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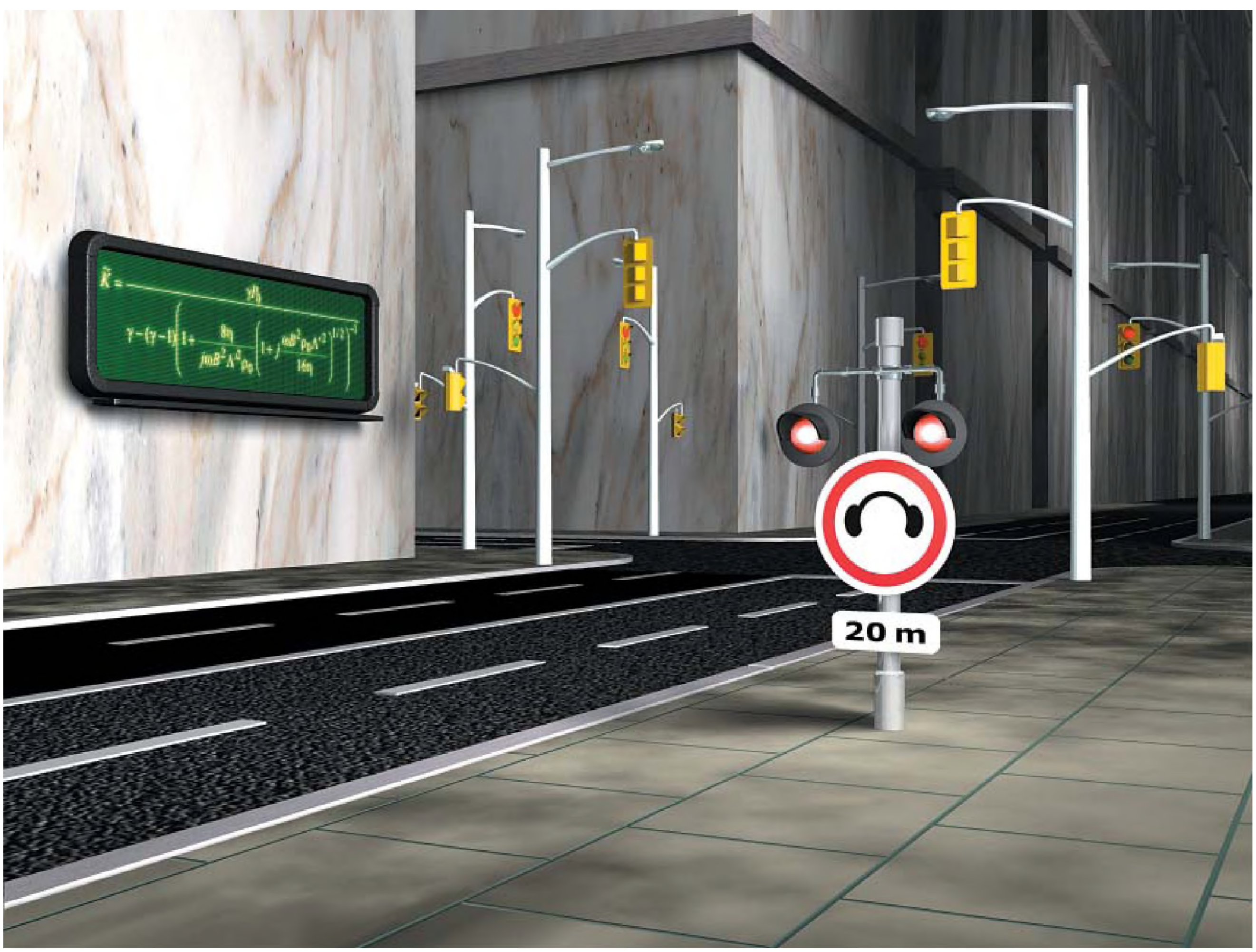

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EDITORIAL / EDITORIAL

One gets dull after nine months' hiatus when others write this page. I just realized it is my turn to say a few words. I must report that our team of editorial staff (three others and I), with periodic assistance from guest editors, have the journal under control and that the task of getting each issue out to our membership operates like clockwork these days. I must take this opportunity to thank Chantal Laroche, Steven Bilawchuck, Karen Fraser, David Quirt and conference chairs for making my task simpler.

The backlog of articles, as I reported during the last AGM, is steady, manageable and makes the editor's role that much more joyous. I still need assistance from the journal's editorial board to make this process seamless, so that future editors can operate the journal easily.

The Acoustical Society of America has their next conference in Vancouver. It will be a joint CAA/ASA meeting and CAA members are actively participating in the organization of the conference. Our president, Stan Dosso, and the former editor-in-chief of Canadian Acoustics, Murray Hodgson are leading the team of organizers. I request that our members participate in the conference in large numbers and make it a grand success for CAA and ASA. Vancouver is beautiful in May. There is also a conference in Banff organized by Alberta Utilities Board immediately following the ASA/CAA conference. What a wonderful way to celebrate spring with two conferences in two of the most beautiful locales in Canada.

Finally, I have reported that the journal may become a bi-monthly rather than a quarterly. I am still seriously considering that option. By the time of our AGM in London, I should have more information. In the meantime, see you in Vancouver.

Ramani Ramakrishnan

On devient presque somnambule après neuf mois de vide quand d'autres personnes écrivent cette page. Je viens de réaliser que c'est à mon tour de dire quelques mots. Je dois dire que notre équipe de rédacteurs (trois autres et moi-même, avec une aide périodique de rédacteurs invités) a le journal sous contrôle, et que la tache, qui consiste à éditer et distribuer chaque édition à nos membres à temps, est devenue pré-réglée comme une horloge ces jours-ci. Je dois saisir l'opportunité pour saluer Chantal Laroche, Steven Bilawchuck, Karen Fraser, David Quirt et les responsables de conférence pour avoir facilité mes taches.

L'accumulation d'articles est stable et gérable, comme je l'ai indiqué lors de la dernière réunion AGM, ce qui rend le travail du rédacteur très plaisant. J'ai toujours besoin d'aide du comité de rédaction du journal afin de mapper le processus de fonctionnement pour que les rédacteurs futurs puissent opérer le journal sans encombre.

L'association ``The Acoustical Society of America`` tient sa prochaine conférence à Vancouver. La conférence est conjointement organisée par ACA/ASA. Les membres de l'Association Canadienne d'Acoustique participent activement à l'organisation de la conférence. Notre président, Stan Dosso, et l'ancien rédacteur en chef du journal, Murray Hodgson chapeautent les équipes organisationnelles. Je demande à tous nos membres de participer à cette conférence pour que ça soit un grand succès pour l'ACA et ASA. Vancouver est aussi une très belle ville à visiter au mois de mai. Il y a aussi une conférence à Banff par ``Alberta Utilities Board``, juste après la conférence de l'ACA/ASA. Quelle joie de célébrer le printemps avec deux conférences dans deux des plus belles villes du canada!

Finalement, J'ai rapporté que le journal pourrait devenir à tirage bimensuel au lieu de trimestriel. Je suis en-train de d'étudier cette option sérieusement. J'aurais plus d'information lors de la prochaine réunion AGM qui se tiendra à London, Ontario. Entre temps, je souhaite vous voir tous à Vancouver.

Ramani Ramakrishnan

WHAT'S NEW ?? QUOI DE NEUF ?

Promotions	Retirements	Promotions	Retraites
Deaths	Degrees awarded	Décès	Obtention de diplômes
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Steven Bilawchuk, aci Acoustical Consultants Inc., Edmonton, Alberta, Email: **stevenb@aciacoustical.com**

Impact of Languages to Speech Privacy and Intelligibility of Closed Spaces

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ABSTRACT

The present study investigates the speech privacy and intelligibility of closed spaces in multicultural environments. Most assessments for speech privacy and speech intelligibility among the current research rely on the subjective measurements utilized with the test materials of English and other Western languages. Effects of different languages and accents in speech privacy and speech intelligibility are usually overseen. Subjective measurements are conducted in this study for closed spaces by using English and a tonal language. The differences in speech privacy between the two languages are evident and significant. It is also found in this study that the existing single word tests used in research and industrial practice for subjectively evaluating speech privacy need modification when closed spaces are considered. The subjective measurement results of this study are compared with the objective measurement index AI.

RÉSUMÉ

Le but de cette recherche est d'étudier l'intimité et l'intelligibilité des conversations dans des espaces clos en milieu multiculturel. La plupart des études se basent sur des données subjectives utilisées dans l'étude des tests basés sur la langue Anglaise et d'autres langues Occidentales. L'influence des accents et d'autes langues sur l'intimité des conversations et l' intelligibilité des conversations ne sont géneralement pas prises en compte. Des experiences subjectives ont été conduites dans cette étude dans des espaces clos en utilisant L'Anglais et une langue tonale. Les differences dans le cadre de l'intimité des conversations entre les deux languages sont évidentes et significatives. Les résultats montrent aussi que le test basé sur la pronunciation d'un seul mot tel qu' utlisé en recherche et dans le milieu industriel pour l'évaluation subjective, doit être modifié lorsque des espaces clos sont considérés. Les résultats de cette étude sont comparés avec les mèthodes objectives utilisées dans l'indice d'articulation (IA).

1. INTRODUCTION

Speech privacy is the opposite concept of speech intelligibility. The lower the speech intelligibility is, the higher is the speech privacy. With this consideration, speech privacy can be assessed by the predictors of speech intelligibility. Generally, there are two families of methods for characterizing the speech intelligibility: the subjective or direct method and the objective or indirect method. The subjective methods involve human subjects in a procedure known as speech intelligibility testing. Listeners are placed in real listening conditions and must transcribe each proposed language unit as they perceive it. The intelligibility score is then derived from the count of the correctly transcribed units. These direct methods are problematic in their reliability and their reproducibility.

The objective methods generally yield an intelligibility index from a measurement of physical characterization of acoustical environment. With these methods, each index is distinguished from the other indices according to the measurement it is based on. There are three types of acoustical measures widely used in the research to date [1-4]: articulation index (AI) or speech intelligibility index (SII) [5-8], speech transmission index (STI) [9,10] and sound early-to-late ratio (C_{50}) [11]. Among the recent research, investigations are also found on intelligibility of rooms [12-15].

It should be noticed that most objective assessments for speech privacy and speech intelligibility are evaluated by the subjective measurements. The subjective measurements, however, are mainly based on studies of English and other Western languages as per the existing standards adopted in research and industrial practice for evaluating speech privacy. The impact on speech privacy by other languages and accents is overseen. In the modern society, however, environments involving different languages and accents are common especially in the places such as international organizations, government and business offices, classrooms and medical clinics of multicultural communities. A systematic investigation on the multilanguage and accent impact on speech privacy in closed spaces is therefore necessary. In this study, subjective measurements using both English and a tonal language, Mandarin are conducted. With the two languages, the differences in speech intelligibility, and hence speech privacy, are studied. The subjective measurement results are also compared with the objective measurement index AI obtained by ASTM E1130 method [6], which is widely used in evaluating speech intelligibility and speech privacy.

2. EXPERIMENTAL MEASUREMENTS

2.1 Objective measurements

The articulation index (AI) method based on the existing standard ASTM E1130 is employed in this study. Noise signals are captured with B&K Dual Channel Real-time Analyzer type 2133, microphones 4189 and 4133, signal amplifier, 1/3 octave filter and speaker. Figure 1 illustrates the experimental setup scheme. Pink noise is used as the sound source in the talker room B and the sound pressure levels in one-third octave bands are measured in the listener room A. In each listener room used in the experiments of this study, at least 4 listener positions are used for the measurements. The measurements and data process procedures are conducted according to ASTM E 1130.

For simulating the real environment of the closed spaces, the measurements are conducted in some typical office rooms of a university building. The volume of office rooms range from 37 – 56 m^3. The partition walls between the closed offices are typical drywalls from floor to ceiling; the ceilings are gypsum-ceiling boards with continuous plenum. The space furnishings in the rooms, where the measurements were conducted, are study tables, chairs, bookcases and file cabinets.

Background noise in the rooms is mainly due to computer-generated noise and rated from NC 37 to 41 in the closed offices. The reverberation time measured is in between 0.21 and 0.37 seconds in the listener rooms. The measurements of the background noise levels and reverberation time show that the occupied closed offices are under normal acoustical conditions and suitable for carrying out the speech intelligibility and speech privacy tests.

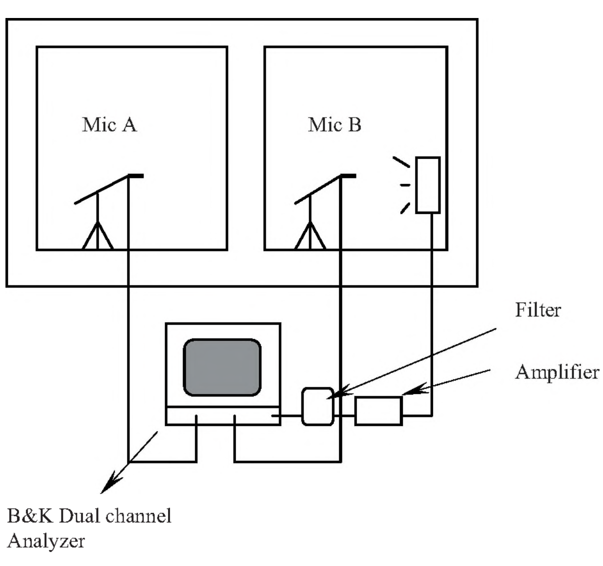

Figure 1. Set-up for AI Measurement

2.2 Subjective measurements

a) Subjects and speech test materials

All the measurements are conducted in typical closed office rooms and classrooms, and both the objective and subjective tests performed in the study are under the same background noise conditions. A total of 47 subjects take part in the speech intelligibility tests for English. They are all native English-speaking adults ranging in age from 19 to 25. A total of 22 subjects take part in the speech intelligibility tests using Mandarin. The subjects are all native Mandarin-speaking adults ranging in age from 25 to 40. All of the subjects showed no evidence of hearing problems.

In performing the experiments, three types of speech test materials are used for measuring speech intelligibility of English: (a) Modified Rhyme Test (MRT) words, (b) multi-choice conversations and articles, and (c) open-set sentence. MRT words are selected from standard ANSI S3.2-1989 [16], and consist of 50 six-word lists of monosyllabic English words. The large majority of the words used have three syllables in a consonant-vowel-consonant sequence.

Almost all the research to date use different test materials of single English words (MRT, PB word, and DRT etc.) in evaluating speech intelligibility. However, in real communication situations, people can understand the whole sentence or conversation even if they just hear a few words. This is due to the coherence of human being in the context, speech tone and intonation when people are speaking. Therefore, the understanding of a whole sentence appears to be more representative for a realistic communication situation than the intelligibility of discrete words that have no logical relation among them. To simulate the communication of human society, new test materials should be utilized in the experiments to represent the real world communication environments. In this study, multi-choice conversations and articles selected from standard English listening tests are employed. The test materials employed consist of short and long conversations together with articles. In the experiments utilizing the conversations and articles, the listeners are required to listen to short and long conversations between two people or a vocal lecture article. After each conversation or reading of an article, there is one or several spoken questions about the listening materials and four answer choices corresponding to each of the questions. All the listening materials are related to common people's communication happening in everyday life. In each test, there are 50 questions to be answered. The open-response-set sentences are also employed in the experiments. In this type of experiments, the listeners are required to either repeat or write down what is heard. For example, on the recording the listener will hear:

"*He's sick of his job*".

In the question sheet, the listener will read:

(A) He doesn't like his work;

(B) He isn't doing a good job;
(C) He became ill at the office;
(D) He's tired of looking for a job.

If the listener hears and comprehends the sentence, he or she may learn from the sentence that the man doesn't like his job, and thus select the best answer (A). In performing the tests, each experiment used includes 30 such open-response-set questions.

Similar to the English test materials, the single words, articles, real conversations and open-set sentences are used in speech intelligibility and privacy experiments of Mandarin. Most English words are multi-syllable. A single syllable of an English word has relatively few phonemes and is usually no meaning. In contrast to English, one Mandarin character has one syllable associated with it and a single character is mostly meaningful and tonal [17]. However, in many cases, one syllable of Mandarin may represent different characters. Tones are extremely important in Mandarin speech because the different tonality of the same monosyllable will give different meaning. There are four tonal patterns in Mandarin: tone 1 (flat tone), tone 2 (rising tone), tone 3 (falling-rising tone) and tone 4 (falling tone). In single word test, there are 40 five-word lists are used; each list includes five single words (characters) which have the same tone and same initial consonant but different vowels. In the experiments with conversations or article materials, the standard Mandarin listening test in Chinese Proficiency Test (HSK) is used. After each conversation or article reading, there will be one or several spoken questions about the listening materials and there are four answer choices for each of the questions. In each experiment, there are 40 questions to be answered. The open-set test consists of several conversations or short articles, the listeners are asked to answer what they heard (no multi-choices are provided). There are total 15 questions in an open-set test.

For both languages, the multi-choice conversations, articles and open-set sentences used in the test are very similar to those listening comprehension tests, such as TOEFL and HSK, which are widely accepted by the academic institutions for evaluating listening comprehensions. The selection of the test materials is based on the considerations that the materials may best reflect realistic communication situations and people's subjective judgement in communication.

b) Subjective measurement procedures

Both English and Mandarin subjective measurements are conducted in the same office pairs as the objective measurements as illustrated in Figure 1. In the closed office environments, one or two talkers sit in the middle of the talker's room, and at least four listeners sit at different positions in the listener's room. Firstly, one of the talkers reads the test materials or two talkers have the conversations in "normal voice level", which corresponds to the voice level used in normal conversation and has an overall level of about 58 dBA. The talkers then read in "raised voice level", which is the voice level often used in addressing the people in a regular classroom or speaking into a microphone about one meter away. In this case, the voice has an overall sound level of about 64 dBA. A recording tape is also played at about 58 and 64 dBA respectively in the talker room. In both situations, the listeners are asked to answer the questions of the test materials on the response sheets. Furthermore, for both languages, the talkers are asked to speak at a speed as that they use in a normal conversation, similar to the speed used for the listening comprehension tests. The test results did not show obvious differences between male and female talkers. The aim of the present research is to assess the language impact to speech privacy in a communication environment close to that of real world including both males and females. However, the gender differences is planned for further studies in future investigations.

It is noted in the tests, that Mandarin shows higher long-term overall sound levels than other languages, in general. This agrees with the results reported by Byrne *et al* [19] in which a comparison of twelve languages (including American English) was performed. Mandarin was found to have the highest average level of 75.2 dB at 20 cm from a speaker's mouth, in comparing with an average of 72 dB of the twelve other languages used for the tests.

3. RESULTS AND DISCUSSION

a) Objective and subjective measurements

The final speech intelligibility scores of the listeners are collected and computed as the arithmetic average of the percent of the correct answers identified by the listeners. The final scores are then accepted as a score representative of the specific listener room.

Table 1 lists the AI results of the objective measurements in four pairs of closed offices. The results of the subjective measurements as the percent of intelligibility for different test materials are listed in Table 2.

According to the standard ASTM E 1374 "Standard Guide for Open Office Acoustics and Applicable ASTM Standard" and ASTM E 1130 "Standard Test Method for Objective Measurement of Speech Privacy in Open Offices Using Articulation Index", together with the classical relationship between AI and speech intelligibility, different level of speech privacy can be conveniently categorized as follows [6]:

1. Confidential Privacy: $AI \leq 0.05$. Speech can be detected but not understood by the receiver. It also implies less than 10% word and 5% sentence intelligibility.
2. Normal Privacy: $0.05 < AI \leq 0.20$. Effort is required for the receiver to understand the speech.
3. Transitional Privacy: $0.20 < AI \leq 0.40$. The corresponding speech is mostly understood and can be distracting.
4. No Privacy: $AI > 0.40$. Speech is clearly understood by the receiver.

From Table1, the objective measurement results show

Table 1. Results of Subjective Measurements and AI Values

Office	No. Sub.	AI (Avg)	Privacy Type
Closed 1	16(E)	0.001(N)	Conf.
	4 (C)	0.04(R)	Conf.
Closed 2	5 (E)	0.001(N)	Conf.
	4 (C)	0.01(R)	Conf.
Closed 3	9 (E)	0.001(N)	Conf.
	5 (C)	0.01(R)	Conf.
Closed 4	7 (E)	0.002(N)	Conf.
	6 (C)	0.01(R)	Conf.

Note: N indicates the normal voice level and R the raised voice level as indicated above. E indicates result for English and C for Mandarin.

Table 2. Results of Subjective Measurements and Percent of Intelligibility

Office	Percent of Intelligibility		
	Single Word	Multiople-choice Conversation	Open-set Sentence
Closed 1	28%(EN) 40%(CN) 49%(ER) 67%(CR)	2%(EN) 1%(CN) 45%(ER) 47%(CR)	35%(ER) 44%(CR)
Closed 2	39%(EN) 44%(CN) 53%(ER) 71%(CN)	1%(EN) 2%(CN) 28%(ER) 38%(CR)	
Closed 3	36%(EN) 42%(CN) 43%(ER) 64%(CR)	1%(EN) 2%(CN) 12%(ER) 47%(CR)	
Closed 4		25%(ER) 40%(CR)	28%(ER) 41%(CR)

that the AI values are all less than 0.05 at normal or raised voice levels in four test offices. This implies that the speech privacy is Confidential Privacy as categorized above. However, from the comparison of AI value and privacy type with speech intelligibility scores of both English and Mandarin as exhibited in Figure 2, it can be seen that there is a good correspondence between the privacy type and the conversation test results at normal voice level. The values of percent of intelligibility for both the English experiments and Mandarin ones are close and the values are varying with the same trends for difference test materials. But this correspondence does not exist in the tests with the raised voice level.

For single word experiments, the Percent of Intelligibility is very high even at normal voice levels as shown in Figure 2. However, the values of Percent of Intelligibility obtained from the experiments with conversations or articles are significantly lower than that of single word experiments. It should be noted that all the Percent of Intelligibility values of both the single word and conversation/article experiments are measured under identical experimental conditions. This may raise fundamental concerns in assessing speech privacy and intelligibility of closes spaces. Speech intelligibility measures the degree of comprehension in a common verbal communication of real world. In the communications of reality, one may understand the meaning of a sentence or a conversation by hearing and comprehending a few “key” words embedded in the conversation. On the other hand, one may completely lose the meaning of a sentence or conversation if he or she only catches some of the words in the sentences and misses the “key” words, even though that the words caught are fully understood by the listener. The

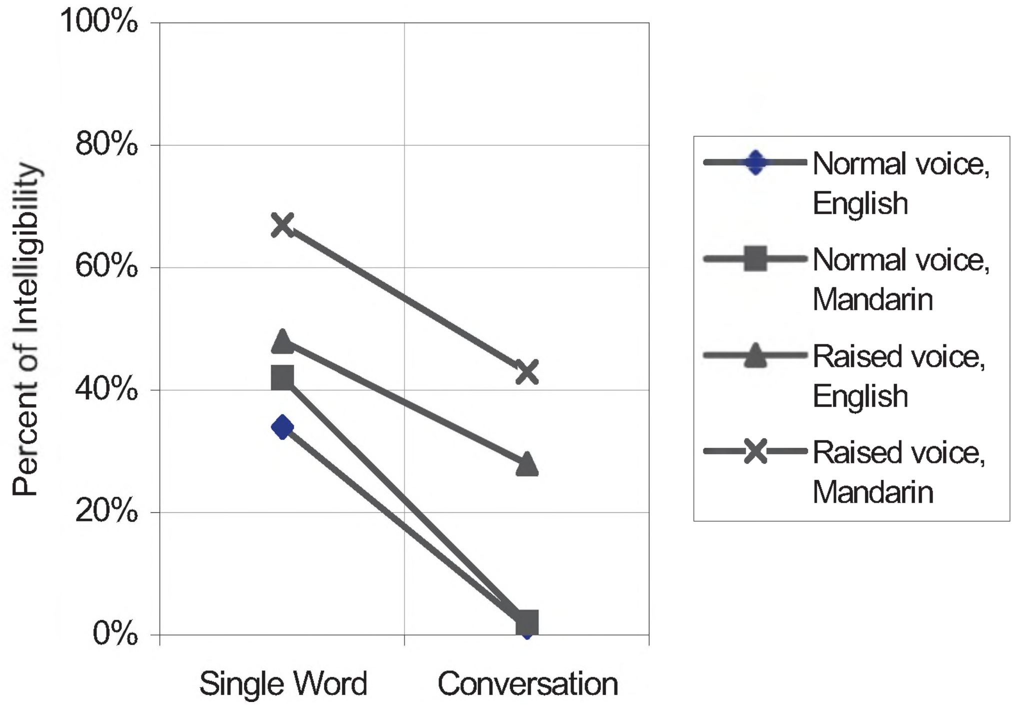

Figure 2. Speech Intelligibility Scores of Test Materials

reliability of speech intelligibility evaluated by single words may get even worse in considering that some words, especially for many of English words, are single-syllabled with few phonemes and many of them are sibilant. It appears that the measurements for speech privacy or intelligibility with single words may not reflect the actual level of speech privacy or intelligibility in reality, and not very reliable for subjectively measuring the speech privacy in the environments of closed spaces. Modifications on the testing materials to be used in the speech privacy measurements seem necessary.

Voice effort level also affects speech intelligibility and privacy significantly in both languages. With respect to English, the percent of intelligibility is increased by 14% for single words, and 27% for conversations comparing with

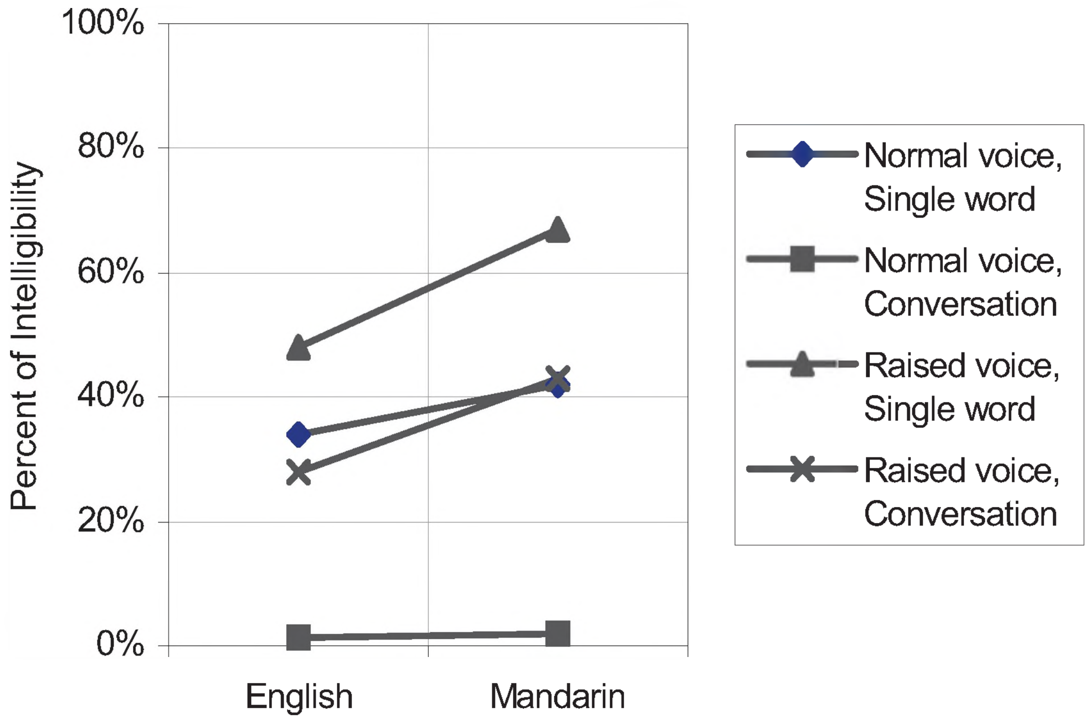

Figure 3. Speech Intelligibility Scores of English and Mandarin

the raised voice level with normal voice level; for Mandarin, the corresponding scores is increased about 22% for single words and 41% for conversations. It may also be observed from Table 1, Table 2 and Figure 2, at the raised voice level, a substantial difference exists between the subjective test and the AI measures. It should be noted that the calculation procedures for obtaining the standard AI values are originally established under open space environments, and the weight factors required for determining AI corresponding each band frequency are also determined under the open space environments. The results of this study suggest that the modification is needed to the standard methods in determining AI values of a closed office.

