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CANADIAN ACOUSTICS publishes refereed articles and news items on all aspects of acoustics and vibration. Articles reporting new research or applications, as well as review or tutorial papers and shorter technical notes are welcomed, in English or in French. Submissions should be sent directly to the Editor-in-Chief. Complete instructions to authors concerning the required camera-ready copy are presented at the end of this issue.

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EDITORIAL / ÉDITORIAL

L'hiver 2008, que l'on peut qualifier de mémorable, est maintenant derrière nous. L'été est à nos portes et le mois de juin signifie pour vous, chers lecteurs de l'Acoustique Canadienne, un éditorial signé par votre rédactrice-adjointe, comme la tradition le veut.

Le numéro de juin se veut une édition à saveur un peu plus francophone. À ce titre, des collègues de Montréal partagent avec nous les résultats d'une étude pilote sur la mesure de l'atténuation terrain des protecteurs auditifs. Cette étude s'inscrit dans une tendance internationale qui vise à mieux comprendre à quel point les travailleurs exposés au bruit sont réellement protégés. Une revue du livre « Nuisances sonores. Prévention, protection, réglementation », signée par Jérémie Voix, un des directeurs de l'association, complète cet apport francophone.

John Bradley nous invite, à travers une autre revue de livre, à lire l'autobiographie de Leo Beranek, un des pionniers de l'acoustique. Trois articles couvrant divers champs de l'acoustique complètent notre numéro de juin. Le premier article nous vient de collègues de DRDC-Atlantique et porte sur le développement d'une technologie permettant la surveillance sous-marine des côtes ou menant à diverses applications en communication acoustique. Le deuxième article en provenance d'Ottawa nous informe sur le choix de critères quantitatifs qui permettraient de mieux rendre compte des effets indésirables du bruit sur la santé des individus, particulièrement dans le contexte de la Loi canadienne sur l'évaluation environnementale. Enfin, nos collègues de Toronto et Mississauga nous font découvrir une application de la transformée de Wavelet pour l'inspection des pipelines.

Le numéro de juin présente un contenu diversifié qui devrait satisfaire la majorité d'entre vous. Nous vous souhaitons bonne lecture! Comme à chaque année, je réitère l'invitation à mes collègues francophones : soumettez-nous les résultats de vos projets. Nous nous ferons un plaisir de les publier.

Bon été!

Chantal Laroche
Rédactrice adjointe

Winter 2008, which can be described as quite memorable to say the very least, is now behind us. Summer is now upon us and with June traditionally comes, dear readers of Canadian Acoustics, an editorial by your associate editor.

Again keeping with tradition, the June issue has a bit of a French twist. Accordingly, colleagues from Montreal share with us results from a pilot study on measures of field attenuation provided by hearing protectors. This study follows an international trend seeking a better understanding of how well noise-exposed workers are really protected. A review of the book "Nuisances sonores. Prévention, protection, réglementation" by Jérémie Voix, one of the association's directors, tops off the French contributions.

John Bradley invites us, through another book review, to read the autobiography of Leo Beranek, a pioneer in acoustics. Three articles in various fields of acoustics complete this June issue. The first article, submitted by colleagues from DRDC-Atlantic, describes a technology designed for underwater coastal surveillance and various acoustic communications applications. From Ottawa, the second article informs us on the choice of quantitative criteria allowing to better account for the adverse health effects of noise, particularly in the context of the Canadian Environmental Assessment Act. Last but not least, colleagues from Toronto and Mississauga present an application of wavelet transform for pipeline inspections

Being quite diversified the content of this June issue should satisfy most of our readers. Enjoy your reading! Keeping with tradition, I again invite my French-speaking colleagues to submit articles. It will be our pleasure to publish your results.

Have a great summer!

Chantal Laroche
Associate Editor

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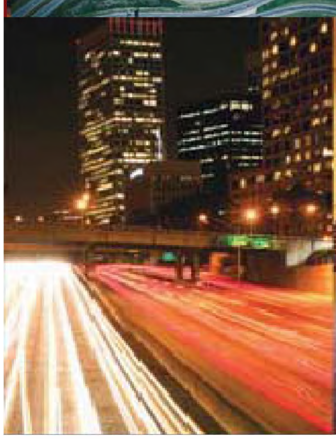

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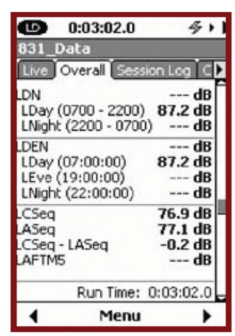

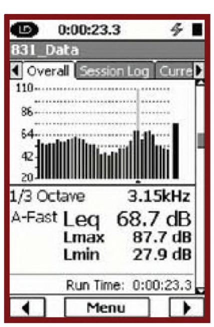

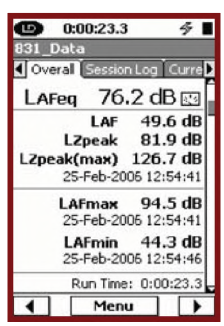

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MÉTHODE DE MESURES TERRAIN DE L'ATTÉNUATION F-MIRE DE PROTECTEURS AUDITIFS DURANT UN QUART DE TRAVAIL

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ABSTRACT

Nowadays, hearing protection devices (HPD) are widely used to protect workers against industrial noise, however, a question worth examining is: "Is the worker truly provided with, at all times, protection that is as effective as what the manufacturer is advertising, based on standardized testing?" It is a commonly known and well documented fact that compared to values obtained from various existing field studies laboratory-measured noise attenuation values overestimate the actual protection being provided to workers. Too few studies are available on this topic, and the issues concerning HPD field measurement are still far from being resolved. Even if several field measurement methods have been developed, none has succeeded in being recognized as a standard. Therefore, the need for a new field measurement method, one which could become a recognized reference, is as relevant as ever.

This paper presents a new field measurement method developed to quantify the in-field attenuation HPDs provide to workers. This method is designed to take ongoing measurements during a complete work shift (8 hours) and enable the measurement of the actual attenuation being provided to the worker in his work environment, for different types and levels of industrial noise. The measurement method is based on the F-MIRE protocol using a miniature double microphone that allows for simultaneous measurement of the sound pressure inside the protector and the sound field surrounding the worker. The time signals recorded are then analyzed in order to determine the overall protection, and also, to assess performance over time. Results from preliminary measurements obtained from factory workers are presented in order to fully illustrate the range of analysis possibilities of this new field measurement method.

SOMMAIRE

L'usage des protecteurs auditifs est répandu comme moyen de protéger les travailleurs en milieu bruyant, mais, une question quant à leur usage mérite d'être posée : « Est-ce que le travailleur bénéficie en tout temps d'une protection aussi efficace que celle annoncée lors des mesures normalisées? ». Il est connu et accepté que la certification des protecteurs auditifs, en comparaison avec les différentes études « terrain » disponibles, surévalue l'atténuation réelle obtenue par les travailleurs. Trop peu d'études traitant de ce sujet sont disponibles et la problématique des mesures « terrain » de l'atténuation, malgré ces données, reste entière à ce jour. Même si plusieurs méthodes de mesures ont été développées, aucune n'a encore réussi à s'imposer pour devenir un standard reconnu et le besoin de développement d'une méthode de mesures « terrain » qui pourrait s'imposer comme référence en la matière est encore bien actuel.

Cet article vise à présenter une nouvelle méthode de mesures « terrain » qui permet de quantifier l'atténuation réelle que procurent les protecteurs auditifs en milieu industriel. Les mesures se font en continu sur un quart de travail (8 heures) et permettent de mesurer l'atténuation en situation réelle de travail, pour différents types de protecteur dans différents types de bruits industriels. Le système utilise la méthode F-MIRE à doublets microphoniques miniatures et permet ainsi la mesure simultanée de la pression sonore à l'intérieur du protecteur ainsi que le champ sonore dans lequel le travailleur se trouve, cela pour les 2 oreilles. Les signaux temporels enregistrés sont ensuite analysés afin de déterminer la protection globale, mais aussi l'évolution de la protection en fonction du temps. Des résultats de mesures préliminaires réalisées en usine sont présentés afin de permettre de bien visualiser toutes les possibilités d'analyse que la nouvelle méthode de mesure offre.

1. INTRODUCTION

Une étude récente a évalué à plus de 9 millions le nombre de travailleurs aux Etats-Unis qui risquent une perte auditive induite par le bruit (Noise-induced hearing loss, NIHL) parce qu'ils sont exposés à un niveau de bruit équivalent pour 8 heures par jour (Time weighted average, TWA), de 85 dB(A) et plus [1]. Au Québec seulement, on parlait déjà, il y a 10 ans, de plus de 500 000 travailleurs soumis à ces niveaux de bruit [2]. Ces chiffres nous démontrent l'urgence de développer des solutions de réduction du niveau de bruit qui affecte les travailleurs. Bien que la réduction des bruits à la source soit la solution qui devrait être privilégiée, dans plusieurs situations, seule la protection auditive est envisageable[3]. D'où l'importance d'accorder une attention particulière à la protection auditive individuelle en milieu de travail.

L'usage des protecteurs auditifs est bien répandu, mais est-ce qu'ils protègent efficacement le travailleur en milieu bruyant? En ce qui concerne leur certification, il est connu et cité dans de nombreux articles traitant du sujet[4-9] que les résultats des tests réalisés en laboratoire pour la certification des protecteurs auditifs sont significativement plus élevés que les valeurs obtenues lors de mesures réalisées dans le cadre d'études dites « terrain », études réalisées directement dans l'environnement du travailleur. La surévaluation lors de la certification nous empêche de connaître la protection réelle obtenue par le travailleur et rend douteux, voir même dangereux, de se fier à l'indice de réduction de bruit (NRR, noise reduction ratio) affiché sur les emballages des protecteurs lorsque vient le temps d'en faire le choix.

La différence entre les mesures de certification et les mesures « terrain » est expliquée en partie par « la méthodologie utilisée qui vise la performance optimale des protecteurs, ce qui ne représente pas la réalité terrain » [4], mais aussi par la difficulté de prendre des mesures « terrain » qui soient représentatives. Bien qu'explorée dans plusieurs études [10-14], la problématique des mesures « terrain » de l'atténuation reste entière et les données disponibles sur le sujet sont bien insuffisantes pour nous permettre de comprendre l'ensemble du problème. La question mainte fois posée reste donc actuelle : « Est-ce que le travailleur bénéficie en tout temps d'une protection aussi efficace que celle annoncée lors des mesures normalisées? ».

Parmi les méthodes développées pour mesurer l'atténuation en milieu industriel, aucune n'a encore réussi à s'imposer pour devenir un standard reconnu. Dans un article précédent, les chercheurs de l'équipe ont présenté une revue de l'ensemble des méthodes de mesures « terrain »[15] et de cet article se dégage certains critères importants qu'une méthode novatrice de mesure terrain devrait posséder afin de pouvoir s'imposer comme standard reconnu :

- méthode basée sur des mesures objectives
- méthode qui limite le temps de production perdu
- mesure directement dans l'environnement de travail
- méthode qui ne modifie pas les habitudes de travail

Inspiré par les récents développements dans les méthodes objectives (F-MIRE) ainsi que par la miniaturisation des équipements d'enregistrement, l'idée du développement d'une nouvelle méthode de mesure terrain, telle que prédite par Lancaster dans sa revue des techniques utilisant la méthode MIRE (Microphone in Real-Ear) [16], a pris forme. La méthode devrait permettre à la fois des mesures objectives, qui ne causeraient aucune perte de production et qui permettraient de mesurer le sujet dans son environnement réel sans modifier ses habitudes de travail. De plus, la méthode possède l'avantage de travailler à partir de fichiers audio. Cela rend possible, en post traitement, de « retourner dans le temps » afin d'écouter ce qui s'est passé lors d'un événement particulier et ainsi être en mesure d'associer, par exemple, une chute rapide de l'atténuation à un problème de communication avec un collègue qui aurait forcé le sujet à enlever ses protecteurs momentanément.

L'atténuation intrinsèque d'un protecteur est un phénomène acoustique mesurable, liée aux matériaux utilisés ainsi qu'à sa géométrie. Par contre, outre les propriétés physiques du protecteur, l'atténuation « réelle » variera en fonction de causes liées à l'utilisation. Tandis que tous reconnaissent que ces causes ont une influence significative sur la performance réelle des protecteurs, très peu d'études ont regardé en détail la protection effective en fonction du temps, cela en situation réelle de travail.

La méthode développée, en plus de répondre aux quatre critères importants cités précédemment, permettra d'apporter un éclairage sur les causes, liée à l'utilisation même des protecteurs, qui créent une variation de l'atténuation, constituante importante de la problématique des mesures « terrain ». Voici une liste non exhaustive de causes de variation de l'atténuation liées à l'utilisation des protecteurs :

- le manque de formation (training);

  Il a été prouvé qu'un employé formé (trained) au bon positionnement de ses protecteurs augmente de façon significative sa protection contre le bruit[12, 17].

- le port intermittent des protecteurs;

  L'efficacité des protecteurs est rapidement compromise par le port intermittent ou irrégulier[18].

- le manque de confort physiologique;

  Il est bien documenté que les protecteurs sont souvent inconfortables (serrent trop la tête, provoquent une douleur aux oreilles, etc.). Le confort est très difficile à étudier étant intrinsèquement un critère subjectif [19].

- le manque de confort perceptuel;

  Les protecteurs peuvent créer un inconfort perceptuel soit en étant une entrave à la communication par une trop forte atténuation, soit par l'effet d'occlusion ressenti par le port de protecteurs.

- les paramètres physiques du sujet et ce qu'il porte;

  Plusieurs études ont évalué l'impact négatif que des paramètres physiques tels que le port de la barbe, les cheveux longs ou simplement le port de lunettes de sécurité ou d'un casque de protection peuvent avoir.

La méthode de mesures développée devrait permettre d'étudier plusieurs de ces causes et de les mettre en perspective avec les variations de l'atténuation en fonction du temps.

Pour répondre à toutes ces attentes, la voie qui a été choisie est celle de l'enregistrement en continu, sur la durée complète d'un quart de travail (8 heures), et en simultanée, de la pression sonore à l'intérieur du protecteur ainsi qu'à l'extérieur (champ sonore dans lequel le travailleur se trouve), cela pour les 2 oreilles. Les signaux temporels enregistrés sont ensuite analysés afin de déterminer la protection globale, mais aussi de donner des informations sur l'évolution de la protection en fonction du temps, liée à l'utilisation.

L'article porte principalement sur la description de cette nouvelle méthode de mesure objective qui possède tous les critères importants afin de devenir une référence en matière de mesure « terrain » de l'atténuation. Il présente ensuite les résultats de mesures préliminaires réalisées en usine afin de permettre de bien visualiser toutes les possibilités d'analyse que la nouvelle méthode de mesure offre.

2. ÉQUIPEMENTS ET PROCÉDURES DE MESURES

Un système de mesures est constitué d'un système d'enregistrement (acquisition des données) et de deux microphones. Le système de mesures permettant de mesurer une seule oreille à la fois, deux systèmes complets sont nécessaires pour instrumenter chaque travailleur étudié, oreille gauche et oreille droite.

Pour faire l'acquisition des données, il faut un système d'enregistrement léger, confortable à porter et robuste afin de pouvoir obtenir des mesures valides, peu importe l'environnement dans lequel le travailleur évolue. Le choix d'un système d'enregistrement qui permet l'acquisition des signaux sonores (en fonction du temps) nous contraint à gérer des fichiers de données énormes, mais, en comparaison avec un système d'acquisition qui ne mesure que les niveaux de pression en fonction du temps, permet beaucoup plus de flexibilité lors de l'analyse des signaux. Il est donc aussi simple d'obtenir les spectres en tiers d'octave, en bandes fines ou autre, que d'évaluer la présence de paroles, les problèmes de communication, la présence de bruits non corrélés, etc.

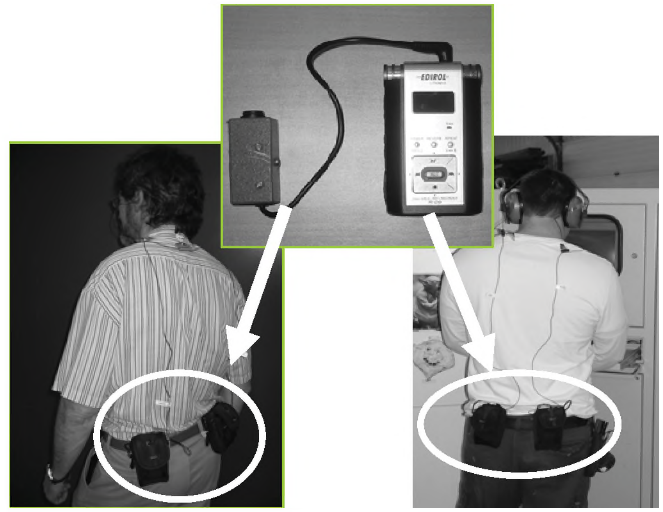

Figure 1 - Système d'enregistrement pour bouchons et coquilles, oreilles gauche et droite

Après plusieurs essais sur différents systèmes d'enregistrement, le système Edirol R-09[20] (24 bits / 44.1kHz) a été choisi. Il permet l'enregistrement, sur des cartes de 4 giga-octets, de fichiers sous le format « *wav* », format qui archive les données sans mode de compression. Avec un poids de moins de 100 grammes, il est suffisamment léger pour ne pas nuire aux travaux du sujet lors des tests.

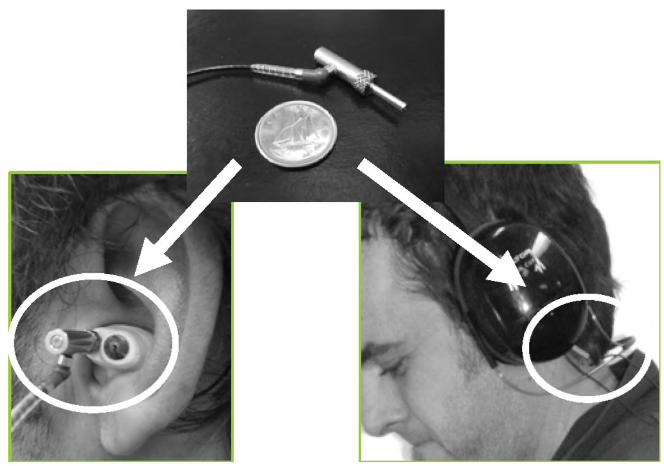

Figure 2 - Doublet microphonique miniature utilisant la technique F-MIRE, inséré dans bouchons et coquilles

Le système de mesures nécessite 2 microphones pour mesurer les pressions sous le protecteur ainsi qu'à l'extérieur du protecteur. Le doublet microphonique développé pour la méthode F-MIRE[21] a été choisi.

La méthode conventionnelle de mesure de l'atténuation étant basée sur la mesure subjective des sujets à leur seuil d'audition (REAT – Real ear attenuation at threshold), il est tentant de chercher à obtenir, lorsqu'on mesure l'atténuation, un résultat qui se compare à ce standard reconnu. Par contre, bien que la méthode F-MIRE permette d'approximer le REAT[21], la nouvelle méthode de mesures terrain n'a pas cette visée pour le moment et seule la différence entre les pressions microphoniques sera considéré pour représenter l'atténuation. Il est important ici de spécifier que la valeur de l'atténuation mesurée par la différence des niveaux microphoniques ne donne qu'une valeur relative mais constitue, pour l'instant, un bon outil de comparaison.

Pour l'étude, il sera possible de mesurer 2 types de protecteurs : des coquilles anti-bruits (peu importe le modèle) et des bouchons moulés. Pour les coquilles, une modification mineure permet d'ajouter un canal de mesure vers l'intérieur de la cavité. Le modèle de bouchon choisi est déjà équipé d'un canal de mesure (sound bore) [22], donc aucune modification n'est nécessaire lors des tests. D'ailleurs, les facteurs de correction et de compensation permettant de comparer la valeur d'atténuation mesurée au REAT sont connus pour les bouchons moulés, mais ce travail reste à faire pour les coquilles.

Les 2 systèmes d'enregistrement sont attachés à la ceinture du sujet dans des pochettes contenant aussi le préamplificateur des microphones. Le fil de chacun des doublets microphoniques est maintenu en place avec une petite pince placée sur l'épaule du sujet. Avant de se rendre en usine pour des mesures, plusieurs tests ont été réalisés en laboratoire afin de valider la précision, le confort et la stabilité du système pour une période de port prolongée.

3. MESURES PRÉLIMINAIRES

Sur la base d'études sérieuses en laboratoire ainsi que de plusieurs enregistrements lors de visites d'industries[23] où le sujet était un des chercheurs de l'étude, des mesures sur des travailleurs en usine ont été tenues. Les mesures ont été réalisées en utilisant des coquilles anti-bruits, modèle Mustang de North Safety Products[24], qui ont été modifiées pour s'adapter à notre système de mesures. Il s'agit du modèle de protecteurs utilisé par les travailleurs de l'usine visitée, mais neufs.

- **Lieu des tests :**

L'essai sur des travailleurs a été réalisé dans une petite manufacture de meuble avec environ 10 employés de production au moment des tests et où les niveaux de bruit ambiant sont relativement faibles en moyenne (entre 75 et 85 dB(A)) par contre, avec des pointes autour de 95 dB(A). Les sources de bruit de l'usine sont des scies à ruban, des scies à onglet, une fraiseuse à commande numérique, des sableuses ainsi que des enceintes acoustiques diffusant une station de radio locale.

- **Sujets de test et déroulement :**

Deux sujets (sujets A et B) ont été instrumentés avec deux systèmes d'enregistrement chacun (binaural). Les sujets étaient, tour à tour, opérateurs de scie à onglet et de fraiseuse à commande numérique. Les mesures ont été réalisées en avant-midi entre 7h30am et 11h00am, incluant une pause de 15 minutes vers les 9h30.

À la fin des mesures, un questionnaire simple a été remis aux sujets afin de valider si le système est confortable, voir s'il a modifié leur façon de travailler et si, par exemple, les tâches réalisées durant l'enregistrement ressemblent à une journée type de travail.

Une fois les signaux temporels téléchargés des cartes mémoire, il est possible de faire un post traitement en utilisant des routines développées pour l'étude dans l'environnement MATLAB.

4. ANALYSE DES RÉSULTATS

La quantité d'informations archivée pour ces tests permet d'étudier la protection sous plusieurs angles et il reste encore à découvrir toutes les possibilités de post traitement que le système offre. A ce jour, les données ont été analysées en bandes de tiers d'octave entre 100Hz à 8000 Hz avec un pas d'analyse de 5 secondes ce qui permet de considérer autant le domaine fréquentiel que le domaine temporel. Les niveaux de pression mesurés sont donnés en décibel et l'échelle du temps en seconde. L'analyse permet d'extraire les niveaux de pression mesurés à l'intérieur des protecteurs et ceux mesurés par les microphones extérieurs.

- **Usage de la fonction de transfert (TF) pour le calcul de l'atténuation**

Pour déterminer l'atténuation, une simple soustraction des deux niveaux est possible. Par contre, lors de l'expérimentation en laboratoire, il a été déterminé que, conformément à ce qui est fait dans la méthode F-MIRE, l'usage de la fonction de transfert entre les signaux des 2 microphones était plus pertinent puisqu'en corrélant le signal mesuré par le microphone intérieur aux bruits environnants, les bruits « internes » produits par le sujet sont largement éliminés du résultat. Les données présentées dans le texte utilisent la fonction de transfert lorsqu'il est question de l'atténuation mesurée.

- **Analyse temps-fréquence**

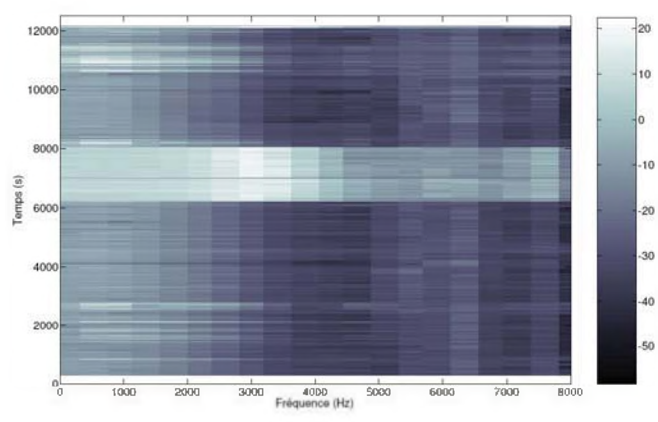

Figure 3 - Atténuation (dB par bandes tiers d'octave) mesurée par la fonction de transfert entre le micro extérieur et le micro intérieur pour l'oreille droite du sujet A.

Une méthode pour présenter les résultats de façon synthétique est d'utiliser une représentation temps-fréquence. La Figure 3 présente, sous forme de spectrogramme, l'atténuation (TF) pour l'oreille droite du sujet A. On y voit clairement qu'entre 6100 et 7900 secondes (environ 30 minutes), le sujet avait enlevé ses protecteurs auditifs (la protection étant, pour cette période, presque nulle). La pause a été tenue entre 6100 et 7100 secondes, mais en écoutant la bande audio, on peut retracer que le sujet était en conversation (coquilles enlevées pour limiter l'entrave à la communication) durant les 15 minutes qui ont suivi cette pause. La ligne plus foncée au milieu de la zone horizontale plus pâle est expliquée par le fait que le sujet a repositionné ses coquilles après la pause pour ensuite les enlever quelques secondes plus tard afin de continuer une discussion.

- **Analyse temporelle par bande de fréquence**

Une autre façon de traiter l'information est de présenter sur une même figure, le niveau de pression extérieur, le niveau de pression intérieur ainsi que l'atténuation par la fonction de transfert. Par exemple, la **Figure 4** présente les données du sujet A, oreille droite en fonction du temps pour la bande tiers d'octave centrée à 1000 Hz.

