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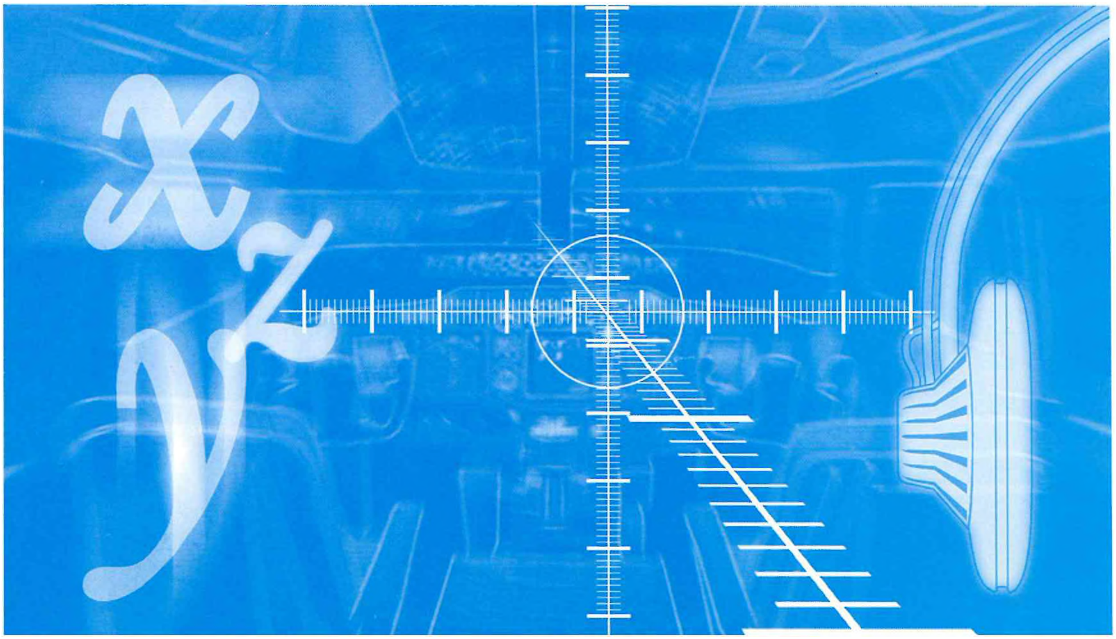

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MESSAGE FROM THE PRESIDENT / MESSAGE DU PRÉSIDENT

For me, there is nothing quite so boring as the nit-picking arguments of some standards committees. On the other hand there can be considerable benefits to this drudgery. For example, the greater number of standards in some European countries has a big influence on the quality of their acoustical environment. While there are moves to international harmonisation of standards, in Canada there is always the influence of our neighbour to the south where any form of regulation is often vehemently opposed. A Canadian compromise between these extremes is needed.

In Canada we currently have very few acoustical requirements for our built environment. Our National Building Code essentially only mentions airborne sound transmission between homes, and even this requirement is lower than in many European countries. There is no mention of impact sound insulation although it has long been included in the building requirements of other countries.

We have no national requirements at all for the acoustical quality of indoor spaces to ensure that they may function for their intended use. For example, a school classroom can be noisy and reverberant to the point that speech communication is difficult. In fact almost all published measurements in classrooms indicate that they are usually too noisy for good communication. Apparently this is not important and we really don't care whether children can understand what is being said to them. We are often told we cannot afford better. I would say that it is a matter of priorities and that acousticians must do their part to produce more and better standards and regulations. Perhaps we need a United Nations rating for the country with the best acoustical environment. I wonder where we would be on that scale?

À mon avis, il n'y a rien de plus ennuyants que les arguments pointilleux de certains comités de normalisation. Par ailleurs, il peut y avoir de nombreux bénéfices à cette corvée fastidieuse. Par exemple, le nombre important de normes dans certains pays européens a une grande influence sur leur environnement acoustique. Alors qu'il y a un mouvement d'harmonisation internationale des normes, au Canada, nous subissons toujours l'influence de notre voisin du sud qui s'oppose avec véhémence à toute forme de normalisation. Un compromis canadien entre ces deux extrêmes est nécessaire.

Au Canada, nous avons actuellement très peu d'exigences acoustiques pour l'environnement à l'intérieur des bâtiments. Notre Code national du bâtiment mentionne essentiellement la transmission sonore aérienne entre les logements, et même cette exigence est moins stricte que dans plusieurs pays européens. On ne fait nullement mention de l'isolation sonore associée aux impacts, même si cela est déjà inclus dans plusieurs codes des bâtiments de d'autres pays.

Nous n'avons aucune exigence pour la qualité sonore des espaces intérieurs afin de s'assurer qu'ils puissent être utilisés à bon escient. Par exemple, une salle de classe peut être bruyante et réverbérante au point où la communication verbale est difficile. En fait, presque toutes les données publiées sur les salles de classe démontrent qu'elles sont trop bruyantes pour assurer une bonne communication. Il semble que cela n'a pas beaucoup d'importance et qu'on ne se préoccupe pas tellement de savoir si les enfants peuvent comprendre ce qui leur est dit. On se fait souvent répondre qu'on ne peut faire mieux. Je dirais que c'est une question de priorités et que les acousticiens doivent faire leur part pour produire un plus grand nombre et de meilleures normes et réglementations. Nous avons peut-être besoin d'un classement des Nations Unies pour le pays avec le meilleur environnement acoustique. Je me demande où nous serions positionnés sur cette échelle.

EDITOR'S NOTE/NOTE DE L'ÉDITEUR

I'd like to announce that I have joined the Faculty of Architecture as an Associate Professor. Please note my new address and details. I still continue to consult for Aiolos Engineering Inc. My Aiolos information is still valid, as I will be at Aiolos Offices for one day a week.

Je voudrais vous annoncer que j'ai rejoins la Faculté d'Architecture comme professeur associé. Merci de bien vouloir noter mes nouvelles coordonnées. Je continue de consulter pour Aiolos Engineering Corp. Mes coordonnées chez Aiolos restent valide, je serais disponible aux bureaux d'Aiolos un jour par semaine.

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MAIL

Floating Point
A Notation for the New Millenium

(v1.2 23-Oct-2000)

This essay presents an alternative to the deciBel, which would allow for simple addition and be easier to explain to the layman. I believe it goes a long way in resolving the differing opinions presented by Chapman and Hickling vs Sherry, Noble and Whicker in the June 2000 issue of Canadian Acoustics. However, I believe the concept has far greater scope and should be adopted for everyday use and taught in grade school. The key concept is the Normalized deci floating point, or df (dee-eff) as a proposed substitute for the deciBel, or dB, for use in situations where power addition is important to the lay person (e.g. for community noise by-laws).

Definition: Floating Point

A representation for a number which expresses the number as the product of a power (exponent) of the base unit (10 for normal use) and a small real number the floating point mantissa (Note: this is NOT a logarithm).
e.g. the number 600 can be expressed as 0.6 times 10^3 or as 6 times 10^2

Proposed notation

State the exponent (power) of the base unit, then the mantissa, separated by a comma (,).
e.g. 600 = 3,0.6 or 2,6.0

Definition

Normalized floating point (any base, but usually 10)
Express the mantissa as a fraction between 0.1 and less than 1 and express the comma and decimal as a semicolon. (This notation is not proposed for standard use, but may be preferred by some persons).
e.g. 600 = 3;6

Definition

Normalized deci floating point (base 10 by definition)
Express the mantissa as a number as between 1 and less than 10, omit the comma, and add the suffix 'df' (pronounced dee-eff).
e.g. 600 = 2,6.0 = 26.0 df

Conversion from df to dB

Express the fp mantissa as a logarithm, multiplied by 10
e.g. 600 = 2,6.0 = 26.0 df = 27.8 dB

The scales for analog Sound Level meters could easily be modified to show both df and dB, thus emphasizing the logarithmic nature of the deciBel. Digital meters should allow switching from df to dB readout.

General relations between df and dB

1. The df is simply a number, whereas the dB is a ratio of powers.
2. The dB is sometimes applied to voltages or pressures, where the reference is actually the pressure squared and the logarithm is multiplied by 20. For df, the unit must be explicitly stated as the pressure squared and the logarithm is always multiplied by 10. The df is universally simply a number.
   Since the reference unit for sound pressure, as a representation of intensity, is –6,20 Pa, I suggest the unit t (for threshold) as a reference unit for pressure squared (i.e. –12,400 Pa^2 = 1 t). For a reference impedance of 400 mks rayls (within 412/400=1.03= within 3%of air), the threshold intensity would be –12,1 Watts/m^2 = -121 dfW/m^2 = 1 pW/m^2 = 1 t. For a plane wave of 1 m^2, the threshold power would be -121 dfW = -120 dBW = 0dBpW = 1 dfpW = 1 pW. For numbers between 1 and less than 10, the df notation is the same as standard real number notation and there is no ambiguity if the 'df' is dropped.
3. To add numbers, express with a common exponent, add the mantissas, and normalize the result if necessary.
   e.g. 600 + 60 = 26 df + 16 df = 1,60 +1,6 = 1,66 = 2,6.6 = 26.6 df
4. To multiply numbers, add the powers(exponents) and multiply the mantissas (two small numbers),or convert to deciBels and add.
   e.g. 20 * 30 = 1,2 * 1,3 = 2,6 = 26 df = 600, or 13 dB + 14.8 dB = 27.8 dB = 26 df.
5. If properly used, the df level, expressed as an integer, will always be within 2 dB of the dB level, which may be sufficiently accurate for some purposes. The following simple relations are adequate for 1 dB accuracy: 1 df =0 dB; 2 df =3 dB; 3 df =4.8 dB; 7 df =8.5 dB; 9 df =9.5 dB. The following additional relationships can be derived:4 df =2*2 = 3dB + 3 dB =6 dB;5 df = 10/2 = 10db - 3db =7 dB;6 df =2*3 = 3 dB + 4.8 dB =7.8dB;8 df= 2^3 = 3*3 dB =9dB.
6. Since the deci-normalized mantissa must always be 1 or greater, the number 60 df is incorrect. If the df mantissa is less than 1, it shall be interpreted as 1.0 (e.g. 60 df = 61 df). For existing by-law use, 5 dB is a factor of 3 (e.g. 65 dB = 63 df = 6,3; 70 dB = 71 df = 7,1 = 6,10)

Possible Alternate Notation

Instead of the comma, use the letter s (for 'shifted' or for 'Strachan'). e.g. 600 = 2s6.0 (6 shifted 2 to the left) = 26 dS).

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AN EVALUATION OF THREE-DIMENSIONAL AUDIO DISPLAYS FOR USE IN MILITARY ENVIRONMENTS

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ABSTRACT

A relatively new technology, the three-dimensional (3-D) audio display, has been proposed for improving operator performance. However, many of the studies supporting 3-D audio displays have been conducted in controlled laboratory settings and it is not clear if all gains in performance will transfer into corresponding real-world applications. The Canadian Department of National Defence (DND) and the defence forces in allied nations are presently investigating 3-D technology for use in operational environments. The implications of the use of 3-D audio technology in real-world applications and recommendations for further research are discussed in this paper.

RÉSUMÉ

On a proposé qu'une technologie relativement nouvelle, l'affichage audio tridimensionnel (3D), puisse améliorer le rendement des utilisateurs. Cependant, comme un bon nombre des études à l'appui de l'affichage audio 3D ont été contrôlées en laboratoire, on ne peut affirmer que tous les gains de rendement se réaliseront en milieu réel. Le ministère canadien de la Défense nationale (MDN) et les forces de défense de certains pays membres de l'Alliance se penchent sur l'emploi possible de la technologie 3D en situation opérationnelle. Dans cet article, il est question des répercussions de l'application de la technologie audio à trois dimensions en milieu réel et des recherches plus approfondies que l'on recommande.

1 INTRODUCTION

A sound source that is presented over headphones can be made to appear as though it would be perceived in the listener's natural free-field environment. The technology used to create this perception is a three-dimensional (3-D) audio display. The effectiveness of a 3-D audio display depends on the listener's ability to localize and discriminate between various sources of information in virtual auditory space. The spatial synthesis of an auditory signal is accomplished by digitally filtering the signal with head-related transfer functions (HRTFs). These HRTFs encode the binaural and spectral cues used in sound localization and discrimination. They are derived via a series of impulse measurements performed at the ears of an observer in response to a sound source placed at various locations in the vicinity of the head (see Wightman and Kistler (1989), for example). While the concept of a 3-D audio display is not new, present technology makes it more feasible and practical to implement.

Investigators have demonstrated that the techniques used for creating and presenting virtual auditory sources have limitations. These include the methods employed to measure HRTFs, the difference in localization performance in virtual auditory space compared to the free-field, and the externalization of the sound image outside of the listener's head (Wightman & Kistler, 1989; Begault, 1991; Wenzel, Arruda, Kistler & Wightman, 1993). It is not known whether these limitations will significantly affect the practical advantages of a 3-D audio display because little experience has been gained with applications in real tasks. Furthermore, it has also been reported that the advantages of 3-D audio are highly task-specific (Perrott, Cisneros, McKinley & D'Angelo, 1996) and that there may be no performance advantages for 3-D compared to 2-D for discriminating messages from two simultaneous talkers (Arrabito, McFadden & Crabtree, 1996). Thus the costs and benefits of equipping future systems with 3-D audio displays versus R&D efforts aimed at enhancing 2-D presentations of auditory information need to be evaluated more closely before the technology is adopted.

The Canadian Department of National Defence (DND) and the defence forces in allied nations are presently investigating 3-D technology for use in military environments. For example, aircrew are often subjected to high workload and have to maintain awareness of a complex, rapidly changing situation while making quick decisions and prompt responses. Other environments include dispersed man-on-the-move communications aboard ships or on the battlefield, where each team member needs to remain aware of the location and status of one or more other team members. In these situations the 3-D audio system must be reliable, effective, durable, flexible and immune to the effects of environmental conditions. To date there has been no known review of 3-D audio technology that addresses these requirements. These issues are discussed in this paper with respect to the use of 3-D audio display technology.

2 RANGE OF APPLICATIONS THE TECHNOLOGY CAN SUPPORT

Three-dimensional audio displays are being explored for improving operator performance in a variety of applications. These include cueing for visual search tasks, improved auditory signal detection and speech intelligibility, localization of signals, and creation of a realistic audio environment for relaxation. Calhoun, Jameson and Valencia (1988) compared the effectiveness of 3-D audio cues for directing subjects' visual attention to peripheral targets. Subjects were engaged in a visual tracking task while periodically responding to cues to identify visual targets at four peripheral locations. The authors found that subjects' response time with 3-D audio cueing was on the average 245 ms faster than non-spatialized auditory cueing, and for the left-right locations only 126 ms longer than the visual cue.

Begault (1993) evaluated a "head-up" spatial auditory air traffic collision avoidance system (TCAS) in a flight simulator. The positions of the visual targets corresponded to aircraft that would activate a TCAS aural advisory. Begault found that the use of a 3-D audio display resulted in an average of 2.2 seconds faster reaction time compared to a single earpiece baseline condition. Enhanced target detection and identification in a flight simulator task was also observed with the use of a 3-D audio display as investigated by Bronkhorst, Veltman and van Breda (1996). These investigators found that search time decreased on average by two seconds with the use of a 3-D audio display compared to visual search with a radar display; they found an additional average two seconds improvement when similar target information was simultaneously presented by both displays. During an in-flight study, pilots reported that a 3-D audio display decreased target acquisition time and visual workload while increasing communication capability and situational awareness (McKinley & Ericson, 1997).

The potential of a 3-D auditory display for improving auditory signal detection and speech intelligibility has also been demonstrated. Arrabito, Cheung, Crabtree and McFadden (2000) measured auditory thresholds when subjects were under sustained +3Gz positive acceleration. They found that subjects reached an average of 6.8 dB lower auditory threshold when a pulsed signal was spatialized at a static position of 90° azimuth on the horizontal plane in virtual auditory space compared to the baseline diotic (the same sound presented to both ears) presentation. In research motivated by the need of aircrew to monitor simultaneous channels of communication (e.g., air traffic control, air traffic information system and company), Ericson and McKinley (1997) investigated the contribution of 3-D audio. They reported improved speech intelligibility when more than two simultaneous talkers were spatialized at different virtual positions when listeners performed a complex divided attention task.

Extended applications of 3-D audio displays have been suggested to support situational awareness and spatial orientation by providing veridical spatial cues to the positions of targets, threats, and beacons (Doll, Gerth, Engelman & Folds, 1986; Furness, 1986). Applications could include auditory cueing to the location of allies (for example, aircraft wingman), or threats. Such applications could be extended from the 'real world' to virtual worlds such as navigation aids and sonar displays. In the area of team performance, the ability of a 3-D audio display to enhance speech intelligibility, especially in the presence of multiple simultaneous talkers, is being explored. Each talker could be spatialized at a different virtual position relative to the listener's head.

A somewhat different benefit was shown in the presentation of a relaxing 3-D audio sound to aircrew during in-flight and layover sleep periods which resulted in enhanced quality and quantity of sleep (Allsten, Downey & Jackson, 1995).

3 PROJECTED IMPACT OF THE TECHNOLOGY ON CURRENT AND FUTURE SPACE LAYOUT

Operator space layout could potentially be changed from a workstation configuration to one that has no physical constraints. For example, a 3-D audio display coupled with head tracking and man-on-the-move communications could improve the situational awareness of command or combat teams that presently are tied to their location because of headset communications systems. The ability of a 3-D audio system to support dispersed teams has been partially demonstrated by Bryden, at the Communications Research Center in Ottawa (Bryden, personal communication, February 10, 2000). Bryden assembled portable workstations consisting of a notebook computer, wireless LAN transceiver, differential GPS receiver (a higher level of accuracy than standard GPS), aviation type headset/microphone and head-mounted electronic compass, in order to conduct outdoor field trials on the effectiveness of directional virtual sound sources as a means of increasing situational awareness. Using this equipment, multiple simultaneous radio communication channels could be presented to listeners in a 3-D audio display.

The spatialization of the sound was created using a combination of HRTFs that were measured from the Knowles Electronic Mannequin for Acoustic Research (KEMAR), and a parametric model. The virtual sound sources were presented on the horizontal plane. Four subjects were each equipped with a portable workstation and were dispersed so that they could not see each other thereby simulating an infantry peacekeeping scenario. Bryden reports that subjects had a sense of situational awareness with respect to the location of each other based on the apparent direction of the virtual position of the radio communication channels. There were two major limitations of the equipment that negatively affected situational awareness: compass instability and latency to head movements.

4 TRANSITION POTENTIAL OF THE TECHNOLOGY

The transition potential of 3-D audio displays from the laboratory setting into real-world applications will depend on several technical factors, as well as issues of cost, availability and reliability. These issues include the robustness of the technology, the effectiveness of HRTFs, the characteristics of the sound to be localized, and the integration of the 3-D audio system with head tracking and underlying communications systems.

4.1 Robustness of the Technology

It should be noted that the above studies have been conducted in controlled environments. The conditions of these trials may not translate well to real-world applications. For example, Perrott et al. (1996) found that the greatest advantage of 3-D aurally aided cueing to the detection and discrimination of visual targets occurred when targets were presented in the rear and peripheral regions of the frontal hemi-field. These investigators used high contrast targets, which are unlikely in real-world situations. Findings such as these suggest the need for caution in the adoption of 3-D audio displays.

To date there have been few reports of the feasibility of a 3-D audio display in field trials. The flight trial of McKinley and Erickson (1997) is one example. In that study, pilots reported that a 3-D audio display decreased target acquisition time and visual workload while increasing communication capability and situational awareness. In another trial, NORAD CMOC crew members reported improved speech intelligibility when evaluating a 3-D audio system in a Ballistic Missile Defence Organization exercise (North and D'Angelo, 1997). Although the investigators of both of these studies collected only qualitative data, their results are encouraging and suggest that a 3-D audio display could improve operator performance in real-world applications.

Some of the issues in transferring laboratory research into real-world applications are exemplified in the debate about the contribution of spatial hearing to the enhancement of speech intelligibility of multiple simultaneous talkers. Cherry (1953) investigated the listener's ability to focus his/her attention on a single sound source or signal in the presence of multiple competing signals and interfering noise. He termed this the "cocktail-party problem". Cherry suggested that spatial separation of sound sources was the major contributor for solving the cocktail party problem. This provides support for the application of 3-D audio displays to improve the intelligibility of multiple competing talkers.

A recent review by Yost (1997) argues that spatial hearing may not be the major cue to solve the cocktail-party problem in real-world situations. Yost notes that, over the past 40 years, data on the benefits of binaural listening over monaural listening have been mostly collected via headphones or in simplified free-field studies, which do not represent real-world listening environments. He points out that these studies have been devoted to measures of selective attention, where the listener is asked to focus on a particular signal source and ignore all others. There is very little information on situations of divided attention, where the listener must attend to several or all of the sound sources in the acoustic environment. Yost suggests that there are seven physical attributes of sound that might be used as a basis for sound source determination. These are spectral separation, spectral profile, harmonicity, spatial separation, temporal separation, temporal onsets and offsets, and temporal modulations. This suggests that the greatest binaural advantage is found for detection tasks in noise, or measures of discrimination, or recognition tasks conducted at very low signal-to-noise ratios. The binaural advantage decreases rapidly with increasing signal level above threshold and is very small when the signal is relatively easy to detect.

The improvement of speech intelligibility of multiple talkers using a 3-D audio display may depend on the number of simultaneous talkers. For example, Arrabito et al. (1996) found that there was no improvement in speech intelligibility when two simultaneous talkers were spatially presented in a 3-D audio display compared to a dichotic presentation. Ericson and McKinley (1997) found that the greatest benefits of spatializing the speech signals of a communication headset may occur when there are more than two talkers or signals to attend to simultaneously. The results of Ericson and McKinley (1997) may be explained by the observation of Cherry (1953). He noted that, in a free-field listening environment, the signal-to-noise ratio at the listener's ears will vary when the noise source is spatially displaced and will be different across the two ears. For example, when the noise source is displaced laterally relative to the listener, the noise level increases in the ipsilateral ear (i.e., the ear closest to the sound source) and decreases in the contralateral ear (i.e., the ear furthest away from the sound source). When there are several sound sources surrounding the listener, these multiple signals reduce the speech to noise ratio at the ear closest to the desired talker. Hence the overall intelligibility level is reduced by the unwanted but necessary binaural signals. Given that the greatest binaural advantage is realized at very low signal-to-noise ratios, it is expected that an increase in speech intelligibility should be observed when more than two competing talkers are presented in a 3-D audio display.

The extension of the research of Ericson and McKinley (1997) has been transferred into a real-world application. A Canadian company has developed and is marketing a 4-channel shipboard communication terminal. Each of the four communication channels are spatialized at different static virtual positions relative to the listener. A company representative reported that users of this system have remarked improved speech intelligibility of multiple simultaneous talkers. The system is primarily targeted as a device for channel separation rather than the display of position information. This latter capability may be utilized in the ensuing future as reported by the company representative.

4.2 Head-Related Transfer Functions

Head-Related Transfer Functions are the digital filters used for spatializing a sound and thus are essential to 3-D audio. Measurement techniques of HRTFs differ across laboratories and are motivated by the different goals of the investigators (see references 2, 3, 5-27 of Moller, Sorensen, Hammershoi & Jensen, 1995). Some of the parameters that vary significantly in the measurement of HRTFs are:

- type of test stimulus (e.g., sinusoidal tones or noise bursts),

- the point in relation to the ear canal where the measurement is made (e.g., at the blocked ear canal or a point somewhere along the ear canal), and

- the number of source positions.

It has been argued that a listener's ability to localize a virtual sound is more accurate when using HRTFs measured from his/her own head ("personal") compared to HRTFs measured from a different head ("generic") (Wightman & Kistler, 1989; Wenzel et al., 1993; Bronkhorst, 1995). Investigators have also shown that generic HRTFs significantly contribute to more reversals (i.e., perceiving the mirror image of the presented sound source) in perceived position of a sound compared to personal HRTFs (Wenzel et al, 1993). Perceiving the mirror image of the sound source may lead to an inaccurate sense of situational awareness. If virtual sources are to be used in a general-purpose 3-D audio display under mission critical conditions, such as those encountered by military personnel, then the HRTFs should be optimized for the targeted application. However, it is presently not practical or affordable to measure the HRTFs for each potential listener. In light of these findings, methods need to be developed to quickly and accurately select a generic HRTF for the targeted application. One vendor of a virtual listening home theater entertainment system requires that the listener select the best available set of HRTFs from a repository measured on many individuals. The selection is made on the basis of a simple virtual sound localization test performed over headphones. This test could be further refined to ensure more accurate spatial synthesis by selecting a localization task emphasizing conditions typical of generic HRTF listening such as front-back reversals and median plane errors (Wenzel et al., 1993).

The criterion for selecting generic HRTFs need not be based exclusively on individuals who are "better localizers" than others due to physiological differences. Good localizers are subjects whose free-field localization performance is better than average and whose headphone localization performance in virtual auditory space closely matches his/her free-field localization performance. F.L. Wightman (personal communication, March 2, 1997) reported that his laboratory has been unsuccessful in documenting any relation between HRTF characteristics and localization performance despite suggestions made in an earlier study (Wightman & Kistler, 1989). While it is clear that some subjects may have less spectral detail to work with because their pinnae are smooth, it is not clear that this translates into poor performance. With several cues to work with, some individuals seem simply to emphasize one or more cues depending on their own physical characteristics.

4.3 Headphones

The spatial synthesis process of virtual sound sources is not solely dependent on the selection of HRTFs (personal versus generic). The headphones contribute to the total transmission and require equalization for the correct reproduction or synthesis of binaural signals (Wightman & Kistler, 1989; Moller, 1992). Headphone equalization is a digital filtering procedure to cancel the distortion caused by the headphones and the resonance effects on the listener's ears. The equalization is specific to the headset and the end-listener. In the past, the equalization procedure has often been overlooked (Moller, 1992). It should be noted that headphone placement on the listener's head is rarely the same and, hence, the headphone equalization step may not always be exact. It may thus be argued that the equalization step might be more detrimental than useful. Proper fitting of the headphone on the listener's head will ensure that spatialization is not degraded. It is critical that both ear cups are over the pinnae, and that the right ear cup is on the right ear and the left ear cup is on the left ear. It should be noted that the author has found that it is common practice for operators, in a ship's operation room for example, to remove the headset from one ear to improve direct communication transmission to those nearby. In such settings, operators will be required to be fitted with headsets that allow them to hear the voices of nearby crew members while providing high fidelity communications. The selection of a headset equipped with a single knob to control the signal volume under both ear cups is preferred over a headset equipped with dual controls to independently adjust the volume in the left and right ears. Independent volume controls interfere with the correct reproduction of spatial cues from the virtual audio sources.

4.4 Stimulus and Bandwidth

The properties of the stimulus for use in virtual auditory space need to be factored into consideration with respect to user performance. For example, localization performance will be affected by the characteristics of the sound to be spatialized. Broadband impulsive sounds are easier to localize than low frequency sounds that have slow amplitude envelopes (Begault, 1991). Begault and Wenzel (1993) found that localization performance was not as accurate when the broadband stimulus used in a similar study by Wenzel et al. (1993) was replaced by speech stimulus. It should be noted that the bandwidth of speech is less than the bandwidth of white noise and this difference might be a factor in accounting for the different results.

The cues for range in virtual environments also need to be factored into consideration with respect to user performance. Begault (1991), for example, reported that these cues are not as well understood as the cues for azimuth and elevation. The signal can also be made to appear that it is outside of the listener's head by adding reverberation cues. This gives the listener a more natural listening advantage. However, the localization error between the presented and the perceived virtual sound source increases with the presence of reverberation (Begault, 1992). Furthermore, speech intelligibility in a virtual environment is poorer with the presence of reverberation cues, as demonstrated by Vause and Grantham (1998).

The bandwidth of the communication system has a typical upper cutoff frequency between 3.5 and 4 kHz (Ericson & McKinley, 1997; King & Oldfield, 1997) which could potentially affect localization performance. If the sole cues afforded by the bandwidth of the communication system are the differences in the time and level of arrival, one could correctly assume the presence of front-back reversals. Front-back reversals are largely resolved with the presence of spectral cues. Spectral cues are contained in the frequency region above 4 kHz and are encoded by the head, pinnae and upper torso (Blauert, 1983). The upper frequency limit of the communication system will be governed by the location of the virtual audio sources in the intended application. In the case of virtual sources positioned on the horizontal plane, an upper frequency limit of 4-5 kHz should be adequate (Blauert, 1983). 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 (King & Oldfield, 1997). However, some communication systems have a hardware imposed upper cutoff frequency of approximately 4 kHz as reported by the representative of the Canadian company that is marketing a shipboard communication terminal. Such a limitation may impose a restriction on the types of 3-D audio applications.

4.5 Head Tracking

The need for head tracking is a significant requirement if 3-D displays are to be implemented for other than the most basic applications. Head tracking can assist the listener with exploratory head movement relative to the apparent direction of the virtual sound source provided that the duration of the sound is sufficiently long. This in turn can assist the listener with disambiguating between sound sources such as front-back reversals which are located in the so-called "cone-of-confusion", i.e., directions that cause similar interaural differences in level and arrival time (Blauert, 1983). For example, Bronkhorst (1995) found that front-back reversals were low when listeners oriented their head to a long-duration sound source but high when listeners localized a short-duration sound source without head movements.