In the computing process for determining AI at raised voice level, it was found that the biggest contribution to the AI value came from low frequencies between 250 to 1000Hz, which are mainly from the vowel sounds in both languages. However, one may keep in mind that the closed partition between sound source and receiver has the direct effects to the sound transmission characteristics as well as the final contribution of each frequency band to the AI results.

It is found in the experiments that the spectrum of voice heard on the other side of the closed partition wall is modified by filtering effect of transmission loss and by some of the resonance effects of the partition wall. Further investigation needs to be carried out on the applicability of the standard AI method for assessing speech privacy in closed office at raised voice level.

b) Comparison of English and Mandarin

Figure 3 shows the average subjective measurement results in four closed offices for English and Mandarin. It can be seen from the figure that the single word intelligibility of Mandarin is generally better than that of English at normal and raised voice levels. It is recognized in the experiments that some English consonants, such as fricatives, nasals, which are presented in high frequencies and provide significant information, are blocked by the closed partition wall in closed spaces. As reported in [18], the tones of Mandarin help to recognize vowels and consequently increase the word intelligibility. The same situation happens in conversation intelligibility and open-set sentence intelligibility experiments at raised voice. The scores of intelligibility of conversation at normal voice are very close for both languages. This is because that the long conversations mask the effect of Mandarin tone recognition as that for the individual word. The intelligibility of whole conversation therefore presents the similar results as that of English. In general, the results of the experiments show that Mandarin has better intelligibility or worse speech privacy than English in closed space environments.

4. CONCLUSIONS

Language impacts on speech privacy and intelligibility in closed spaces such as offices were investigated in the present study. Based on the subjective and objective experiments performed and the analyses carried out in the study, the following can be stated.

1. A series of subjective experiments are conducted in closed spaces with employment of English and a tonal language, Mandarin. The objective measurements with the Articulation Indices (AI) are also performed and compared with the subjective measurement results for speech intelligibility in closed spaces. Similar studies are not found in the current literature.
2. The experimental results suggest that single word tests seem not very suitable for subjective measurements of speech privacy evaluation in closed spaces, regardless of the languages used.
3. The results of ASTM standard method are consistent with subjective test only at normal speech voice level. However, differences are found at raised voice levels for both English and Mandarin.
4. The results of the study also showed the evaluation differences in intelligibility and speech privacy in closed spaces between the two different languages. Generally, as found in the experiments and analyses, Mandarin has better intelligibility or worse speech privacy than that of English in closed space environments. The language impact on speech privacy and intelligibility in a closed environment is evident. Hence, speech privacy is actually language dependent. Strictly speaking, different language has different speech indelibility rate under the identical environment. The language impact must therefore be considered in future office design.
5. Several interesting acoustic characteristics are found in this study that is significant in the acoustical designs for closed offices to be used in multicultural environments.

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Inverse Acoustical Characterization Of Open Cell Porous Media Using Impedance Tube Measurements

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ABSTRACT

Unlike porous models developed for particular absorbing materials and frequency ranges, the Johnson-Champoux-Allard model is a generalized model for sound propagation in porous materials over a wide range of frequencies. This model is nowadays used widely across the acoustic research community and by industrial sector. However to use this model, the knowledge, particularly, of the intrinsic material properties defining the model is necessary. Using the proposed porous model and with the knowledge of the intrinsic properties, the calculation of the desired acoustical indicators as well as the design and optimization of several acoustic treatments for noise reduction can be done efficiently and rapidly. The model of Johnson-Champoux-Allard is based on five intrinsic properties of the porous medium: the flow resistivity, the porosity, the tortuosity, the viscous characteristic length, and the thermal characteristic length. While the open porosity and airflow resistivity can be directly measured without great difficulties, the direct measurements of the three remaining properties are usually complex, less robust, or destructive. To circumvent the problem, an inverse characterization method based on impedance tube measurements is proposed. It is shown that this inverse acoustical characterization can yield reliable evaluations of the tortuosity, and the viscous and thermal characteristic lengths. The inversion algorithm contains an optimization process and hence it is verified that the identified optimal three parameter, even though derived from a mathematical optimum for a given experimental configuration (sample's thickness, measured frequency range), are the intrinsic properties of the characterized porous material.

RÉSUMÉ

À la différence de certains modèles adaptés à une gamme de matériaux poreux insonorisant et/ou à de fréquences, le modèle de Johnson-champoux-Allard peut décrire la propagation du son dans les milieux poreux de façon générale et assez précise. Du fait que ce modèle soit bien adapté à une vaste gamme de matériaux et de fréquences, il est largement utilisé de nos jours par la communauté scientifique ainsi que par le secteur industriel. L'utilisation de ce modèle nécessite cependant la connaissance en particulier de cinq paramètres qui décrivent de façon macroscopique la géométrie interne du réseau interconnecté de pores d'un matériaux poreux. Connaissant ces paramètres, le calcul des indicateurs acoustiques ainsi que la conception, l'optimisation de nouveaux traitements acoustiques pour la réduction du bruit peuvent être effectués efficacement et rapidement. Les cinq paramètres sont : la porosité, la résistance à l'écoulement, la tortuosité, les dimensions caractéristiques visqueuse et thermique. Alors que les paramètres tels la porosité et la résistance à l'écoulement peuvent être mesurés directement facilement et avec assez de précision, la mesure directe de la tortuosité et des deux dimensions caractéristiques est généralement plus complexe, moins robuste ou destructive. Pour contourner ce problème, une méthode d'identification inverse de ces paramètres basée sur des mesures fines en tube d'impédance est proposée. Il est montré que cette méthode inverse de caractérisation acoustique permet une identification fiables de la tortuosité et des dimensions caractéristiques. Puisque cette méthode inverse est basée sur une procédure d'optimisation, il est vérifié que les paramètres issus de l'inversion ne sont pas que des optimums mathématiques valides seulement pour une configuration expérimentale donnée (épaisseur d'échantillon, gamme fréquentielle de mesure), mais aussi des propriétés intrinsèques au matériau caractérisé.

1. INTRODUCTION

In acoustics, the propagation and dissipation of acoustic and elastic waves within an open cell air-saturated porous medium is described by the Biot theory[1,2]. Following this theory, three waves propagate within the material: two compression waves – one mostly related to the fluid phase and the other to the solid phase, and one shear wave in the solid phase. Under acoustic excitations, the solid frame of the material can be assumed acoustically rigid (i.e. motionless) over a wide range of frequencies[3-5]. Consequently, only a compression wave, governed by the Helmholtz equation, now propagates in the fluid phase[3]. The porous medium is seen as an equivalent fluid with effective density $\tilde{\rho}$ and bulk modulus $\tilde{K}$. These effective properties accounts for the viscous and thermal losses that attenuate the compression wave. At the macroscopic level, these losses are related to five geometrical parameters of the porous medium: the open porosity ϕ, the airflow resistivity σ, the tortuosity α_∞, the viscous characteristic length Λ, and the thermal characteristic length Λ'. A detailed description of these 5 parameters can be found elsewhere[3,6].

Several works have been done to link the effective properties to the geometrical parameters[3]. In this work, a five-parameter model (the above five parameters) based on the works by Johnson *et al*[7] and Champoux and Allard[8], is selected. In this model, the effective density is given by Johnson *et al*[7], and depends on the porosity, resistivity, tortuosity, and viscous characteristic length. Similarly, the effective bulk modulus is given by Champoux and Allard[8], and depends on the porosity and thermal characteristic length. It is important to point out that the five-parameter model used in this paper may suffer from imprecision at low-frequencies. More accurate models include, in addition to the above five parameters, the static thermal permeability[9], and two adjustable parameters for the thermal[10] and viscous[11] effects. These low-frequency corrections become important for materials having a behaviour that diverge strongly from cylindrical pore materials and/or having an interior structure presenting a rapid variation of pore section. In the present work different reasons motivate the choice of using the five-parameter model instead of others. Firstly, the Johnson-Champoux-Allard model is one of the most commonly used generalized models for describing, accurately, the sound propagation in porous materials over a wide range of frequencies. The success with which this rigid model has been applied to many porous materials depend largely upon its ability to account simply for the random geometry of common porous materials available nowadays with no adjustable parameters since all the five parameters defining the model have a physical meaning and can be directly measured experimentally.

Secondly, when comparing the five-parameters model to more complicated new models in which more than five parameters are used, Henry[12] pointed out that the differences between the models are only at low frequencies and for a global acoustical indicators such as the absorption coefficient or the surface impedance, the differences are relatively small for the commonly used porous materials. In addition, there are not enough experimental data available in the literature concerning the values of these additional low frequency parameters. Consequently, it will be difficult to handle, successfully, the physical constraints for these new parameters if the corresponding models are retained in the inverse characterization. However, it is possible to confine the proposed inverse characterization to higher frequency ranges, where the low-frequency parameters will have little impact, and where the five parameters model will gives precise results.

Thirdly and due to its robustness, the Johnson-Champoux-Allard model is nowadays implemented in several well known commercial vibro-acoustic softwares. Using the Johnson-Champoux-Allard model and with the knowledge of the five intrinsic properties the calculation of the desired acoustical indicators, as well as the design and the optimization of several acoustic treatments for noise reduction can be done efficiently and rapidly. However, while parameters such as the porosity and airflow resistivity can be easily measured, directly, using standard techniques[13-15], the review of different methods[6,16…23] that have been developed for measuring the three other parameters shows that they are more difficult to determine with enough accuracy. In addition the developed techniques usually require more sophisticated and expensive set-ups.

Tortuosity can be measured by a non-acoustical direct method which is based on the work of Brown[16] and is successfully demonstrated by Johnson *et al*[17]. In this method, the porous material is filled with an electrolyte, and the electrical resistivity of the saturated material is measured and linked to the tortuosity. The method naturally applies to non-conductive frame and may be destructive. Poor results may be obtained if the operational procedure is not followed carefully, such as to make sure that the electrolyte completely saturates the porous network, which is difficult to do for highly resistive acoustical materials. The thermal characteristic length can also be obtained by a non-acoustical technique. Henry *et al*[18] showed that the specific surface measured by the BET technique[19] can be related to the thermal characteristic length. The BET technique is cumbersome, costly, and, for typical acoustical foams, may yield large errors[20].

Alternative methods, based on acoustical ultrasound measurements, have been developed over the past ten years to circumvent the difficulties inherent in the direct characterization of the tortuosity and characteristic lengths. These methods use the exact high-frequency asymptotic limit of the effective density and bulk modulus. Frequency[20-23] and temporal[6,24,25] methods for ultrasonic wave propagation in rigid porous materials have been proposed. These methods are very promising; however, they are not easily adaptable by conventional acoustic laboratories. Also, they suffer from two major limitations. The first limitation is related to the high attenuation of the ultrasound waves in the material. For highly dissipative materials or thicker layers, the ultrasound techniques are hardly applicable. The second limitation is related to the smallness of the wavelength compared to the pore size. As the wavelength approaches the pore size, diffusion of the ultrasound waves and heterogeneities of the structure at this scale will most likely affect the measurement and create large errors in the evaluation of the three parameters[20]. These two limitations are encountered for a number of sound absorbing materials.

In this paper, an alternative acoustical method to the ultrasound techniques is proposed for the measurements of the tortuosity and characteristic lengths. The method derives from the solution of an inverse characterization problem proposed by the authors[26,27]. The method is easy to implement in the sense that it relies on standardized impedance tube measurements and global optimization algorithms. The method is robust in the sense that it works for a wide range of sound absorbing materials for which their rigid-frame behavior can be modeled as an equivalent fluid under acoustical excitations – true for most poroelastic materials above a certain frequency range.

In the following, the equivalent fluid model for porous materials is first recalled to introduce the inverse characterization problem. Second, the selected cost function is developed and discussed. Third, the method is applied to the characterization of four porous materials (two foams and two fibrous). Fourth, the inversion results are validated through comparisons between simulations and measurements over a wide range of frequencies and for different configurations of layered materials. Finally, the conclusion and the perspectives of the method are discussed.

2. INVERSE CHARACTERIZATION

2.1 Acoustical model

Following the objective of this work and the above discussion, it is proposed to investigate the feasibility of an inverse characterization to identify the tortuosity, and the viscous and thermal characteristic lengths of an open cell

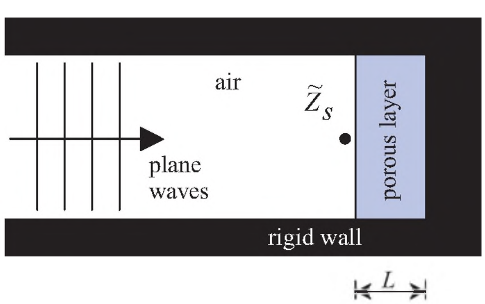

Figure 1. Porous material set on an impervious rigid wall: Normal incidence.

air-saturated porous medium based on simple standardized acoustical measurements in an impedance tube. A schematic of the problem under consideration is depicted in Figure 1. It consists of an open cell air-saturated porous layer bonded onto the impervious rigid termination of a waveguide. The walls of the waveguide are assumed rigid, impervious, and perfectly reflective. The porous layer is also bonded to the wall all over its contour. Normal incidence acoustical waves excite the front face of the porous layer. At the interface of the air cavity and porous layer, the normalized surface impedance from the air cavity side is given by[3]:

$$\tilde{Z}_s = \frac{\tilde{Z}}{Z_0} = -j\frac{\tilde{Z}_c}{\phi Z_0}\cot\left(\tilde{k}L\right), \tag{1}$$

where $\tilde{Z}$, $\tilde{Z}_c$, $\tilde{k}$, and ϕ are the surface impedance (the ratio of acoustic pressure to the associated particle velocity), the characteristic impedance of the equivalent fluid, the complex wave number, and the open porosity of the porous sample, respectively. Z_0 is the characteristic impedance of the air. The tilde symbol (~) indicates that the associated variable is complex-valued and frequency dependent, and $j=\sqrt{-1}$.

To eliminate the effects of the elasticity of the frame of the porous sample, the acoustical excitations are in a frequency range where the porous layer behaves mostly as acoustically rigid, i.e. for frequencies greater than the decoupling frequency[4]. Since the frame of the material is assumed motionless, only a longitudinal compression wave in the fluid phase propagates along its axis. Under this rigid-frame assumption, the fluid saturating the interconnected cells of the porous material can be macroscopically described as an equivalent homogeneous fluid of effective density $\tilde{\rho}$ and effective bulk modulus $\tilde{K}$. In this case, following the equivalent fluid model based on the works by Johnson *et* al[7] and Champoux and Allard[8], the characteristic impedance and complex wave number of the "rigid" porous layer are given by :

$$\tilde{Z}_c = \sqrt{\tilde{\rho}\tilde{K}} \tag{2}$$

and

$$\tilde{k} = \omega\sqrt{\frac{\tilde{\rho}}{\tilde{K}}} \tag{3}$$

with the effective density $\tilde{\rho}$:

$$\tilde{\rho} = \rho_0\alpha_\infty\left(1+\frac{\phi\sigma}{j\omega\rho_0\alpha_\infty}\left(1+j\frac{4\omega\rho_0\eta\alpha_\infty^2}{\sigma^2\phi^2\Lambda^2}\right)^{1/2}\right) \tag{4}$$

and the bulk modulus $\tilde{K}$:

$$\widetilde{K} = \frac{\gamma P_0}{\gamma - (\gamma - 1)\left(1 + \frac{8\eta}{j\omega B^2 \Lambda'^2 \rho_0}\left(1 + j\frac{\omega B^2 \rho_0 \Lambda'^2}{16\eta}\right)^{1/2}\right)^{-1}},$$

(5)

In Equations 2 thru' 5, ω is the angular frequency, P_0 is the barometric pressure, and γ, B^2, ρ_0, and η are the specific heat ratio, Prandtl number, density, and dynamic viscosity of the saturating air, respectively. The five remaining properties in Eqs. (4) and (5) are those defining the complexity of the porous network. They are the open porosity ϕ, static airflow resistivity σ, tortuosity α_∞, viscous characteristic length Λ, and thermal characteristic length Λ'.

2.2 Cost function

In the previous section, the normalized surface impedance $\widetilde{Z}_s$ was analytically related to the five macroscopic properties of the porous network, the properties of the saturating air, and the thickness of the sample. Since the open porosity and the airflow resistivity can be determined with acceptable accuracy using standard techniques, only the tortuosity and the two characteristic lengths are unknown in the right hand side of Eq. (1). Consequently, through precise measurements of the normalized surface impedance on a porous sample and using its analytical expression (Eq. (1)), a non-linear regression fit can be designed and optimized to identify the three intrinsic remaining unknowns parameters (α_∞, Λ, Λ'). By defining the unknown parametric vector $\mathbf{a} = \{\alpha_\infty, \Lambda, \Lambda'\}$, the approach is then to design a cost function that measures the agreement, over a specific frequency range, between an observed normalized surface impedance $\widetilde{Z}_s^o$ and a numerical prediction $\widetilde{Z}_s^e(\mathbf{a})$ for a given estimate of the adjustable vector **a**.

The cost function is conventionally arranged so that small values represent close agreement. For the purpose of this study, the following cost function is then considered:

$$R(\mathbf{a}) = \frac{1}{2}\sum_{i=1}^{N}\left|\widetilde{Z}_{s_i}^e(\mathbf{a}) - \widetilde{Z}_{s_i}^o\right|^2, \qquad (6)$$

where superscripts *e* and *o* stand for estimated and observed, respectively, *N* is the total number of computed frequencies retained from the frequency range of interest. The estimated values are obtained from Eq. (1) for a given parametric vector **a**. The observed values $\widetilde{Z}_s^o$ are the measured normalized surface impedance of the porous sample to be characterized. These data can be measured in an impedance tube following the standard test procedure described in ASTM E1050-86.

The inverse characterization problem related to the impedance tube configuration shown in Figure 1, is to find the parametric vector $\mathbf{a} = \{\alpha_\infty, \Lambda, \Lambda'\}$, such that

$$\begin{cases} R(\mathbf{a}) \to 0 \\ \mathbf{LB} \le \mathbf{a} \le \mathbf{UB} \end{cases}, \qquad (7)$$

where **LB** and **UB** are the lower and upper bounds that limit the research domain on the adjustable parametric vector **a**.

Due to errors in the measurements of the surface impedance and the other properties needed in Eq. (1), the first condition in Eq. (7) is hardly likely to be met. Hence, a minimization of the cost function makes it easier to find the optimal parametric vector **a**. The minimization procedure will be discussed in section 2.4.

The bounds in Eq. (7) are necessary to limit the domain of research on **a,** and to ensure that realistic values are obtained for the searched parameters during the solution process. In this study, the bounds on **a** have been derived from the literature as discussed in the introduction.

By definition, the tortuosity cannot be lower than 1. Also, published and in-house measurements on a wide variety of commonly used acoustical porous materials have shown that the tortuosity is usually lower than 4. For the case of a material made up from parallel cylindrical pores perpendicular to the input surface, both characteristic lengths are equal

However, for common porous materials, the viscous characteristic length is smaller than the thermal characteristic length. Moreover, the following relations are found in the literature[3]:

$$\Lambda = \frac{1}{c}\left(\frac{8\alpha_\infty\eta}{\sigma\phi}\right)^{1/2}; \qquad 0.3 \le c \le 3.3 \qquad (8)$$

and

$$\Lambda' = \frac{1}{c'}\left(\frac{8\alpha_\infty\eta}{\sigma\phi}\right)^{1/2}; \qquad 0.3 \le c' \le c, \qquad (9)$$

where *c* and *c'* are pore shape parameters related to the viscous and thermal dissipation, respectively. From the above discussion and Eqs. (8) and (9), the lower and upper bounds in Eq. (7) can then be built from the following constraints:

$$\begin{cases} 1 \le \alpha_\infty \le 4 \\ \frac{1}{3.3}\left(\frac{8\alpha_\infty\eta}{\sigma\phi}\right)^{1/2} \le (\Lambda, \Lambda') \le \frac{1}{0.3}\left(\frac{8\alpha_\infty\eta}{\sigma\phi}\right)^{1/2} \\ \Lambda \le \Lambda' \end{cases} \qquad (10)$$

The upper and lower bounds on the characteristic lengths will vary from one iteration to the next in the minimization process.

It should be pointed out that a cost function based on other acoustical indicators, such as the reflection coefficient or the absorption coefficient, could be designed. However, the discussion about the best indicator to use for the procedure is beyond the scope of this paper.

2.3 Analysis of cost function

In this section, the cost function Eq. (6) is analyzed. To do so, an open cell foam material is considered. Although the analysis is performed on a specific foam, the obtained results may apply to other sound absorbing materials. For a proper analysis of the cost function, the observed impedance $\tilde{Z}^o$ is obtained by simulations using Eqs. (1)-(5) in view of eliminating the effects of experimental errors. In this ideal case, the solution of the inverse characterization problem of Eq. (7) should lead to the exact properties of the studied material. The studied material is a 49.92-mm thick layer of Foam 1. Its material properties are given in Tables I and II. The sound absorption curve for this material is shown in Figure 2 . It is a typical curve for sound absorbing materials. The curve may be divided into three zones: Zone I – below the first maximum, Zone II – around the first maximum, and zone III – above the first maximum.

First, if the tortuosity is fixed to its exact value of 1.315, the evaluation of Eq. (6) over the domain $[60 \leq \Lambda \leq 365\ \mu m\ ,\ 60 \leq \Lambda' \leq 730\ \mu m]$ – included in the domain given by the second equation of Eq. (10) – shows different contour plots depending upon the selected frequency range in the calculation.

If the frequency range of the inversion corresponds to Zone I of Figure 2, the contour plot of the cost function presented in Figure 3(a), shows a rapid variation along the Λ'-axis and a slow variation along the Λ-axis. If the frequency range of the inversion now corresponds to Zone III, the contour plot, presented in Figure 3(b) shows a slow

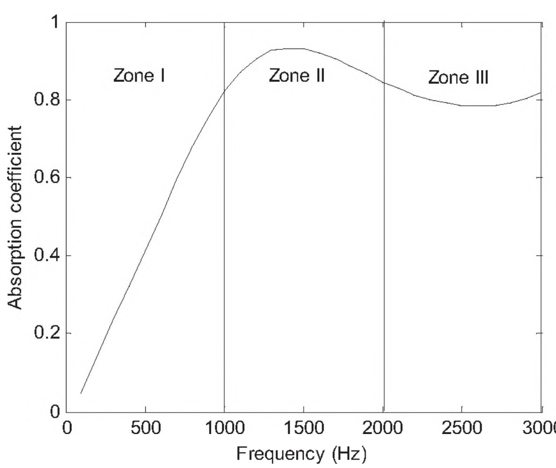

Figure 2. Absorption coefficient of a 49.92-mm thick layer of Foam 1.

The properties of the foam are given in Tables I and II. The curve is obtained using Eqs. (1)-(5).

Table I. Material properties of the studied materials measured using direct methods.

Properties		Foam 1	Foam 2	Fibrous 1	Fibrous 2	Screen	Units
Name	Symbol						
Static airflow resistivity	σ	4 971	8 197	21 235	50 470	450 000	Ns/m^4
Open porosity	ϕ	0.97	0.95	0.94	0.89		
Density	ρ_1	21.6	23.9	89.6	150.0		kg/m^3

variation along the Λ'- axis and a rapid variation along the Λ- axis. These results are logical since at low frequencies the thermal dissipation usually dominates over the viscous dissipation, and for higher frequencies, it is the viscous dissipation that dominates. Consequently, an ideal frequency range for the inverse characterization should cover a part of Zones I and III so the cost function may have a same level of sensitivity to both characteristic lengths. However due to the fact that zone I includes information about parameters such as flow resistivity and porosity that have the highest weight at low frequencies and on which the inversion highly depends, one conclude that this zone must be included in the inversion. On the other hand, the zone II seems to be a good alternative to zone III since it contains the maximum absorption and could be seen like bridge information between zone I and III. In order to confirm this choice the same numerical study as above has been performed on the cost function defined on a frequency range covering zones I and II. The result is shown in Figure 4(a). In this case, the variations of the cost function along both axes are similar.

Similar contour plots are also obtained for other tortuosity values apart from the exact tortuosity of 1.315; however, the minimum of the cost function is located elsewhere. The dots in Figure 4(a) represent the locations of the minima for different tortuosity values ranging from 1 to 1.6. Theoretically, one can conclude from this observation that there exists only one minimum in the characteristic length mapping for a given tortuosity plane. Nevertheless, the minimum related to the exact tortuosity of 1.315 is the lowest minimum and leads to the exact characteristic lengths (Λ=123.19 μm, Λ'=289.54 μm). In Figure 4(b) the evolution of the cost function minima in function of the tortuosity is presented. It is noted that there exists only one minimum. As expected, for this ideal theoretical case, the minimum of the minima (optimal solution) falls to zero only at the exact tortuosity value of 1.315.

In conclusion, using an appropriate minimization algorithm for the inverse characterization problem of Eq. (7), the selected cost function should theoretically lead to the exact solution for the parametric vector **a** under the condition that an appropriate frequency range is used.

2.4 Solution of inverse characterization

Due to errors in the measurements of the observed impedance $\widetilde{Z}_s^o$ and the other properties needed in Eq. (1) to estimate $\widetilde{Z}_s^e$, the first condition in Eq. (7) – i.e. $R(\mathbf{a}) = 0$ – is hardly likely to be met. Hence, a more practical way to state the inverse characterization problem is to find the parametric vector **a** that minimizes the cost function $R(\mathbf{a})$ and satisfies the constraint $\mathbf{LB} \leq \mathbf{a} \leq \mathbf{UB}$.