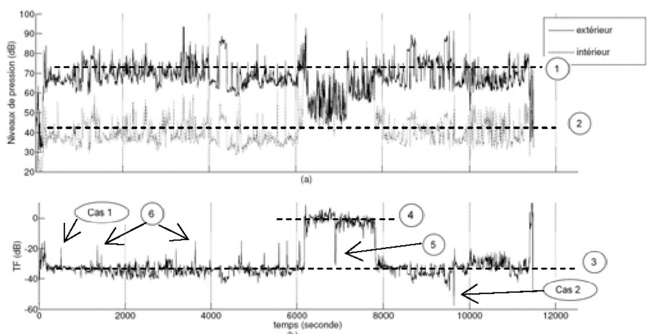

Figure 4 - Niveau de pression des micros extérieur et intérieur (a) et atténuation mesurée par la fonction de transfert (b) pour le sujet A, oreille droite, à la bande de fréquence de 1000 Hz.

De la Figure 4, on tire des informations pertinentes pour l'analyse à cette bande de fréquence :

1. Les niveaux de bruits sont d'environ 75 dB;
2. Les niveaux protégés sont faibles (entre 40 et 60 dB);
3. La protection mesurée est bonne et assez constante durant l'avant-midi (environ 30 dB);
4. Le sujet A a enlevé ses protecteurs durant sa pause. En enlevant ses protecteurs, il soumet les 2 microphones aux mêmes niveaux de pression. Son niveau de protection est alors nul;
5. Après la pause, il a remis ses coquilles pendant quelques secondes avant des les enlever à nouveaux;
6. Il apparait des événements qui semblent « anormaux » avec des pointes où l'atténuation chute ou augmente considérablement (voir analyse à la section suivante).

- **Analyse des événements « anormaux »**

Les événements « anormaux » méritent d'être regardés de plus prêt et c'est grâce aux bandes audio qu'il est possible de le faire. Deux événements sont étudiés avec plus de détails : Cas 1 à la seconde 505, l'atténuation chute de plus de 10 dB. Cas 2 à la seconde 9635, l'atténuation augmente de près de 20 dB.

Cas 1 – perte de l'atténuation

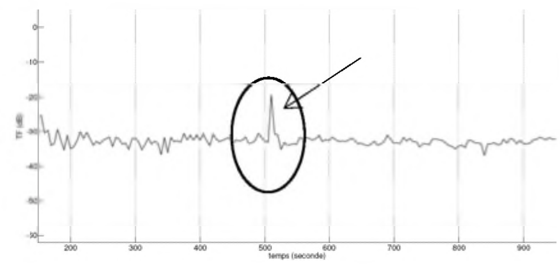

Figure 5 - Agrandissement autour de la seconde 505, atténuation mesurée par la fonction de transfert (TF) de l'oreille droite du sujet A à 1000 Hz.

Le cas 1 (**Figure 5**) présente une perte d'atténuation d'environ 10 dB survenue autour de la seconde 505. A l'écoute, on entend le sujet éternuer. Les niveaux de bruits internes générés lors d'un éternuement sont normalement supérieurs à ceux transmis au microphone extérieur et comme les 2 signaux sont corrélés (ils viennent du même événement), l'effet produit par l'éternuement apparait dans la fonction de transfert (TF). D'autres événements du genre se sont produits durant la matinée, en réécoutant, on entend alors le sujet parler, siffler ou tousser.

Cas 2 – Augmentation de l'atténuation

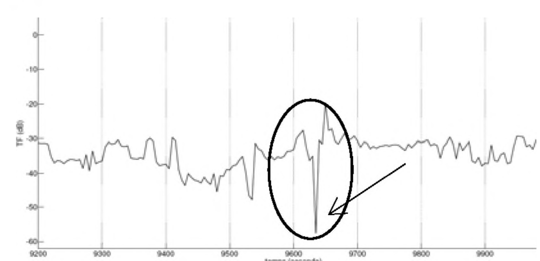

Figure 6 - Agrandissement autour de la seconde 9635, atténuation mesurée par la fonction de transfert (TF) de l'oreille droite du sujet A à 1000 Hz.

Le cas 2 (**Figure 6**) présente une augmentation de près de 20 dB de l'atténuation à la seconde 9635. Le sujet utilisait, à ce moment, une soufflette à air comprimé, le jet a touché le microphone extérieur et créé une turbulence locale que le microphone a traduit en signal acoustique. Nécessairement, le signal de turbulence n'a pas été mesuré par le microphone interne, ce qui a fait monter l'atténuation d'un seul coup.

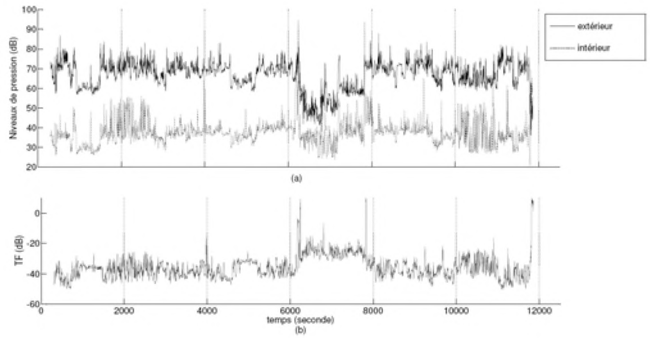

Figure 7 - Niveau de pression des micros extérieur et intérieur (a) et atténuation mesurée par la fonction de transfert (b) pour le sujet B, oreille gauche, à la bande de fréquence de 1000 Hz.

Le même type d'analyse (temporelle) a été effectué avec le sujet B et des résultats semblables ont été mesurés (voir **Figure** 7). De la même façon, certains événements anormaux sont observés. À l'écoute, on établit qu'il s'agit des mêmes causes que pour le sujet A.

o Analyse de la pause café – cas spécial du repositionnement des coquilles

En comparant la Figure 4 et la Figure 7 pour la période entre 6100 et 7900 secondes, période de la pause du matin, on remarque que la protection du sujet B (dans la bande de fréquence de 1000 Hz) reste autour de 20 dB, même durant la pause alors que la protection du sujet A est presque nulle. La photographie suivante (Figure 8), prise lors de la pause, permet d'expliquer cette différence. Le sujet A a enlevé ses coquilles et les a posées autour de son cou alors que le sujet B les a repositionnées sur sa tête (au dessus de ses oreilles) donnant ainsi l'impression, en regardant les données, que le travailleur est encore protégé.

Figure 8 - Positionnement des coquilles durant la pause (le sujet A porte ses coquilles autour du cou et le sujet B, les portent au dessus de ses oreilles)

Il s'agit là d'une faiblesse du protocole de mesures dont il faudrait tenir compte lors d'une campagne de mesure à plus grande échelle. Il faudrait alors indiquer clairement aux sujets d'étude d'éviter ce comportement.

o Temps de non-port et confort des protecteurs

Une des forces du système de mesure, bien que non essentielle pour le calcul de l'atténuation globale, est de pouvoir déceler lorsque le sujet enlève ses protecteurs. Un protecteur, tout aussi efficace qu'il soit, s'il n'est pas porté, ne procure aucune protection au travailleur et lorsque porté, son efficacité décroit rapidement si le port est intermittent ou irrégulier. Comme exemple, un travailleur portant un protecteur procurant réellement une atténuation de 25 dB voit sa protection diminuer à environ 17 dB si, durant son quart de travail de 8 heures, il ne porte pas ses protecteurs durant 30 minutes[18].

Outre le calcul du temps de non-port, il est intéressant, et maintenant possible, d'étudier chacun des événements individuellement. Comme le système de mesure permet, grâce à la bande audio, de réécouter les événements, il est possible de déterminer pourquoi le travailleur a retiré ses protecteurs à telle ou telle occasion.

À l'analyse des mesures préliminaires, l'équipe a été surprise de constater que les 2 sujets évalués n'ont pas enlevé leurs protecteurs une seule fois en zone bruyante, hormis quelques très courtes périodes de quelques secondes afin de repositionner leurs coquilles. Un taux de port aussi élevé ne concorde d'ailleurs pas avec la littérature sur le sujet[10, 25], mais comme les sujets évalués sont les responsables de l'implantation du programme de protection de l'ouïe dans leur usine, on peut supposé qu'étant bien conscientisés à l'importance de la protection auditive, ils agissent de cette façon en temps normal et qu'il n'ont pas modifié leur comportement pour le temps des mesures. Il a tout de même été possible de déceler que la raison du repositionnement des coquilles à plusieurs reprises était reliée au manque de confort des protecteurs.

Pour les tests, des coquilles anti-bruits de même modèle que celles utilisées par les sujets, mais neuve, ont été adaptées avec le conduit de mesure permettant d'insérer le microphone à l'intérieur du protecteur, alors que les protecteurs normalement utilisés par les 2 sujets étaient vieux et usés. Sur des coquilles, lorsque l'arceau de serrage ainsi que le coussin d'appui sont usés, il est connu que l'atténuation des coquilles est grandement affectée[26], par contre, le confort en est souvent amélioré. Afin de prendre en compte la réalité de l'usure des protecteurs, si d'autres tests étaient réalisés avec cette méthode de mesure, il serait important de réaliser les tests directement avec le protecteur du travailleur. S'il s'agit de coquilles, la modification nécessaire pour l'installation du conduit de mesure pourrait se faire entre 2 quarts de travail. À la fin des mesures, des coquilles neuves du même modèle pourraient être données aux sujets afin de remplacer celles qui auront été modifiées.

o Questionnaire de validation

A la fin des travaux, lors de la journée de test, un questionnaire a été remis et rempli par les 2 sujets dans le but de vérifier directement avec eux, leur appréciation du système de mesures mais aussi afin de vérifier si les mesures s'étaient déroulées comme une journée normale de travail.

Aux questions portant sur les habitudes de travail, les sujets étaient unanimes pour dire que le système n'a pas modifié leur façon de travailler, qu'il est très confortable à porter et qu'ils répéteraient volontiers l'expérience. Il s'agit là d'éléments très importants afin de s'assurer d'obtenir des résultats significatifs lors des enregistrements. Le seul commentaire négatif était en relation avec l'utilisation des protecteurs neufs qui serraient plus qu'à l'habitude sur leurs oreilles.

- **Variabilité des mesures**

Les mesures préliminaires obtenues grâce au système présentent une grande variabilité, les niveaux de protections pouvant varier de près de 10 dB. Ce détail a obligé les chercheurs de l'étude à se pencher sur un phénomène qui n'avait pas été pris en compte lors de la mise en œuvre de l'étude : la variation de l'atténuation en fonction de l'angle d'incidence du bruit[27]. En effet, il a été trouvé que pour un champ sonore directif constant, l'atténuation procurée par un protecteur (bouchon ou coquille) peut varier en fonction de l'angle d'incidence de cette source de bruit sur le protecteur, pour certaines bandes de fréquence.

Lors d'autres tests dans une usine où le champ sonore était beaucoup plus élevé (plus de 100 dB(A)) mais aussi plus diffus, il a été trouvé que les niveaux d'atténuation variaient moins que dans une usine où le champ sonore est dominé par des sources localisées à certains endroits précis, produisant ainsi un champ sonore plus directif[23].

Pour mieux comprendre le phénomène de directivité, d'autres tests devront être fait et les résultats des ces tests devraient permettre de tenir compte de l'influence de la directivité sur l'atténuation mesurée afin d'améliorer la méthode de mesures développée.

5. CONCLUSION ET PERSPECTIVES

Le défi était de concevoir une méthode de mesures qui serait objective, qui limiterait le temps de production perdu et qui permettrait les mesures directement dans l'environnement de travail du sujet, sans en modifier ses habitudes de travail. Bien que la méthode soit encore à ses premiers pas, les résultats obtenus sont encourageants.

Les travaux de calibration du système ainsi que les essais préliminaires en industrie auront permis de prendre conscience et de régler certaines faiblesses de la méthode (ex : l'influence du positionnement des coquilles sur les tempes, l'instrumentation des coquilles usagées au lieu des neuves). Bien qu'une variabilité de la protection soit mesurée à l'aide du système, l'analyse, en parallèle avec l'écoute des bandes audio a permis de valider les résultats.

Un aspect intéressant de la méthode de mesures, outre sa capacité de fournir des réponses sur la question de l'atténuation en milieu industriel, est sa capacité de permettre d'observer et de mieux comprendre les causes qui font varier l'atténuation dues à l'utilisation. Et bien que le système ne fasse que commencer à révéler toutes ses capacités d'analyse sur cet aspect, il nous a été possible, pour le cas de cet étude, de faire un lien avec les quelques repositionnements de leurs protecteurs et le manque de confort des protecteurs neufs utilisés pour l'étude.

Les techniques de mesures objectives ayant évoluées au cours des dernières années, particulièrement avec le développement du protocole F-MIRE, en y additionnant la miniaturisation des systèmes d'enregistrement, il est maintenant possible de mesurer l'atténuation réelle que procurent les protecteurs d'un travailleur, de façon continue et cela dans son environnement de travail, sans modifier sa façon de travailler.

La nouvelle méthode de mesures terrain développée par l'ÉTS en partenariat avec l'IRSST devrait permettre, dans un futur rapproché, de fournir un nouvel éclairage sur la protection réelle des travailleurs et sur les habitudes de port des protecteurs. A terme, la méthode devrait faciliter le choix de protecteurs personnalisés au besoin du travailleur, voir même, devenir un outil de conception pour le développement de protecteurs plus performants et plus confortables.

Il reste encore à développer un protocole plus poussé d'analyse des mesures qui permettra de mettre en évidence l'effet de multiples facteurs comportementaux, physiques et environnementaux.

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USING A CHANGE IN PERCENT HIGHLY ANNOYED WITH NOISE AS A POTENTIAL HEALTH EFFECT MEASURE FOR PROJECTS UNDER THE *CANADIAN ENVIRONMENTAL ASSESSMENT ACT*

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ABSTRACT

Health Canada is in the process of developing a document, *Guidance for Environmental Assessment: Health Impacts of Noise (Guidance)* on how to assess noise impacts in environmental assessments. The guidance document is needed to assist Health Canada in providing consistent expert advice on the health effects of project noise, when requested under the *Canadian Environmental Assessment Act* (CEAA). Differences exist between various noise mitigation criteria used in environmental assessments from across Canada. Therefore, the first step for Health Canada to provide consistent advice is to establish quantitative criteria for adverse health effects as a function of project-related long-term changes in noise. The criteria should be based on scientific research that has demonstrated a reasonable cause-effect association between an adverse impact on public health and well-being and community noise exposure. This paper shows that: (i) there is a substantial amount of community-based social and socio-acoustic research and (ii) precedent from U.S., European and International standard and policy setting bodies, to justify the use of a change in percentage highly annoyed with noise (%HA_n) as one of the health endpoints for an environmental assessment. Furthermore, viewing high noise annoyance as an adverse health effect is consistent with Health Canada's definition of "health". This paper also shows that %HA_n is preferable as a long term endpoint than the use of noise complaints. To add to this, there have been recent nation-wide Canadian social surveys on high noise annoyance that further support its use as an adverse health effect to be considered in Canadian environmental assessments.

SOMMAIRE

Santé Canada est à développer un document, dont la première ébauche s'intitule *Guidance for Environmental Assessment : Health Impacts of Noise (Guidance)*, expliquant comment mesurer les effets du bruit dans le cadre des évaluations environnementales. Ce document est nécessaire à Santé Canada pour l'aider à donner des conseils éclairés cohérents relativement aux effets sur la santé du bruit engendré par différents projets, lorsque des questions lui sont posées à ce sujet en vertu de la *Loi canadienne sur l'évaluation environnementale*. Les critères de mitigation sur le bruit utilisés dans les évaluations environnementales diffèrent à l'échelle du pays. Par conséquent, pour fournir des conseils judicieux, Santé Canada doit d'abord définir des critères quantitatifs sur les effets indésirables sur la santé en fonction des changements à long terme de l'exposition au bruit engendré par des projets de construction. Les critères doivent être fondés sur des recherches scientifiques qui démontrent un lien de cause à effet entre, d'une part, un effet indésirable sur la santé publique et le bien-être, et de l'autre, une exposition de la communauté au bruit. Cet article indique i) qu'un grand nombre d'enquêtes sociales et socio-acoustiques sont réalisées dans les communautés et ii) que des autorités chargées de l'établissement des politiques et des normes américaines, européennes et internationales ont établi des précédents qui justifient le recours au changement du pourcentage de personnes très incommodées par le bruit (%HA_n) comme l'un des paramètres ultimes de santé dans le cadre d'une évaluation environnementale. De plus, le fait de considérer la nuisance par le bruit comme un effet indésirable sur la santé concorde avec la définition de la « santé » établie par Santé Canada. Cet article montre que le pourcentage de personnes très incommodées par le bruit (%HA_n) est un paramètre ultime à long terme plus pratique que l'utilisation des plaintes relatives au bruit. En outre, les résultats de récentes enquêtes sociales menées à l'échelle nationale sur la question de la nuisance par le bruit tendent à confirmer l'utilisation de ce paramètre comme effet indésirable sur la santé dans le cadre des évaluations environnementales au Canada.

1. INTRODUCTION

The Canadian Environmental Assessment Act (CEAA) [1] requires that certain projects undergo an environmental assessment before receiving federal government approval. The intent of the environmental assessment process is to ensure that actions are taken to promote sustainable development and to ensure that projects are not likely to cause significant adverse environmental effects. Environmental effects may include health effects from project related noise. In the implementation of the CEAA, Responsible Authorities (i.e. the federal authority responsible for a project's environmental assessment) are designated to make the critical decision as to whether the project is likely to cause significant adverse environmental effects. As noise is an issue in many projects, the Responsible Authorities may request specialist information and knowledge from Health Canada or other specialists, as prescribed under CEAA, [2,3] regarding the health effects of noise and the potential need for mitigation.

The nature of project noise varies widely. Transportation and industrial projects reviewed to date at Health Canada for noise effects involve the development of infrastructure. For transportation projects, examples have included: (i) the development, extension or widening of freeways, highways and arterial roadways, (ii) addition of railway lines and rail yards and (iii) building of new runways to major airports. These are generally done to increase capacity for greater road, rail and air transport operations, leading to a long term increase in these types of noises. New rail yards lead to long term increases in highly impulsive noise from shunting. Highly impulsive noise is characterized by ISO 1996-1 as "any source with highly impulsive characteristics and a high degree of intrusiveness" [4]. The examples provided in the ISO standard are small arms fire, hammering on metal or wood, nail guns, drop-hammer, pile driver, drop forging, punch presses, pneumatic hammering, pavement breaking, or metal impacts in rail-yard shunting operations.

Energy industry projects have included: (i)gas pipelines, with the low frequency noise (i.e. less than 100 Hz) from gas compressor stations being a particular concern, (ii)oil (including tar sand) refineries and tar sand mines which contain a mix of continuous, intermittent, highly impulsive and tonal noise (i.e., sound characterized by a single frequency component or narrow-band components that emerge audibly from the total sound [4]) as found in many other industrial facilities and (iii)wind turbine installations. Various other projects have included development of gold mines. One unusual, major environmental assessment involved the expansion of low flying military training flights, with its peculiar potential for short rise time and high sound level aircraft noise events in otherwise quiet rural areas.

Typically, but by no means always, public concerns about a project relate to the long term operational noise and this is often given precedence following general guidance on determination of the significance of an adverse effect for CEAA [2]. Project proponents will usually forecast project-related changes in the acoustical environment from the construction phase up to about 10-20 years after full-scale operations begin. Timescales of less than a year are normally not considered for operations. In our experience, there is no typical change in noise level that would characterize all of these projects; a broad range is found for project noise, from on the order of 30 decibels A-weighted (dBA) above the existing ambient to less than the existing ambient. Some of these changes may occur gradually as would be expected with an increase in road traffic volume as a result of highway widening, or rapidly from the expansion of an airport [5], or the building of a highway extension.

Sometimes construction noise can be very high and be of relatively long duration e.g., 1-2 years continuously or lasting for several months at a time (with winter breaks) over a period of a number of years. In these cases, it too, or alone, can be the focus of concern of residences in the vicinity of the project. Construction of tunnels, bridges and port facilities can involve pile driving, a highly impulsive noise but usually for no more than a few months at a time. Only where there is continuous construction for a significant fraction of a year is the proposed percentage highly annoyed criterion intended for use.

The need for the Guidance stemmed from Health Canada's reviews of a number of environmental assessments across Canada in which there were different mitigation criteria used to protect the public from project-related changes in noise, even if similar changes in noise environments were being assessed. Given these differences, and the large number and variety of environmental assessments on noise, one of the goals of the Guidance is to indicate how to assess noise impacts on health, including the basic information requirements for an environmental assessment. This should help ensure that an environmental assessment can provide a transparent, quantitative determination of the health effects arising in an average community from predicted project-related changes in noise. This enables comparisons with Provincial criteria for project noise, providing the potential for informed cooperation and coordinated action between the federal and provincial governments on the environmental assessments (one of the stated purposes of CEAA), at least with regard to noise issues.

Given that the advice pertains to another authority's (i.e., the Responsible Authority's) decision on the significance of an effect, the advice that Health Canada provides on the health effects of noise is generally based only on well-accepted scientific evidence for a link between noise exposure and health. Therefore, this paper provides a review and analysis of the hypothesis that a change in percentage highly annoyed with noise (%HA_n) can be used as one of the health effect measures in environmental assessments for noise. Only peer review papers as well as available guidance documents, reports and conference papers published in English and judged by the authors to be most influential and pertinent for this review have been included. The analysis examines the evidence for the following supporting arguments for the hypothesis: 1) community noise annoyance is consistent with definitions of a health endpoint, 2) the $\%HA_n$ has the potential to be linked with chronic stress and other health effects, 3) the $\%HA_n$ has support as the principal measure of community reaction to noise, 4) community noise annoyance, as measured by the $\%HA_n$ has a well-established dose-response relationship with day-night sound level (DNL) and day-evening-night (DENL) sound level, the main descriptors for assessing community noise impacts in the U.S.A. and in the European Union Environmental Noise Directive [6], respectively and 5) there is a precedent for a change in $\%HA_n$ to be used as a criterion for environmental assessment of noise.

Limitations to the use of $\%HA_n$ as the only health effect measure will also be discussed. Some limitations result from the fact that other health effects need to be taken into account and are not fully done so by the $\%HA_n$. There are also limitations to the $\%HA_n$ dose-response curve, which will be discussed. As discussed in subsequent sections, $\%HA_n$ dose response relationships have been identified in a number of meta-analyses of social surveys of community noise annoyance towards steady-state acoustical environments. A change in $\%HA_n$ refers to the difference in $\%HA_n$ between the steady-state noise environment with the project and the steady-state noise environment without the project. The change in $\%HA_n$ is not intended to assess the immediate response towards a project's initial change in noise levels, but to those which are projected to occur in the long-term, at which time any potential over-reaction to the initial change, particularly a step change, can be expected to reach a steady state. One might expect that an initial potential over-reaction may subside in the steady state if the community adapts to the change; learns to effectively cope with the change and/or relocates. However, Brown and van Kamp [7] have recently reviewed the literature on how annoyance changes with time and have suggested that an initial over-reaction towards a change in noise levels may occur and not necessarily subside with time. The authors concluded that more research that specifically targets change in annoyance is needed before this can be supported or refuted. The model proposed by Brown and van Kamp could be used in future studies to elucidate how community noise annoyance changes with time.

In a recent position paper on transportation noise and annoyance [8], prepared for the European Commission by an expert working group, source-specific dose response relationships are identified as being applicable to environmental health impact assessment, giving insight to the situation that is expected in the long term. However, the position paper also notes that these annoyance responses are not applicable to a particular individual or group of individuals because the large amount of scatter in the data produces large prediction intervals. The magnitude of the prediction interval for any single community has been analyzed by Schomer [9,10], Green and Fidell [11], Fidell and Schomer [12] and Fidell and Silvati [13]. For example, Fidell and Schomer [12] have quantified the prediction interval for a community at the 95% confidence level to be between 2% and 50% highly annoyed at a DNL sound level of 65 dBA.

With their estimated confidence intervals, as opposed to prediction intervals, the dose response relationships are applicable only as the average response for a large population of adults sampled from a number of communities from several developed nations. This can be interpreted as the response of an average adult population (community) with no response bias [11]. Put in another way, in the application to environmental assessment, where, usually, the only data provided are the sound levels in the presence and absence of the project, the $\%HA_n$ cannot be assumed to be representative of the particular community where the project is occurring, but rather to an average community. This is the only level of assessment that is technically feasible at this time. As discussed later, we have adjusted the relationship between DNL and $\%HA_n$ when an area is assumed to have a greater expectation for and value placed on peace and quiet. The currently unrealistic alternative would be to conduct a socio-acoustic survey for each environmental assessment so that non-acoustic variables could be accounted for in predicting $\%HA_n$. The potential for greater predictive power using community-based subjective adjustments has been proposed by Schomer [9], but not formally tested.

1.1 Defining "health"

Clearly, if one considers the definitions of "health", as put forth by the World Health Organization (WHO) [14], and fully adopted by Canadian federal, provincial and territorial governments [3], a high degree of community annoyance from noise constitutes an adverse health effect. The definitions are: "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" and, "the extent to which an individual or a group is able, on the one hand, to realize aspirations and to satisfy needs, and on the other, to change or cope with the environment".

Treating "high annoyance" towards community noise as a health impact is consistent with the definitions of "health". Although it could be argued that the accepted broad definition of "health" could provide a framework for considering any degree of annoyance to be applied to CEAA, lesser degrees can reasonably be judged to be excluded as CEAA is concerned with the Responsible Authorities' decision as to whether significant adverse health effects are likely to occur. General guidance on significance is provided by the Canadian Environmental Assessment Agency [2], which administers the CEAA. The Agency states: "Minor or inconsequential effects may not be significant. On the other hand, if the effects are major or catastrophic, the adverse environmental effects will be significant."

Clearly, to help the Responsible Authorities with their decision, Health Canada's advice regarding the potential need for noise mitigation could not reasonably use degrees of annoyance at the low to moderately annoyed range of the spectrum. There must also be some reason to consider the change in high annoyance with noise to be a major effect. Other policies or criteria descriptions provide the only reasoning via precedents.