The spatial sound image coupled with a head tracker significantly depends on the number of spatial locations measured for the HRTFs. Smooth motion of a virtual auditory signal (head movement, moving sound source) requires high spatial resolution (equal to or less than 5°) (Hartung, Braasch & Sterbing, 1999). Having a smaller number of measured sound source positions requires the between-source interpolation procedure to be more precise. The advantage of measuring HRTFs with a lower spatial resolution results in minimizing the measurement time. Approximately one hour was required to measure HRTFs with a 10-15° spatial resolution of the whole sphere (Hartung et al., 1999). Minimizing the measurement time of HRTFs will necessitate appropriate interpolation techniques which yield high spatial resolution and synthesis. Hartung et al. (1999), for example, found that subjects could distinguish between measured and interpolated HRTFs for some of the tested directions based on location and/or timbre. In a related study Cheng and Wakefield (1999) found that listeners' localization performance was better using interpolated rather than non-interpolated

HRTFs. Although the tasks asked of the subjects in these two studies are not directly comparable (discrimination versus localization), it is interesting to note that a possible explanation for the different findings may be attributed to the source of the measured HRTFs. The HRTFs in the study by Hartung et al. (1999) were measured from the KK1412 acoustic mannequin developed by Head Acoustics while those in the study by Cheng and Wakefield (1999) were measured on humans. The results of these studies suggest that the number of measured spatial positions and the source of the measured HRTFs could affect listener performance in the targeted application.

A range of head tracking technologies are available, most of them developed from head-mounted display systems. Technologies include mechanical linkages, inertial, magnetic and electro-magnetic, electronic, infra-red and ultrasonic. Head tracking in user-on-the-move applications, especially on dispersed personnel, cannot be accomplished using conventional head trackers such as electro-magnetic or infra-red trackers. For example, the Polhemus 3Space Fastrak tracker consists of a transmitter emitting a magnetic field which is detected by the receiver. This device requires a workspace that is not much larger than the operator workspace and thus cannot be used for man-on-the-move applications. Hence it may be necessary to require reliance on the global positioning system (GPS). GPS provides satellite signals that can be processed in a GPS receiver, enabling the receiver to compute position, velocity, and time estimates. The accuracy of the GPS is categorized by "standard", "precise" and varying levels of precision between these two extremes. Standard GPS is provided without charge or restrictions to the end-user. Precise positioning is more accurate than standard GPS and can be accessed only by authorized users with specially equipped receivers. In the man-on-the-move application, the receiver can be mounted on the helmet. The required degree of situational awareness will dictate the accuracy of the GPS. In the trial of dispersed personnel conducted by Bryden (personal communication, February 10, 2000) the electronic compass exhibited instability and high latency in reacting to rapid subject head movements. There were also drop-outs in the differential GPS and during these instances, the bearing inaccuracies were unacceptably high. Given these results, it may be necessary to decrease the head compass latency and use higher precision in the GPS receiver.

4.6 Environmental Conditions

The transfer of user performance from a laboratory setting into a real-world application has been shown to degrade due to environmental factors. For example, McKinley and Ericson (1997) observed a gradual degradation in localization performance from the laboratory baseline conditions to the flight trial. During the baseline study conducted in the laboratory, subjects could point their heads to a sound source presented in the free-field with an accuracy of 4-5° versus 6-7° for the same task but in the presence of 115 dB SPL ambient pink noise. The minimal audible angle (MAA) that subjects could discern targets was 12° azimuth under conditions of low level and high speed flight. However, it should be noted that McKinley and Ericson (1997) do not clearly indicate if any of the subjects who participated in the baseline study also participated in the flight trial. Furthermore, the head pointing and MAA tasks are not directly comparable. Nevertheless, it is probable that the environmental conditions could have affected localization performance despite the aforementioned observations.

Ambient noise and electromagnetic interference are examples of environmental conditions that need to be factored into consideration when exploring the use of 3-D audio. In settings where the level of the ambient noise is relatively low, such as that found in the operations room of a ship (typically less than 80 dB(A) based on levels measured by DCIEM personnel), the ambient noise should not affect performance when using a 3-D audio display. On the other hand, the cockpit noise levels of military aircraft range from 95 to 115 dB SPL under normal operating cruising conditions (Ericson & McKinley, 1997). McKinley and Ericson (1997) demonstrated that a 3-D audio display could increase user performance in high levels of ambient noise such as that found in cockpits. However, the author of this paper has empirical data for sound localization in virtual auditory space that was collected in quiet (71 dB(A)) and in the presence of ambient Leopard tank noise (approximately 110 dB(A)). Localization performance was poorer in the latter condition compared to the former.

The surrounding metallic structure (e.g., overhead beams, frames, instrument panel, etc.) found within personnel compartments (e.g., cockpit, armored vehicle, operations room, etc.) could significantly degrade the performance of commercial-off-the-shelf electromagnetic head trackers. The head tracker used in the flight trial reported by McKinley and Ericson (1997) was a modified Polhemus 3Space Fastrak magnetic head tracker which reduced the amount of electromagnetic interference. Mechanical trackers would be spared from electromagnetic interference; however, the mobility of the end-user would be smaller compared to electromagnetic trackers and thus could impede the operator's performance. The most likely technology for a head tracker in an operational space would be one of the small inertial tracker or an ultrasonic tracker that have recently come on the market. These latter technologies are reported to be immune from the effects of electromagnetic interference and can cover a large user space.

5 IMPACT OF THE TECHNOLOGY ON PERSONNEL WORKLOAD AND SAFETY

Three-dimensional audio should reduce the workload of operators. For example, McKinley and Ericson (1997) reported that a 3-D audio display decreased visual workload. Increased communication capability when listening to simultaneous messages has been demonstrated by Ericson and McKinley (1997), and McKinley and Ericson (1997). The time taken to react to visual warnings using spatial auditory cueing could be reduced 10-50 percent as demonstrated by Perrott et al. (1996).

Increased operator safety may also be realized with the use of a 3-D audio display, based on reduced response time to alerting signals, improved operator performance, and reduced risk of hearing loss. At present, the level of auditory warnings presented over the communication system used by aircrew is frequently too loud (Patterson, 1982). Many of the existing auditory warnings disrupt thought and verbal communication amongst crew members (Patterson, 1982). In addition, continuous loud sounds hold the crew's attention beyond the point where the problem has been identified, often incapacitating aircrew (Patterson, 1982). Auditory warnings in a 3-D audio display may be detected as much as 6 dB lower compared to a diotic presentation Based on the results of Arrabito et al. (2000). This represents an approximate 50% reduction in the acoustic amplitude of the stimulus. Thus the overall amplitude level of the communication system can be reduced without sacrificing detectability. Lower headphone amplitude could reduce the risk of hearing loss.

It should not be assumed that all operators can benefit equally from the use of a 3-D audio display. In fact operators who have a hearing impairment may impose a safety hazard on themselves and/or fellow crew members due to disrupted spatial cues which could lead to inaccurate localization judgements. Hearing impairment may be broadly categorized as either conductive or sensorineural (Moore, 1989). Conductive hearing loss usually occurs when there is a defect in the middle ear. Normally this results in hearing loss across all frequencies. Sensorineural hearing loss most commonly arises from a defect in the cochlea, but may also result from defects in the auditory nerve or higher centres in the auditory system. Often, the extent of the loss increases with frequency, especially in the elderly.

The above two types of hearing losses have been studied with respect to their effects on localization performance in the free-field (Noble, Byrne & LePage, 1994). In that study 87 bilateral hearing impaired individuals (mean age 65.6 years, s.d. 13.8 years) participated. Of these, 66 had sensorineural hearing loss and 21 had conductive or mixed hearing loss. Localization judgements were tested in four spatial regions relative to the listener: frontal horizontal plane (FHP), median vertical plane (MVP), lateral horizontal plane (LHP) and lateral vertical plane (LVP). The investigators found that both hearing impaired groups exhibited poorer localization performance compared to the tested control group of normal hearing individuals. In particular, the sensorineural group was more accurate than the conductive/mixed group in the FHP. The difference in performance can be attributed to the inability of individuals with conductive/mixed hearing loss to access interaural time difference cues, which dominate FHP judgements. In the MVP, localization performance was poor for both hearing impaired groups but to a greater extent for the sensorineural group. The loss of higher frequencies lead to the collapsing of vertical locations onto the horizontal plane, which suggests that the poorer performance of those subjects with sensorineural hearing loss was attributable to the absence of high-frequency pinnae-based cues. Both groups performed poorly in the LHP with performance being mostly attributed to high-frequency hearing loss, which caused difficulty in front/rear discrimination. These investigators concluded that hearing impaired listeners rely on the same auditory cues as do normally hearing listeners, and that there is no indication that impaired listeners can learn to compensate for their hearing deficiencies by using other types of information (e.g., head movement) to process localization cues.

The effect of sensorineural hearing loss on localization performance in virtual auditory space has also been studied (Smith-Olinde, Koehnke & Besing, 1998). The stimulus was spatialized using the KEMAR HRTFs and localization judgements were tested in the FHP. These investigators reported that localization for the hearing impaired group was poorer compared to the normal listeners.

Based on the results of Noble et al. (1994) and Smith-Olinde et al. (1998), hearing impaired listeners may partially benefit in improved performance with the use of a 3-D audio display. However, the range of applications must not require conditions of high situational awareness. Furthermore, it may be prudent that users of a 3-D audio display be audiometrically screened on an on-going basis to ensure normal hearing acuity. This is particularly vital for personnel with advancing age who might have acquired presbycusis (the loss of hearing sensitivity at high frequencies with increasing age). Moreover, the hearing threshold levels at specific frequencies may also serve as a predictor of localization performance for certain positions in auditory space (Noble et al., 1994).

A final point that merits attention from a safety perspective is the treatment and occurrence of localization judgements that result in reversals. Some present reports are misleading in their treatment of data on reversals. In localization studies reversals are commonly resolved by coding the subjects' response as if it were indicated in the correct hemisphere (Oldfield & Parker, 1984; Wightman & Kistler, 1989; Wenzel et al., 1993). Clearly, resolving reversals in this manner for critical mission applications could be fatal. For example, there is no tolerance for reversals if virtual sources are to serve to cue aircrew to the spatial location of a potential lethal threat such as another aircraft.

Investigators have also reported greater occurrence of reversals in virtual auditory space regardless of the choice of HRTFs (personal or generic) compared with localization in the free-field. Wightman and Kistler (1989) found that the percentage of front-back reversals on average when using personal HRTFs was almost twice as high for virtual auditory space as for free-field (11% versus 6%). Wenzel et al. (1993), who performed a similar experiment to Wightman and Kistler (1989), found that front-back reversals were higher in virtual auditory space than in free-field (31% versus 19%) when generic HRTFs were used. The cause of this imperfection in the simulation of virtual sound sources is not yet fully understood. Bronkhorst (1995), for example, attributes this imperfection to an incorrect simulation of high frequency spectral cues above 7 kHz probably caused by a distortion introduced by the HRTF measurements performed with probe microphones in the listener's ear canals. However, Martin, McAnally and Senova (submitted) recently evaluated a HRTF measurement technique from their laboratory. They compared virtual and free-field localization performance across a wide range of sound-source locations for three subjects. For each subject, virtual and free-field localization performance was found to be indistinguishable, as indicated by both front-back reversal rates and average localization errors. The development of a system of such high fidelity is a significant milestone in the maturation of virtual audio technology.

6 CONCLUSIONS AND RECOMMENDATIONS

Operator performance has been demonstrated to improve with the use of a 3-D audio display in a range of laboratory studies, as discussed in this paper. The benefit of increased performance can result in reduced workload and increased situational awareness. A 3-D audio display can also assist with the reduction of the overall amplitude of the communication system without sacrificing detectability and thus ensuring safe headphone levels of auditory warnings which at present are frequently too loud (Patterson, 1982). Quicker reaction time with the use of a 3-D audio display compared to conventional aural presentation has also been reported. Improved reaction time could be extremely critical in emergency situations where appropriate and evasive action must be made quickly and correctly. Further gains in decreased workload and/or quicker reaction time may result if information is presented in a bimodal display and thus it is recommended that this be further investigated.

Real-world applications of 3-D audio are likely given its apparent benefits as demonstrated by the outcome of the field trials discussed in this paper. The development by a Canadian company of a commercial shipboard communication product for the spatialization of up to four static talkers indicates that industry is seriously investigating the performance gains with a 3-D audio presentation. Before the implementation of 3-D audio into real-world applications, it is essential that investigators first determine the nature and extent of "gaps" in research and technical knowledge bases relative to this new technology. For example, Arrabito et al. (1996) demonstrated the lack of advantages found for 3-D audio compared to a 2-D audio display. In this instance it appears that R&D efforts should be focused on a 2-D audio display when listeners need to attend to only two competing talkers.

In a real-world application such as one of a complex divided attention task, the binaural synthesis of the signals must provide accurate localization performance to the end-listener in order to maintain a precise and consistent sense of situational awareness. This type of task is the most stringent as far as the quality of the binaural synthesis of signals is concerned, but potentially offers the greatest benefit. More fundamental research is needed to quantify the real advantage gained by spatializing the communication signals for such tasks, in terms of speech intelligibility, total information transfer and/or situational awareness (Ericson & McKinley, 1997).

Furthermore, in spite of the support for 3-D audio technology, performance will be ultimately dependent on the hearing ability of the end-listener. It has been demonstrated that the loss of hearing results in poorer localization performance compared to normal hearing listeners. Poor localization ability may be fatal in critical mission applications and thus hearing loss needs to be factored into consideration. Further research into the effects of hearing loss on localization performance in virtual auditory space with the use of personal and generic HRTFs needs to be conducted. Testing should be performed in free-field and virtual auditory space in a similar way to the methods reported by Wightman and Kistler (1989), and Wenzel et al. (1993).

At present, several critical factors are impeding the transition potential of 3-D audio technology into real-world applications. These include the choice of personal versus generic HRTFs, environmental factors and communication bandwidth. In particular, performance in virtual auditory space is more accurate and results in fewer localization reversals with personal HRTFs compared to generic ones. However, personal HRTFs are traditionally derived from binaural measurements in the ears of the end-listener seated in an anechoic chamber (a room without reverberation cues down to a specific cutoff frequency). This requires a substantial investment in infrastructure and equipment, and is presently impractical in most applications. Methods thus need to be developed to quickly and accurately select and/or modify a generic HRTF for the targeted application. To implement man-on-the-move applications will require further investigation into head tracking systems and interpolation techniques of HRTFs. The effect of ambient noise on user performance using either personal or generic HRTFs also needs investigation. The hardware limitation imposed on the communication bandwidth needs to be addressed. Until the above issues are more fully understood and resolved it may be prudent to proceed cautiously before the adoption of a 3-D audio system. Advances in these issues are being made as demonstrated by the results of Martin et al. (submitted) which suggest that the imperfection in the simulation of virtual sound sources is an obstacle that may have been surmounted. This represents a significant achievement in the reproduction of spatial synthesis. In the meantime, it is suggested that defence forces examine archived audiograms given that there is a partial relationship between hearing threshold levels and localization performance as reported by Noble et al. (1994). This would serve as a criterion for evaluating the benefits of a 3-D audio display.

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A COMPARISON OF MODAL DECOMPOSITION ALGORITHMS FOR MATCHED-MODE PROCESSING

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ABSTRACT

This paper compares a variety of modal decomposition methods used in matched-mode processing (MMP) for ocean acoustic source localization. MMP consists of decomposing far-field acoustic measurements at an array of sensors to obtain the constituent mode excitations (modal decomposition), and then matching these excitations with modelled replica excitations computed for a grid of possible source locations. Modal decomposition can be ill-posed and unstable if the sensor array does not provide an adequate spatial sampling of the acoustic field, so the results of different approaches can vary substantially. Solutions can be characterized by modal resolution and solution covariance; however the ultimate test of the utility of the various methods is how well they perform as part of a MMP source localization algorithm. In this paper, the resolution and variance of the methods are examined using an ideal ocean environment, and MMP results are compared for a series of realistic synthetic test cases, including a variety of noise levels and sensor array configurations. Zeroth order regularized inversion is found to give the best results.

SOMMAIRE

Cet article compare différentes méthodes de décomposition modale utilisées en matched-mode processing (MMP) pour la localisation de source acoustique marine. La méthode MMP consiste à décomposer le champ acoustique mesuré par un réseau de capteurs pour obtenir les excitations modales présentes (décomposition modale), et ensuite à faire correspondre ces excitations avec les excitations calculées par un modèle numérique pour une grille de positions possibles de la source. Le problème de décomposition modale peut être mal posé et instable si les capteurs du réseau ne fournissent pas un échantillonnage spatial adéquate du champ acoustique. Les résultants de differentes approaches peuvent donc varier considérablement. Les solutions peuvent être caractérisées par la résolution modale et la covariance de la solution. Cependant, le critère ultime d'utilité des différentes méthodes est de savoir leur degré de perfomance dans l'algorithme MMP pour la localisation de source. Dans cet article, la résolution et la variance des méthodes sont examinées en utilisant un environnement océanique idéal. Les résultats obtenus avec la méthode MMP sont comparés pour une série de cas réalistique et synthétiques, comprenant différents niveaux de bruit et différentes configurations du réseau de capteurs. Les meilleurs résultats sont obtenus avec la méthode d'inversion basée sur une régularisation d'ordre zéro.

1. INTRODUCTION

Localization of acoustic sources is an important problem in underwater acoustics. Two common approaches to this problem are beamforming (e.g., Burdic[1]) and matched-field processing[2−5] (MFP). Beamforming assumes the incident acoustic fields consist of plane waves, and searches for the inter-sensor time delay and corresponding incidence angle that maximizes the total acoustic power. This provides the bearing of the acoustic source, but not its range and depth. MFP localization matches acoustic pressure fields measured at an array of sensors with replica fields computed for a grid of possible source locations using a numerical propagation model, and can provide localization in range, depth, and bearing. A third method for localizing an acoustic source is matched-mode processing (MMP), which is similar to MFP, but decomposes the measured fields to obtain the excitations of the constituent propagating modes, and matches these with modelled replica excitations.

A potential advantage of MMP over MFP is that subsets of the complete mode set can be considered. Thus, for example, in cases where bathymetry or geoacoustic parameters of the seabed are poorly known, the matching can be applied only to low-order modes which interact minimally with the bottom.[7,8] However, a potential disadvantage of MMP involves the modal decomposition itself. Modal decomposition represents a linear inverse problem that is non-unique (an infinite number of solutions exist) and can be unstable (small errors on the measured data can lead to large errors on the solution). MMP can provide poor results when the sensor array inadequately samples the acoustic field. If an array contains fewer sensors than there are propagating modes, the highest-order mode functions are under-sampled (spatially aliased), and the inversion is singular. Alternatively, if the array aperture spans too small a fraction of the water column, the lowest-order modes are poorly sampled, leading to an ill-conditioned decomposition problem.

Standard techniques of inverse theory, such as least squares, singular-value decomposition (SVD), and zeroth-order regularization, have been applied to compute a generalized pseudo-inverse for the modal decomposition problem.[9-14] The constructed solution can be characterized in terms of the modal resolution and solution variance. However, for this paper, the ultimate test of a modal decomposition method is how well it performs in source localization, quantified here by the probability of correct localization for realistic synthetic test cases.

This paper compares a variety of modal decomposition techniques by considering solution resolution and variance, and localization performance. Although several papers have compared different approaches to modal decompostion in various ways,[10-13] a truly comprehensive comparison considering resolution, accuracy and localization performance has not been carried out. The paper is organized as follows. Section 2 reviews the underlying theory, including the normal-mode model, pertinent results from linear inverse theory, and an overview of modal decomposition methods. Section 3 provides modal resolution and solution variance comparisons for an ideal ocean environment using a variety of array configurations. In Sec. 4, MMP source localization results for realistic testcases are compared. Finally, Sec. 5 summarizes the paper.

2. THEORY

2.1 Normal Modes

In the far-field, the normal-mode model for the acoustic pressure signal s at depth z due to a point source at a depth z_s and range r can be written as[4,5]

$$s(r,z) = b \sum_{m=1}^{M} \phi_m(z)\phi_m^*(z_s)\frac{e^{ik_m r}}{\sqrt{k_m r}}, \qquad (1)$$

where $*$ denotes complex conjugation, ϕ_m and k_m represent the mth mode function and horizontal wavenumber respectively, M is the total number of propagating modes, and $b = e^{i\pi/4}\sqrt{2\pi}/\rho(z_s)$ where ρ is density. The mode functions are eigenfunction solutions of the depth-separated wave equation, and form an orthonormal set according to[6]

$$\int_0^\infty \frac{\phi_m(z)\phi_n^*(z)}{\rho(z)}dz = \begin{cases} 0 & \text{if } m \neq n, \\ 1 & \text{if } m = n. \end{cases} \qquad (2)$$

The mode function shape depends on $c(z)$ and the boundary conditions applied at the ocean surface and bottom.

In the special case of an ideal ocean consisting of a homogeneous water column ($\rho(z) = \rho$ and $c(z) = c$) of depth h and perfectly-reflecting boundary conditions of a pressure release surface ($s(r,0) = 0$) and a rigid seafloor ($\partial s(r,h)/\partial z = 0$), the mode functions and radial wavenumbers are given by

$$\begin{aligned} \phi_m(z) &= \sqrt{\frac{2\rho}{h}}\sin(\kappa_m z), \\ k_m &= [\omega^2/c^2 - \kappa_m^2]^{1/2}, \end{aligned} \qquad (3)$$

and the vertical wavenumbers κ_m by

$$\kappa_m = \frac{(2m-1)\pi}{2h}. \qquad (4)$$

The horizontal wavenumbers are either real ($\omega^2/c^2 > \kappa_m^2$), corresponding to trapped modes, or purely imaginary ($\omega^2/c^2 < \kappa_m^2$), corresponding to evanescent modes that decay exponentially with range. For a general ocean environment, including variable ocean sound speeds and a layered elastic bottom, simple analytic expressions do not exist for ϕ_m, k_m, and κ_m, but they can be computed numerically using a model such as ORCA.[15]

If the acoustic signal is recorded at a vertical line array (VLA) of N sensors, (1) can be written as a linear matrix equation

$$\mathbf{A}\,\mathbf{x} = \mathbf{s}, \qquad (5)$$

where $\mathbf{s} = [s(z_1), \ldots, s(z_N)]^T$ represents the signal vector and T denotes transpose, $\mathbf{A}$ is an $N \times M$ matrix with columns consisting of the sampled mode functions

$$\mathbf{A} = \begin{bmatrix} \phi_1(z_1) & \ldots & \phi_M(z_1) \\ \vdots & \ddots & \vdots \\ \phi_1(z_N) & \ldots & \phi_M(z_N) \end{bmatrix}, \qquad (6)$$

and $\mathbf{x}$ is a vector of the mode excitations at the receivers

$$\mathbf{x} = b\left[\ \phi_1(z_s)\frac{\exp[ik_1 r]}{\sqrt{k_1 r}}, \ldots, \phi_M(z_s)\frac{\exp[ik_M r]}{\sqrt{k_M r}}\ \right]^T. \qquad (7)$$

Note that $\mathbf{x}$ contains all the information regarding source location (range r and depth z_s). In practical cases, the signal is contaminated by additive noise $\mathbf{n}$, so (5) becomes

$$\mathbf{A}\,\tilde{\mathbf{x}} = \mathbf{s} + \mathbf{n} \equiv \mathbf{p}, \qquad (8)$$

where $\mathbf{p}$ is the vector of measured acoustic pressures $\mathbf{p} = [p(z_1), \ldots, p(z_N)]^T$. Modal decomposition consists of solving (8) for an estimate $\tilde{\mathbf{x}}$ of the true mode excitations $\mathbf{x}$.

2.2 General Linear Inverse Theory

The modal decomposition problem presented in the previous section is representative of a class of discrete linear inverse problems. This and the following section provide an overview of results from linear inverse theory relevant to this paper; more complete treatments are available in Refs. 17–20. If the matrix $\mathbf{A}$ is square and well-conditioned, an exact inverse $\mathbf{A}^{-1}$ and a solution to the inverse problem $\mathbf{x} = \mathbf{A}^{-1}\mathbf{p}$ exist. However, $\mathbf{A}$ is often neither square nor well-conditioned, so methods of linear inverse theory must be employed to obtain a solution. Specific modal decomposition inversion methods for constructing solutions are discussed in Sec. 2.3. This section introduces general methods of examining the characteristics of a solution $\bar{\mathbf{x}}$ obtained using any generalized inverse $\mathbf{A}^{-g}$ (e.g., Menke[19]),

$$\bar{\mathbf{x}} = \mathbf{A}^{-g}\,\mathbf{p}. \tag{9}$$

The solution can be characterized by three properties: (i) data misfit, (ii) model resolution, and (iii) solution covariance.

The data misfit (i.e., the level to which the solution fits the data) is typically quantified by

$$\begin{aligned} X^2 &= |\mathbf{G}(\mathbf{A}\,\bar{\mathbf{x}} - \mathbf{p})|^2 \\ &= \mathbf{p}^\dagger\,(\mathbf{A}\mathbf{A}^{-g} - \mathbf{I})^\dagger\,\mathbf{G}^\dagger\mathbf{G}\,(\mathbf{A}\mathbf{A}^{-g} - \mathbf{I})\,\mathbf{p}, \end{aligned} \tag{10}$$

where $\mathbf{G}$ is a diagonal matrix with the reciprocal of the estimated standard deviation ξ_i for the ith datum p_i on the main diagonal, $\mathbf{I}$ is the identity matrix, and $\dagger$ denotes conjugate (Hermitian) transpose. If the data errors are assumed to be independent, zero-mean, Gaussian-distributed random variables, minimizing (10) leads to the maximum-likelihood solution. Under the assumption of Gaussian noise, the misfit in (10) is distributed according to the central χ^2 distribution.[16] In addition, if the noise terms all have the same standard deviation ξ, (10) simplifies to

$$\chi^2 = \mathbf{p}^\dagger[\mathbf{A}\,\mathbf{A}^{-g} - \mathbf{I}]^2\,\mathbf{p}/\xi^2. \tag{11}$$

If $\mathbf{A}^{-g}$ acts like a right inverse, then $\mathbf{A}\mathbf{A}^{-g} = \mathbf{I}$ and $\chi^2 = 0$. The closer $\mathbf{A}\mathbf{A}^{-g}$ is to $\mathbf{I}$, the smaller the misfit. However, for noisy data, the solution should not be expected to fit the data too closely. For Gaussian noise, a statistically meaningful level for misfit is $\chi^2 = 2N$, the expected value for N complex (noisy) data.[16,20] For the case of correlated noise, (10) can be generalized by replacing the $\mathbf{G}^\dagger\mathbf{G}$ term by the inverse of the estimated data covariance matrix $\langle\mathbf{n}\mathbf{n}^\dagger\rangle$, where $\langle\cdot\rangle$ represents the expected value.

Model resolution indicates how well individual parameters of the model can be resolved. Noting that $\langle\mathbf{p}\rangle = \mathbf{A}\langle\bar{\mathbf{x}}\rangle$ from (8), it follows that for the noise-free case, $\bar{\mathbf{x}} = \mathbf{A}^{-g}\,\mathbf{s} = \mathbf{A}^{-g}\,\mathbf{A}\langle\bar{\mathbf{x}}\rangle$, or

$$\bar{\mathbf{x}} = \mathbf{R}\langle\bar{\mathbf{x}}\rangle, \tag{12}$$

where

$$\mathbf{R} = \mathbf{A}^{-g}\mathbf{A} \tag{13}$$

is defined to be the model resolution matrix. If $\mathbf{R} = \mathbf{I}$, each model parameter is perfectly resolved. If $\mathbf{R}$ is diagonally dominant (small non-zero off-diagonal terms), each parameter is well-resolved. However, if $\mathbf{R}$ has significant non-zero off-diagonal terms, the parameters of $\bar{\mathbf{x}}$ represent weighted averages of the expected parameters, and cannot be individually resolved. Resolution matrices for several different modal decomposition methods and VLA configurations are illustrated in Sec. 3.

The solution covariance is defined as

$$\mathbf{C} = \langle[\,\bar{\mathbf{x}} - \langle\bar{\mathbf{x}}\rangle][\,\bar{\mathbf{x}} - \langle\bar{\mathbf{x}}\rangle]^\dagger\rangle = \mathbf{A}^{-g}\langle\mathbf{n}\mathbf{n}^\dagger\rangle(\mathbf{A}^{-g})^\dagger. \tag{14}$$

For Gaussian errors with the same standard deviation ξ, $\langle\mathbf{n}\mathbf{n}^\dagger\rangle = \xi^2\mathbf{I}$, and

$$\mathbf{C} = \xi^2\,\mathbf{A}^{-g}\,(\mathbf{A}^{-g})^\dagger. \tag{15}$$

The mth diagonal element C_{mm} gives the variance of the mth model parameter $\bar{x}_m$, with the solution standard deviations given by $\sigma_m = \sqrt{C_{mm}}$. Note that these standard deviations are with respect to the expected solution $\langle\bar{\mathbf{x}}\rangle$, which only coincides with the true solution for even- and over-determined problems. The off-diagonal terms of $\mathbf{C}$ represent the covariances between solution parameters.

In general, for linear inverse problems, there is a trade-off between solution variance and resolution. The following section illustrates how particular solutions can be developed for the modal decomposition problem by exploiting this trade-off.

2.3 Modal Decomposition Methods

This section briefly reviews the various inversion methods applied to modal decomposition. One of the simplest approaches to modal decomposition is the sampled-mode shapes (SMS) filter. This method is based on the assumption that the modes are orthogonal and applies $\mathbf{A}^\dagger$ as the general inverse to (8) to obtain[9,21]

$$\bar{\mathbf{x}} \approx \mathbf{A}^\dagger\,\mathbf{p}. \tag{16}$$

Equation (16) provides a fast (no matrix inversion) and effective solution as long as the modes are well-sampled over their entire extent so that the columns of $\mathbf{A}$ are approximately orthonormal. Buck *et al.*[13] noted that the generalized SMS inverse is optimal for detecting a single mode in spatially white noise, but is non-optimal for more than one mode when the spatial modal sampling does not preserve mode orthogonality. They suggest normalizing $\mathbf{A}^\dagger$ by applying a matrix $\mathbf{W}$ so that the diagonal elements of $\mathbf{W}\mathbf{A}^\dagger\mathbf{A}$ are unity, where

$$\mathbf{W} = \mathrm{diag}\left[||\phi_1(z)||^{-2}, \ldots, ||\phi_M(z)||^{-2}\right] \tag{17}$$

and $||\phi_m||^2 = \sum_j |\phi_m(z_j)|^2/\rho(z_j)dz$ for j sampled depth points. The modal resolution (13) for the SMS pseudo-inverse is found to be

$$\mathbf{R} = \mathbf{W}\,\mathbf{A}^\dagger\,\mathbf{A}, \tag{18}$$

and the solution covariance (14) is

$$\mathbf{C} = \xi^2\,\mathbf{W}\,\mathbf{A}^\dagger\,\mathbf{A}\,\mathbf{W}^\dagger. \tag{19}$$

This method can perform poorly if an adequate sampling of the modes (to ensure orthogonality) is not possible, particularly in practical cases of an acoustically penetrable seabed where the mode functions extend into the bottom.

