty.ne.jp

19-22 March: 25th International Acoustical Imaging Symposium, Bristol, UK. Contact: 25th IAIS, Medical Physics and Bioengineering Department, Bristol General Hospital, Bristol BS1 6SY, UK; Web: www.bris.ac.uk\depts\medphys

20-24 March: Meeting of the German Acoustical Society (DAGA), Oldenburg, Germany. Contact: DEGA, FB Physik, Universität Oldenburg, 26111 Oldenburg, Germany; Fax: +49 441 798 3698; Email: dega@aku.physik.uni-oldenburg.de

3-4 April: Structural Acoustics 2000, Zakopane, Poland. Contact: AGH, Al.Mickiewicka 30, 30-059 Krakow, Poland; Fax: +48 12 423 3163; Web: www.cyf-kr.edu.pl/ghpanusz

16-19 April: 3rd Biennial Spring Conference on Environmental & Occupational Noise for the Energy Industry, Calgary, Alberta, Canada. Contact: Glynn Jones (occupational noise), Fax: (403) 244-3234, Email: ehp@cadvision.com, or Nigel Maybee (environmental noise), Fax: (403) 259-6611, Email: nigel@hfpacoustical.com

17-19 May: 9th International Meeting on Low Frequency Noise and Vibration, Aalborg, Denmark. Contact: W. Tempest, Multi-Science Publishing Co. Ltd., 5 Wates Way, Brentwood, Essex CM15 9TB, UK; Fax: +44 1277 223453.

23-26 May: Meeting of the Russian Acoustical Society, Moscow, Russia. Contact: N.N. Andrejev Acoustical Institute, 4 Shvernika ul., Moscow 117036, Russia; Fax: +7 095 126 8411; Email: ras@akin.ru

24-26 May: Joint International Symposium on Noise Control & Acoustics for Educational Buildings and 5th Turkish National Congress on Acoustics, Istanbul, Turkey. Contact: Turkish Acoustical Society YTU Mim. Fak., 80750 Besiktas-Istanbul, Turkey; Fax: +90 212 261 0549; Web: www.takder.org

30 May-3 June: 139th Meeting of the Acoustical Society of America, Atlanta, GA. Contact: Acoustical Society of America, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502; Tel: 516-576-2360; Fax: 516-576-2377; Email: asa@aip.org; Web: asa.aip.org

CONFÉRENCES

La liste de conférences ci-jointe a été offerte en majeure partie par l'Acoustical Society of America. Si vous avez des nouvelles à nous communiquer, envoyez-les par courrier ou fax (coordonnées incluses à l'envers de la page couverture), ou par courrier électronique à desharnais@drea.dnd.ca

2000

15-17 mars: Rencontre de printemps de la Société d'acoustique du Japon, Tokyo, Japon. Info: Acoustical Society of Japan, Ikeda-Building, 2-7-7, Yoyogi, Shibuya-ku, Tokyo, 151-0053 Japan; Fax: +81 3 3379 1456; Email: kym05145@nifty.ne.jp

19-22 mars: 25e Symposium international d'imagerie acous-tique, Bristol, Royaume-Uni. Info: 25th IAIS, Medical Physics and Bioengineering Department, Bristol General Hospital, Bristol BS1 6SY, UK; Web: www.bris.ac.uk\depts\medphys

20-24 mars: Rencontre de la Société allemande d'acoustique (DAGA), Oldenburg, Allemagne. Info: DEGA, FB Physik, Universität Oldenburg, 26111 Oldenburg, Germany; Fax: +49 441 798 3698; Email: dega@aku.physik.uni-oldenburg.de

3-4 avril: Acoustique structurale 2000, Zakopane, Pologne. Info: AGH, Al.Mickiewicka 30, 30-059 Krakow, Poland; Fax: +48 12 423 3163; Web: www.cyf-kr.edu.pl/ghpanusz

16-19 avril: 3e conférence de printemps bisannuelle sur le bruit occupationnel et environnemental pour l'industrie de l'énergie, Calgary, Alberta, Canada. Info: Glynn Jones (bruit occupationnel), Fax: (403) 244-3234, Email: ehp@cadvision.com, or Nigel Maybee, Fax: (403) 259-6611, Email: nigel@hfpacoustical.com

17-19 mai: 9e rencontre internationale sur le bruit et les vibrations de basse fréquence, Aalborg, Danemark. Info: W. Tempest, Multi-Science Publishing Co. Ltd., 5 Wates Way, Brentwood, Essex CM15 9TB, UK; Fax: +44 1277 223453.