1.2 Noise annoyance and stress

Presumably, the relevance to the CEAA of "high annoyance" would be enhanced if it was also found to be related to (or contribute to) other adverse physiological effects, potentially leading to conditions of disease or infirmity. Some evidence suggests that this may be the case (see discussion in [15,16]). The suggested mechanistic framework is as follows. "Annoyance" is recognized as a psychological state that represents a degree of mental distress towards (in this case) noise [15]. In greater magnitudes, chronic annoyance likely reflects an inability to cope with the noise. Chronic high annoyance with noise has the potential to increase one's allostatic load by constantly requiring that one adapts to the noise. The process of this adaptation is known as allostasis and the wear-and-tear that this on-going adaptation has on the body is known as allostatic load. Processes that lead to allostatic load can include ongoing exposure to multiple stressors (from mundane to major). In susceptible individuals, this could potentially lead to an increase in allostatic load, which may lead to reduced physical and mental health, including cardiovascular disease, sleep disorders, depression and anxiety [17-23].

Some of the quantifiable indices of allostatic load include systolic and diastolic blood pressure, epinephrine, norepinephrine, cortisol levels, waist-hip ratio, ratio of total cholesterol to high density lipoprotein levels [24-26]. It has been shown that lower allostatic load scores correlate with better physical and mental health [27]. The reader interested in a more thorough discussion on the concept of allostasis and allostatic load is referred to excellent reviews by McEwen [24-26].

There is a well-documented wide-scatter in the range of $\%HA_n$ [12,28,29] at any given noise level and the incidence of adverse physiological health effects attributed to noise [30-33], which together makes it exceedingly difficult to demonstrate a strong correlation between the expression of annoyance with noise and the prevalence of illness. Despite this, there are some clues in the literature that indicate high noise annoyance may increase one's risk of illness. First, there is evidence that exposure to rather mundane daily stressors (e.g. family arguments or work deadlines) can worsen one's health and subjective well-being [34]. Jacobs [35] recently showed that having a negative mood when confronted with minor daily stressors was associated with elevated cortisol [35]. Also, long term psychological stress has been shown to increase the risk of developing cardiovascular disease among men and women in the Atherosclerosis Risk in Communities study [23]. Also, the Cardiovascular Occupational Risk Factors Detection in Israel Study (CORDIS), which is both cross-sectional and longitudinal in design, has shown that high noise annoyance scores had a statistically significant additive impact on noise-associated increases in cholesterol levels (an index of allostatic load) [36]. These authors noted that special attention should be given to individuals highly annoyed, in studying the health effects of industrial noise. While the CORDIS study was concerned with industrial noise exposure, this does not minimize the finding that those who were highly annoyed by noise showed higher levels of plasma cholesterol levels. If self-reported long term high annoyance with noise in the industrial and community settings can be considered as a similar reaction, then it is plausible that the effect on allostatic load could be similar in the two settings.

Further support for the use of $\%HA_n$ being potentially related to physiological health effects is based on the findings of a recent WHO study on housing and health status [37,38]. This study, coined the Large Analysis and Review of European Housing and Health Status (LARES), showed that, after adjusting for several potential confounding variables, self-reported annoyance (at a level equivalent to highly annoyed) among adults (18-59 years) towards traffic noise was statistically associated with elevated relative risks (adjusted odds ratios (OR), 95% confidence intervals) for the prevalence of a variety of illnesses, as diagnosed by a physician. For example, two conditions were hypertension (OR, 1.42, CI approximately 0.35) and migraines (OR, 2.19, CI approximately 0.6). The LARES study also showed that the pattern for the prevalence of illness was similar for annoyance towards general neighbourhood noise.

It has also recently been shown [39] that, although road traffic noise overall was not associated with treatment for hypertension, when the authors investigated subgroups they did observe this association among females, but not males. When the analysis was restricted to those indicating they were annoyed by traffic noise (adjusted for gender, body mass index and age), the prevalence ratio for being treated for hypertension among annoyed males (but not females) increased as the equivalent Leq 24 traffic noise levels increased. The respective prevalence rates were 3.8%, 9.4% and 13.8% at traffic noise levels below 50dBA, between 50-54 dBA and above 55 dBA. The prevalence ratio of 1.7 was statistically significant for those above 55 dBA (95% CI 1.0-2.7).

It is also relevant to this discussion that the results from a recent nation-wide traffic noise survey conducted on a representative sample of more than 2500 respondents aged 15 years and older, showed that Canadian's indicated that their annoyance towards traffic noise had a perceived negative impact on their health. Although self-reported health status was not statistically related to $\%HA_n$, subjects were asked a separate question to rank the impact that their annoyance towards road traffic noise had on their health. On a scale from 0 to 10, where 0 was equivalent to "no effect" and 10 was equivalent to "very strong effect," 39% of those who claimed they were highly annoyed by road traffic noise responded 7 and above. Those who were highly annoyed were significantly more likely to indicate that this high annoyance had a negative impact on their health compared to those who were less annoyed [40]. Unfortunately, this survey did not probe the health endpoints that Canadians felt were adversely impacted by high annoyance.

2. ASSESSING COMMUNITY NOISE IMPACTS IN THE U.S.A. WITHOUT $\%HA_n$

Prior to the development of a relationship between $\%HA_n$ and DNL, assessment of community noise impacts focused primarily on complaint analysis and speech interference criteria. It is important to briefly review these, as a number of jurisdictions in Canada have noise criteria which appear to be traceable to these ways of assessing community noise impacts, apparently without consideration of $\%HA_n$.

Rosenblith et al. [41] and Stevens et al. [42] studied the characteristics of community reaction resulting from changes in noise exposure. This constituted an analysis of about 20 complaint-based case studies that ultimately formed the "community noise rating" (CNR), which was the first attempt in the U.S. to adjust for a number of factors as a way of improving the prediction of community reaction to the noise level of an intruding source. These factors included: ambient noise levels, presence of tonal noise, the community's experience with the source and time of day. The decibel adjustments were typically made in 5 dB intervals based primarily on the researcher's intuition and limited ability to determine sound levels at a greater certainty than 5 dBA [43]. These adjustments were the basis for the normalized day-night sound level.

In 1972, the U.S. Noise Control Act was established. The Environmental Protection Agency's (EPA) "Levels" document was published in 1974 to support the mandate of the Noise Control Act [44]. As there were only a few large-scale social surveys on noise exposure and $\%HA_n$, the EPA had, as its central aim, to identify sound levels that would protect public health and well-being using speech interference and complaints, rather than a measure of annoyance.

The noise complaint assessment in the "Levels" document was based on the results of 55 case studies of complaints plotted against day-night sound level (DNL)[1] and normalized DNL of the intruding noise. A recent discussion and summary of the normalized DNL correction factors has been given by Schomer (2002) [9]. The results for the normalized DNL of the intruding noise are shown in Figure 1. Two interpretations of the complaints data were provided. The first interpretation was that a "no reaction" response corresponded to a normalized outdoor DNL of 55 dBA for the intruding noise, whereas "widespread" complaints may be expected when the normalized DNL of the intruding noise exceeds the ambient DNL by approximately 5 dBA. The second interpretation was that the mean measured outdoor DNL level associated with "no reaction" was 55 dBA, for vigorous reaction it was 72 dBA and for three intermediate degrees of reaction, which included the "widespread" complaint category, the mean value was 62 dBA. The EPA also noted that there was no evidence in the 55 case studies of even sporadic complaints when the measured DNL was less than 50 dBA.

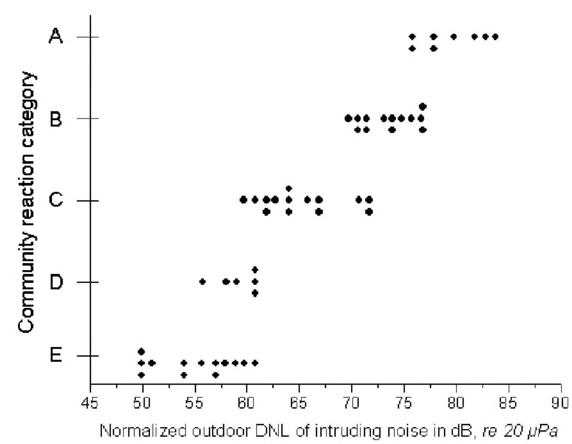

Figure 1. Adapted from the EPA *Levels* document [43] the figure shows the different levels of community reaction towards intruding noise plotted from 55 case studies as a function of the normalized DNL. Data points in the figure are normalized to: residential urban residual noise; some prior exposure; windows partially open; no pure tones or impulses. Community reaction categories: (A) vigorous community reaction; (B) severe threats of legal action or strong appeals to authorities to stop noise; (C) widespread complaints or single threat of legal action; (D) sporadic complaints; (E) no reaction although noise is generally noticeable.

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[1]DNL is a nighttime adjusted 24 hr equivalent continuous sound level (Leq), calculated from energy equivalent A-weighted day and nighttime sound levels with a 10 dB adjustment added to sound levels between 2200-0700.

Speech interference was also used by the EPA to recommend a 55 dBA DNL criterion level, which included a 5 dB margin of safety. This guidance was derived from laboratory-based studies on sentence intelligibility that involved steady, continuous sound. Then, using data for outdoor to indoor transmission loss and typical living room and bedroom absorption, it was found that the outdoor level that would permit (on average) 100% sentence intelligibility throughout a typical living room or bedroom with windows open was 60 dBA (this corresponded to 45 dBA indoors). Outdoors, this same level would allow at least 95% (satisfactory) sentence intelligibility when speaking in a normal voice up to 2 metres, according to the EPA "Levels" document [44].

The US Federal Highway Administration (FHWA) [45] uses noise abatement criteria which are partially based on speech interference. The criteria consider a traffic noise impact to occur when: 1) the projected traffic noise levels approach or exceed the FHWA noise abatement criteria (NAC) table, excerpts of which are provided in Table 1; or 2) the projected traffic noise levels substantially exceed (i.e., by 10 -15 dB) the existing noise levels in an area.

Table 1: Noise abatement criteria (NAC) hourly A-weighted sound level-decibels (dBA)

Leq(h)[2]	Descriptor of activity category
57 (outdoors)	Lands on which serenity and quiet are of extraordinary significance and serve an important public need and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose.
67 (outdoors)	Picnic areas, recreation areas, playgrounds, active sports areas, parks, residences, motels, hotels, schools, churches, libraries, and hospitals.
52 (indoors)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums.

The 52 dBA indoor level in Table 1 is well above that recommended in the ANSI standard [46] on acoustical criteria for learning spaces, such as classrooms. ANSI specifies a maximum indoor Leq (1hr) of 35 dBA for steady background sound levels in rooms between 283m^3 and 566m^3 and a reverberation time of 0.7sec. The recommended 35dBA limit may increase to 40 dBA depending on the contribution of transportation noise to the loudest 1hr period. The ANSI standard also specifies that C-weighted levels from building services and utilities (e.g. HVAC) shall not exceed the A-weighted criteria by more than 20 dB.

[2] The worst hourly traffic noise impact is considered to occur when truck volumes and vehicle speeds are greatest.

3. COMMUNITY REACTIONS TO NOISE

As noted above, a number of Canadian jurisdictions appear to consider either complaints or speech interference in the development of their noise mitigation criteria for environmental noise impacts and in some cases, both complaints and annoyance [47-52]. Therefore, it is important to trace the need ascertained for this health effect measure, compare it to other measures of community noise impact and review its level of acceptance in Canadian and international policy.

Around 1976, the U.S. Department of Housing and Urban Development (HUD) sponsored research to determine if self-reported annoyance could be the primary measure of long-term community reaction to noise. This led to the discovery (detailed in Section 5) of a preliminary relationship between $\%HA_n$ and DNL that suggested annoyance responses could be used in place of, or in addition to, complaints.

Although complaints were the primary measure of assessing community reaction to noise to the mid 1970's, official records showed that complaints tended to be in response to momentary noise events, often from limited households and primarily from noise contours considered to be acceptable acoustical living environments [28,53]. In addition, processing manually logged and unstructured complaints was problematic.

The $\%HA_n$ was recognized by HUD as reflecting a long-term integrated response resulting from the exposure to long term energy averaged noise levels and their ability to interfere with ongoing daily activities. Indeed, annoyance scores are correlated with responses to questions that specifically probe activity interference, other annoyance questions, coping strategies (e.g. window closing), and even complaints. Most importantly, these responses are correlated with noise levels [4,54]. In a recent nation-wide Canadian survey it was shown that %HA by road traffic noise was statistically related to: 1) increasing vocal effort during conversation outdoors, 2) interference with the ability to sleep, 3) interference with the ability to hear people, the TV and radio and 4) interference with reading and writing [40]. Several years ago, Job [55] reviewed the factors influencing the relationship between noise exposure and reaction. Reaction to noise included, but was not limited to annoyance. One of the more interesting findings from his study was that noise by itself failed to account for more than 29% of the variation in reaction and that attitude towards the source and noise sensitivity could explain as much, or more, of the variability in reaction than the noise did. It is unclear from Job's review however how much of the reaction was self-expressed annoyance, but there is little doubt that annoyance is influenced by variables other than noise.

Annoyance can lead to publicly expressed complaints, but the literature on this clearly shows that certain conditions must be present before complaints are made [54,56,57]. In their review of the factors that influence social surveys, Fields and Hall [54] noted that the validation of annoyance scales have been limited to various measures of self-report and therefore are susceptible to certain biases, including response bias, demand characteristics such as experimenter expectancies and social desirability. One caveat to self-report is that there can be a misunderstanding or confusion about the response scales. For instance, it is not at all straightforward that one can equate one's subjective feelings about a noise source, to either the adjectival response categories or the numerical rating scales (see below). Despite these concerns, it is generally agreed upon that it is possible to capture the subjective response towards community noise level on an annoyance scale that ranges from "not at all annoyed" to "very much or extremely annoyed" [29,58].

According to Fields and Hall [54], the conditions necessary for the emergence of individualized complaints are similar to those on a group level. A necessary, but insufficient factor on its own is dissatisfaction with the noise situation. There must also be a readily identifiable person/group that is viewed by the public as being responsible for the noise problem (e.g., airport authorities). Similarly, people must know *how* to register their complaint. It has been noted that when a telephone complaint number is publicized, complaints increase [59]. There must also be a belief that complaining will result in a positive change. A testament to this is the observation that in Australia 31% of the people surveyed who knew that they *could* complain indicated that they did not. The reason for this finding was the lack of confidence that complaining would bring about a change in the noise situation [54]. For complaints, but not annoyance, it is also important that a person or group feels that the noise is preventable. Fields and Hall [54] and Fields [60] also noted that research showed that a newly introduced source can dramatically increase complaints because it also provided an opportunity to express noise concerns about pre-existing sources. Complainants are more likely to be among the portion of the population characterized as being highly annoyed on social surveys, but they are still the minority of this group.

In the United States, complaints have been shown to be related to noise levels, but not as strongly as annoyance responses. While there appears to be little doubt that complaints do reflect an underlying existing noise problem, Fields and Hall [54] wrote:

"*...the accumulated body of research has led to the firm conclusion that complaint records are misleading indicators of the extent or causes of noise effects in populations... Official complaint records seriously underestimate the extent of noise effects. Surveys consistently show that many more people are disturbed by noise than complain.*" p18

Data prior to 1987 indicated that complaints were more strongly influenced by social status, occupation, income, and property value and were strongly impacted by the person's attitude towards the source. It was the more affluent neighborhoods that complained about aircraft noise, which likely reflected the stronger belief that their complaints would result in change [54]. Luz [53] also concluded that complaints do not necessarily increase with an increasing DNL.

There are other reasons that annoyance may be a preferable measure of community response to noise. These include the observations that complaints often: i) come from the same individuals or households, ii) tend to be in response to atypical noise events and iii) often arise from areas where community noise levels are considered acceptable living environments (see references in [54]). It should also be recalled that while 50 years ago, Rosenblith and Stevens [42] developed the CNR based on a systematic study of complaints, they clearly acknowledged the limitations to this as an approach to fully understanding the noise problem in a community:

"*Our information on the community response, however, is gleaned from comments on the number of telephoned complaints and the number of letters of complaint and from impressions of the severity of the disturbance voiced by the complainers. A carefully planned and executed opinion survey of communities exposed to noise would give much more precise data on the response. Such surveys are rarely made, however.*" p.65

The %HA_n has been accepted by two U.S. federal agencies as a potential noise impact [61,62] and is used in U.S. [63] and ISO [4] standards as such a measure. Noise annoyance is also referred to as a harmful effect by the European Union [6] and identified as one of the health effects of noise for which guideline levels have been set by the WHO [14]. Schomer [64] recently discussed noise annoyance criteria recommended by national and international organizations that set standards pertaining to community noise.

In Canada, some federal and provincial environmental noise criteria show some consistency with the use of annoyance. In British Columbia [52] and Quebec [50], the highway noise guidance appears to be based on a 6.5% change in HA_n. Transport Canada's land use guideline for aircraft noise recognizes that annoyance due to aircraft noise may start to occur within the Noise Exposure Forecast (NEF) 25[3] (approximate DNL 56.5 dBA) noise contour and that developers should be aware of this and inform all

[3] Canadian NEF is based on peak planning day, which has approximately 1.4 times the average number of operations per day. The DNL can be approximated by adding 31.5 dB to the Canadian NEF.

prospective tenants or purchasers of residential units within these boundaries. Within the NEF 30 and 35 noise contours, Transport Canada does not recommend that new residential projects take place [65]. However, they suggest that projects may be suitable in these areas if the Responsible Authority is satisfied that acoustical mitigation measures have been adequately incorporated into the building design of the development and that the developer is informed of the fact that, within these noise level contours, speech interference and annoyance resulting from aircraft noise exposure are "*...on average, established and growing at NEF 30 and very significant by NEF 35.*" The developer should also inform all prospective inhabitants of this as well.

4. USE OF DNL AS A MEASURE OF ENVIRONMENTAL NOISE

The DNL is one of the two descriptors (the other being day-evening-night sound level, DENL) for which a dose response relationship for $\%HA_n$ has been developed. Given that there remains some controversy surrounding its use, this section briefly describes some of the rationales in its favour and briefly compares it to DENL.

The DNL is a nighttime adjusted 24-hr Leq, which is typically evaluated over a long time period such as a year, or fraction of a year, so that it is useful for assessing long-term health effects. The nighttime adjustment is used to account for the expected increased annoyance due to noise-induced sleep disturbance and to the increased residential population at night relative to daytime by a factor of 2-3. Indeed, the most recent Canadian noise survey indicated that Canadians overwhelmingly want noise levels at night to be lower than at any other time period during the day [40]. In calculating the DNL (see footnote 3 above), noise levels at nighttime are artificially treated as though they were ten decibels greater than they actually are. There is no widely accepted rationale for setting the nighttime adjustment at 10 dB but the EPA "Levels" document suggests that in quiet areas the nighttime levels naturally drop by about 10 dB at night and this level of adjustment has been used with success in the US. Indeed, Shepherd [66] noted that the basis for the magnitude of the nighttime adjustment was based on the first aircraft noise study around the London Heathrow Airport, where it was found that daytime and nighttime community annoyance was nearly equal, even though nighttime noise levels dropped by about 10 dB. Likewise, the WHO has suggested nighttime noise guidelines for sleep disturbance in residences 10 dB below daytime/evening guidelines for serious annoyance [14]. A nighttime 10 dB adjustment in Canada is consistent with some provincial guidelines [48,51,52,67], although NEF contours are based on a +12 dB nighttime adjustment.

The publication of the EPA "Levels" document marked the beginning of the wide-spread usage by federal agencies in the U.S. of DNL as the metric of choice for describing noise impacts and setting noise criteria [61,62,68,69]. In the EU, the Environmental Noise Directive [6] uses the variant, DENL.

The DNL has been criticized because it does not account for different sound characteristics, such as tones or low frequencies; however, the same could be said for any energy equivalent metric, including the 24 hour Leq. Furthermore, a normalized or adjusted DNL can be used to predict annoyance towards steady-state sounds that contain audible tones (see discussion below and [4]). As with other metrics that are based on the A-weighting, the DNL has been criticized for underestimating the impact due to low frequency noise sources and not being able to account for rare loud events. On the other hand, a single 20-sec aircraft flyover with an Lmax of 95 dBA is equivalent to a daily DNL of 65 dBA. Thus, a typical single event will be taken into account by a daily DNL.

Some have also objected to the inflexible onset (2200-hr) of the nighttime penalty, even though this would likely be viewed by many as a good thing because it makes the onset of the "quiet time" predictable. On a physiological level, the concern over the inflexible onset time may be legitimate, but there is no doubt that people become less tolerant of intruding noise after a certain hour that tends to correspond to the time of day when most people would be going to sleep in order to attain somewhere around 8 hours of continuous sleep. By introducing a 5dB evening penalty, the DENL is more gradual, but it is not clear that the DENL is significantly superior to predicting the response to noise (at least for annoyance) than the DNL. For the reader interested in a detailed review of the historical development of DNL, Fidell and Schultz published a critical review of the DNL that goes beyond the scope of the present discussion [70].

5. ESTABLISHING THE DOSE-RESPONSE RELATIONSHIP FOR $\%HA_n$

Finegold has recently presented a thorough review of the historical development of the dose-response relationship for $\%HA_n$ up until 2002 [71]. Briefly, there are 4 clear phases of development of the ISO dose-response relationship for $\%HA_n$ [4]. These include the development of the original Schultz curve [29], two U.S. updates [72,73] and the transportation noise source dependent dose-response curves by Miedema and Vos [74]. These and other peer-reviewed articles for impulsive [75-81] and tonal [82-84] noise led to the current rating level synthesis of ISO 1996-1 [4]. More recently, a 5th update has been provided by Fidell and Silvati [13], which used several curve fitting functions to describe the relationship between aircraft noise and $\%HA_n$. Depending on the assumptions made to fit the data, they found that a curve could miss data points of greatest interest (i.e., between 55-75 DNL). For example, when averaged in 5 dB bins, the Finegold et al [73] curve underestimated the mean $\%HA_n$ at all data points between 45 dBA DNL and 75 dBA DNL. Fidell and Silvati stated a preference for a theory-based prediction model originally presented by Green and Fidell [11]. They argued that such a model was more defensible than regression analyses because it requires less elaborate assumptions. Their analysis represents the most exhaustive approach to date, accounting for nearly 53,000 interviews across 326 sites.

Any dose-response function that has been derived by forcing a curve to fit data points that go beyond the actual data values should be interpreted with caution. It is more appropriate to fit the smoothest curve to the data points that are available without making any assumptions concerning values of $\%HA_n$ that have not been empirically validated. Thorough discussions on the introduction of bias resulting from various curve fitting approaches have been published by Schomer [10], Fidell and Silvati [13], Fidell and Schomer [12] and Fidell [28].

The functions shown in Figure 2 for $\%HA_n$ are some of the various dose-response functions developed for general transportation noise [29,72,73] and aircraft noise [4,6,11,13] as a function of DNL. They were developed from a multitude of socio-acoustic surveys. These surveys were designed to, as much as possible; assess annoyance as an integrated response to living in a steady-state environment and not to isolated events. Between two extreme anchors, varying degrees of annoyance could occupy four, five, six, seven or more categories that would either be named, or assigned a numerical value. One of the advantages to the use of numerical scales was that they readily subjected themselves to mathematical analyses.

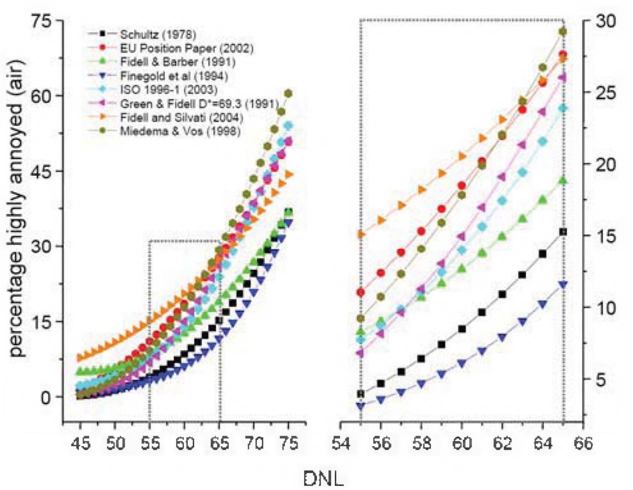

Figure 2. The Left panel shows the various dose-response functions for general transportation noise (Schultz 1978; Finegold et al. 1994; Fidell et al. 1991) and aircraft noise (EC 2002; Green and Fidell 1991; Fidell and Silvati 2004 logistic fit; Miedema & Vos, 1998; ISO 2003). The EC position paper endorses a DENL, which has been converted to DNL here by adding 0.6 dB to the DNL. The plotted ISO curve includes a 5dB adjustment for aircraft noise. The Right panel shows an exploded view of the DNL range, for the various dose-response functions, that is most applicable to environmental assessments.

The birth of socio-acoustic surveys included scales of annoyance that were generated from a combination of the subject's answers to a number of questions about activity interference or the spontaneous mention of noise as an annoying aspect of the environment. This non-standardized methodology meant that many of the social surveys were difficult to compare to one another and it was a challenge to characterize responses as belonging specifically to a high degree of annoyance (discussed below). The reader is referred to Fields and Hall [54] for a thorough discussion of the questions that have been used in the past to assess annoyance in social surveys.

Comparisons across studies showed that standardized annoyance questions were needed. This was the impetus for the publication of the ISO technical specification (TS) 15666 [58], which proposed two standardized questions to be used to assess annoyance. The questions have been translated (using forward and backward translation) into nine languages to facilitate international comparisons. The ISO/TS specifies two questions; one that has a 5-point adjectival and a second that has an 11 point numerical scale.