As shown in the previous section, to find the best-fit parametric vector **a,** it is necessary to find the global minimum of the inverse chacaterization problem. Several techniques are available to minimize a multivariable function[28,29]. However, with the non-linear dependencies in terms of the vector **a** in Eq. (6), the minimization must proceed iteratively, i.e. a sequence of approximate solutions is generated. Moreover, for this minimization problem, there may be multiple, equal or unequal, minimal solutions. A standard algorithm such as Newton-Raphson method cannot avoid the possibility of mistaking a local minimum for a global minimum. It follows that the minimization technique adopted must be able to identify the global minimum (global solution) among all the local solutions and also to handle constraints (in order to localize the reliable physical solutions). Also, an important task that should be examined to retain a minimization algorithm among others is its ability to deal with noisy data and to extract

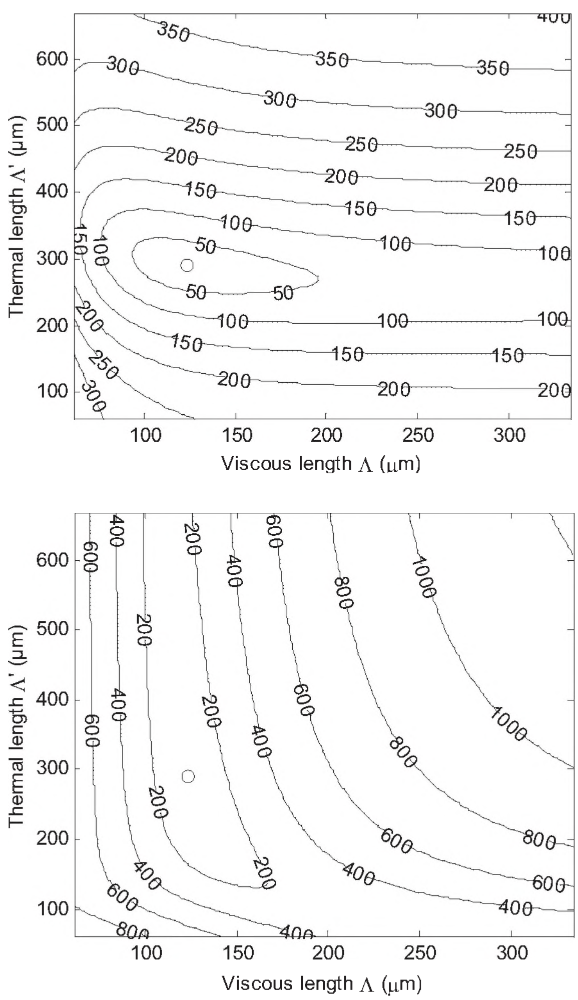

Figure 3. Contour plot of the cost function versus the characteristic lengths for the exact tortuosity of 1.315. (a) Results obtained from Eq. (6) using the frequency range covering "Zone I" in Figure 2 (b). Results obtained from Eq. (6) using the frequency range covering "Zone III" in Figure 2.

The contour plot is related to a 49.92-mm thick layer of Foam 1. The small circle shows the location of the theoretical minimum, i.e. R = 0.

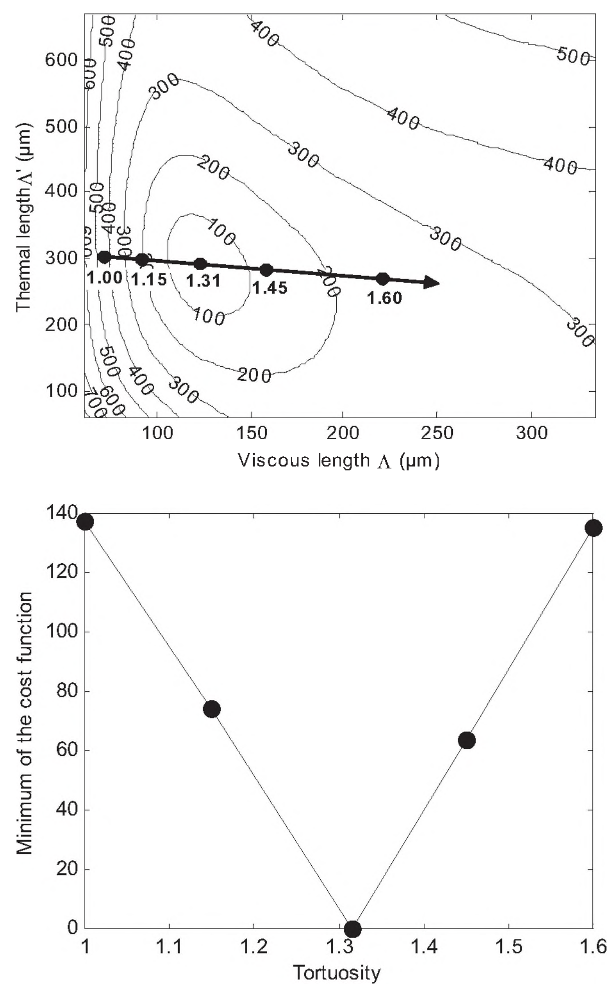

Figure 4. (a) Contour plot of the cost function versus the characteristic lengths for the exact tortuosity of 1.315 and the frequency range covering "Zones I and II". The dots indicate the locations of the minima for other tortuosity values ranging from 1 to 1.6. (b) Evolution of the minima as a function of the tortuosity. The dots are the minima shown in (a) transposed along the tortuosity axis. The graphs are related to a 49.92-mm thick layer of Foam 1.

information from noise.

Following the above discussion, a number of algorithms have been implemented and tested[26]. The one offering the best performance was a differential evolution algorithm[30-32]. In the following, the differential evolution global optimisation algorithm is summarized.

2.5 Differential evolution algorithm

Like genetic algorithms, differential evolution is part of the evolutionary algorithm class that is based on an analogy between evolution of living species and the process of optimization. The main difference between differential evolution and genetic algorithm is that differential evolution operates directly on problem unknowns. Unlike genetic algorithm, no binary coding of variables is required which makes differential evolution easier to implement. Differentail evolution algorithm interprets the value of the cost function at a point like optimum measures of physical form of this point. Then, guided by the principle of the survival of most suitable, a first population of the vectors is transformed into vector of solution during the repeated cycles of the mutation, the recombination, and the selection. The total structure of the differential evolution algorithm resembles the majority of the methods of search based on an initial population. Two alignments are updated; each one holds a population of N-Dimensional vectors with real values. Primary alignment holds the current population, while secondary alignment accumulates the vectors that are selected for the next generation. The selection occurs by competition between the existing vectors and the trial vectors. The trial vectors employed by differential evolution are formed by the mutation and the recombination of the vectors in primary alignment. The mutation is an execution that makes small random changes with one or more parameters of an existing vector of population. The mutation is crucial for the diversity of update in a population, and is typically carried out by the perturbation. A convenient source of the suitably measured perturbations and which makes differential evolution different from the Evolutionary Strategies[29] is the population itself. Each pair of vectors (X_A, X_B) in primary alignment defines a differential of vector, X_A - X_B. When these two vectors are selected by chance, their weighed difference can be employed to perturb another vector in primary alignment X_C:

$$X'_C = X_C + F(X_A - X_B) \tag{11}$$

The weight F is a user-supplied constant. The optimal value of F for the majority of the functions was found to lie in the range [0.4, 1][26]. An effective variation of this scheme implies to maintain the best vector so far, X^*. This can be combined with X_C and then perturbed, yielding:

$$X'_C = X_C + F(X^* - X_C) + F(X_A - X_B) \tag{12}$$

Then, in mutation, the most successful member of a population influences all trial vectors.

Recombination, or the crossover, provides an alternative and complementary means of creating viable vectors. Conceived to resemble the normal process by which a child inherits the DNA from its parents, new parameter combinations are built from the components of existing vectors. This effectively scrambles information on successful combinations, allowing the search for an optimum to concentrate on the most promising area of the space of solution.

Each primary array vector X_C of alignment is targeted for the recombination with X'_C to produce a trial vector X_T. Thus, the trial vector is the child of two parents, a noisy random vector and the primary array vector against which it must compete. The recombination is determined by a crossover constant C, where $0 \leq C \leq 1$. In exponential crossover, a starting parameter is selected at random. Then C is compared to uniformly distributed random number from within the interval [0, 1]. Subsequent trial vectors parameters are chosen from X'_C until the random generator of number produces a value larger than C (or until all the parameters have been determined). In binary crossover, the random experiment is performed for each parameter. If the random number is smaller than C, the trial vector parameter is chosen from X'_C, otherwise it comes from X_C. In both cases, when C =1, every trial vector parameter comes from X'_C, making with the trial vector X_T an exact replica of the noisy random vector. Once new trial solutions have been generated, selection determines which one among them will survive into the next generation. Each child X_T is confronted to its parent X_C in the primary array. Only the best candidate is then allowed to advance into the next generation. For more details about how crossover process using the constant C is working in differential evolution, the reader must refer to the work of Price[30,32] .

In all, only three parameters control the differential algorithm: the population size N, the weight F applied to the differential in mutation, and the constant C that mediates the crossover operation. Several numerical tests have been performed[26] and the results were used to set up an adequate and robust evolutionist optimization algorithm to solve the problem stated by Eq.10 in the shortest time. Then, the final parameteric estimation set up, using differential evolution algorithm, was applied for identification of material intrinsic propertries from real experimental data.

Many reasons are behind the choice of using a global optimization technique such as differential evolution instead of others optimization algorithms. First of all, there may be multiple, equal, or unequal optimal solutions for the inverse characterization problem proposed in this paper, since it is an over determined problem with more equations than unknowns. Therefore, a simple standard minimization procedure like a well-known Newton-Raphson scheme cannot avoid the possibility of mistaking a local minimum for a global minimum. In addition for a local optimization technique, the obtained solutions depend narrowly on the trial guess (initial parameters to start the minimization). It follows that a global optimization algorithm such as differential evolution scheme has to be adopted in this problem in order to be able to identify, efficiently, the global minimum (optimal solution) among all the local solutions. Differential evolution algorithm is retained also due to its flexibility to handle different kind of constraints on the unknown parameters with a robust convergence behaviour. It must be emphasized finally, that compared to many robust global optimization algorithms, such as adapted simulated annealing and genetic algorithms, differential evolution has shown a net robustness and superiority[32].

3. RESULTS

3.1 Inverse characterization of porous samples

Using the inverse characterization problem described in the previous section, two foams and two fibrous sound absorbing materials are characterized. The airflow resistivity, bulk density, and open porosity of the materials have been measured with direct methods[13-15] and are presented in Table I. The inverse characterization operates on the frequency range 500-1600 Hz which is within the range of a large diameter (10 cm) B&K 4206 impedance tube. Even though such impedance tube allows accurate measurements down to 200 Hz, the lower limit is fixed to 500 Hz for two reasons. Firstly, using only data above 500 Hz will eliminate the imprecise data at low frequencies which are associated with systematical errors of the experimental set-up (the limited microphone spacing compared to the wavelengths at these frequencies). Secondly, the five-parameter model used in this inverse characterization problem is imprecise at low frequencies[12],

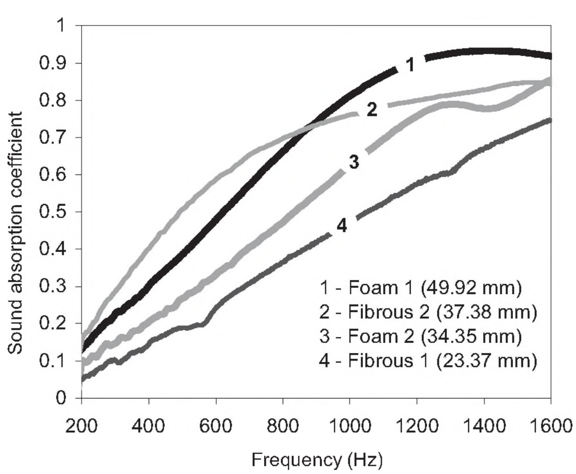

Figure 5. Absorption coefficient of the four porous materials.
The curves are averaged over three samples for each material. The mean thickness is indicated in parenthesis.

Table II. Results of the inverse characterization on the studied porous materials.
Three samples per material are used. The thickness of each sample is given in the second column. The intrinsic properties obtained by the proposed inverse characterization are given in the five last columns. The mean properties for each material are written in bold face.

Material	Thick. L (mm)	Tortuo. α_∞	Viscous Length Λ' (μm)	Thermal Length Λ' (μm)	c $0.3 \le c \le 3.3$	c' $0.3 \le c' \le c$
Foam 1	49.75	1.30	119.11	286.09	1.67	0.69
	50.36	1.30	116.92	297.98	1.70	0.67
	49.66	1.34	133.55	284.56	1.52	0.71
	49.92	**1.31**	**123.19**	**289.54**	**1.63**	**0.69**
Foam 2	34.43	1.49	152.50	206.14	1.10	0.81
	34.63	1.35	104.10	221.00	1.53	0.72
	34.00	1.43	142.70	210.00	1.15	0.78
	34.35	**1.42**	**133.10**	**212.65**	**1.26**	**0.77**
Fibrous 1	23.46	1.00	51.31	121.16	1.67	0.71
	23.37	1.00	46.13	125.54	1.86	0.68
	23.27	1.00	48.42	96.47	1.77	0.89
	23.37	**1.00**	**48.62**	**114.39**	**1.77**	**0.76**
Fibrous 2	37.91	1.00	39.76	123.65	1.44	0.46
	36.68	1.00	35.61	137.37	1.60	0.42
	37.54	1.00	49.15	81.79	1.17	0.70
	37.38	**1.00**	**41.51**	**114.27**	**1.41**	**0.45**

and hence eliminating data below the 500 Hz limit is a practical way to recover the best estimation of the unknown parameters. In addition, even if the data seems to be clean in the absorption coefficient curve of the material, the error could be important while dealing with the impedances curves. On the other hand, it is interesting to present results (both measurements and simulations) in a large frequency band even for frequencies below 500 Hz to show how the retained rigid model compare to experiments at these frequencies. This will be a good indication of the quality of the identified parameters used for simulations. Consequently all the presented results are shown down to 200 Hz. The measurements of the acoustical parameters follow standard ASTM E 1050-86[33]. To prevent acoustical leaks around the edge of a sample, pressurized water jet cutting is used to achieve a perfect circular shape. The diameter of a sample is slightly greater (1% greater) than the inside diameter of the tube so that its edges be considered bonded to the wall due to friction. This reinforces also the rigid frame behavior of the material on which the inverse characterization model relies.

The room ambient temperature and barometric pressure during impedance tube measurements are (a) Foam 1: 21.5°C and 992 mbar, (b) Foam 2: 24.6 °C and 977 mbar, (c) Fibrous 1: 22.6°C and 1002 mbar, and (d) Fibrous 2: 24.6 °C and 977 mbar. These room conditions are necessary to have a good evaluation of the air properties used in Eqs. (4) and (5).

Under these experimental conditions and set-up, the measured absorption coefficients are shown in Figure 5 for the four materials to be characterized. The presented absorption is averaged over 3 samples. The thickness of each sample and the mean thicknesses are given in Table II. As previously stated in section 2.3, the ideal frequency range should cover Zones I and II of the absorption coefficient curve of the material as shown in Figure 2. However, the absorption coefficient curves presented in Figure 5 show that while Zone I is completely covered for the four porous materials considered, Zone II is only partially covered for Foam 1 and Fibrous 2, and is completely missing for Foam 2 and Fibrous 1. This is mainly due to the experimental setup used. In fact, the large impedance tube and the microphone spacing used in the measurements have limited the higher frequency limit, and consequently the frequency Zone II or III. The large impedance tube was retained in order to use the same large samples (10 cm in diameter) that have been used for the porosity and airflow resistivity measurements. It will be shown later, that covering both Zones I and II is not a necessary condition to achieve a good estimation of the unknown parameters. It will speed up the convergence of the optimizer since it deals with less experimental data. Also, in Figure 5, one may note that for Foam 2, the absorption coefficient curve presents a dip around 1400 Hz which is believed to be associated to the frame elasticity of the foam. The equivalent fluid model on which the inverse characterization relies cannot account for this elastic behavior. However, it will be shown that it does not affect noticeably the inversion since it is a local effect occurring only around the frame resonance – the rest of the curve being of a rigid type. Hence, the equivalent fluid model

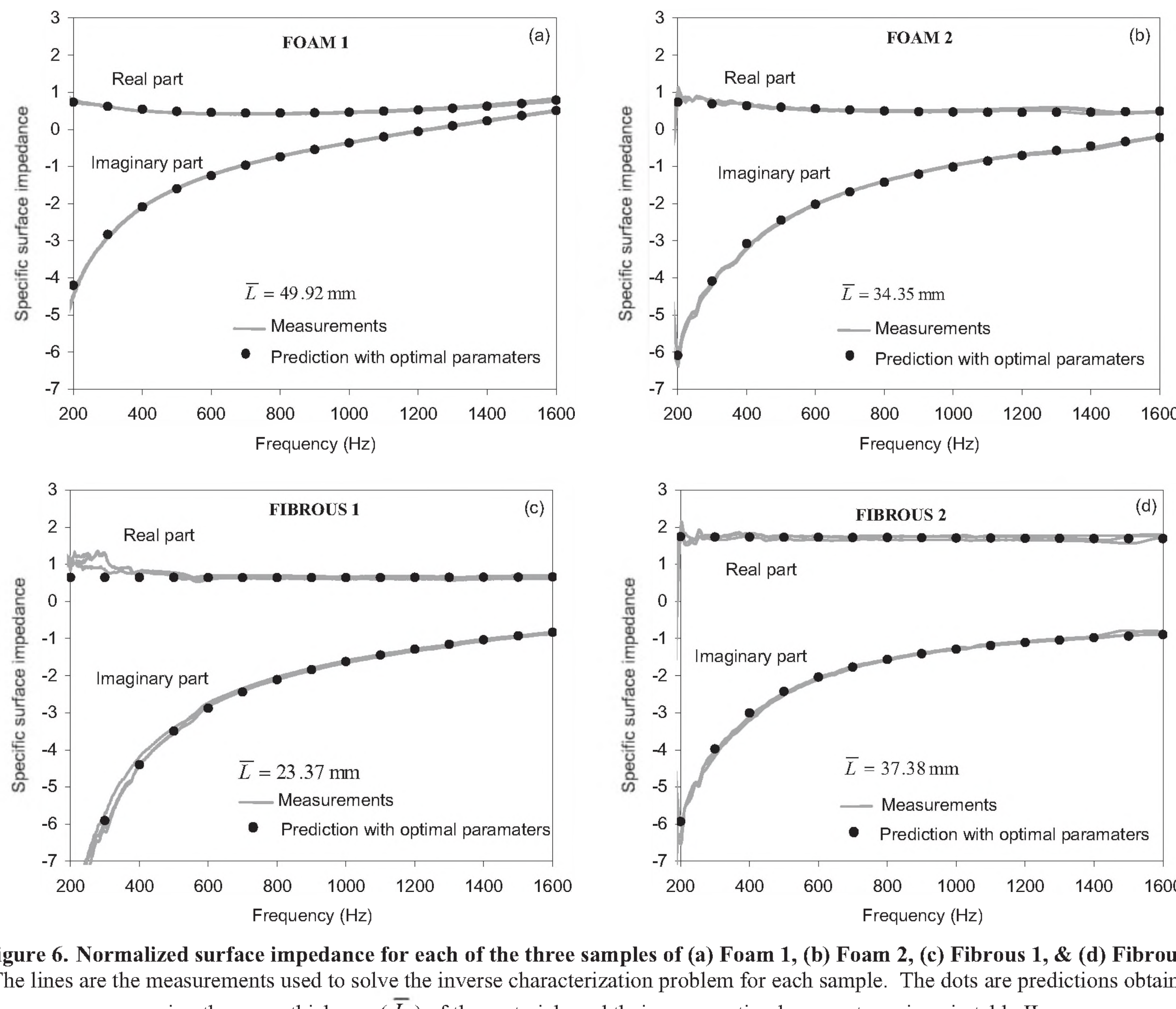

Figure 6. Normalized surface impedance for each of the three samples of (a) Foam 1, (b) Foam 2, (c) Fibrous 1, & (d) Fibrous 2. The lines are the measurements used to solve the inverse characterization problem for each sample. The dots are predictions obtained using the mean thickness ($\overline{L}$) of the materials and their mean optimal parameters given in table II.

behind the inverse characterization acts like a filter, filtering the elastic behavior of the frame and capturing mainly the rigid behavior. Figure 6 shows the normalized surface impedances on which the inverse characterization problem Eq. 7 will be applied. For each material, three samples are tested. The optimal parameters (tortuosity and characteristic lengths) identified by the inverse characterization for each material samples, and their mean values are reported in Table II. Also, the pore shape factors *c* and *c*' defined in Eqs. 8 and 9 are given in Table II.

Following the inverse characterization results of Table II, one can note that the identified tortuosity and characteristic lengths for the three samples of a given material are close to each other. For the fibrous materials, a tortuosity near unity and ratios Λ'/Λ of 2.35 and 2.75 are found respectively for Fibrous 1 and Fibrous 2. This is in accordance with the physics of fibrous materials that predicts a characteristic lengths ratio $\Lambda'/\Lambda \approx 2$ for ideal cylindrical fibers, and a tortuosity near unity for common fibrous materials[34]. For the foams, the values found are typical values compared to published data on foams. The discrepancies between some estimated values of a given porous material, especially in the case of Fibrous 2, may be due to the sensitivity of the mounting conditions from one sample to another, heterogeneities between samples, and uncertainties on the thickness – difficult to measure with precision for fibrous materials. Using the mean thicknesses and the mean optimal parameters given in Table II, good agreements are obtained when predictions of the normalized surface impedance, using Eqs.(1)-(5), are compared to the measured impedances Figure 6.

3.2 Validation results

To validate the proposed inverse characterization procedure and verify that the optimal identified parameters are good estimates of the physical intrinsic properties of the tested materials, three validation tests are performed.

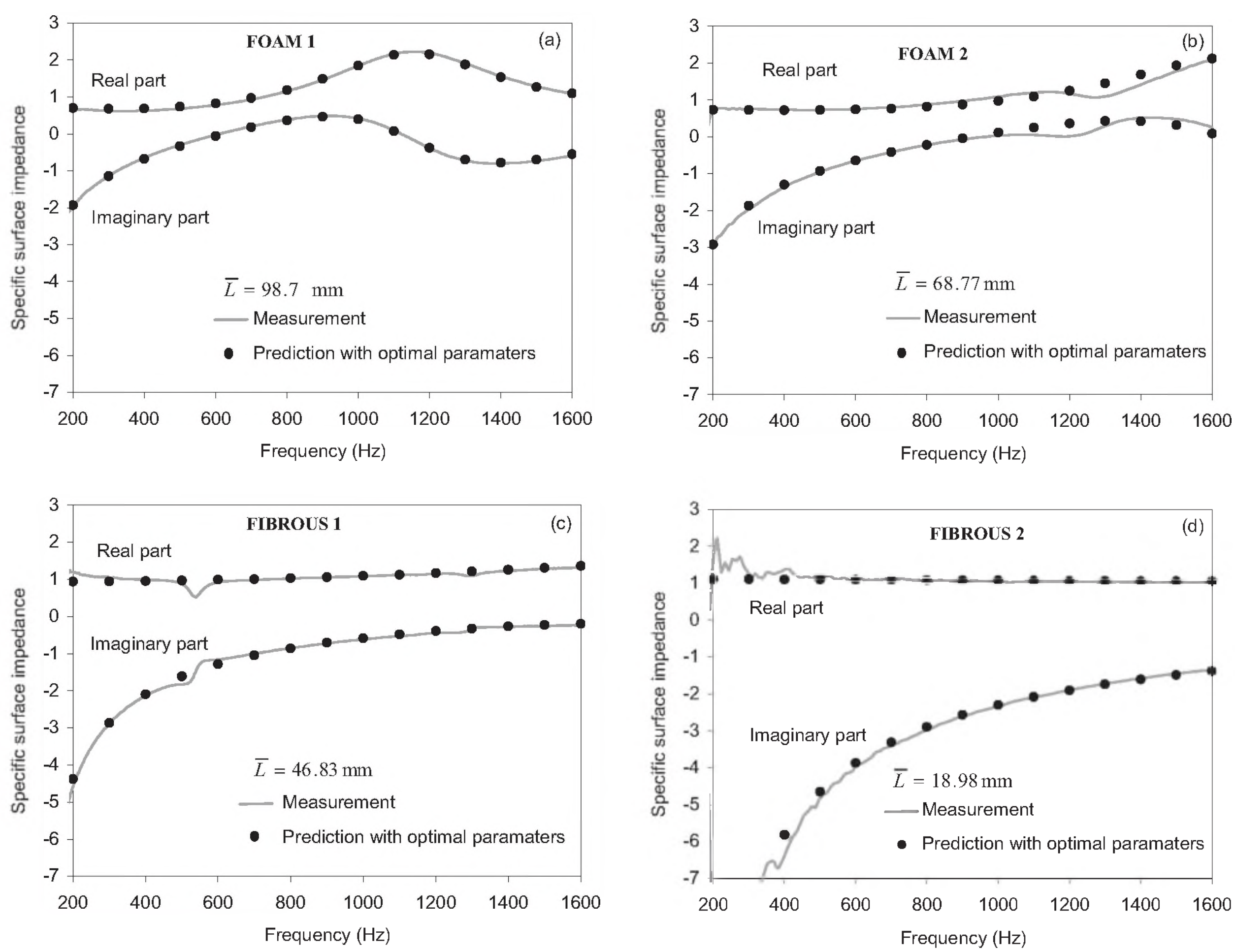

Figure 7. Normalized surface impedance for a thickness different from the one used for the inverse characterization on (a) Foam 1, (b) Foam 2, (c) Fibrous 1, and (d) Fibrous 2.

Comparisons between impedance tube measurements and predictions using the mean optimal material parameters given in table II.

Comparisons for different thicknesses

The first validation test is to compare predictions to measurements for thicknesses different from those used for the inverse characterization. The thicknesses of the new test samples are: Foam 1, 98.7 mm; Foam 2, 68.77 mm; Fibrous 1, 46.83 mm; Fibrous 2, 18.98 mm. Figure 7 shows the comparisons in terms of normalized surface impedance. The predictions use the mean optimal parameters of Table II. A good agreement between the predicted and measured surface impedances is still observed for these new configurations. Consequently, the optimal parameters seem to be independent of the thickness.

Comparisons for a different frequency range

The second validation test is to compare numerical predictions to measurements for a frequency range different from the one used for the inverse characterization. Figure 8 shows the comparisons for the frequency range, 200 Hz to 6500 Hz. In this case, the small (29 mm) B&K 4206 impedance tube is used. The predictions use the mean optimal parameters of Table II. In this validation test also, it is observed that the predicted results, using the optimal parameters, correlate with impedance tube measurements. Consequently, the optimal parameters seem to be independent of the frequency range.

Comparisons for different multilayered materials.

The third validation test is to compare predictions to measurements for multilayered materials instead of single layered material used in the inverse characterization. The predictions for the multilayered materials are based on the wave approach, also known as the transfer matrix method[3].