23-26 mai: Rencontre de la Société d'acoustique russe, Moscou, Russie. Info: N.N. Andrejev Acoustical Institute, 4 Shvernika ul., Moscow 117036, Russia; Fax: +7 095 126 8411; Email: ras@akin.ru

24-26 mai: Symposium international conjoint sur le contrôle du bruit et acoustique pour les immeubles d'éducation, et 5e Congrès national turc d'acoustique, Istanboul, Turquie. Info: Turkish Acoustical Society YTU Mim. Fak., 80750 Besiktas-Istanbul, Turkey; Fax: +90 212 261 0549; Web: www.takder.org

30 mai-3 juin: 139e rencontre de l'Acoustical Society of America, Atlanta, GA. Info: Acoustical Society of America, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502; Tél.: 516-576-2360; Fax: 516-576-2377; Email: asa@aip.org; Web: asa.aip.org

5-9 June: International Conference on Acoustics, Speech and Signal Processing (ICASSP-2000), Istanbul, Turkey. Contact: T. Adali, EE and Computer Science Department, University of Maryland Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250; Fax: +1 410 455 3639; Web: icassp2000.sdsu.edu

6-9 June: 5th International Symposium on Transport Noise and Vibration, St. Petersburg, Russia. Contact: East-European Acoustical Association, Moskovskoe Shosse 44, 196158 St. Petersburg, Russia; Fax: +7 812 1279323; Email: noise@mail.rcom.ru

14-17 June: IUTAM Symposium on Mechanical Waves for Composite Structures Characterization, Chania, Crete, Greece. Contact: IUTAM 2000, Applied Mechanics Laboratory, Technical University of Crete, Chania 73100, Greece; Fax: +30 821 37438; Web: www.tuc.gr/iutam

4-7 July: 7th International Congress on Sound and Vibration, Garmisch-Partenkirchen, Germany. Contact: H. Heller, DLR, Postfach 3267, 38022 Braunschweig, Germany; Fax: +49 531 295 2320; email: hanno.heller@dlr.de; WWW: www.iiav.org/icsv7.html

10-13 July: 5th European Conference on Underwater Acoustics, Lyon, France. Contact: LASSSO, 43 Bd du 11 novembre 1918; Bat. 308; BP 2077, 69616 Villeurbanne cedex, France; Fax: +33 4 72 44 80 74; Web: www.ecua2000.cpe.fr

28-30 August: Inter-Noise 2000, Nice, France. Contact: SFA, 23 avenue Brunetière, 75017 Paris, France; Fax: +33 1 47 88 90 60; Web: www.inrets.fr/services/manif

31 August – 2 September: International Conference on Noise and Vibration Pre-Design and Characterization Using Energy Methods (NOVEM), Lyon, France. Contact: LVA, INSA de Lyon, Bldg. 303, 20 avenue Albert Einstein, 69621 Villeurbane, France; Fax: +33 4 7243 8712; Web: www.insa-lyon.fr/Laboratoires/lva.html

3-6 September: 5th French Congress on Acoustics — Joint meeting of the Swiss and French Acoustical Societies, Lausanne, Switzerland. Contact: M.-N. Rossi, Ecole Polytechnique Fédérale, 1015 Lausanne, Switzerland; Fax: +41 21693 26 73.