<u>Adjectival rating scale:</u>

Thinking about the last [12 months or so], when you are here at home, how much does noise from [noise source] bother, disturb or annoy you? *Not at all, Slightly, Moderately, Very, or Extremely*

<u>Numerical rating scale:</u>

This question is introduced with the following statement: "*This question uses a 0 to10 opinion scale for how much (source) noise bothers, disturbs or annoys you when you are here at home. If you are not at all annoyed choose 0; if you are extremely annoyed choose 10; if you are somewhere in between, choose a number between 0 and 10.*"

Question:

Thinking about the last [12 months or so], what number from 0 to 10 best shows how much you were bothered, disturbed or annoyed by [source] noise?

A substantial amount of research went into the development of these questions [85] so that responses were 1) indicative of a long-term integrated response to noise; 2) the respondent's own response; 3) pertinent to the noise experienced at the respondent's home; and 4) able to adequately capture a negative response. A more detailed description of these questions is provided in [58,85], including the rationale for the choice of wording and why both questions are required. These questions have been implemented world-wide and used in two national social surveys conducted in Canada to quantify the percentage of Canadians highly annoyed by traffic noise [40,86].

5.1 Source-dependent dose-response functions

Miedema and Vos [74] from the Environment Section of The Netherlands Organization for Applied Scientific Research Prevention and Health (TNO) in Leiden, The Netherlands have, over several years, built an archival database containing socio-acoustic surveys, conducted in Europe, North America and Australia, pertaining to transportation noise sources. The database contained, as of 1997, original data from 38 different studies with data from individual respondents in addition to 8 studies that were limited to group level data. In total, their new source-specific dose-response functions for transportation noise exposure and annoyance were based on 55 data sets from 45 different socio-acoustic surveys that contained 58 065 respondents, resulting in a total of 63 969 respondents since some would be counted more than once if they contributed to multiple data sets. This nearly doubled the amount of surveys used to generate the dose-response functions that preceded theirs [29,72,73].

To the extent possible, Miedema and Vos tried to address the concerns raised by Fields [54] in his review of the Fidell et al. [72] and Schultz [29] curves. This resulted in the elimination of several data sets used originally by Schultz [29] and Fidell et al. [72]. The minimum requirements concerning the relationship between DNL and $\%HA_n$ used in their research were 1) DNL (at the most exposed facade) and $\%HA_n$ had to pertain to one and the same source of transportation noise (air, road, or rail). Failure to meet this criteria resulted in the removal of 6 studies used in the analysis by Fidell et al. [72]; 2) $\%HA_n$ had to be derived from the response to a question about the general noise annoyance from the source concerned and not inferred based on rankings or activity interference. Nine of the published studies used by Fidell et al. [72] did not meet this criteria but Miedema and Vos had original data available to them from four of these nine surveys and were able to satisfy this criteria for these four; 3) the $\%HA_n$ had to be derived with a cut-off sufficiently close to 72 on a scale from 0 to 100 (they did not define what they meant by "sufficiently"). Failure to meet this criteria resulted in the elimination of five additional studies because the cut offs for three of them were 50, one was 60 and another was between 50 and 60. Using these inclusion criteria the dose-response functions included 22 of the 35 datasets originally used by Schultz [29] and Fidell et al. [72].

When DNL was not directly available, the authors calculated it by relying on certain models with some assumptions. Depending on the source, they used the: 1) event pattern model (air); 2) traffic intensity model (traffic); 3) stair case model (traffic); 4) Leq pattern model (air, road and rail). The DNL was divided into intervals of 5 dB to produce $\%HA_n$ as a function of DNL for each survey. If the 5 dB interval contained less than 100 cases, it was combined with the adjacent interval that had fewer observations. The authors repeated this step until every DNL interval contained at least 100 cases. For each mode of transportation, a quadratic ordinary least squares regression was carried out, weighing each point according to the number of observations on which it was based. Scores below 45 dBA DNL and above 75 dBA DNL were excluded from the analyses. The original fitting of the data showed that the threshold for high annoyance should be set at a DNL of 42 dBA. Subsequent analyses then forced the curves to zero at this threshold. Using multilevel modeling, the resulting $\%HA_n$ curves for each steady-state noise source, when 42 dBA was considered equal to 0 $\%HA_n$ were:

$$\text{Air: } = -0.02(\text{DNL}-42) + 0.0561(\text{DNL}-42)^2 \quad \text{Eq.1}$$

$$\text{Road: } = 0.24(\text{DNL}-42) + 0.0277(\text{DNL}-42)^2 \quad \text{Eq.2}$$

$$\text{Rail: } = 0.28(\text{DNL}-42) + 0.0085(\text{DNL}-42)^2 \quad \text{Eq.3}$$

At a given exposure level, aircraft noise predicted the highest $\%HA_n$, followed by the noise from road traffic and rail traffic, respectively. The multilevel approach predicted greater aircraft annoyance at the high sound level than the least squares model. The authors also argued for the multilevel model because it more effectively accounted for the scatter in the data. It is only with this model that the 95% confidence intervals are mutually exclusive between the sources at high sound levels. The authors claim that the multilevel modeling results supported the contention that the three modes of transportation engendered different degrees of annoyance and should therefore be considered separately. Until this time, aircraft noise was considered to cause relatively higher annoyance than the other sources [11,73], but not to the extent that the data justified a separate function for it. Indeed, Finegold has objected to treating the sources differently because their differences are within the range of uncertainty in estimating noise exposures within and between studies (i.e., less than 5 dB). He also noted that source differences did not exist across the entire range of the curves and may only be apparent at sound levels that are very high (above 70 dBA DNL) [71]. While some of the studies used by Miedema and Vos directly compared aircraft noise to traffic noise (five studies) and three studies directly compared rail noise to road traffic noise, no studies directly compared annoyance from aircraft noise to annoyance from rail noise. The community response to aircraft noise is unknown while rail noise is present, and vice versa.

A relevant concern with respect to the different modes of traffic noise is that annoyance may be different when traffic is from a highway, local roads or arterial/district type roads that might be free flowing or interrupted. However, Miedema and Vos found no systematic differences between the road types (based on 19 datasets), beyond that which could be accounted for by variations in noise levels.

Miedema and Vos emphasized that, in their analysis, DNL was determined at the most exposed facade and therefore lower exposure to ground transportation noise could have led to the apparent differences in annoyance between these sources and aircraft. These potential exposure differences could be due to people ensuring their bedroom was as far away from the most exposed facade as possible. This could effectively reduce exposure to ground transportation without having an effect on aircraft noise exposure. Kryter [87] expressed a similar argument in his objections to the single function originally synthesized by Schultz [29], suggesting that annoyance towards aircraft noise should be higher. Kryter [87] reasoned that one's "effective noise exposure" is higher from a source that originates from above (and has a more spatially uniform transmission loss) compared to traffic, which would be influenced more by interfering structures [87] (see also [88,89]).

In the EU, the Environmental Noise Directive requires mapping of DENL. As a result, efforts have been made to standardize noise impact criteria in terms of this quantity. The DENL is defined as a 24 hr energy average of annually energy averaged daytime (0700-1900 hr), evening (1900-2300 hr), and night-time (2300-0700hr) sound levels. In the 24 hr energy average there is a 5 dB adjustment to noise in the evening and a 10 dB adjustment to noise in the night. Miedema and Oudshoorn [90] have used more sophisticated analytical methods to re-define the dose-response functions for transportation sources, using both DNL and DENL. Again, data outside the 45 dB DNL and 75 dB DNL were excluded because these authors considered annoyance at these extremes to be unreliable; due to uncertainty in noise data at the low end and the inclusion of what they called "survivors" at the high extremes. In this analysis, respondents that skipped specific annoyance questions because of their response on a filter question were included and assigned to the two lowest annoyance categories. Miedema and Oudshoom claimed that this minimized the risk of underestimating annoyance when filter questions were used. In total, this revised analysis was based on 27 081 aircraft respondents, from 19 studies, 19,172 road traffic respondents from 26 studies and 7,632 rail respondents from 8 studies. Their analyses for DENL and $\%HA_n$ have been published by the EU in a position paper on dose-response relationships between transportation noise and annoyance [8]. The resultant dose-response functions for transportation noise sources are as follows:

air: $-9.199 \times 10^{-5}(DENL-42)^3 + 3.932 \times 10^{-2}(DENL-42)^2 + 0.2939(DENL-42)$ Eq.4

road: $9.868 \times 10^{-4}(DENL-42)^3 - 1.436 \times 10^{-2}(DENL-42)^2 + 0.5118(DENL-42)$ Eq.5

rail: $7.239 \times 10^{-4}(DENL-42)^3 - 7.851 \times 10^{-3}(DENL-42)^2 + 0.1695(DENL-42)$ Eq.6

These functions are intended only for predicting annoyance on a population level to steady-state transportation noise sources. As discussed in the Introduction, these functions are *not* applicable to local, complaint-type situations or to the assessment of the short-term effects of a change of noise environment.

5.2 ISO and U.S. Standards

The ISO has published a standard [4] for assessment procedures for environmental noise, which can be done in terms of the $\%HA_n$. The relationship between the rating level (RL) and $\%HA_n$ is given by:

$\%HAn = 100/[1+\exp(10.4-0.132*RL)]$ Eq.7

The RL in Eq 7 is typically an adjusted DNL, with adjustments made depending on the type of noise source and source characteristics (e.g., tonality). The ISO standard specifies that the relationship for road traffic noise is obtained when RL equals DNL. The resulting curve nearly coincides with Schultz's original curve. If the RL is DNL with a +5dB aircraft noise adjustment, then the resulting ISO curve is quite similar to Fidell and Silvati's most recent logistic curve [13] for aircraft noise. Indeed, the meta-analysis by Green and Fidell [11] showed that, on average, people were more willing to report high annoyance towards aircraft noise than they were towards road and rail noise at the same sound level. The relative difference in the threshold for reporting high annoyance was found to be around 5 dB less for aircraft noise. The adjustment recommended for aircraft noise is +3 dB to + 6 dB in ISO 1996-1 [4].

ANSI [63] recommended an adjusted DNL in the same manner as the ISO standard [4] as the metric of choice for predicting community annoyance to long term noise from all types of environmental sounds in isolation or when combined.

It should be noted that there have been objections raised against the use of an adjusted or normalized noise metric with the argument that such adjustments only represent post-hoc "band-aid" solutions that do not serve to improve the predictive power between the adjusted DNL and the $\%HA_n$ [13,91]. This however is not entirely true and there are examples in the literature that show how very strong community opposition to aircraft operations could have been better anticipated if the predicted DNL was adjusted to account for factors like living in a quiet rural area and having little prior experience with aircraft noise [9]. In keeping with both the EPA and aforementioned ISO standard, Health Canada proposes a +10dB adjustment to the project sound level for assessing $\%HA_n$ when the project is to be undertaken in a quiet rural area.

6. USING A CHANGE IN $\%HA_N$ AS NOISE MITIGATION CRITERIA

The US Federal Transit Administration, (FTA) has a guidance manual [61] for characterizing impacts for all mass transit projects including, rapid, light or commuter rail, diesel/electric buses and their storage and maintenance yards. This guidance has been adopted by the US Federal Rail Administration (FRA) [62] for high speed rail projects. The guidance was adopted from a report prepared for the U.S. Department of Transportation (DoT), by Hanson et al [92]. The impacts are shown in Figure 3 as a function of noise levels from the new noise source *in combination* with the existing noise levels. The function differs with land use category. For land uses where people normally sleep and/or reside (category 2) the criterion for severe impact is based on an increase of 6.5% in $\%HA_n$ for baseline DNL values from 43 DNL to 77 DNL.

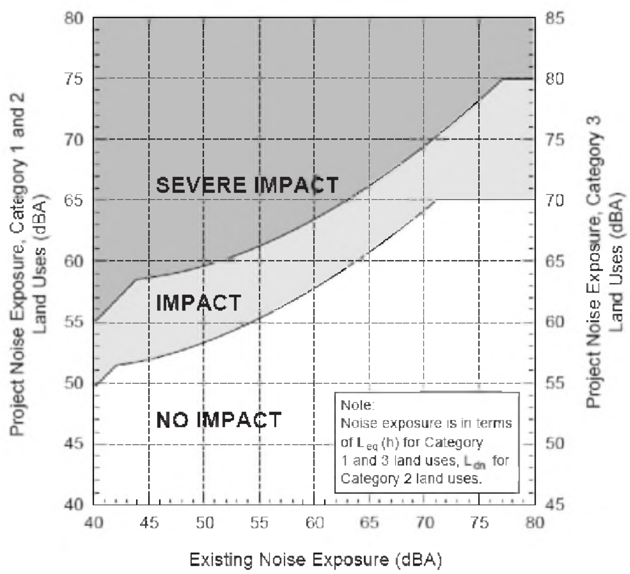

Figure 3. Plot originally presented by the US Federal Transit Administration [55] showing the magnitude of noise impact for various land use categories. For baseline DNL values from 43 DNL to 77 DNL, the "severe" noise impact reflects an increase in sound levels that equates to a 6.5% increase in the %HAn.

The rationale provided by Hanson et al. [92] for using a 6.5% increase in $\%HA_n$ as the threshold for a severe noise impact is as follows: 1) the onset of a normally unacceptable noise zone is defined by the US HUD [69] as a DNL of 65 dBA. This is also the threshold level at which the US FAA would consider noise mitigation as something that should be investigated; 2) The common use of a 5 dBA increase in DNL as the minimum required for a change in community reaction. This usage appears to be traceable to the finding in the US EPA "Levels" document regarding the changes in community reaction as a function of DNL and normalized DNL (see section 2); 3) the finding that a step from 60 DNL to 65 DNL corresponds to a change of about 6.5% in $\%HA_n$ according to Eq 7, at least for all sources and settings where adjustments do not apply (i.e., RL = DNL). Therefore the upper curve in Figure 3, from the ambient sound levels of 43 DNL to 77 DNL, is obtained using Eq 7 by solving for DNL when the increase in $\%HA_n$ is fixed at 6.5%.

Due to the non-linear nature of the dose-response relationship for $\%HA_n$ between 43 DNL and 77 DNL, the threshold for the increase in sound levels to achieve a severe impact becomes smaller as the baseline sound levels increase. Hanson et al. [92] indicated that:

"The justification for this is that people already exposed to high levels of noise will notice and be annoyed by only a small increase in the amount of noise in their community. In contrast, if the existing noise levels are quite low, a greater change in the community noise will be required for the equivalent level of annoyance." p. 3-7

Health Canada has used the change of 6.5% HA_n criterion in reviews of environmental assessments to indicate the potential severity of project noise impacts. In these reviews, the U.S. FTA criterion was extended to projects other than mass transit by assuming that the RL for mass transit projects is the same as for road traffic (i.e. DNL). For other projects, the RL adjustments for different sources provided in ISO 1996-1 [4] were used to determine the $\%HA_n$. Application of the U.S. FTA criterion to quiet rural areas was also made using tentative adjustments of 10 dB. As noted above, ISO 1996-1 notes that research has shown that there is a greater expectation for and value placed on "peace and quiet" in quiet rural areas. This greater expectation for "peace and quiet" may be equivalent to a rating level adjustment of up to 10 dB.

In figure 4, sound level increases are shown as a function of initial sound levels from 45 dBA DNL to 75 dBA DNL. The sound level increases were determined for a corresponding increase in the $\%HA_n$ of 6.5%, using different dose-response relationships that have been applied to aircraft noise. Despite the differences in the $\%HA_n$ dose response curves in Figure 2, a 6.5% increase in $\%HA_n$ results in a similar decibel change for the 5 functions specific to aircraft noise [4,6,11,13,74]. For example, the sound level increases agree to within approximately 2-3 dBA. More variability is introduced by inclusion of the three functions [29,71,72] in which there are no distinctions between transportation noise sources. Moving from the highest to the lowest initial sound level, this variability is about 2-8 dBA.

In the FTA guidance manual [61], the $\%HA_n$ criterion is limited to a baseline sound level of 77 DNL because of the asymptotic nature of the dose-response relationship above this value. Also, HUD's site acceptability standards [69] for community noise indicated that beyond 75 dBA DNL, sites were considered unacceptable. For an existing DNL greater than 77 dBA, the FTA guidance manual considers the impact severe when the project DNL exceeds 75 dBA

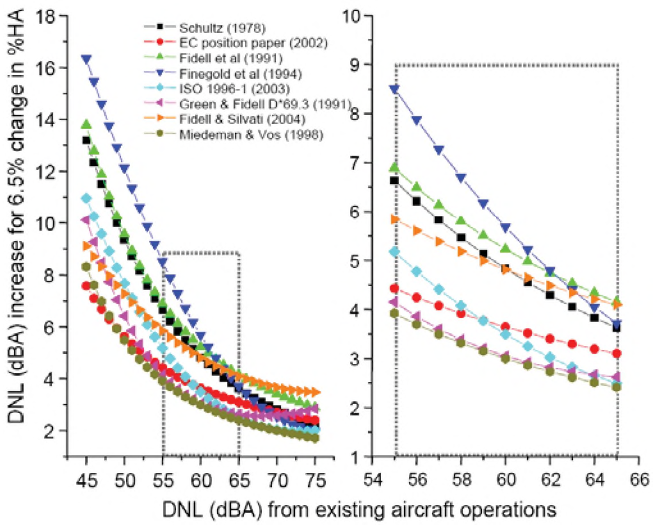

Figure 4. The Left panel shows sound level increases as a function of initial aircraft sound levels from 45 dBA DNL to 75 dBA DNL. The sound level increases are shown for a corresponding increase in the %HAn of 6.5%, using different dose-response relationships that have been applied to aircraft noise, including the ISO curve [48] with a +5dB adjustment for aircraft noise. The Right panel shows an exploded view of the DNL range for the various dose-response functions that is most applicable to environmental assessments.

7. LIMITATIONS and ALTERNATIVES TO $\%HA_N$

The use of a $\%HA_n$ criterion is not the only published noise mitigation criterion that could be used for environmental assessment purposes. First and foremost, it is important to be aware of the usefulness of various existing federal, provincial and territorial Canadian noise mitigation criteria for environmental assessment and land use [47,49-52,65,93]. Other U.S. Federal criteria may also be useful. As noted above, the FHWA has its own criterion based primarily on speech interference but also on “substantial change” (i.e. 10-15 dB increase) in the noise environment, even when this change leads to sound levels which do not necessarily interfere significantly with speech. For highways and for DNL levels less than 43 dB without the project, the FTA changes its guidance to that of the U.S. FHWA using an increase of 15 dB [45] (see section 2).

An example where an extra criterion is necessary pertains to low frequency sounds, which readily induce rattle indoors. Using the ISO dose-response relationship for $\%HA_n$, it is currently not possible to assess the potential magnitude of low frequency noise effects. To evaluate these impacts, separate proposals have been made [9,94,95].

International noise mitigation targets have been developed, which are based on lowest observed adverse effect levels. For example, the WHO guideline levels (also adopted by the World Bank Group [96]) indicate that to avoid serious annoyance during the daytime and evening, the 16-hr Leq should not exceed 55 dBA. The guideline level for serious annoyance has also been adopted by the Organization for Economic Cooperation and Development (OECD) in urban areas with a 5 dB lower value for rural communities. These guidelines do not specify how, or if, noise sources other than road traffic or non-tonal and non-impulsive industrial noise are accounted for.

The WHO also has guideline levels to avoid sleep disturbance. The 8 hr nighttime Leq within the bedroom should not exceed 30dBA for continuous sounds and the indoor A-weighted maximum sound level for single events should not exceed 45 dBA. To avoid speech interference, indoor sound levels should not exceed 35 dBA Leq, either 16 hours in residences, or during class time for schools. As discussed in Section 2, noise mitigation targets were also provided by the U.S. EPA based on dose response relationships for percent sentence intelligibility and equivalent continuous sound level for approximately steady noises [44]. A relatively new noise mitigation criterion based on sound exposure level (SEL) for an aircraft noise event and temporary speech interference has also been suggested [97].

Recently developed dose-response relationships for sleep disturbance appear to hold promise as complements to $\%HA_n$ for impact assessment. These include dose-response relationships for self-reported percentage highly sleep disturbed from road and rail noise [98] and percent of behaviourally confirmed awakenings from aircraft noise events [99,100]. A recent analysis by Anderson and Miller [101] provided a method for predicting awakenings from aircraft operations. Their method is encouraging because it attempts to account for variables that are known to influence noise-induced awakenings, such as the number of noise events.

8. CONCLUDING REMARKS

There are a variety of Canadian, U.S. and international criteria and targets for noise mitigation with respect to environmental assessment and land use. As a result, there is a place for environmental assessments under CEAA to provide predictions of the magnitude of health effects due to project-related changes in community noise. This information should be grounded on science-based evidence.

There has been more than 50 years of social and socio-acoustical research that either directly or indirectly studied the impact that community noise has on annoyance. These studies have consistently showed that an increase in community noise level was associated with an increase in the percentage of the community indicating that they are highly annoyed. The relationship between noise levels and high annoyance is stronger than any other self-reported measure, including complaints. Defining high noise annoyance as an adverse health effect is certainly consistent with Health Canada's definition of what constitutes "health". New Canadian research on road traffic noise also shows a significant percentage of respondents have indicated that this high annoyance has a negative impact on their health [40].

Dose-response relationships for predicting high annoyance have a history of using DNL as the noise metric and have improved substantially over the years by incorporating adjustments into the DNL to account for variables that are unique to either the noise source and/or the exposed community. The culmination of these meta-analytic synthesis curves has been the publication of the ISO standard for predicting high annoyance using an adjusted DNL (i.e. rating level). This standard has been adopted without modification by CSA [102].

As discussed above, there are alternatives and important complements to the use of $\%HA_n$ in environmental assessments. However, it seems reasonable to conclude that a change in $\%HA_n$ can be used in environmental assessments as *one of* the measures of the magnitude of an adverse health effect caused by project related noise. This follows from the scientific evidence provided above, and the fact that $\%HA_n$ has been used to assess impact severity in environmental assessments in US government guidance documents.

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Wavelets Application in Acoustic Emission Signal Detection of Wire Related Events in Pipeline

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ABSTRACT

As a popular nondestructive test, acoustic emission (AE) testing has been widely used in many physical and engineering fields such as leak detection and pipeline inspection. Among those applied AE tests, a common problem is to extract the physical features of the ideal events, so as to detect similar signals. In acoustic signal processing, those features can be represented as joint time-frequency distribution. However, classical signal processing methods only give global information on either time or frequency domain, while local information is lost. Although the short-time Fourier transform (STFT) is developed to analyze time and frequency details simultaneously, it can only achieve limited precision. Wavelet transform is a time-scale-frequency technique with adaptable precision, which makes better feature extraction and detail detection. This paper is an application of wavelet transform in acoustic emission signal detection where strong noise exists. Developed for industrial applications, the techniques presented are both accurate and computationally implemental for embedded systems. In addition, STFT is compared with wavelet transform to show the advantages of wavelet transforms in this particular application.

SOMMAIRE

Étant aujourd'hui l'un des plus populaires essais non destructifs, le contrôle par émissions acoustiques (EA) est utilisé dans divers domaines, relevant tant de la physique que de l'ingénierie. On les retrouve principalement pour la détection des fuites, ou encore pour l'inspection des pipelines. Dans les différentes applications, on retrouve un problème commun, celui d'obtenir les caractéristiques physiques des événements idéaux afin de détecter les signaux semblables. Dans le traitement des signaux acoustiques, ces caractéristiques peuvent être représentées simultanément dans le domaine du temps et de la fréquence. Cependant, la méthode classique du traitement des signaux donne seulement des informations générales sur ces domaines, mais ne fourni pas une analyse détaillée. En effet, bien que la transformé de Fourier à court terme a été développé pour analyser le temps et la fréquence simultanément, elle dispose d'une précision limitée. La transformé de Wavelet est une méthode de type temps-fréquence-échelle, avec une précision adaptable, qui permet d'obtenir un relevé plus précis et de meilleure qualité. Ce dossier présente une application de la transformé de Wavelet pour la détection d'une émission acoustique qui contenant beaucoup de perturbations. Développées pour l'industrie, les techniques présentées sont à la fois précises et facilement applicables aux systèmes intégrés. Afin de faire ressortir les avantages de la transformé de Wavelet dans ce type d'application, vous trouverez une comparaison entre cette dernière et la méthode de Fourier à court terme.

1 INTRODUCTION

Acoustic Emission (AE) testing has been widely used in physical and architecture fields due to its efficiency, reliability and lower operation costs. In steel pipelines, when a present defect expands, tension energy is released, and an acoustic signal is generated [1]. AE techniques are used to observe and monitor these events. Although some events occur before monitoring, or are too weak to be detected during inspection, various events occur due to temperature, pressure, physical defect development and environmental conditions so that they become detectable. Previous studies showed that the amplitude of AE signal is proportional to the released energy [2], and the frequency distribution is related with the size of the defect [3]. For instance, in leak detection of a pipeline, the AE signal detected from larger leak hole contains more low frequency components. This can be explained that larger hole creates smaller pressure, which results in lower frequency components.

The AE events that occur in pipeline usually create two types of signals: one is a mechanical wave which propagates along the steel wire in the pipe at high frequency (above 100 kHz), another is a low frequency wave (about 30 kHz) that propagates through the medium (gas or liquid) inside the pipe. Stulen and Muravev showed in their research [1,4]that the attenuation of the waves has a square relationship with their frequency, and the coefficient of this relationship is distinguished by the particular medium. Observed values for attenuation (in dB/ft) in several gases and water are $4.9 \times 10^{-11} f^2$ and $7.8 \times 10^{-14} f^2$, respectively, where f is the frequency. Therefore, AE signals propagating through the steel wire attenuate very quickly because the frequency is high. However, those low frequency waves that propagate in the medium can be detected even at sites hundreds of meters away from the original signals. In addition, this kind of wave interacts with the pipe wall so that it can be detected by sensors mounted outside of the pipe.

For AE signal detection and feature extraction, many acoustic signal processing methods have been used. Classical frequency analysis [3]gives very rough information about the signal, such as global spectrum, frequency peaks and SNR, which makes the detection work ambiguous. In fact, time variant features that can be depicted by changing signal frequency components with time, is the main character of acoustic signals. This is similar to music composition. Each musical tone is the combination of certain frequency bands, and different tones arrive at different times to make the music. Therefore, we need to know the arrival time and location of those frequency components in the time domain, in order to discriminate different AE signals and detect the right events. Therefore, in the time-frequency plane, these local details are much more important than global information.