The least-squares (maximum likelihood) solution is determined by minimizing the χ^2 misfit

$$\chi^2 = (\mathbf{A}\,\bar{\mathbf{x}} - \mathbf{p})^\dagger\,\mathbf{G}^\dagger\,\mathbf{G}\,(\mathbf{A}\,\bar{\mathbf{x}} - \mathbf{p}) \qquad (20)$$

by setting $\partial\chi^2/\partial\bar{\mathbf{x}} = 0$ to yield

$$\bar{\mathbf{x}} = [\mathbf{A}^\dagger\,\mathbf{G}^\dagger\,\mathbf{G}\,\mathbf{A}]^{-1}\,\mathbf{A}^\dagger\,\mathbf{G}^\dagger\,\mathbf{G}\,\mathbf{p}. \qquad (21)$$

Note that if $\mathbf{A}$ is orthogonal and the data have the same uncertainty, the least-squares solution (21) reduces to the SMS solution (16). The least-squares approach provides an unbiased estimate of the true solution (i.e., the solution to the noise-free problem) provided the matrix in square brackets is non-singular. In addition to the possibility of singularity, the matrix can be ill-conditioned, leading to an unstable inversion (i.e., small errors in the data can lead to large errors in the solution).

A common approach for solving ill-conditioned inversions is based on singular-value decomposition (SVD).[16] The SVD of $\mathbf{GA}$ is given by

$$\mathbf{GA} = \mathbf{U}\,\mathbf{\Lambda}\,\mathbf{V}^\dagger, \qquad (22)$$

where $\mathbf{U}$ and $\mathbf{V}$ are $N \times M$ and $M \times M$ matrices whose columns are orthonormal eigenvectors, and $\mathbf{\Lambda}$ is a $M \times M$ diagonal matrix of singular values ordered according to decreasing magnitude. Using (22) in (21), the SVD solution to the linear inverse problem is given by

$$\bar{\mathbf{x}} = \mathbf{V}\,\mathbf{\Lambda}^{-1}\,\mathbf{U}^\dagger\,\mathbf{G}\,\mathbf{p} = \sum_{m=1}^{M} \mathbf{v}_m\,\mathbf{u}_m^\dagger\,\frac{1}{\lambda_m}\,\mathbf{G}\,\mathbf{p}, \qquad (23)$$

where the $\mathbf{v}_m$ and $\mathbf{u}_m$ represent the mth columns of $\mathbf{V}$ and $\mathbf{U}$, respectively. Equation (23) is not defined if one or more λ_m are zero, which corresponds to a singular matrix in (21). An ill-conditioned matrix is characterized by one or more λ_m being very small. Equation (23) indicates that small λ_m can cause the errors on the data $\mathbf{p}$ to have a greatly magnified effect on the solution $\bar{\mathbf{x}}$ (i.e., small λ_m cause instability). Yang[10] and Voronovich *et al.*[11] apply SVD to modal decomposition, but decompose $\mathbf{A}^\dagger\mathbf{G}^\dagger\mathbf{GA}$ instead of $\mathbf{GA}$. However, the SVD of $\mathbf{GA}$ is recommended, because its singular values are the square roots of the singular values of $\mathbf{A}^\dagger\mathbf{G}^\dagger\mathbf{GA}$, which are more numerically stable for small singular values.[16] To stabilize ill-conditioned inversions, the reciprocals of zero or small singular values in (23) can be set to zero, thereby removing their effect on the inversion. If $M - Q$ small singular values are omitted, (23) becomes

$$\bar{\mathbf{x}} = \sum_{m=1}^{Q} \mathbf{v}_m\mathbf{u}_m^\dagger\,\frac{1}{\lambda_m}\,\mathbf{G}\,\mathbf{p}, \qquad Q \le M. \qquad (24)$$

How small λ_m needs to be in order to be omitted from the inversion is somewhat arbitrary. Omitting singular values generally decreases the solution variance at the expense of parameter resolution, which can be seen as follows. The solution covariance for (24) is obtained by substituting $\mathbf{A}^{-g} = \sum_{m=1}^{Q} \mathbf{v}_m\mathbf{u}_m^\dagger\mathbf{G}/\lambda_m$ (from 24) into (14), which yields

$$\mathbf{C} = \sum_{m=1}^{Q} \mathbf{v}_m\mathbf{v}_m^\dagger\,\frac{1}{\lambda_m^2}. \qquad (25)$$

The $1/\lambda_m^2$ term in (25) is large for small λ_m, so neglecting these λ_m can significantly reduce the solution variance. The resolution matrix (13) for this case is found to be

$$\mathbf{R} = \sum_{m=1}^{Q} \mathbf{v}_m\,\mathbf{v}_m^\dagger. \qquad (26)$$

If $Q = M$ in (26), then $\mathbf{R} = \mathbf{I}$ (as $\mathbf{V}$ is orthonormal), indicating unique modal resolution. However, for $Q < M$, columns of $\mathbf{V}$ are omitted, and the resolution is degraded.

The number of singular values removed must be carefully chosen so that resolution is not unduly sacrificed in an effort to reduce variance. In an Arctic application of MMP, Yang[10] noted that the singular values divided naturally into two groups, with the singular values in one group being several orders of magnitude larger than those in the other. He proposed that the large singular values correspond to eigenvectors that span the mode "signal space" while the eigenvectors associated with the small singular values span the mode "noise space," providing a physical basis for neglecting the small singular values. However, when the singular values do not divide naturally into groups, deciding which ones to omit is more difficult. An objective approach is to require that the data be fit to a statistically appropriate level: for example, omit small λ_m until the χ^2 misfit is approximately equal to its expected value. Note that the formulation in (24) applies to both over- and under-determined inversions, although for $Q < M$, the solution is not unbiased: removing singular values stabilizes the inversion by implicitly determining the "smallest" solution in the sense that $|\bar{\mathbf{x}}|$ is biased to be as close to zero as possible.[16]

A variation of the smallest solution can be formulated using zeroth-order or smallest regularization, which is based on minimizing an objective function Ψ that combines a term representing the data mismatch and a term representing the magnitude of the solution[16]

$$\Psi = |\mathbf{G}(\mathbf{A}\,\bar{\mathbf{x}} - \mathbf{p})|^2 + \theta\,|\mathbf{H}\,\bar{\mathbf{x}}|^2. \qquad (27)$$

In (27), $\mathbf{H}$ represents an arbitrary weighting, known as the regularization matrix, and θ is a trade-off parameter that controls the relative importance of the two terms in the minimization. Minimizing Ψ with respect to $\bar{\mathbf{x}}$ leads to

$$\bar{\mathbf{x}} = [\mathbf{A}^\dagger\,\mathbf{G}^\dagger\,\mathbf{G}\,\mathbf{A} + \theta\,\mathbf{H}^\dagger\,\mathbf{H}]^{-1}\,\mathbf{A}^\dagger\,\mathbf{G}^\dagger\,\mathbf{G}\,\mathbf{p}. \qquad (28)$$

For the simple case of an identity weighting in (27), (28) can be expressed as

$$\bar{\mathbf{x}} = \sum_{m=1}^{M} \mathbf{v}_m\mathbf{u}_m^\dagger\,\frac{\lambda_m}{\lambda_m^2 + \theta}\,\mathbf{G}\,\mathbf{p}. \qquad (29)$$

From (29), it is apparent that the factor $\lambda_m/(\lambda_m^2+\theta)$ serves as a weighting for the contribution associated with the mth singular value, rather than the factor $1/\lambda_m$ in (23). For an appropriate choice of θ in (28), this weighting is small for small λ_m (rather than large), and a stable inversion is achieved. The trade-off parameter θ in (28) can be set so as to just stabilize the inversion; alternatively, θ can also be set to achieve the expected χ^2 misfit (determining the appropriate trade-off parameter is considered in detail in Collison,[7] and Collison and Dosso[8]). Buck *et al.*[13] and Timonov *et al.*[14] considered smallest regularizations with identity weightings. Voronovich *et al.*[11] considered two forms of (28), one with $\mathbf{H}=\mathbf{I}$, and the other with $\mathbf{H}=\mathrm{diag}\,[|\phi_1(z_s)|^{-1},\ldots,|\phi_M(z_s)|^{-1}]$ so as to concentrate the minimization on the mode amplitudes whose excitations at the source are small.

In the case where there are fewer sensors than modes, the modal decomposition is under-determined, with $M-N$ zero singular values indicating spatially aliased modes. For SVD inversion, Yang[10,22] suggested neglecting the aliased high-order modes (effectively set $M=N$) and then inverting the resulting square, non-singular mode matrix. This method only inverts the properly sampled low-order modes. However, omitting the aliased modes from the inversion effectively relegates them to be part of the noise, thereby reducing the signal-to-noise ratio (SNR) by an unknown amount.

3. MODAL RESOLUTION AND VARIANCE IN THE IDEAL OCEAN

The resolution and variance of the modal decomposition results are determined by the VLA configuration and the type of inversion applied. Both of these properties directly affect the success of MMP localization. This section investigates the resolution and variance of various modal decomposition schemes for a simple ocean environment.

The ideal ocean model consists of a uniform water column and boundary conditions of a pressure release surface and a rigid seafloor. Figure 1 illustrates the ideal ocean example used here, consisting of a 300-m water column with a sound speed and density of 1500 m/s and 1.0 g/cm^3, respectively. A 30-Hz source at $(r,z)=(6$ km, 100 m) in this environment produces 12 propagating modes, shown in Fig. 2. These modes are sine waves confined to the water column (Sec. 2.1), so uniform modal sampling can be explained simply using the sampling theorem of time series analysis (see Ref. 7). Thus, the ideal ocean provides an appropriate starting example to analyze resolution and variance for modal decomposition.

3.1 Under-sampled Case

This section considers the effect of spatial sampling on modal resolution and solution variance. To consider the effects of under-sampling the modes, seven different VLA configurations are considered involving from 12 to 6 sensors; in each case, the sensors are equally spaced over the entire water column. For a 12-sensor VLA, Fig. 3 shows resolution matrices (normalized by their largest values) and corresponding solution standard deviations for various inversion techniques. The SNR of the data in Fig. 3 is taken to be 15 dB, where the (per sensor) SNR is defined

$$\mathrm{SNR}=10\log\left[|\mathbf{s}|^2/|\mathbf{n}|^2\right]. \qquad (30)$$

From Fig. 3, it is apparent that 12 sensors adequately sample the 12 modes, as indicated by the diagonal resolution matrices. In this figure, the solution standard deviations σ_m are scaled by the true mode excitation values. These (scaled) standard deviations provide a relative measure of the uncertainty of the constructed solution. The SVD inversion in Fig. 3a produces fairly large relative standard deviations. The SMS pseudo-inverse gives only slightly smaller standard deviations, as shown in Fig. 3b. The standard deviations from using smallest regularization (Fig. 3c) are significantly smaller than the other approaches.

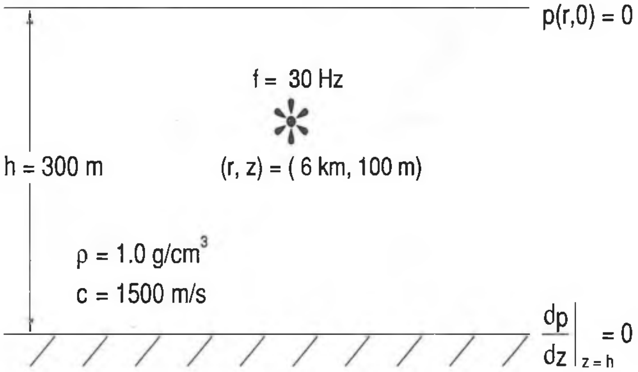

Figure 1: Schematic diagram of the ideal ocean environment.

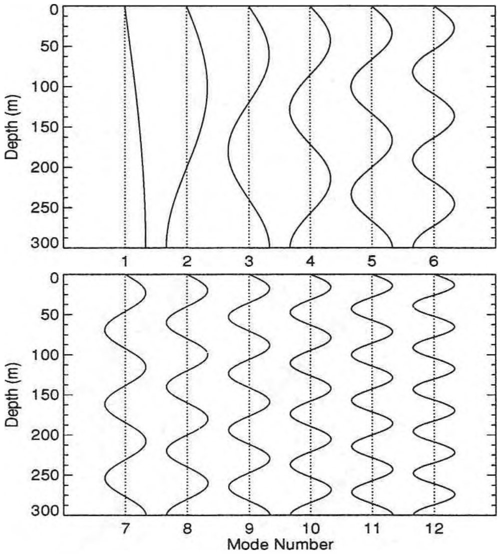

Figure 2: Normal modes for the ideal ocean environment described in Fig. 1.

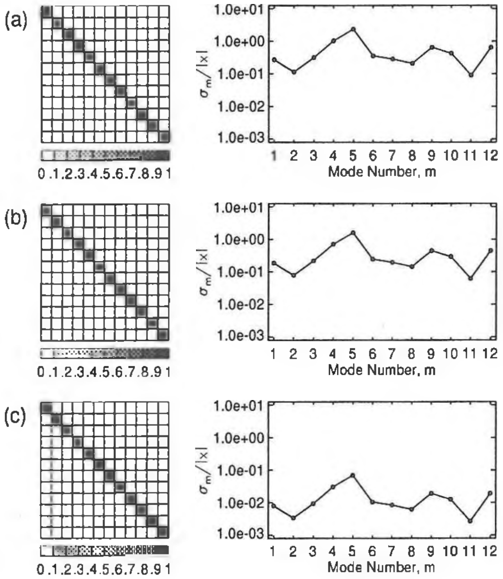

Figure 3: Resolution matrices (normalized by largest values) and corresponding solution standard deviations (normalized by true excitation values) using a 12-sensor VLA spanning the water column for (a) SVD , (b) SMS, and (c) smallest regularization with $\mathbf{H} = \mathbf{I}$.

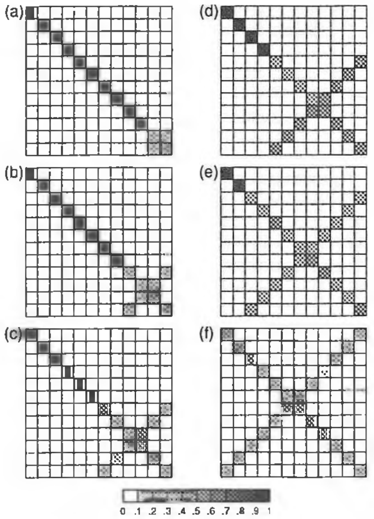

Figure 4: Resolution matrices for 11–6 sensors spanning the water column are given in (a)–(f), respectively. $\mathbf{A}^{-g}$ uses stabilized SVD.

As mentioned previously, spatial aliasing occurs when the modes are insufficiently sampled, resulting in poor resolution. For the ideal ocean, spatial aliasing (and resolution) can be explained by a simple application of the sampling theorem, which states that critical sampling of a sine wave is two points per cycle.[16] In this case, the mode frequency is $f_m = (2m-1)/4h$, according to (4). The spatial power at f_m can contain aliased energy from higher frequencies $f_m + jf_s$ ($j = 1, 2, \ldots$) where $f_s = 1/\Delta z$ is the sampling frequency and Δz is the sampling interval (i.e., the inter-sensor spacing). To avoid aliasing, a mode function must be sampled at least twice per cycle, so the critical (or Nyquist) frequency is $f_c = f_s/2$. Thus, if $f_m \leq f_c$ for all m, the modes are uniquely determined; however, aliasing occurs when $f_m > f_c$. For example, a 12 sensor VLA has $f_s = 12/300 \text{ m}^{-1}$ and $f_c = 24/1200 \text{ m}^{-1}$, so all of the modes are uniquely sampled as $f_1 < \ldots < f_{12} = 23/1200 < f_c = 24/1200 \text{ m}^{-1}$; whereas, for a 11-sensor VLA, $f_c = 22/1200 \text{ m}^{-1}$ so the spectral components for f_{12} are aliased. Spectral components at frequencies greater than the Nyquist frequency are aliased with components at lower frequencies for which

$$|f_m| = |f_{m-i} + jf_s|, \tag{31}$$

where $j = \pm 1, \pm 2, \ldots$ and $1 \leq i < m$. Equation (31) determines the lower frequency components with which the higher frequency components are aliased.[7] For instance, returning to the 11-sensor VLA case, the spectral components for f_{12} are aliased with those for f_{11}, determined by evaluating (31) with $j = -1$; this is in complete agreement with the resolution analysis results in Fig. 4a.

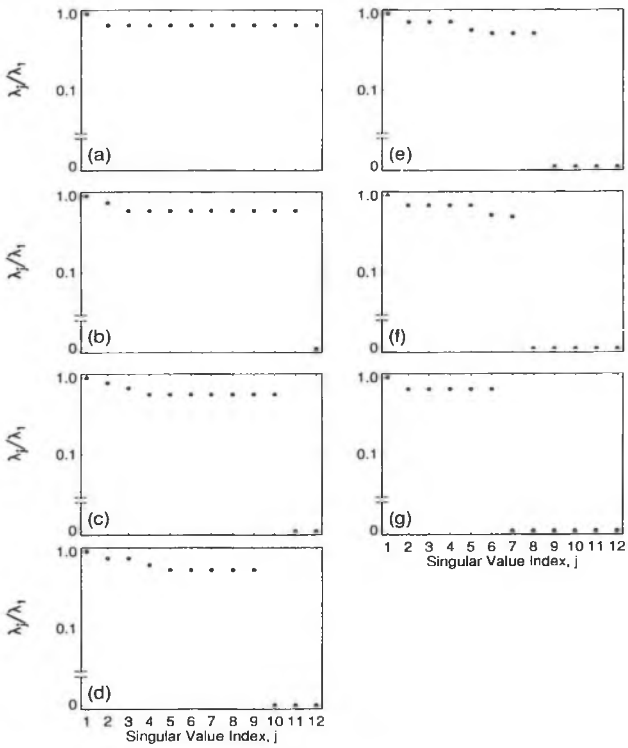

Figure 5: Singular value spectra (normalized by largest value) for 12–6 sensors are shown in (a)–(g), respectively. Note the discontinuity of all vertical axes.

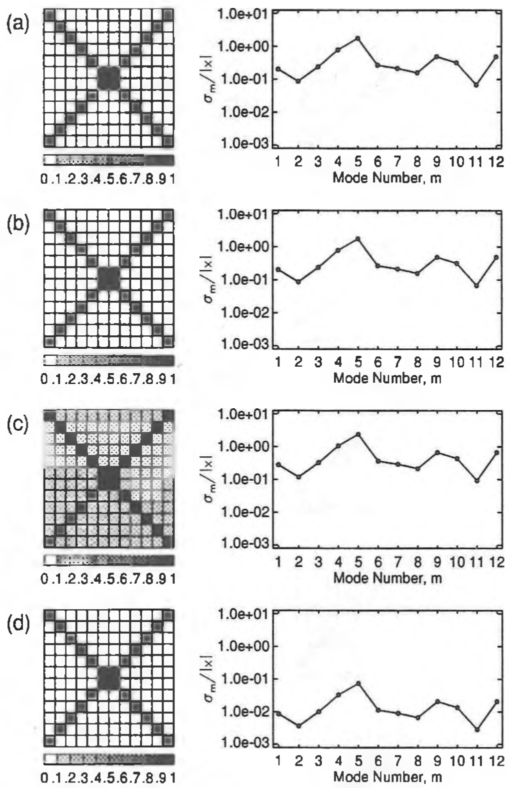

Figure 6: Normalized resolution matrices and solution standard deviations using a 6-sensor VLA for: (a) stabilized SVD, (b) fitted SVD, (c) SMS, and (d) smallest regularization.

The number of high-order modes that are aliased is directly related to the number of zero singular values, as illustrated by comparing Figs. 4 and 5b–g which show the computed resolution matrices and singular value spectra for 11–6 sensors. These figures indicate that as the number of sensors is decreased by one, there is correspondingly one additional zero singular value and one additional aliased pair (linear combination) of modes. In Fig. 4, the higher-order modes are each aliased with only one lower-order mode because the modes are sine functions. For a more general ocean environment and more complicated mode functions, predicting mode aliasing via the sampling theorem is not as simple; however, this information is always provided by modal resolution matrices. Figures 4f and 5g show that for a 6-sensor VLA, there are 6 zero singular values and all modes are affected by aliasing (i.e., the 6 highest-order modes are aliased with the 6 lowest-order ones). This provides an interesting case in which to consider the resolution and standard deviations for various inversion techniques, as shown in Fig. 6. Figure 6a shows the resolution and standard deviations for a stabilized SVD pseudo-inversion omitting the 6 zero singular values. These results are quite similar to the fitted SVD pseudo-inversion, i.e., omitting 7 singular values so $\chi^2 \approx 2N$, as shown in Fig. 6b. Figure 6c and d show the resolution and deviations for SMS pseudo-inversion and smallest regularization, respectively. The standard deviations for smallest regularization are an order of magnitude smaller than those for the other three modal decomposition methods.

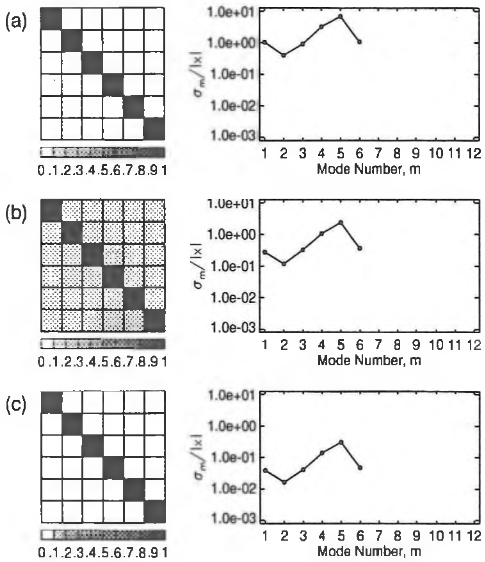

Figure 7: Normalized resolution matrices and solution standard deviations using a 6-sensor VLA for:(a) SVD inversion, (b) SMS, and (c) smallest regularization, all neglecting the aliased high-order modes.

Figure 7 shows inversion results for the same methods when the aliased high-order modes are neglected in the inversion (i.e., delegated to noise), as suggested by Yang.[10,22] Neglecting the aliased high-order modes leads to well resolved low-order modes, but to substantially larger standard deviations for the modes retained than in Fig. 6 (due to the increased noise). Fig. 7c indicates that smallest regularization still provides the smallest standard deviations with respect to the other methods.

3.2 Short-aperture Case

This section considers modal resolution and variance for short-aperture arrays. The VLA configurations considered here all contain 12 sensors and span various fractions of the water column from the entire column (well-sampled) to just the top half. Figure 8 shows the singular value spectra for VLA configurations with apertures of 1.0–0.5 of the water column. The singular values decrease in a continuous manner and do not exhibit the abrupt cut-off evident in the under-sampled case (Fig. 5). In this case, it is not obvious where to truncate the spectrum in an SVD inversion.

One approach is to consider the trade-off between the modal resolution and solution variance. In the case of a well-conditioned **A**, all the singular values can be included in the inversion, which leads to perfect resolution and small solution standard deviations. For ill-conditioned **A**, perfect resolution, although possible, occurs at the expense of large solution variance. Figure 9 illustrates the trade-off between resolution and variance for an aperture of 0.5 and SNR=15 dB for various inversion techniques. Figure 9a shows that including all singular values leads to ideal resolution, but that the inversion is unstable with exceedingly large standard deviations. Figure 9b–d shows the trade-off between resolution and solu-

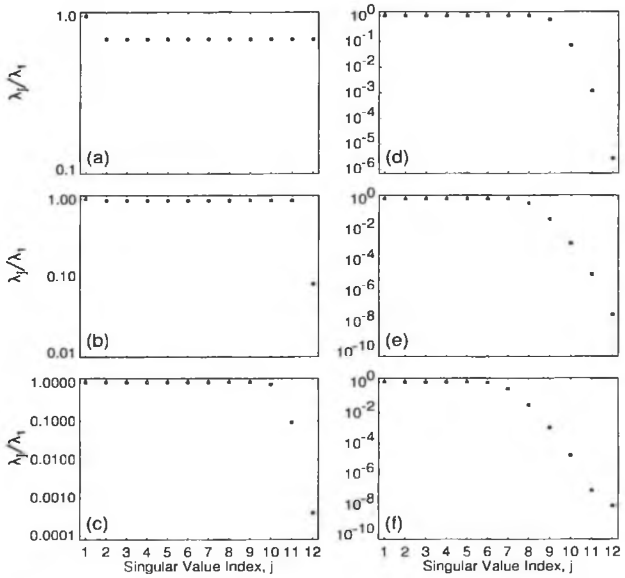

Figure 8: Singular value spectra (normalized by largest value) for apertures of 1.0–0.5 of the water column are shown in (a)–(f), respectively.

tion accuracy for SVD pseudo-inversions. As more singular values are omitted, the resolution of the low-order modes degrades, and the accuracy improves (standard deviations decrease). The fitted SVD pseudo-inversion, shown in Fig. 9e, has significantly smaller standard deviations than the other SVD cases. Figure 9f shows the resolution and accuracy for the SMS pseudo-inversion. For this case, the maximum value of resolution is off the main diagonal (indicating significant modal cross-terms). Figure 9g gives results for smallest regularization. The resolution is similar to that of the fitted SVD pseudo-inversion (Fig. 9e), but the solution standard deviations are substantially smaller.

4. SOURCE LOCALIZATION RESULTS

This section compares various approaches to modal decomposition by considering MMP source localization results for three SNRs, and a variety of VLA configurations. To compare the results of MMP source localization based on various decomposition techniques, it is useful to consider a realistic ocean environment. Source localization techniques are illustrated and compared here for synthetic acoustic data computed for the shallow-water environment illustrated in Fig. 10. The environment consists of a 300-m water column with a typical N.E. Pacific continental shelf sound-speed profile[23] overlying a 50-m thick sediment layer and semi-infinite basement. The sediment layer has a compressional speed of c_p=1650 m/s, shear speed of c_s=300 m/s, density of ρ=1.6 g/cm^3 and compressional and shear attenuations of α=0.3 dB/λ (where λ is the acoustic wavelength). The basement has c_p=2000 m/s, c_s=800 m/s, ρ = 2.1 g/cm^3, and α=0.5 dB/λ. This environment supports 12 propagating modes at a source frequency of 40 Hz, as shown in Fig. 11. In order to compare various approaches to MMP, 100 independent acoustic data sets **p** are computed by adding 100 different random realizations of uncorrelated Gaussian noise **n** to an acoustic signal **s** computed with the wavenumber integration model SAFARI[24] for a source located at (r, z)=(6 km, 100 m). The replica mode excitations used in the matching process are computed using the normal mode model ORCA[15] for all test cases.

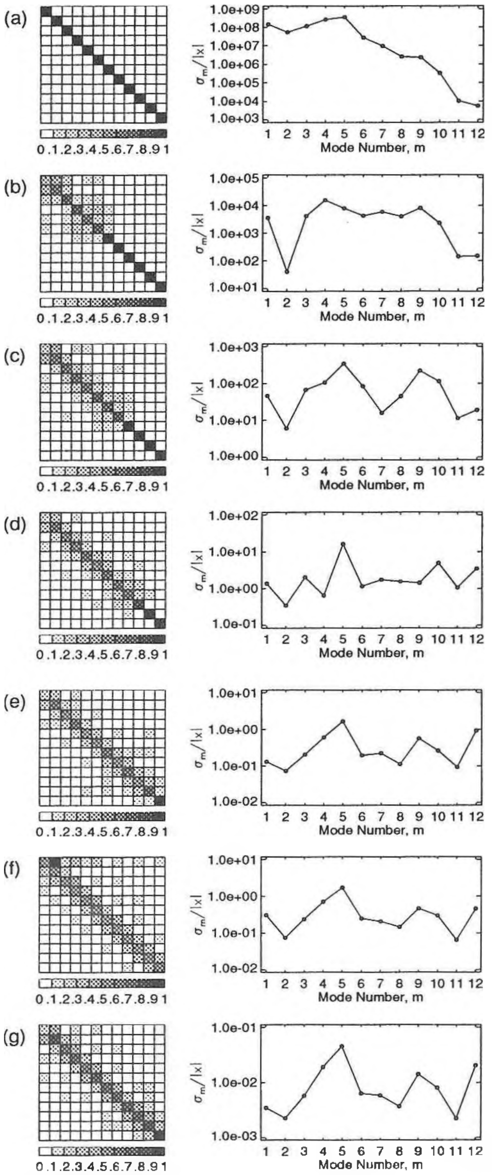

Figure 9: Resolution matrices and solution standard deviations using a 0.5-aperture VLA for (a) SVD (including all λ_j); and SVD omitting λ_j for which (b) $|\lambda_j/\lambda_1| < 10^{-6}$, (c) $|\lambda_j/\lambda_1| < 10^{-4}$, (d) $|\lambda_j/\lambda_1| < 10^{-2}$; (e) fitted SVD; (f) SMS; and (g) smallest regularization.