13-15 September: International Conference on Noise and Vibration Engineering (ISMA 25), Leuven, Belgium. Contact: Mrs. L. Notré, K. U. Leuven, PMA Division, Celestijnenlaan 300B, 3001 Leuven, Belgium; Fax: +32 16 32 24 82; Email: lieve.notre@mech.kuleuven.ac.be

17-21 September: Acoustical Society of Lithuania First International Conference, Vilnius, Lithuania. Contact: Acoustical Society of Lithuania, Kriviu 15-2, 2007 Vilnius, Lithuania; Fax: +370 2 223 451; Email: daumantas.ciblys@ff.vu.lt

3-5 October: WESPRAC VII, Kumamoto, Japan. Contact: Computer Science Dept., Kumamoto Univ., 2-39-1 Kurokami, Kumamoto, Japan 860-0862; Fax: +81 96 342 3630; Email: wesprac7@cogni.eecs.kumamoto-u.ac.jp

5-9 juin: Conférence internationale sur l'acoustique, la parole et le traitement de signal (ICASSP-2000), Istanboul, Turquie. Info: T. Adali, EE and Computer Science Department, University of Maryland Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250; Fax: +1 410 455 3639; Web: icassp2000.sdsu.edu

6-9 juin: 5e symposium international sur le bruit et vibrations du transport, St Petersbourg, Russie. Info: East-European Acoustical Association, Moskovskoe Shosse 44, 196158 St. Petersburg, Russia; Fax: +7 812 1279323; Email: noise@mail.rcom.ru

14-17 juin: Symposium IUTAM sur les ondes mécaniques pour la caractérisation de structures composites, Chania, Crète, Grèce. Info: IUTAM 2000, Applied Mechanics Laboratory, Technical University of Crete, Chania 73100, Greece; Fax: +30 821 37438; Web: www.tuc.gr/iutam

4-7 juillet: 7e Congrès international sur le son et les vibrations, Garmisch-Partenkirchen, Allemagne. Info: H. Heller, DLR, Postfach 3267, 38022 Braunschweig, Germany; Fax: +49 531 295 2320; email: hanno.heller@dlr.de; WWW: www.iiav.org/icsv7.html

10-13 juillet: 5e Conférence européenne sur l'acoustique sous-marine, Lyon, France. Info: LASSSO, 43 Bd du 11 novembre 1918; Bat. 308; BP 2077, 69616 Villeurbanne cedex, France; Fax: +33 4 72 44 80 74; Web: www.ecua2000.cpe.fr

28-30 août: Inter-Noise 2000, Nice, France. Info: SFA, 23 avenue Brunetière, 75017 Paris, France; Fax: +33 1 47 88 90 60; Web: www.inrets.fr/services/manif

31 août – 2 septembre: Conférence internationale sur l'utilisation des méthodes d'énergie pour la prévision vibroacoustique (NOVEM), Lyon, France. Info: LVA, INSA de Lyon, Bldg. 303, 20 avenue Albert Einstein, 69621 Villeurbane, France; Fax: +33 4 7243 8712; Web: www.insa-lyon.fr/Laboratoires/lva.html

3-6 septembre: 5e Congrès français d'acoustique — Rencontre conjointe des Sociétés suisse et française d'acoustique, Lausanne, Suisse. Info: M.-N. Rossi, Ecole Polytechnique Fédérale, 1015 Lausanne, Suisse; Fax: +41 21693 26 73.

13-15 septembre: Conférence internationale d'ingénierie sur le bruit et les vibrations (ISMA 25), Leuven, Belgique. Info: Mrs. L. Notré, K. U. Leuven, PMA Division, Celestijnenlaan 300B, 3001 Leuven, Belgium; Fax: +32 16 32 24 82; Email: lieve.notre@mech.kuleuven.ac.be

17-21 septembre: 1e Conférence internationale de la Société d'acoustique de Lithuanie, Vilnius, Lithuanie. Info: Acoustical Society of Lithuania, Kriviu 15-2, 2007 Vilnius, Lithuania; Fax: +370 2 223 451; Email: daumantas.ciblys@ff.vu.lt

3-5 octobre: WESPRAC VII, Kumamoto, Japon. Info: Computer Science Dept., Kumamoto Univ., 2-39-1 Kurokami, Kumamoto, Japan 860-0862; Fax: +81 96 342 3630; Email: wesprac7@cogni.eecs.kumamoto-u.ac.jp

3-6 October: EUROMECH Colloquium on Elastic Waves in Nondestructive Testing, Prague, Czech Republic. Contact: Z. Prevorovsky, Institute of Thermomechanics, Dolejskova 4, 182 00 Prague 8, Czech Republic; Fax: +420 2 858 4695; Email: ok@bivoj.it.cas.cz