This requirement cannot be satisfied by classical Fourier transform. To solve this time-frequency problem, Short-time Fourier transform (STFT) was applied to signal processing [5]. STFT uses small windows to localize a signal in the time domain, and then applies Fourier transform to get the frequency distribution only in this window. However, this STFT window, or atom, has certain size and precision restrictions, which locks the time-frequency at certain resolution level. The wavelet transform, which was first created in seismology, was introduced to signal processing to solve this multi-resolution problem [6].

This paper presents part of the research that aims to detect the real AE events accompanied by strong noise. Both STFT and Wavelet transform are implemented to thoroughly analyze the time-frequency occurrence of both AE signal and noise. After comparison, Wavelet transform techniques are chosen for the final application. Using features extracted in wavelet domain, experiments are carried out over a large number of industrial data.

The remaining of the paper is organized as the following: Section 2 reviews the current applied technology, gives the physical condition and environment for the AE signal detection, as well as extracted features. Section 3 provides the basis of wavelet transform and STFT. Section 4 analyzes these two methods in detail. Section 5 is experiment results of the proposed method. Section 6 concludes the paper.

2 CURRENT APPLIED TECHNOLOGY

In industry, people are using AE testing for detecting wire related events (WRE) in pipelines. Signals from the pipelines provide the observed data for this research. The environment and preconditions are described below.

2.1 Physics conditions

The tested portion of the pipeline was constructed in 1975 with Lined Cylinder Pre-stressed Concrete Cylinder Pipe (PCCP)[7], as shown in Fig. 1. The PCCP is constructed by first casting a steel cylinder outside of a concrete core, pre-stressed wire around it. This high strength wire is de-

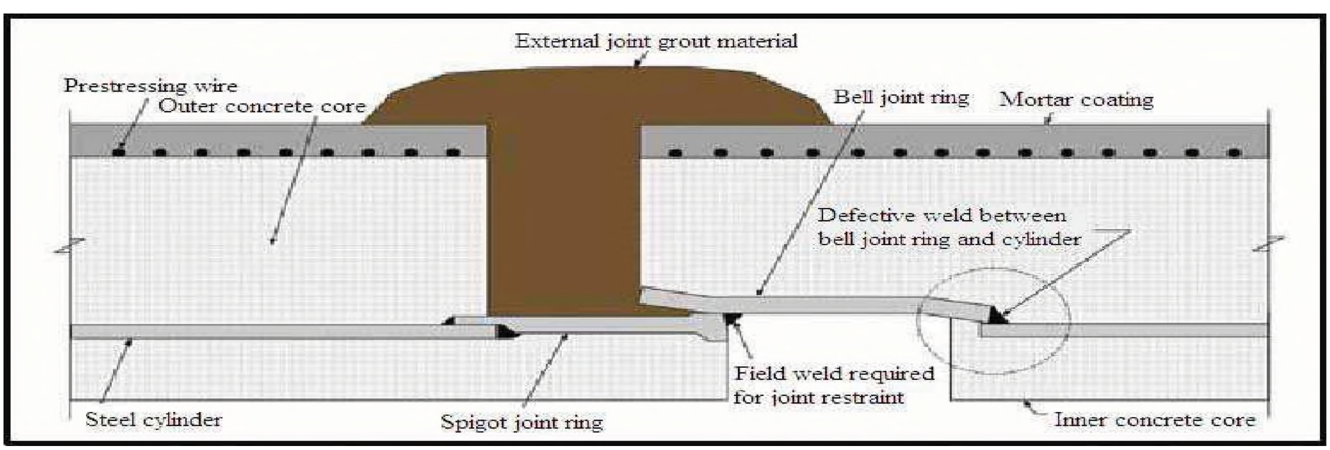

Figure 1: Lined cylinder PCCP.

signed to force the core tighter, and is then coated with a mortar coating, so as to provide corrosion protection to the wire. Therefore, this pre-stressing wire is the key component of the PCCP, and the main purpose of AE testing here is to take precautions against the corrosion and breakage of the wire. Once the wire break or split occurs, the tension energy embedded in the wires will be released, and acoustic waves will be generated. After propagating through the medium inside the pipe, these waves can be detected and recorded by acoustic sensors as long as the amplitude of the signal is higher than the defined threshold.

In current practice, two types of sensors have been used to detect WRE signals: hydrophone and accelerometer. Hydrophones are constructed of ceramic materials and can detect acoustic signals by sensing the vibration that is propagated through water. Hydrophones are installed through valves into the water column inside the pipeline, as shown in Fig. 2(a). Accelerometers are installed on the surface of the pipeline, as shown in Fig. 2(b). Incentive to use accelerometers in AE testing is to assist hydrophones, as hydrophones are more sensitive than accelerometers. They are also used in the case of empty pipelines.

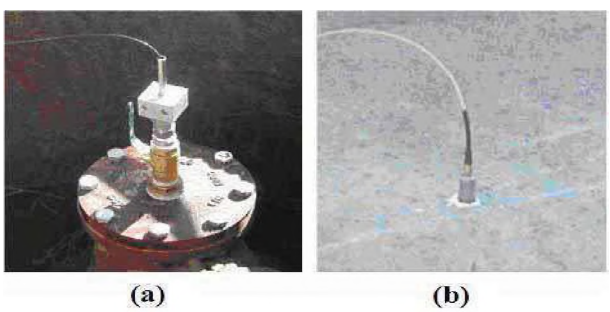

Figure 2: (a) Hydrophone sensor. (b) Accelerometer sensor.

Once the AE event occurs, the signal will propagate both ways along the pipeline, and may be detected by the closest pair of sensors. Sometimes if the amplitude is large enough, the signal might be detected by the third or the forth sensor. As studied in [1], the detected result is reliable with sensor spacing at 262 meters distance, and this can vary according to landscape, temperature, pipe structure, . Therefore, an ideal WRE signal should be detected by two sensors closest to it, and the arrival time difference can be used to localize the defect's position. If the signal is only picked up by one sensor, then the position cannot be accurately localized, and the recorded data will not be considered as useful.

2.2 Acoustic signal features

Fig. 3 is an example of AE event signal detected by the closest two sites: site 1 is 68.6 meters from the event where the sensor is a hydrophone; site 2 is 90.8 meters from the event where the sensor is an accelerometer. Some features of this WRE signal are shown in Fig. 4. Figs. 4(a), 4(c), and 4(e) show the time domain, frequency domain and the Gabor time-frequency domain respectively, of the recorded signal at site 1; Figs. 4(b), 4(d), and 4(f) provide the corresponding information of the recorded signal at site 2 [4].

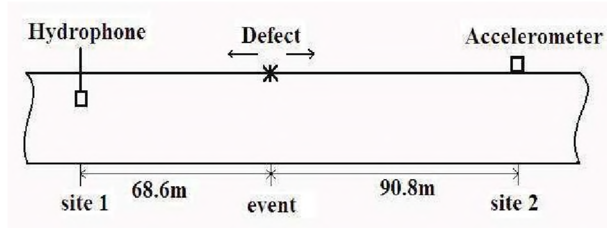

Figure 3: An AE event detected by two sites.

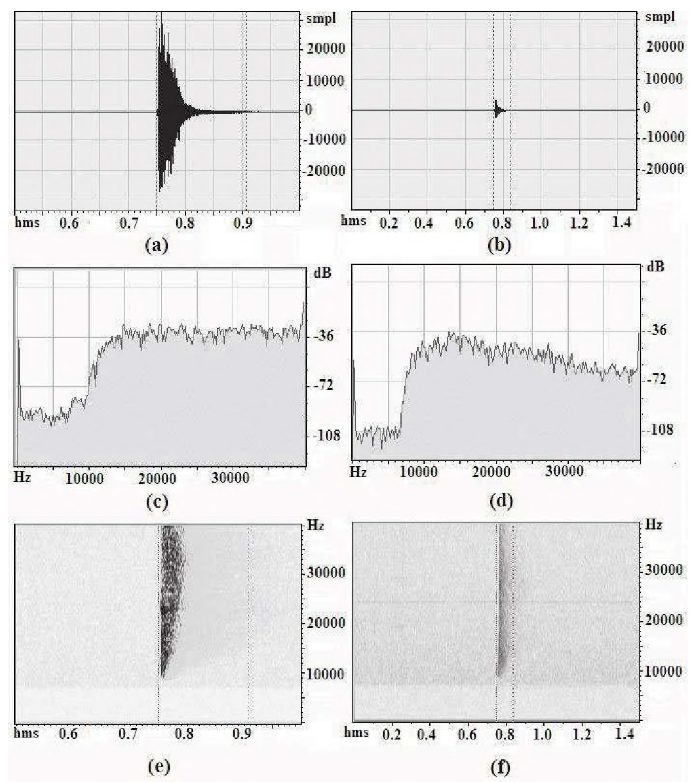

Figure 4: (a), (c) and (e) are the time domain, frequency domain, and Gabor transform, respectively, of the signal recorded by Hydrophone; (b), (d) and (f) represent the same signal recorded by Accelerometer.

Figs. 4(a) and 4(b) clearly show the signal amplitude recorded by the hydrophone is much larger than that recorded by the accelerometer. In the Gabor transform, Figs. 4(e) and 4(f), larger amplitude and energy intensity in the signal will make the color darker. From the time-frequency analysis shown in Figs. 4(e) and 4(f), the signal-to-noise ratio (SNR) of the left one is much higher than the right one, because the left signal has greater energy. Although the noise level of these two signals are almost the same (shown as the gray level of the background), the larger energy in the left signal results in a larger SNR.

Some observations can be drawn as follows:

- In the time domain [Figs. 4(a), 4(b)]:

The duration of the signal is usually less than 0.05 seconds. The intensity of the signal should be much larger than the background. while in frequency domain (Figs. 4(c), 4(d)) this corresponds to the spectrum amplitude of the signal, and in the time-frequency Gabor window (Figs. 4(e), 4(f)) it means the color of the signal should be much darker than the background.

- In the frequency domain [Figs. 4(c), 4(d)]:

These figures show the "real-time" spectrum of the signal. This WRE signal has the following unit step form, as shown in Fig. 5(a), where the solid line is the spectrum shape at the beginning time , and the dashed line is the spectrum shape at the ending time.

For the beginning of the signal in time axis: 7 kHz is the start frequency of all sounds (mostly background), 12 kHz is the start frequency of the WRE signal, and the highest frequency is above 40 kHz.

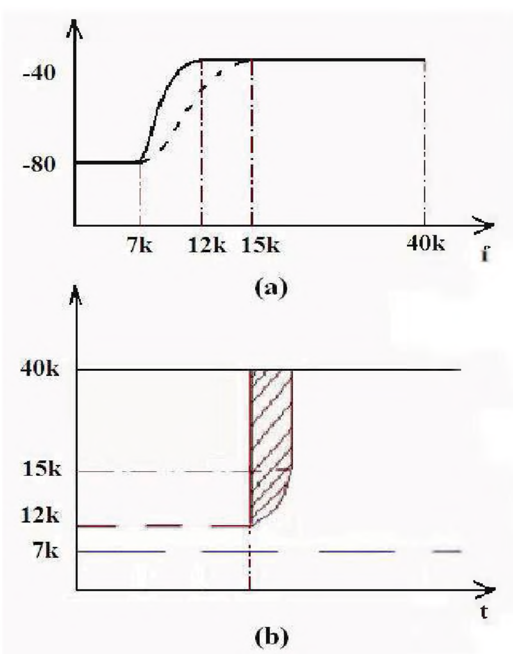

Figure 5: (a) frequency response of an WRE signal: solid line is the spectrum shape at the beginning time; dashed line is the spectrum shape at the ending time. (b) Gabor windowed time-frequency distribution of an WRE signal.

For the ending of the signal in time axis: 15 kHz is the start frequency of WRE signal, the highest is above 40 kHz. These parameters can be different in particular situations, while the shape should be similar. As shown in Figs. 4(c) and 4(d), the high frequency decrease greatly due to the attenuation of signal propagating through the pipeline to the accelerometers.

- In the time-frequency Gabor window [Figs. 4(e), 4(f)]:

As shown in those Gabor figures, the power density starts at above 7 kHz, while lower than 7 kHz the color is all white, which means that there is no frequency component in this part. From the beginning of the signal at 0.75 seconds until the ending at 0.80 seconds, the shape of the power density is like a vertical downward knife, as shown in Fig. 5(b). This knife shape is also referred to "J" shape in the industry. The peak of the knife is the beginning of the signal with 12 kHz frequency, which decreases earliest and at the fastest speed; hence, at the ending time, 15 kHz becomes the start frequency. In addition, the intensity of the signal from 15 kHz to 40 kHz is almost uniformly distributed, and this feature makes the two vertical parallel lines.

3 APPLICATION OF WAVELETS COMPARED WITH STFT

3.1 Basis of STFT

Fourier transform is defined to obtain the frequency distribution of a signal when the signal is transformed through the whole time domain. In addition, the stationarity of the signal is also required. In other words, the spectrum information of the signal has been averaged through the whole time domain, which results in the loss of real-time spectrum occurrence [8].

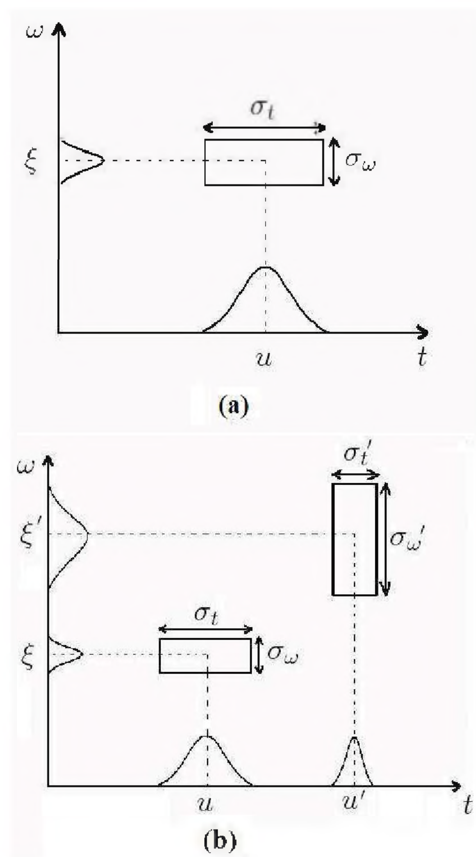

Figure 6: (a) the STFT window. (b) the graphical interpretation.

Short-Time Fourier transform (STFT) was introduced by Gabor [6]to compensate the limitation of classical Fourier transform and it provides an original joint time-frequency method. It uses a measuring window to restrict the Fourier transform in a limited time range and then obtain the spectrum on this time range. As Fig. 1(a) shows, this real and symmetric window $g(t)$ is delayed by u on time domain, and modulated by the frequency ξ [9]:

$$g_{u,\xi}(t) = e^{i\xi t} g(t-u) \tag{1}$$

The STFT of a signal $f(t) \in L^2(\mathcal{R})$ is:

$$S\{f(u,\xi)\} = < f, g_{u,\xi} > = \int_{-\infty}^{\infty} f(t) g(t-u) e^{-i\xi t} dt \tag{2}$$

where S stands for applying STFT to $f(t)$ with the (u, ξ) window, $< f, g_{u,\xi} >$ is the inner product of $f(t)$ and $g_{u,\xi}(t)$, and $L^2(\mathcal{R})$ is the whole function space. Therefore, the multiplication by $g(t-u)$ localizes the Fourier integral of $f(t)$ in the neighborhood of $t = u$, as shown in Fig. 1(a). In the figure, (u, ξ) is the center of the window in time-frequency domain, while σ_t and σ_ω are the width and length of the window, respectively. Therefore, after taking STFT, the energy of $f(t)$ is spread over both time interval $[u - \sigma_t/2, u + \sigma_t/2]$ and frequency interval $[\xi - \sigma_\omega/2, \xi + \sigma_\omega/2]$.

As discussed by Kaiser [10], STFT provides an inaccurate and inefficient method of time-frequency plane analysis, as it imposes a scale to do the localization. First, the inaccuracy comes from the aliasing of high and low frequency components, which actually do not fall into the frequency of the window [11]. Secondly, several window lengths must be selected and applied to determine the most appropriate one. Even though the appropriate window size has been determined, the provided time-frequency analysis is not only single resolution, but always averaged on both time and frequency dimensions.

STFT does not change the fact that the information in this time-frequency box is still averaged over both sides and that the information of sudden changes is lost. To satisfy the requirement of obtaining the occurrence of time-frequency information, Wavelet transform is introduced to perform this time-frequency-scale transformation, aiming at combining amplitude and spectrum decomposition together and as accurately as possible. In principle, when applied to the detection of discontinuities, short time phenomenon, and abrupt changes in a signal, Wavelet transform has better performance than other signal processing methods. It also provides higher resolution and better precision in presenting real-time changes of a signal's spectrum density function, thus, it is an essential way to characterize time-frequency structures [6]

3.2 Basis of wavelet transform

Wavelet transforms can be used to analyze non-stationary signals via decomposing and reconstructing them with wavelet basis or wavelet functions. There are two types of wavelet transform: Continuous Wavelet transform (CWT) and Discrete Wavelet transform (DWT). The term "wavelet basis" usually refers to orthogonal wavelets in the Hilbert space, while "wavelet function" generally represents either orthogonal or non-orthogonal wavelets [12]. In DWT, orthogonal wavelet basis is often applied to give the most compact representation of the signal. However, for time series analysis, CWT with non-orthogonal wavelet functions are recommended as it is highly redundant at large scales, and the wavelet spectrum is highly correlated [11]. In the proposed algorithm, CWT is also selected to apply the time-scale analysis for the time domain acoustic signals.

In CWT, a signal with finite energy is projected on a continuous collection of frequency bands, which compose the whole function space $L^2(\mathcal{R})$. The wavelet functions are the scaled shifts of one generating function $\psi_0(t) \in L^2(\mathcal{R})$, which is a continuous function in both the time domain and the frequency domain called the mother wavelet. These wavelet functions are given as:

$$\psi(t) = \frac{1}{\sqrt{a}} \psi_0 \left(\frac{t-b}{a} \right) \tag{3}$$

where a is a positive scale factor and b can be any real number that defines the shift. The normalization factor $\frac{1}{\sqrt{a}}$ is introduced to ensure the wavelet function have unit energy at each sale a.

CWT uses these wavelet functions to transfer time series into a time-scale wavelet domain, which provides a very detailed localization on both time t and scale a directions. Mathematically, it is defined as the convolution of the signal $f(t)$ with chosen wavelet functions [13]:

$$W_f(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} f(t) \psi_0^* \left(\frac{t-b}{a} \right) dt \tag{4}$$

where W_f represents the wavelet transform of $f(t)$, and '$*$' donates the complex conjugation operation. Valens also emphasized in his article [13]that it is important the wavelet functions are not specified in this mathematical wavelet frame, which is a clear ridge between wavelet transform and other transforms including Fourier transform. It is essential that wavelet transform designed a framework in which one can design wavelets for their own properties.

3.3 Comparison of CWT and Fourier transform

Compare equation (4) with continuous Fourier transform:

$$F_f(\omega) = \int_{-\infty}^{\infty} f(t) e^{-j\omega t} dt \tag{5}$$

It is apparent that Fourier transform is a specialized form of wavelet by substituting the wavelet functions with infinite and periodical sine and cosine waves. If we only take the wave in one period as the wavelet function (similar to what STFT does), then the period can be considered as the scale factor, as both of these two methods are sampling and quantizing signals so as to decompose them. As "period" in Fourier transform and "scale" in wavelet transform are proportional, frequency and scale are inversely proportional to each other. That is, high frequency components refer to small scales in wavelet domain, and both of them represent small details in the signal.

When facing the non-localizable problem of Fourier transform, researchers introduced STFT to impose the localization grid onto the signal. Unfortunately, this method leads to a confusing way of explaining frequency components in the time-frequency domain, as we discussed at the very beginning of this section. The particular window in STFT is a scale factor. However, if its size is constant, it can only represent the averaged frequency components inside the window, but not the real frequency components. This is why Kaiser regards it as inaccurate in building up the time-frequency analysis [10].

Therefore, compared to regarding wavelet transform as an extension of Fourier transform, it is more appropriate to state that Fourier transform is a particular case of wavelet transform, as wavelet transform is not only a transform but a framework for researchers to fill in their own wishes.

3.4 Applying CWT to discrete time sequence

Although CWT has been chosen for the time series analysis, a discrete form of CWT is needed for discrete time sequence and for the computational implementation. We can make the assumption of a time sequence, $x(n)$, with equal time step Δ_t and $n = 0, 1, \cdots, N-1$. Assume the wavelet function is given as $\psi_0(t)$, where t is a non-dimensional time parameter to form the function. Take Morlet wavelet for example (details will be provided in next section):

$$\psi_0(t) = \pi^{-\frac{1}{4}} e^{j\omega_0 t} e^{-\frac{t^2}{2}} \qquad (6)$$

This is a complex sine wave modulated by a Gaussian function, and ω_0 donates the non-dimensional frequency parameter. Then wavelet transform in (4) can be written as [11]:

$$W_f(a,b) = \sqrt{\frac{\Delta_t}{a}} \sum_{n=0}^{N-1} \left\{ x(n)\psi_0^* \left[\frac{(n-b)\Delta_t}{a} \right] \right\} \qquad (7)$$

In this equation, it can be seen that the convolution should be done for N times for each scale a. Thus, we can use discrete Fourier transform (DFT) to complete these N times convolution simultaneously. The DFT is calculated as:

$$\hat{X_k} = \frac{1}{N} \sum_{n=0}^{N-1} x(n) e^{-\frac{2\pi jkn}{N}} \qquad (8)$$

According to Fourier's properties, convolution in time domain corresponds to multiplication in frequency domain. Hence equation (7) can be written as:

$$W_f(a,b) = FFT^{-1}\left\{ \sqrt{\frac{2\pi a}{\Delta_t}} \sum_{n=0}^{N-1} \left[\hat{X_k} \hat{\Psi_0}^*(a\omega_k) e^{i\omega_k b \Delta_t} \right] \right\} \qquad (9)$$

where ω_k is the angular frequency defined as:

$$\omega_k = \begin{cases} \frac{2\pi k}{N\Delta_t}, & k \leq \frac{N}{2} \\ -\frac{2\pi k}{N\Delta_t}, & k > \frac{N}{2} \end{cases} \qquad (10)$$

3.5 Morlet wavelet

There are several known mother wavelets in CWT, for example, Morlet, Meyer and Mexican hat wavelet. All the mother wavelets must satisfy the conditions of zero mean and unit energy, respectively given as:

$$\int_{-\infty}^{\infty} \psi(t)dt = 0$$
$$\int_{-\infty}^{\infty} |\psi(t)|^2 dt = 1 \qquad (11)$$

Among these wavelet functions, Morlet wavelet is the earliest wavelet function used in CWT. It is a complex wavelet that contains the real part and the imaginary part, represented by a solid wave and a dashed wave respectively in Fig.7(a). The frequency domain representation of Morlet is a single symmetric Gaussian peak, as shown in Fig.7(b), which provides a better localization result in both time and frequency domain than the sharp peak of a sinusoid.

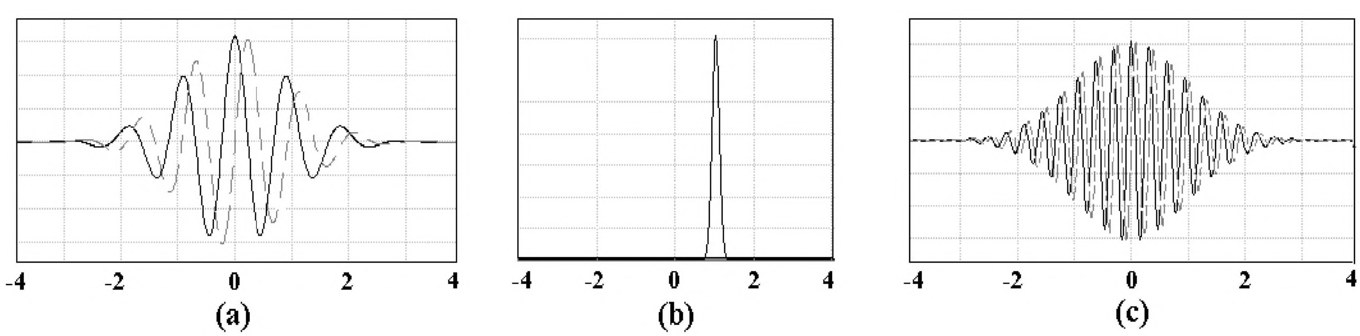

Figure 7: (a) Morlet wavelet with $\omega_0 = 6$. (b) spectrum of Morlet wavelet in (a). (c) Morlet wavelet with $\omega_0 = 20$.

In the Morlet wavelet equation (6), there is an admissibility condition of $\omega_0 > 5$. This ω_0 corresponds to the number of waves in Morlet. As shown in Figs. 7(a) and 7(c), the wave numbers are 6 and 20, respectively.

4 RESULTED ANALYSIS

4.1 Comparison of STFT and wavelet transform

In the CWT implementation, the Morlet wavelet has been chosen; and for the STFT illustration, the Gauss window is selected. The signals from industrial data are all '.wav' files with 1.5 seconds duration. In our experiment, all the signals are normalized to the same amplitude level in time domain. This means the amplitude of those accelerometer signals has been largely amplified. Furthermore, in both CWT and STFT computation, only the main part of the signal is processed, , the duration from $0.75s$ to $0.80s$ (in the following figures it is from 0 to 6, as there are 6000 samples). The pre-signal and post-signal noise has been removed to concentrate on feature extraction and to minimize the computational work.

4.1.1 Scale vs. frequency

When comparing wavelet transform with Fourier transform, it should be noted that frequency in Fourier transform and scale in wavelet transform are inversely proportional to each other. Hence, scale has a certain relationship with frequency. In [14], the following equation states this relationship especially for Morlet wavelet

$$a = \frac{b}{\omega} \tag{12}$$

where b is a constant, a is the scale parameter, and ω is the circular frequency of the signal.