Source localization results are considered for three noise levels of SNR = 15, 5, 0 dB, and for a number of VLA configurations that sample the 12 modes in various ways: (i) well-sampled, with 12 sensors equally spaced over

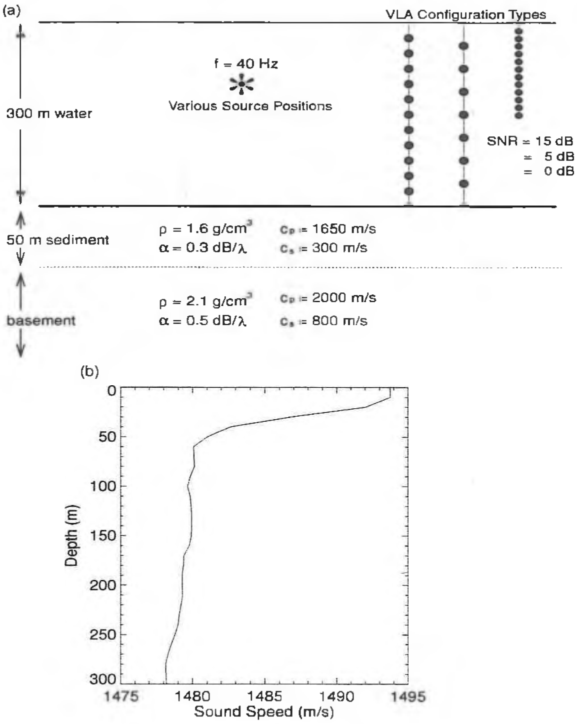

Figure 10: (a) Schematic diagram of the shallow-water environment. Three types of VLA configurations and three SNRs are considered for various source positions. (b) Ocean sound-speed profile.

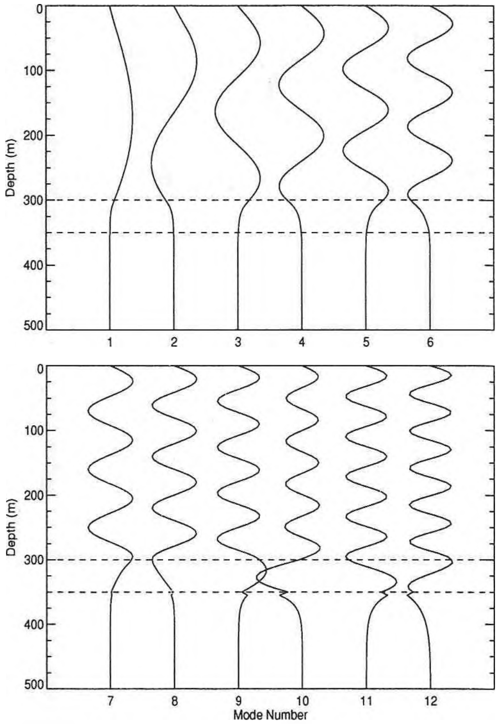

Figure 11: Normal modes produced by a 40-Hz source in the ocean environment described in Fig. 10. Dashed lines denote the water-sediment and sediment-basement interfaces.

the entire water column; (ii) under-sampled, with fewer than 12 sensors equally spaced over the water column; and (iii) short-aperture, with 12 sensors spanning only a fraction of the water column. MMP source localization results are presented for four modal decomposition methods: (i) SMS pseudo-inversion; (ii) stabilized SVD pseudo-inversion omitting singular values λ_j for which $|\lambda_j/\lambda_1| < 10^{-6}$; (iii) fitted SVD pseudo-inversion omitting singular values so $\chi^2 \approx 2N$; and (iv) smallest regularization with $\chi^2 = 2N$. To localize the source, a search grid was adopted that extended from 0–12 km in range with a range increment of 100 m, and 0–300 m in depth with a depth increment of 10 m (i.e., a total of $120 \times 30 = 3600$ grid points). The estimated source location corresponds to the grid point at which the match between the mode excitations was a maximum. The match is quantified using the normalized Bartlett processor

$$B = \frac{|\tilde{\mathbf{x}}^\dagger \, \mathbf{x}(r,z)|^2}{|\tilde{\mathbf{x}}|^2 \, |\mathbf{x}(r,z)|^2}, \tag{32}$$

where $\tilde{\mathbf{x}}$ represents the constituent mode excitations from the measured fields, and $\mathbf{x}(r,z)$ represents the replica excitations. The correlation at each grid point is indicated on a depth-range plot, known as an ambiguity surface, to obtain a visual representation of the source localization.

Figure 12 shows ambiguity surfaces for the smallest regularization approach to MMP at SNR=5 dB. In this figure, the ambiguity surfaces are plotted in a decibel scale using $-10\log(1-B)$. Figure 12a shows that for a well-sampled case, the source is correctly localized at (r,z)=(6 km, 100 m), with no strong sidelobes. For the under-sampled case, Fig. 12b, the highest peak is located in a sidelobe at (2.5 km, 210 m), resulting in an incorrect localization. For a short-aperture array (Fig. 12c), the source is again incorrectly localized in a sidelobe at (10.4 km, 230 m), and there is no significant peak in the correct source area.

The ambiguity surfaces in Fig. 12 are based on a single set of noisy data. To obtain a more representative comparison of the four approaches to MMP, statistics are compiled for 100 noisy data sets. The relative MMP performance is measured by the estimated probability of correct localization $\hat{P}$, taken to be the fraction of times (for the 100 noisy data sets) that the estimated source location is within a suitably small region about the true source location, defined by ± 200 m in range and ± 10 m in depth.

Figure 13 summarizes the comparative performance of the four approaches to MMP for three SNRs and various VLA configurations. The error bars on each probability measure indicate 90% confidence level for the true probability, computed using[25]

$$\hat{P} \pm 1.645\sqrt{\frac{\hat{P}(1-\hat{P})}{n}}, \tag{33}$$

with $n = 100$ data sets. The first column of Fig. 13 shows localization results for under-sampled cases, and

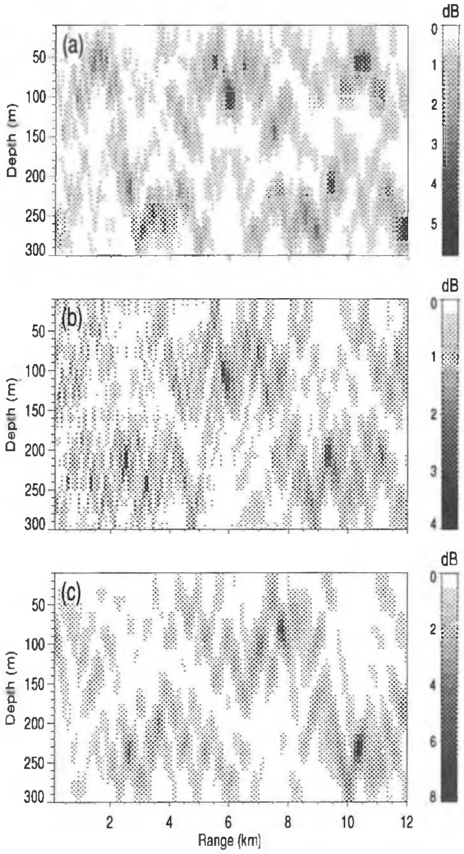

Figure 12: Ambiguity surfaces for (a) well-sampled case, (b) under-sampled case of 6 sensors, and (c) short-aperture case of half the water column, using the smallest regularization approach to MMP at SNR=5 dB.

the second column shows the results for short-aperture cases. In each plot, the well-sampled case (12 sensors, aperture of 1.0) is also included as the right-most point. The rows of the figure correspond to SNRs of 15, 5, and 0 dB (top to bottom).

From Fig. 13, it is apparent that as SNR decreases the localization results for all methods degrade, regardless of the VLA configuration. For a relatively high SNR of 15 dB, Fig. 13a shows that with 7–12 sensors, all the decomposition methods lead to a high probability of source localization. However, with 6 sensors, smallest regularization localizes substantially better than the other three methods (also the case for SNR=5 dB in Fig. 13b). With SNR $\leq$ 5 dB, the under-sampled localization results obtained using smallest regularization and stabilized SVD are quite similar while SMS gives slightly poorer results (Fig. 13b and c). The fitted SVD method has consistently poorer localization results. For array apertures less than or equal to 0.8 of the water column, all methods produce poor localization results, as indicated in Fig. 13d–f. At SNR $\leq$ 5 dB, Fig. 13e and f shows that SMS and smallest regularization have substantially larger probabilities of correct localization than the other two methods for apertures of 0.9 and 1.

As described in Sec. 2.3, Yang[10,22] suggested neglecting the aliased high-order modes for stabilized SVD inversion. To investigate this idea, the aliased modes were neglected in all four modal decomposition methods, with the source localization results given in Fig. 14. Neglecting the aliased high-order modes generally leads to equivalent or better localization results for all methods. The largest improvement in localization results is obtained for SMS. This is likely due to the resulting square mode matrix being closer to orthogonal than the original (singular) rectangular matrix, improving the approximation $\mathbf{A}^{-g} = \mathbf{W}\mathbf{A}^{\dagger}$. Neglecting modes has the added benefit of providing faster inversions, since the dimension of the mode matrix is reduced. From Figs. 13 and 14, it appears that smallest regularization gives slightly better source localization results for more cases than the other methods.

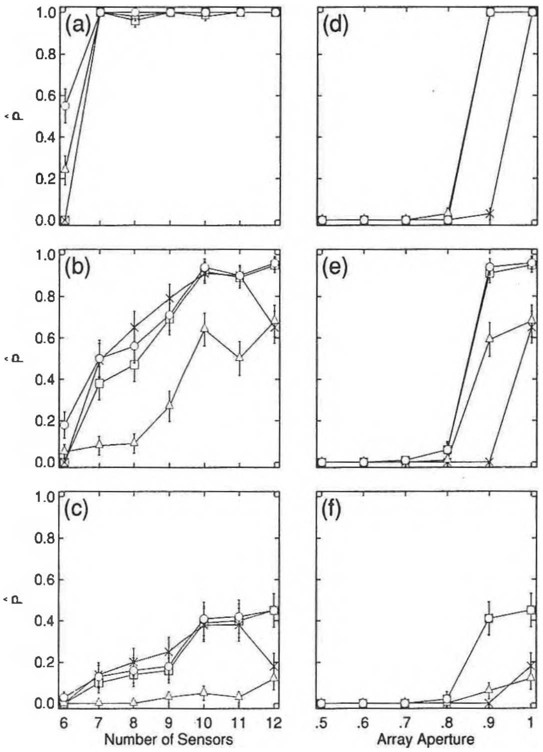

Figure 13: Estimated probability of correct localization $\hat{P}$ for SMS (squares), stabilized SVD (crosses), fitted SVD (triangles), and smallest regularization (circles). Results are given for under-sampled cases and SNRs of (a) 15 dB, (b) 5 dB, and (c) 0 dB. (d)–(f) are the same as (a)–(c), but give results for short-aperture cases. Error bars denote 90% confidence intervals for P.

The probabilities of correct localizations shown in Figs. 13 and 14 indicate the relative success of each approach to MMP, but give no indication of the actual distribution of the localization. This can be illustrated by probability ambiguity surfaces (PAS), which show the estimated source positions for the 100 localizations. Figure 15 gives PAS for the well-sampled case with SNR=5 dB. Smallest regularization and SMS (Figs. 15a and b) localize most sources in the correct area, with the incorrect localiza-

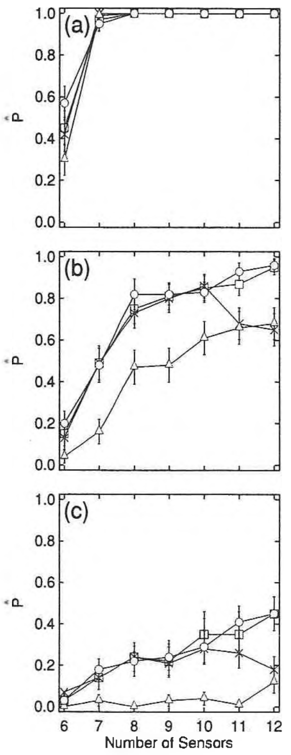

Figure 14: Estimated probability of correct localization $\hat{P}$ for SMS (squares), stabilized SVD (crosses), fitted SVD (triangles), and smallest regularization (circles). Aliased high-order modes are neglected prior to all inversions. Results are given for the under-sampled cases with SNRs of (a) 15 dB, (b) 5 dB, and (c) 0 dB.

tions corresponding to sidelobes of the ambiguity surface (Fig. 12). The SVD methods do not localize as well, as indicated in the increased probabilities of source localization outside of the correct region. The two SVD methods have similar values of $\hat{P}$ for this case, but their PAS indicate that the methods do not always localize at the same position.

Figure 16 shows the PAS for the four approaches to MMP using a 6-sensor VLA at 5 dB, both including and omitting the aliased high-order modes. In Fig. 16a–d, MMP using smallest regularization is the only method that localizes sources in the correct region. It is apparent from the PAS in Fig. 16e–h that neglecting the aliased high-order modes improves all methods to varying degrees. The SMS and stabilized SVD methods are substantially improved, while smallest regularization and fitted SVD are only slightly improved using this array configuration. In this figure, the incorrect localizations again concentrate in areas that correspond to ambiguity-surface sidelobes. Figure 17 shows PAS for a 0.5-aperture VLA with SNR=5 dB. In this figure, smallest regularization, SMS, and fitted SVD approaches to MMP all have high probabilities of localization at an incorrect position corresponding to a sidelobe. Stabilized SVD (Fig. 17d) also localizes incorrectly, but at a different location than the other three methods that does not seem to correspond to a sidelobe from the original ambiguity surface (Fig. 12c).

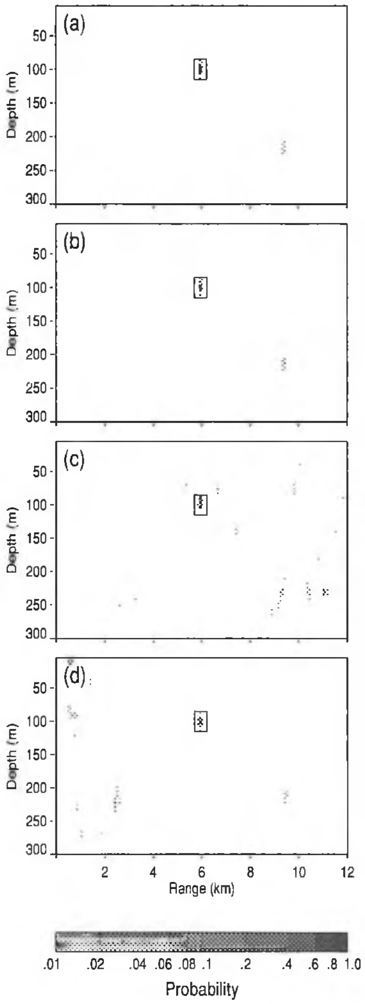

Figure 15: PAS using (a) smallest regularization, (b) SMS, (c) fitted SVD, and (d) stabilized SVD approaches to MMP for the well-sampled case with SNR=5 dB. Gray scale levels indicate the probability of localization for each grid point, and the black boxes indicate the area of correct localization.

5. SUMMARY

This paper presents a comprehensive comparison of a variety of approaches to modal decomposition. These comparisons include resolution and variance analyses, and matched-mode processing localization results. The modal methods considered include the sampled mode shape filter, singular value decomposition pseudo-inversion, and smallest regularized inversion. SVD and regularization can be applied to just stabilize the inversion, or to fit noisy (complex) data to the expected value of $\langle \chi^2 \rangle = 2N$ (this can be done exactly for regularization and approximately for SVD). Stabilized and fitted SVD, and fitted regularized inversions were considered here (results for stabilized regularization are similar to those for stabilized

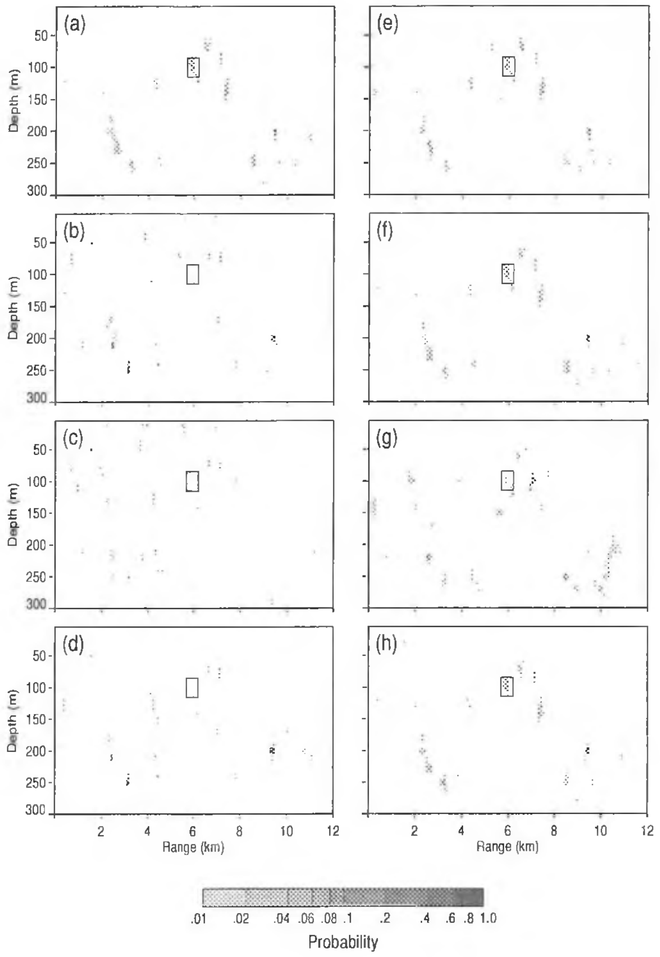

Figure 16: PAS for a 6-sensor VLA using (a) smallest regularization, (b) SMS, (c) fitted SVD, and (d) stabilized SVD with SNR=5 dB. (e)–(h) are the same as (a)–(d), but omit the aliased high-order modes.

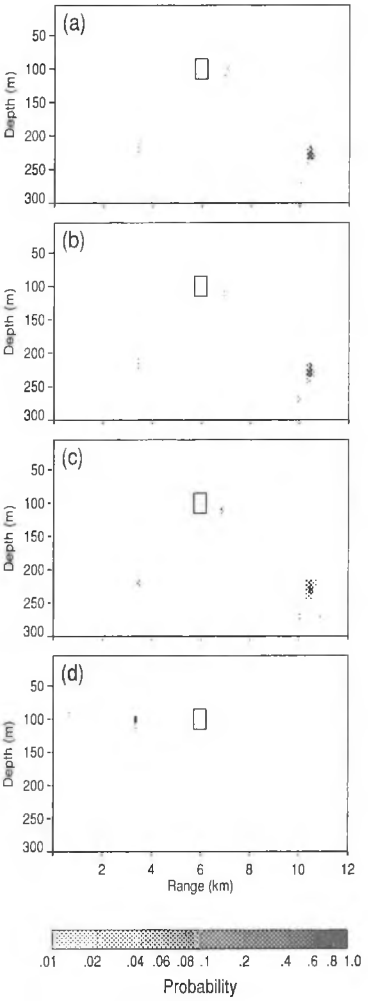

Figure 17: PAS for a 0.5-aperture VLA with SNR=5 dB, using (a) smallest regularization, (b) SMS, (c) fitted SVD, and (d) stabilized SVD.

SVD). These methods were compared for vertical array configurations that properly sampled the acoustic field, and for configurations that under-sampled the field (fewer sensors than modes) or that sampled only a fraction of the water column. High, moderate, and low signal-to-noise ratios were considered. In addition, the idea of omitting aliased high-order modes in under-sampled cases, previously suggested for stabilized SVD inversion, was applied here to all inversion methods.

Modal resolution and variance were examined for the case of a homogeneous ocean with reflecting boundary conditions. In this environment, the modes are sine functions, and hence the resolution analysis can also be explained by simple application of the sampling theorem. For under-sampled cases, the regularized inversion provided the smallest standard deviations. Omitting the aliased high-order modes degraded the accuracy of all methods, but yielded unique resolution of the modes retained. For short-array cases, the singular value spectrum does not exhibit an obvious cut-off, so the number of singular values required to stabilize SVD inversion is somewhat arbitrary, and was shown to control the trade-off between modal resolution and accuracy. Of all the methods, the regularized inversion appeared to provide the best compromise between resolution and accuracy.

The performance of the various modal decomposition algorithms within MMP localization was quantified by the probability of correct localization for a realistic shallow-water environment. For under-sampled cases, it was found that the localization results for regularized, stabilized SVD, and SMS inversions were similar, with fitted SVD performing considerably poorer (as non-zero singular values were omitted in an attempt to approximate $\chi^2 = 2N$). Omitting aliased higher-order modes generally improved the results of all methods, with the regularized inversion giving the best overall results by a small margin. Interestingly, SMS inversion provided the second best results, benefiting the most from omitting aliased modes. Localization results were poor for array apertures of ≤ 0.8 of the water column for this environment. For apertures > 0.8, the regularized and SMS inversions provided the best localization results.

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CANADIAN STANDARDS ASSOCIATION ACTIVITY IN ACOUSTICS

2000 UPDATE

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ABSTRACT

This article gives an update of Canadian Standards activities in Canada, especially those of the Canadian Standards Association. They currently have 10 Acoustics Standards and two more with significant acoustics content. Two committees and a variety of subcommittees involving many Canadian acousticians and industry representatives write and review these standards for the Acoustics commmunity. An overview is given of the main activities and future directions of these groups

RÉSUMÉ

Cet article présente une mise a jour des activités de normalisation au Canada, tout particulièrement celles de l'Association canadienne de normalisation. L'association a présentement 10 normes acoustiques et deux autres comportant des normes acoustiques détaillées. Deux comités et divers sous-comités comprenant plusieurs acousticiens canadiens et représentants de l'industrie rédigent et passent en revue ces normes pour la communauté acoustique. Une vue d'ensemble de leurs activités premières ainsi que la direction future de ces groupes y est présenté.

1.0 Introduction

This article is intended to give an update for 2000 of acoustics standards activity in Canada, concentrating on the CSA acoustical standards activities. The Standards Council of Canada oversees all Canadian standards bodies, including CGSB, CSA and the Technical Advisory Groups formulating Canada's input to ISO and IEC international standards. There have been CSA standards in Acoustics for over 25 years and the Z107 Committee on Acoustics and Noise Control is still active in many areas. The Canadian Standards Association is the largest standards writing body in Canada and one of the largest in the world.

Standards are not regulations. They are developed by groups which are intended to represent diverse interests, not by regulators. In some cases, such as the Electrical Code, provincial or federal regulations may refer to standards, effectively giving them the force of law. In other cases, such as the playground safety standard, it is up to the users to decide whether they want their playground to meet the requirements of the standard.

Several Acoustics standards are referred to by regulations, notably Z107.56, Procedures for Measurement of Occupational Noise Exposure. It is referred to in the Federal and BC regulations and the proposed Alberta regulation. In most other provinces its use is voluntary but measurements taken using it are accepted as valid by most regulators. The hearing protector standard Z94.2, is also widely cited.

Others, such as Z107.21 and Z107.25 for motorboats and motorcycles, were intended for use in regulations, but the regulations were not written and these standards have been withdrawn.

2.0 Committee Activities

There are two CSA Technical Committees in Acoustics. Z94 is responsible for the Hearing Protection Standard Z94.2 which defines Type A, B, and C type hearing protectors and is widely referred to in occupational noise regulations. They are currently undertaking a major review of this standard in light of changes to the US hearing protector standards and procedures. This should mean the introduction of the user fit hearing protector measurements, similar to those used by ANSI and now recognized as being more representative of how hearing protectors are used in industry than the old technician fitted testing methods.

Z107, the Acoustics and Noise Control Technical Committee, is responsible for all other Acoustics standards. Several members belong to both committees and provide liaison between them.

Z107 is divided into 9 subcommittees. These include: Hearing Measurement, Vibration, Powered Machines Industrial Noise, Transportation Noise, Editorial (which reviews all proposed standards), Building Acoustics, Instrumentation Calibration and liaison with the Canadian

Steering Committee for ISO TC43 and TC43(1). Each subcommittee is responsible for the standard or standards within its area.

As global harmonisation becomes more important, CSA has started to adopt and endorse international standards where possible rather than writing their own. In areas where standards apply to goods coming from or going to other countries, use of international standards makes considerable sense.

Adopting a standard, which means republishing it, with changes or additions if necessary, costs less than half the cost of writing a new standard. Endorsing, which means that the standard has been reviewed and found suitable for Canadian use is the least expensive option, but less useful because the standard is not so readily available. Given our location, adopting or endorsing international or US acoustical standards has been common practice for years.

Table 1 shows all the Canadian Standards currently in force and also lists two standards whose Acoustics sections were written with the assistance of the Z107 committee. This table will also soon be found at the CAA website and will be kept up to date there. Meanwhile the list can be found at http://www.csa-intl.org/onlinestore/GetCatalogDrillDown.asp?Parent=6

3.0 Current Activities

Some current highlights include:

3.1 Transportation

The newest standard to be published is Z107.9, Highway Noise Barriers. It came out in early 2000 and sold out its first printing of 100 within months. This standard is an adaptation of the Ontario MTO Highway Noise Barrier specification. It is intended to provide municipalities, developers, road and highway departments, railways and industry with a standard specification which can be used to define the construction of barriers intended for long term use in Canadian conditions.

Specific manufacturers' barrier designs are certified as complying with the standard in such areas as: materials used, weathering and corrosion resistance testing, STC, NRC, etc. Each barrier installation is reviewed and certified for compliance with such items as footings design, material sample testing, welding, caulking, backfilling, etc.

As can be seen, this is much more than simply an acoustics standard, but it fills an important need in the industry and drafts have been used by several municipalities in recent years. Essentially it allows regulators, consultants or engineers to specify a barrier's construction and associated longevity simply by referring to one standard.

The US Highway Barrier Design Manual is already harmonised with the CSA standard, as is the Ontario OPS. ANSI is also looking at adopting the standard or harmonising with it. This ultimately could mean that a certified barrier would be qualified to be used anywhere in North America.

3.2 Industry

The Industrial Noise Subcommittee is the most varied and active subcommittee.

Ongoing activities include:

- A working group looking at adopting the ISO 1996 rating systems for community noise (for tonality and impulse corrections among others) with an informative annex describing their use in the Canadian context, discussed below,
- A writing group preparing Guidelines For The Declaration Of Machinery Noise Emission Levels, discussed below.
- An ad-hoc writing group preparing an acoustics chapter for a new version of the CSA Office Ergonomics standard, discussed below
- A group looking at adopting or endorsing ISO 9613 (2) on propagation of industrial noise and either integrating it with or replacing the current CSA standard.

3.2.1 Guidelines For The Declaration Of Machinery Noise Emission Levels

One of the initiatives underway under the auspices of the Industrial Noise subcommittee is a writing group preparing Guidelines For The Declaration Of Machinery Noise Emission Levels which would be a voluntary guide for noise labelling of machinery for use in Canada and compatible with the European regulations to allow machinery to be sold into that market.

Labels in this context refer to a statement of sound levels produced by the equipment which would be included with the instruction or maintenance manual. Measurements are made according to ISO standards and include estimates of the likely variability of the measurements.

This initiative may ultimately make it much easier for Canadian industry to buy quiet machinery with confidence and for Canadian manufacturers to sell into the European market.

3.2.2 Office Acoustics

Another of the initiatives listed above is a working group formed by the Industrial Noise Subcommittee to assist the Office Ergonomics committee with a major revision to their standard. A similar group assisted them at the last minute with an Acoustics chapter to the existing standard when it was published 10 years ago. This section has now been completely rewritten, expanded and brought up to date. It is also being aimed specifically at non-acoustical users to give them an idea of the issues involved and the resources available to them to provide good acoustical conditions in offices.

3.2.3 Adoption of ISO1996

A working group chaired by Chris Krajewski and including several Ontario consultants is examining using ISO 1996 as a way of updating the way tonal and impulse sounds are handled in community noise. They are currently running round robin tests of the procedures with various sample sounds.

3.3 Building Acoustics

The Building Acoustics subcommittee is currently trying to influence the rewriting of ASTM 336 so that it can be endorsed or adopted and be compatible with our National Building Code. The alternative would be to adopt and modify it or to write a Canadian Standard.

3.4 Instrumentation and Calibration

The Instrumentation and Calibration subcommittee have no standards of their own; instead they have endorsed or adopted IEC instrumentation standards and ANSI standards which can then be referred to in Canadian regulations and other standards. Every five years or more frequently the standards are reviewed automatically to ensure that the latest standards are being endorsed and that they are still suitable for use in Canada. In addition, the chairman, George Wong, is actively involved with the ISO and IEC working groups.

3.5 Editorial

The Editorial subcommittee also has no standard of their own. They have endorsed the ANSI Standard for Acoustics Terminology and have had input into it. This standard is updated regularly by ANSI and is reviewed by this subcommittee each time it is revised. The Editorial subcommittee main job is to review every standard written by a Z107. subcommittee, both as a final technical review and to ensure it meets the CSA editorial requirements. They are currently reviewing the labeling standard.

3.6 Main Z107.9 Committee

The committee meets twice a year, once during the Canadian Acoustics Week and once in the spring. They review progress by each subcommittee and vote on any new work proposals. The main committee is the last technical hurdle for a standard. The CSA will then have their editors put it into final form. The steering committee, to which the main committee reports, approves work and reviews completed standards, however they cannot make technical changes.

One other initiative that the main committee has been trying to propose for some years is a Guideline to provide a standard which summarises the major Canadian and International Standards for Canadian industry users. This is intended to make Acoustical Standard more accessible to Canadian users. Recently they were given authorization to proceed with this project.

New members are encouraged and anyone interested may contact Cameron Sherry, the Chairman, or the author, the vice chair. This article is the first in a series which will provide more information on the activities underway in all areas of Acoustics Standards in Canada.