16-18 October: 2nd Iberoamerican Congress on Acoustics, 31st National Meeting of the Spanish Acoustical Society, and EAA Symposium, Madrid, Spain. Contact: Spanish Acoustical Society, c/Serrano 144, 28006 Madrid, Spain; Fax: +34 91 411 7651; email: ssantiago@fresno.csic.es

16-20 October: 6th International Conference on Spoken Language Processing, Beijing, China. Contact: ICSLP 2000 Secretariat, Institute of Acoustics, PO Box 2712, 17 Zhong Guan Cun Road, 100 080 Beijing, China; Fax: +86 10 6256 9079; Email: mchu@plum.ioa.ac.cn

4-8 December: 140th Meeting of the Acoustical Society of America, Newport Beach, CA. Contact: Acoustical Society of America, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502; Tel: 516-576-2360; Fax: 516-576-2377; Email: asa@aip.org; Web: asa.aip.org

2001

30 April-3 May: 2001 Society of Automotive Engineers (SAE) Noise & Vibration Conference and Exposition, Traverse City, MI. Contact: Patti Kreh, SAE Int'l., 755 W. Big Beaver Rd., Suite 1600, Troy, MI 48084; Tel.: 248-273-2474; Fax: 248-273-2494; Email: pkreh@sae.org

28-30 August: Inter-Noise 2001, The Hague, The Netherlands. Email: secretary@internoise2001.tudelft.nl; Web: internoise2001.tudelft.nl

2-7 September: 17th International Congress on Acoustics (ICA), Rome, Italy. Contact: A. Alippi, Dipartimento di Energetica, Universita di Roma "La Sapienza," Via A. Scarpa 14, 00161 Rome, Italy; Fax: +39 6 4424 0183; WWW: www.uniroma1.it/energ/ica.html

10-13 September: International Symposium on Musical Acoustics (ISMA 2001), Perugia, Italy. Contact: Perugia Classico, Comune di Perugia, Via Eburnea 9, 06100 Perugia, Italy; Fax: +39 75 577 2255; Email: perugia@classico.it

17-19 October: 32nd Meeting of the Spanish Acoustical Society, La Rioja, Spain. Contact: Serrano 144, Madrid 28006, Spain; Fax: +34 91 411 76 51; Web: www.ia.csic.es/sea/index.html

3-6 octobre: Colloque EUROMECH sur les ondes élastiques pour les tests non-destructifs, Prague, République tchèque. Info: Z. Prevorovsky, Institute of Thermomechanics, Dolejskova 4, 182 00 Prague 8, Czech Republic; Fax: +420 2 858 4695; Email: ok@bivoj.it.cas.cz

16-18 octobre: 2e congrès ibéro-américain sur l'acoustique, 31e Rencontre nationale de la Société d'acoustique espagnole, et Symposium de l'EAA, Madrid, Espagne. Info: Spanish Acoustical Society, c/Serrano 144, 28006 Madrid, Spain; Fax: +34 91 411 7651; email: ssantiago@fresno .csic.es

16-20 octobre: 6e conférence internationale sur le traitement de la langue parlée, Beijing, Chine. Info: ICSLP 2000 Secretariat, Institute of Acoustics, PO Box 2712, 17 Zhong Guan Cun Road, 100 080 Beijing, China; Fax: +86 10 6256 9079; Email: mchu@plum.ioa.ac.cn

4-8 décembre: 140e recontre de l'Acoustical Society of America, Newport Beach, CA. Info: Acoustical Society of America, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502; Tél.: 516-576-2360; Fax: 516-576-2377; Email: asa@aip.org; Web: asa.aip.org

2001

30 avril-3 mai: Conférence et exposition 2001 de la Société des Ingénieurs d'autos (SAE) sur le bruit et les vibrations, Traverse City, MI. Info: Patti Kreh, SAE Int'l., 755 W. Big Beaver Rd., Suite 1600, Troy, MI 48084; Tél.: 248-273-2474; Fax: 248-273-2494; Email: pkreh@sae.org

28-30 août: Inter-Noise 2001, La Haye, Pays-Bas. Email: secretary@internoise2001.tudelft.nl; Web: internoise2001 .tudelft.nl