Fig. 8 shows a typical WRE signal recorded by hydrophone, in both wavelet's time-scale distribution and STFT's time-frequency distribution, respectively. In addition, the 3D illustration of the wavelet domain is given to show the scale components clearly. The amplitude of the signal is described in red and blue colors. Generally, the color changing from blue to red implies the increased amplitude. Pure blue color represents only the background where no signal exists.

As shown in Fig. 8(b), in wavelet domain, the signal starts at scale 10, which corresponds to about 10 kHz in frequency domain in Fig. 8(c). It should be noted that the axis of scale a in Fig. 8(b) and frequency v in Fig. 8(c) are inversely distributed as explained before. The part of smaller than scale 2 in wavelet domain corresponds to above 30 kHz in STFT figures. This shows that high frequency components are highly compressed in wavelet domain due to Wavelet transform's characteristics. The part of larger than scale 8 corresponds to frequency lower than 12 kHz in STFT figures, and the details in this region have been significantly enhanced in wavelet domain.

4.1.2 Multi-resolution vs. single resolution

These compressing and enhancing properties make Wavelet transform more advanced than Fourier transforms such as STFT. Wavelet transform has multi-resolution for different scales. This property meets the need of our research appropriately. While for STFT, there is only one consistent resolution for the whole signal in time-frequency plane, thus the resolution of those frequency components cannot be distinguished for different uses. In this AE application, we would like to both enlarge low frequency components and compress high frequency components. These two objectives can be easily achieved using Wavelet transform rather than STFT. Because in STFT, different frequency components will be enlarged or shrunk together, as it has only one consistent resolution.

4.1.3 Detailed exhibition vs. averaged information

Except for above facts, the resolution of using STFT in AE signal processing is too low, and the details of the signal are wholly averaged over the STFT window. This means, if we want smaller unit length and more details in the frequency domain, the unit length in the time domain will be increased as the area of this time-frequency piece should keep the same. While for wavelet transform technique, the problem has been solved, as it is designed to exhibit the sharp discontinuities and fast changes. This is also shown in Figs. 8(a) and (b): in the time domain, there is a clear gap in the middle of the signal (white box framed), and in the wavelet domain this is apparently shown with the same gap length. However, in the STFT analysis of Fig. 8(c), the gap has been averaged that it is hard to notice. From this we can see that the unit time length in STFT is too large to detect the real-time changes of the amplitude, which results in losing signal features in the joint time-frequency occurrence.

4.2 Comparison of hydrophone and accelerometer

Fig. 10 compares the wavelet and STFT domain of a WRE signal recorded by accelerometer. As described before, this signal has certain differences with the hydrophone signal, in both amplitude and joint time-frequency structure.

As shown in Fig. 10, the overall amplitude of this accelerometer signal is smaller than previous signal in Fig. 8, although this signal is normalized. This is clearly shown in STFT figures, Fig. 10(c) and Fig. 8(c), due to STFT's low resolution and average of those larger-amplitude details. Moreover, the 3D meshing models of wavelet in Fig. 10(d) and Fig. 8(d) also illustrate this phenomenon. For the hydrophone's 3D model in Fig. 8(d), there are several red hilltops in the signal duration. While for the accelerometer in Fig. 10(d), there is only one clear peak.

Another feature here to distinguish accelerometer signals with hydrophone is the blank region (green box framed) around scale 2, which doesn't clearly appear in hydrophone's figures. This blank region corresponds to about $30 - 35$ kHz in frequency domain, which demonstrates the attenuation of high frequency in accelerometer's cases.

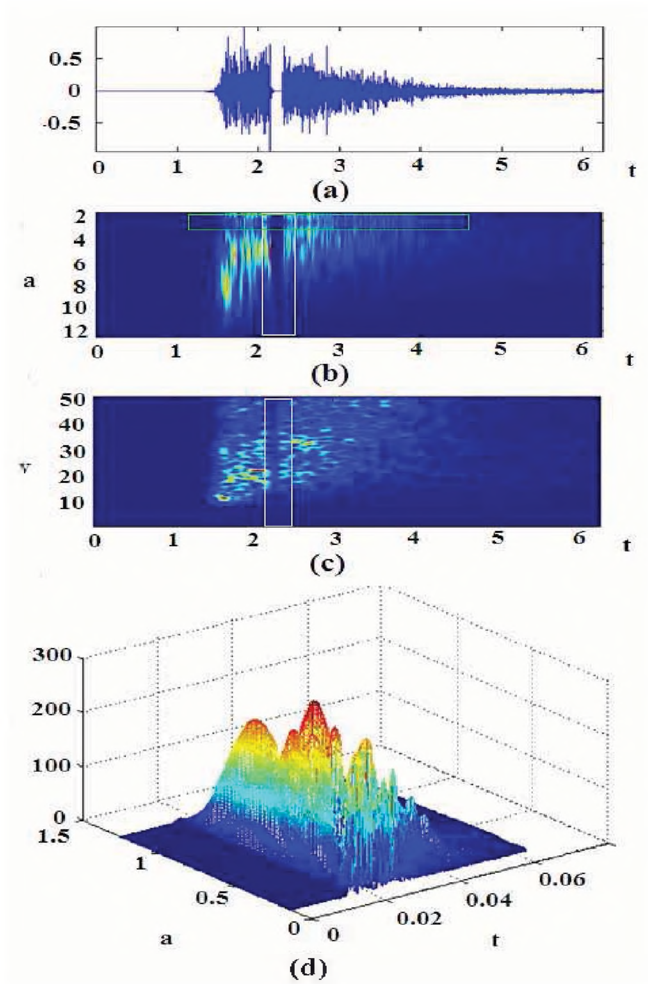

Figure 8: Transforms of a Hydrophone WRE signal: (a) time domain. (b) wavelet domain. (c) STFT for the signal. (d) 3D illustration of the wavelet domain.

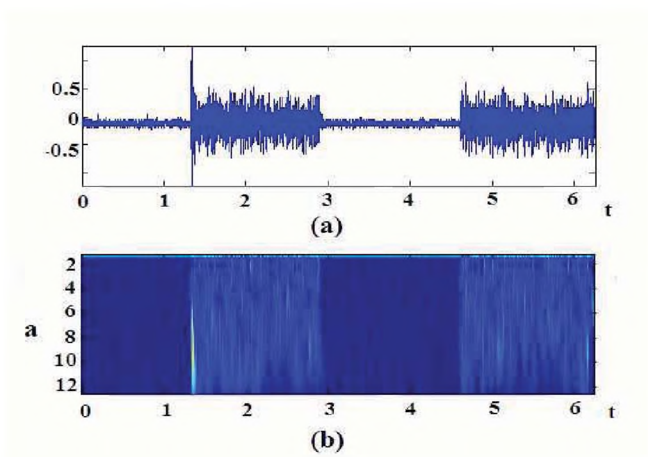

Figure 9: Wavelet transform of the first noise signal: (a) time domain. (b) wavelet domain shows very scattered density of noise signal 1.

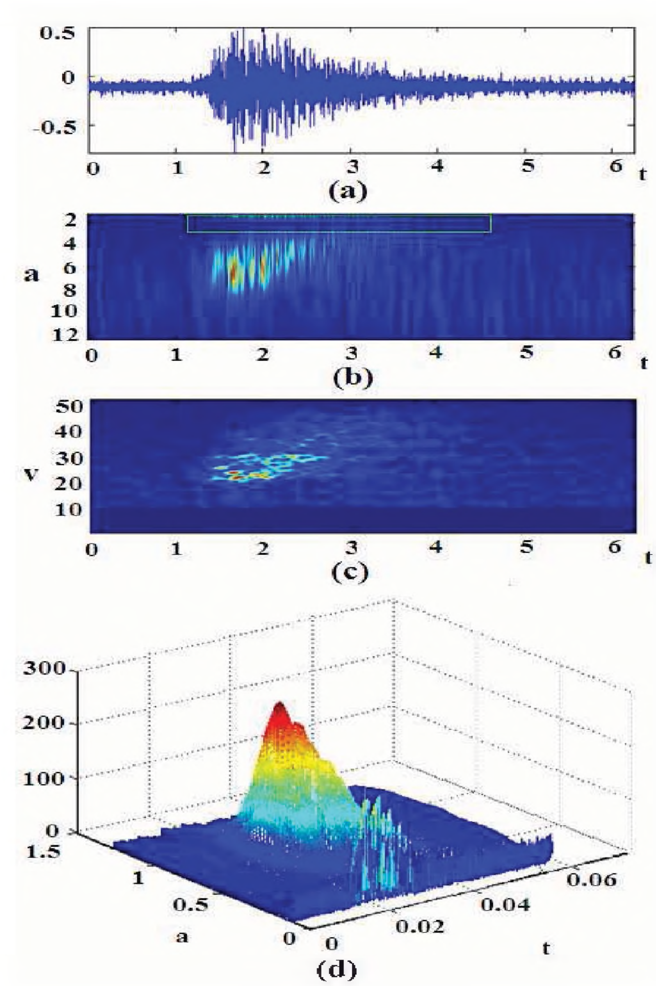

Figure 10: Transforms of a Accelerometer WRE signal: (a) time domain. (b) wavelet domain. (c) STFT for the signal. (d) 3D illustration of the wavelet domain.

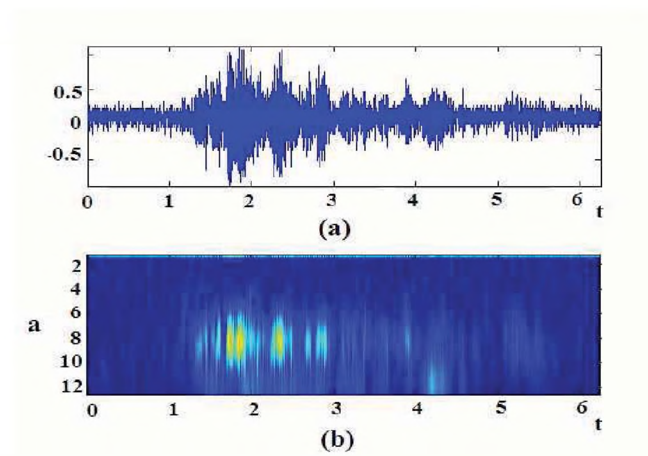

Figure 11: Wavelet transform of the second noise signal: (a) time domain. (b) wavelet domain shows large scale noise(low frequency) of noise signal 2.

4.3 Features of WRE signal in wavelet domain

This part deals with purpose of this research, which is to filter out most non-WRE signals and to detect the real WRE signals. Therefore, certain criteria should be set up as a dynamic filter. Before setting the criteria, features of ideal WRE signal should be summarized based on previous analysis. In addition, due to the different conditions of hydrophone and accelerometer, the features are distinguished according to different cases.

From the above analysis, the similar result obtained in section 2 can be concluded. However, due to Wavelet transform's high precision and enhancement of the abrupt changes in signal, we can see from the above figures that the large scale part, corresponding to low frequency component, decreases with time lapse almost linearly. This feature is important for the detection of real WRE signals. However, in the Gabor window mentioned in section 2, "the sharp of the knife", which describes the low frequency declining, does not seem to have this clear linear shape.

Figs. 9 and 11 exhibit two non-WRE data, which are typical noise signals with certain features: one is mess noise with scattered energy density; another is low-frequency noise, which locates much more in large scale part than in small scale part. These two types are the typical noise signals existing in the pipeline inspection.

From the plentiful industrial data, certain features of WRE signal have been concluded, which are also shown in Figs. 8 and 10:

- The energy should be concentrated in the main signal duration locating at 0.75s to 0.80s.
- Less than 20% of the energy lies in the location of scale $a > 8$, corresponding to low frequency region of $f < 12kHz$.
- More than 40% of the energy lies in the location between scale $2 < a < 6$, corresponding to median and high frequency region of $15kHz < f < 40kHz$.

In these three features, it is very important that the energy of real AE signal should be very condensed, which means most of the power should lie in the shown time band. The recorded data is most likely to be random noise if the ratio of power is too small, indicating that the energy is not concentrated around the certain spectrum. A large amount of noisy signals can be eliminated through pre-processing based on this feature. Wavelet analysis is not needed in this preprocessing.

Table 1 gives the parameters for above three features according to the results of bountiful tests. The given ratios are calculated as following:

$$PDR = \frac{\text{the energy of signal from 0.75s to 0.80s}}{\text{the energy of the whole signal}}$$

$$LSR = \frac{\text{the energy of signal in scale interval } a > 8}{\text{the energy of the whole signal}}$$

$$SSR = \frac{\text{the energy of signal in scale interval } 2 < a < 6}{\text{the energy of the whole signal}}$$

These parameters are chosen to be tolerant enough not to miss weak WRE signals, but still get rid of most noise data. It should be noticed that these features are distinguished for hydrophone and accelerometer, due to their different signal characteristics: the parameters chosen for hydrophone are more strict than accelerometer in all three features, as hydrophone signals have higher SNR and are easier to be detected.

Table 1: Threshold of Hydrophone(Hyd) and Accelerometer(ACC) WRE signals

	Hyd	ACC
Power-density-ratio(PDR)	4.85%	4.25%
Large-scale-ratio(LSR)	15%	22%
Small-scale-ratio(SSR)	40%	33%

5 IMPLEMENTATION AND EXPERIMENT RESULTS

As mentioned at the beginning, the purpose of this research is to filter out non-WRE signals and detect the real WRE signals. The experiment is carried out in two steps: first, get rid of the obvious non-WRE signals in order to save storage and reduce computational demand; secondly, detect the real WRE signals.

5.1 Implementation

The algorithms of both wavelet and STFT are implemented in Matlab 7.1 platform. The wavelet detection procedure is a four-step program, shown as following, where PDR, LSR and SSR refer to the ratios in Table 1:

1. Extract only the main part of the signal, which locates at 0.75 to 0.80 seconds in the recorded duration.
2. Calculate the power-density-ratio (PDR) of the extracted signal over the whole signal:
   If the ratio is larger than the threshold – consider as suspected WRE for further process;
   If the ratio is smaller than the threshold – obvious non-WRE, filter out.
3. Wavelet transform of the suspected WRE.
4. Calculate the scale ratio of transformed WRE:
   the large scale ratio (LSR) should be less than the threshold;
   the small scale ratio (SSR) should be greater than the threshold.

In these four steps, the first two steps aim to get rid of most obvious non-WRE data, and they achieve desirable results. The last two are not always satisfied due to the variety of WRE, and the wavelet features should be modified according to particular practical demands. As this is industrial application, the probability of miss detection should be as small as possible. It is a compromised situation to sacrifice the detection accuracy. Therefore, in real implementation, for the forth step, satisfying either feature will be considered as suspected-WRE, so as to reduce the miss detection probability.

5.2 Computational complexity issue

As the method and algorithm will be fully implemented in embedded system for industrial installation, it should minimize the processing time. Otherwise there might be missed signals during the processing time.

In the four steps, when doing wavelet transform, signals with more detail and noise usually take longer time to process, which means it is essential to get rid of the obvious non-WRE signals before wavelet transform procedure. Therefore, the first two steps of PDR filtering should be robust enough to filter out as many non-WRE signals as possible, while passing all the WRE signals.

Although the computation of PDR in the pre-processing is very easy, the threshold of PDR used in the first round of filtration has a large impact on the computational complexity of the second round of analysis that involves wavelet transform. A higher PDR threshold reduces the computational demand of the wavelet process but may result in missed detection of the weak WRE signals. Fewer WRE signals will be miss-detected but the processing becomes more complex if a lower PDR threshold is used. Different thresholds for hydrophone and accelerometers are used to produce the results presented in the following section. These thresholds are selected according to different practical requirement.

5.3 Results

In our experiment, over 5000 signals are tested to compare the miss alarm (MA) and false alarm (FA). Here MA represents a real WRE signal that is not detected; and FA represents a noise signal that is mis-detected as WRE signal. 6 groups of data are listed as bellow:

Table 2: Results of 6 tested groups

	1	2	3	4	5	6
Type	ACC	Hyd	ACC	Hyd	ACC	Hyd
Tested	41	28	89	269	517	756
Detected	38	28	11	15	66	2
Confirmed	41	28	3	14	3	0
MA	3	0	0	0	0	0
FA	0	0	8	1	63	2

In Table 2, the first two groups are all confirmed WRE signals for Accelerometer (ACC) and Hydrophone (Hyd), respectively. We can see that Hydrophone signals are all detected, while three Accelerometer signals are missed. When double checking the missed data, we figure out that one of them is too weak to be detected, and the other two have too many low frequency components. However, all of them satisfy at least one feature. While in real applications, these signals will be automatically considered as suspected-WRE, and subjected to further inspection.

The two groups in the middle are samples of observed data when certain AE event occurs.It can be seen that most of the signals are noise, and about 5% of the data are WRE signals. Also it is clear that the algorithm claimed above detected all the signals, and especially in Hydrophone case it works better.

The last two groups are real data from the same source as the middle groups. However, these are the data randomly picked from daily monitoring, and we can see that over 99% of them are noise. Due to different condition, we can see that for Hydrophone, 99.9% of the noise is excluded, while for Accelerometer, more false alarms happened because of looser criteria. Consequently, in industrial application the proposed algorithm and criteria will not only greatly reduce the labor work of manual detection that the company is now using, as it is such a tedious and biased work to discriminate signals using eyes and ears, but also hugely increase the accuracy of detection.

6 CONCLUSIONS

In this paper, the Morlet wavelet is used to extract the features of WRE signal in Pre-stressed Concrete Cylinder Pipes (PCCP). Compared with Short-Time Fourier transform, the Wavelet transform provides better signal detection due to its inherent ability to detect abrupt changes. Also from the experimental results we can see that wavelet transform is a robust technique in time-scale-frequency analysis. In summary, wavelet analysis is an efficient technique for AE signal processing, especially in extracting detailed features, and detecting signals under investigation.

7 ACKNOWLEDGEMENT

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ANALYSIS OF A BARREL-STAVE FLEXTENSIONAL TRANSDUCER USING MAVART™ AND ATILA FINITE ELEMENT CODES

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ABSTRACT

A small barrel-stave flextensional transducer, designed and tested at Defence Research and Development Canada – Atlantic (DRDC Atlantic), is a candidate source for underwater coastal surveillance and acoustic communications applications. This high-power transducer (in excess of 190 dB re 1 μPa @ 1 m) has an outside diameter, length and mass of 5.7 cm, 12.7 cm, and 1.1 kg, respectively. The measured fundamental flexural resonance frequency was 1.8 kHz with a transmitting voltage response of 118 dB re 1 μPa/V @ 1m and an omnidirectional radiation pattern. Two computer models were developed for this transducer using finite element codes MAVART™ (Model to Analyze the Vibrations and Acoustic Radiation of Transducers) and ATILA (Analysis of Transducers by Integration of Laplace equations). Comparisons are made between the calibration measurements and the model predictions. [[2]Summer student supported in part by Sensor Technology Limited.]

SOMMAIRE

Un petit transducteur flextensionnel à douves, conçu et mis à l'essai à Recherche et développement pour la défense Canada – Atlantique (RDDC Atlantique), est une source possible pour des applications de surveillance côtière sous-marine et de communications acoustiques. Ce transducteur de grande puissance (supérieure à 190 dB, rapportée à 1 □Pa à 1 m) a un diamètre extérieur de 5,7 cm, une longueur de 12,7 cm et une masse de 1,1 kg. La fréquence fondamentale de résonance en flexion mesurée était de 1,8 kHz avec une réponse en tension d'émission de 118 dB, rapportée à 1 □Pa/V à 1 m, et un diagramme de rayonnement omnidirectionnel. Deux modèles informatisés ont été élaborés pour ce transducteur à l'aide des codes à éléments finis MAVART™ (modèle pour analyser les vibrations et le rayonnement acoustique de transducteurs) et ATILA (analyse de transducteurs par intégration d'équations de Laplace). Des comparaisons sont effectuées entre les mesures d'étalonnage et les prédictions à partir des modèles. [[2]Stagiaire d'été rémunéré en partie par Sensor Technology Limited.]

1. INTRODUCTION

The Class I barrel-stave flextensional transducer is capable of low frequency operation in a relatively small package [1]. This transducer is composed of the five basic components shown in Fig. 1: a driver consisting of sixteen piezoelectric washers, two glass ceramic insulators, two stiff carbon steel endplates, a set of six aluminum staves, and a central stainless steel stress rod. With longitudinal piston motion of the driver, the endplates displace axially causing the staves to flex in the radial direction. Since the staves are curved, the relatively small driver displacements are transformed into larger stave displacements [2].

Much of the design and development of the barrel-stave transducer has been accomplished through the use of finite element modeling, reducing costs and prototype turnaround times. At DRDC Atlantic, transducer modeling has made extensive use of the MAVART™ (**M**odel to **A**nalyze the **V**ibrations and **A**coustic **R**adiation of **T**ransducers) and ATILA (**A**nalysis of **T**ransducers by **I**ntegration of **LA**place Equations) finite element codes.

MAVART™ is a finite element code under development at DRDC Atlantic for transducer design since 1976. This coupled-physics code makes it possible to model and analyze the electro-mechanical-acoustic interactions of piezoceramic- and electrodynamic-driven transducers in fluid media. In MAVART™, the coupling of elastic and electrical fields is carried out by augmenting elastic matrix variables with constituitive relations for the driving materials. The surrounding fluid is modeled similarly with the nodal pressures becoming the finite element variable. The Helmholtz integral is used to determine the effect of the infinite fluid force on the finite-element-modeled fluid. All variables are assumed to vibrate sinusoidally at the selected frequency. The complex solution consists of fluid node pressures, voltages at nodes on the drive elements and displacements of solid element nodes. These solutions are post-processed into stresses and strains, far-field transmitting responses, hydrophone sensitivities, directivity indices, electrical admittances, and fluidic pressure gradients [3]. MAVART™ presently exists in 2D, 3D and magnetic versions. Geometry construction of finite element models is carried out using the DRDC Atlantic-developed ModelMaker™ add-on for Mathematica® [4].

Beginning in the late 1970s, the finite element model ATILA was developed by researchers in France at the Institut Supérieur d'Electronique du Nord in collaboration with the Centre d'Etude et de Recherche de Détection Sous-

Marine. Although the program was originally intended as a design tool for sonar transducers, ATILA has been used to study many types of active and passive mechanical structures in any type of acoustic fluid media. ATILA can handle 2D and 3D problems as well as elastic, piezoelectric, magnetostrictive, and electrostrictive materials [5–6]. Elastic and electroacoustic quantities calculated by ATILA include displacement fields, stress fields, near-field and far-field pressures, electrical impedances, transmitting voltage and current responses, open circuit voltage receiving sensitivities, and beam patterns.

In this paper, 2D MAVART™ and ATILA finite element models were developed for the barrel-stave transducer. Measured fundamental flexural and longitudinal resonance frequencies were matched using several geometric and material approximations. Measured response levels were achieved by using damping in the models. This is the first time that finite element modeling results of this barrel stave transducer have been published in the open literature.

2. Transducer Component Dimensions

The dimensions of the main components of the barrel-stave flextensional transducer shown in Fig. 1 are given in this section. The driver consists of a ring-stack of sixteen piezoceramic lead zirconate titanate washers poled through the thickness and connected in parallel electrically. Each washer has an outside diameter of 30 mm, an inside diameter of 7 mm, and a thickness of 5.6 mm. At each end of the piezoceramic ring-stack is a machinable glass ceramic insulator with the same diameters as the washers but a thickness of about 6 mm.

Figure 1: Barrel-stave flextensional transducer components clockwise from upper right: sixteen piezoceramic washers, two ceramic glass insulators, two hexagonal endplates, six concave aluminum staves (the two shown separately are 12.7 cm long), and a stress rod located along the axis of the transducer.

Two hexagonal endplates are bonded to the insulators. The carbon steel endplates have a 7-mm-diameter hole in the center (to allow the stress rod to pass through), an edge length of 27 mm, and a thickness of 12.5 mm. A 4.8-mm-diameter stainless steel stress rod is used to apply a compressive bias to the ring-stack. Six concave aluminum staves are bonded and bolted to the sides of the hexagonal endplates. The staves are 12.7 cm long, have a maximum thickness of 5 mm, and a radius of curvature of 20.0 cm. Since this transducer's shape is fully described over $1/n^{th}$ of its circumference, it is said to have n-fold symmetry. In the case of this projector, since its geometry is fully described over $1/6^{th}$ of its circumference, it is 6-fold symmetric.

3. Finite Element Models

Two finite element models were developed using the transducer design codes MAVART™ and ATILA. The first author used the former code, the other two authors the latter. Apart from transducer dimensions and material properties, the models were developed independently. A 2D barrel stave model was developed in 1996 at DRDC Atlantic and analyzed in MAVART but the analysis was confined to the first resonance and described a different version of the barrel stave projector [7].

3.1. MAVART™ barrel-stave transducer model

The barrel-stave flextensional transducer geometry and mesh were generated using the ModelMaker™ [8] add-on to Mathematica®. As seen in Fig. 2, the single quadrant model was composed of 342 quadratic elements (Table 1) with 1321 nodes. The elements included quadrilateral axially-poled piezoceramic elements, quadrilateral solid elements, fluid-to-solid elements, fluid elements and fluid-to-fluid infinite elements. Air was modeled in the volume between the inside of the stave material and the outside of the driver.