Table 1- CSA Acoustics Standards

CAN3-Z107.4-M86

Pure Tone Air Conduction Audiometers for Hearing Conservation and for Screening

Audiomètres tonals à conduction aérienne pour la préservation de l'ouïe et pour le dépistage

CAN/CSA-Z107.6-M90

Pure Tone Air Conduction Threshold Audiometry for Hearing Conservation

Z107.51-M1980 (R1994)

Procedure for In-Situ Measurement of Noise from Industrial Equipment

Z107.52-M1983 (R1994)

Recommended Practice for the Prediction of Sound Pressure Levels in Large Rooms Containing Sound Sources

Z107.53-M1982 (R1994)

Procedure for Performing a Survey of Sound Due to Industrial,Institutional, or Commercial Activities

CAN3-Z107.54-M85 (R1993)

Procedure for Measurement of Sound and Vibration Due to

Blasting Operations

Méthode de mesure du niveau sonore et des vibrations émanant des opérations de dynamitage

CAN/CSA-Z107.55-M86

Recommended Practice for the Prediction of Sound Levels Received at a Distance from an Industrial Plant

Pratique recommandée pour la prévision des niveaux sonores reçus à une distance donnée d'une usine

Z107.56-94

Procedures for the Measurement of Occupational Noise Exposure

Méthode de mesure de l'exposition au bruit en milieux de travail

Z94.2-94 • CAN/CSA-Z94.3-92

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Protecteurs auditifs

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Z62.1-95 Chain Saws

CAN/CSA-Z412-M89 Office Ergonomics

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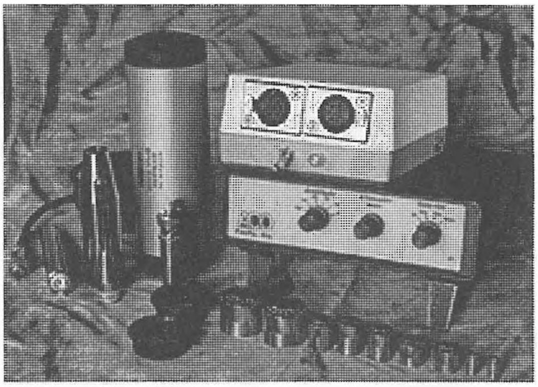

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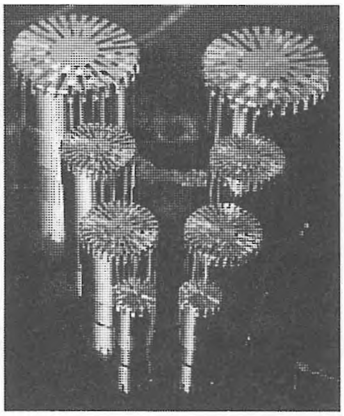

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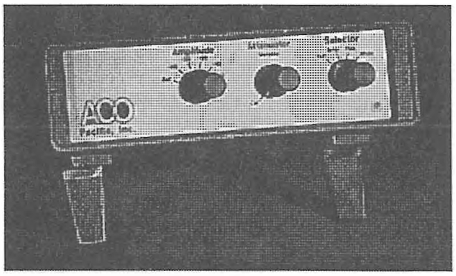

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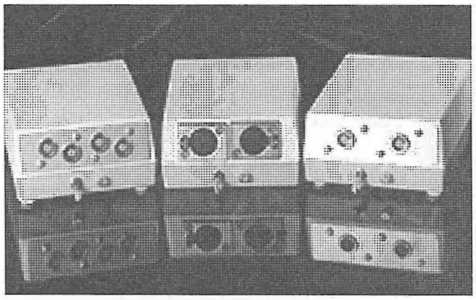

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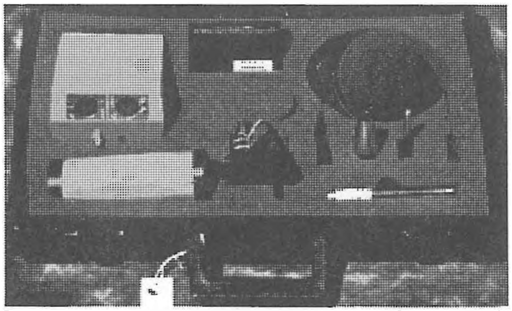

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STATISTICAL FACTORS AFFECTING MACHINERY NOISE EMISSION DECLARATIONS

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1.0 Introduction

Occupational noise-induced hearing loss is a significant public health problem in Canada. To help reduce workplace noise, purchasers of machinery need to be able to make meaningful comparisons of machinery noise emissions with: (i)emissions from other machines, (ii)purchase specifications and (iii)occupational noise limits. This can be achieved if technical specifications and instruction manuals for machinery contain noise emission declarations; realistic, but conservative, estimates of the sound pressure levels and sound power levels emitted by machine(s) under standard conditions.

Guidelines for machinery noise emission declarations in Canada are being prepared by the Canadian Standards Association (CSA). They are based, in part, on ISO 4871[1], one of a series of international standards that can be used as an efficient way to either meet European regulatory requirements for noise emission declarations or to verify declarations.

The purpose of this study was to examine the implications of using ISO 4871 for the declaration and verification of the noise emission values of machinery manufactured in batches. For measurement of noise emission values to be feasible, the values must be based on measurements of a relatively small sample of machines from the batch. From health and safety considerations, it is important that there be a reasonably high probability that the noise emission value of machinery purchased for a workplace will not exceed the declared value. For the benefit of the manufacturer, there should also be a relatively high probability that a noise emission declaration for a batch will be verified, either by a purchaser or a regulatory authority. Therefore, this study examined the dependence of these probabilities on three factors: (i) the number of machines used to determine a noise emission declaration, (ii) reproducibility of the measurements and (iii) the difference between the total standard deviation and the reference standard deviation of the measurements.

2.0 Calculation details

The statistics of the declaration were calculated based on the following model for the measured noise emission value L_i, for the *i*th machine in a sample from a batch:

$$L_i = \mu + \sigma_P X_i + \sigma_R Y \tag{1}$$

where μ, was the true mean noise emission value for the entire batch the X_i, and Y values were normally distributed random numbers with mean 0 and standard deviation 1, and σ_P was the true standard deviation of production for the entire batch. The value σ_P characterized the variation in the noise emission values due to production differences between machines. The remaining quantity σ_R, was the standard deviation of reproducibility. This quantity, normally obtained from a standard or test code, characterized the variation in the L_i due to random differences between the results of measurements of the same machine carried out under changed conditions of measurement. The value of σ_R normally includes repeatability differences but they were assumed negligible in these calculations. Except for the X_i, and Y all quantities in equation 1 are in decibels (dB). A new set of X_i and a new Y was generated for each trial.

The estimated mean noise emission value L_{avg} for the entire batch was calculated using[1]:

$$L_{avg} = \sum_{i=1}^{N} L_i \Big/ N \approx \mu \tag{2}$$

where *i*=1 to *N*, and *N* was the number of machines measured.

The estimated standard deviation of production s_P was calculated from the sample measurements and given by

$$s_P = \sqrt{\sum_{i=1}^{N} (L_i - L_{avg})^2 \Big/ (N-1)} \approx \sigma_P \tag{3}$$

The estimated total standard deviation s_t, for the batch was given by

$$s_t = \sqrt{s_P^2 + \sigma_R^2} \approx \sigma_t \tag{4}$$

where σ_t was the true total standard deviation for the batch. Note that σ_R would be obtained from the test code, or standard used to make the measurement, and was assumed to be the true value.

For each trial, the declared value for the batch , L_d, was obtained according to informative Annex A of ISO 4871from the equation

$$L_d = L_{avg} + 0.94\, s_t + 0.56\, \sigma_M \tag{5}$$

where σ_M was the reference standard deviation, a total standard deviation (as in equation 4) specified for a type of machine and considered to be typical for batches. A fixed value of $_M$ of 2.5 dB was chosen, as recommended in ISO 4871.

One of the quantities to be calculated was the probability that a noise emission declaration for a batch would be verified. This was obtained as the average, over 8000 trials, of the fraction of machines in a sample of three, that met the following criterion from ISO 4871

$$L_d - L_{avgV} > 0.56\, \sigma_M \tag{6}$$

where L_{avgV} was the estimated mean noise emission value measured by the verifier from a sample of 3 machines using equation 2. The values of L_i needed for L_{avgV} were obtained from equation 1. However, in each trial, the X_i and Y constants used to obtain L_{avgV} were uncorrelated with the constants used in the determination of L_d.

The other quantity of interest was the probability that the true noise emission value of a purchased machine was less than the declared value for the batch, L_d. This was obtained as the average, over 8000 trials, of the fraction of machines that met the criterion

$$\mu + \sigma_P X_i < L_d \qquad (7)$$

where the true mean noise emission value from the ith machine was modeled as $\mu + \sigma_P X_i$. In each trial, the comparisons in equation 6 and 7 use the same three machines. This means that for each trial, the X_i constants used in equation 7 were the same as used to obtain the L_{avgV} in equation 6.

For a given L_d, the probability of verification was also calculated using the Student-t distribution[2]. The Welch-Satterthwaite formula[2] was used to determine the effective number of degrees of freedom. Typically, this calculation and the simulation gave results that agreed to within 1%.

3.0 Results

The results are given in Table 1. The first line of Table 1 shows that the probability of verification was 95% and the proportion of machines with noise emission values less than the declared value was 93% if three conditions were fulfilled[3]: (i) there were a large number of machines in the sample used to obtain the noise emission declaration, (ii) there were no reproducibility differences between the manufacturer and verifier and (iii) the total standard deviation, σ_t, was approximately equal to the reference standard deviation, σ_M.

A realistic example using a survey grade measurement is given in the last line of Table 1. None of the three conditions were met, which resulted in reductions in both the probability of verification and the number of machines with noise emission values below the declared value. The effect of each condition is illustrated below.

If conditions (i) and (ii) were fulfilled but the total standard deviation exceeded the reference standard deviation of 2.5 dB, the percentage of machines with noise emission values below the declared value decreased. However, the probability of acceptance remained unchanged. This is shown by comparison of the second row of Table 1 with the first row. Here, exaggerated production variations (σ_P=10dB) make the total standard deviation much larger than 2.5dB, and the percentage of machines below the declared value dropped to 86%.

For the third row of Table 1, the measurement reproducibility condition (ii) was violated. This reduced the probability of verification, even though the total standard deviation, σ_t, was the same as in the first row. However, because σ_t was unchanged, the percentage of machines below the declared value remained the same. The likelihood of verification would increase if the manufacturer and verifier made measurements under identical conditions.

If conditions (ii) and (iii) were fulfilled but only 3 machines were used to calculate the declaration, the probability of verification was reduced and the proportion of machines with noise emission values below the declared value was also diminished. This is indicated by comparison of the first and fourth rows of Table 1. This resulted from the fact that, over the 8000 trials, the small sample size caused significant variations in the estimates of the mean and total standard deviation. This is shown by the wide range of differences between the declared and measured values in the fourth row of Table 1.

If, in each trial, the difference between the measured and declared values was doubled, the probability of verification would typically exceed 95%. The proportion of machines with noise emission values less than the declared value would also increase to over 93%.

4.0 Conclusions

To produce consistent declared values that allow simple comparisons between machinery, the CSA guidelines recommend the use of ISO 4871 and its informative Annex A. Declarations according to this standard are conservative estimates of the noise produced by the machines. To avoid difficulties when using declarations, manufacturers should be conservative in the estimation of errors. Purchasers should be aware that the declaration is a statistical upper limit, and some machines are expected to exceed the declared value.

References

[1] ISO 4871 (1996), "Acoustics - Declaration and verification of noise emission values of machinery and equipment"

[2] ISO GUM (1995), "Guide to the expression of uncertainty in measurement"

[3] ISO 7574 (1985), Part 4, "Acoustics - Statistical methods for determining and verifying stated noise emission values of machinery and equipment"

Table 1: Probability of acceptance for declaration, and percentage of machines less than declared value. Values are given for the number of machines used for declaration, N, the true standard deviation of reproducibility, sR, and the true standard deviation of production, sP. Note that the standard deviations are theoretical true values, not the approximate values from measurements. For reference, the difference between declared and measured value is also included, the values given represent the range for 8000 trials.

N used by declarer	σ_R dB	σ_P dB	declared - measured value, dB	probability of acceptance	% < declared value
∞	0	2.5	3.8	94%	93%
∞	0	10	10.8	95%	86%
∞	2.5	0	3.8	74%	93%
3	0	2.5	1 to 9	81%	87%
3	4	2.5	5 to 10	76%	88%

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Implications of the GTAA Mitigation Measures for Aircraft Noise

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Introduction

In February 1997 the Ontario Ministry of Municipal Affairs (MMA) revised the aircraft policy to prohibit residential development above NEF/NEP 30. The previous threshold was NEF/NEP 35. In order to satisfy the development industry the MMA permitted any development that was already draft approved to proceed under the old policy. However, the Greater Toronto Airport Authority (GTAA) appealed these plans to the Ontario Municipal Board (OMB). In order to ensure that the GTAA withdrew its objection at the OMB an agreement between the GTAA and the developers was formulated. Each developer of the residential lands was required to enter into a binding agreement with the GTAA and the City of Mississauga that stipulated very specific conditions. These conditions are summarized below. Further the City of Mississauga, the municipality in which the Toronto International Airport is located, required that all the conditions be strictly followed. The importance of this is discussed in subsequent sections.

Aircraft Noise Warning Agreement

The Aircraft Noise Warning Agreement is a long and complex document that addresses many issues in addition to the construction conditions that are summarized below. One additional item of particular note is that the agreement required significant warning signs to be placed at the development site and at the sales pavilions. The details of the dimensions and locations of the signs were also stipulated in the agreement.

a) All dwelling units are to be centrally air-conditioned.

b) All exterior walls of dwelling units are to be constructed with brick veneer or other exterior finish providing a minimum STC rating of 55, for the full height, between the foundation wall and the roof.

c) All roofs of dwelling units, including, without limitation, mansard roofs and dormers, shall be constructed such that any boundaries between the exterior and habitable interior space shall meet a minimum STC rating of 55.

d) Windows for all dwelling units shall be designed and built such that there is compliance with CMHC indoor noise guidelines. Openable portions must not be without a sash.
e) Bathroom and kitchen exhaust systems, roof vents, chimneys and similar openings to be configured or acoustically treated to prevent transmission of exterior sound to the inside in excess of CMHC residential noise guidelines.

f) The air conditioning outside condensing units shall comply with MOE NPC-216, or its successor.

Implications

As indicated above the imposition of these requirements did have implications. On the positive side strict enforcement of these mitigation measures ensured that a "simplistic" approach was taken to implementation of the mitigation. That is, every house was constructed with the same mitigation and consequently the review of the installation of the mitigation was simplified. However, there were some difficulties with the implementation of this agreement.

- All houses regardless of the actual NEF/NEP contour had to be constructed following the requirements of the GTAA Agreement.

- Brick veneer construction while rated at STC 55 also has the added benefit of mass, while other types of construction that are rated at STC 55 do not have the same mass as brick. This results in inferior performance at the frequencies most critical to aircraft noise.

- In some cases the use of brick veneer was excessive because the windows could have been selected to provide increased attenuation, while still maintaining the indoor sound level limits.

- By strictly enforcing only the mitigation described in the agreement placed restrictions on the architectural aspects of the development.

- The strict enforcement of the noise mitigation measures was contrary to the usual approach in the City of Mississauga, because the City normally permits the acoustical requirements to be re-evaluated at the time of building permit issuance and the mitigation modified as required provided that the indoor sound levels are achieved in accordance with the guidelines.

- In some cases the builders followed the normal City of Mississauga process and had to make modifications to the houses after the houses were constructed to ensure strict compliance with the GTAA Agreement.

- Requiring that all air conditioning units comply with NPC-216 was also contrary to the normal City of Mississauga process. The City normally requires that air conditioning condenser units have a 7.6 bel rating. Using NPC-216 resulted in air conditioning units that were rated significantly quieter than 7.6 bels. This is overkill in an area where the ambient is significantly influenced by aircraft noise because under the Ontario Ministry of the Environment guidelines aircraft noise is not included in the ambient.

Not all builders were part of this agreement when it was first implemented. Consequently many builders experienced construction difficulties as well as financial difficulties, attempting to implement these measures when they realized the cost of implementation and the subsequent follow-up that was required to ensure compliance.

Ensuring that all dwellings were constructed in accordance with the agreement required intimate involvement of the acoustical engineer prior to the issuance of building permits. The house plans had to be checked in detail and specific schedules detailing the required wall construction, window construction (for each window), acceptable methods of treating the external duct openings and the bel rating of the air conditioning unit had to be included with each house model. Any modifications to the house plan required a re-certification by an acoustical engineer.

The inspection of each house did not take place once the house was completed, as is the usual process but rather as the house was being built to ensure that all the required elements were in fact incorporated into the house.

By entering into this agreement with the GTAA and the City of Mississauga, the developers and the builders, in most cases, avoided the costly OMB process. However, the implementation of the terms of the agreement proved to be onerous and expensive for the builders. The effectiveness of the mitigation measures remains to be seen.

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Residential Development vs. Railway Yards

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Introduction

A rail yard is comprised of many noise sources. Unlike a highway a rail yard does not generally emit a constant hum but rather produces separate and distinct sounds. A rail yard can have extended periods of time where no activity and consequently no sounds are evident. In the case of a complaint a rail yard is not subject to provincial noise guidelines nor to any municipal noise by-laws. In fact, most noise by-laws provide exemptions for the railways. Rail yards are federally regulated by the Canadian Transportation Act, which is administered by the Canadian Transportation Agency (CTA). While the CTA can and does enforce the act, the rail activities of the rail operators are not regulated by specific numerical limits. Rail operators are permitted to expand their activities within their boundaries without requiring any approvals.

Despite this seemingly "untouchable" existence, rail yard activities are the subject of complaints and as a result of this the CTA has imposed restrictions on rail activities on a case by case basis. In the case of existing residences adjacent to rail yards, often the only mitigation is relocation of the activities and/or curtailment of the activities. Due to the nature of the operation it is often very difficult (if not impossible) and costly to curtail and/or alter the rail operations. For this reason permitting new residential development adjacent to rail yards is short sighted and may result in catastrophic consequences.

As a result of many hours of sound level measurements made within rail yards and at adjacent receptors and observations of rail yard activities, we have gained a better understanding of the nature of rail yards as well as the sound levels associated with each of the activities. Understanding the operations that take place within a rail yard is important to assisting the planners, engineers and municipalities in developing comprehensive plans that do not expose residential receptors to the wide range of noises and do not expose the railways to controls that are not always practicable nor feasible. The discussion that follows provides a brief description of each of the sources, provides the sound levels of the different types of activities that take place within a rail yard and explores some mitigation options.

Rail Yard Sources

Typically rail yards fall into two categories, a flat yard and a hump yard. The most significant distinction is that in a hump yard trains are made up by pushing rail cars over a hump where the momentum created by the fall enables the rail car to roll unassisted into the classification tracks below until contacting another rail car. The force of the impact "couples" the two cars. This process continues until the train is complete. Acoustically the distinction is that in order to control the distance it travels and the speed of its impact, as the rail car reaches the bottom of the hump, computer activated wheel retarders are applied to modify the car's speed to ensure it reaches the last car in the track at only 4 mph. The braking action of the retarders on the wheels emits a very loud squeal.

The types of sources in a rail yard include (but not limited to):

- Coupling;
- Stretching;
- Locomotive repair;
- Locomotive idling;
- Locomotive load testing;
- Bulk transfer (which could include a shaking device);
- Wheel squeal;
- Wheel retarders;
- Bells/whistles/sirens;
- Auto loading;
- Pre-tripping activities; and
- Leased areas for material transfer.

Each of these sources merits a detailed discussion and analysis, which is outside the scope of this paper. However, a brief discussion of the most "notorious" sources is provided below. In addition, a table is provided summarizing the range of sound levels for the various activities. This is a representative list and is not intended to imply that these activities do not or cannot produce sound levels of different magnitudes.

Coupling Noise

The most distinct and most anticipated sound from a rail yard is coupling noise. This sound is created when two rail cars collide. The resultant sound is classified as impulsive. There is a wide variation in the magnitude of the sound, which depends on the type of rail cars being processed, the speed of the impact, weight of the rail cars, whether the cars are empty or full and the method used to couple the cars.

Locomotive Idling

Locomotives idle within rail yards and on rail lines. In a rail yard the locomotive engine is not always turned off between assignments. Therefore one or more locomotives may be idling in any given area within the yard, especially in the winter when automatic shutdown devices are not activated.

Wheel Retarders

Wheel retarders are generally used in a hump yard to slow rail cars down as they accelerate down the hump. A squeal is emitted during this process. Inert retarders are placed at the ends of the classification tracks to keep free rolling cars from running out the ends. After the train is built, all the cars are dragged through the inert retarders which causes a squeal as each wheel passes through.

Bulk Transfer

The bulk transfer operation involves the use of vacuum systems and/or gravity systems to transfer dry goods from rail cars to trucks or storage areas and visa versa. The noise sources associated with this activity include the vacuum pumps and shakers/vibrators.

Wheel Squeal

Wheel squeal can be emitted any time a rail car moves on the rails, but generally occurs when a rail car goes around a curve, through switches, an incline and when brakes are applied.

Table 1
Sample Sound Levels

Activity	Distance (m)	Range of Sound Levels
Coupling	6	101 dBAI
	15	93 to 101 dBAI
	20	92 dBAI
	35	82 dBAI
	40	81 dBAI
	70	77 dBAI
	100	67 dBAI
	115	65 dBAI
	200	57 to 59 dBAI
Coupling (Llm)	50	82 dBAI to 86 dBAI
Locomotive Idling	50	68 dBA
Stretching	50	79 dBAI
Auto loading	30	79 dBAI
Wheel retarders	50	72 dBA to 116 dBA (max)
Bulk transfer		
vacuum pumps	5	95 dBA
Shakers	13	84 dBA
Gas transfer	20	101 dBA
Pre-tripping activities	20	90 dBAI
Wheel squeal	200	60 to 80 dBA
Locomotive moving	200	62 to 73 dBA
Air brake release	200	73 dBAI

Mitigation Options

The activities and sound levels provided above are only some of the noise sources associated with rail yards. The variation in the location of the activity, magnitude of the sound level and characteristic of the sound does not lend themselves to adequate mitigation. In addition, intervening development, atmospheric conditions and type and elevation of the intervening topography will all affect the propagation of the sound as well as the effectiveness of the mitigation. The various options for mitigation are discussed below.

- relocation of the activity;
- sound barriers;
- modifications to the operation;
- lubrication of the tracks and wheels;
- cessation of the activity;
- no residential receptor permitted adjacent to a rail yard. Separation distances many vary from 300 m to 1000 m plus additional intervening mitigation;
- in the case of new housing, modifications to the house design.

By their very nature, rail yard activities do not easily lend themselves to mitigation at source. The activities are generally all external and take place over very large distances. A rail yard can be 2 to 8 km in length and 300 m to 3.5 km in width. In addition a rail yard operates 24 hours per day, 7 days per week.

The least desirable options, from the railways' perspective are the ones that limit the operation. This includes limitations on the method of operation, type of operation, location of the operation and hours of operation. The use of sound barriers also has its limitations because the magnitude of the sound level is often too great to permit a sound barrier to be effective. The other limitation of sound barriers is that because of the large distances covered by a rail yard, the sound barrier would need to be very long to adequately provide the required coverage. The height, length and maintenance issues associated with sound barriers often make them cost prohibitive, particularly when compared to the overall benefit. However, in the case of existing residences these may be the only options.

The situation is entirely different in the case of new residential developments proposed adjacent to rail yards. The most simplistic and effective mitigation is to not permit residential development adjacent to rail yards or to permit residential development, but with large separation distances. From a municipal and developers' perspective these are the least desirable options. However, acoustically it is not always possible to achieve the desired attenuation through the use of sound barriers and special house designs. In addition these solutions may not be desirable for the following reasons:

- prohibitive cost of tall sound barriers;
- undesirability of tall sound barriers;
- restrictions to the house design that are difficult to sell and ultimately are not enforceable.

The magnitude of the sound, in combination with the characteristic of the sound and the unpredictability of when and where the sound will occur are the fundamental reasons that even with the incorporation of mitigative measures residential developments and rail yards are incompatible uses. Understanding the nature of the rail activities as well as the variability in the sound level is imperative to ensuring that the proper degree of mitigation is incorporated into any proposed residential development.

Oberst Beam Excitation Using Piezo Electric Actuators

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Acoustics and Vibration Group (G.A.U.S.), Université de Sherbrooke, Sherbrooke, Quebec J1K 2R1

1. Introduction

The «Oberst beam» is a classical method for the characterization of damping material based on a multilayer cantilever beam (base beam + one or two layers of other materials). As the base beam is made of a rigid and lightly damped material (steel, aluminum), the most critical aspect of this method is to properly excite the beam without adding weight or damping. So, exciting the beam with a shaker is not recommended because of the added mass. Alternative solutions are suggested in [1], electro-magnetic non-contacting transducer (tachometer pick-up, for example) can provide a good excitation but it is limited to ferro-magnetic materials. As aluminum and stainless-steel are widely used for the base beam, a small bits of magnetic material must be fastened adhesively to achieve specimen excitation. This method creates two other problems. The first one is the difficulty to properly measure the excitation force and the second one is the added damping due to the magnetic materials bits in the case of non-magnetic base beam.

However, the measurement of the motion of the beam can be easily made using a non-contact transducer (a laser vibrometer for example).

2. Presentation of the method

2.1. Piezo electric actuators excitation

When two piezo-electric actuators are placed facing each other on both sides of a structure and cabled out of phase, they create a bending moment which is proportional to the applied voltage. This applied voltage can directly be used to calculate the velocity *vs* force transfer functions (FRF) used in the determination of modal parameters.

In the case of the Oberst beam, two piezo electric actuators have been glued near the root of the beam, where the displacements are small to lower energy loss due to added damping (Figure 1).

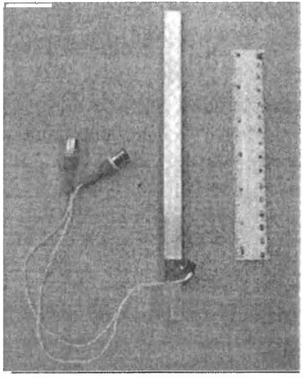

Fig. 1. Oberst beam excited using two piezo electric actuators

The beam used in this study has the following dimensions: length (*l*), 8''; width (*b*), ½'', thickness (*h*), 0.100'' and the material is aluminum. The piezo electric actuators are ¾'' long (l_{act}).

2.2. Added damping

The first problem was the matter of the added damping due to the gluing of the piezo electric actuators. As they are made out of ceramics, the intrinsic damping may be high. So, the overall damping of the beam has been measured before and after the gluing of the actuators (Table 1).

Mode order	Frequency (Hz)	Damping without actuators	Damping with actuators
1	47.1	0.09%	0.11%
2	295.8	0.14%	0.13%
3	827.2	0.18%	0.19%
4	1616.3	0.06%	0.13%
5	2668.5	0.07%	0.21%

Table 1. Base beam damping with and without piezo-electric actuators

Some damping has been added to the base beam for the 4th and 5th modes, but for the first three modes, there is no significant added damping. However, the overall damping remains low for all modes and should not interfere with the measurement of highly damped material.

2.3. Non covered length

A set of theoretical equations has been developed to determine the damping of each layer of a composite cantilever beam [2] under the assumption that the beam is entirely covered. In the present case it is not possible to cover the area occupied by the actuators with the material under test.

The structural damping is included in the complex part of the Young modulus and can be expressed as follow.

$$\hat{E} = E \cdot (1 + j \cdot \eta) \qquad (1)$$

The *Euler-Bernouilli* equation (2) for thin beam shows that the dissipated energy is included in the first term of and is proportional with both the fourth derivative of the displacement and the frequency. The fourth derivative of the displacement is directly equal to the displacement multiplied by a modal constant.

$$E.I \frac{\partial^4 w}{\partial x^4}(x,t) + \rho.A \frac{\partial^2 w}{\partial t^2}(x,t) = f(x,t) \qquad (2)$$

An estimation of the error on the measurement of the damping may be done using two indicators. The first one (ε_f) (3.1) is the ratio of the frequency shift of modes between the entirely covered beam and the partially covered beam. The second one (ε_w) (3.2) is the ratio of the area under modal shape curve between 0 and l for the entirely covered beam and between l_{act} and l for the entirely covered beam.

$$\varepsilon_f = \left|1 - (f_n^{covered} / f_n^{partial})^2\right| \qquad (3.1)$$

$$\varepsilon_w = \left| 1 - \int_{l_{act}}^{l} w(x).dx \Big/ \int_{0}^{l} w(x).dx \right| \qquad (3.2)$$

Table 2 gives the estimated error using the beam described above and a damping material stuck on one side of the beam (density: 1740 kg/m³, thickness: 1mm).

Mode order	Error due to frequency shift ε_f	Error due to non covered area ε_w
1	0.001%	0.09%
2	0.004%	0.47%
3	0.002%	1.19%
4	0.001%	2.12%
5	0.010%	3.20%

Table 2. Estimated error on damping

As expected, the error increases as the mode order increases only for the estimation of the non-dissipated energy in the root area, but the effect of frequency shift is negligible in the case of the tested material.

The maximum estimated error is about 3% on the fifth mode which is reasonable in the case of damping measurement or the modal parameter estimation.

3. Measurement of damping

3.1. Composite damping

Some methods are available to measure the modal damping, the most used is the half-power bandwidth which can be very imprecise when experimental curves are directly used, curve fitting methods are preferred. In this study, a semi-direct algorithm is proposed. The calculation of $F(\omega)$, the beam displacement divided by the bending moment can be written as in equation (4).

$$F(\omega) = \sum_{n=1}^{\infty} K_n . \frac{e^{(-\omega_n/\omega)}}{\omega - \omega_n} \qquad (4)$$

K_n is the modal amplitude and is a function of force amplitude and the measurement point position. Near the ith mode, the contribution of other modes can be neglected, the function $F(\omega)$ and its first derivative can be written as in equations (5.1) and (5.2).

$$F(\omega) \approx K_i . \frac{e^{(-\omega_i/\omega)}}{\omega - \omega_i} \qquad (5.1)$$

$$\frac{\partial F(\omega)}{\partial \omega} \approx F(\omega).\left(\frac{1}{\omega} - \frac{1}{\omega - \omega_i}\right) \qquad (5.2)$$

If A_m and $\tilde{A}_m$ are the experimental values of FRF and first derivative respectively near the ith mode, equations (5.1) and (5.2) can be combined and give equation (6.1) and (6.2).

$$\omega_i = \frac{\tilde{A}_m . \omega^2}{\tilde{A}_m . \omega - 1} \qquad (6.1)$$

$$K_i = A_m . \frac{\omega - \omega_i}{e^{-\omega_i/\omega}} \qquad (6.2)$$

Equation (6.1) and (6.2) give values than can be calculated from a certain number of frequency points near the resonance and averaged for a more precise estimation of modal parameters. Figure 2 represents the experimental and optimized curves for the two first modes of the damped beam.