2-7 septembre: 17e Congrès international sur l'acoustique (ICA), Rome, Italie. Info: A. Alippi, Dipartimento di Energetica, Universita di Roma "La Sapienza," Via A. Scarpa 14, 00161 Rome, Italy; Fax: +39 6 4424 0183; WWW: www.uniroma1.it/energ/ica.html

10-13 septembre: Symposium international sur l'acoustique musicale (ISMA 2001), Perugia, Italie. Info: Perugia Classico, Comune di Perugia, Via Eburnea 9, 06100 Perugia, Italy; Fax: +39 75 577 2255; Email: perugia@classico.it

17-19 octobre: 32e rencontre de la Société espagnole d'acoustique, La Rioja, Espagne. Info: Serrano 144, Madrid 28006, Spain; Fax: +34 91 411 76 51; Web: www.ia.csic.es/sea/index.html

Appel de Communications
Semaine canadienne d'acoustique 2000
Hôtel Delta, Sherbrooke, Qc
28-29 septembre, 2000

COMITÉ D'ORGANISATION

GAUS
GROUPE D'ACOUSTIQUE DE L'UNIVERSITÉ DE SHERBROOKE

La semaine de l'acoustique canadienne de l'an 2000 se déroulera à l'hôtel Delta de Sherbrooke, Québec, du 28-29 septembre 2000. La semaine sera organisée, sous l'égide de la société canadienne d'acoustique, par le groupe d'acoustique de l'Universite de Sherbrooke. Le professeur Noureddine Atalla de l'université de Sherbrooke agira comme président et le professeur Alain Berry de l'université de Sherbrooke agira comme directeur du programme technique.

Courriel : caa2000@gaus.gme.usherb.ca
Site web : http://www-gaus.gme.usherb.ca

PROGRAMMES SCIENTIFIQUES ET TECHNIQUES

Le comité d'organisation planifie un programme technique de grand calibre avec une emphase particulière sur **le contrôle du bruit industriel**. Le congrès comprend des conférences générales, des communications sur invitation, des sessions et des expositions techniques. Les sujets traités recouvrent :

Le contrôle actif du bruit et des vibrations
Les méthodes analytiques et numériques
Aéroacoustique
Psycho-acoustique
Acoustique musicale
Normalisation canadienne
Contrôle du bruit industriel
Vibro-acoustique
Propagation du son
Physio-acoustique
Qualité du son
Règlements et bruit environnemental
Matériaux acoustiques
Acoustique architecturale
Acoustique sous-marine
Perception et production du langage
Audiologie

Enseignement et démonstration en acoustique et Vibrations, **et tout autre sujet relevant de l'acoustique.**

RÉSUMÉS

Les résumés de 250 mots maximums doivent être soumis avant le 31 mai 2000. Les résumés devront être préparés suivant les instructions incluses dans ce numéro d'*Acoustique canadienne*. Les soumissions par courrier électronique sont fortement encouragées; les documents peuvent être édités avec n'importe quel traitement de texte. Pour ceux qui n'ont pas accès au courrier électronique, les documents digitaux sur disquette ou papier devront être envoyés à l'adresse indiquée ci-dessous. Une notification d'acceptation des résumés sera envoyée aux auteurs avant le 15 juin 2000 avec un formulaire d'inscription. Un sommaire de la présentation devra être envoyé avant le 31 juillet 2000. Cette échéance sera strictement respectée afin de pouvoir publier le programme dans les actes d'*Acoustique canadienne*.

Les propositions pour les sessions spéciales sur un sujet particulier en acoustique sont les bienvenues. Contactez Dr A. Berry (alain.berry@gme.usherb.ca) avant le 31 mai 2000 si vous désirez organiser une session spéciale durant la conférence de cette année.

La participation d'étudiants à cette semaine canadienne d'acoustique est fortement encouragée. Des prix seront attribués aux meilleures présentations. Les étudiants doivent indiquer leur intention de participer en remplissant le formulaire « Prix annuels relatifs aux communications étudiants » et en le joignant à leur résumé. Les étudiants présentant une communication peuvent aussi faire une demande de subvention pour leur frais de déplacement s'ils résident à plus de 150 km de Sherbrooke. Pour demander cette subvention, les étudiants doivent soumettre le formulaire de demande de remboursement pour frais de déplacement inclus dans ce numéro.