This method assumes layers of infinite extent and is essentially based on the representation of plane wave propagation in different media in terms of transfer matrices. This approach is well suited for the analysis of multilayers

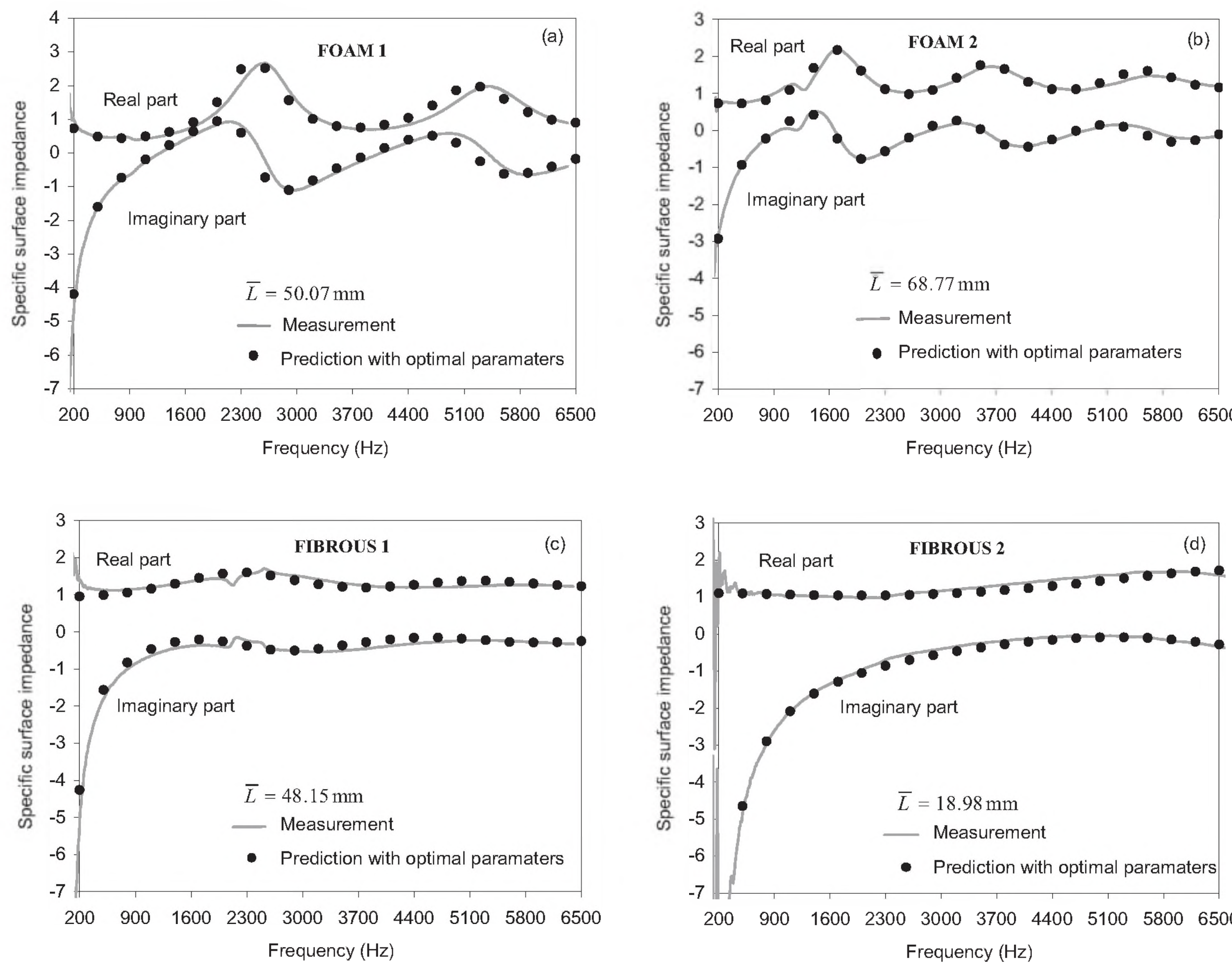

Figure 8.Normalized surface impedance for a frequency range different from the one used for the inverse characterization on (a) Foam 1, (b) Foam 2, (c) Fibrous 1, and (d) Fibrous 2.

Comparisons between impedance tube measurements and predictions using the mean optimal material parameters given in table II.

made up from a combination of elastic, porous-elastic and fluid layers. Figure 9(a) compares the predicted and measured absorption coefficient for a two-layer configuration made from a 24.70-mm thick layer of Foam 1, and a 23.37-mm thick layer of Fibrous 1 backed by the rigid wall. A similar comparison for a three-layer configuration is presented in Figure 9(b). The multilayered configuration is made up from a 23.37-mm thick layer of Fibrous 1, a 0.35-mm thick micro-porous screen, and a 24.70-mm thick layer of Foam 1 backed by the rigid wall. Since the used micro-porous film was defined mainly by its airflow resistivity, given in Table I, it was then modeled using the Delany and Basely model[35]. A final comparison over the frequency range 0-6300 Hz is presented in Figure 9(c). The multilayered configuration is made from a 34.54-mm thick layer of Foam 2, and a 18.35-mm thick layer of Fibrous 2 backed by the rigid wall. In this case, the small (29 mm) B&K 4206 impedance tube is used.

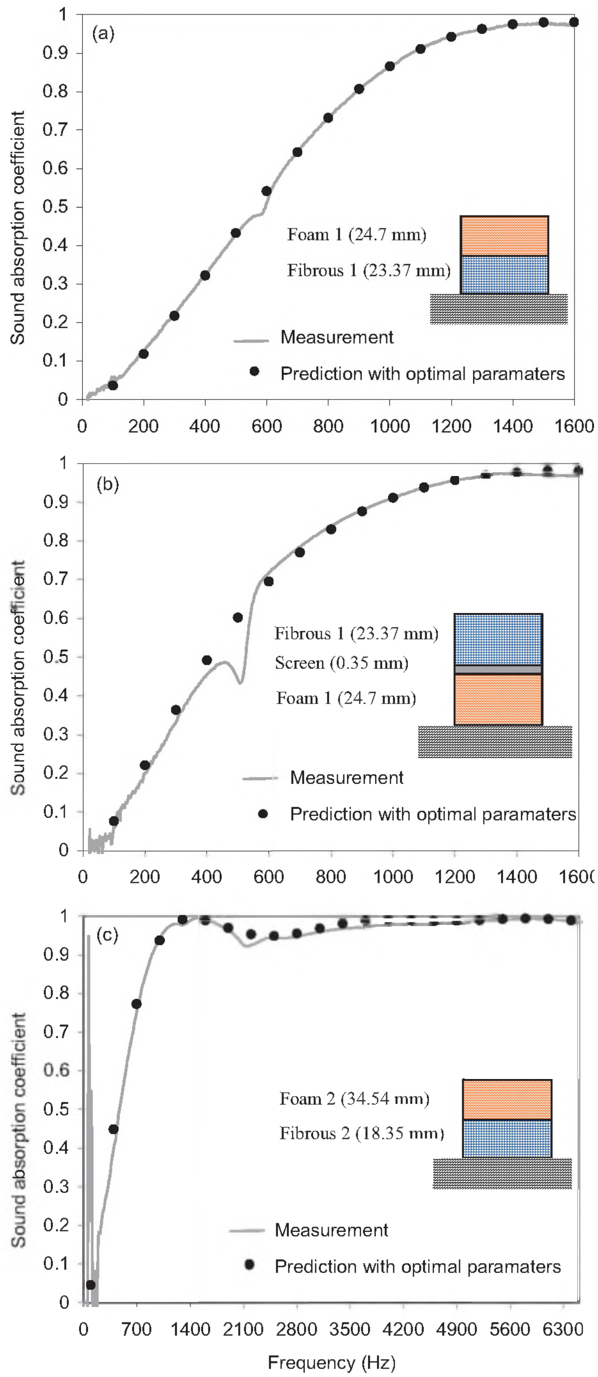

Figure 9. Sound absorption coefficient for multilayered configurations.

Comparisons between impedance tube measurements and predictions using the mean optimal material parameters given in Table II.

For the three multilayered configurations, good agreements are found between predictions and measurements; except where elastic resonances – not captured by the equivalent fluid model – occur. Consequently, the optimal parameters found with the inverse characterization seem to be independent of the layered configuration.

Following the good agreements between predictions and measurements for the three previous validation tests, it is shown that the optimal parameters (tortuosity, and viscous and thermal characteristic lengths) found with the proposed acoustical inverse characterization method, are not dependent of the material's thickness, frequency range, and layered configuration. Therefore, the optimal solution found by the inverse characterization problem yields good estimates of the intrinsic geometrical parameters of the tested porous materials.

4. SENSITIVITY ANALYSIS

In this section, the sensitivity of an inverse characterization to errors associated to the directly measured airflow resistivity and open porosity is discussed. The errors considered here are those related to the apparatus used for the flow resistivity and porosity measurements. To minimize all kind of errors (systematic and random), precise apparatuses, based on the published works[13-15], were used. With these apparatus, the maximum errors associated to the measured resistivity σ and porosity ϕ are respectively $\Delta\sigma$ = 1.6 % and $\Delta\phi$ = 2 %.

To analyze the influence of these errors on the identified tortuosity and two characteristic lengths, the errors were introduced in the optimization procedure. Since the errors $\Delta\sigma$ and $\Delta\phi$ are introduced simultaneously, they may occur both together or not, and in different direction. Therefore, there are a total of 9 possible error combinations to be considered in the sensitivity analysis.

Table III. Sensitivity of the inverse characterization due to errors on directly measured static airflow resistivity and open porosity for Foam 1 (sample1, Table II).

$\Delta\sigma$ = 1.6 % (79.54 N.m/s^4), $\Delta\phi$ = 2 % (0.0194).

Case number	Applied error ($\pm\Delta\sigma,\pm\Delta\phi$)	$\sigma \pm \Delta\sigma$ (N.m/s^4)	$\phi \pm \Delta\phi$	Inversion results α_∞	Λ (μm)	Λ' (μm)
1	**(0, 0)**	**4971**	**0.970**	**1.30**	**119.19**	**286.09**
2	(0, +)	4971	0.9894	1.29	112.55	318.66
3	(0, -)	4971	0.9506	1.31	126.74	255.05
4	(+, 0)	5050	0.970	1.30	120.66	284.97
5	(-, 0)	4891	0.970	1.29	117.62	287.22
6	(+, +)	5050	0.9894	1.29	113.94	317.68
7	(-, -)	4891	0.9506	1.30	125.04	256.36
8	(-, +)	4891	0.9894	1.28	111.20	319.66
9	(+, -)	5050	0.9506	1.31	128.52	253.72
			Mean	1.30	119.50	286.60
	Maximum absolute error (%)			1.54	7.82	11.73

Table IV. Sensitivity of the inverse characterization due to errors on directly measured static airflow resistivity and open porosity for Fibrous 1 (sample1, Table II).

$\Delta\sigma$ = 1.6 % (807.52 N.m/s^4), $\Delta\phi$ = 2 % (0.0178).

Case number	Applied error ($\pm\Delta\sigma,\pm\Delta\phi$)	$\sigma \pm \Delta\sigma$ (N.m/s^4)	$\phi \pm \Delta\phi$	Inversion results α_∞	Λ (μm)	Λ' (μm)
1	**(0, 0)**	**50470**	**0.890**	**1.00**	**39.76**	**123.65**
2	(0, +)	50470	0.9078	1.00	38.90	134.12
3	(0, -)	50470	0.8722	1.00	40.38	113.31
4	(+, 0)	51277	0.890	1.06	43.73	110.25
5	(-, 0)	49662	0.890	1.00	40.02	136.79
6	(+, +)	51277	0.9078	1.17	54.71	122.21
7	(-, -)	49662	0.8722	1.00	41.03	126.73
8	(-, +)	49662	0.9078	1.00	38.83	147.61
9	(+, -)	51277	0.8722	1.01	39.72	98.17
			Mean	1.03	41.90	123.65
	Maximum absolute error (%)			17	37.60	20.61

Only two from the four porous materials under tests are considered in this sensitivity analysis: Foam 1 with the lowest flow resistivity, and Fibrous 2 with the highest flow resistivity. The sensitivity analysis is conducted only on one sample for each material. This is sufficient to give a trend on how the identified parameters are affected by the errors associated to the directly measured properties σ and ϕ. The results obtained are presented in Table III for Foam 1, and in Table IV for Fibrous 2. From these results, one can note that the overall maximum error on the three parameters occur when the errors on both σ and ϕ are introduced: (+, +), (-, -), (+, -), and (-, +). For Foam 1, the maximum error occurs for the thermal characteristic length (11.73 %). For Fibrous 1, the maximum error occurs for the viscous characteristic length (37.6%). These maximum errors are overestimated, since the extreme error combinations used in this analysis are unlikely to occur in reality. Nevertheless, introducing the errors on σ and ϕ in the inverse characterization, and taking the mean value for each of the resulting parameters averages out the errors. This is observed in Table III and IV, where the mean values on the three characterized parameters are close to the case with no error (case number 1).

Finally, it is worth mentioning that extensive study performed on several porous materials[26] showed that the variation of the mean of the identified parameters from one sample to another is almost always more important than the variation due to the effect of the errors associated to the directly measured parameters. Consequently, using different samples of the same material and using the obtained mean values and their standard deviations is a practical way to use the inverse characterization problem.

5. CONCLUSION

In this paper, an inverse acoustical characterization procedure for the identification of tortuosity and characteristic lengths of sound absorbing porous materials using impedance tube was proposed. The method relies on the solution of an inverse characterization problem solved using a global optimizer based on differential evolution algorithm. It was shown that the proposed inverse characterization method theoretically leads to a unique solution (optimal solution) in terms of the tortuosity, and the viscous and thermal characteristic lengths.

The proposed acoustical inversion procedure was used to characterize four acoustic materials (two foams and two fibrous). The optimal parameters identified for tortuosity and the two characteristic lengths by inversion were consistent with published and known values for foam and fibrous materials. To validate the inverse characterization results, and to verify that the optimal parameters identified are good estimates of the intrinsic properties of the materials, three validation tests were successfully performed. The validations tests were based on configurations different than those used for the inverse characterization. From the validation tests, it was shown that the optimal parameters identified by inversion are not dependent of the material's thickness, frequency range, and layered configuration. Therefore, the optimal solution found by the inverse characterization is very good estimate of the intrinsic tortuosity and characteristic lengths of the tested porous materials.

The results of this paper show that the presented inverse acoustic characterization technique leads to reliable estimates of the physical properties of the tested materials. The suggested technique is simple to use but robust enough to be applied, with success, to a large range of sound absorbing materials. Consequently it can be seen as a promising and a good alternative characterization technique to the existing ones.

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Medical Examination of Hearing Required by Quebec Regulations: A Relevance Analysis

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ABSTRACT

The relevance of Quebec regulations imposing medical hearing evaluations on certain workers or job applicants has been evaluated. In pursuing the sole legitimate public health objective of regulation (ensuring the safety of others), it is essential to identify valid evaluation tools that can be used to establish criteria regarding when a hearing deficiency leads to disabilities that impede the safe performance of all the requirements of a given job, despite all possible work and workplace adaptations. Current regulations are heterogeneous in establishing such criteria and do not ensure the implementation of preventive measures. Furthermore, they emphasize individual hearing abilities and often fail to consider the nature of the work environment. A conceptual framework that emphasizes the interaction between the person and the work environment is discussed.

RÉSUMÉ

La pertinence des règlements imposant des examens médicaux de l'audition à certaines catégories de travailleurs ou de postulants à un emploi a été évaluée. Dans le contexte de la poursuite du seul objectif légitime qui est d'assurer la protection d'autrui, il est essentiel d'identifier des outils d'évaluation valides qui peuvent être utilisés pour établir au préalable quand exactement une déficience auditive conduit à des incapacités qui entravent la performance sécuritaire de toutes les exigences d'un travail donné, malgré toutes les adaptations possibles de la tâche et de l'environnement de travail. Les règlements actuels sont très hétérogènes à cet égard et n'assurent pas la mise en place de mesures préventives. Par ailleurs, l'approche réglementaire met l'emphase sur les capacités auditives individuelles et ne prend souvent pas en considération l'état du milieu de travail. Un cadre d'analyse qui met l'accent sur l'interaction entre la personne et l'environnement de travail est discuté.

1. INTRODUCTION

In 1995, the Quebec Provincial Medical Committee on Occupational Health set up a task force commissioned to study the relevance of regulations imposing medical examinations on certain categories of workers or job applicants in order to make appropriate recommendations, if need be, to the Quebec National Public Health Director.

The analysis approach arose out of Strategy #6 of the Health and Well-Being Policy, which is to "guide the health and social services system towards the most effective and least costly solutions" and allows to reach one of the ministerial objectives to "systematically, and on an ongoing basis, evaluate the quality and effectiveness of interventions, technologies and, more broadly, health and social services." [1]

To eliminate the regulatory constraints maintaining inappropriate medical practices, the Quebec Medical Council recommended in 1997 that "each act and regulation prescribing medical examinations be periodically evaluated" and that "a sunset clause provide for terminating the application of those that have not been reviewed within a reasonable schedule to take into consideration the evolution of knowledge."[2]

Finally, in 1999, the Task Force on the Complementarity of the Private Sector in Pursuing the Fundamental Objectives of Quebec's Health System (Arpin Report) echoed these recommendations by suggesting the necessity of "ceasing to guarantee services that are medically or socially not required."[3]

To date, relevance evaluations for sections of the *Regulation respecting the application of the Public Health Protection Act* that require medical examinations for diagnostic radiology workers and food handlers in certain forestry camps [4,5] have led the Quebec Council of Public Health Directors to recommend the abolition of these regulatory examinations to the Ministry of Health and Social Services who shared their opinion in this matter. More recently, the evaluation conducted by the Provincial Medical Committee on Occupational Health regarding the By-law respecting standards of the Sûreté du Québec and municipal police forces for the hiring of constables and cadets (c. P-13, r.14), was adopted by the Council of Public Health Directors [6].

The present paper will deal more specifically with the relevance of medical hearing evaluations required by regulation before hiring and/or during the course of employment. Four Quebec regulations that impose such requirements have been identified [7]:

- The By-law respecting standards of the Sûreté du Québec and municipal police forces for the hiring of constables and cadets (P-13, r.14) states that "an audiometric evaluation of the candidate must be carried out in standardized conditions and that a candidate will be considered unemployable when there is evidence of: (i) an average hearing loss at 1 000, 2 000 and 3 000 Hertz greater than 25 decibels; (ii) a hearing loss at 500, 1 000, 2 000 and 3 000 Hertz greater than 35 decibels; (iii) a hearing loss at 4 000 Hertz greater than 45 decibels."[8]

- Section 215 of the Regulation respecting occupational health and safety in mines (S-2.1, r.19.1), states that "The operator of a hoist used for the transportation of persons shall have a medical certificate issued by a physician within the 12 months preceding his entry in duty, and renewed annually, certifying that he has been examined and that he does not present any physical or mental handicaps or deficiencies in sight or hearing which, in the exercise of his duties, could endanger the safety of the persons being transported."[9]

- Section 136 of the *Regulation respecting occupational health and safety* (S-2.1, r.19.01) provides that "the employer shall, in conjunction with an audiometric program, make hearing protectors available to workers or shall limit their noise exposure time."[10]

- The *Regulation respecting access to driving a road vehicle in connection with the health of drivers* (C-24.2, r.0.1.0001) under the Highway Safety Code states that "A corrected or uncorrected average hearing loss greater than 40 decibels for the better ear at frequencies of 500, 1 000 and 2 000 hertz is essentially incompatible with driving a bus, an emergency vehicle, a minibus and a taxi."[11]

Similar regulations are in place in many industrial countries. Plausibly promulgated for the purpose of protecting the public, they do not necessarily meet recognized objectives, such as the objectives of hearing tests, as well as public health and occupational health objectives.

1.1 Objectives of hearing tests

Upon hiring and throughout employment, although not explicitly stated in the regulations identified, the objectives pursued by the medical hearing evaluation or audiometric program are most likely to permit the early identification of hearing loss or to judge an employee's fitness for work. Protecting the public or fellow workers are also possible objectives, especially in the case of the *Regulation respecting conditions of access to driving a road vehicle relative to the health of drivers* (C-24.2, r.0.1.0001), since workplace noise [12,13,14] and hearing loss [15] are recognized as factors associated with occupational accidents [16].

1.2 Public health objectives

According to the principles underlying public health practice, the administration of medical examinations for prevention purposes is justified only when solid scientific evidence exists that such examinations genuinely ensure improved quality of life or a reduction in avoidable or premature morbidity and mortality. The ethics and principles of public health in fact require that only those medical practices for which preventive effectiveness is demonstrated at the population level should be offered, and only for problems which have real importance both to the individual concerned and the general population.

1.3 Occupational health objectives

In the context of occupational health, other objectives may also be legitimately pursued. For example, the administration of medical examinations may be justified, from an employer's point of view, by the need to judge a person's ability to perform a job, thus the absence of disabilities that could represent an unacceptable risk for the company. The World Health Organization has proposed criteria for recognizing when these activities are legitimate [17,18].

1.4 Regulatory objectives

Imposing screening tests by legislation and regulation however involves conflicts between the individual right to privacy and the collective right to safety. In this regard, the Quebec College of Physicians concluded in 1997 that "treatment of the sick imposes on the physician a duty of diligence" whereas "a work-related medical examination imposes a duty of reserve" (seeking only the information necessary for judging fitness to perform a job) [19]. When the government imposes a burden on its citizens, it should also be bound to a duty of reserve at the individual level and to an obligation of results at the population level.

From a public health standpoint, the only objective that can legitimately justify imposing medical examinations on a worker or applicant is to ensure the safety of others. And because the consequences of such examinations may be to deprive an individual of his right to work under the Canadian Charter of Rights and Freedoms, it is necessary to give reasonable proof of their validity in identifying disabilities that may significantly imperil the health or safety of others. Furthermore, the obligation of results implies that the benefits obtained from the proposed examinations [20] and their efficiency [21] should have been clearly established in advance [22]. In addition to the direct costs of carrying out the various examinations imposed by legislation or regulation, the medical acts required are defined as insured services and are thus reimbursed by the Quebec Health Insurance Board. As thousands of citizens must submit to these requirements, the resources required represent considerable sums for our society [23, 24]. It is therefore essential to verify whether the scientific bases, which alone can justify imposing these burdens on categories of Quebec citizens, are all present. In addition, and in a general way, preference should be given to other means that do not undermine individual rights and freedoms.

Given the existence of other mechanisms to address disease prevention among workers (i.e: an organization specific health program under section 113 of the *Occupational Health and Safety Act* (R.S.Q., S-2.1)), it is not legitimate for the government to impose medical examinations for the purpose of protecting the "individual himself" or preventing the emergence or progression of work-related diseases. The government must rather favor a legal and regulatory approach that creates an obligation to provide safe and healthy working environments based on existing medical knowledge as well as technological and organizational possibilities. A legal approach limiting individual rights requires evidence of its absolute necessity and the absence of less constraining alternatives. To this end, the rationale and context for the use of hearing tests in the early identification of hearing loss to prevent its progression is presented in the Appendix.

2. ANALYSIS FRAMEWORK

In pursuing the sole legitimate objective (protection of others) regulatory examinations must be analyzed to answer the following questions:

- Are there specific tasks or jobs where particular hearing abilities are essential, and where hearing disabilities that have been compensated for by individual rehabilitation or environmental adaptations would endanger fellow workers or the public? If the answer is negative, a medical assessment is not appropriate. The fact nevertheless remains that hearing tests in a non-regulatory clinical context may be useful to appreciate the nature of the required rehabilitation or environmental adaptations in some cases.

- If the answer to the previous question is positive, for each particular situation, do valid tests exist to identify all individuals, and only those individuals, who suffer from such disabilities? If such tests do not exist, the administration of standard tests is obviously impossible and clinical assessment on a case-by-case basis might be the only alternative.

- If such valid tests are available, are they the ones required by the acts and regulations? If not, are the medical examinations currently imposed effective in this respect? If not, the act or regulation in question should be abolished or amended.

In summary, can we correctly identify the persons who suffer from a hearing deficiency for which they have however been "optimally" rehabilitated, but who suffer from disabilities such that they cannot perform in a manner safe for others all the requirements of a given job, despite all possible work and workplace adaptations? It is therefore appropriate to establish in advance when a hearing deficiency leads to such disabilities.

3. ANALYSIS OF REGULATORY EXAMINATIONS

3.1 Examinations to be analyzed

The requirements contained in the four regulations identified are very heterogeneous and very unspecific: sometimes a "hearing test", "an audiometric testing program" or "a medical hearing examination" is demanded, other times the regulation demands that the absence of a hearing disability be established, without however saying how. Similarly, the auditory thresholds used to establish a "passing mark" for the test, if stated, differ from one regulation to the next, while several regulations give the assessing physician the authority to determine who will pass or fail the test. The heterogeneity of the legislative and regulatory requirements at least highlights the lack of consistency of the acts and regulations, although in principle they all aim the same objectives. The question is to determine under such conditions whether one or the other, or all these very different regulatory requirements really make it possible to ensure that fellow workers or the public are protected.

3.2 Analysis

Are there specific tasks or jobs where particular hearing abilities are essential, and where hearing disabilities would endanger fellow workers or the public? Intuitively, one can suppose that for certain tasks or jobs, a worker must possess minimum hearing abilities in order to avoid endangering the safety of others (i.e: the operator of a hoist in a mine who has to perceive auditory signals on which the miners' safety depends).

Supposing that some of these conditions are identified, can these disabilities be compensated for by individual rehabilitation or environmental adaptations? Before administering any examination whatsoever to an individual, this question must first be answered. Many forms of adaptation or rehabilitation (visual rather than auditory signals, hearing aids, assistive listening devices, etc) exist. However, if for a given situation they are not applicable or do not sufficiently compensate for the hearing disabilities, do valid tests exist to identify all individuals having disabilities that cannot be compensated for through rehabilitation?

For lack of a more explicit definition of the examinations required by the regulations studied, the discussion will focus on the standard hearing tests carried out by the Screening Expertise Center of the Quebec National Public Health Institute. These examinations, administered to identify the various stages of noise-induced hearing loss among workers, include the auditory history questionnaire, the tympanometric examination and the tonal audiometric examination in air conduction and are carried out in accordance with the standards of the Quebec Standards Bureau [25].

Since the hearing function is a complex psycho-acoustic experience reaching far beyond the simple perception of a sound, these examinations can identify a loss of auditory sensitivity, but in no way allow the evaluation of disabilities to which it may lead. The auditory history questionnaire gathers information on the identity of the worker and his exposure to noise but no question deals, in detail, with hearing disabilities. The external auditory canal and tympanometric examinations are complements to the screening audiogram, whose only function is to determine the auditory thresholds for pure tones of different frequencies. It does not measure, for example, a worker's sound discrimination or frequency selectivity abilities. Frequency selectivity is defined as the ability to perceive a sound stimulus in the presence of one or more other sound stimuli. Such abilities, which are often altered in persons with acquired noise-induced hearing loss, are those that may be the greatest source of significant functional limitations. The tools available to assess these hearing abilities outside the clinical setting are currently incomplete and are still at the experimental stage.

Even the simplest auditory task (detecting the presence of a sound) is influenced by the properties of the sound wave and the environment in which it propagates. For example, detecting a back-up alarm against a background noise in a reverberant space, while wearing hearing protectors, is not the same as detecting a pure sound emitted through earphones in an audiometric room. Another more complex auditory task consists of discriminating between several acoustic signals. This task draws on frequency selectivity and temporal resolution abilities [26], as well as memorization of the signal's characteristics so it can be faithfully perceived.

The localization of sound sources is also an auditory task of great importance for several types of job. Being able to identify the origin or distance of a sound source may be crucial for ensuring the safety of a worker or other persons nearby (i.e: a worker being crushed to death by failing to localize the back-up signal emitted by a heavy vehicle [16]).

Finally, understanding speech requires much more complex processing than any other auditory activity and is strongly influenced by several factors external to the person (distortions introduced by the use of an electronic device, ambient noise levels, use of hearing protection, etc.) In addition, all auditory tasks listed previously are likely to be disturbed when hearing protectors are worn, whatever the individual's auditory thresholds may be.

Once the listening, communication or localization requirements are identified, how can the disabilities responsible for creating situations of handicap that represent a danger for fellow workers or the public be assessed? Although some attempts have been made, hearing tests allowing the valid identification of the ability to perform job assignments have not yet been developed [27] for all workplace situations, and under all circumstances. New tests have been or are being developed, but at best are at the beginning of implementation in the community (i.e: the "Hearing In Noise Test" (HINT) [28], the Guide for Clinical Measurement of Auditory Localization Ability [29] and the "Source Azimuth Identification In Noise Test (SAINT)."[30])

Despite the existence of certain tests, the regulatory approach emphasizes individual hearing abilities and usually does not take into consideration the fact that the work environment itself is unhealthy, even dangerous, from an auditory standpoint because of the presence of other determinants that influence the perception of acoustic signals (i.e: ambient noise levels, the quality of communication systems, the design of warning signals relative to the ambient noise and the hearing abilities of the worker population).

In summary, neither the medical assessment nor the audiogram enables us to appreciate hearing disabilities [31], which are themselves at the source of situations of handicap. Because they are inappropriate in answering the questions raised previously, it cannot be reasonably argued that these examinations really ensure the protection of others. Moreover, these examinations do not enable us to adequately guide workers towards appropriate habilitation and rehabilitation services when such resources exist.