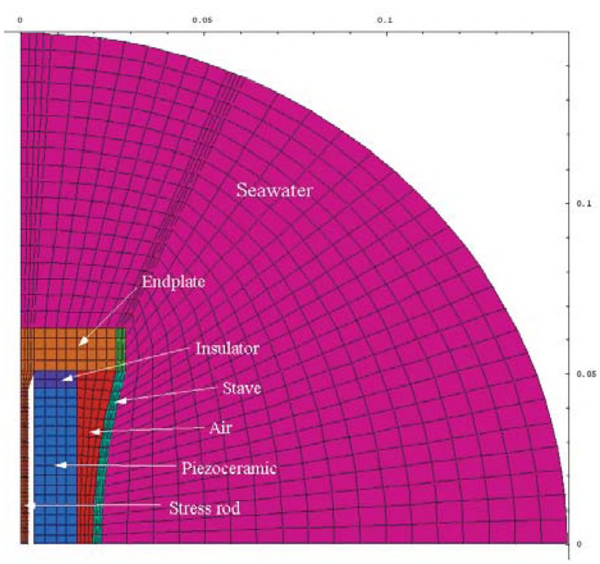

Figure 2: 2D MAVART™ barrel-stave transducer model.

The dimensions of the piezoceramic ring-stack washers, insulators, endplates and most of the stress rod were the same as those in the actual projector (Section 2). The transition of the stress rod diameter to the larger endplate inside diameter was varied to retain topological congruence. The outside diameter of the endplate (assumed to be circular) was the difference between the stave thickness and the outside diameter of the transducer. The stave thickness was set at 2.5 mm instead of the crescent-shaped cross-section of the actual stave. The aluminum at the stave/endplate intersection was modeled as isotropic as there is no appreciable movement here, relative to the endplate.

The material matrix of the aluminum used for the staves had to account for the fact that the model could not include the inter-stave slots or variation in stave wall thickness over the transducer's circumferential direction. This deviation from a truly isotropic stave material was necessary to give the finite element model its ability to breath and radiate sound in a manner similar to the actual transducer. Both material damping and a fictitious transversely isotropic aluminum were selected so that the first resonance of the model matched that of the measured values in both frequency and TVR. The tangential stiffness of the transversely isotropic aluminum used in the stave was reduced by a factor of 155.

3.2. ATILA Barrel-stave Transducer Model

A 2D finite element grid was used to model the barrel-stave flextensional transducer with ATILA. Using appropriate displacement boundary conditions along the central axial and radial planes, symmetry in both the longitudinal and circumferential directions reduced the problem to solving the one-quarter cross-section shown in Fig. 3. In total, the model consisted of 1688 elements and 3617 nodes. A breakdown of the elements by material type is given in Table 1. Quadrilateral elements were used for the solid materials and triangular elements for the seawater, the latter elements created using ATILA's automatic mesh generator.

The hexagonal endplates were modeled as circular plates by assuming that their cross-sectional areas were identical. The aluminum staves were assumed to have a constant thickness of 2.54 mm instead of a crescent-shaped cross-section. The curved portion of the staves was assumed to be a fictitious transversely isotropic aluminum with the hoop (tangential) compliance increased by a factor of 210. Damping was included in the ring-stack to achieve the best fit to the experimentally determined TVR level at the fundamental flexural resonance.

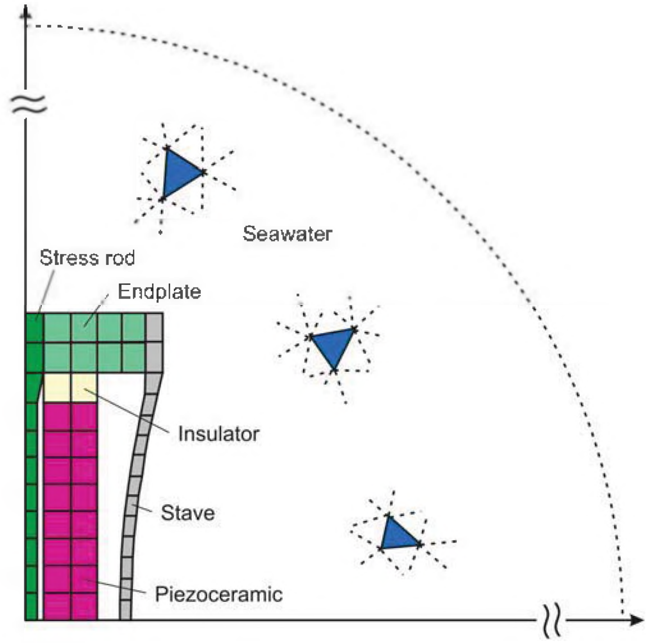

Figure 3: 2D ATILA barrel-stave transducer model.

Table 1: MAVART™ and ATILA element comparisons.

Number of Elements		
Material	MAVART™	ATILA
Stress rod	44	11
Piezoceramic	16	16
Insulator	2	2
Endplate	12	8
Stave	22	14
Air	37	0
Seawater	209	1637

4. Results

Post-processing of the finite element models yielded transmitting voltage responses (TVRs) in both the axial and radial directions, as well as directivity patterns near the first and second resonance frequencies.

Both finite element models' predictions of performance both in TVR (see Figs. 4 and 5) and directivity pattern (see Figs. 6 and 7) are in good agreement especially near the first two resonances.

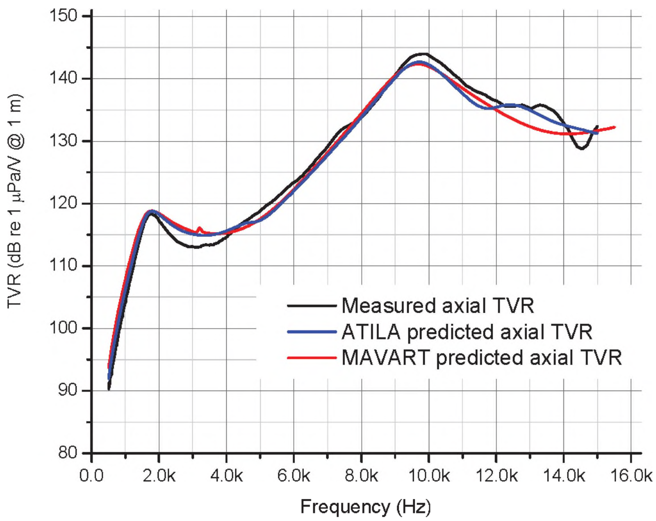

Figure 4: Measured versus modeled axial TVRs.

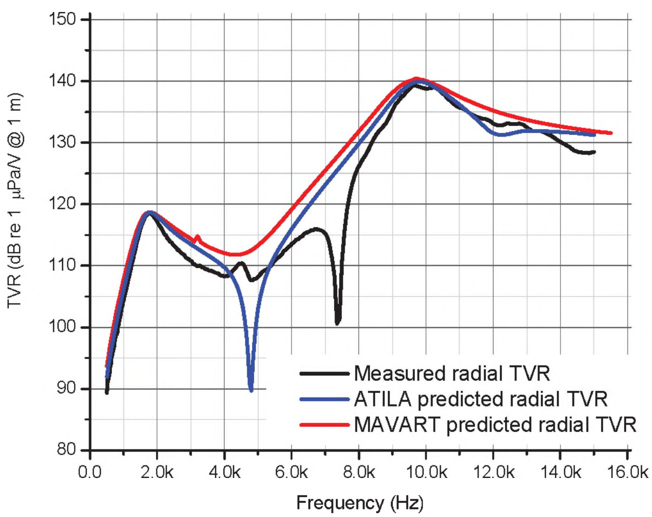

Figure 5: Measured versus modeled radial TVRs.

Variations in radial TVR levels between predictions and measured data in the 3–8 kHz band may be due to 3D effects not be fully described in a 2D model or to the presence of the waterproof rubber boot material covering the projector which was not modelled. The difference in transversely isotropic aluminum stiffness ratio between models or the presence of air inside the projector in the MAVART™ model may explain the inter-model radial TVR discrepancy. Further investigation into these disparities is under way with the added benefit of a new single-fold segment 3D model of this transducer.

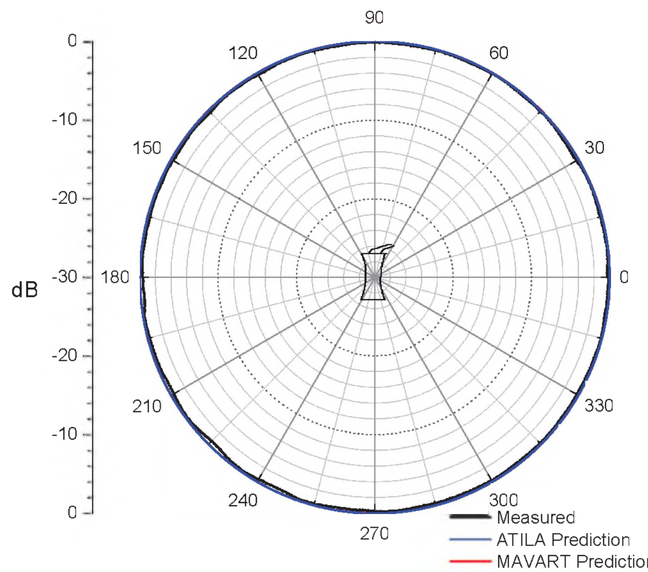

Figure 6: XZ directivity pattern at 1.5 kHz.

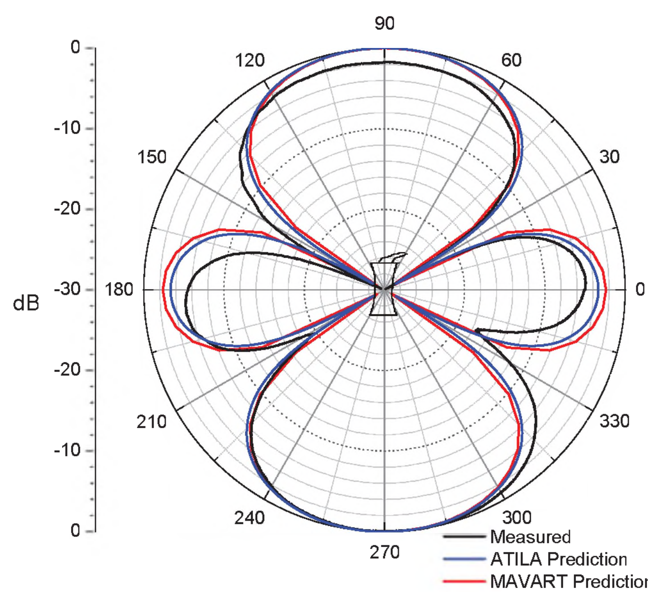

Figure 7: XZ directivity pattern at 9 kHz.

The 2 dB asymmetry seen the projector's measured endfire directivity pattern at 9 kHz is due to the presence of the wiring and waterproofing on one end of the transducer (see Fig. 7). Note also that the measured directivity pattern at 9 kHz is rotated counter-clockwise a few degrees. The modelled response pattern shape at 9 kHz is consistent over all angles. The level disagreement seen in the x-direction between the measurement and model may be due to boot material losses or 3D stave effects.

As can been seen in the results, these models make it possible to quickly model the fundamental performance of this 6-fold symmetric barrel-stave transducer and aid in its further development.

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Titre: Nuisances sonores Prévention, protection, réglementation
Auteur : Louise SCHRIVER-MAZZUOLI
Editeur : DUNOD; Collection : L'usine nouvelle
Année : 05/2007; Nombre de pages : 190
N° ISBN : 9782100502226; Reliure : Relié

Cet ouvrage traite de la prévention, la protection et la réglementation relatives aux nuisances sonores.
Les trois premiers chapitres constituent une introduction aux bases de l'acoustique et la psychoacoustique. Les caractéristiques physiques du son sont présentées au premier chapitre, les concepts de perception auditive sont abordés au deuxième chapitre et le troisième chapitre présente la physiologie de l'oreille et recense les effets du bruit sur la santé.
Les chapitres 4, 5 et 6 sont des chapitres techniques et appliqués qui traitent de la mesure du bruit. Les indicateurs d'impact et de gêne environnementaux utilisés pour quantifier et qualifier l'exposition des individus aux nuisances sonores sont présentés au chapitre 4, tandis qu'au chapitre 5 sont présenté les différents indices utilisés pour évaluer le confort acoustique dans les bâtiments. Le chapitre 6 présente les appareils de mesure du bruit (sonomètre, dosimètres, etc.) ainsi que les techniques de mesure des indices de qualité sonore des bâtiments (eux-mêmes déjà présentés au chapitre 5).
Le chapitre 7 et 8 décrivent succinctement les diverses solutions de prévention en milieu urbain (bruit de transport, bruit environnemental ou bruit de voisinage). La réduction du bruit en milieu de travail est abordée au chapitre 7 et complétée au chapitre 8 par le traitement acoustique des locaux.
Finalement le chapitre 9 passe en revue les récents éléments de réglementations adoptés en France.

Cet ouvrage constitue une introduction rapide, simple mais couvrant bien l'ensemble de la problématique parfois complexe des nuisances sonores. Les références aux textes normatifs et législatifs sont récente, mais ne concerne que le territoire français. On pourra regretter l'absence de références bibliographiques plus complètes permettant au novice d'approfondir ses connaissances et à l'expert de bien voir d'où proviennent certaines données ou idées émises.

Ce livre est à recommander à toute personne souhaitant acquérir des notions en acoustique et appréhender les moyens de lutte contre le bruit.

Jérémie Voix, Ph.D., Sonomax, Montréal

ICSV16 PRESS RELEASE

The Sixteenth International Congress on Sound and Vibration (ICSV16), sponsored by the International Institute of Acoustics and Vibration (IIAV) and the Polish Acoustical Society (PTA) will be held in Krakow, Poland, 5-9 July, 2009, in cooperation with the International Union of Theoretical and Applied Mechanics (IUTAM), the American Society of Mechanical Engineers International (ASME International), and the Institution of Mechanical Engineers (IMechE). The congress has received the honorary patronate of the Mayor of the City of Krakow. The venue of the ICSV16 is the AGH University of Science and Technology.

Theoretical and experimental research papers in the fields of acoustics, noise and vibration are invited for presentation. Companies are invited to take part in the ICSV16 Exhibition and sponsoring.

Krakow has traditionally been one of the leading centres of Polish scientific, cultural and artistic life. The intellectual potential of Krakow is created by 22 universities, nearly 20,000 academic lecturers and 190,000 students. As the former capital of Poland with a history encompassing over a thousand years, the city remains the spiritual heart of Poland. It is a major attraction for local and international tourists and welcomes seven million visitors annually. In 1978, UNESCO added Krakow's historic centre to the list of World Heritage Sites.

Deadline for submission of abstracts (http://www.iiav.org/icsv16): 1 December, 2008.
Deadline for proposals for structured sessions (icsv16@iiav.org): 1 November 2008.

Congress website: **www.icsv16.org**

IIAV is an international non-profit scientific society affiliated to the International Union of Theoretical and Applied Mechanics (IUTAM). IIAV currently has over 500 individual members in 55 countries and is supported by 32 national and international scientific societies and organisations.

For further details contact:
Marek Pawelczyk Marek.Pawelczyk@polsl.pl or Malcolm J. Crocker crockmj@auburn.edu

Riding the Waves – A Life in Sound, Science and Industry
by Leo Beranek
The MIT Press
List Price $24.95 US
235 pp., ISBN 978-0-262-02629-1

'Riding the Waves – A Life in Sound, Science and Industry' is the autobiography of Leo Beranek, arguably the most famous living acoustician. Although the book mentions many significant acoustic events, it is not overly technical, but is a truly fascinating and enjoyable read. Beranek's life has covered most of the 20^{th} century and on into the 21^{st} century. He was writing textbooks on acoustics before many of us were born and as this book proves, his unbelievable productivity continues. His many significant achievements are so numerous and extensive it is difficult to summarise them without repeating large parts of this book. However, all of these remarkable and historic achievements started with a family struggling to survive on an Iowa farm in 1914.

The author starts by describing the hardships of his early life such as 2 hour wagon rides to school and various early entrepreneurial efforts to earn enough to support his education, including running his own radio repair business. His chance encounter with a professor from Harvard led to a scholarship to Harvard and eventually a doctorate for Beranek.

Graduating at the beginning of the Second World War provided many opportunities and with Beranek's energy and drive led to many great successes. In 1946 he became the technical director of the MIT Acoustics Laboratory and his academic career flourished. It was shortly after this that Bolt Beranek and Newman (BBN) was formed and developed into a large acoustical consulting business that trained many of today's well known acoustical consultants. Although BBN was very significant in the acoustics field, it grew to be even greater in computing with significant contributions to the birth of the Internet.

With a life full of so many great successes, the events surrounding the acoustical problems of the Lincoln Center were particularly difficult for Beranek. In his Prologue he describes it as giving him a chance to reflect and to acquire new perspectives. He later describes with some pride the more recent successes of the new concert halls in Japan on which he has worked.

Although much of his story is related to a life working in acoustics, there is much more. The story of his leading a group of businessmen to take over and develop a Boston television station hovers suspensefully on the brink of disaster for several years. Again Beranek's skills and boundless energy won the day and the station was a huge success.

If you work in acoustics you should read this book to better understand the history of the development of acoustics in the US and the life of Leo Beranek. To paraphrase a quote from the back cover of this book, it gives clear evidence that the fabled American Dream is in this case a demonstrable fact.

John Bradley
Institute for Research in Construction
National Research Council

George W. Bush awards National Medal of Science to Leo Beranek, September 2, 2003.

EXCERPTS FROM "*SCANNING THE JOURNALS*", IN *ECHOS*, ASA

"A Sound Use for Heat" is the title of an article on **thermoacoustics** in the November/December issue of *American Scientist*. The article focuses largely on the work of Orest Symko and his colleagues at the University of Utah (see *ECHOES*, Summer 2006 issue). Their work has been directed especially toward converting waste heat from computers, electronics, power plants, and automobiles into electricity. To accomplish this, the heat is first used to generate sound, which is then converted into electricity by means of piezoelectric transducers. The thermoelectric converters, which have no moving parts, can work with a temperature difference as low as 25 degrees Celsius, although larger temperature gradients increase efficiency.

A novel program at the National Science Foundation (NSF) to support **innovative ways of communicating science** has attracted few applicants, according to an article in the 30 November issue of *Science*. The 4-year-old Discovery Corps Fellowship (DCF) program, which gives 2-year, $200,000 grants to both postdocs and experienced investigators for research and outreach, has attracted few applicants, and in a time of tight funding, a new program solicitation that's about to hit the streets could be its last. Fellows say one big obstacle is that the scientific community, for all its handwringing about a scientifically illiterate public, still views outreach as a dubious activity for those on an academic career path.

Two letters discussing spontaneous activity in **developing auditory systems** appear in the 1 November issue of *Nature*. Spontaneous activity in the developing auditory system is required for neuronal survival as well as the refinement and maintenance of tonotopic maps in the brain. However, the mechanisms responsible for initiating auditory nerve firing in the absence of sound have not been determined. Supporting cells in the developing rat cochlea are found to release glutamate, triggering discrete bursts of action potentials in primary auditory neurons.

EXCERPTS FROM "*ACOUSTICS IN THE NEWS*", IN *ECHOS*, ASA

Twenty-two varieties of beaked whales roam the seas, diving as deep as a mile to feed on bottom-dwelling squid and small fish on the dark ocean floor. According to a story in the October 15 issue of the *Washington Post*, the realization that sonar can disorient or frighten whales sufficiently to leave them beached and dying has spurred protests and lawsuits. The Navy first denied but now acknowledges the problem, but it has resisted efforts to limit testing of their sonar, saying it is essential to national security. The Navy has now funded a $6 million project to learn more about beaked whales and their response to sonar and loud ocean noises. The goal is to learn more about beaked whales by attaching sophisticated motion detectors to record the timing, depth and angles of their dives and ascents to see how the animals react when exposed to sounds approaching the intensity of sonar signals. Beaked whales can dive for periods as long as 85 minutes.

Test sections of asphalt rubber in the Seattle area are drawing favorable comments, according to a story in the December 17 issue of *The Seattle Times*. Recent tests show older asphalt registers about 105 decibels when measured with a microphone on a rear wheel of a vehicle about 2 inches above the pavement. Brand-new conventional asphalt registers about 100 decibels, while new rubberized asphalt tends to be about 95 to 96 decibels. Pound for pound, asphalt rubber and polymer asphalt are more expensive than conventional asphalt, but since they're placed at half the thickness, they end up costing about the same. However, the life span of asphalt rubber tends to be several years shorter. Since 1988, the Arizona Department of Transportation has used asphalt rubber in more than 3,000 miles of pavement overlays. Arizona now recycles 70 percent of its used tires back into the highways, eating up about 1,500 tires per lane mile of highway.

Quiet hotels were the subject of two articles in *The New York Times*. Although luxury hotels have often made efforts to "soundproof " their rooms, an article in the October 21 issue describes efforts by AmericInn, a mid-range hotel chain, to reduce room noise by using masonry blocks filled with sound-absorbing foam, in addition to drywall that is 5/8-inch thick instead of 1/2-inch. It also installs gaskets and door sweeps to minimize hallway noise and obtain a Sound Transmission Class test of 50 or higher. The Fairmont Vancouver Airport hotel recently created a "quiet zone" on its sixth floor for daytime sleepers. Loews Hotels have been offering guests free sound-masking machines that emit white noise for light-sleeping guests. An article in the October 2 issue cites other examples of construction with double-glazed windows and insulated walls. Older luxury hotels often were built "like the Maginot Line," with enormous thick walls but when hotels add plumbing or wiring to such a structure they have a temporary noise problem. Some hotels, especially in the luxury market, deliberately encourage the kind of bustle and excitement in lobbies and bars that can lead to noise seeping into guest rooms. One hotel was recently built with 8-inch thick walls between rooms.

A federal judge limited the Navy's ability to use mid-frequency sonar on a training range off the Southern California coast, according to a story in the January 4 issue of the *Washington Post*. The court ruled that the loud sounds would harm whales and other marine mammals if not tightly controlled. The order banned the use of sonar within 12 nautical miles of the coast and expanded from 1100 yards to 2200 yards the "shut down" zone in which sonar must be turned off whenever a marine mammal is spotted. The judge also forbade sonar use in the Catalina Basin, an area with many marine mammals. The decision is a blow to the Navy, which has argued that it needs the flexibility to train its sonar operators without undue restrictions.

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Canadian Acoustical Association

Minutes of the Board of Directors Meeting
26 April 2008
Toronto, Ontario

Present: Christian Giguère (chair), Dalila Giusti, David Quirt, Alberto Behar, Rich Peppin, Stan Dosso, Tim Kelsall, Clair Wakefield, Vijay Parsa, Frank Russo, Jérémie Voix

Regrets: Ramani Ramakrishnan, Nicole Collison

The meeting was called to order at 10:06 a.m. Minutes of the Board of Directors meeting of 9 October 2007 were approved as published in Canadian Acoustics (December 2007 issue). *(Moved A. Behar, second S. Dosso, carried).*

President's Report

Christian Giguère reported that there have been no major problems in the affairs of the Association. He suggested that the current priority is to update the website by adding online capabilities to support the Treasurer and Secretary. He noted the addition of new members, and welcomed Frank and Jérémie to the Board. He noted that David has requested replacement as Secretary in the fall.

One item arising from the President's report was debate of a request received from ICBEN to sponsor their upcoming conference. It was decided that CAA would not provide financial support *(Moved A. Behar, second R. Peppin, carried)*

Secretary's Report

David Quirt reported that routine processes of the Association are proceeding with few problems. Secretarial operating costs for the year to date were $774 (similar to last year), mainly for mailing costs and postal box rentals.

To ease membership renewal, the Secretary and Treasurer have continued the option of payments by VISA; about 39% used this method. Online handling of the payment process and updating of membership address data are anticipated. (See Website report.)

Issues of Noise News International were mailed to 45 members who requested this option, and are now arriving from the publisher in the USA shortly after the cover date.

With respect to routine CAA communications:

- Forms for annual filing with Corporations Canada have just been received.
- Invoice from I-INCE has been received and transferred to Treasurer for payment.
- Invoice from ICA was processed earlier.

David reported that memberships have risen. Renewals are essentially unchanged from last year, but many new members were enrolled at the Montreal conference. Last year the total was 338 on 20 April, and this year's paid-up total on that date is 377.

Mailing list (20 April)	Canada	USA	Other	Change
Member	215	20	9	**+20**
Student	60	1	5	**+19**
Sustaining	36	3	1	–
Direct	3	1	–	–
Indirect	10	8	4	–
		Total = 377		**+39**

As usual, this report prompted discussion of possible changes in membership categories, and the related issue of promoting increased membership.

The category of Direct Subscriber has dwindled, and it was agreed that this option should be eliminated before implementation of online processing. The Secretary was delegated to contact these subscribers to implement conversion to Member or some other option. *(Moved D. Giusti, second T. Kelsall, carried)*

The alternatives of keeping an annual membership period, or switching to quarterly start dates aligned with issues of *Canadian Acoustics* were discussed. The latter option would eliminate the significant effort to mail back issues to new members joining between January and August. Another option would be to keep a fixed annual period but align it with our financial year, beginning 1 September. It was agreed that we need a careful assessment of how this would mesh with our bylaws and accounting rules. An ad hoc group (Christian, Tim, Dalila, Dave) will seek expert advice and report to the Board at the next meeting

Rich launched a far-ranging discussion of options for promoting membership including: an online journal, conference enhancements such as tutorial sessions, online library of technical resources, some forms of professional recognition, and multi-year memberships. Other possible categories of membership were identified in previous minutes. It was agreed that such changes will be delayed until our enhanced website services are operational. Board members will send ideas to Rich, who will compile a report for the next meeting.

Treasurer's Report

The Treasurer, Dalila Giusti, submitted a report including a preliminary financial statement for the fiscal year to date. Most expenses were essentially as budgeted. The invoicing backlog for advertising revenue is nearly eliminated.

The immediate problem is that interest on our capital fund has been very low and will not cover the anticipated $8950 for prizes in 2007/08. Investment strategy for the capital fund was discussed. Interest on GIC's and government bonds (our traditional investments) has dropped again. The Secretary will proceed with (previously authorized) adjustment of our investments, to ensure some yield on all funds.

Dalila noted her intent to propose a fee increase at the October meeting. The Treasurer's report was accepted. *(Moved S. Dosso, second V. Parsa, carried)*

Editor's Report

The Editor, Ramani Ramakrishnan, submitted a brief e-mail report on issues related to content and publication process for *Canadian Acoustics*. Ramani is on sabbatical until September, but operation of the journal is proceeding essentially as usual, since most stages of publication are handled via email transfer of files.