HÉBERGEMENT

L'hébergement des participants à la Semaine Canadienne d'Acoustique et les communications se tiendront à l'hôtel delta (http://www.deltahotels.com/properties/sherbrk.html), situé au centre-ville de Sherbrooke. Les participants bénéficient de tarifs spéciaux pour les chambres, commençant à 95$ par nuit. Pour réserver votre chambre, contacter l'hôtel delta par téléphone (1 800 268-1133) ou fax (819-822-8990) en mentionnant votre participation à la Semaine Canadienne d'Acoustique 2000. Les tarifs préférentiels sont garantis jusqu'au 27 août 2000.

Pour d'autres hôtels et auberges visiter le site web de la ville de Sherbrooke au http://www.sders.com/tourisme.

TRANSPORT

Sherbrooke est situé à 150 km de l'aéroport Dorval à Montréal. Un service de Bus lie régulièrement l'aéroport Dorval au centre-ville de Sherbrooke. Un service de navette peut être organisé sur demande. Si vous êtes intéressés par un tel service, contacter Rémy Oddo (819) 821-8000 x1965, remy.oddo@gme.usherb.ca

EXPOSITIONS

Une exposition permanente, présentant les développements récents des techniques sur les équipements en acoustique et vibration, les instruments, les matériaux et les logiciels, se tiendra en parallèle aux autres présentations.
Des espaces seront disponibles pour des Expositions de sociétés et d'organisations dans le domaine de l'acoustique. Des **commanditaires** pour les causes alimentaires et/ou déjeuners sont aussi les bienvenus. Si vous êtes intéressés par l'une de ses offres, contacter Rémy Oddo (819) 821-8000 x1965, remy.oddo@gme.usherb.ca

DATES IMPORTANTES

31 mai, 2000	Échéance pour la soumission des résumés
15 juin, 2000	Notification d'acceptation des résumés
31 juillet, 2000	Échéance pour la réception des sommaires et les premières inscriptions
28-29 septembre, 2000	Semaine Canadienne d'Acoustique 2000

Pour plus d'informations contacter :

Semaine Canadienne d'Acoustique 2000
c/o Dr. Noureddine Atalla
Génie mécanique, Université de Sherbooke
Sherbooke (Qc), Canada J1K 2R1
Téléphone : (819) 821-8000 x1209 Fax : (819) 821-7163
Noureddine.atalla@gme.usherb.ca

Call for papers
Acoustics Week in Canada 2000
Delta Hotel, Sherbrooke, Qc
2000, September 28-29

ORGANISING COMMITTEE

GAUS
GROUPE D'ACOUSTIQUE DE L'UNIVERSITÉ DE SHERBROOKE

Acoustics Week in Canada 2000 will be held at the Delta hotel, in Sherbrooke, Quebec, in 2000 September. The week will open on Thursday, September 28 and will conclude in the afternoon of September 29. The conference, sponsored by the Canadian Acoustics Association, will be organized by the groupe d'acoustique de l'université de Sherbrooke. Professor Noureddine Atalla of l'université de Sherbrooke is the president of CAA2000. Professor Alain Berry of l'université de Sherbrooke is the Technical Program Chair.

Conference Email : caa2000@gaus.gme.usherb.ca
Web Site : http://www-.gaus.gme.usherb.ca

SCIENTIFIC AND TECHNICAL PROGRAMS

The organizing committee is planning a high caliber and motivating technical program. The program will deal with topics from throughout the field of acoustics and vibrations with a special emphasis **on industrial passive and active control**. The meeting will consist of an opening plenary lecture, invited and contributed papers and exhibits. Technical papers in all areas of noise control engineering will be considered for presentation at the conference. The following technical areas are of particular interest:

Active Noise Control for Industry
Analytical and Numerical prediction tools in Acoustics
Building acoustic
Outdoor sound propagation
Speech perception and production
Occupational Hearing Loss and Hearing protection
Industrial Noise Control - case studies
Structural acoustics and vibrations
Aeroacoustics
Psycho-acoustics
Musical acoustics
Canadian Standards
Acoustic materials