3.3 Broader perspective

To complement this relevance analysis, particularly for those who believe that a regulatory examination may be justified for the sole purpose of protecting the individual concerned, and in order to make a judgment supported by an even broader perspective, it is also useful to consider the results of critical analysis of the scientific literature carried out by expert committees. These committees seek to determine who, in the generally asymptomatic population, will benefit

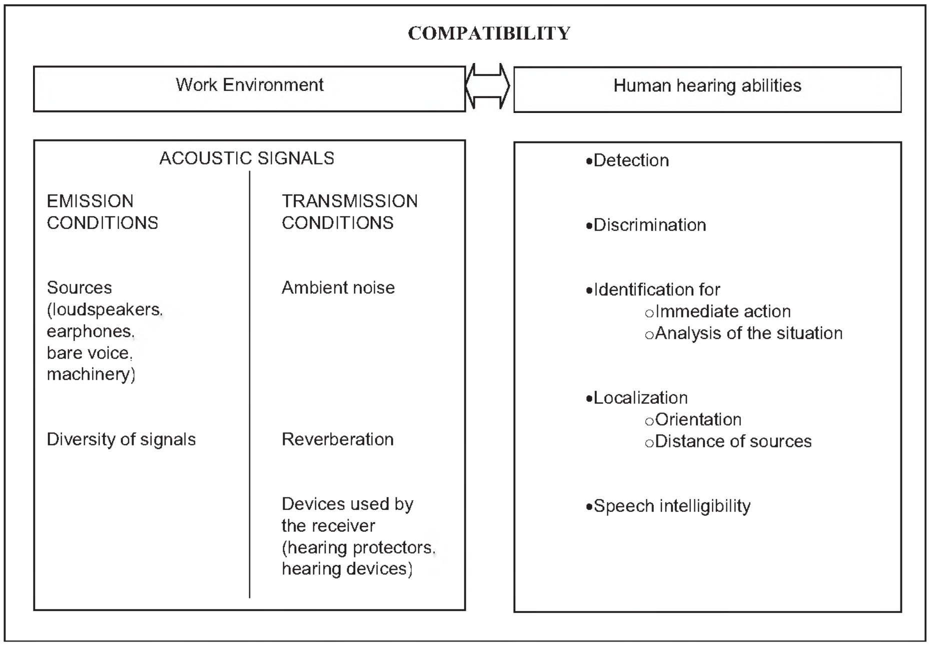

Figure 1. Conceptual model for analyzing compatibility between work requirements and hearing abilities.
The conditions involved in the transmission of acoustic signals are taken into consideration in the definition of occupational requirements. Emphasis is placed on the interaction between the individual and the work environment, rather than solely on the individual (Hétu R[31]).

from certain medical examinations likely to allow the early identification of certain diseases. Any medical examination that is not appropriate, based on the risk factors present in the work environment, especially when its use is not recognized as *relevant for the general population* for the purpose of *case finding*, must therefore be regarded as unnecessary and abusive, and is therefore to be avoided. It could not be legitimate to use such an examination in a context other than one of evaluation and treatment of persons who are ill or who seek a consultation (the diagnostic and therapeutic approach).

So, for the benefit of the general population, the Canadian Task Force on Preventive Health Care recommends to family physicians that they look for hearing impairment among senior citizens. The high prevalence of this impairment in the senior population and the possibility of offering means to minimize the situations of listening and communication handicap justify this recommendation. However, the Task Force does not make the same recommendation for the adult population, although it has sufficient data to "support noise reduction and hearing protection programs" for this population [32]. The U.S. Preventive Services Task Force, for its part states even more explicitly that there is insufficient evidence to recommend for or against routinely screening asymptomatic adolescents and working-age adults for hearing impairment [33]. Consequently, since the scientific literature is silent as to the usefulness of hearing tests among asymptomatic adults, they should not be imposed by regulation, even for the sole purpose of protecting the person concerned.

If intuitively we feel that certain functional limitations can endanger fellow workers or the public, we must recognize, that to our knowledge, there is currently no tool available that enables a matching of specific auditory requirements by type of task or work and individual hearing abilities. This lack of tools in no way justifies subjecting groups of individuals to irrelevant examinations. The duty of reserve and the obligation of results that the government must impose on itself do not allow to limit itself to an obligation of means and doing its best under the circumstances, not even in the meanwhile. Consequently, we must conclude that the medical examinations required by the various regulations are inappropriate for achieving the desired goals, whatever they may be.

4. ANALYSIS FRAMEWORK FOR ASSESSING THE CONTRIBUTION OF HEARING TESTS TO THE PROTECTION OF OTHERS

Hétu proposed the adoption of a renewed conceptual framework based on an ecological perspective of activities involving hearing. This new model, illustrated in figure 1, emphasizes the interaction between the person and the work environment [31]. Laroche established its relevance in four cases of complaints filed with the Canadian and Quebec Human Rights Commissions in recent years [34]. These two authors point out that the different hearing abilities required by a task will vary depending on the type of acoustic signals to be processed and the conditions involved in the transmission and reception of such signals [35,36]. As Hétu points out, an examination of the interaction between the environmental demands and the individual's hearing abilities may reveal inconsistencies, either because the environment is inadequate or because the person presents limited abilities to respond to environmental constraints. To remedy these limitations, we must design environments that are better adapted to normal human hearing abilities or resort to hearing devices (hearing aids and assistive listening devices) that allow the deficient function to be corrected or supplemented. Hétu strongly insists on the necessity of exploring all possible accommodations (i.e: use of hearing devices, adaptation of sound warning systems in industrial settings [36,37], spontaneous adaptations adopted by workers themselves and work-related experience [31]) in order to maximize compatibility between the environment and human skills.

5. CONCLUSION

Sections of the regulations examined, like other acts and regulations that require medical examinations, have the effect of "freezing" professional practices by making them insensitive to the evolution of scientific knowledge. The Canadian Task Force on Preventive Health Care has determined that effective action to prevent occupational hearing loss in the adult population resides in "noise reduction programs" [32] at the source or along its propagation paths.

With regards to the sole legitimate goal of third party protection, the examinations imposed by these four regulations do not ensure the safety of others when they are simply not left to the evaluator's discretion. Also, because the criteria for hearing impairment used to establish the presence of a danger for the public or fellow workers have not been defined, and because workplace monitoring of hearing is not recognized as a scientifically valid intervention by recognized groups of experts, the government cannot claim to meet the obligation of results to which it must bind itself when imposing burdens on citizens and thereby unnecessarily limiting their individual rights. As well, the functional abilities of detection, discrimination, recognition, localization and speech understanding which ensure an adequate match with the work requirements are not assessed by the audiogram, but remain in the field of scientific research [28] or at the stage of assessment for implementation in the community. These functional abilities are currently usually assessed in an interview carried out by specialized personnel and, more rarely, through analysis and field observation of work assignments.

Furthermore, the scientific literature and consulted documents demonstrate that the current context of administration of regulatory examinations does not ensure the implementation, although mandatory in work environments, of preventive measures that could help control the emergence or progression of occupational hearing loss. Finally, if the departments or agencies that have the authority to promulgate such regulatory requirements wish to maintain them, they should first ensure that the recommendations of the Public Health Concertation and Coordination Committee, aimed at assuming the obligation of results set forth in the Health and Well-Being Policy [38], are adequately implemented.

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7. ACKNOWLEDGMENTS

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8. APPENDIX

Regarding the objectives of prevention or early identification of hearing loss to prevent its progression, certain findings concerning workplace hearing tests were identified by members of the Advisory Committee to the Public Health General Directorate of the Department of Health and Social Services at the beginning of its mandate. Although these objectives are not related to the sole legitimate objective of regulation described before, they seemed to be pursued in the *Regulation respecting industrial and commercial establishments* and the *Workplace Quality Regulation* (These two regulations have been repealed and replaced by the *Regulation respecting occupational health and safety).* The following findings are noted because they are related to the requirements of these regulations and allow a better understanding of all that must guide the use of hearing tests in the workplace, even outside a regulatory context:

- "Occupational hearing loss is a frequent and debilitating problem for workers... [Even if activities aimed at sensitizing the work community to the harmful effects of noise are conducted], in many cases they are not successful in inciting the implementation of noise reduction measures, even when the technological resources are available. Constraints such as motivation and employer resources are also strong determinants [39].
- Hearing tests must be supported by firm action aiming the elimination of noise sources and the adoption of effective protective measures to prevent occupational hearing loss.
- Any hearing evaluation program must provide for follow-up of workers with hearing problems. Support must also be provided for rehabilitation and compensation efforts.
- A screening program consisting of a series of tests repeated with a certain regularity..., may have perverse effects: targeting the worker instead of the stressor, a feeling of false security, metrological difficulties, the insufficiency of resources to provide proper follow-up, etc. Furthermore, the screening process is sometimes directed away from its underlying purposes, for example when used to provide experimental proof that, in a given factory, noise exposure is great enough to produce occupational hearing loss or just the opposite. It is improper to use hearing tests to demonstrate over and again such a claim [40].
- Nor is it proper to use hearing tests to search out hypersensitive workers. Early identification efforts of so-called vulnerable individuals are useless because, among other reasons, the hearing tests are incapable of validly identifying them" [41].

Let's mention by the way why the use of hearing tests is greatly limited by the measuring qualities of audiometry:

- The hearing test is influenced by several sources of random or systematic errors that can alter the precision of the auditory threshold measurement. Under optimum screening conditions, the measurement error can be limited to ± 5 dB for the 0.5-4 kHz frequency range and to ± 8 dB at 6 kHz. It is thus difficult to talk of a significant deterioration in hearing between two screening tests unless the variation in thresholds exceeds 10 dB for the 0.5-4 kHz range and 15 dB for 6 kHz. The conditions for carrying out the tests must be such that their validity and reliability can be guaranteed and that the measurement error is kept to a minimum [42].
- Even assuming a minimum error of measurement, the testing schedule must take into consideration the acquisition time course of occupational hearing loss. This makes it possible to optimize the relative validity (sensitivity, specificity) of the procedure [43].

For the most sensitive individuals (5% of the population) confirmed to be otologically normal, the hearing deterioration rate associated with occupational noise rarely exceeds one (1) decibel per year after 5 to 10 years of noise exposure, even at the frequency most sensitive to the effects of noise (4 kHz), for the most harmful levels of exposure ($LAeq_3$ (8h), 90-100 dB_A), and in the absence of hearing protection [44].

Given the seniority-related context of noise exposure commonly encountered in the work environment, one would often have to wait ten years or more to detect a significant deterioration and this, under optimal conditions of validity. Can we then claim that a given testing program is effective in the early identification of any hearing deterioration when the work environment continues to be knowingly harmful throughout this period?

The Advisory Committee also recognized the irreversibility of traumatic hearing loss and the necessity of combining the concept of handicap with that of natural history. Hearing alterations are at first temporary, but become permanent in the long run. It is when the symptoms generate permanent listening and communication difficulties at work, at home and in leisure activities that it is appropriate to speak of a severe situation of handicap, with the consequences it entails for the victim. Indeed, hearing loss is rated the same as a below-the-knee amputation in terms of disability adjusted life-years (DALYs) [45].

"To make legitimate the use of a hearing test with noise-exposed workers, it is important that the test be valid and intervene in the development of the disease at a stage where it is possible to improve the prognosis, and that, for a significant proportion of workers... In this context, ... hearing tests must be part of an overall intervention process and cannot alone guarantee the initiation of preventive measures... If the natural history of occupational hearing loss includes a sufficiently long latency period to allow interventions to influence the prognosis for this disease,... the tests are part of a very precise stage in a process of behavior modification leading to the adoption of appropriate preventive measures. In the absence of evaluation studies specifically addressing the advantages and limitations of the hearing test in this behavior modification process... it's use may be justified at some very precise stages:

> To complete the work environment analysis through knowledge of the health status of workers identified as being at risk for developing a hearing loss (AROHS, section 113.1);
>
> To contribute to the first step in a process of behavior modification leading to the adoption of effective preventive measures (AROHS, section 113.2), namely "recognition of the situation of risk" through an awareness campaign [46,41].

The scientific literature however shows that "despite our knowledge of the consequences of excessive noise exposure and occupational hearing loss, as well as the availability of technologies allowing control over the exposure in many circumstances, the situation is improving very little," [47] and that, despite the application of the two above-mentioned regulations. Moreover, the Advisory Committee has recommended that hearing tests, if necessary, normally be conducted at intervals of at least five years in certain very restricted and well-identified contexts for certain categories of workers. It is also recognized that the only preventive method that has demonstrated effectiveness is noise reduction at the source or along its propagation paths, which should no doubt be regulated in light of contemporary scientific knowledge.

Also, the Advisory Committee states that "we cannot support the merit of a systematized workplace hearing testing operation if efforts made to ensure follow-up remain in vain" [41]. The regional disparities in terms of resources to ensure the diagnosis and rehabilitation of affected workers are a major and inescapable difficulty within the framework of a regulatory obligation applicable throughout the Quebec territory [48].

In response to the Advisory Committee's report, the Quebec Provincial Medical Committee on Occupational Health (QPMCOH) concluded that "firm action aimed at eliminating noise sources and the adoption of effective protective measures in order to prevent occupational hearing loss may, under certain conditions, be supported by hearing tests" [48]. It's members unanimously recognized that it is crucial "to ensure that professional services are available both for rehabilitation and compensation" and that "this requirement is currently not being met everywhere" [48] in Quebec.

In addition, the QPMCOH states that "although there is no doubt in anyone's mind that conducting hearing tests is useful for determining the hearing status of workers who have been exposed to noise for many years, opinions are more divided as to their usefulness for pursuing the objectives of health programs" [48] (i.e: preventing the progression of occupational hearing loss).

It is preferable that the relevance assessment of conducting such tests instead be done on a case-by-case basis, according to the principles of public health. The recommendations made by the Quebec Provincial Medical Committee on Occupational Health in response to the report of the Advisory Committee of the Department of Health and Social Services Public Health General Directorate should be repeated here. Its members unanimously agreed that:

1 Hearing tests can provide information about the workplace that is likely to satisfy the needs of the knowledge function; but as such information has not been demonstrated to be indispensable for carrying out an approach aimed at modifying the environment, it is up to the responsible physician to judge the relevance of such tests according to the characteristics of the environment.

2 Current scientific knowledge does not allow us to draw conclusions as to the usefulness, effectiveness or efficiency of hearing tests as a tool for raising the awareness of workers and employers, favoring modification of the work environment or of individual behaviors.

3 Hearing tests should only be conducted if one can provide follow-up [...] in rehabilitation and adequate support in view of compensation. It is agreed upon that the use of hearing tests for knowledge purposes must respect this general principle, taking into account the accessibility to such minimal follow-up [48].

Furthermore, the Medical Committee considers "unavoidable the necessity that actions, aimed first at reducing noise at the source or implementing effective protective measures other than the mere recommendation to use means of individual protection, be initiated. Failing to do so renders monitoring actions meaningless" [48]. The current regulatory obligations to this effect should be reinforced so as to compel employers to concentrate their energies and resources on reducing noise and on adapting work positions to the residual hearing abilities of workers, rather than to the endless search for cases.

These recommendations are consistent with those proposed by recognized learned societies and are much more in keeping with an approach aimed at respecting the duty of reserve enacted by the Quebec College of Physicians, an ethical obligation to which the government itself should not evade.

Tire Noise Assessment Of Asphalt Rubber Crumb Pavement

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ABSTRACT

Due to ever-increasing traffic volumes, various mitigating techniques are commonly employed to reduce tire noise. One such method is the use of Asphalt Rubber Crumb (ARC) pavement as a surface coat for conventional asphalt. Crushed rubber tires are heated to a gel-state and mixed in with the conventional asphalt, resulting in a more porous and less stiff surface material. Measurements were conducted at a pilot paving location where sections of old conventional pavement were repaved with new ARC and new conventional pavement. These locations enabled direct comparison between the two paving materials. Measurements conducted included: long term environmental noise monitoring, short term specific vehicle observed sound levels, specific controlled vehicle drive-by tests and subjective observations. The paper outlines the measurement methods and the results obtained.

SOMMAIRE

Compte tenu de la croissance continuelle du volume de trafic routier, différentes techniques de contrôle sont couramment utilisées afin de réduire le bruit émanant des pneus. Une de ces méthodes est l'utilisation de pavage d'éclats de caoutchouc asphalté (« Asphalt Rubber Crump », ARC) comme enduit de surface apposé sur les asphaltes conventionnels. Des pneus de caoutchouc pressé sont réchauffés jusqu'à l'état de gel et mélangés avec de l'asphalte conventionnel, résultant en un matériel de surface plus poreux et moins rigide. Des mesures ont été faites sur un site pilote recouvert de pavage où des sections de pavé conventionnel ont été repavées avec le nouveau ARC et du nouveau pavé conventionnel. Ceci a permis de faire des comparaisons directes entre les deux types de matériaux de pavage. Les mesures inclues : la surveillance à long terme de l'environnement sonore, les niveaux sonores court terme de véhicules spécifiques, des tests spécifiques de passages contrôlés de voitures et des observations subjectives. L'article présente les méthodes de mesures et les résultats obtenus.

1. INTRODUCTION

With the ever increasing traffic volumes and prevalent desire to minimize residential noise levels, various noise mitigating methods are commonly employed. The most common source of traffic noise (away from intersections) is the noise generated by the interaction of vehicle tires and the road surface. The noise levels generated are dependent on many factors such as tire composition, road condition, vehicle speed, number of tires, and road composition. It is the latter, road composition, that is the subject of this paper.

The use of Asphalt Rubber Crumb (ARC) pavement is widespread in the southern United States, and has a proven track record of performance [1]. Use of ARC in Canada, however, has been limited mainly to pilot projects covering relatively short sections of road. The purpose of this paper is to present and discuss measured noise level results obtained during a pilot ARC paving project conducted in and around Edmonton, Alberta in 2003.

2. PAVEMENT DESCRIPTION

Typical conventional asphalt pavement is comprised of aggregate (small rock) and a binder of 5% to 6% conventional asphalt cement by total weight [2]. The ARC mix used for the study contained approximately 7.5% to 8.5% asphalt rubber binder by total weight. The asphalt rubber binder itself contained approximately 19% rubber crumb by weight, thus about 1.4% to 1.6% of the total ARC pavement contained the rubber crumb. The rubber crumb typically comes from recycled vehicle tires. For this study the primary source was large truck tires.

In production, the asphalt mix is heated to approximately 190^{o} C and the rubber crumb is added, then the temperature is increased to 205^{o} C. This temperature is not actually hot enough to melt the rubber, rather the rubber becomes gel-like and bonds with the asphalt cement. Once the production process is complete, the ARC pavement is transported and applied using the same methods as conventional asphalt.

The final product (as a road surface) looks more coarse and porous than conventional asphalt as shown in Figure 1.

The physical mechanics of how the ARC reduces tire noise are not presented in this paper. In general, however, the material is more porous and sound absorbing than conventional asphalt. In addition, although the ARC surface feels rougher than conventional asphalt, there is a greater flexibility (because of the rubber content) which results in more "give" under the pressure of the tire.

3. MEASUREMENT DESCRIPTION

Various road sections in and around the Edmonton area were paved with ARC as part of the 2003 pilot project. Most sections used ARC over existing conventional asphalt that was old and cracking. As such, the direct comparison of *before* and *after* would not necessarily point to the benefits of ARC overe conventional pavement. At one highway location, however, a 7 km stretch of old conventional pavement was re-surfaced with ARC pavement, and an adjacent 14 km stretch was re-surfaced with new conventional pavement. As such, a direct comparison could be made with *before* and *after* conditions for both ARC and conventional pavement.

One common method for measuring road noise is outlined in ISO 11819-1 [3]. This method requires the use of a radar gun to determine each vehicle's specific speed, as well as measuring a minimum number of specific vehicle types. The data collected is then used to calculate the Statistical Pass-By Index (SPBI). It is this single value which can be used to compare the different measurement locations. Several factors rendered this method undesirable for the purposes of this study. For example, the overall number of various vehicle types within a 1-day period, for example, would not have been sufficient to meet the requirements of the standard. In addition, the primary information desired was a comparison of *before* and *after* which did not warrant as detailed traffic and vehicle speed information as that gathered via the standard. Finally, the standard does not provide information on the relative frequency content of the measured noise.

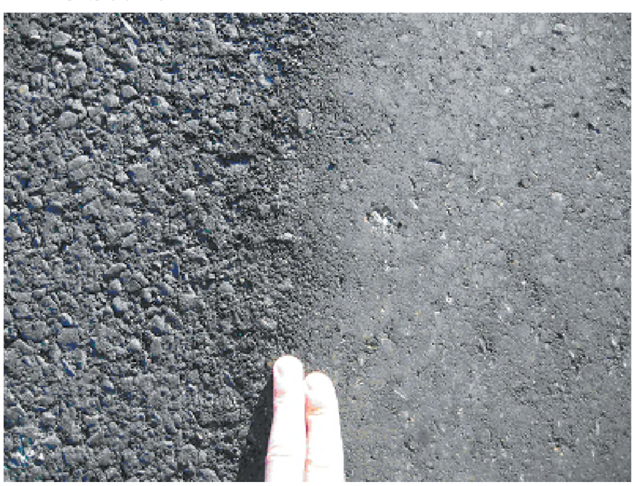

Figure 1. ARC and Conventional Asphalt

It was desired to have a 1/3 octave spectral comparison of *before* and *after*. It should be noted that although the exact measurement methods outlined in ISO 11819-1 were not used, much of the document was used as a reference for other measurement parameters such as microphone locations, and environmental concerns.

Several different types of measurements were conducted at the study location to quantify the amount of noise reduction. The highway section in question consisted of a single lane in each direction and a posted speed limit of 100 km/hr. Each of the measurement methods are described in Sections 3.1 thru' 3.4.

3.1. LONG TERM NOISE MONITORING

A 26-hour environmental noise monitoring was conducted at both the ARC and conventional pavement locations both *before* and *after* the application of the new surface. The noise monitoring was conducted using a 30-second L_{eq} time period in both broadband (linear and A-weighted) and 1/3 octave band spectral analysis. In each case, the noise monitor was located approximately 20m from the centerline of the road. The key was to maintain the same location for both the *before* and *after* measurements to minimize the effects of distance attenuation, ground absorption, air absorption, and surface reflections. The 26-hour time was used so that a 2-hour observation period could be used at the same time on two consecutive days to document traffic conditions. This was important to determine the consistency in traffic from the *before* period to the *after* period (more than 1-month time lapsed while paving commenced).

3.2. SHORT TERM MAXIMUM SOUND LEVELS

While on site for the 2-hour observation periods, the short term maximum sound levels obtained with specific vehicle pass-bys were noted. These maximum sound levels were collected and analyzed statistically to determine further the consistency in traffic conditions for each observation period, as well as give another measure of the amount of noise reduction. The different vehicle classifications were; light autos (car, minivan, mini-pickup), busses, large trucks with single rear axles, and large trucks with multiple rear axles. Vehicles which did not fit into these categories or were considered non-typical (i.e. modified muffler, unusually loud engine and such) were not recorded.

3.3. CONTROLLED VEHICLE TESTING

The final measurement involved the use of a specific vehicle for controlled drive-by testing. A 2002 Dodge Grand Caravan (a very common vehicle type) was driven by the sound level meter (located exactly 10m from the centerline of the road at a height of 1m) at a constant speed (100 km/hr), in each road direction. The tests were conducted with the engine on (operating with cruise control) and off. This was accomplished by accelerating the vehicle up to slightly higher than 100 km/hr, then shifting into neutral and turning the engine off approximately 200m before passing by the sound level meter.

The sound level meter was set to measure with 1-second L_{eq} sound levels in both broadband (linear and A-weighted) and 1/3 octave band spectra. The measurements were started once the vehicle was within approximately 200 – 300m of the sound level meter and stopped once it had passed to approximately 200 – 300m away from the sound level meter. As with the other measurements, the controlled drive-by testing was conducted at both the ARC and conventional asphalt locations both *before* and *after* repaving.

3.4 SHORT TERM SUBJECTIVE OBSERVATIONS

While on site for the 2-hour observation periods, subjective observations were noted. These included notes on the relative frequency content of the vehicle noise, specific noise sources emanating from the vehicles, qualitative assessment of broadband sound levels, and estimation of the maximum audible distance of the vehicle. In addition, the subjective notes, and audio recordings were obtained for specific vehicle pass-bys. This information was used to confirm site observations.

4.0 RESULTS AND DISCUSSION

4.1 LONG TERM NOISE MONITORING

The results of the long term noise monitoring are presented in Table 1. It can be seen that there was a reduction in sound levels with the application of the ARC and conventional asphalts. The amount of reduction with the ARC, however, was greater. It should be noted that two key external factors affected the measured sound levels. First, the sound levels obtained at the conventional asphalt section during the *before* time-period were notably higher than typical due to the presence of many dump-trucks hauling material used for paving the ARC section. It is estimated that the day-time sound levels would have been approximately 2-3 dBA lower than those measured resulting in less of a reduction from *before* to *after*. Second, the sound levels obtained at the ARC section during the *after* time-period were slightly higher than they otherwise would have been due to the presence of farm machinery (swathing machine) operating in the adjacent field during the daytime. As a result, the daytime sound levels would have been approximately 1-2 dBA lower, resulting in a larger reduction in the sound levels from *before* to *after*. Both of these factors would have resulted in L_{eq}Day and L_{eq}24 sound reductions of approximately 6 dBA for the ARC section and 2 dBA for the conventional section.

It should also be pointed out that the number of vehicles on the study highway during the night-time is typically less than 10 vehicles per hour. As a result, even small changes in vehicle counts for the night-time period will result in large changes to the L_{eq}Night. Due to this, the L_{eq}Night is not particularly useful for comparison at this location. It can be seen that there was more of a reduction at the conventional location compared to the ARC location during the night-time.

Table 1. Long Term Noise Monitoring Results

	Leq24 (dBA)	LeqDay* (dBA)	LeqNight (dBA)
Before (ARC)	57.8	59.2	52.9
After (ARC)	53.1**	54.9**	44.8
Difference (ARC)	-4.7	-4.4	-8.1
Before (Conventional)	58.7***	60.0***	54.8
After (Conventional)	54.5	56.3	46.0
Difference (Conventional)	-4.2	-3.7	-8.8

* Day-time hours are 07:00 – 22:00; night-time hours are 22:00 – 07:00

** Farm machinery operating in nearby field during day-time (results estimated to be 1-2 dBA higher than normal)

*** Abnormally high volume of dump-trucks during day-time (results estimated to be 2-3 dBA higher than normal)

The long term noise monitoring 1/3 octave band spectral results are shown in Figs. 2 and 3. Both pavement types resulted in only moderate sound level reductions in the low to mid frequencies (up to approximately 800Hz). Beyond 800Hz, however, the ARC resulted in much greater sound level reductions than the conventional pavement. These frequencies are important as they cover the range to which humans are the most sensitive and cover a large portion of the range of human speech frequencies.