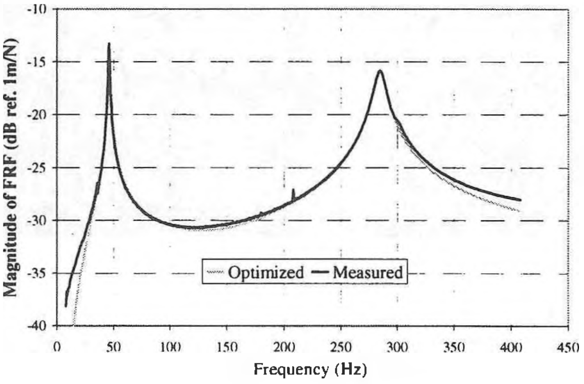

Fig. 2. Experimental and optimized FRF for the damped beam

This method always gives a good agreement as long as the experimental datas are properly measured.

3.2 Damping of tested material

Finally, the damping properties of the tested material have been directly calculated using formulas given in [1]. Table 3 gives the results for the Young modulus and damping ratio calculated using composite damping and modal frequencies estimated using the method developed in this study.

Mode order	Damping (%)	Young Modulus (MPa)
1	83.3	660
2	97.9	930
3	91.3	1520
4	ASTM E756 validity criteria not passed	
5	$(f_c/f_n)^2.(1+D.T)<1.01$	

Table 3. Estimated error on damping

4. Conclusion

The excitation of a cantilever beam using piezo electric actuator provides a good alternative to other excitation methods. The main advantage is its ease of settlement and of use, because it requires few adjustments and precaution. Moreover, the errors in the estimation of damping are small.

The proposed algorithm for the calculation of modal parameters has been specially developed to use a more precise estimation of modal parameters than a simple half-power bandwidth method without using an advanced modal testing software.

5. References

[1]: ASTM E756 - 98, *Standard Test Method for Measuring Vibration-Damping Properties of Materials*, American Society for Testing and Materials

[2]: A. D. Nashif, D.I.G. Jones, J.P. Henderson, *Vibration Damping*, John Wiley & Sons, 1985

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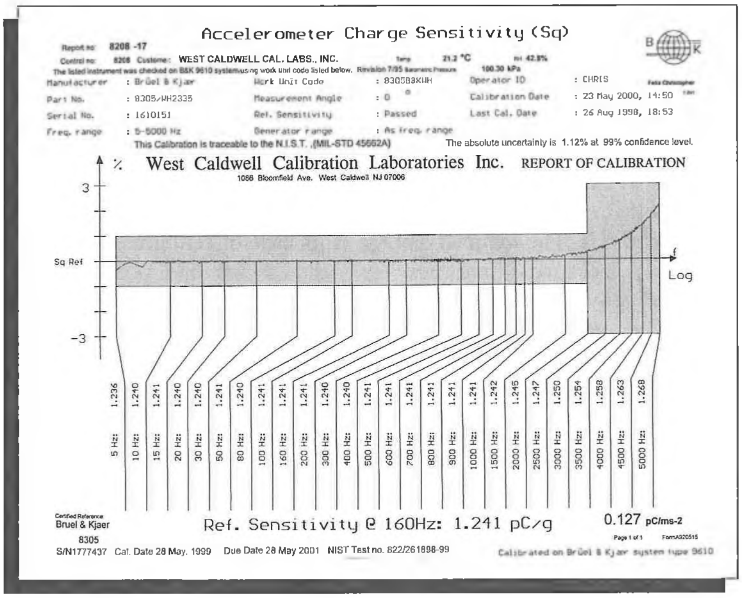


Accelerometer Charge Sensitivity (Sq)

Report no: 8208 -17
Control no: 8208 Custome: WEST CALDWELL CAL. LABS., INC. Temp 21.2 °C RH 42.8%
The listed instrument was checked on B&K 9610 systemusing work unit code listed below. Revision 7/95 Barometric Pressure 100.30 kPa

Manufacturer	: Brüel & Kjær	Work Unit Code	: 830588KWH	Operator ID	: CHRIS
Part No.	: 8305/WH2335	Measurement Angle	: 0 °	Calibration Date	: 23 May 2000, 14:50
Serial No.	: 1610151	Ref. Sensitivity	: Passed	Last Cal. Date	: 26 Aug 1998, 18:53
Freq. range	: 5-5000 Hz	Generator range	: As freq. range		

This Calibration is traceable to the N.I.S.T. ,(MIL-STD 45662A) The absolute uncertainty is 1.12% at 99% confidence level.

West Caldwell Calibration Laboratories Inc. REPORT OF CALIBRATION
1086 Bloomfield Ave. West Caldwell NJ 07006

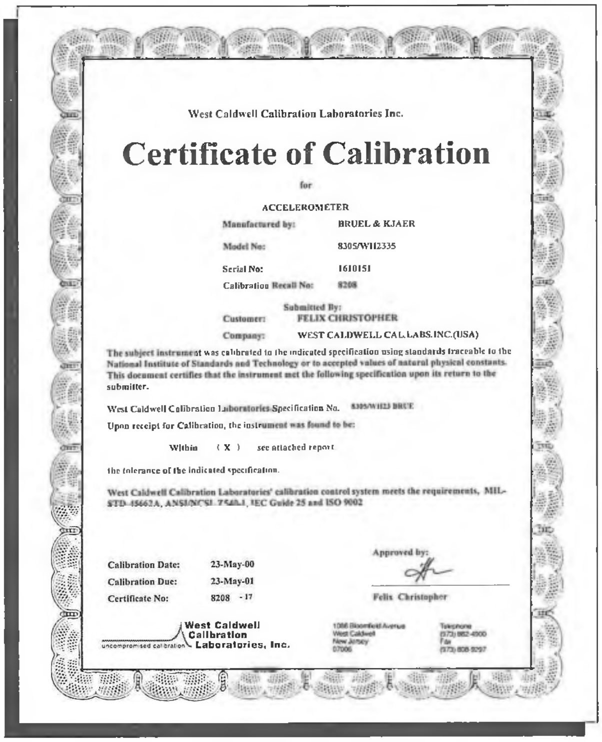
5 Hz:	1.236
10 Hz:	1.240
15 Hz:	1.241
20 Hz:	1.240
30 Hz:	1.240
50 Hz:	1.241
80 Hz:	1.240
100 Hz:	1.241
160 Hz:	1.241
200 Hz:	1.241
300 Hz:	1.240
400 Hz:	1.240
500 Hz:	1.241
600 Hz:	1.241
700 Hz:	1.241
800 Hz:	1.241
900 Hz:	1.241
1000 Hz:	1.241
1500 Hz:	1.242
2000 Hz:	1.245
2500 Hz:	1.247
3000 Hz:	1.250
3500 Hz:	1.254
4000 Hz:	1.258
4500 Hz:	1.263
5000 Hz:	1.268

Certified Reference
Bruel & Kjaer
8305
S/N1777437 Cal. Date 28 May. 1999 Due Date 28 May 2001 NIST Test no. 822/261898-99

Ref. Sensitivity @ 160Hz: 1.241 pC/g 0.127 pC/ms-2

Page 1 of 1 FormA920515
Calibrated on Brüel & Kjær system type 9610

Accelerometer calibration performed on the system chosen by the U.S. Air Force [PMEL]



West Caldwell Calibration Laboratories Inc.

Certificate of Calibration

for

ACCELEROMETER

Manufactured by: BRUEL & KJAER
Model No: 8305/WH2335
Serial No: 1610151
Calibration Recall No: 8208

Submitted By:
Customer: FELIX CHRISTOPHER
Company: WEST CALDWELL CAL.LABS.INC.(USA)

The subject instrument was calibrated to the indicated specification using standards traceable to the National Institute of Standards and Technology or to accepted values of natural physical constants. This document certifies that the instrument met the following specification upon its return to the submitter.

West Caldwell Calibration Laboratories Specification No. 8305/WH23 BRUE

Upon receipt for Calibration, the instrument was found to be:

Within (X) see attached report

the tolerance of the indicated specification.

West Caldwell Calibration Laboratories' calibration control system meets the requirements, MIL-STD-45662A, ANSI/NCSL Z540-1, IEC Guide 25 and ISO 9002

Calibration Date: 23-May-00
Calibration Due: 23-May-01
Certificate No: 8208 -17

Approved by:
Felix Christopher

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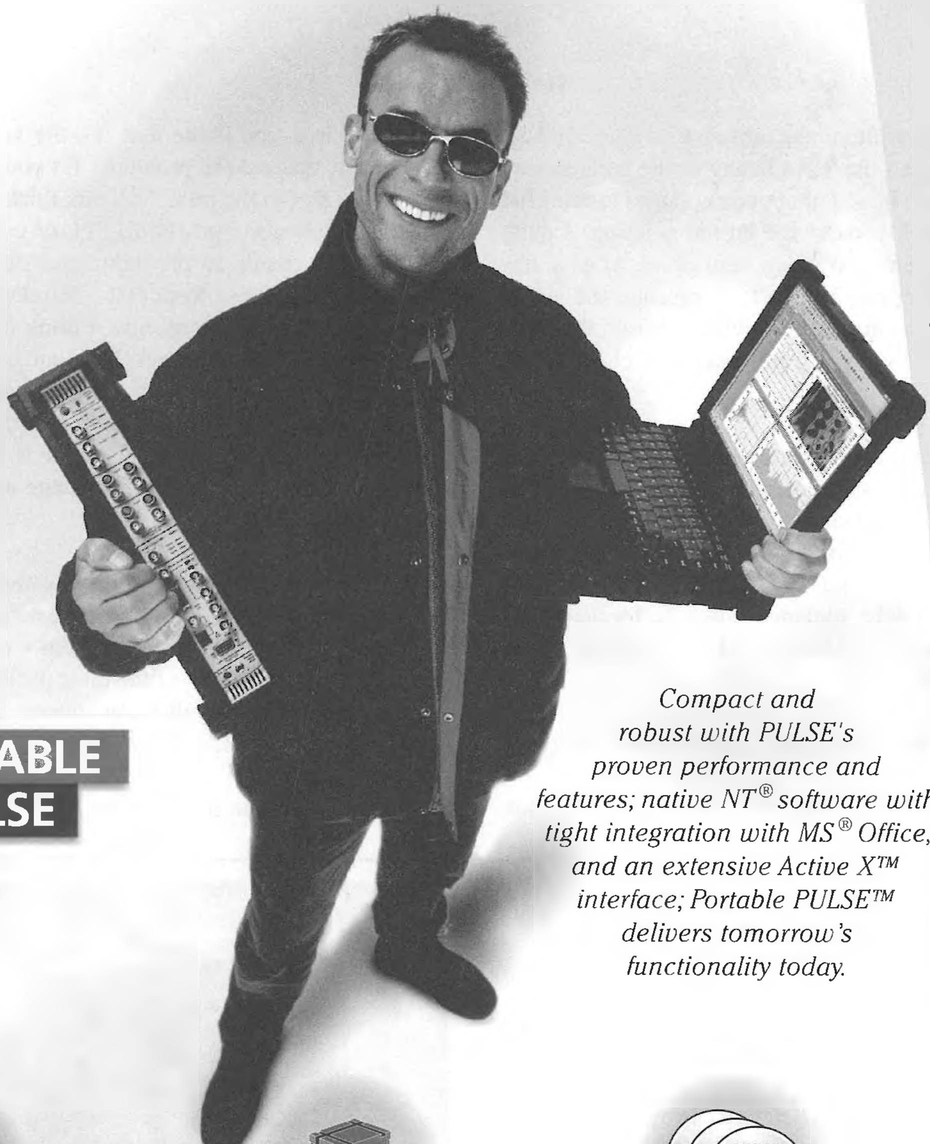
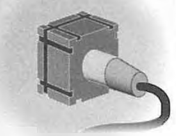
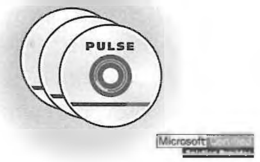






PULSE

Editor's Note: *The following section from the article, 'Montreux Jazz Festival,' by Julian Mainprize is reprinted with permission. The full article was published in the October 2000 issue of "professional sound."*

100 dB LAW!

One of the interesting things at the jazz festival is the 100 dB SPL law: at no time can the SPLs in any of the halls exceed 100 dB SPL - ah, the Swiss! For anyone not used to this kind of restriction at a rock concert the intitial reaction is quite shocking - it does seem too quiet. However, after a few songs into the first set one begins to appreciate the added coherence. Though you might miss a little cut from the snare drum, you can really hear every instrument so clearly - it's quite an ephiphany!

But as one can imagine, certain acts who already exceed this SPL limit on-satge without reinforcement can be stubborn about adjusting. Jean-Claude's philosophy in such a case, "'Listen Boys? You turn down or you pack up and go home.' There is no discussion. The festival has a reputation for good quality sound and the audience pays a lot for their tickets, so we cannot fool around with that. Everybody has to play by the same rules."

I asked Jean-Claude how he mixes given the restrictions.

"It is not just the rock bands that are loud. When you look at the A-curve you'll see that it's the vocals and the solo instruments that are the problem. So you just have to compensate for that in the mix. You mix thick - the bass is never a problem, you never go 100dB SPL or you'll smash down a wall. It all depends on the tightness of the band. You can create a big sound just from that. You don't do it with loudness, you do it with the energy. I think it makes sense also because most of the musicians have ear problems already so why do the same to the audience? It's important to work with the band on-stage. It has to sound clear. Normally, when a band plays you need about 6 dBs of headroom between what's coming from the satge and what's coming from the PA."

Well, the Swiss have done it again. Festival Director Claude Nobs has cut no corners to combine a first-rate line up of musicians, technicians and equipment - not to mention the scenery - and created one of the most prolific music festivals in the world. If your wallet can support the Swiss lifestyle for a couple of weeks, this festival is not to be missed.

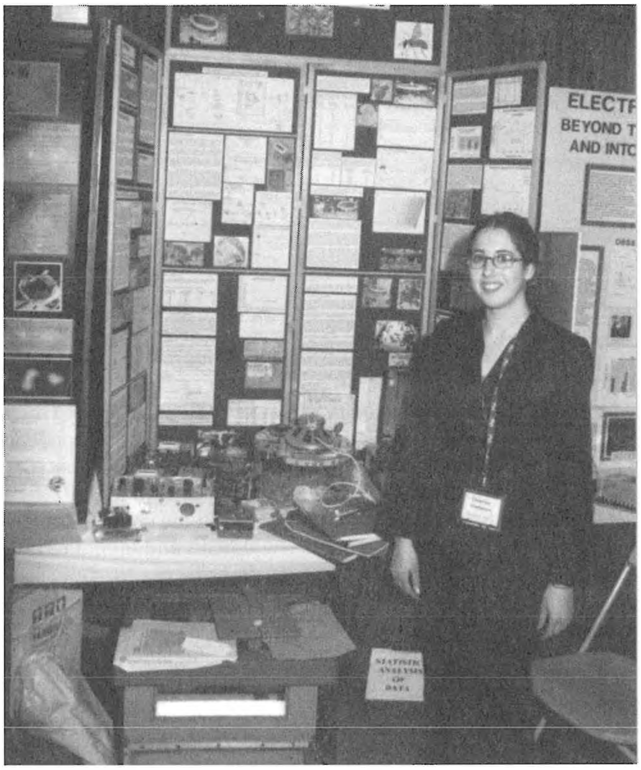
By Julian Mainprize; jmainprize@hotmail.com

Canada Wide Science Fair

Report by Annabel Cohen

Charina Cameron from the Grade 12 class at Horton High School in Wolfville, N. S. received the Canadian Acoustical Association Award for the best project in the area of acoustics at that Canada Wide Science Fair held in May, in London, Ontario. Her project was entitled "Bee Heard". Her purpose was to determine whether honeybees can perceive sounds. She made an elliptical experimentation beehive chamber that had a sound source. Laser beams were used as activity sensors. Instruments were calibrated and controls established. The clustering times under a light were compared under different sound frequencies, and in conditions of airborn and structure born sound. Statistical analyses indicated more sensitivity to vibrations at high pitches through solids than to sounds in air.

CAA members Erica Wong and Dr. Meg Cheesman, of the Dept. of Communication Disorders, University of Western Ontario kindly served as judges.



Sounds of Our Times: Two Hundred Years of Acoustics.

Robert T. Beyer

ISBN 0-387-98435-6

The English philosopher C.S. Lewis once wrote: "Most of all, perhaps, we need an intimate knowledge of the past. Not that the past has any magic about it, but because we cannot study the future, and yet need something to set against the present, to remind us that the basic assumptions have been quite different in different periods and that much which seems certain to the uneducated is merely temporary fashion."

If this strikes any kind of resonance with you and if you have any interest in acoustics then Robert Beyer's *Sounds of Our Times* should be on your bookshelf. Beyer has produced a highly readable, well illustrated 444 page tome covering just about everything you'd want to know about the last two hundred years of acoustic research. And if you can't find what you're looking for in the book, you can consult one of the most exhaustive sets of references I've ever seen. Most of the 10 chapters have more than 100 references, Chapter 9 has 261. All this, Beyer tells us in the Introduction, came out of a four year long retirement project! I can't think of any other retirement that has proved so useful to one's profession.

Sounds of Our Times picks up where F.V. Hunt's *Origins in Acoustics* left off, around the beginning of the 19th century. Each of the ten chapters covers a loosely defined epoch. Chapters are divided into areas of interest that are easily followed from one age to the next. So, for example, if you're interested in Tartini tones (where two loud musical sounds of different pitches can create a third tone with a pitch equal to the difference between the two tones) you can easily follow the path of discovery from the eighteenth century to the present. In Chapter 1 we learn that Italian violinist Giuseppe Tartini was one of several people to "discover" the phenomenon. In Chapter 3 we learn that Herman von Helmholtz added the concept of summation tones and that he was alert to possible non-linear explanations both inside and outside the ear. His work applied a recently invented sound source; the siren. The siren was invented by Charles Cagniard de la Tour then quickly improved on by several scientists, including von Helmholtz. The story picks up again in the late 19th century when Rûckner and Edser use sirens, horns, tuning forks and the mirror of a Michelson interferometer to provide objective evidence of Tartini tones. In the 1990s we learn of the connection between Tartini tones and otoacoustic emissions, i.e. sound generated *inside* the cochlea. This information has recently been applied to the study non-linear distortions in hearing aids. Thus weaves the inter-disciplinary pattern of the history of acoustics.

The book works well on several levels. It reads well from one end to the other. Chapter size chunks are easily bitten off. Historical threads are easily followed then expanded on through the references. The inventions of the 19th century provide very interesting reading. If you're fascinated with the new analytical possibilities presented by modern computers, think of what it must have been like the first time sound was made visible! Inventions like this, the telephone, and the phonograph are clearly reviewed in a single chapter. Tyndal and von Helmholtz have a chapter dedicated to their work; Rayleigh gets a chapter all to himself.

Seemingly everything is covered in this book. Interested in the origin of the decibel? Well you'll find it in Chapter 7. Echolocation by bats? Try Chapter 8. The latest developments in solitons, chaos and frequency doubling cavitation bubbles are found in the final chapter. The range of the author's scholarship is reflected in quotes from such disparate sources as the Bible, Victor Hugo, von Helmholtz and R. Murray Schafer in the preambles to each of the ten chapters.

Nothing in this world is perfect though. There are a number of typographical errors and these become tiring at times. The book suffers from a slightly inward looking American bias. Canadian Acoustics readers will be interested to learn of the "onset of World War II ... in 1941". As a result of this bias, room acoustics is not particularly well covered; the majority of post-war room acoustics research having gone on outside the U.S. Harold Marshall has been re-christened Herbert.

These however are pedantic quibbles. Beyer readily admits when he's out of his depth. Indeed, his diffidence is engaging. It's a natural extension of his style, which could be best described as a cross between rigourous scientific presentation and a fireside chat. So do yourself a favour, pick up this book, pour yourself a drink and set yourself down for a good read.

John O'Keefe
Aercoustics, Toronto, ON
Tel: 416-249-3361
e-mail: jokeefe@aercoustics.com

ACOUSTICS WEEK IN CANADA 2000 IN SHERBROOKE: RECORD PARTICIPATION

Acoustics Week in Canada 2000 took place at the Delta hotel, in Sherbrooke, Quebec, in September 2000. The week opened on Thursday, September 28 and concluded in the afternoon of September 29. The conference, sponsored by the Canadian Acoustics Association, was organized by the groupe d'acoustique de l'université de Sherbrooke (GAUS). Professor Noureddine Atalla of l'université de Sherbrooke was the Conference Chair and Professor Alain Berry of l'université de Sherbrooke was the Technical Program Chair.

About 148 participants attended the conference where 90 papers have been presented. The technical sessions dealt with topics from varied areas of acoustics and vibrations with a special emphasis on industrial passive and active control. Twelve companies exhibited the latest technologies in acoustics and vibration equipment, instrumentation, materials and prediction software. The meeting also consisted of two plenary lectures. Prof. Robert Bernhard from Purdue Univeristy gave the opening lecture on strategies for active and passive control. Prof. Jean Nicolas from l'université de Sherbrooke, gave the second plenary lecture on Innovation and Acoustics. The participants had also a chance to visit the acoustic and vibration facilities of the GAUS and in particular the vibroacoustic lab, the control and transducers lab and the complete porous material characterization lab that represent a unique facility in North America.

CAA2000 was exceptional by the record number of participants, the quality of the technical papers, the smoothness of the organization and the number of exhibitors. In particular, several foreign delegates mainly form the USA and France, attended the conference which gave it an international flavor.

Organising Committee: (L - R) - C. Clavet, P. Vachon, A. Berry, N. Atalla (kneeling), L. Morency and J. Wojtowicki (R. Oddo - absent)

CONFÉRENCE ANNUELLE DE l'ASSOCIATION CANADIENNE d'ACOUSTIQUE à SHERBROOKE: PARTICIPATION RECORD.

La conférence annuelle de l'Association Canadienne d'Acoustique s'est tenue à l'hôtel Delta de Sherbrooke du 27 au 29 Septembre, sous la présidence de Noureddine Atalla, professeur au département de génie mécanique et chercheur au GAUS. Alain Berry, également professeur au département de génie mécanique et directeur du GAUS, assurait la présidence du programme technique. Environ 148 congressistes ont participé à cet événement, où ont été présentées 90 communications scientifiques. Les principales sessions techniques portaient sur le contrôle du bruit et des vibrations, les méthodes et logiciels de modélisation vibroacoustique, les matériaux acoustiques, l'acoustique architecturale, le contrôle actif de bruit et de vibrations, le bruit et l'industrie du transport, ainsi que l'audition et la parole. Une douzaine d'entreprises étaient également présentes pour exposer des équipements ou des logiciels de pointe dans le domaine de l'acoustique. Deux conférences plénières y ont été prononcées, l'une sur "l'innovation et l'acoustique" par le Pr. Jean Nicolas, fondateur du GAUS et actuel vice-recteur à la recherche, l'autre sur "les stratégies optimales de contrôle actif et passif du bruit" par le Pr. Robert Bernhard, un chercheur de Purdue University (USA) mondialement reconnu dans le domaine. Les participants à la conférence ont eu la possibilité de visiter les différentes infrastructures du GAUS à la faculté de génie, dont le Laboratoire de Vibroacoustique, le Laboratoire de Contrôle et Transducteurs, et le Laboratoire de Caractérisation des Matériaux Acoustiques. De l'avis de nombreux délégués, l'édition 2000 de cette conférence annuelle a été exceptionnelle, tant par le nombre de participants que par la qualité des communications scientifiques et le nombre d'exposants. On y a noté la forte représentation de chercheurs étrangers, en particulier français et américains, ce qui a donné à l'événement une touche internationale.

Abstracts of M.A.Sc Theses - University of British Columbia

Andrew Wareing

Acoustical Modeling of Rooms with Extended-Reaction Surfaces

The acoustical modeling of rooms has always been a great challenge, especially when efforts are made to incorporate known acoustical phenomena that are complicated to model. Knowledge of the acoustical behaviour of room surfaces is fundamental to predicting the sound field in a room. Surfaces are classified, acoustically, as of either extended or local reaction. All known room-prediction models assume, whether implicitly or explicitly, that surfaces are of local reaction. How can extended-reaction surfaces be incorporated into room-prediction models? What is the significance to predicted steady-state sound pressures in rooms with surfaces modeled as extended vs. local reaction? This thesis is a detailed account of research dedicated to answering these questions. The main research goal was to develop a computationally efficient room-prediction model that included phase, and was applicable to rooms with extended- and local-reaction surfaces. A literature review concluded that a beam-tracing model with phase, and a transfer-matrix approach to model the surfaces were the best choice. The transfer-matrix model is applicable to extended- or local-reaction surfaces. These surfaces are modeled as multi-layers of fluid, solid or porous materials. Biot theory was used in the transfer-matrix formulation of the porous layer. The new model consisted of the transfer-matrix model integrated into the beam-tracing algorithm. The model is valid for specular reflection only, and calculations were performed in the frequency domain. Both models were validated and applied to three different room configurations: a 3m ´ 3m ´ 3m small office; a 10m ´ 3m ´ 3m corridor; and a 10m ´ 10m ´ 3m small industrial workroom. The test surfaces consisted of a glass plate, double drywall panels, double steel panels, carpet and a suspended-acoustical ceiling. Two predictions were made for each test surface in each room configuration; one for extended and one for local reaction. Results showed significantly higher predicted sound-pressure levels in rooms with a suspended-acoustical ceiling modeled as extended reaction, at low frequency. Rooms with walls of double drywall panels modeled as an extended-reaction surface showed significantly higher predicted sound-pressure levels. Sound-pressure levels were shown to be nearly equal in rooms with a single glass panel, carpet, and fibre-glass modeled as an extended- or local-reaction surface. An analysis of the reflection coefficients of these surfaces was performed to explain the results.

Pierre Germain

Active Control of Run-Up Noise from Propeller Aircraft

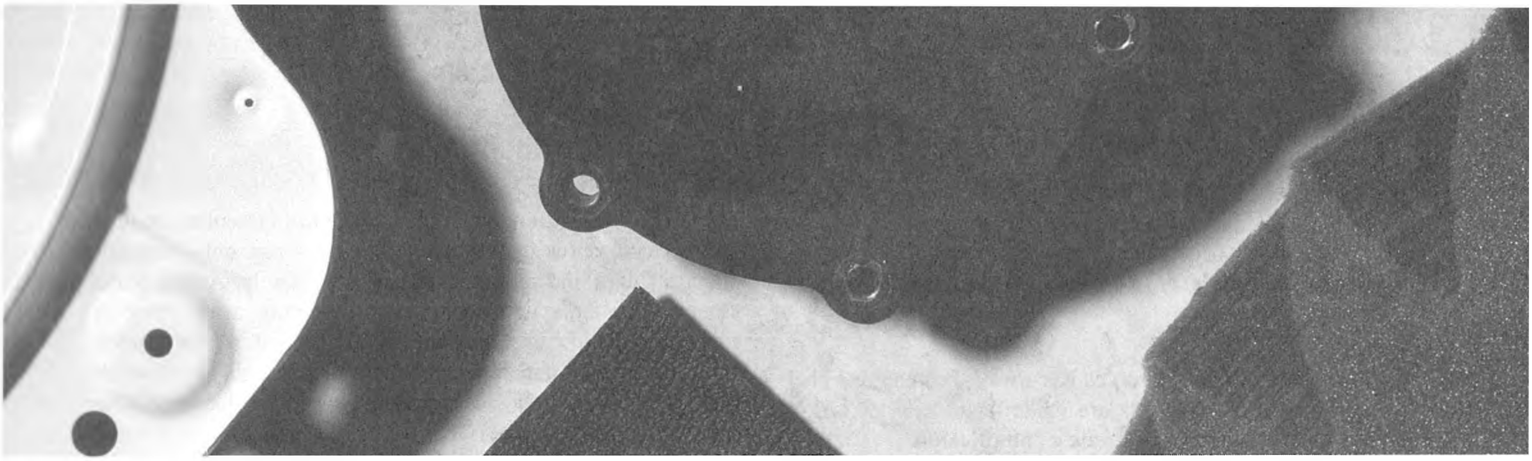
Engine run-ups are part of the regular maintenance schedule at Vancouver Airport. The noise generated by the run-ups propagates into neighbouring communities, disturbing the residents. This research focuses on controlling run-up noise from propeller aircraft. It is well known that passive control measures - such as aircraft enclosures and acoustic barriers - can only attenuate sound at high and mid frequencies. Conversely, Active Noise Control (ANC) a new technology involving using noise to reduce noise, is an inexpensive alternative to enclosures. Propeller aircraft generate tonal noise that is highly compatible with ANC. Tests on a Beechcraft 1900D found that the fundamental frequency of 112 Hz, as well as the first three harmonics, generated high noise levels in a community 3 km away from the run-up site. The insertion loss of an existing blast fence at the run-up site was measured, and found only to be efficient above 200 Hz. Computer simulations for different arrangements of ANC systems aimed at reducing run-up noise in residential areas were performed. Large triangular zones of local attenuation of 10 dB or more were obtained when 9 or more control channels were used. Increases of noise were predicted outside of these areas, but these were minimized as more control channels were employed. Using an ANC system in conjunction with a barrier, such as the existing blast fence, was shown to provide attenuation at all frequencies. ANC experiments were conducted in an anechoic chamber using 1 and 3 control channels. The fundamental and first harmonic of the Beechcraft 1900D noise were significantly attenuated with ANC. The experimental data correlated well with the theoretical predictions, validating the simulations. The results from both the computer simulations and experiments indicated the great potential of controlling run-up noise with multi-channel ANC systems. However, implementing a real ANC system at Vancouver Airport would require further evaluating the required size of the quiet zone as well as selecting the number of control sources and the distance from the primary source to the control sources accordingly.