Underwater acoustics
Physiological acoustics
Sound quality
Legislation /Environmental Noise
Education and Demonstration in Noise Control Engineering**, and other related topics**

ABSTRACTS

Abstracts of maximum 250 words must be submitted by May 31, 2000. The abstract should be prepared and sent in accordance with the instructions appearing in this issue of *Canadian Acoustics*. Submission by e-mail is strongly encouraged; files can be prepared in any word processing software. For those without access to e-mail, digital files on diskette or paper copy should be mailed to the address given in the instructions. Notification of acceptance of abstracts will be sent to authors by June 15, 2000 along with a registration form. Summary papers are due July 15, 2000. This deadline will be strictly enforced to meet the publication schedule of the proceeding issue of *Canadian Acoustics*.

Proposals for **Special Sessions** on a particular topic in acoustics are welcome. Contact Dr. Alain Berry (alain.berry@gme.usherb.ca) prior to Mai 31, 2000 if you are interested in having a special session at this year's meeting.

Student participation in Acoustics Week in Canada is strongly encouraged. Awards are available to students whose presentations at the conference are judged to be particularly noteworthy. To qualify, students must apply by enclosing an *Annual Student Presentation Award* form with their abstract. Students presenting papers may also apply for a travel subsidy to attend the meeting if they live at least 150 km from Sherbrooke, Qc. To apply for this subsidy, students must submit an *Application For Student Travel Subsidy*, included in this issue.

ACCOMMODATION

Accommodation and meeting space for delegates of Acoustics Week in Canada 2000 will be at the Delta Hotel (http://www.deltahotels.com/properties/sherbrk.html) located in downtown Sherborooke, Qc. The special room rate for delegates is $95.00 per night. To reserve your accommodation, please contact the hotel directly by telephone (1 800 268-1133), Fax (819-822-8990) and mention the identification code: GPACOU. The reservation cut-off date is August 27, 2000. After these dates, the special rates are subject to availability.

There are several other hotels for every budget, located within walking distance from the conference site.
For details, check the tourist web site of Sherbrooke : http://www.sders.com/tourisme.

TRANSPORTATION

Sherbrooke is 150-km from Dorval Airport in Montreal. A regular bus service links the airport to Downtown Sherbrooke. A special transport service can be organized, on request. If you are interested in such a service, please contact Rémy Oddo (819) 821-8000x1965, remy.oddo@gme.usherb.ca

EXHIBITS

A permanent exhibition showing the latest technologies in acoustics and vibration equipment, instrumentation, materials and software will be open continuously during the congress.

Space will be available for **exhibits** by companies and organizations in the field of acoustics. **Sponsorship** of nutrition breaks and/or lunches is also welcome. If you are interested in either of these opportunities, please contact Rémy Odd (819) 821-8000x1965, remy.odd@gme.usherb.ca

IMPORTANT DATES

May 31, 2000	Deadline for submission of abstracts
June 15, 2000	Notification of acceptance of abstracts
July 31, 2000	Deadline for receipt of summary paper and early registration
September 28-29, 2000	Acoustics week in Canada 2000

For more information contact:

Acoustics Week in Canada 2000
c/o Dr. Noureddine Atalla
Génie mécanique, Université de Sherbooke
Sherbooke (Qc), Canada J1K 2R1
Téléphone : (819) 821-8000 x1209 Fax : (819) 821-7163
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INSTRUCTIONS TO AUTHORS FOR THE PREPARATION OF MANUSCRIPTS

Submissions: The original manuscript and two copies should be sent to the Editor-in-Chief.

General Presentation: Papers should be submitted in camera-ready format. Paper size 8.5" x 11". If you have access to a word processor, copy as closely as possible the format of the articles in Canadian Acoustics 18(4) 1990. All text in Times-Roman 10 pt font, with single (12 pt) spacing. Main body of text in two columns separated by 0.25". One line space between paragraphs.

Margins: Top - title page: 1.25"; other pages, 0.75"; bottom, 1" minimum; sides, 0.75".

Title: Bold, 14 pt with 14 pt spacing, upper case, centered.