4.2. SHORT TERM MAX SOUND LEVELS

As mentioned previously, 2-hour observation periods at the start and end of the long term noise monitoring were used to obtain maximum sound levels for specific vehicle types. Tables 2 and 3 contain the averaged sound levels as well as their respective standard deviations for the various vehicle types during each of the 2-hour periods. The results displayed

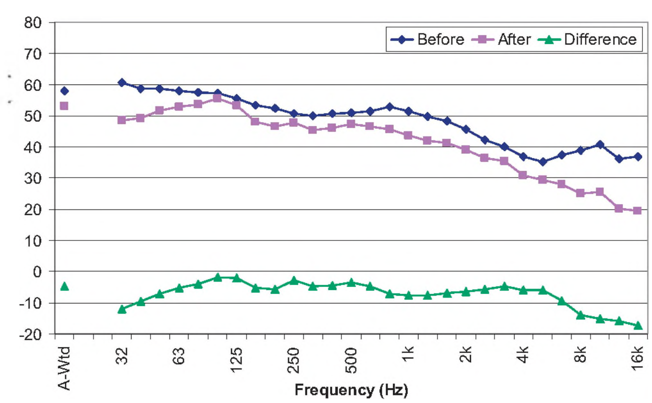

Figure 2. ARC Section 1/3 Octave 26-hour Results

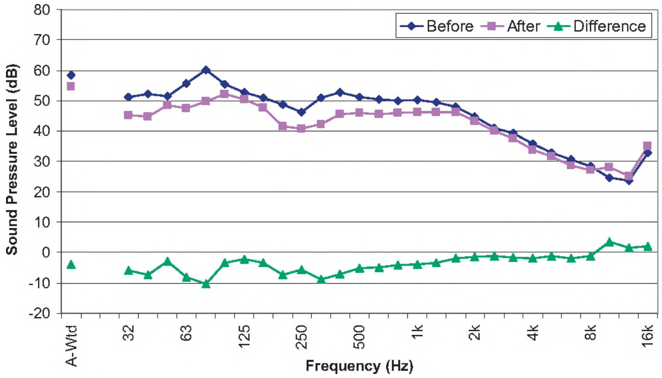

Figure 3. Conventional Section 1/3 Octave 26-hour Results

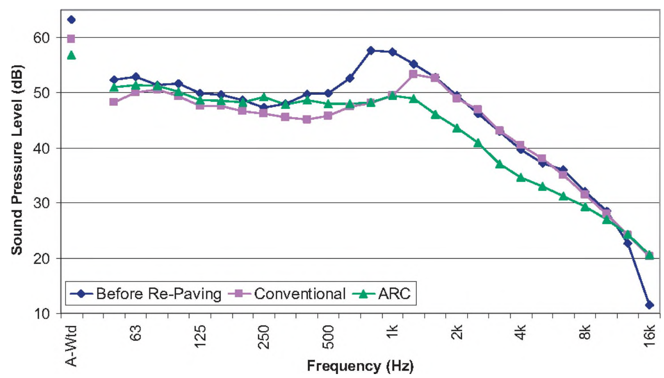

Figure 4. Controlled Vehicle Test 1/3 Octave Band Results

in Tables 2 and 3 match very well with those of the long term results once the various noise anomalies (farm machinery and dump-trucks as mentioned previously) are taken into account. It can be seen that for the light autos, the sound level reductions are much greater with the ARC section than the conventional pavement section. There is an increased amount of reduction with larger vehicles as well, but the difference between the ARC and conventional is not as great. This gives evidence that less of the total noise emanating from the larger vehicles is associated with tire noise than compared to the light autos (which is as expected).

4.3. CONTROLLED VEHICLE TESTING

The final measurements were with the use of a controlled vehicle pass-by. The parameters for the test are described in section 3.3. Figure 4 shows the 1/3 octave band sound levels for the *before* measurements and both *after* measurements (ARC and conventional pavement). The results shown are the average of the cumulative measurement L_{eq}'s for the 4 individual pass-by's for each location.

At frequencies below 500 Hz, there is little difference between the three curves. Between 630 Hz and 1 kHz, there is a significant reduction in the sound levels (approximately 10 dB) for both the *after* ARC and conventional sections compared to the *before* measurements. Beyond 1.25 kHz, however, the conventional *after* results are essentially identical to the *before* results while the ARC results are approximately 5 dB lower. Again, these results match well with those of the long term noise monitoring.

In addition to the 1/3 octave band frequency results, the controlled vehicle tests also illustrate the increase in the

	Day 1 (*before*) Max Avg. (dBA)	Day 1 (*before*) Std. Dev (dBA)	Day 2 (*before*) Max Avg. (dBA)	Day 2 (*before*) Std. Dev (dBA)	Day 1 (*after*) Max Avg. (dBA)	Day 1 (*after*) Std. Dev (dBA)	Day 2 (*after*) Max Avg. (dBA)	Day 2 (*after*) Std. Dev (dBA)	Average Difference (*After - Before*) (dBA)
Light Autos (E)	72.2	2.2	71.6	1.9	64.7	1.3	63.2	1.7	-7.9
Light Autos (W)	70.3	2.1	70.8	1.6	64.1	1.4	64.1	1.9	-6.5
Large Truck, Single-Axle (E)	N/A	N/A	N/A	N/A	71.0	0.0	N/A	N/A	N/A
Large Truck, Single-Axle (W)	73.0	1.7	N/A	N/A	70.5	4.9	68.7	3.2	-3.4
Large Truck, Multi-Axle (E)	76.0	0.0	80.9	1.2	76.0	N.A	N/A	N/A	-2.4
Large Truck, Multi-Axle (W)	N/A	N/A	77.9	2.9	76.0	N/A	74.0	1.0	-2.9

Table 2. Maximum Observed Sound Levels at ARC Location

	Day 1 (*before*) Max Avg. (dBA)	Day 1 (*before*) Std. Dev (dBA)	Day 2 (*before*) Max Avg. (dBA)	Day 2 (*before*) Std. Dev (dBA)	Day 1 (*after*) Max Avg. (dBA)	Day 1 (*after*) Std. Dev (dBA)	Day 2 (*after*) Max Avg. (dBA)	Day 2 (*after*) Std. Dev (dBA)	Average Difference (*After - Before*) (dBA)
Light Autos (N)	71.6	2.1	71.3	1.8	69.6	1.5	69.0	1.5	-2.2
Light Autos (S)	71.3	1.7	70.4	2.1	69.3	1.6	69.2	1.3	-1.6
Large Truck, Multi-Axle (N)	77.4	1.9	78.9	1.6	76.0	N/A	N/A	N/A	-2.1
Large Truck, Multi-Axle (S)	79.2	1.7	78.6	2.1	79.0	N/A	80.0	N/A	0.6

Table 3. Maximum Observed Sound Levels at Conventional Location

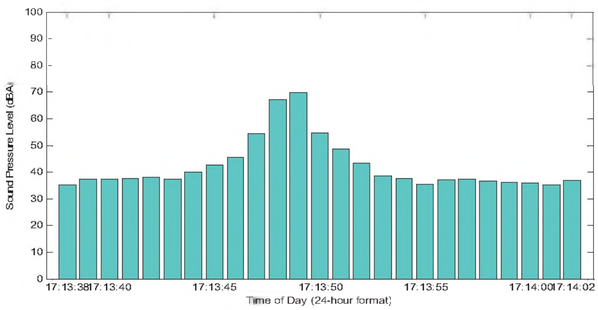

Figure 5. Time Domain Pass-by Sound Levels at ARC Section

slope for the rise and fall of the sound levels resulting from the passing vehicle. Figures 5 and 6 show the sound levels vs. time for the ARC and conventional sections, respectively, during a "typical" vehicle passage. Each of the bars represents 1 second of time. It can be seen that the rise and fall times for the ARC section are much steeper than those of the conventional section. Thus, in conjunction with reduced maximum sound levels, the ARC pavement also reduces the length of time during which the higher vehicle pass-by sound levels occur. The net effect is that residents in proximity to the roadway would experience both lowered maximum sound levels and shorter exposure times (both of which affect the L_{eq} sound levels).

4.4 SUBJECTIVE OBSERVATIONS

At all times during the various measurement periods, subjective observations were noted. In general, it was noted that the use of ARC resulted in lower overall noise levels, as well as a substantially notable reduction in the mid to high frequencies. Essentially, it sounded as if the tire noise was somewhat "muffled" compared to both the old and new conventional pavement. The new conventional pavement was noted to have a slightly noticeable reduction in noise levels, but the frequency content of the noise did not change.

One of the most important observations was related to the distance at which a vehicle could be heard. While observing the old conventional asphalt, an individual vehicle (in absence of other noise sources) could be heard for more than 1 km and up to 2 km in some cases. This remained essentially the same after the application of the new conventional pavement. With the application of the ARC, however, vehicles could generally not be heard beyond 300 – 400m. At several times during the *after* measurements for the ARC section, vehicles would essentially "sneak up" on the observer whereas during the *before* measurements, the observer knew well in advance when a vehicle was coming.

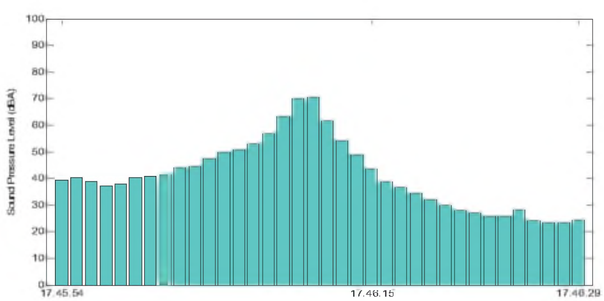

Figure 6. Time Domain Pass-by Sound Levels at Conventional Section

5.0 FUTURE WORK

Although the pilot study revealed much information regarding the noise attenuation capabilities of ARC pavement, there are still many important unknowns which should be addressed. Of prime importance for most locations within Canada is the effect of winter. The noise attenuation capabilities of ARC are unknown at freezing temperatures. In addition, the effects of one or several freeze/thaw cycles should be investigated. Road surface conditions such as partial snow or dirt/mud coverage and varying stages of road repair could also have an impact on the noise levels. Also, variable mixtures of ARC could be investigated to find an optimal mixture for noise reduction. Finally, other vehicle related aspects such as different vehicle speeds could be investigated to determine the relative reduction levels for highway conditions compared to urban roads with slower speeds.

6.0 CONCLUSIONS

The use of asphalt rubber crumb pavement as a road surface material has been quantitatively and subjectively noted to reduce tire noise levels compared to conventional asphalt pavement. The various measurement techniques used to quantify the level of reduction all achieved similar results and the measured data corroborated well with subjective observations. Further work is also required to determine the longevity of the noise reduction benefits.

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Effect Of Traffic Characteristics And Road Geometric Parameters On Developed Traffic Noise Levels

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ABSTRACT

The main objective of this study was to evaluate the major factors affecting traffic noise levels at signalized intersections. To achieve this objective, traffic noise levels and the factors expected to affect it were measured at 40 signalized intersections. Equivalent, maximum, and minimum noise levels were measured during one minute interval including the green time interval. The traffic volume and composition was taped using a video camera, while the traffic speed was measured using speed radar. The geometric parameters of the intersections approaches, including number and width of driving lanes, approaches width and slope, were collected. Also, pavement surface texture was evaluated using the British pedulum. The collected data was analyzed to evaluate the effect of the main factors controlling traffic noise levels. Results of the analysis indicated that equivalent noise levels are mainly dependent on traffic volume, while the maximum noise levels were found to be dependent on the number of heavy vehicles passing through the intersection and horn effect. On the other hand, the minimum noise levels were mainly dependent on pavement surface texture. When noise levels at different distances from the signal stop line were considered, traffic speed was found to have a significant effect on equivalent noise levels.

SOMMAIRE

L'objectif principal de cette étude était d'évaluer les facteurs importants qui peuvent influencer les niveaux de bruit du trafic aux intersections routières comportant des feux de signalisation. Pour atteindre cet objectif, les niveaux de bruit du trafic et les facteurs susceptibles de les affecter ont été mesurés à 40 intersections. Les niveaux équivalents, maxima et minima ont été mesurés pendant des périodes de 1 minute, incluant l'intervalle de temps où le feu était vert. Le volume de trafic ainsi que sa composition ont été enregistrés à l'aide d'une caméra vidéo, alors que la vitesse a été mesurée à l'aide d'un radar. Les paramètres géométriques d'approche des intersections, incluant le nombre et la largeur des voies, la largeur des approches et la pente ont été répertoriés. De plus, la texture de la surface du pavage a été évaluée selon le « pedulum » britannique. Les données ont été analysées dans le but d'évaluer les facteurs principaux qui contrôlent les niveaux de bruit du trafic. Les résultats indiquent que les niveaux de bruit équivalents dépendent principalement du volume de trafic, alors que les niveaux maxima sont plutôt attribuables aux nombre de poids lourds qui empruntent l'intersection et à l'effet des klaxons. Par ailleurs, les niveaux minima sont surtout reliés à la texture de la surface de pavage. Lorsque les niveaux de bruit à des distances variables de la ligne d'arrêt sont considérés, la vitesse du trafic s'avère avoir un effet significatif sur les niveaux équivalents de bruit.

1. INTRODUCTION

In recent years the, highway traffic noise has been an increasing concern to both the public and governments. Many studies indicated that one of the major sources of noise in our environment is those associated with transportation. Traffic noise tends to be a dominant noise source in urban as well as rural environments.

Vehicle noise is a combination of the noises produced by the engine, exhaust, and tires. The level of highway traffic noise depends mainly on: traffic volume, composition of traffic, traffic speed, and road geometric parameters. Generally, heavier traffic volumes, higher speeds, and greater number of trucks are expected to increase the loudness of traffic noise. The loudness of traffic noise can also be increased by defective mufflers or other faulty equipment on vehicles (Newman and Beattie, 1985).

Simulation of urban traffic noise in the central part of Bangkok, was the main objective of a study performed by Pamanikabud and Tharasawatpipat (1999). The analyzed data consisted of traffic characteristics and its noise levels. The single model approach, applied to build a single stop-and-go traffic flow noise model for one side of the road way, can be applied to both sides of an urban roadway. Another approach of analysis was applied by developing two similar separate models for a deceleration lane and an acceleration lane on both sides of an urban road. The separate acceleration and deceleration lane models found to be effective in forecasting interrupted flow traffic noise on Bangkok's urban road net work.

A new method was proposed Di Nijs (1989) to measure the noise level as a function of the number of motor revolutions and the speed of a vehicle while it is on the road. This method leads to detailed time plots. The measurements of sound level, number of motor revolutions, and the speed of a vehicle were taken for three vehicle classes: passenger car, van, and lorry. Results indicated that the sound levels increase per road segment at intersections compared to those at road segments with free traffic flow. The increases in sound level was in the range of 6 to 8 dB at road segments close to the edges of intersections.

2. PROBLEM STATEMENT

As part of an international plan to minimize the negative environmental impact of road traffic, a better understanding of factors controlling traffic noise and quantification of its impact is needed. In the last two decades, Amman, Jordan's capital, as well as most other cities in the world, has been exposed to continuous growth of urban and suburban residential areas accompanied by the resultant growth of noise levels along highways. This causes one of the most invasive forms of pollution. In Jordan, currently, there is no regulation relating to noise pollution in urban planning, and only a few studies have reported the evaluation of the dramatic increase in noise pollution due to the impact of traffic. Therefore, this research is considered a step forward towards evaluating the effect of different traffic characterisitics and road geometric parameters on developed traffic noise levels at signalized intersections where noise levels are anticipated to be high.

3. RESEARCH OBJECTIVE

The aim of this study was to evaluate highway traffic noise pollution at signalized intersections in Amman. In order to achieve the objective of this study, three major tasks were undertaken: data collection, evaluation of the effect of the opposite direction traffic on developed noise levels, and data analysis including statistical analysis and evaluation of significant variables.

4. DATA COLLECTION

The data collection included: selection of evaluated intersections, noise measurements, traffic volume and composition, traffic speed, road geometric parameters, surface texture, and the effect of opposite direction traffic on measured noise levels. The following paragraphs explains in detail the methodology used for the collection of various types of data in this study.

4.1 Selection of Signalized Intersections

The main signalized intersections in Amman were selected for evaluation and traffic noise levels were measured at these intersections. Signalized intersections that are located in areas where bridges and tunnels were under construction were not included in this study, due to the fact that noise levels would be affected by the constructions activities. Signalized intersections that are in vicinity of bridge or tunnel or followed by another intersection or rotary within a distance of less than 400 m were not considered. so as to avoid the influences of these features. To provide enough database that could be used in statistical analysis, a total of forty intersections representing the signalized intersections in Amman were studied. The selected intersections are three leg and four leg signalized intersections distributed all over Amman and have different traffic volumes that ranged between 5 and 130 vehicle/minute/approach and different geometric design parameters (number of lanes, lane width, approach width, and roadway slope).

4.2 Noise Measurements

Noise measurements in this study were performed from June, 3, 2001 to October, 2001. All measurements were during daylight hours under favorable weather conditions for traffic noise data collection (dry weather and low wind speed). A total of 4745 noise measurements were performed at all approaches to these forty intersections. One thousand five hundred and twenty eight (1528) measurements were performed at a distance of 0 m from the signal stop line, while the rest were performed at distances of 50, 100, 150, 200, 250, and 300 m from the signal stop lines. Noise levels were measured using an integrating sound level meter (ISLM) Type 1. The Precision Integrating Sound Level Meter Type 2230 (Bruel and Kjaer) was used to measure simultaneously, the maximum noise level (L_{max}), minimum noise level (L_{min}), and equivalent noise level (L_{eq}). This type of ISLM has an accuracy of 0.1 dB which is sufficient to yield valid data for the purpose of this study.

After calibrating the microphone, the ISLM was set on a specially designed stand at 1 m away from the driving lane and at 1.5 m above the road surface as shown in Figure 1. For each measurement the device was switched on at the beginning of each green time interval, measurements were performed for a duration of 1 minute, after which the device was switched to the pause mode and the noise levels were recorded. The device was reset before performing another trial.

For each measurement in the study, two trials were performed during the morning peak hours between 7:30-9:30 a.m, another two trials during the afternoon peak hours between 1:00-3:00 p.m, and one trial during the evening peak between 5:30-7:30 p.m. All of these trials were taken during representative working days of the week. If a horn was used during noise measurements, horn effect was notified.

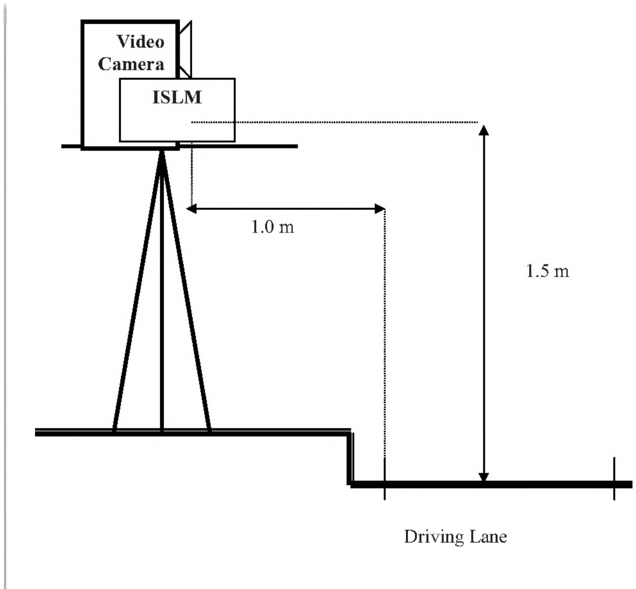

Figure 1. Noise levels and traffic volume measurement setup

4.3 Traffic volume and composition

A Video Camera was used to video tape the traffic movement through each intersection. The video camera which is a charged coupled device (CCD) has a flying erase head, power zoom, and high speed shutter (8X-auto focus). The video tape used was an 8mm video cassette.

The camera was set on the stand besides the ISLM as shown in Figure 1, and switched on at the same time with the ISLM. The number of vehicles and the number of heavy vehicles were determined by replaying the recorded tapes.

4.4 Traffic Speed

Speeds measurements were performed at distances of 50, 100, 150, 200, 250, and 300 m from the signal stop line at each approach of the intersections. The Laser Speed Detection Radar was used to measure the traffic speeds. The device has speed accuracy of (± 1 km/hr), with laser power output of 52 Micro-Watt. In order to detect speed, the radar was set up on a stand placed at a proper location to view vehicles passing the approach of the intersection under evaluation. The speed measurements were performed during the whole minute in which the noise levels were measured. The reported speed represents the weighted average speed for the minute during which the noise levels were measured.

4.5 Road Geometric Parameters

Approach and lane widths were measured using a plastic tape of 30 meter long. The number of lanes also was determined according to the existed stopped rows of vehicles at each approach for the signalized intersection. However, at distances 50, 100, 150, 200, 250, and 300 m the lane widths and number of lanes were not well defined at more than half of the evaluated intersections. Due to this limitation, the effect of road geometric parameters on noise levels was considered only at the signal stop line.

The slope of intersections approaches were determined using a level device. The level was set at a suitable intermediate point between two points on the approach, 50 to100 m apart. The level readings at the two points were taken. The slope was determined by dividing the difference in level readings by the horizontal distance between the two points.

4.6 Evaluation of Pavement Surface Texture

The pavement surface's micro-texture was evaluated indirectly by measuring the surface frictional properties using the British Pendulum Skid Resistance Tester according to ASTM E303-83. The device is a dynamic pendulum impact-type tester used to measure the energy loss when a rubber slider edge is propelled over a test surface. The tester is suited for field tests on flat surfaces. The values measured are British Pendulum Number (BPN) and represents the frictional properties of the surface. Measurement were taken at the outer wheel path and at distances of 0, 50, 100, 150, 200, 250, and 300 m from the signal stop line at each approach of the evaluated intersections.

5. EFFECT OF OPPOSITE DIRECTION TRAFFIC ON MEASURED NOISE LEVELS

At intersection approaches where the movement of traffic is allowed in two directions at the same time, noise levels were expected to be affected by opposite direction traffic. Four intersections were selected for the purpose of evaluating the effect of opposite direction traffic on measured noise levels. A test was performed in the early morning at 6:00 a.m when the intersection was almost free of traffic flow. Two vehicles were driven in opposite directions to pass each other in front of the noise measurement setup. The equivalent noise level (L_{eq}) was measured for three trials and the results at the first evaluated intersection were 71.4 dB, 71.6 dB, and 71.3 dB. The same test was repeated using only one vehicle passing in front of noise measurement setup at the same speed as that for the two vehicles in the first stage of the test. The measured equivalent noise levels (L_{eq}) for three trials were 71.5 dB, 71.3 dB, and 71. 2 dB. The test results indicated that the differences between the measured (L_{eq}) in the two stages of the tests are negligible. This means the effect of opposite traffic on measured L_{eq} is insignificant.

Another test was performed at the same intersection at 6:30 a.m. when few vehicles pass through the intersection. The measured L_{eq} were 74.4 dB, 74.8 dB, and 74.1 dB when the traffic was traveling only in one direction and were 74.6 dB, 74.8 dB, and 74.5 dB when similar traffic volumes existed in the same direction accompanied by traffic in the opposite direction. Similar tests were repeated at the other three signalized intersections and similar results were obtained.

Based on the above results, it can be concluded that the effect of opposite direction traffic on the measured noise levels is negligible. This may be explained by the fact that the distance between the opposite direction traffic and the noise measurement device is relatively large in comparison to distance between the near lane and the noise measurement device. Also, at high noise levels, the addition of other sources of lower or similar noise levels will not significantly affect the measured noise level. The above results agrees with those obtained by Bjorkman (1988).

6. RESULTS AND DISCUSSION

The collected data was statistically analyzed to evaluate the effect of each variable believed to have an effect on the measured noise levels. The evaluated variables included traffic volume, composition of traffic, traffic speed, and pavement surface texture in addition to road geometric parameters (number of lanes, lane width, approach width and slope). Statistical characteristics of collected data are summarized in Table 1. Table 2 presents the correlation coefficients for measured noise levels and evaluated variables. The following sections discuss the effect of different evaluated variables on measured noise levels.

6.1 Effect of Traffic Volume

Noise levels found to be significantly affected by traffic volume. Figure 2 presents the scatter gram of the relationship between L_{eq} and traffic volume. This figure indicates that the equivalent noise level (L_{eq}) is highly correlated to the traffic volume. The correlation coefficient, shown in Table 2, was found to be 0.892. As it can be seen from Figure 2, higher traffic volume causes higher equivalent noise levels. The highest measured L_{eq} was about 92 dB at a traffic volume of 120 vehicles per minute. While it ranged between 68 and 76 at 10 vehicles per minute. Also, based on the same figure, the relationship between L_{eq} and traffic volume seems to be linear. The variation in L_{eq} at the same traffic volume can be explained by the fact that other parameters affecting noise levels including number of lanes, lane width, traffic speed, road slope and surface texture, and distance from signal stop line. When the effect of traffic volume on L_{eq} was considered at only 0 m from the signal stop line, the variation in L_{eq} for similar traffic volumes was considerably reduced as shown in Figure 3.

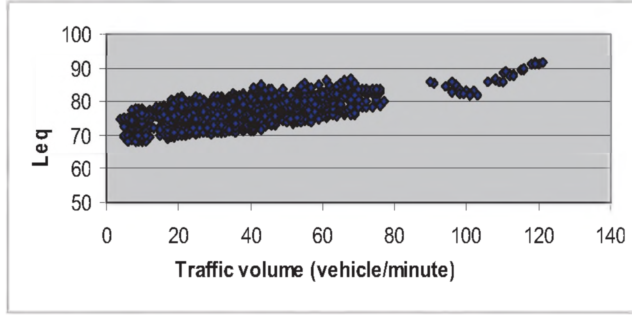

Figure 2. Effect of traffic volume on measured equivalent noise level

The correlation between maximum noise level and traffic volume and minimum noise level are not as strong as that between equivalent noise levels and traffic volume. The correlation coefficient between L_{max} and traffic volume was 0.305. While the correlation between L_{min} and traffic volume was -0.114, which indicates that L_{min} is inversely proportional to traffic volume.