Charles Tsun Kei Ng

A Study of the Optimal Classroom Acoustical Design by Ray-Tracing Prediction and Scale-Model Measurement

Poor classroom acoustical design reduces the learning efficiency of the students. This report examines factors that govern the optimal classroom acoustical design with respect to the classroom geometry and the distribution of absorbent material. Two methods used in this report are Ray-Tracing prediction and Scale-Model measurement. In terms of classroom geometry, this report identifies the acoustical benefits of reflectors in the front part of the classroom, tilted ceiling/floor classrooms, and fan-shaped classrooms. On the other hand, long/wide rectangular classrooms are not recommended. In investigating the influence of distribution of absorbent material, it was found to be less important compared to that of the classroom shape. Reflective surfaces placed at the front part of classroom can generally improve the speech intelligibility at the rear. In the future, more innovative classroom shapes can be investigated.

Theses Supervisor: Dr. Murray Hodgson, UBC



The ABC's of Noise Control

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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

4-7 December: 8th Australian International Conference on Speech, Science, and Technology, Canberra, Australia. Contact: S. Barlow, Secretary SST-2000, School of Computer Science, Australian Defence Academy, Northcott Drive, Canberra, ACT 2600, Australia; Web: www.cs.adfa.edu.au/ssst2000

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

14-17 January: 4th European Conference on Noise Control (euro-noise 2001), Patras, Greece. Contact: LFME, University of Patras, P.O. Box 1400, Patras 26500, Greece; e-mail: euronoise2001@upatras.gr

4-8 February: Midwinter Meeting, Association for Research in Otolaryngology, St. Petersburg, FL. Contact: ARO Office, 19 Mantua Rd., Mt. Royal, NJ 08061; Tel.: 856-423-7222; Fax: 856-423-3420; E-mail: meetings@aro.org; WWW: www.aro.org/mwm/mwm.html

22-25 March: "New Frontiers in the Amelioration of Hearing Loss," St. Louis, MO. Contact: Sarah Uffman, CID Department of Research, 4560 Clayton Ave., St. Louis, MO 63110; Tel.: 314-977-0278; Fax: 314-977-0030; E-mail: suffman@cid.wustl.edu

26-29 March: German Acoustical Society Meeting (DAGA 2001), Hamburg-Harburg, Germany. E-mail: dega@aku.physik.uni-oldenburg.de

9-11 April: Acoustical Oceanography, Southampton, UK. Fax: +44 1727 850553; Web: www.ioa.org.uk

23-25 April: 1st International Workshop on Thermoacoustics, s'Hertogenbosch, The Netherlands. Contact: C. Schmid, Acoustical Society of America, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502, USA; Web: www.phys.tue.nl/index.html

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

4-7 décembre: 8e conférence australienne internationale sur la parole, science et technologie, Canberra, Australie. Info: S. Barlow, Secretary SST-2000, School of Computer Science, Australian Defence Academy, Northcott Drive, Canberra, ACT 2600, Australia; Web: www.cs.adfa.edu.au /ssst2000

4-8 décembre: 140e rencontre 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; Couriel: asa@aip.org; Web: asa.aip.org

2001

14-17 janvier: 4e Conférence européenne sur le contrôle du bruit (euro-noise 2001), Patras, Grèce. Info: LFME, University of Patras, P.O. Box 1400, Patras 26500, Greece; Couriel: euronoise2001@upatras.gr

4-8 février: Rencontre mi-hiver de l'Association pour la recherche en otolaryngologie, St. Petersburg, FL. Info: ARO Office, 19 Mantua Rd., Mt. Royal, NJ 08061; Tél.: 856-423-7222; Fax: 856-423-3420; Couriel: meetings@aro.org; WWW: www.aro.org/mwm/mwm.html

22-25 mars: "Nouvelles frontières dans l'amélioration de la perte d'audition," St. Louis, MO. Info: Sarah Uffman, CID Department of Research, 4560 Clayton Ave., St. Louis, MO 63110; Tél.: 314-977-0278; Fax: 314-977-0030; Couriel: suffman@cid.wustl.edu

26-29 mars: Rencontre de la Société allemande d'acoustique (DAGA 2001), Hamburg-Harburg, Allemagne. Couriel: dega@aku.physik.uni-oldenburg.de

9-11 avril: Océanographie acoustique, Southampton, Royaume-Uni. Fax: +44 1727 850553; Web: www.ioa.org.uk

23-25 avril: 1er atelier international sur la thermo-acoustique, s'Hertogenbosch, Pays-Bas. Info: C. Schmid, Acoustical Society of America, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502, USA; Web: www.phys.tue.nl/index.html

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

21-25 May: 5th International Conference on Theoretical and Computational Acoustics (ICTCA2001), Beijing, China. Contact: E. C. Shang, CIRES, University of Colorado, NOAA/ETL, Boulder, Colorado, USA; Fax: +1 303 497 3577; Web: www.etl.noaa.gov/ictca01

28-31 May: 3rd EAA International Symposium on Hydroacoustics, Jurata, Poland. Contact: G. Grelowska, Polish Naval Academy, Smidowkcza 69, 81-103 Gdynia, Poland; Fax: +48 58 625 4846; Web: www.amw.gdynia.pl/pta/sha2001.html

4-8 June: 141st Meeting of the Acoustical Society of America, Chicago, IL. 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

2-6 July: 8th International Congress on Sound and Vibration, Kowloon, Hong Kong. Fax: +852 2365 4703; Web: www.iiav.org

15-19 August: ClarinetFest 2001, New Orleans, LA. Contact: Dr. Keith Koons, ICA Research Presentation Committee Chair, Music Dept., Univ. of Central Florida, P.O. Box 161354, Orlando, FL 32816-1354; Tel.: 407-823-5116; E-mail: kkoons@pegasus.cc.ucf.edu

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

7-10 October: 2001 IEEE International Ultrasonics Symposium Joint with World Congress on Ultrasonics, Atlanta, GA. Contact: W. O'Brien, Electrical and Computer Engineering, Univ. of Illinois, 405 N. Mathews, Urbana, IL 61801; Fax: 217-244-0105; WWW: www.ieee-uffc.org/2001

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

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; Couriel: pkreh@sae.org

21-25 mai: 5e Conférence internationale sur l'acoustique théorique et de calcul (ICTCA2001), Beijing, Chine. Info: E. C. Shang, CIRES, University of Colorado, NOAA/ETL, Boulder, Colorado, USA; Fax: +1 303 497 3577; Web: www.etl.noaa.gov/ictca01

28-31 mai: 3e Symposium international EAA sur l'hydro-acoustique, Jurata, Pologne. Info: G. Grelowska, Polish Naval Academy, Smidowkcza 69, 81-103 Gdynia, Poland; Fax: +48 58 625 4846; Web: www.amw.gdynia.pl/pta/sha2001.html

4-8 juin: 141e rencontre de l'Acoustical Society of America, Chicago, IL. Info: Acoustical Society of America, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502; Tel: 516-576-2360; Fax: 516-576-2377; Couriel: asa@aip.org; Web: asa.aip.org

2-6 juillet: 8e Congrès international sur le son et les vibrations, Kowloon, Hong Kong. Fax: +852 2365 4703; Web: www.iiav.org

15-19 août: ClarinetFest 2001, Nouvelle Orléans, LA. Info: Dr. Keith Koons, ICA Research Presentation Committee Chair, Music Dept., Univ. of Central Florida, P.O. Box 161354, Orlando, FL 32816-1354; Tél.: 407-823-5116; Couriel: kkoons@pegasus.cc.ucf.edu

28-30 août: Inter-Noise 2001, La Haye, Pays-Bas. Couriel: 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; Couriel: perugia@classico.it

7-10 octobre: Symposium international IEEE 2001 sur les ultrasons, combiné avec le Congrès mondial sur les ultrasons, Atlanta, GA. Info: W. O'Brien, Electrical and Computer Engineering, Univ. of Illinois, 405 N. Mathews, Urbana, IL 61801; Fax: 217-244-0105; WWW: www.ieee-uffc.org/2001

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

2002

4-8 March: German Acoustical Society Meeting (DAGA 2002), Bochum, Germany. Contact: J. Blauert, Institute of Communication Acoustics, Ruhr-Universität Bochum, 44780 Bochum, Germany; Fax: +49 234 321 4165; Web: www.ika.ruhr-uni-bochum.de

16-21 September: Forum Acusticum 2002 (Joint EAA-SEA-ASJ Meeting), Sevilla. Fax: +34 91 411 7651; Web: www.cica.es/aliens/forum2002

2002

4-8 mars: Rencontre de la Société allemande d'acoustique (DAGA 2002), Bochum, Allemagne. Info: J. Blauert, Institute of Communication Acoustics, Ruhr-Universität Bochum, 44780 Bochum, Germany; Fax: +49 234 321 4165; Web: www.ika.ruhr-uni-bochum.de

16-21 septembre: Forum Acusticum 2002 (Rencontre conjointe EAA-SEA-ASJ), Séville. Fax: +34 91 411 7651; Web: www.cica.es/aliens/forum2002

MAJOR THEMATIC GRANT ON ACOUSTIC ECOLOGY

PETER WALL INSTITUTE FOR ADVANCED STUDIES AT UNIVERSITY OF BRITISH COLUMBIA ANNOUNCES MAJOR THEMATIC GRANT ON ACOUSTIC ECOLOGY

The Peter Wall Institute for Advanced Studies has made a Major Thematic Grant award to a team of researchers led by **Dr. Kathy Pichora-Fuller**, School of Audiology and Speech Sciences and Director of the Institute for Hearing Accessibility Research (IHEAR). The team consists of 18 researchers from six different faculties: Applied Science, Arts, Education, Graduate Studies, Medicine and Science. This team will work on a project called Acoustic Ecology that will increase understanding of how people listen in everyday life. The grant has a value of $500,000 over three years.

The Acoustic Ecology project is a direct follow-up to Pichora-Fuller's successful Peter Wall Institute Exploratory Workshop entitled Acoustic Ecology: Listeners and Their Relationships to Sound Environments, which took place February 12-15, 2000. This workshop brought together past Canadian and international researchers in computer science, education, electrical engineering, linguistics, music, neuro-science, physiology, psychology, anthropology and audiology to consider research questions in three broad areas of acoustic ecology: the environment, the listener and listening itself.

The Major Thematic Grant award will allow the UBC research team to expand the interdisciplinary research initiated by the exploratory workshop, particularly in these three areas:

- 3-D psychology of listening, including the study of listening performance/experience in controlled static and dynamic 3-D scenarios;
- listener relationships, both interpersonal and person-environment;
- environment optimization for listeners, including the acoustical, technological and social features of the listening environment.

The Peter Wall Institute for Advanced Studies awards Major Thematic Grants to support research that will make significant contributions to basic knowledge through interdisciplinary teams of researchers from UBC and outstanding international experts.

The Canadian Acoustical Association
l'Association Canadienne d'Acoustique

PRIZE ANNOUNCEMENT

A number of prizes, whose general objectives are described below, are offered by the Canadian Acoustical Association. As to the first four prizes, applicants must submit an application form and supporting documentation to the prize coordinator before the end of February of the year the award is to be made. Applications are reviewed by subcommittees named by the President and Board of Directors of the Association. Decisions are final and cannot be appealed. The Association reserves the right not to make the awards in any given year. Applicants must be members of the Canadian Acoustical Association. Preference will be given to citizens and permanent residents of Canada. Potential applicants can obtain full details, eligibility conditions and application forms from the appropriate prize coordinator.

Edgar and Millicent Shaw Postdoctoral Prize in Acoustics

This prize is made to a highly qualified candidate holding a Ph.D. degree or the equivalent, who has completed all formal academic and research training and who wishes to acquire up to two years supervised research training in an established setting. The proposed research must be related to some area of acoustics, psychoacoustics, speech communication or noise. The research must be carried out in a setting other than the one in which the Ph.D. degree was earned. The prize is for $3000 for full-time research for twelve months, and may be renewed for a second year. Coordinator: Sharon Abel, Mount Sinai Hospital, 600 University Avenue, Toronto, ON M5G 1X6. Past recipients are:

1990	*Li Cheng*	*Université de Sherbrooke*	*1995*	*Jing-Fang Li*	*University of British Columbia*
1993	*Roland Woodcock*	*University of British Columbia*	*1996*	*Vijay Parsa*	*University of Western Ontario*
1994	*John Osler*	*Defense Research Estab. Atlantic*	*1999*	*Jingnan Guo*	*University of British Columbia*

Alexander Graham Bell Graduate Student Prize In Speech Communication and Behavioural Acoustics

The prize is made to a graduate student enrolled at a Canadian academic institution and conducting research in the field of speech communication or behavioural acoustics. It consists of an $800 cash prize to be awarded annually. Coordinator: Don Jamieson, Department of Communicative Disorders, University of Western Ontario, London, ON N6G 1H1. Past recipients are:

1990	*Bradley Frankland*	*Dalhousie University*	*1995*	*Kristina Greenwood*	*University of Western Ontario*
1991	*Steven D. Turnbull*	*University of New Brunswick*	*1996*	*Mark Pell*	*McGill University*
	Fangxin Chen	*University of Alberta*	*1997*	*Monica Rohlfs*	*University of Alberta*
	Leonard E. Cornelisse	*University of Western Ontario*	*1998*	*Marlene Bagatto*	*University of Western Ontario*
1993	*Aloknath De*	*McGill University*	*1999*	*William Hodgetts*	*University of Western Ontario*
1994	*Michael Lantz*	*Queen's University*	*2000*	*Janna Rieger*	*University of Alberta*

Fessenden Student Prize in Underwater Acoustics

The prize is made to a graduate student enrolled at a Canadian university and conducting research in underwater acoustics or in a branch of science closely connected to underwater acoustics. It consists of $500 cash prize to be awarded annually. Coordinator: David Chapman, DREA, PO Box 1012, Dartmouth, NS B2Y 3Z7.

1992	*Daniela Dilorio*	*University of Victoria*	*1996*	*Dean Addison*	*University of Victoria*
1993	*Douglas J. Wilson*	*Memorial University*	*1999*	*Nicolle Collison*	*University of Victoria*
1994	*Craig L. McNeil*	*University of Victoria*	*2000*	*Vanessa Corre*	*University of Victoria*

Eckel Student Prize in Noise Control

The prize is made to a graduate student enrolled at a Canadian academic institution pursuing studies in any discipline of acoustics and conducting research related to the advancement of the practice of noise control. It consists of a $500 cash prize to be awarded annually. The prize was inaugurated in 1991. Coordinator: Murray Hodgson, Occupational Hygiene Programme, University of British Columbia, 2206 East Mall, Vancouver, BC V6T 1Z3.

1994	*Todd Busch*	*University of British Columbia*	*1997*	*Andrew Wareing*	*University of British Columbia*
1995	*Raymond Panneton*	*Université de Sherbrooke*	*1999*	*Pierre Germain*	*University of British Columbia*
1996	*Nelson Heerema*	*University of British Columbia*	*2000*	*Lillian Ciona*	*University of Western Ontario*

Directors' Awards

Three awards are made annually to the authors of the best papers published in *Canadian Acoustics*. All papers reporting new results as well as review and tutorial papers are eligible; technical notes are not. The first award, for $500, is made to a graduate student author. The second and third awards, each for $250, are made to professional authors under 30 years of age and 30 years of age or older, respectively. Coordinator: Kathy Pichora-Fuller, University of British Columbia, Vancouver, BC.

Student Presentation Awards

Three awards of $500 each are made annually to the undergraduate or graduate students making the best presentations during the technical sessions of Acoustics Week in Canada. Application must be made at the time of submission of the abstract. Coordinator: Karen Fraser, CN Rail, Toronto ON , Tel: (416) 217-6466.

The Canadian Acoustical Association
l'Association Canadienne d'Acoustique

ANNONCE DE PRIX

Plusieurs prix, dont les objectifs généraux sont décrits ci-dessous, sont décernés par l'Association Canadienne d'Acoustique. Pour les quatre premiers prix, les candidats doivent soumettre un formulaire de demande ainsi que la documentation associée au coordonnateur de prix avant le dernier jour de février de l'année durant laquelle le prix sera décerné. Toutes les demandes seront analysées par des sous-comités nommés par le président et la chambre des directeurs de l'Association. Les décisions seront finales et sans appel. L'Association se réserve le droit de ne pas décerner les prix une année donnée. Les candidats doivent être membres de l'Association. La préférence sera donnée aux citoyens et aux résidents permanents du Canada. Les candidats potentiels peuvent se procurer de plus amples détails sur les prix, leurs conditions d'éligibilité, ainsi que des formulaires de demande auprès du coordonnateur de prix.

PRIX POST-DOCTORAL EDGAR ET MILLICENT SHAW EN ACOUSTIQUE

Ce prix est attribué à un(e) candidat(e) hautement qualifié(e) et détenteur(rice) d'un doctorat ou l'équivalent, qui a complèté(e) ses études et sa formation de chercheur, et qui désire acquérir jusqu'à deux années de formation supervisée de recherche dans un établissement reconnu. Le thème de recherche proposée doit être relié à un domaine de l'acoustique, de la psycho-acoustique, de la communication verbale ou du bruit. La recherche doit être menée dans un autre milieu que celui où le candidat a obtenu son doctorat. Le prix est de $3000 pour une recherche plein temps de 12 mois avec possibilité de renouvellement pour une deuxième année. Coordonnatrice: Sharon Abel, Mount Sinai Hospital, 600 University Avenue, Toronto, ON M5G 1X6. Les récipiendaires antérieur(e)s sont:

1990	*Li Cheng*	*Université de Sherbrooke*	*1995*	*Jing-Fang Li*	*University of British Columbia*
1993	*Roland Woodcock*	*University of British Columbia*	*1996*	*Vijay Parsa*	*University of Western Ontario*
1994	*John Osler*	*Defense Research Estab. Atlantic*	*1999*	*Jingnan Guo*	*University of British Columbia*

PRIX ÉTUDIANT ALEXANDER GRAHAM BELL EN COMMUNICATION VERBALE ET ACOUSTIQUE COMPORTEMENTALE

Ce prix sera décerné à un(e) étudiant(e) inscrit(e) dans une institution académique canadienne et menant un projet de recherche en communication verbale ou acoustique comportementale. Il consiste en un montant en argent de $800 qui sera décerné annuellement. Coordonnateur: Don Jamieson, Department of Communicative Disorders, University of Western Ontario, London, ON N6G 1H1. Les récipiendaires antérieur(e)s sont:

1990	*Bradley Frankland*	*Dalhousie University*	*1995*	*Kristina Greenwood*	*University of Western Ontario*
1991	*Steven D. Turnbull*	*University of New Brunswick*	*1996*	*Mark Pell*	*McGill University*
	Fangxin Chen	*University of Alberta*	*1997*	*Monica Rohlfs*	*University of Alberta*
	Leonard E. Cornelisse	*University of Western Ontario*	*1998*	*Marlene Bagatto*	*University of Western Ontario*
1993	*Aloknath De*	*McGill University*	*1999*	*William Hodgetts*	*University of Western Ontario*
1994	*Michael Lantz*	*Queen's University*	*2000*	*Janna Rieger*	*University of Alberta*

PRIX ÉTUDIANT FESSENDEN EN ACOUSTIQUE SOUS-MARINE

Ce prix sera décerné à un(e) étudiant(e) inscrit(e) dans une institution académique canadienne et menant un projet de recherche en acoustique sous-marine ou dans une discipline scientifique reliée à l'acoustique sous-marine. Il consiste en un montant en argent de $500 qui sera décerné annuellement. Coordonnateur: David Chapman, DREA, PO Box 1012, Dartmouth, NS B2Y 3Z7.

1992	*Daniela Dilorio*	*University of Victoria*	*1996*	*Dean Addison*	*University of Victoria*
1993	*Douglas J. Wilson*	*Memorial University*	*1999*	*Nicolle Collison*	*University of Victoria*
1994	*Craig L. McNeil*	*University of Victoria*	*2000*	*Vanessa Corre*	*University of Victoria*

PRIX ÉTUDIANT ECKEL EN CONTRÔLE DU BRUIT

Ce prix sera décerné à un(e) étudiant(e) inscrit(e) dans une institution académique canadienne dans n'importe quelle discipline de l'acoustique et menant un projet de recherche relié à l'avancement de la pratique en contrôle du bruit. Il consiste en un montant en argent de $500 qui sera décerné annuellement. Ce prix a été inauguré en 1991. Coordonnateur: Murray Hodgson, Occupational Hygiene Programme, University of British Columbia, 2206 East Mall, Vancouver, BC V6T 1Z3.

1994	*Todd Busch*	*University of British Columbia*	*1997*	*Andrew Wareing*	*University of British Columbia*
1995	*Raymond Panneton*	*Université de Sherbrooke*	*1999*	*Pierre Germain*	*University of British Columbia*
1996	*Nelson Heerema*	*University of British Columbia*	*2000*	*Lillian Ciona*	*University of Western Ontario*

PRIX DES DIRECTEURS

Trois prix sont décernés, à tous les ans, aux auteurs des trois meilleurs articles publiés dans l'*Acoustique Canadienne*. Tout manuscrit rapportant des résultats originaux ou faisant le point sur l'état des connaissances dans un domaine particulier sont éligibles; les notes techniques ne le sont pas. Le premier prix, de $500, est décerné à un(e) étudiant(e) gradué(e). Le deuxième et le troisième prix, de $250 chacun, sont décernés à des auteurs professionnels âgés de moins de 30 ans et de 30 ans et plus, respectivement. Coordonnateur: Kathy Pichora-Fuller, University of British Columbia, Vancouver, BC.

PRIX DE PRÉSENTATION ÉTUDIANT

Trois prix, de $500 chacun, sont décernés annuellement aux étudiant(e)s sous-gradué(e)s ou gradué(e)s présentant les meilleures communications lors de la Semaine de l'Acoustique Canadienne. La demande doit se faire lors de la soumission du résumé. Coordonnateur: Karen Fraser, CN Rail, Toronto ON, Tel: (416) 217-6466.

Canadian Acoustical Association
l'Association Canadienne d'Acoustique

2000 PRIZE WINNERS / RÉCIPIENDAIRES 2000

ALEXANDER GRAHAM BELL PRIZE IN SPEECH COMMUNICATION AND BEHAVIOURAL ACOUSTICS
PRIZ ALEXANDER GRAHAM BELL EN COMMUNICATION VERBALE ET ACOUSTIQUE COMPORTEMENTALE

Janna Rieger, University of Alberta

"Acoustic analysis of speech associated with the use of automatic speech recognition"

FESSENDEN STUDENT PRIZE IN UNDERWATER ACOUSTICS
PRIX ÉTUDIANT FESSENDEN EN ACOUSTIQUE SOUS-MARINE

Vanessa Corre, University of Victoria

"Shallow water geoacoustic inversion using a two-stage matched field tomography method"

ECKEL STUDENT PRIZE IN NOISE CONTROL
PRIX ÉTUDIANT ECKEL EN CONTRÔLE DU BRUIT

Lillian Ciona, University of Western Ontario

"Participation in noisy leisure activities in a sample of high school students"

DIRECTORS' AWARDS / PRIX DES DIRECTEURS

Professional ≥30 years / Professionel ≥30 ans:

Chantal Laroche, University of Ottawa

"Study of noise levels in neonatal intensive care unit"

Student / Étudiant(e):

Steve Aiken, University of Western Ontario

"Behavioural speaker identification: A forensic application "

STUDENT AWARDS / PRIX ÉTUDIANT

Tanya Bergerson, University of Toronto

"Duration discrimination in younger and older adults"

Ian Toms, University of Prince Edward Island

"Identification of tonic in popular and baroque music in young and older adults using a dual keyborad apparatus"

Youseff Atalla, University of Sherbrooke

"Inverse problem for a complete characterization of rigid porous materials using a standing wave tube apparatus"

CANADA WIDE SCIENCE FAIR AWARD IN ACOUSTICS

Charina Cameron, Horton High School, Wolfville, Nova Scotia

"Bee Heard"

CONGRATULATIONS / FÉLICITATIONS

Charina Cameron receiving the Canada Wide Science Fair acoustics prize from CAA Director Dr. Meg Cheesman

Call for Papers
Acoustics Conference in Canada 2001
Nottawasaga Inn, Alliston, Ontario
October 1, 2 and 3, 2001

Organizing Committee

The Acoustics Conference in Canada 2001 will be held at the Nottawasaga Inn located in Alliston, Ontario, which is approximately 45 minutes to an hour from the Toronto Airport. The conference will commence on Monday October 1, 2001 and end on Wednesday October 3, 2001. Members of the CAA located in the Greater Toronto Area will organize the conference sponsored by the Canadian Acoustical Association. The conference chair is Dalila Giusti of Jade Acoustics Inc. The technical chairs are Tim Kelsall of Hatch Associates and Alberto Behar.

Conference e-mail: caa2001@jadeacoustics.com
Web site: http://www.caa2001.com

Scientific and Technical Papers

The emphasis for the 2001 Conference will be to ensure that all areas of acoustics are represented. The sessions will include opening plenary lectures, invited and contributed papers, panel discussions and exhibits. In order to ensure that all areas of acoustics are represented the technical chairs are putting together a group of highly skilled and motivated individuals to act as session chairs. They can only be successful if the membership, including students, attend the conference and present papers.

The following technical areas are proposed to be included:

Industrial Noise
Outdoor sound Propagation
Hearing Protection
Physiological Acoustics
Computer Applications
Transportation Noise
Building Acoustics
Speech Perception
Acoustic Materials
Sound Quality
Canadian Standards
Community Noise
Vibration
Occupational Hearing Loss
Underwater Acoustics
Legislation/Environmental Noise
Instrumentation
Musical Acoustics

Abstracts

Abstracts of a maximum of 250 words must be submitted by June 1, 2001. 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 below. Notification of acceptance of abstracts will be sent to the authors by June 20, 2001 along with a registration form. Summary papers are due by July 31, 2001. This deadline will be strictly enforced in order to meet the publication schedule of the proceedings issue of *Canadian Acoustics*.

For specific information regarding the technical topics contact:

Tim Kelsall
Hatch Associates Ltd.
2800 Speakman Dr.
Mississauga, Ontario L5K 2R7
e-mail: Tkelsall@Hatch.ca
Telephone: (905) 403-3932
Fax: (905) 855-8270

Alberto Behar, Noise Control
45 Meadowcliffe Dr.
Scarborough, Ontario
M1M 2X8
e-mail: albehar@trigger.net
Telephone/fax: (416) 265-1816

Students

Student participation at the CAA 2001 Conference 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 Conference if they live at least 150 km from Alliston, Ontario. To apply for this subsidy, students must submit an *Application for Student Travel Subsidy* included in this issue.

Accommodations

Accommodations and meeting space for the delegates of the 2001 Conference will be at the Nottawasaga Inn (www.NottawasagaResort.com) located just north of Toronto, Ontario. The Conference rate will be $110.00 per night. To reserve your accommodation, please contact the Inn directly at (416) 364-5068.

It is important to note that the rooms are only guaranteed for the CAA Conference up to **July 1, 2001.** After that date the rooms are subject to availability. This is extremely important because there are not many alternative accommodations in the area.

Exhibits

A permanent exhibition showcasing the latest technology in acoustics and vibration equipment, instrumentation, materials and software will be open continuously during the Conference.
Space will be available for exhibits by companies and organizations in the field of acoustics. Sponsorship of the breaks and/or lunches is also welcome. If you are interested in either of these opportunities please contact Dalila Giusti.

Important Dates

June 1, 2001 Deadline for submission of abstracts June 20, 2001 Notification of acceptance of abstracts July 1, 2001 Deadline for guaranteed rooms July 31, 2001 Deadline for receipt of summary papers & early registration October 1 to 3, 2001 Acoustics Conference in Canada 2001.

For more information contact:

Dalila Giusti, Jade Acoustics Inc.
545 North Rivermede Rd. Ste 203
Concord, Ontario L4K 4H1
e-mail: dalila@jadeacoustics.com
Telephone: (905) 660-2444; Fax: (905) 660-4110

Appel de Communications
Semaine Canadienne d'acoustique 2001
Nottawasaga Inn, Alliston, Ontario
1, 2 et 3 Octobre 2001

Comité Organisateur

La semaine canadienne d'acoustique 2001 aura lieu à l'auberge Nottawasaga à Alliston, en Ontario. Alliston se situe à une distance approximative de 45 à 60 minutes de l'aéroport de Toronto. La conférence débutera le lundi 1er octobre 2001, pour conclure le mercredi 3 octobre 2001. Les membres de l'ACA de la région de Toronto organiseront la conférence commanditée par l'Association Canadienne d'Acoustique. La présidente du congrès est Dalila Giusti de la compagnie Jade Acoustics Inc. Les conseilliers techniques sont Tim Kelsall de Hatch Associates et Alberto Behar.

Courriel pour la conférence : caa2001@jadeacoustics.com
Site internet : http://www.caa2001.com

Articles Scientifiques et Techniques

L'emphase de la conférence sera mise sur la représentation de tous les domaines en acoustique. Les séances inclueront des exposés plénières, des communications invitées et proposées, des panels de discussion ainsi qu'une exposition. De façon à assurer que tous les domaines d'acoustique soient représentés au sein de cette conférence, les conseillers techniques ont approché un groupe d'individus motivés et très expérimentés qui agiront en tant que responsables de sessions. Cependant, le succès de ce congrès dépend fortement de la participation de tous les membres, incluant les étudiants.