Authors/addresses: Names and full mailing addresses, 10 pt with single (12 pt) spacing, upper and lower case, centered. Names in bold text.

Abstracts: English and French versions. Headings, 12 pt bold, upper case, centered. Indent text 0.5" on both sides.

Headings: Headings to be in 12 pt bold, Times-Roman font. Number at the left margin and indent text 0.5". Main headings, numbered as 1, 2, 3, ... to be in upper case. Sub-headings numbered as 1.1, 1.2, 1.3, ... in upper and lower case. Sub-sub-headings not numbered, in upper and lower case, underlined.

Equations: Minimize. Place in text if short. Numbered.

Figures/Tables: Keep small. Insert in text at top or bottom of page. Name as "Figure 1, 2, ..." Caption in 9 pt with single (12 pt) spacing. Leave 0.5" between text.

Photographs: Submit original glossy, black and white photograph.

References: Cite in text and list at end in any consistent format, 9 pt with single (12 pt) spacing.

Page numbers: In light pencil at the bottom of each page.

Reprints: Can be ordered at time of acceptance of paper.

DIRECTIVES A L'INTENTION DES AUTEURS PREPARATION DES MANUSCRITS

Soumissions: Le manuscrit original ainsi que deux copies doivent être soumis au rédacteur-en-chef.

Présentation générale: Le manuscript doit comprendre le collage. Dimensions des pages, 8.5" x 11". Si vous avez accès à un système de traitement de texte, dans la mesure du possible, suivre le format des articles dans l'Acoustique Canadienne 18(4) 1990. Tout le texte doit être en caractères Times-Roman, 10 pt et à simple (12 pt) interligne. Le texte principal doit être en deux colonnes séparées d'un espace de 0.25". Les paragraphes sont séparés d'un espace d'une ligne.

Marges: Dans le haut - page titre, 1.25"; autres pages, 0.75"; dans le bas, 1" minimum; latérales, 0.75".

Titre du manuscrit: 14 pt à 14 pt interligne, lettres majuscules, caractères gras. Centré.

Auteurs/adresses: Noms et adresses postales. Lettres majuscules et minuscules, 10 pt à simple (12 pt) interligne. Centré. Les noms doivent être en caractères gras.

Sommaire: En versions anglaise et française. Titre en 12 pt, lettres majuscules, caractères gras, centré. Paragraphe 0.5" en alinéa de la marge, des 2 cotés.

Titres des sections: Tous en caractères gras, 12 pt, Times-Roman. Premiers titres: numéroter 1, 2, 3, ..., en lettres majuscules; sous-titres: numéroter 1.1, 1.2, 1.3, ..., en lettres majuscules et minuscules; sous-sous-titres: ne pas numéroter, en lettres majuscules et minuscules et soulignés.

Equations: Les minimiser. Les insérer dans le texte si elles sont courtes. Les numéroter.

Figures/Tableaux: De petites tailles. Les insérer dans le texte dans le haut ou dans le bas de la page. Les nommer "Figure 1, 2, 3,..." Légende en 9 pt à simple (12 pt) interligne. Laisser un espace de 0.5" entre le texte.

Photographies: Soumettre la photographie originale sur papier glacé, noir et blanc.

Références: Les citer dans le texte et en faire la liste à la fin du document, en format uniforme, 9 pt à simple (12 pt) interligne.

Pagination: Au crayon pâle, au bas de chaque page.

Tirés-à-part: Ils peuvent être commandés au moment de l'acceptation du manuscrit.

The Canadian Acoustical Association

l'Association Canadienne d'Acoustique

SUBSCRIPTION INVOICE

Subscription for the current calendar year is due January 31. New subscriptions received before July 1 will be applied to the current year and include that year's back issues of Canadian Acoustics, if available. Subscriptions received from July 1 will be applied to the next year.

FACTURE D'ABONNEMENT

L'abonnement pour la présente année est dû le 31 janvier. Les nouveaux abonnements reçus avant le 1 juillet s'appliquent à l'année courante et incluent les anciens numéros (non-épuisés) de l'Acoustique Canadienne de cette année. Les abonnements reçus après le 1 juillet s'appliquent à l'année suivante.

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