Table 1 Statistical characteristic of evaluated variables

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION
L_{eq} (dB)	4745	68	91.6	76.092	3.142
L_{max} (dB)	4745	75.7	115.4	88.519	7.327
L_{min} (dB)	4745	53.9	69.5	63.685	2.619
Traffic Volume(veh/min)	4745	6	121	33.926	14.609
Speed (km/hr)	4745	4.6	110	48.912	27.725
BPN	4745	33	72	48.844	7.73
Heavy vehicle no.	4745	0	6	1.156	1.502
Slope%	4745	- 6	8	0.181	2.688
No .of lanes	1528	2	5	3.46	0.908
Lane width (m)	1528	2	3.6	2.818	0.298
Approach width (m)	1528	5	18	9.852	2.531
Green time interval (sec)	1528	15	90	32.375	12.387
Distance from C.L. to noise level meter (m)	1528	3.5	10	5.926	1.265

Table 2 Correlation matrix of evaluated variables

		L_{min}	L_{max}	L_{eq}	Traffic Volume	Traffic Speed	Distance from Signal	BPN	No. of Heavy Vehicles	Road Slope	Use of Horn			
L_{min}	Pearson Correlation	1	0.0938852	0.0722508	-0.1143211	0.1105943	0.1417418	-0.974642	0.0814465	0.049786	0.028370248	-0.129	-0.111	-0.192
	Sig. (2-tailed)		9.185E-11	6.289E-07	2.818E-15	2.179E-14	1.012E-22	2.59E-23	1.929E-08	0.000602	0.406283561	0.0007	0.0034	4E-07
	N	4745	4745	4745	4745	4745	4745	4745	4745	4745	859	4745	4745	4745
L_{max}	Pearson Correlation	0.0938852	1	0.3221974	0.3055429	0.1429921	0.079512	-0.0925175	0.9169178	0.0390859	0.066689908	0.2960	-0.104	0.2362
	Sig. (2-tailed)	9.185E-11		2.59E-23	2.59E-23	4.239E-23	4.15E-08	1.714E-10	2.59E-23	0.0070874	0.00507102	1E-5	0.0062	3E-10
	N	4745	4745	4745	4745	4745	4745	4745	4745	4745	859	4745	4745	4745
L_{eq}	Pearson Correlation	0.0722508	0.3221974	1	0.5899675	0.5699654	0.6048446	-0.0628985	0.2219457	0.0060096	-0.003771491	0.43244	-0.0416	0.44031
	Sig. (2-tailed)	6.289E-07	2.59E-23		2.59E-23	2.59E-23	2.59E-23	1.452E-05	2.59E-23	0.0067898	0.912110438	4.1E-22	0.02738	4.1E-22
	N	4745	4745	4745	4745	4745	4745	4745	4745	4745	859	4745	-0.0416	4745
Traffic Volume	Pearson Correlation	-0.1143211	0.3055429	0.5899675	1	0.0692866	0.0248924	0.1246131	0.2732668	-0.091471	-0.00838802	0.45746	-0.0223	0.4779
	Sig. (2-tailed)	2.818E-15	2.59E-23	2.59E-23		1.777E-06	0.0864365	6.983E-18	2.59E-23	2.746E-10	0..806078388	4.1E-22	0.55645	4.1E-22
	N	4745	4745	4745	4745	4745	4745	4745	4745	4745	859	4745	4745	4745
Traffic Speed	Pearson Correlation	0.1105943	0.1429921	0.5699654	0.0692866	1	0.9153735	-0.106196	0.0690311	-0.048363	-0.01066890	0.3986	0.28349	0.415
	Sig. (2-tailed)	2.179E-14	4.239E-23	2.59E-23	1.777E-06		2.59E-23	2.234E-13	1.94E-60	0.0008608	0.754854177	4.1E-22	0.9733	4.1E-22
	N	4745	4745	4745	4745	4745	4745	4745	4745	4745	859	4745	4745	4745
Distance from Signal	Pearson Correlation	0.1417418	0.079512	0.6048446	0.0248924	0.9153735	1	-0.1415062	-0.0051165	0.0059894	-0.022740813	0.91	0.18	1
	Sig. (2-tailed)	1.012E-22	4.15E-08	2.59E-23	0.0864365	2.59E-23		1.192E-22	0.7245749	0.6799941	0.50565449	0	0	0
	N	4745	4745	4745	4745	4745	4745	4745	4745	4745	859	4745	4745	4745
BPN	Pearson Correlation	-0.9746419	-0.0925175	-0.0628985	0.1246131	-0.106196	-0.1415062	1	-0.0819836	-0.0600078	-0.028688601	0.16	0.06	0.2
	Sig. (2-tailed)	2.59E-23	1.714E-10	1.452E-05	6.983E-18	2.234E-13	1.192E-22		1.555E-08	3.531E-05	0.41035049	0	0.11	0
	N	4745	4745	4745	4745	4745	4745	4745	4745	4745	859	4745	4745	4745
No. of Heavy Vehicles	Pearson Correlation	0.0814465	0.9169178	0.2219457	0.2732668	0.0690311	-0.0051165	-0.0819836	1	0.0055019	0.055124855	0.212	-0.124	0.151
	Sig. (2-tailed)	1.929E-08	2.95E-23	2.59 E-23	2.59E-23	1.94E-06	0.7245749	1.555E-08		0.7049631	0.106416187	2E-8	0.001	6E-05
	N	4745	4745	4745	4745	4745	4745	4745	4745	4745	859	4745	4745	4745
Road Slope	Pearson Correlation	0.04975	0.0390859	0.0060096	-0.0914714	-0.048363	0.0059894	-0.060007	0.0055019	1	-0.039004282	-0.12	-0.08	-0.147
	Sig. (2-tailed)	0.00060	0.0070874	0.0067898	2.746E-10	0.0008608	0.6799941	3.531E-05	0.7047361		0.253481125	0.0015	0.0349	0.0001
	N	4745	4745	4745	4745	4745	4745	4745	4745	4745	859	4745	4745	4745
Use of Horn	Pearson Correlation	0.02837	0.0666699	-0.0037715	-0.008388	-0.010668	-0.0227408	-0.028683	0.0551249	-0.039004	1	0.062	0.0042	0.0526
	Sig. (2-tailed)	0.40628	0.005071	0.0091211	0.8060784	0.7548542	0.5056545	0.401035	0.1064162	0.253481		0.1025	0.9123	0.166
	N	4745	4745	4745	4745	4745	4745	4745	4745	4745	859	4745	4745	4745
Number of Lanes	Pearson Correlation	-0.129	0.2960	0.43244	0.45746	0.3986	0.91	0.16	0.212	-0.12	0.062	1	-0.20415	0.9136334
	Sig. (2-tailed)	0.0007	1E-5	4.1E-22	4.1E-22	4.1E-22	0	0	2E-8	0.0015	0.1025		5.6E-08	4.075E-22
	N	1528	1528	1528	1528	1528	1528	1528	1528	1528	1528	1528	1528	1528
Lane Width	Pearson Correlation	-0.111	-0.104	-0.0416	-0.0223	0.28349	0.18	0.06	-0.124	-0.08	0.0042	-0.29415	1	0.1760842
	Sig. (2-tailed)	0.0034	0.0062	0.02738	0.55645	0.9733	0	0.11	0.001	0.0349	0.9123	5.85E-08		3.008E-06
	N	1528	1528	1528	1528	1528	1528	1528	1528	1528	1528	1528	1528	1528
Approach Width	Pearson Correlation	-0.192	0.2362	0.44031	0.4779	0.415	1	0.2	0.151	-0.147	0.0526	0.913634	0.17608	1
	Sig. (2-tailed)	4E-07	3E-10	4.1E-22	4.1E-22	4.1E-22	0	0	6E-05	0.0001	0.166	4.08E-22	3E-06	
	N	4745	4745	4745	4745	4745	4745	4745	4745	4745	4745	4745	4745	4745

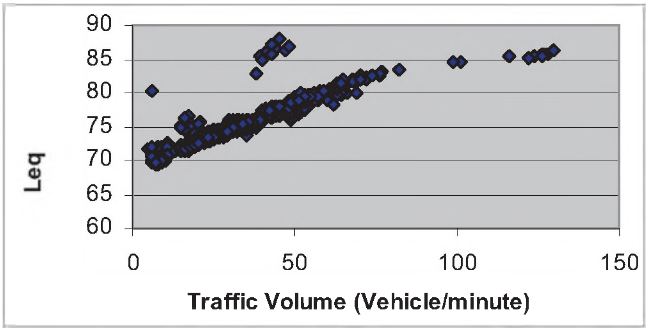

Figure 3. Effect of traffic volume on measured equivalent noise level at 0 m from Signal Stop line

6.2 Effect of Traffic Speed

Results of the study revealed that traffic speed is significantly correlated with equivalent noise levels. The correlation coefficient was 0.569, as shown in Table 2. Figure 4 shows the scatter plot for equivalent noise levels versus traffic speed. A drop in measured L_{eq} was monitored as speed increased up to about 10 km/hr, while a significant increase in measured L_{eq} was monitored as traffic speeds increased more than 35 km/hr. The L_{eq} ranged between 68 to 79 dB at a speed of 20 Km/hr, while it ranged between 77 to 83 dB at speed of 100 km/hr.

The traffic speed effect on equivalent noise levels varies as distances from the intersections' signal stop line increased. At 0, 100, and 150 m from the signal stop line, speed was found to have a significant effect on L_{eq}. While at 150 and 200 m from the signal stop line, the traffic speed effect on L_{eq} was not significant. This may attributed to the fact that, at 150 and 200 m from the signal stop line, vehicle speeds tend to be similar at different gears, This lead to different engine labor at similar speeds, resulting in different noise levels being emitted at similar speeds. At 250 m and 300 m distances from the intersections, equivalent noise levels were significantly increased as traffic speed increased. This is because the fourth gear was most probably used at distances between 250 and 300 m while the speed continued to increase, so the engine labor was higher for the same gear leading to higher equivalent noise levels as the distance increased. Figure 4 shows the variation of equivalent noise levels as

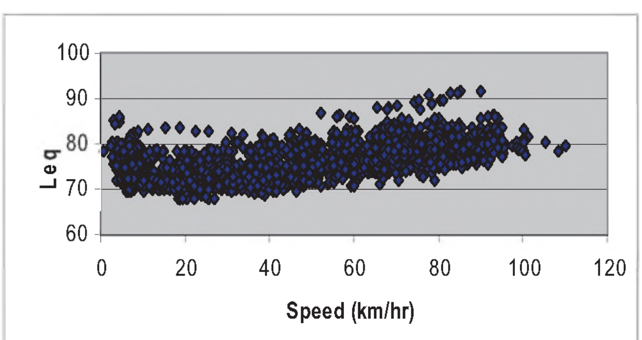

Figure 4. Effect of traffic speed on measured equivalent noise level

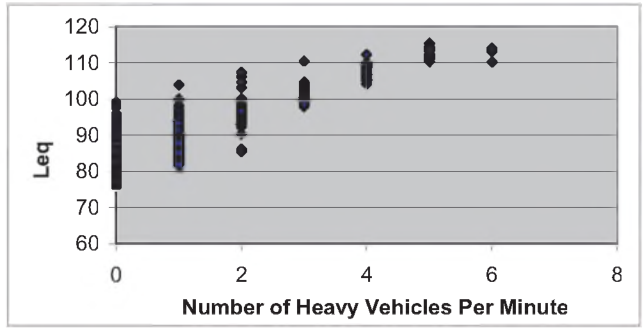

Figure 5. Effect of number of heavy vehicles on measured maximum noise level

the speed increase. This agrees with results obtained at road segments with free traffic flow. Makarewicz and Sato (1996) reported that the sound pressure level of free traffic flow without heavy vehicles showed an increase as the equivalent traffic speed increased.

It was found that traffic speed has less effect on maximum and minimum noise levels than that on equivalent noise level. The correlation coefficient between L_{max} and traffic speed was 0.143. The correlation coefficient between L_{min} and traffic speed was 0.110.

6.3 Effect of Heavy Vehicles

The maximum noise level (L_{max}) was found to be highly affected by the existence of heavy vehicles in the traffic passing the intersection. Figure 5 shows the scatter plot of the maximum noise levels versus the number of heavy vehicles. The correlation coefficient for this relationship was 0.916 as shown in Table 2. The scatter plot and correlation coefficient indicated a strong relationship between the two parameters. Greater numbers of trucks increased L_{max}. This is due to the fact that heavy vehicles have larger engines and exhaust systems, which result in high noise emissions levels. In addition it was found that the equivalent noise levels and minimum noise levels were less affected by the number of heavy vehicles, the correlation coefficient between L_{eq} and heavy vehicles was 0.221, while it was 0.081 between L_{min} and heavy vehicles. The small effect of heavy vehicles on L_{eq} is due to the small number of heavy vehicles in the traffic composition causing little effect on measured L_{eq}. In the case of significant numbers of heavy vehicles in the traffic stream, the heavy vehicle is expected to have a significant effect on the measured L_{eq} as concluded in a study performed by Ramalingeswave and Seshagri Rao (1991). This study reported that L_{eq} is directly proportional to the percentage of heavy vehicles in the traffic stream.

6.4 Effect of the Number of Lanes and Lane Width

Figure 6 shows a scatter plot of the relationship between the equivalent noise levels and the number of lanes in each direction of the intersection approach under evaluation. The correlation coefficient between the equivalent noise levels and

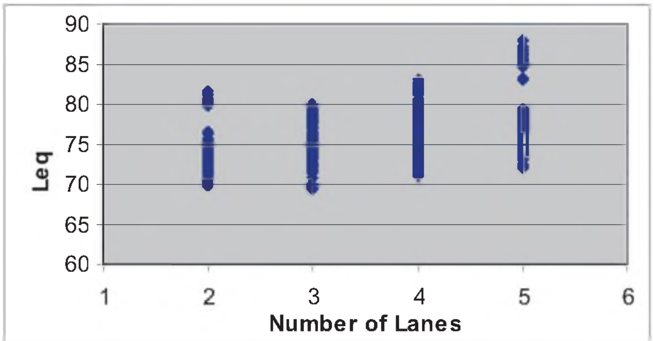

Figure 6. Effect of number of lanes on measured equivalent noise level

the number of lanes is found to be 0.432 as shown in Table 2. The scatter plot and the correlation coefficient indicate that increasing the number of lanes would cause a slight increase in the average equivalent noise levels.

Figure 7 shows the relation between the equivalent noise level and lane width. The correlation coefficient between the equivalent noise levels and lane width is equal to -0.0416, as shown in Table 2. Based on figure 7 and the correlation coefficient, there is a clear relationship between equivalent noise levels and lane width.

Minimum and maximum noise level were found to be insignificantly affected by the number of lanes. However it was found to be weakly affected by lane width with a correlation coefficient of -0.129 and 0.296 respectively. Lower L_{min} was monitored as the lane width increased. This can be explained by the fact that wider lanes provides enough space for attenuation and absorption of noise emissions, which in turn will cause lower values of measured minimum noise levels. The maximum noise level was found to be insignificantly related to the number of lanes, and lanes width.

6.5 Effect of Approach Width

The equivalent noise level seems to be insignificantly affected by the approach width as shown in Figure 8. Although the correlation coefficient is 0.440, as shown Table 2, indicates a relatively strong relationship between L_{eq} and approach width, figure 8 shows a relatively weak relationship between the same parameters. This figure indicates that a

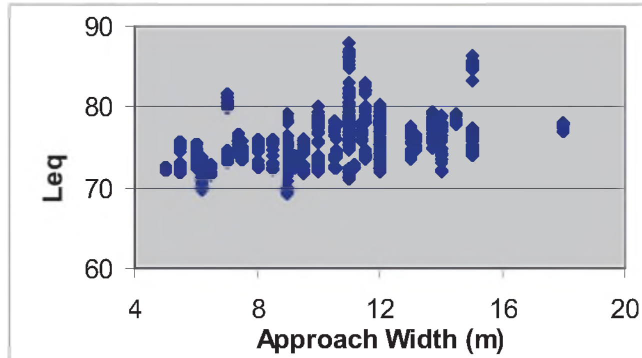

Figure 8. Effect of approach width on measured equivalent noise level

wider approach will cause a slight increase in the equivalent noise level. The maximum and minimum noise levels were found to be insignificantly related to the approach width.

6.6 Effect of Intersection Approach Slope

As shown in the scatter plot, Figure 9, and correlation coefficient indicated a weak relationship between L_{eq} and the approach slope. The correlation coefficient between equivalent noise level and the approach slope, as shown in Table 2, is -0.083. This small magnitude of coefficient indicates weak relationship between the measured slope and monitored L_{eq}. The negative sign of the coefficient means that the increase of road slope will cause a drop in the measured equivalent noise level. In reality, increasing the road slope is expected to cause an increase in the equivalent noise levels, since vehicles exhibits higher engines labor as the gradient of the road increase. The unexpected results in this study can be explained by the fact that most of the approaches slopes were ranged between –3% and 2% which indicated relatively little variation in measured slopes to cause a clear effect on the measured noise levels. Also, the increase of slope causes reduction in speed leading to lower traffic flow, which might cause lower noise emission. The opposite effect of approach slope on measured Leq led to a weak relationship between the two parameters. Maximum and minimum noise levels were found to be insignificantly affected by approach slope.

6.7 Effect of Pavement Surface Texture

The pavement surface texture was evaluated by

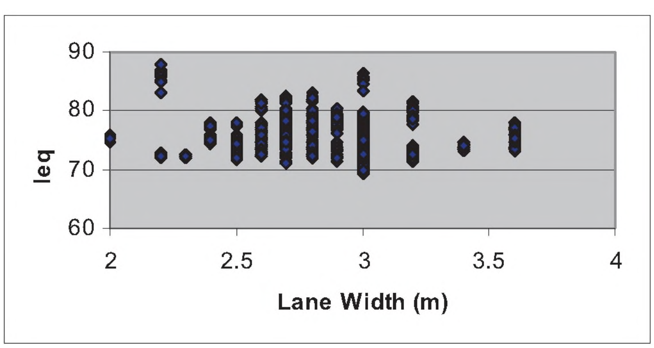

Figure 7. Effect of lane width on measured equivalent noise level

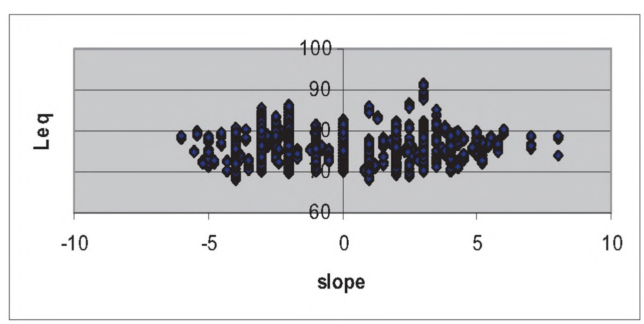

Figure 9. Effect of approach slope on measured equivalent noise level

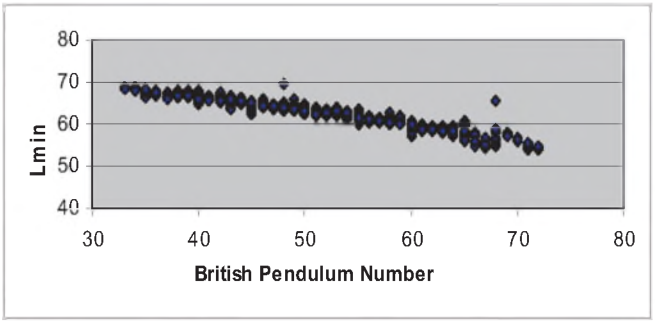

Figure 10. Effect of pavement surface texture on measured minimum noise level

measuring the surface frictional properties using the British Pendulum Tester, and expressed by the British Pendulum Number (BPN). The pavement surface texture was found to be related to the minimum noise levels at intersections. Figure 10 presents a scatter plot between minimum noise levels and BPN. The figure indicates that, increasing the value of BPN cause a decrease in the minimum noise levels, which mean that the rough surface texture properties will reduce the minimum noise levels at intersections. This based on the fact that pavements with a higher BPN have a rougher surface micro texture properties that provides which provide a higher percent of air voids, The voids absorb the noise emissions; especially those resulted from the interaction between vehicles and pavements surfaces. Pavements with smoother surface usually have less percent of air voids, resulting in less noise being absorbed, thus the minimum noise levels would be higher. L_{min} was about 67 dB at a BPN of 35, while it drop to 58 db at a BPN of 65 dB.

The correlation coefficient between minimum noise levels and BPN is -0.974 as shown in Table 2, which indicates a very strong relationship. However, the relationship between BPN and equivalent or maximum noise levels found to be weak as indicated by correlation coefficients in Table 2.

6.8 Horn Effect

The effect of horn use on equivalent, minimum, and maximum noise level was found to be insignificant at all evaluated distances from the signal stop line. However when the data collected at 0 m from the signal stop line was analyzed, it was found that the horn use is weakly related to L_{max} with a correlation coefficient of 0.129.

7. CONCLUSIONS

Based on this study, the following conclusion can be drawn:

1. Traffic volume is directly proportional to the equivalent and maximum noise levels and is inversely proportional to the minimum noise level.
2. As expected, noise levels increased with increasing vehicles speeds.
3. The number of heavy vehicles is directly proportional to noise levels. It is strongly correlated to L_{max}, while its correlation with L_{eq} and L_{min} is relatively weak.
4. The number of lanes were found to have a significant effect on $L_{eq,}$ while it has an insignificant effect on both L_{max} and L_{min}.
5. Lane width has a significant effect on L_{min}. However its effect on L_{eq} and L_{max} is insignificant.
6. In general, approach width has an insignificant effect on noise levels.
7. Approach slope has an insignificant effect on monitored noise levels.
8. As pavement surface skid resistance increased, lower L_{min} was monitored.
9. Use of horn was found to have a significant effect only on L_{max} at 0 m from the signal stop line.
10. Traffic on the far side of the road has a negligible effect on measured equivalent noise level.

8.0 REFERENCES

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NEWS / INFORMATIONS

CONFERENCES

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2005

14-17 March: 31st Annual Meeting of the German Acoustical Society (DAGA). Munich, Germany. Web: www.daga2005.de

15-17 March: Spring Meeting of the Acoustical Society of Japan. Nakaura 5th Bldg., 2-18-20 Sotokanda, Chiyoda-ku, Tokyo 101-0021, Japan. Fax +81 3 5256 1022, Web: www.asl.gr.jp/index-en.html

19-23 March: International Conference on Acoustics, Speech, and Signal Processing. Philadelphia, PA, USA. Web: www.icassp2005.org

21-22 March: Sonar Transducers and Numerical Modelling in Underwater Acoustics. Teddington, UK. Fax: +44 1727 850553, Web: www.npl.co.uk/acoustics/events/ioaconference2005

17-18 April: Joint Workshop on Hands Free Speech Communication and Microphone Arrays. Rutgers University, Piscataway, New Jersey, USA. www.caip.rutgers.edu/hscma2005/title.html

18-21 April: International Conference on Emerging Technologies of Noise and Vibration Analysis and Control. Saint Raphael, France. Fax: +33 4 72 73 87 12, email: goran.pavic@insa-lyon.fr

16-19 May: SAE Noise and Vibration Conference, Grand Traverse Resort, Traverse City Michigan. Contact: Mrs. Patti Kreh, SAE International, 755 W Big Beaver Rd, Ste 1600, Troy, Michigan, 48084. Tel: (248) 273-2474, E-mail: pkreh@sae.org

16-20 May: 149th Meeting of the Acoustical Society of America, Vancouver, BC, Canada. Contact: Acoustical Society of America, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502; Tel: 516-576-2360; Fax: 516-576-2377; E-mail: asa@aip.org; Web: asa.aip.org

23-26 May: Alberta Acoustical Society Spring Conference on Environmental and Occupational Noise. Banff, Alberta. Web: www.eub.gov.ab.ca/BBS/new/announcements

1-3 June: 1st International Symposium on Advanced Technology of Vibration and Sound. Hiroshima, Japan. Web: http://dezima.ike.tottori-u.ac.jp/vstech2005

15-17 June: ISCA Workshop on Plasticity in Speech Perception. London, UK. Web: www.psp2005.org.uk

20-23 June: IEEE Oceans05 Europe. Brest, France. Web: www.oceans05europe.org

23-24 June: 2nd Congress of the Alps-Adria Acoustics Association (AAAA2005). Opatija, Croatia. Web: http://had.zea.fer.hr

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2005

14-17 mars: 31st Annual Meeting de l'Acoustical Society du Germany (DAGA). Munich, Germany. Web: www.daga2005.de

15-17 mars: printemps Meeting de l'Acoustical Society du Japan. Nakaura 5th Bldg., 2-18-20 Sotokanda, Chiyoda-ku, Tokyo 101-0021, Japan. Fax +81 3 5256 1022, Web: www.asl.gr.jp/index-en.html

19-23 mars: Conference Internationale sur Acoustics, Speech, et Signal Processing. Philadelphia, PA, USA. Web: www.icassp2005.org

21-22 mars: Sonar Transducers et Numerical Modelling dans Underwater Acoustics. Teddington, UK. Fax: +44 1727 850553, Web: www.npl.co.uk/acoustics/events/ioaconference2005

17-18 avril: Joint Workshop on Hands Free Speech Communication and Microphone Arrays. Rutgers University, Piscataway, New Jersey, USA. www.caip.rutgers.edu/hscma2005/title.html

18-21 avril: Conference International sur Emerging Technologies de Noise et Vibration Analysis et Control. Saint Raphael, France. Fax: +33 4 72 73 87 12, email: goran.pavic@insa-lyon.fr

16-19 mai: SAE Noise and Vibration Conference, Grand Traverse Resort, Traverse City Michigan. Contact: Mrs. Patti Kreh, SAE International, 755 W Big Beaver Rd, Ste 1600, Troy, Michigan, 48084. Tel: (248) 273-2474, E-mail: pkreh@sae.org

16-20 mai: 149^{e} rencontre de l'Acoustical Society of America, Vancouver BC, Canada. Info: Acoustical Society of America, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502; Tél.: 516-576-2360; Fax: 516-576-2377; Courriel: asa@aip.org; Web: asa.aip.org

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1-3 juin: 1st Symposium International sur Advanced Technology de Vibration et Sound. Hiroshima, Japan. Web: http://dezima.ike.tottori-u.ac.jp/vstech2005

15-17 juin: ISCA Workshop on Plasticity in Speech Perception. London, UK. Web: www.psp2005.org.uk

20-23 juin: IEEE Oceans05 Europe. Brest, France. Web: www.oceans05europe.org

23-24 juin: 2nd Congress de l'Association Acoustique Des Alps-Adria (AAAA2005). Opatija, Croatia. Web: http://had.zea.fer.hr

28 June - 1 July: International Conference on Underwater Acoustic Measurements: Technologies and Results. Heraklion, Crete, Greece. Web: http://UAmeasurements2005.iacm.forth.gr

04-08 July: Turkish International Conference on Acoustics 2005. Web: www.tica05.org/tica05

11-14 July: 12th International Congress on Sound and Vibration (ICSV12). Lisbon, Portugal. Web: www.icsv12.ist.utl.pt

18-22 July: 17th International Symposium on Nonlinear Acoustics (ISNA 17). Pennsylvania State University, PA, USA. Web: http://outreach.psu.edu/c&i/isna17

6-10 August: Inter-Noise, Rio de Janeiro, Brazil. Web: www.internoise2005.ufsc.br

28 August - 01 September: World Congress on Ultrasonics Merged with Ultrasonic International (WCU/UT05), Web: www.ioa.ac.cn/wcu-ui-05

28 August – 2 September: Forum Acusticum Budapest 2005, Budapest, Hungary. Fax: +36 1 202 0452; Web: www.fa2005.org; E-mail: sea@fresno.csic.es

4-8 September: 9th Eurospeech Conference, Lisbon, Portugal. Contact: Fax: +351 213145843. Web: www.interspeech2005.org

4-8 September: 9th Eurospeech Conference (EUROSPEECH2005). Lisbon, Portugal. Web: www.interspeech2005.org

5-9 September: Boundary Influences in High Frequency, Shallow Water Acoustics. Bath, UK (Details to be announced later)

11-15 September: 6th World Congress on Ultrasonics (WCU 2005). Beijing, China. Web: www.ioa.ac.cn/wcu2005

14-16 September: Autumn Meeting of the Acoustical Society of Japan. Sendai, Japan. Web: www.asj.gr.jp/index-en.html

18-21 September: IEEE International Ultrasonics Symposium. Rotterdam, The Netherlands. Web: www.ieee-uffc.org

27-29 September: Autumn Meeting of the Acoustical Society of Japan. www.asj.gr.jp/index-en.html

17-21 October: 150th Meeting of the Acoustical Society of America JOINT with NOISE-CON 2005, Minneapolis, Minnesota. Contact: Acoustical Society of America, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502; Tel: 516-576-2360; Fax: 516-576-2377; E-mail: asa@aip.org; Web: asa.aip.org

19-21 October: 36th Spanish Congress on Acoustics and 2005 Iberian Meeting on Acoustics. Terrassa-Barcelona, Spain. Web: www.ia.csic.es/sea/index.html

2006

15-19 May: IEEE International Conference on Acoustics, Speech, and Signal Processing (IEEE ICASSP 2006). Toulouse, France. Web: http://icassp2006.org

5-7 June: 6th European Conference on Noise Control (Euronoise2006). Web: www.acoustics.hut.fi/asf

28 juin - 1 juillet: Conference Internationale sur Underwater Acoustic Measurements: Technologies and Results. Heraklion, Crete, Greece. Web: http://UAmeasurements2005.iacm.forth.gr

04-08 juillet: Turkish International Conference sur Acoustics 2005. Web: www.tica05.org/tica05