A special issue was published in March 2008, which featured papers from a workshop on acoustics of marine mammals. The intent is to publish a special conference issue each year.

The implementation of online publication of the journal has not advanced significantly.

CAA Conferences – Past, Present & Future

2007 (Montreal): No final report or transfer of funds has been received for the conference in Montreal.

2008 (Vancouver): Organization of the conference is on schedule, with Murray Hodgson as Chair. One interesting innovation is organizing room-sharing for students staying in the conference hotel. See the announcements in March and June issues of *Canadian Acoustics*.

2009 (Niagara): Organization of the conference is on schedule, with Moustafa Osman and Ramani Ramakrishanan leading the team.

Subsequent meetings: Sites for later meetings were discussed. Desirable options included Banff, Québec, or the Atlantic provinces, if teams can be established.

Awards

Frank Russo presented a report.

- The prize announcement is ready for the June issue of *Canadian Acoustics*.
- All the prize coordinators have agreed to continue for another term.
- For the Vancouver meeting, banquet tickets will be provided for winners who are registered.
- Submission deadlines are imminent, and there are applications for many, but not all, awards.

Some new ideas for award funding were discussed, especially for student presentations.

CAA Website

Christian led discussion on the CAA website, on behalf of Geoff Morrison (who is currently located in Australia).

The first issue was between the alternatives of customizing a complete package (several suppliers have association website packages) or developing additions for online integration of membership list and credit card payments into the existing site. After discussion of costs and risks, the Board decided to proceed with a custom system, with some refinement of the detailed specifications prepared by Geoff. Christian will relay specific changes decided by the Board, so Geoff can prepare a revised version for rapid e-mail review by the Board. The Board authorized funding of up to $3500 to proceed with a development contract. *(Moved R. Peppin, second T. Kelsall, carried)*

The Board then discussed proposed options for online payments. Several options have been identified; cost comparison is complex. The Board expressed a preference for the system offered by TD Bank, rather than PayPal.

Other Business

Christian led the discussion on how to handle a ballot on “Survey Of Legislation, Regulations, And Guidelines For Control Of Community Noise” circulated by I-INCE to all member bodies (of which CAA is one).

The Board decided it is not appropriate for the Board members to approve/endorse such a report as the nominal voice of Canada or the CAA. After some discussion it was decided to (a) Abstain because we have no mechanism to endorse reports or recommendations, and (b) forward the report to CSA Committee Z107 who have a balanced membership matrix and established review process, so that they may submit comments in due course.

Adjournment

Meeting adjourned at 4:10 p.m. *(Moved D. Giusti, second C. Wakefield, carried.)*

The Canadian Acoustical Association
L'Association Canadienne d'Acoustique

PRIZE ANNOUNCEMENT • ANNONCE DE PRIX

A number of prizes and subsidies are offered annually by The Canadian Acoustical Association. Applicants can obtain full eligibility conditions, deadlines, application forms, past recipients, and the names of the individual prize coordinators on the CAA Website (http://www.caa-aca.ca). • Plusieurs prix et subventions sont décernés à chaque année par l'Association Canadienne d'Acoustique. Les candidats peuvent se procurer de plus amples renseignements sur les conditions d'éligibilités, les échéances, les formulaires de demande, les récipiendaires des années passées ainsi que le nom des coordonnateurs des prix en consultant le site Internet de l'ACA (http://www.caa-aca.ca).

CAA conference Student Travel subsidies: visit **http://www.caa-aca.ca/conferences/Vancouver2008/**
Subventions pour frais de déplacement pour étudiants au congrès annuel de l'ACA :
voir **http://www.caa-aca.ca/conferences/Vancouver2008/**

EDGAR AND MILLICENT SHAW POSTDOCTORAL PRIZE IN ACOUSTICS • PRIX POST-DOCTORAL EDGAR AND MILLICENT SHAW EN ACOUSTIQUE

$3,000 for full-time postdoctoral research training in an established setting other than the one in which the Ph.D. was earned. The research topic must be related to some area of acoustics, psychoacoustics, speech communication or noise. • $3,000 pour une formation recherche à temps complet au niveau postdoctoral dans un établissement reconnu autre que celui où le candidat a reçu son doctorat. Le thème de recherche doit être relié à un domaine de l'acoustique, de la psycho-acoustique, de la communication verbale ou du bruit.

ALEXANDER GRAHAM BELL GRADUATE STUDENT PRIZE IN SPEECH COMMUNICATION AND HEARING • PRIX ÉTUDIANT ALEXANDRE GRAHAM BELL EN COMMUNICATION VERBALE ET AUDITION

$800 for a graduate student enrolled at a Canadian institution and conducting research in the field of speech communication or hearing • $800 à un(e) étudiant(e) inscrit(e) au 2e ou 3e cycle universitaire dans une institution canadienne et menant un projet de recherche en communication verbale ou en audition.

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

$500 for a graduate student enrolled at a Canadian institution and conducting research in underwater acoustics or in a branch of science closely connected to underwater acoustics. • $500 à un(e) étudiant(e) inscrit(e) au 2e ou 3e cycle universitaire dans une institution canadienne et menant un projet de recherche en acoustique sous-marine ou dans une discipline reliée à l'acoustique sous-marine.

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

$500 for a graduate student enrolled at a Canadian institution and conducting research related to the advancement of the practice of noise control. • $500 à un(e) étudiant(e) inscrit(e) au 2e ou 3e cycle universitaire dans une institution canadienne et menant un projet de recherche relié à l'avancement des pratiques en contrôle du bruit.

RAYMOND HÉTU UNDERGRADUATE PRIZE IN ACOUSTICS • PRIX ÉTUDIANT RAYMOND HÉTU EN ACOUSTIQUE

One book in acoustics of a maximum value of $150 and a one-year subscription to *Canadian Acoustics* for an undergraduate student enrolled at a Canadian institution and having completed, during the year of application, a project in any field of acoustics or vibration. • Un livre sur l'acoustique d'un montant maximal de 150 $ et un abonnement d'un an à la revue *Acoustique Canadienne* à un(e) étudiant(e) inscrit(e) dans un programme au 1er cycle universitaire dans une institution canadienne et qui a réalisé, durant l'année de la demande, un projet dans le domaine de l'acoustique ou des vibrations.

CANADA-WIDE SCIENCE FAIR AWARD • PRIX EXPO-SCIENCES PANCANADIENNE

$400 and a one-year subscription to *Canadian Acoustics* for the best project related to acoustics at the Fair by a high-school student • $400 et un abonnement d'un an à la revue *Acoustique Canadienne* pour le meilleur projet relié à l'acoustique à l'Expo-sciences par un(e) étudiant(e) du secondaire.

DIRECTORS' AWARDS • PRIX DES DIRECTEURS

One $500 award for the best refereed research, review or tutorial paper published in *Canadian Acoustics* by a student member and one $500 award for the best paper by an individual member • $500 pour le meilleur article de recherche, de recensement des travaux ou d'exposé didactique arbitré publié dans l'*Acoustique Canadienne* par un membre étudiant et $500 pour le meilleur article par un membre individuel.

STUDENT PRESENTATION AWARDS • PRIX POUR COMMUNICATIONS ÉTUDIANTES

Three $500 awards for the best student oral presentations at the Annual Symposium of The Canadian Acoustical Association. • Trois prix de $500 pour les meilleures communications orales étudiant(e)s au Symposium Annuel de l'Association Canadienne d'Acoustique.

STUDENT TRAVEL SUBSIDIES • SUBVENTIONS POUR FRAIS DE DÉPLACEMENT POUR ÉTUDIANTS

Travel subsidies are available to assist student members who are presenting a paper during the Annual Symposium of The Canadian Acoustical Association if they live at least 150 km from the conference venue. • Des subventions pour frais de déplacement sont disponibles pour aider les membres étudiants à venir présenter leurs travaux lors du Symposium Annuel de l'Association Canadienne d'Acoustique, s'ils demeurent à au moins 150 km du lieu du congrès.

UNDERWATER ACOUSTICS AND SIGNAL PROCESSING STUDENT TRAVEL SUBSIDIES • SUBVENTIONS POUR FRAIS DE DÉPLACEMENT POUR ÉTUDIANTS EN ACOUSTIQUE SOUS-MARINE ET TRAITEMENT DU SIGNAL

One $500 or two $250 awards to assist students traveling to national or international conferences to give oral or poster presentations on underwater acoustics and/or signal processing. • Une bourse de $500 ou deux de $250 pour aider les étudiant(e)s à se rendre à un congrès national ou international pour y présenter une communication orale ou une affiche dans le domaine de l'acoustique sous-marine ou du traitement du signal.

NEWS / INFORMATIONS

CONFERENCES

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 stevenb@aciacoustical.com

2008

12-15 May. 10th Spring School on Acousto-optics and Applications. Sopot, Poland. Web: http://univ.gda.pl/~school

04-06 June. 5th International Styrian Noise, Vibration & Harshness Congress. Graz, Austria. Web: www.accgraz.com

18-27 June. Summer School in Underwater Acoustics. Heraklion, Greece. Web: http://ssuua08.iacm.forth.gr

29 June - 04 July: Joint Meeting of European Acoustical Association, Acoustical Society of America, and Acoustical Society of France. Paris, France. Web: www.sfa.asso.fr/en/index.htm

06-10 July. 15th International Congress on Sound and Vibration. Daejeon, Korea. Web: www.icsv15.org

7-10 July: 18th International Symposium on Nonlinear Acoustics (ISNA18). Stockholm, Sweden. E-mail: benflo@mech.kth.se

21-25 July. 9th International Congress on Noise as a Public Health Problem. Mashantucket, CT, USA. Web: www.icben.org

27-30 July. Noise-Con 2008. Dearborn, MI, USA.

27-31 July. 10th Mechanics of Hearing Workshop. Keele University, UK. Web: www.mechanicsofhearing.com

28 July - 1 August: 9th International Congress on Noise as a Public Health Problem. Mashantucket, Pequot Tribal Nation, (CT, USA). Web: www.icben.org

25-29 August. 10th International Conference on Music Perception and Cognition. Sapporo, Japan. Web: http://icmpc10.typepad.jp

08-12 September: International Symposium on Underwater Reverberation and Clutter. Lerici, Italy. Web: http://isurc2008.org

09-11 September: 6th International Symposium on Ultrasonic Doppler Methods for Fluid Mechanics and Fluid Engineering. Prague, Czech Republic. Web: http://isud6.fsv.cvut.cz

10-12 September. Autumn Meeting of the Acoustical Society of Japan. Fukuoka, Japan. Web: www.asj.gr.jp/index-en.html

15-17 September: International Conference on Noise and Vibration Engineering (ISMA2008). Leuven, Belgium. Web: www.isma-isaac.be

16-18 September: Underwater Noise Measurement. Southampton, UK. Web: www.ioa.org.uk/viewupcoming.asp

22-26 September: Interspeech 2008 - 10th ICSLP, Brisbane, Austrailia. Web: wwwinterspeech2008.org

23-25 September. Underwater Noise Measurement. Southampton, U.K. Web: www.ioa.org.uk/viewupcoming.asp

6-8 October. Canadian Acoustical Association Acoustics Week in Canada. Vancouver, BC. Web: www.caa-aca.ca

14-15 October: Underwater Noise Measurement, Impact and Mitigation. Southampton, U.K. Web: http://underwaternoise2008.lboro.ac.uk

CONFÉRENCES

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 courriel à stevenb@aciacoustical.com

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21-23 October. 13th Conference on Low Frequency Noise and Vibration. Tokyo, Japan. Web: www.lowfrequency2008.org

21-24 October. Acustica 2008. Coimbra, Portugal. Web: www.spacustica.pt

26-29 October: Internoise 2008, Shanghai, China. Web: www.internoise2008.org

01-05 November. IEEE International Ultrasonic Symposium. Beijing, China. Web: www.ieee-uffa.org/ulmain.asp?page=symposia

05-07 November: Iberoamerican Acoustics Congress (FIA 2008). Buenos Aires, Argentina. Web: www.fia2008.com.ar

10-14 November. 156th Meeting of the Acoustical Society of America, Miami, Florida, USA. Web: www.asa.aip.org

24-26 November. Australian Acoustical Society National Conference. Victoria, Australia. Web: www.acoustics.asn.au

17-19 December: Symposium on the Acoustics of Poro-Elastic Materials (SEPAM). Bradford, UK. Web: http://sapem2008.matelys.com

2009

05-08 April: Noise and Vibration: Emerging Methods (NOVEM2009). Oxford, UK. Web: www.isvr.soton.ac.uk/NOVEM2009

13-17 April: 2nd International Conference on Shallow Water Acoustics. Shanghai, China. Web: www.apl.washington.edu

19-24 April. International Conference on Acoustics, Speech, and Signal Processing. Taipei, R.O.C. Web: icassp09.com

18-22 May. 157th Meeting of the Acoustical Society of America, Portland, Oregon, USA. Web: www.asa.aip.org

05-09 July: 16th International Congress on Sound and Vibration (ICSV16). Krakow, Poland. Web: www.icsv16.org

23-26 August: Internoise 2009, Ottawa, Canada.

23-27 August: International Confress on Acoustics 2010. Sydney, Australia. Web: www.acoustics.asn.au

06-10 September: Interspeech 2009. Brighton, UK. Web: www.interspeech2009.org

19-23 September: IEEE 2009 Ultrasonics Symposium. Rome, Italy. E-mail: pappalar@uniroma3.it

26-28 October: Euronoise 2009. Edinburgh, UK. Web: www.euronoise2009.org.uk

2010

19-24 March. International Conference on Acoustics, Speech, and Signal Processing. Dallas, TX, USA. Web: icassp2010.org

23-27 August: International Confress on Acoustics 2010. Sydney, Australia. Web: www.acoustics.asn.au

26-30 September: Interspeech 2010. Makuhari, Japan. Web: www.interspeech2010.org

11-14 October: IEEE 2010 Ultrasonics Symposium. San Diego, California, USA. E-Mail: b.potter@vectron.com

21-23 octobre. 13th Conference on Low Frequency Noise and Vibration. Tokyo, Japan. Web: www.lowfrequency2008.org

21-24 octobre. Acustica 2008. Coimbra, Portugal. Web: www.spacustica.pt

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NEWS

We want to hear from you! If you have any news items related to the Canadian Acoustical Association, please send them. Job promotions, recognition of service, interesting projects, recent research, etc. are what make this section interesting.

--- THIRD ANNOUNCEMENT ---

ACOUSTICS WEEK IN CANADA

Vancouver, 6 - 8 October 2008

Acoustics Week in Canada 2008, the annual conference of the Canadian Acoustical Association, will be held in Vancouver, British Columbia from 6 to 8 October 2008. This is the premier Canadian acoustical event of the year, and is being held in beautiful, vibrant Vancouver, making it an event that you do not want to miss. The conference will include three days of plenary lectures, technical sessions on a wide range of areas of acoustics, the CAA Annual General Meeting, an equipment exhibition, and the conference banquet and other social events.

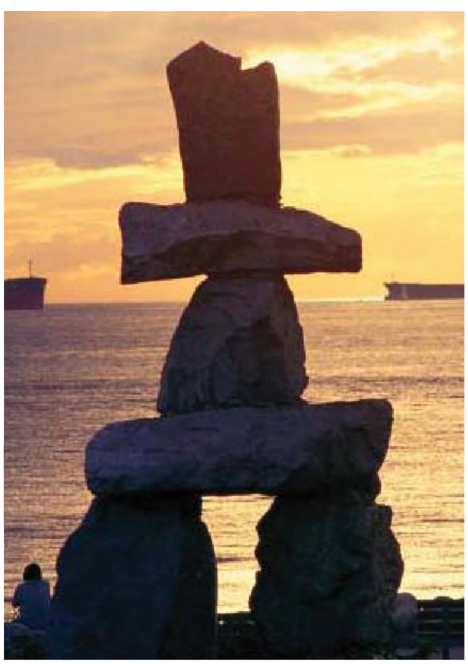
Venue and Accommodation – The conference will be held at the Coast Plaza Hotel & Suites [http://www.coasthotels.com/hotels/canada/bc/vancouver/coast_plaza/overview], in the dynamic West End of downtown Vancouver, steps from the beach at English Bay, walking distance to beautiful Stanley Park and trendy Robson Street, near Granville Island and Chinatown. Participants registering with the hotel before 5 September 2008 will receive the reduced room rate of $129/night (single or double). Stay at the conference hotel to be near all activities and your colleagues, and to help make the conference a financial success, to the benefit of all CAA members.

Plenary Lectures – Each day of the conference will begin with a plenary lecture:

- Stan Dosso, University of Victoria: Studying the Sea with Sound
- John Esling, University of Victoria: Origins of Constricted Voice Quality—First Sounds of Speech
- Barry Truax, Simon Fraser University: Micro to Macro—Composing Microsound and Soundscapes

Special Sessions – Special sessions consisting of invited and contributed papers are currently being organized on the following topics:

- Acoustical Consulting—Challenges and Opportunities
- Architectural and Classroom Acoustics
- Auditory Scene Analysis
- Biomedical Acoustics
- Environmental Noise/Vibration
- Green Building Acoustics
- First Nations Languages Acoustics
- Occupational Noise
- Occupational Noise Standards
- Psychological Acoustics
- Second Language Acquisition Acoustics
- Sound Absorbing Materials
- Speech Perception
- Speech Production and Speech Disorders
- Thermoacoustics
- Vibroacoustics



If you would like to propose and/or organize a special session in your technical area, please contact the Conference Chair or Technical Co-Chair as soon as possible.

Equipment Exhibition – The conference will include a one-day exhibition of acoustical equipment and products on Tuesday, 7 October 2008. If you are an equipment supplier interested in participating in the exhibition, please contact the Exhibition Coordinator as soon as possible.

Social Events – The conference will begin on Monday morning with an opening ceremony and welcome by Elder Larry Grant, Musqueam Indian Band (http://www.musqueam.bc.ca/Home.html). On Monday evening, a reception will be held for all delegates, followed by a visit to Christ Church Cathedral in downtown Vancouver, where acoustical consultant Michael Noble, BKL will discuss renovations to improve the Cathedral's acoustical environment, after which delegates will experience the acoustics during an organ recital.

Courses / Seminars – If you would like to propose to offer a course / seminar in association with Acoustics Week in Canada, please contact the Conference Chair. Assistance can be provided in accommodating such a course / seminar, but it must be financially independent of the conference.

Student Participation – The participation of students is strongly encouraged. Travel subsidies and reduced registration fees will be available. A hotel room-sharing program will be available to reduce costs. Student presenters are eligible to win prizes for the best presentations at the conference.

Paper Submission – Following are the deadlines for submission of abstracts, and of two-page summaries for publication in the proceedings issue of *Canadian Acoustics*: submission of abstracts: 13 June 2008; notification of abstract acceptance: 20 June 2008; submission of two-page summaries: 10 July 2008. Publication of two-page summaries is conditional on registration.

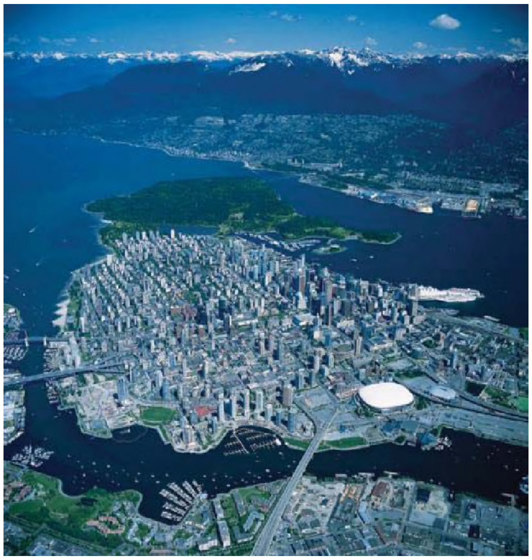
Registration – details of registration fees and the registration form will be made available on the conference website. Early registration at a reduced fee is available until 5 September 2008.

Local Organizing Committee

- *Conference Chair: Murray Hodgson [murray.hodgson@ubc.ca]*
- *Technical Co-Chair: Kimary Shahin [kns3@sfu.ca]*
- *Venue: Linda Rammage [linda.rammage@vch.ca]*
- *Treasurer: Mark Cheng [mark_cheng@yvr.ca]*
- *Equipment Exhibition: Mark Bliss [bliss@bkl.ca]*
- *Audio/Visual: Christine Harrison [christine.harrison@worksafebc.com]*
- *Student Issues, Translation: Hind Sbini [sbihi@interchg.ubc.ca]*
- *Administrator: Bernadette Duffy [bduffy@interchg.ubc.ca]*

Conference Website at http://www.caa-aca.ca/

--- TROISIEME ANNONCE ---



SEMAINE CANADIENNE D'ACOUSTIQUE

Vancouver, 6 - 8 Octobre 2008

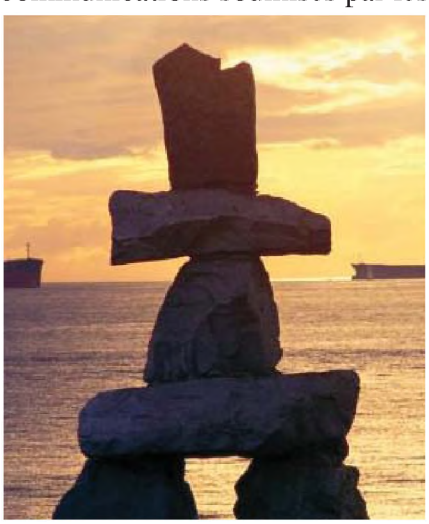
La conférence annuelle de l'Association Canadienne d'Acoustique (ACA) se tiendra à Vancouver en Colombie-Britannique du 6 au 8 octobre 2008. Il s'agit du plus important événement canadien de l'acoustique de l'année, et aura lieu à Vancouver, une des plus pittoresques et vibrantes villes canadiennes. Trois jours de sessions plénières, ainsi que des sessions techniques parallèles seront présentées, couvrant un large éventail du domaine de l'acoustique. La conférence comprendra aussi la réunion annuelle générale de l'ACA, l'exposition de divers équipements acoustiques, un banquet et autres événements sociaux.

Lieu du congrès et hébergement – La conférence se tiendra au Coast Plaza Hotel & Suites [http://www.coasthotels.com/hotels/canada/bc/vancouver/coast_plaza/overview], dans le quartier dynamique West End du centre-ville de Vancouver, à quelques pas de la plage de la baie des Anglais (English Bay), à proximité du fameux parc Stanley et de la chic rue Robson, et proche du marche populaire de l'île Granville, et du Chinatown. Les délégués qui réserveront leur chambre avant le 5 septembre 2008 bénéficieront d'un tarif préférentiel de $129/nuit (occupation simple ou double). Choisissez cet hôtel pour participer pleinement au congrès, à proximité de toutes les activités et de vos collègues, et pour assurer le succès de la conférence pour le bénéfice de tous les membres de l'ACA.

Sessions plénières – Une session plénière sera tenue au début de chaque jour de la conférence:

- Stan Dosso, Université de Victoria: Studying the Sea with Sound
- John Esling, Université de Victoria: Origins of Constricted Voice Quality—First Sounds of Speech
- Barry Truax, Université Simon Fraser: Micro to Macro—Composing Microsound and Soundscapes

Sessions spéciales – Des sessions spéciales présentées par des conférenciers invités ou par des communications soumises par les délégués sont actuellement organisées autour des sujets suivants :



- Consultation en acoustique—défis et opportunités
- Acoustique architecturale et de salles de classes
- Analyse de scène auditive
- Acoustique biomédicale
- Bruit environnemental/ Vibration
- Acoustique bâtiments verts
- Matériaux absorbants
- Acoustique de l'acquisition d'une seconde langue
- Bruit en milieu de travail
- Psychoacoustique
- Standards du bruit en milieu de travail
- Perception du langage
- Troubles du débit
- Thermoacoustique
- Vibroacoustique

Si vous désirez suggérer un sujet de session spéciale et/ou organiser une de ces sessions, veuillez communiquer avec le président du congrès ou le directeur scientifique.

Exposition technique – Le mardi, 7 octobre 2008 sera consacré à l'exhibition d'instruments et autres produits de l'acoustique. Si vous êtes un fournisseur d'équipement intéressé de participer, veuillez contacter la personne en charge de la coordination de l'exhibition.

Activités – La conférence débutera le lundi matin avec une cérémonie d'ouverture avec un discours de bienvenue par Elder Larry Grant, Musqueam Indian Band (http://www.musqueam.bc.ca/Home.html). Lundi soir, une réception est prévue, suivie par une visite de la Cathédrale Christ Church au centre-ville où Michael Noble, consultant chez la firme BKL, présentera les rénovations récentes qui ont été entreprises pour améliorer l'environnement acoustique de la Cathédrale. Les délégués pourront par la suite assister à un récital d'orgue.

Cours / Séminaires – Si vous désirez présenter un cours/séminaire en association avec la semaine canadienne d'acoustique, veuillez contacter le président du comite d'organisation. Sous condition d'une indépendance financière, l'accommodation d'un cours/séminaire pourra être appuyée.

Participation étudiante – La participation des étudiants au congrès est vivement encouragée. Des aides financières pour le déplacement et une réduction pour l'inscription seront mises à disposition. Un programme pour faciliter le partage des chambres sera mis sur pied pour réduire les dépenses. Les étudiants présentant leurs travaux seront éligibles pour les prix des meilleures présentations au congrès.

Soumission des présentations – Les dates limites sont comme suite: pour la soumission des résumés le 13 juin 2008; notification d'acceptation: 20 juin 2008; les sommaires de deux pages aux actes: 10 juillet 2008. La publication des résumés de deux pages est sujette à l'inscription à la conférence.

Inscription – Les détails ainsi que le formulaire d'inscription seront mis en ligne sur le site Web de la conférence. Une réduction sera effective pour toute inscription avant le 5 septembre 2008.

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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".

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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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