Les domaines techniques suivants sont proposés:

Le bruit industriel
La propagation du son à l'extérieur
Les matériaux acoustiques
L'acoustique sous-marine
Les applications informatiques
Le bruit relié aux moyens de transport
La législation relié au bruit environnemental
L'acoustique des bâtiments
La perception de la parole
Les normes canadiennes
L'acoustique physiologique
Le bruit communautaire
Les pertes auditives en milieu de travail
Vibration
La protection de l'ouïe
L'instrumentation
La qualité de son
L'acoustique musicale

Résumés

La date limite de soumission des résumés (maximum de 250 mots) est le 1er juin 2001. Ces abrégés doivent être préparés et soumis selon les instructions retrouvées dans l'édition courante de la revue Acoustique canadienne. Les soumissions par courriel sont fortement encouragées; les fichiers peuvent être préparés à l'aide de tout logiciel de traitement de texte. Pour les gens n'ayant pas accès au courriel, les fichiers électroniques sur disquette ou les copies sur papier peuvent être envoyés par la poste à l'adresse publiée ci-dessous. Un avis, accompagnée d'un formulaire d'inscription, sera envoyée d'ici le 20 juin 2001 aux auteurs des résumés qui auront été approuvés. Les articles de résumés devront être reçus avant le 31 juillet 2001. Afin de respecter l'horaire de publication de l'édition "compte-rendu" de la revue Acoustique canadienne,cette date limite devra être respectée.

Pour obtenir de plus amples informations au sujet des thèmes techniques,veuillez vous adresser à:

Tim Kelsall, Hatch Associates Ltd
Courriel: Tkelsall@Hatch.ca
Téléphone: (905) 403-3932
Télécopieur: (905) 855-8270

Alberto Behar, Noise Control
courriel: albehar@trigger.net
téléphone/télécopieur: (416) 265-1816

Étudiants

La participation des étudiants à la conférence de l'ACA 2001 est fortement encouragée. Des prix seront accordés aux étudiants dont la présentation à la conférence aura été jugée particulièrement emarquable. Afin d'être éligibles à ces prix, les étudiants doivent remplir le formulaire du Prix Annuel de Présentation Étudiante. Ce formulaire devrait être envoyé avec le résumé. Les étudiants qui habitent dans une région suffisamment éloignée d'Alliston (plus de 150km), et qui désirent présenter leur article à la conférence, devraient également faire application pour une subvention de voyage, afin de défrayer leurs coûts de déplacement.

Logement

Les délégués de la conférence seront logés à l'Auberge Nottawasaga (www.NottawasagaResort.com), située au nord de Toronto. Le tarif pour la conférence est de 110.00$ par nuit. Veuillez s'il-vous-plait communiquer avec l'auberge au (416) 364-5068 pour les réservations.

Il est important de noter que les chambres seront garanties aux membres de l'ACA participant à la conférence jusqu'au 1er juillet 2001. Après cette date, la disponibilité des chambres n'est pas garantie. Puisque les autres options de logement dans la région sont limitées, il est extrêmement important de faire les réservations avant cette date.

Exposants

Lors de la conférence, une exposition permanente portant sur les dernières technologies entourant l'équipement, l'instrumentation, les matériaux et les logiciels reliés aux domaines de l'acoustique et des vibrations, sera ouverte à tous. Un espace sera disponible pour les exposants provenant d'organismes et de compagnies spécialisés dans le domaine de l'acoustique. La commandite de période de pauses et/ou de collations serait également appréciée. Si l'une ou l'autre de ces suggestions vous intéresse, veuillez vous adresser à Dalila Giusti.

Dates À Retenir

Le 1er juin 2001 Date limite pour la soumission des résumés Le 20 juin Avis pour les résumés approuvés Le 1er juillet 2001 Date limite pour la réservation de chambres garanties Le 31 juillet 2001 Date limite pour la soumission des papiers résumés et l'inscription à l'avance Du 1er au 3 octobre 2001 Semaine canadienne d'Acoustique 2001

Pour de plus amples informations, veuillez communiquer avec:

Dalila Giusti,
Jade Acoustics Inc.
545 North Rivermede Rd. Ste 203, Concord, Ontario L4K 4H1
Courriel: dalila@jadeacoustics.com
Téléphone: (905) 660-2444; Télécopieur: (905) 660-4110

CAA Student Travel Subsidy and Student Presentation Award
Application Form
DEADLINE FOR RECEIPT 1, August, 2001

Procedure

- Complete and submit this application at the same time as the abstract to the Technical Chair of the Conference. Both must be received on or before deadline listed above.
- By 31 August 1999, the CAA Secretary will notify you of the Travel Subsidy funding that you can expect to receive.
- Subsidy cheques will be mailed directly to you within 30 days of the end of the Conference

Eligibility Requirements

In order to be eligible for the Travel Subsidy you must meet the following requirements:

1. Full-time student at a Canadian University;
2. Student Member in good standing of the Association;
3. Distance traveled to the Conference must exceed 150 km (one way);
4. Submit a summary paper for publication in the Proceedings Issue of Canadian Acoustics with the applicant as the first author;
5. Present an oral paper at the Conference. Due to limited funding, a travel subsidy can only be given to the presenter of the paper even though there may be more than one student authors.

Section A: All applicants must complete this section

Name of Student:____________________

Address:____________________
(where the cheque is to be sent)

Title of the proposed paper:____________________

Is the paper to be judged in the Student Presentation Award(s) [Yes/No]:____________________

Name and Location of the University: ____________________, ____________________

Faculty and Degree Being Sought: ____________________, ____________________

Section B: Complete this section only if you are applying for the CAA Student Travel Subsidy

I hereby apply for a travel subsidy from the CAA

Proposed Method of Transport to conference:____________________
Brief description of the route and method of transportation (e.g., bus, train, air, etc.)

Estimated Cost of Transportation:____________________
Provide least expensive transportation cost.

Date of Departure to, and Return from the Conference: ____________________, ____________________

Other Sources of Travel Funding:____________________
List other sources of travel funding and the amount

Signature of Applicant	**Signature of University Supervisor**
____________________	____________________
I certify that the Information provided above is correct	I certify that the applicant is a full time student
____________________	____________________
Print Name	Print Name

Subvention de l'ACA pour les Frais de Déplacement des Etudiants et Prix Récompensant les Présentations d'Etudiants - Formulaire d'Inscription
DATE LIMITE DE RÉCPTION, 1 AOUT 2001

Procédure

- Compléter le formulaire et le soumettre en même temps que le sommaire au Président Technique de la Conférence. Tous deux doivent être reçus avant la date limite indiquée ci-dessus.
- Le Secrétariat de l'ACA vous enverra une note avant le 31 Août 1999 indiquant la Subvention que vous êtes susceptible de recevoir.
- Les chèques de Subvention vous seront directement envoyés dans les 30 jours suivant la fin de la Conférence.

Conditions d'Eligibilité

1. Pour avoir droit à la Subvention pour les Frais de Déplacement, vous devez remplir les conditions uivantes:
2. Etre étudiant à temps plein dans une Université Canadienne;
3. Etre Membre de l'ACA;
4. La distance parcourue jusqu'à la Conférence doit être supérieure à 150km (aller simple);
5. Soumettre un sommaire en vue de sa publication dans les actes d'Acoustique Canadienne, l'étudiant doit être le premier auteur du sommaire;
6. Présenter une communication orale pendant la conférence. En raison du financement limité, une Subvention pour les Frais de Déplacement ne peut être attribuée qu'à l'étudiant présentant la communication même si plusieurs étudiants sont auteurs du sommaire.

Section A: Tous les candidats doivent remplir cette section

Nom de l'étudiant:____

Adresse: ____
(où le chèque doit être envoyé)

Titre de la communication proposée: ____________________________________

La communication est elle inscrite au concours pour le Prix Récompensant les Communications d'Etudiants [Oui/Non]: __________

Nom et adresse de l'université: ____________________________________

Faculté et niveau d'étude en cours: ____________________________________

Section B: Compléter cette section si vous postulez pour une Subvention des Frais de Déplacement
Je postule par le présent document à une Subvention de l'ACA pour des Frais de Déplacement

Moyen de Transport proposé pour se rendre a la conférence: ____________________________
Brève description du trajet et du moyen de transport (i.e bus,train,avion etc.)

Coût estimé du Transport: ____________________________________
Fournir le coût de transport le moins élevé
Date de Départ pour la Conférence et de Retour: ____________________________

Autres sources de financement pour le transport:____________________________
donner la liste des sources de financement et leur montant

Signature du candidat	**Signature du superviseur**
________________________	________________________
Je certifie que les informations fournies ci dessus sont correctes	Je certifie que le signataire est un étudiant à temps plein
________________________	________________________
Nom	**Nom**

Canadian Acoustical Association
Minutes of the Annual General Meeting
28 September 2000

Sherbrooke, Quebec

Meeting called to order at 4:07 p.m.

Minutes of the last AGM 18 October 1999 were approved as written in the December 1999 issue of Canadian Acoustics. (Moved by M. Cheesman, seconded by N. Atalla, carried).

President's Report

J. Bradley, reported that the Operations Manual is continuing to be updated to help identify recurring voting items such as voting to set membership fees at the AGM, voting to allocate funds for the student travel subsidy, etc.

(Acceptance of the President's report was moved by R. Ramakrishnan, seconded by K. Pichora-Fuller, carried).

Secretary's Report

T. Nightingale was very pleased to report that the membership is reasonably constant when compared to the last three years. The total paid membership (including non-voting journal subscriptions) is 343 as of 20 September 2000.

The Secretary introduced the proposal for "Member Emeritus" and read the description that was approved by the Board the day before at the BoD meeting. M. Cheesman moved that,

"If the member has been an active and longtime member who has retired from full time employment by reason of age or infirmity then, the member should qualify, at the discretion of the Board, to be an Emeritus Member paying the same fees and enjoying the same rights as a student member. Such a membership will be described as Member Emeritus."

The motion was seconded by T. Kelsall. All were in favour and the motion was carried.

The Secretary reported on the likely donation from the Signal Processing Institute Fund (SPIF) of $10,000 to support student travel to conferences that have significant material on signal processing and underwater acoustics.

The Secretary informed the Membership of the operating costs for secretarial activities in FY 99/00, which were $1480. Approximately $300 higher than an average year due to costs incurred as a result of mailing a notice of by-law change to the voting membership.

(Acceptance of the Secretary's report was moved by K. Fraser, seconded by D. Stredulinsky, carried).

Treasurer's Report

The Treasurer discussed the Auditor's report, which indicates the Association has very stable finances with revenues exceeding operating costs. This was due partly to the significant surplus generated by the conferences and that several prizes were not awarded (i.e., no applicants).

The Treasurer has made application for a Visa merchant account for the association. This should make payment of dues and conference registrations much easier.

R. Ramakrishnan proposed a motion, "To keep the membership dues and subscription costs the same as last year, that is FY 99/00." The motion was seconded by D. Giusti. All were in favour and the motion was carried.

The President discussed the Board's interpretation of the "sustaining subscriber," as there has been some confusion as to what the subscription entitled. It was agreed that the purpose of the "sustaining subscriber" was to enable Canadian Acoustics to be distributed to all at a reasonable cost and that the 'subscription' did not entitle the company, or individual, to the rights and privileges of membership.

(Acceptance of the Secretary's report was moved by M. Cheesman, seconded by R. Ramakrishnan, carried).

Membership Chair's Report

No report was given.

Editor's Report

R. Ramakrishnan reported that he has been successful at attracting research papers and technical articles. Currently, there are enough papers and articles for the June 2001 issue. Thus, there is the possibility of increasing the frequency of Canadian Acoustics (CA) from quarterly to six times a year. The Editor requested that acoustics research groups submit an overview for publication in the CA.

(Acceptance of the Editor's report was moved by M. Cheesman, seconded by K. Pichora-Fuller, carried).

Past and Future Conferences

1999 Victoria: S. Dosso, Conference Chair, had previously presented a detailed final report for this very successful conference.

2000 Sherbrooke: N. Atalla, reported that the conference had approximately 154 registrants and that the Organizing Committee expects to have a small surplus. It was requested that extra copies of the Proceedings Issue (September CA) be printed so that all conference registrants could be given a copy. The President thanked Nouraddine Atalla and Alain Berry for their work in organizing the largest conference to date.

2001 Toronto: D. Giusti, reported on the various possibilities for the Toronto conference. After considerable discussion a consensus was reached and the conference will be held on October 1st - 3rd at the Nottawassaga Resort north of Toronto.

2002 Charlottetown: A. Cohen has agreed to organize the conference this year.

Award Coordinator's Report

K. Pichora-Fuller provided a report summarizing the Awards activities this year. The following is a summary by prize:

Edgar and Millicent Shaw Postdoctoral Prize in Acoustics: No applications have been received. S. Abel after several years of serving as the prize coordinator will be stepping down. The Board thanked Sharon for her efforts.

Alexander Graham Bell Graduate Student Prize in Speech Communication and Behavioural Acoustics: One or more applications have been received. D. Jamieson is the prize coordinator.

Fessendon Student Prize in Underwater Acoustics: One or more applications have been received. D. Chapman is the prize coordinator.

Eckel Student Prize in Noise Control: One or more applications have been received. M. Hodgson is the prize coordinator.

CAA Canada-Wide Science Fair Award (Youth Science Foundation): M. Cheesman judged this since the fair was held in London. A. Cohen is the prize coordinator.

Raymond Hetu Memorial Undergraduate Award: Book prize: Approximately $2200 dollars has been donated by the membership to honour the memory of Dr. Hetu. C through the issuance of a $100-$200 book prize. C. Laroche has agreed to act as prize coordinator.

Directors' Awards: For best papers in *Canadian Acoustics (December through September issues)*. K. Pichor-Fuller is the prize coordinator.

(Acceptance of the Award Coordinator's report was moved by R. Ramakrishnan, seconded by M. Cheesman, carried).

By-Law Changes

J. Bradley explained the need to revise the by-laws to make it easier to obtain quorum at Board meetings. In the revised by-laws three members of the Executive, the President, Treasurer, and Executive Secretary, will also be members of the Board and can therefore exercise a vote. Also in the revisions, a provision was made to allow for student memberships at a reduced rate. A revised set of by-laws was sent to all members earlier this year as an attachment to Canadian Acoustics. The proposed revisions as they appeared in the mailing were read to the membership. N. Atalla moved that, "the revised by-laws, as they appear in the special mailing, be approved and adopted and that they be filed with the Crown." The motion was seconded by D. Havelock. All 24 members present were in favour and the motion was carried.
{Secretary's note: In late October, the Crown officially acknowledged and approved our by-law changes. }

Nomination Committee

C. Sherry, a past President of the Association, informed the Membership that the Committee recommends that the Executive (President; J. Bradley, Treasurer; D. Giusti, and Secretary; T. Nightingale), and Board Members (N. Atalla, M. Cheesman, D. DeGagne, K. Fraser, M.K. Fuller, T. Kelsall, D. Stredulinsky, D. Whicker) be reelected for another one-year term. The President asked for nominations from the floor. None were forwarded. A. Berry moved that, "the slate as forwarded by the Nomination Committee be elected." The motion was seconded by D. Stredulinsky. All were in favour and the slate was elected by acclamation.

Other Business

The President asked if there was any business from the floor. None was forwarded.

Adjournment

R. Ramakrishnan moved to adjourn the meeting, seconded by D. Giusti, carried. Meeting adjourned at 4:47 p.m.

Special Action Items Arising from the Meeting

J. Bradley
File the revised by-laws with the Crown.

Canadian Acoustical Association
Minutes of the Board of Directors Meeting
27 September 2000

Sherbrooke, Quebec

Present: J. Bradley, T. Nightingale, D. Giusti, N. Atalla, M. Cheesman, K. Fraser, T. Kelsail, Kathy Pichora-Fuller, R. Ramakrishnan, D. Stredulinsky.

Regrets: D. DeGagne, D. Jamieson, J. Hemingway, D. Whicker.

Meeting called to order at 6:30 p.m.

Minutes of the 13 May Board of Directors' meeting were approved as written in the June 2000 issue of Canadian Acoustics. (Moved by R. Ramakrishnan, seconded by K. Fraser, carried).

President's Report

J. Bradley reported that revisions to the by-laws have been completed and will be presented at the AGM (29 September 2000) for a vote. The Operations Manual is continuing to be updated to help identify recurring voting items such as setting membership fees at the AGM, allocating funds for the student travel subsidy, etc.

(Acceptance of the President's report was moved by R. Ramakrishnan, seconded by K. Pichora-Fuller, carried).

Secretary's Report

T. Nightingale was very pleased to report that the membership is reasonably constant when compared to the last three years. The total paid membership (including non-voting journal subscriptions) is 343 as of 20 September 2000. Approximately, the same time one year earlier the number was 346. Two years earlier it was 341.

In response to the request of the Board, the Secretary modified the draft description of the membership category "Member Emeritus" that had been forwarded at the last Board meeting. A "member emeritus" would receive the Journal at a reduced cost, namely that currently enjoyed by Student Members. After considerable discussion the following was presented as a motion by R. Ramakrishnan:

"If the member has been an active and longtime member who has retired from full time employment by reason of age or infirmity then, the member should qualify, at the discretion of the Board, to be an Emeritus Member paying the same fees and enjoying the same rights as a student member. Such a membership will be described as Member Emeritus."

The motion was seconded by T. Kelsall, carried and will be brought before the membership at the AGM for their consideration and vote.

The Secretary reported that it may be some time before the CAA receives the $10,000 donation by the Signal Processing Institute Fund (SPIF) to support the travel of students to conferences that have significant material on signal processing and underwater acoustics. The Board decided to form a Committee in advance of the receipt of the funds to recommend how it should be administered and disbursed. The Committee will be chaired by D. Stredulinsky and will present the Board with a draft at the May 2001 meeting.

The Secretary presented a balance sheet indicating operating costs for secretarial activities in FY 99/00. They were $1480 which is approximately $300 higher than an average year, and is due to the cost incurred as a result of mailing a notice of by-law change to the voting membership. There is approximately $340 in the secretarial account.

N. Atalla moved that the Secretary be issued a cheque for $400 to cover regular maintenance of the databases until the Board next meets in May 2001. The motion seconded by D. Stredulinsky, carried.

(Acceptance of the Secretary's report was moved by R. Ramakrishnan, seconded by D. Stredulinsky, carried).

Treasurer's Report

The Treasurer tabled the report of the Auditor, Paul A. Busch. (A summary table from the report is provided at the end of these minutes). The report indicates that the Association's finances are solid with revenues exceeding operating costs. This was due partly to the significant surplus generated by recent conferences and the fact that several prizes had not been awarded (i.e., no applicants).

The Treasurer has made application for a VISA merchant account for the Association. This should make payment of dues and conference registrations much easier.

The Treasurer prepared a detailed budget for FY 00/01 (identifying all significant expenditures e.g., journal printing, prizes, I-INCE membership, website, secretarial operating costs, etc.). The planned budget which forecasts a small surplus of about $3,300 was approved by the Board subject to the inclusion of some relatively minor expenses such as membership in the ICA and the fees for the VISA account. The Board agreed with the Treasurer's intent to purchase accounting software (Mind Your Own Business ~ $300) to help improve efficiency.

(Acceptance of the Secretary's report was moved by M. Cheesman, seconded by R. Ramakrishnan, carried).

Membership Chair's Report

No formal report was given.

Editor's Report

R. Ramakrishnan reported that he has been successful at attracting research papers and technical articles. Currently, there is a slight backlog so the possibility of increasing the frequency of Canadian Acoustics (CA) from quarterly to six times a year is a possibility. There was considerable discussion regarding the possible affect on finances and advertising revenues. The Treasurer was requested to investigate this and contact Chris Hugh who kindly looks after the advertising in CA. A short report at the next meeting in May was requested.

(Acceptance of the Editor's report was moved by M. Cheesman, seconded by K. Pichora-Fuller, carried).

Past and Future Conferences

1999 Victoria: S. Dosso, Conference Chair, had previously presented a very detailed final report.

2000 Sherbrooke: N. Atalla reported that the conference should have in excess of 150 registrants and that the Organizing Committee expects to have a small surplus. It was requested that extra copies of the Proceedings Issue (September CA) be printed so that all conference registrants could be given a copy. This was considered to be a good idea and it was suggested that between 100 and 150 additional copies could be printed (with an additional cost of about $350).

2001 Toronto: D. Giusti, reported on the various possibilities for the Toronto conference. After considerable discussion a consensus was reached and the conference will be held on October 1st - 3rd at the Nottawassaga Resort north of Toronto.

2002 Charlottetown: A. Cohen has agreed to organize the conference this year.

Award Coordinator's Report

K. Pichora-Fuller provided a report summarizing the Awards activities this year. The following is a summary by prize:

Edgar and Millicent Shaw Postdoctoral Prize in Acoustics: No applications have been received. S. Abel after several years of serving as the prize coordinator will be stepping down. The Board thanked Sharon for her efforts.

Alexander Graham Bell Graduate Student Prize in Speech Communication and Behavioural Acoustics: One or more applications have been received. D. Jamieson is the prize coordinator.

Fessendon Student Prize in Underwater Acoustics: One or more applications have been received. D. Chapman is the prize coordinator.

Eckel Student Prize in Noise Control: One or more applications have been received. M. Hodgson is the prize coordinator.

CAA Canada-Wide Science Fair Award (Youth Science Foundation): M. Cheesman judged this since the fair was held in London. A. Cohen is the prize co-ordinator.

Raymond Hetu Memorial Undergraduate Award: Book prize: Approximately $2200 dollars has been donated by the membership to honour the memory of Dr. Hetu. C through the issuance of a $100-$200 book prize. C. Laroche has agreed to act as prize cordination.

Directors' Awards: For best papers in *Canadian Acoustics (December through September issues)*. K. Pichor-Fuller is the prize co-ordinator.

(Acceptance of the Award Coordinator's report was moved by R. Ramakrishnan, seconded by M. Cheesman, carried).

By-Law Changes

As noted in President's report the by-laws have been revised make it easier to obtain quorum at Board meetings. In the revised by-laws three members of the Executive, the President, Treasurer, and Executive Secretary, will also be members of the Board and can therefore exercise a vote. In the revisions, a provision was made to allow for student memberships at a reduced rate. The revised by-laws will be brought before the membership at the next Annual General Meeting for their consideration and vote.

CAA Website

D. Whicker provided a report that was given by the Secretary. The board has chosen "CAA-ACA.CA" as the preferred domain name, but efforts to get this registered have stalled. T. Nightingale will help with filing the application. Previously, D. Whicker and B. MacKinnon had very kindly offered to design and build the website. The Board thanked Doug and Barry and agreed to recognize their efforts by placing a credit on the website. The Board asked that they begin designing the site and, if it is completed before the domain name is secured than the material could be mounted at our existing site, which is hosted by the University of Western Ontario.

Other Business

There was some discussion regarding the recent formation of the Alberta Acoustical Association and how this will affect the CAA.

Adjournment

K. Pichora-Fuller moved to adjourn the meeting, seconded by M. Cheesman, carried. Meeting adjourned at 9:35 p.m.

Special Action Items Arising from the Meeting

T. Nightingale

Complete and file application for "CAA-ACA.CA" domain name

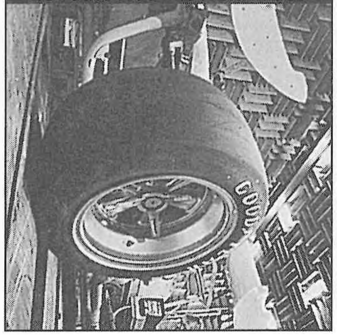
D. Whicker

Find a suitable service provider and, in conjunction with B. MacKinnon, design and build the English version of the CAA website.

D. Giusti

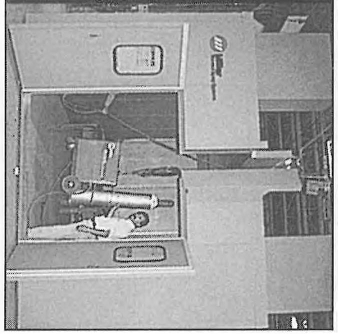
Revise the business plan for FY 00/01 in time for the spring Board meeting.

AUTOMOTIVE TEST CHAMBER

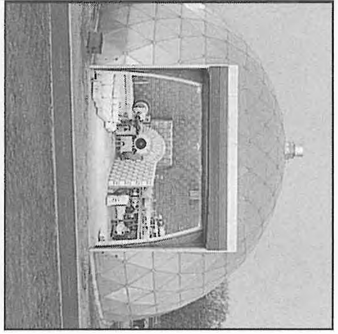


ARCHITECTURAL ACOUSTICS

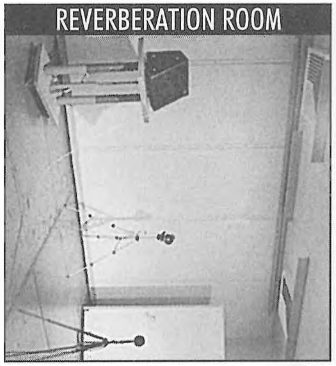
O.E.M. ENCLOSURE



ENGINE TEST FACILITY



REVERBERATION ROOM



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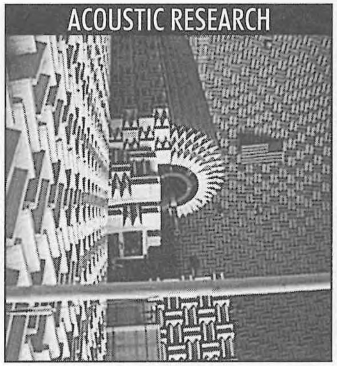

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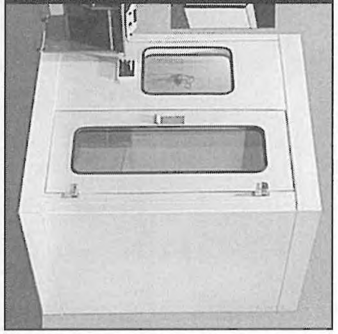
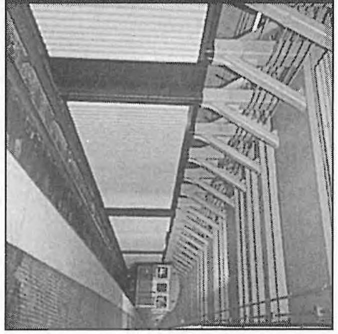


ECKOUSTIC FUNCTIONAL PANELS



The Canadian Acoustical Association
l'Association Canadienne d'Acoustique

MEMBERSHIP DIRECTORY 2000 / ANNUAIRE DES MEMBRES 2000

The number that follows each entry refers to the areas of interest as coded below.

Le nombre juxtaposé à chaque inscription réfère aux champs d'intérêt tels que condifés ci-dessous

Areas of interest		Champs d'intérêt
Architectural acoustics	1	Acoustique architecturale
Engineering Acoustics / noise Control	2	Génie acoustique / Contrôle du bruit
Physical Acoustics / Ultrasonics	3	Acoustique physique / Ultrasons
Musical Acoustics / Electroacoustics	4	Acoustique musicale / Electroacoustique
Psycho- and Physio-acoustics	5	Psycho- et physio-acoustique
Shock and Vibration	6	Chocs et vibrations
Hearing Sciences	7	Audition
Speech Sciences	8	Parole
Underwater Acoustics	9	Acoustique sous-marine
Signal Processing / Numerical Methods	10	Traitement des signaux / Méthodes numériques
Other	11	Autre

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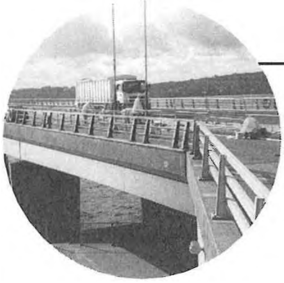
Vibration Insulation

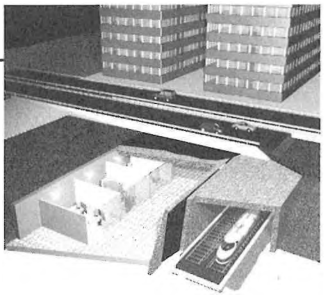
2 ways Regupol Regufoam

1 goal **Optimal vibration absorption and insulation of <u>structure-borne sound</u> using recycled rubber and foam materials.**



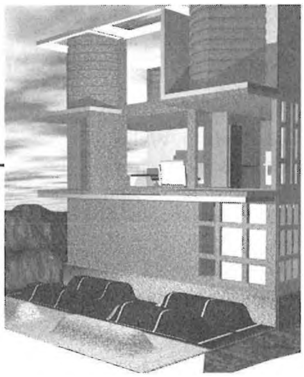
Road Construction

For rail and tunnel construction, as well as for road and bridge construction, Regupol and Regufoam are used for vibration insulation and shockproofing.



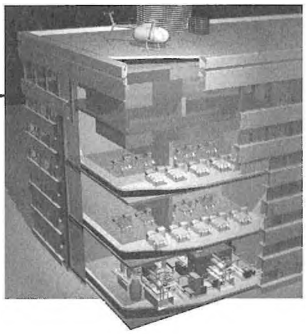
Foundations

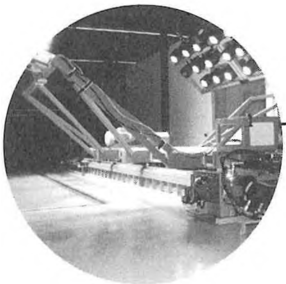
To protect against ground vibration, Regupol and Regufoam insulate large buildings with appropriate load distribution slabs.



High-Rise Building

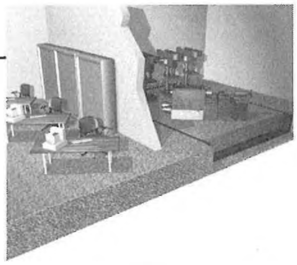
Whether for elevator motors, pumps, ventilation systems or block-type thermal power stations, structure-borne sound insulation and vibration absorption with Regupol and Regufoam are simple and permanent.





Industry

Here Regupol and Regufoam are used for the active insulation of machines and passive insulation of floor slabs for precision measuring instruments, laboratory facilities or measuring chambers. Both subcritical and supercritical bearings are possible.



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Business Development Manager

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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.

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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.

Line Widths: Line widths in techincal drawings, figures and tables should be a minimum of 0.5 pt.

Photographs: Submit original glossy, black and white photograph.

Scans: Should be between 225 dpi and 300 dpi. Scan: Line art as bitmap tiffs; Black and white as grayscale tiffs and colour as CMYK tiffs;

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.

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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.

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