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28 août – 2 septembre: Forum Acusticum Budapest 2005, Budapest, Hongrie. Fax: +36 1 202 0452; Web: www.fa2005.org; E-mail: sea@fresno.csic.es

4-8 septembre: 9e Conférence d'Eurospeech, Lisbon, Portugal. Contact: Fax: +351 213145843. Web: www.interspeech2005.org

4-8 septembre: 9th Eurospeech Conference (EUROSPEECH2005). Lisbon, Portugal. Web: www.interspeech2005.org

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14-16 septembre: Autumn Meeting de la Society Acoustical du Japan. Sendai, Japan. Web: www.asj.gr.jp/index-en.html

18-21 septembre: IEEE International Ultrasonics Symposium. Rotterdam, The Netherlands. Web: www.ieee-uffc.org

27-29 septembre: Autumn Meeting de l'Acoustical Society du Japan. www.asj.gr.jp/index-en.html

17-21 octobre: 150e rencontre de l'Acoustical Society of America AVEC NOISE-CON 2005, Minneapolis, Minnesota. Info: Acoustical Society of America, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502; Tél.: 516-576-2360; Fax: 516-576-2377; Courriel: asa@aip.org; Web: asa.aip.org

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2006

15-19 mai: IEEE Conference Internationale sur Acoustics, Speech, et Signal Processing (IEEE ICASSP 2006). Toulouse, France. Web: http://icassp2006.org

5-7 juin: 6th European Conference on Noise Control (Euronoise2006). Web: www.acoustics.hut.fi/asf

5-9 June: 151st Meeting of the Acoustical Society of America, Providence, Rhode Island. Contact: Acoustical Society of America, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502; Tel: 516-576-2360; Fax: 516-576-2377; E-mail: asa@aip.org; Web: asa.aip.org

26-28 June: 9th Western Pacific Acoustics Conference. Seoul, Korea. Web: www.wespac8.com/WespacIX.html

3-7 July: 13th International Congress on Sound and Vibration (ICSV13). Vienna, Austria. Http://info.tuwien.ac.at/icsv13

13-15 September: Autumn Meeting of the Acoustical Society of Japan. Web: www.asj.gr.jp/index-en.html

17-21 September: Interspeech 2006 - ICSLP. Web: www.interspeech2006.org

28 November – 2 December: 152nd meeting, 4th Joint Meeting of the Acoustical Society of America and the Acoustical Society of Japan, Honolulu, Hawaii. Contact: Acoustical Society of America, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502; Tel: 516-576-2360; Fax: 516-576-2377; E-mail: asa@aip.org; Web: asa.aip.org

3 - 6 December: INTER-NOISE 2006, Honolulu HA, USA (Same Hotel at ASA meeting the week preceeding)

2007

17-20 April. IEEE International Congress on Acoustics, Speech, and Signal Processing (IEEE ICASSP 2007). Honolulu, HI, USA

9-12 July: 14th International Congress on Sound and Vibration (ICSV14). Cairns, Australia. Email: n.kessissoglou@unsw.edu.au

27-31 August: Interspeech 2007. E-mail: conf@isca-speech.org

2-7 September 19th International Congress on Acoustics (ICA2007), Madrid Spain. (SEA, Serrano 144, 28006 Madrid, Spain; Web: www.ia.csic/sea/index.html)

9-12 September: ICA2007 Satellite Symposium on Musical Acoustics (ISMA2007). Barcelona, Spain. Web: www.ica2007madrid.org

2008

23-27 June: Joint Meeting of European Acoustical Association, Acoustical Society of America, and Acoustical Society of France. Paris, France E-mail: phillipe.blanc-benon@ec-lyon.fr

5-9 juin: 151e rencontre de l'Acoustical Society of America, Providence, Rhode Island. Info: Acoustical Society of America, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502; Tél.: 516-576-2360; Fax: 516-576-2377; Courriel: asa@aip.org; Web: asa.aip.org

26-28 juin: 9e Conférence Western Pacific Acoustics. Seoul, Korea. Web: www.wespac8.com/WespacIX.html

3-7 juillet: 13th Congress Internationale sur Sound et Vibration (ICSV13). Vienna, Austria. Http://info.tuwien.ac.at/icsv13

13-15 septembre: Autumn Meeting de l'Acoustical Society du Japan. Web: www.asj.gr.jp/index-en.html

17-21 septembre: Interspeech 2006 - ICSLP. Web: www.interspeech2006.org

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9-12 juillet: 14th Congress Internationale sur Sound et Vibration (ICSV14). Cairns, Australia. Email: n.kessissoglou@unsw.edu.au

27-31 août: Interspeech 2007. E-mail: conf@isca-speech.org

2-7 septembre 19e Congrès international sur l'acoustique (ICA2007), Madrid Spain. (SEA, Serrano 144, 28006 Madrid, Spain; Web: www.ia.csic/sea/index.html)

9-12 septembre: ICA2007 Satellite Symposium sur Musical Acoustics (ISMA2007). Barcelona, Spain. Web: www.ica2007madrid.org

2008

23-27 juin: Rencontre jointe de l'European Acoustical Association, l'Acoustical Society of America, et l'Acoustical Society of France. Paris, France E-mail: phillipe.blanc-benon@ec-lyon.fr

NEWS

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EXCERPTS FROM "*WE HEAR THAT*", IN *ECHOS*, ASA

ASA Fellow **Eric Ungar** was presented with a Lifetime Achievement Award at the Shock and Vibration Symposium in Virginia each, VA in October, sponsored by the Shock and Vibration Information Center. His citation reads "Through a half century of research, consulting, and teaching, Dr. Eric E. Ungar has made singular and distinctive contributions to the discipline of Shock and Vibration. His analyses of the excitation and control of structural vibrations will long remain a foundation upon which others can build."

ASA Fellow **Juergen Meyer** was awarded the Honorary Medal of the Verband Deutscher Tonmeister (VDT) in November for outstanding contributions to sound, particularly for teaching 36 years at the Detmold Music Academy (Tonmeister education) and for attendance at all Tonmeister meetings and reading a paper every time since 1960.

ASA Fellow **Guillermo Gaunaurd** has been elected Associate Fellow of the American Institute for Aeronautics and Astronautics (AIAA).

ASA Fellow **Thomas Rossing** has been elected a Fellow in the Institute of Electrical and Electronics Engineers (IEEE) "for contributions to engineering education, acoustics, and magnetic devices."

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

Shallow water is usually a noisy environment because shipping lanes exist along coastlines. Submarines typically radiate in the same frequency band as shipping noise, less than 1 kilohertz. Passive sonar, which only receives a signal, is used mainly for antisubmarine warfare (ASW) and to study ocean biology According to an article in the October issue of *Physics Today*, it is possible to focus an acoustic signal more accurately when that signal travels through a complicated medium than when it doesn't. Various research groups have combined multisensor apertures with a complex medium to enhance signal processing in applications such as communications, medical ultrasonics, seismology, and matched-field acoustics. The proximity and complexity of the boundaries, and the oceanography in shallow water, influence the sonar's performance.

Bird songs frequently contain trilling sounds that demand extremely **fast vocal control**. According to a paper in the 9 September issue of *Nature*, doves control their syrinx by using superfast muscles similar to those that operate acoustic organs such as the rattle of a rattlesnake. The syrinx of ring doves generates the familiar cooing sound which contains a trill whose elements are generated at repetition rates up to 30 Hz. When doves coo, respiratory airflow excites membranes in the syrinx, causing them to vibrate. The vibrations depend on the tension in the membranes which is modified by activating two pairs of syringeal muscles.

The August issue of *Acoustics Australia* has reprinted a paper on "**The Sonar of Dolphins**" by Whitlow Au from the Proceedings of the WESPAC8 held in Melbourne, April 2003. The sonar of dolphins, which has undergone evolutionary refinement for millions of years, is the premier sonar system for short-range applications. It far surpasses the capability of technological sonar. A capability to perform time-varying gain is very different from that of a technological sonar.

The December issue of the *American Journal of Physics* includes a paper on "The physics of **bat echolocation**: Signal processing techniques." Some 813 species of small nocturnal bats echolocate by making use of structured tonal signals rather than simple broadband clicks. They have brains that are adapted for processing acoustic signals and exhibit a wide variety of ear and nose sizes and shapes to improve the focusing of transmitted and received sound waves. It is shown, by calculation and simulation, how the measured echolocation performance of bats can be achieved.

Ultrasound scans could soon be much more detailed, thanks to a novel material that can bend sound waves the "wrong" way, according to an article in the 4 September edition of *New Scientist*. This property, known as **negative refraction**, means the material should bring sound waves to a focus far sharper than today's medical scanners. (See Fall 2004 issue of *ECHOES*) The material used by scientists at the University of Manitoba is known as a "phononic crystal," a synthetic structure of tungsten carbide beads just 0.8 mm across, painstakingly packed to form a slab 12 layers thick. When the crystal is immersed in water, any sound with a wavelength similar to the bead size is diffracted as it enters the material, leading to the unusual properties. At a frequency of 1.57 MHz, for example, the crystal brings sound to a focus by bending it in a chevron pattern, so that waves that are initially diverging are brought together.

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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).

Deadline: Shaw, Bell, Fessenden, Eckel and Hétu Prizes: **30 April 2005**
Échéance: Prix Shaw, Bell, Fessenden, Eckel et Hétu: **30 Avril 2005**

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 BEHAVIOURAL ACOUSTICS • PRIX ÉTUDIANT ALEXANDRE GRAHAM BELL EN COMMUNICATION VERBALE ET ACOUSTIQUE COMPORTEMENTALE

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

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

$500 for a graduate student enrolled at a Canadian academic 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 dans une institution académique 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 academic 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 dans une institution académique canadienne et menant un projet de recherche relié à l'avancement de la pratique du contrôle du bruit.

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

One book in acoustics of a maximum value of $100 and a one-year subscription to *Canadian Acoustics* for an undergraduate student enrolled at a Canadian academic institution and having completed, during the year of application, a project in any field of acoustics or vibration. • Un livre sur l'acoustique et un abonnement d'un an à la revue *Acoustique Canadienne* à un(e) étudiant(e) inscrit(e) dans un programme de 1er cycle dans une institution académique 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.

CALL FOR PAPERS

Acoustics Week in Canada 2005
October 12-14
Lamplighter Inn and Conference Centre, London, Ontario

The 2005 annual conference of the Canadian Acoustical Association will be held in London, Ontario, Canada on October 12-14, 2005. London is located between Toronto and Detroit and is home to Canada's National Centre for Audiology, the Boundary Layer Wind Tunnel, and the National Research Council's Integrated Manufacturing Technologies Institute. Please join us to participate in three days of papers on diverse areas of acoustics. In addition to the technical sessions, you are invited to attend the exhibits, standards meeting, annual general meeting, and banquet.

Plenary Sessions

Two distinguished Canadian researchers will give plenary lectures. Richard Seewald, Canada Research Chair in Infant Hearing, will speak about his work on hearing and hearing loss in infants. Brock Fenton, Professor and Chair of the Biology Department at the University of Western Ontario, will discuss echolocation and bat behavior.

Special Sessions

Several special sessions will be offered that will include invited and contributed papers. If you are interested in organizing a special session, please contact Vijay Parsa (parsa@nca.uwo.ca).

Associated Events

The Canadian Standards Association (CSA) Committee Z 107 in Acoustics and Noise Control will hold a meeting during the conference. Contact Tim Kelsall (tkelsallhatch.ca), for more information. All interested participants are welcome to attend.

Tours through acoustics-related laboratories in and around the University of Western Ontario will be organized.

Exhibits & Sponsors

An exhibit hall of measurement equipment and other acoustical products will be located across from the meeting rooms. The exhibit area will also be the central coffee break area. Please contact the conference convener for exhibitor information and sponsorship of various aspects of this meeting.

Student Participation

CAA has a very strong emphasis on encouraging student research. The meeting provides an opportunity to learn first hand about current research and applied work in many aspects of the science of sound as found in university, government, and industry. All student research papers in areas related to acoustics may be submitted for presentation. For student members who are presenting papers, there is a travel subsidy that is available upon application. In addition, student members enrolled in Canadian universities may also enter a competition for the best student presentation award.

Abstract submissions

Submission of abstracts may be made electronically on or before June 24, 2005.
Abstract submission information and a sample abstract are available on the CAA London 2005 website (http://caa-aca.ca/london-2005.html).

Summary papers

An optional two-page summary paper must be received by August 5, 2005 for inclusion in the conference issue of Canadian Acoustics (September 2005). This conference issue has become the archival record of new acoustical research activities in Canada each year. Complete submission information is available on the CAA London 2005 website (http://caa-aca.ca/london-2005.html).

Registration

Registration forms are available on the conference website. Early registration closes on September 15, 2005. All conference participants must register for the conference. A registration desk will be open throughout the conference.

Venue and Accommodation

The conference will be held at the Lamplighter Inn and Conference Centre in London. London is approximately 2 hours driving distance from Toronto and Detroit and is served by several major airlines.

The Lamplighter offers standard rooms (2 queen beds) or upgraded rooms (king suites) at a CAA delegate room rate of Cdn$109/night and Cdn$119/night (+ taxes), respectively. (1-888-232-6747; www.lamplighterinn.ca). Please stay at this hotel to be with your colleagues and to support the CAA.

Hospitality

CAA conferences are always an opportunity to meet old friends and to make new ones over a coffee during the conference, or over a drink after the sessions. There are many nearby bars and restaurants and of course there will be a banquet as part of the conference.

The Stratford Theatre Festival is located 45 minutes from the conference site. Tickets and information for the Festival can be found at the Festival website (http://www.stratfordfestival.ca).

Contacts

Conference convener: M. F. Cheesman (cheesman@uwo.ca)
Technical chair: V. Parsa (parsa@nca.uwo.ca)

Important Dates	
Deadline for receipt of abstracts by email	June 24
Notice of acceptance of abstracts by email	July 8
Deadline for receipt of summary paper (Electronic submission)	August 5
Deadline for early registration rates	September 15
CAA annual conference – Lamplighter Inn and Conference Centre, London, Ontario	October 12-14

APPEL DE COMMUNICATIONS

Semaine canadienne d'acoustique 2005
12- 14 octobre
Lamplighter Inn et Conference Centre, London, Ontario

Le congrès annuel de l'ssociation canadienne d'acoustique se tiendra à London en Ontario du 12 au 14 octobre 2005. London est situé entre Toronto et Détroit et est le site du Centre national d'audiologie du Canada, d'un tunnel aérodynamique et de l'Institut des technologies de fabrication intégrée du CNRC. Joignez-vous à nous afin de participer à trois jours de communications scientifiques ayant pour sujets les divers domaines de l'acoustique. En plus des réunions techniques, vous êtes également invités à participer à l'exposition technique, les rencontres de comité de normalisation, l'Assemblée générale annuelles de l'association et le banquet.

Assemblées plénières

Deux distingués chercheurs canadiens présideront des assemblées plénières. Richard Seewald, détenteur d'une chaire canadienne de recherche en pédoaudiologie, discutera de ses travaux concernant l'audition et l'hypoacousie chez les enfants. Brock Fenton, professeur et directeur du Département de biologie à l'université Western Ontario discutera pour sa part d'écholocalisation et du comportement des chauves-souris.

Sessions Plénières

Plusieurs sessions spéciales seront offertes et porteront sur les sujets proposés par les délégués. Afin de suggérer un sujet de présentation particulier ou pour organiser une de ces sessions, veuillez communiquer avec Vijay Parsa (parsa@nca.uwo.ca).

Événements associés

Le comité de normalisation Z 107 en acoustique et contrôle du bruit de l'ACNOR tiendra une réunion au cours du congrès. Pour plus d'informations veuillez contacter Tim Kelsall (tkelsallhatch.ca). Tous les participants intéressés à y assister sont les bienvenus. Des visites des laboratoires d'acoustiques de l'université Western Ontario et de ceux situés à proximités de l'université seront également organisées.

Expositions et commandites

Un hall d'exposition sera situé entre les salles du congrès où y seront présentés différents équipements de mesure et certains produits en acoustiques. C'est dans cette aire d'exposition que se tiendra aussi les pauses-café. Veuillez communiquer avec le président de la congrès pour toute question concernant les expositions et les différents aspects des commandites pour ce congrès.

Participation étudiante

L'ACA accorde beaucoup d'importance à la participation des étudiants. Le congrès donne la chance aux étudiants de mieux connaître les recherches en cours et les travaux appliqués dans plusieurs aspects de la science du son dans tous les milieux; autant gouvernementaux, universitaires, qu'industriels. Toute communication scientifique concernant un domaine relié à l'acoustique peut y être soumise. Les membres étudiants qui présenteront une communication pourront soumettre une demande de subvention pour frais de déplacement au congrès et pourront se voir mériter l'un des prix récompensant les meilleures présentations étudiantes.

Envoi des résumés

Les résumés de présentation peuvent être soumis électroniquement jusqu'au 24 juin 2005. Un exemple de résumé et l'information requise sont disponibles sur le site de l'ACA London 2005 (http://caa-aca.ca/london-2005.thml).

Actes du congrès

La date d'échéance pour soumettre l'article de deux pages pour la revue Acoustique Canadienne, édition spéciale du congrès, est le 5 août 2005. Cette édition spéciale est un portrait des nouvelles recherches en acoustique de l'année. L'information concernant la soumission de l'article de 2 pages est disponible sur le site de l'ACA London 2005 (http://caa-aca.ca/london-2005.thml).

Inscriptions

Les formulaires d'inscriptions sont disponibles sur le site internet du congrès. La date limite pour se prévaloir du taux préférentiel d'inscription est le 15 septembre 2005. Tous les participants doivent s'inscrire au congrès. Un bureau d'inscription restera ouvert tout au long du congrès.

Lieu du congrès et hébergement

Le congrès se tiendra au Lamplighter Inn and Conference Centre. London est à environ 2 heures de route de Toronto et Détroit et est déservi par la majorité des compagnies aériennes. L'hôtel offrira des chambres régulières (2 lits Queen) ou des suites (lits King) à des tarifs préférentiels pour les délégués du congrès; soit 109$/nuit et 119$/nuit (+taxes), respectivement. Pour réservations ou informations : 1-888-232-6747 ou www.bestwesternontario.com/french/lamplighter.html . Nous vous invitons à choisir cet hôtel afin de participer pleinement du congrès et d'encourager l'ACA.

Autres attraits

Les congrès de l'ACA sont toujours une excellente occasion de rencontrer d'anciens amis et collègues ou encore d'en rencontrer d'autres autour d'un café durant le congrès, ou d'un verre après les sessions techniques. Plusieurs bars et restaurants sont à proximité et bien sûr, un banquet sera offert durant le congrès.

Le festival de théâtre de Stratford est situé à 45 minutes du site du congrès. Les billets et les informations concernant ce festival sont disponibles sur le site web du festival (http://www.stratfordfestival.ca).

Personnes ressources

Présidente du congrès : M. F. Cheesman (cheesman@uwo.ca)
Organisateur technique : V. Parsa (parsa@nca.uwo.ca)

Dates à retenir	
Date d'échéance pour la réception des résumés	24 juin
Avis d'acceptation des résumés	8 juillet
Date d'échéance pour la réception des articles de 2 pages (soumission électronique)	5 août
Date d'échéance pour les inscriptions à taux préférentiel	15 septembre
Le congrès annuel - Lamplighter Inn and Conference Centre, London, Ontario	12-14 octobre

INSTRUCTIONS TO AUTHORS FOR THE PREPARATION OF MANUSCRIPTS

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

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

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

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

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

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

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

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

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

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

Photographs: Submit original glossy, black and white photograph.

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

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

Page numbers: In light pencil at the bottom of each page.
Reprints: Can be ordered at time of acceptance of paper.

DIRECTIVES A L'INTENTION DES AUTEURS PREPARATION DES MANUSCRITS

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

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

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

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

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

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

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

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

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

Largeur Des Traits: La largeur des traits sur les schémas technique doivent être au minimum de 0.5 pt pour permettre une bonne reproduction.

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

Figures Scanées: Doivent être au minimum de 225 dpi et au maximum de 300 dpi. Les schémas doivent être scannés en bitmaps tif format. Les photos noir et blanc doivent être scannées en échelle de gris tifs et toutes les phoots couleurs doivent être scannées en CMYK tifs.

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

Pagination: Au crayon pâle, au bas de chaque page.
Tirés-à-part: Ils peuvent être commandés au moment de l'acceptation du manuscrit.

The Canadian Acoustical Association
l'Association Canadienne d'Acoustique

Application for Membership

CAA membership is open to all individuals who have an interest in acoustics. Annual dues total $60.00 for individual members and $20.00 for Student members. This includes a subscription to ***Canadian Acoustics***, the Association's journal, which is published 4 times/year. New membership applications received before August 31 will be applied to the current year and include that year's back issues of ***Canadian Acoustics***, if available. New membership applications received after August 31 will be applied to the next year.

Subscriptions to *Canadian Acoustics* *or* Sustaining Subscriptions

Subscriptions to ***Canadian Acoustics*** are available to companies and institutions at the institutional subscription price of $60.00. Many companies and institutions prefer to be a Sustaining Subscriber, paying $250.00 per year, in order to assist CAA financially. A list of Sustaining Subscribers is published in each issue of ***Canadian Acoustics***. Subscriptions for the current calendar year are due by January 31. New subscriptions received before August 31 will be applied to the current year and include that year's back issues of ***Canadian Acoustics***, if available.

Please note that electronic forms can be downloaded from the CAA Website at **caa-aca.ca**

Address for subscription / membership correspondence:

Name / Organization ______________________________

Address ______________________________

City/Province ________________ Postal Code __________ Country ________________

Phone ______________ Fax ______________ E-mail ______________

Address for mailing Canadian Acoustics, if different from above:

Name / Organization ______________________________

Address ______________________________

City/Province ________________ Postal Code __________ Country ________________

Areas of Interest: (Please mark 3 maximum)

1. Architectural Acoustics
2. Engineering Acoustics / Noise Control
3. Physical Acoustics / Ultrasound
4. Musical Acoustics / Electro-acoustics
5. Psychological / Physiological Acoustic
6. Shock and Vibration
7. Hearing Sciences
8. Speech Sciences
9. Underwater Acoustics
10. Signal Processing / Numerical Methods
11. Other

For student membership, please also provide:

__________ __________ __________ __________

(University) *(Faculty Member)* *(Signature of Faculty Member)* *(Date)*

I have enclosed the indicated payment for:

[ ] CAA Membership $ 60.00
[ ] CAA Student Membership $ 20.00
[ ] Institutional Subscription $ 60.00
[ ] Sustaining Subscriber $ 250.00
includes subscription (4 issues /year) to ***Canadian Acoustics.***

Payment by: [ ] Cheque
[ ] Money Order
[ ] VISA credit card *(Only VISA accepted)*

For payment by VISA credit card:

Card number ______________________________

Name of cardholder ______________________________

Expiry date ______________________________

____

(Signature) (Date)

Mail application and attached payment to:

D. Quirt, Secretary, Canadian Acoustical Association, PO Box 74068, Ottawa, Ontario, K1M 2H9, Canada

l'Association Canadienne d'Acoustique
The Canadian Acoustical Association

Formulaire d'adhésion

L'adhésion à l'ACA est ouverte à tous ceux qui s'intéressent à l'acoustique. La cotisation annuelle est de 60.00$ pour les membres individuels, et de 20.00$ pour les étudiants. Tous les membres reçoivent ***l'Acoustique Canadienne***, la revue de l'association. Les nouveaux abonnements reçus avant le 31 août s'appliquent à l'année courante et incluent les anciens numéros (non-épuisés) de ***l'Acoustique Canadienne*** de cette année. Les nouveaux abonnements reçus après le 31 août s'appliquent à l'année suivante.

Abonnement pour la revue *Acoustique Canadienne* et abonnement de soutien

Les abonnements pour la revue ***Acoustique Canadienne*** sont disponibles pour les compagnies et autres établissements au coût annuel de 60.00$. Des compagnies et établissements préfèrent souvent la cotisation de membre bienfaiteur, de 250.00$ par année, pour assister financièrement l'ACA. La liste des membres bienfaiteurs est publiée dans chaque issue de la revue ***Acoustique Canadienne***. Les nouveaux abonnements reçus avant le 31 août s'appliquent à l'année courante et incluent les anciens numéros (non-épuisés) de ***l'Acoustique Canadienne*** de cette année. Les nouveaux abonnements reçus après le 31 août s'appliquent à l'année suivante.

Pour obtenir des formulaires electroniques, visitez le site Web: **caa-aca.ca**

Pour correspondence administative et financière:

Nom / Organisation ______________________________

Adresse ______________________________

Ville/Province ______________ Code postal __________ Pays ______________

Téléphone ____________ Téléc. __________ Courriel ______________

Adresse postale pour la revue Acoustique Canadienne

Nom / Organisation ______________________________

Adresse ______________________________

Ville/Province ______________ Code postal __________ Pays ______________

Cocher vos champs d'intérêt: (maximum 3)

1. Acoustique architecturale
2. Génie acoustique / Contrôle du bruit
3. Acoustique physique / Ultrasons
4. Acoustique musicale / Electro-acoustique
5. Physio / Psycho-acoustique
6. Chocs et vibrations
7. Audition
8. Parole
9. Acoustique sous-marine
10. Traitement des signaux /Méthodes numériques
11. Autre

Prière de remplir pour les étudiants et étudiantes:

__________ __________ __________ __________

(Université) (Nom d'un membre du corps professoral) (Signature du membre du corps professoral) (Date)

Cocher la case appropriée:
[ ] Membre individuel $ 60.00
[ ] Membre étudiant(e) $ 20.00
[ ] Abonnement institutionnel $ 60.00
[ ] Abonnement de soutien $ 250.00 (comprend l'abonnement à ***L'acoustique Canadienne)***

Méthode de paiement:
[ ] Chèque au nom de l'Association Canadienne d'Acoustique
[ ] Mandat postal
[ ] VISA *(Seulement VISA)*

Pour carte VISA: Carte n° ______________

Nom ______________

Date d'expiration ______________

____

(Signature) (Date)

Prière d'attacher votre paiement au formulaire d'adhésion. Envoyer à :

Secrétaire exécutif, Association Canadienne d'Acoustique, Casier Postal 74068, Ottawa, K1M 2H9, Canada

The Canadian Acoustical Association
l'Association Canadienne d'Acoustique

SUSTAINING SUBSCRIBERS / ABONNES DE SOUTIEN

The Canadian Acoustical Association gratefully acknowledges the financial assistance of the Sustaining Subscribers listed below. Annual donations (of $250.00 or more) enable the journal to be distributed to all at a reasonable cost. Sustaining Subscribers receive the journal free of charge. Please address donation (made payable to the Canadian Acoustical Association) to the Secretary of the Association.

L'Association Canadienne d'Acoustique tient à témoigner sa reconnaissance à l'égard de ses Abonnés de Soutien en publiant ci-dessous leur nom et leur adresse. En amortissant les coûts de publication et de distribution, les dons annuels (de $250.00 et plus) rendent le journal accessible à tous nos membres. Les Abonnés de Soutien reçoivent le journal gratuitement. Pour devenir un Abonné de Soutien, faites parvenir vos dons (chèque ou mandat-poste fait au nom de l'Association Canadienne d'Acoustique) au secrétaire de l'Association.

ACI Acoustical Consultants Inc.
Mr. Steven Bilawchuk - (780) 414-6373
stevenb@aciacoustical.com - Edmonton, AB

ACO Pacific Inc.
Mr. Noland Lewis - (650) 595-8588
acopac@acopacific.com - Belmont, CA

Acoustec Inc.
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courrier@acoustec.qc.ca - Québec, QC

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